Can Carbon Sinks Be Operational?
RFF Workshop Proceedings

Roger A. Sedjo and Michael Toman

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Abstract

An RFF Workshop brought together experts from around the world to assess the feasibility of using biological sinks to sequester carbon as part of a global atmospheric mitigation effort. The chapters of this proceeding are a result of that effort. Although the intent of the workshop was not to generate a consensus, a number of studies suggest that sinks could be a relatively inexpensive and effective carbon management tool. The chapters cover a variety of aspects and topics related to the monitoring and measurement of carbon in biological systems. They tend to support the view the carbon sequestration using biological systems is technically feasible with relatively good precision and at relatively low cost. Thus carbon sinks can be operational.

Key Words: carbon, sinks, global warming, sequestration, forests

JEL Classification Numbers: Q10, Q15, Q21, Q23, Q24

Contents

Can Carbon Sinks Be Operational?
RFF Workshop Summary

Roger A. Sedjo and Michael Toman*

On April 30, 2001, Resources for the Future (RFF) hosted a workshop, “Can Carbon Sinks Be Operational?” at which participants assessed the feasibility of using biological sinks to sequester carbon as part of a global atmospheric mitigation effort. Sequestration involves increased uptakes in atmospheric carbon into terrestrial ecosystems or reduced emissions from these systems. Much of the emphasis in the workshop was on forest systems, though other forms of biological carbon also were considered.

The RFF carbon sink workshop brought together a number of the world’s foremost authorities to examine the operational feasibility of biological sinks. A number of short papers were commissioned to address the question from a variety of disciplinary perspectives. Forest ecologists and economists, as well as specialists in other disciplines, were represented among the participants.

The significant obstacle to an international regime whereby sink activities will be encouraged is the perception that sinks are too uncertain to be a viable tool for carbon management. Common concerns about sinks that were addressed at the workshop include measurement, monitoring, permanence, and leakages and related side effects. If there is inadequate confidence in the ability of sinks to contribute to carbon management, international negotiators may not fully recognize the contribution of sinks and thus not create mechanisms to reward the provision of carbon sequestration services. In this case a market demand for carbon sinks would not develop, and the incentives and rewards for supplying carbon storage in biological sinks would not materialize.

Although the RFF workshop was not intended to generate consensus, the strong sentiment of many participants was that failure to incorporate sinks in climate mitigation efforts would be an unfortunate outcome. A number of studies have suggested that sinks could be

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relatively inexpensive and effective for carbon management. The forthcoming Third Assessment Report of the Intergovernmental Panel on Climate Change also suggests that the potential of sinks to sequester carbon is substantial, often at a low cost. Land use and forestry projects require relatively unsophisticated technology, although they may require institutional and political change in some countries to be truly effective. While further work is needed to develop effective and credible sinks mechanisms, the obstacles are mainly technical and can be overcome.

It would thus be a mistake, in the view of many workshop participants, for international negotiations to circumscribe the role of sinks from the start. In particular, some of the current debate over sinks actually is a debate over the stringency of different national emissions targets (and associated cost burdens) for “Annex B” (industrialized countries) under the 1997 Kyoto Protocol. This debate should be kept separate from the broader issue of sinks’ potential and the steps needed to realize that potential.

In what follows we summarize the discussion of key issues at the workshop.

1. Problems of measurement and monitoring for sinks do exist but are manageable. The consensus of workshop participants was that sinks can have a substantial effect on atmospheric carbon and can be measured and monitored with sufficient accuracy to allow sink management, accounting, and financial incentives for carbon sequestration services. It was well recognized by this group that some errors in measurement would occur. However, the relevant question is, What error is tolerable? Every measurement of greenhouse gas fluxes has some element of uncertainty. Techniques and methods of sampling design and measurement of individual carbon pools in forestry projects exist and are based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys—principles that have been well tested throughout the world. Experience has shown that with the use of these techniques, carbon pools can readily be estimated to be within ±10% of the mean, at a modest cost.

Well-established methods for monitoring carbon stocks typically involve sample plots. Additionally, remote-sensing technology, both from satellites and from low-flying airplanes can be used. Promising advances in this area include various innovations in camera capacity, filters, laser profilers, and so forth. Such systems produce estimates of forest features and biomass that are highly correlated with estimates attained with on-the-ground methods.

Considerable time at the workshop was given to measurement and monitoring issues: which pools should be monitored, for example, and which can be ignored if they are too difficult or expensive to track. It was agreed that some sinks were more difficult and more costly to measure than others. Also, with sampling procedures there is a trade-off between precision and costs. Above-ground biomass, for example, is easier and less costly to measure for a given degree of precision than, for example, soils. Forest soil carbon is, however, highly stable under most conditions. Thus, despite the presence of carbon in forest soils, it may be prudent to exclude it from estimates of carbon debits or credits, at least until measurement and monitoring procedures are further improved.

One presenter discussed monitoring and verification of carbon in vegetation using inventories and remote sensing information—an approach used to measure forest carbon across the United States. Other papers addressed carbon measurement for Costa Rica and for pilot projects in Bolivia and Brazil. The potential of increasingly sophisticated aerial and remote-sensing surveys was noted, and some participants had direct experience with such approaches. Sample size and sampling costs were discussed in the context of measurement errors. The question of site biomass and carbon for a dynamic, growing forest that also has woody debris was addressed.

2. The issue of permanence is readily solvable. The concern is that most biological sinks, including forests, are subject to unplanned disturbances and hence cannot, with a high degree of confidence, be built into national or project-level carbon accounting. Many workshop participants believe this overstates the problem. Although there will be some variability within these systems and individual forest sinks may come and go, the objective is to increase the aggregate amount of forest sinks though time. Monitoring can detect major changes in storage, and regulatory systems can be designed to hold sink owners responsible for such releases through various insurance and payment (and payment withholding) mechanisms. Carbon credit users would obtain extra credits through financial bonds that allowed additional carbon credits to be purchased on the sport market.

Disturbances and risks are a cause for concern for individual projects and may make incentive system payments more complicated, but unless there is a regionwide (or global) increase in disturbances, the law of large numbers suggests that individual failures are still consistent with a net increase in carbon sink mitigation. Furthermore, risk and uncertainty are not unique to carbon sinks and can be addressed through various insurance schemes, whether external or self-insurance, public or private.

3. Getting the baseline right is a problem, but not a problem unique to biological sinks. Baseline issues arise in connection with energy projects as well as sink projects. Moreover, project baselines and national baselines involve different problems. Where the baseline is tied to afforestation, reforestation, and deforestation, as in Article 3.3 of the Kyoto

Protocol, the establishment of a baseline involving those activities is reasonably straightforward. However, where a comprehensive approach is called for, as might be interpreted in Article 3.4, the problem becomes more complex and may involve a national system of sink monitoring.

Identifying the portion of changes in carbon storage due to management is challenging. Furthermore, although developed countries may have the resources and expertise to establish a reasonable baseline, developing countries may not. However, the importance of getting the baseline right can vary with the circumstances, such as the way that incentives are structured.

Consider, for example, a case in which transitions between land use categories (particularly forest and agricultural land) in the absence of any policy are relatively small. This probably characterizes the overall U.S. situation but it may not be the case for many developing countries. Suppose a subsidy is offered for the conversion of agricultural land to forest. Since baseline conversions of agricultural land to forest are small, most conversions observed when the policy is in effect could be attributed to the specific policy. To compute the change in carbon, one need only consider those acres that changed from agriculture to forest, since all other land use transitions—forest to forest, agriculture to agriculture, forest to agriculture—are the same both in the baseline and under the policy. The change in carbon for all acres that changed from agriculture to forest gives us a pretty good estimate of the change in carbon that can be attributed to the policy, and to the extent that these differ, we know the direction of the bias.

Although that argument works for a conversion subsidy, it may not work for a conservation subsidy in developing countries. In the case of the conservation subsidy, landowners would be paid to keep their land in forest. But what we observe under the policy is not a good approximation of the effects of the conservation policy: Many owners of forest land would keep their land in forest without the policy. Accordingly, it becomes necessary to sort out the owners who conserved their land in response to the policy and those who would have done this in any case. In other words, we need to identify the relevant baseline.

4. Leakage is a legitimate concern when monitoring forest carbon sinks. Leakage arises when activities undertaken in a specific sequestration project have ramifications outside the project that affect its global goals. The most obvious leak is the creation of a protected forest, in which the carbon pool is protected, that deflects the pressures for deforestation to a similar forest elsewhere. Project leakage can be accounted for through the use of a countrywide baseline. In the absence of such baselines, rules of thumb will have to be developed to make rough corrections for leakage.

5. Liability for failed sequestration projects remains an active area of discussion. Some participants argued that liability should fall on the seller when the project is in an Annex B country with an effective national carbon cap; but liability for specific sequestration projects in developing countries should reside with buyers. The liability issue might also be substantially lessened through a process of carbon "renting," in which payments are made on a periodic basis, after the sequestration service has been provided.

The short papers generated for the workshop bring together a variety of views and perspectives on carbon sinks. Although differences exist among the workshop participants, the reader of the papers will detect substantial agreement on the critical problems and how they may be addressed. The fact that carbon offsets are being created by the private sector and traded nationally and internationally indicates the market's early recognition of the importance of carbon sinks and their operational aspects.

Can Carbon Sinks Be Operational? Some Issues…..

Richard A. Birdsey

USDA Forest Service

Global Change Research Program

Roger A. Sedjo

Resources for the Future

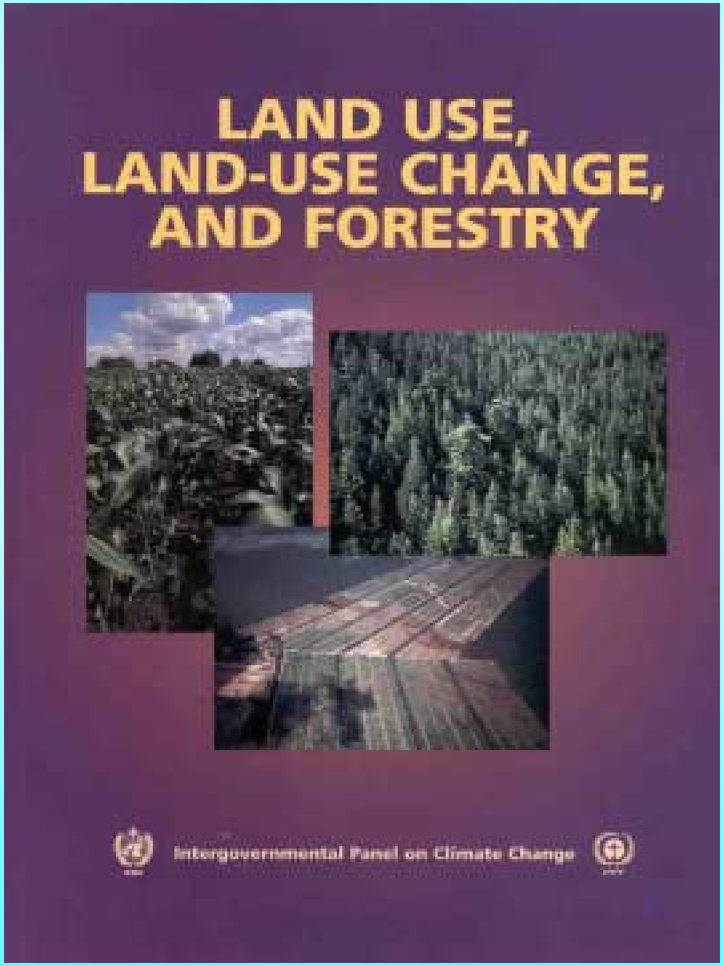
Resources for the Future Workshop

Washington, DC

April 30, 2001

Can Carbon Sinks Be Operational? Some Issues…..

- Definitions →
- Measurements →
- Accounting →
- Permanence →
- Leakage →
- Implementation →
- Research →



LAND USE,
LAND-USE CHANGE,
AND FORESTRY

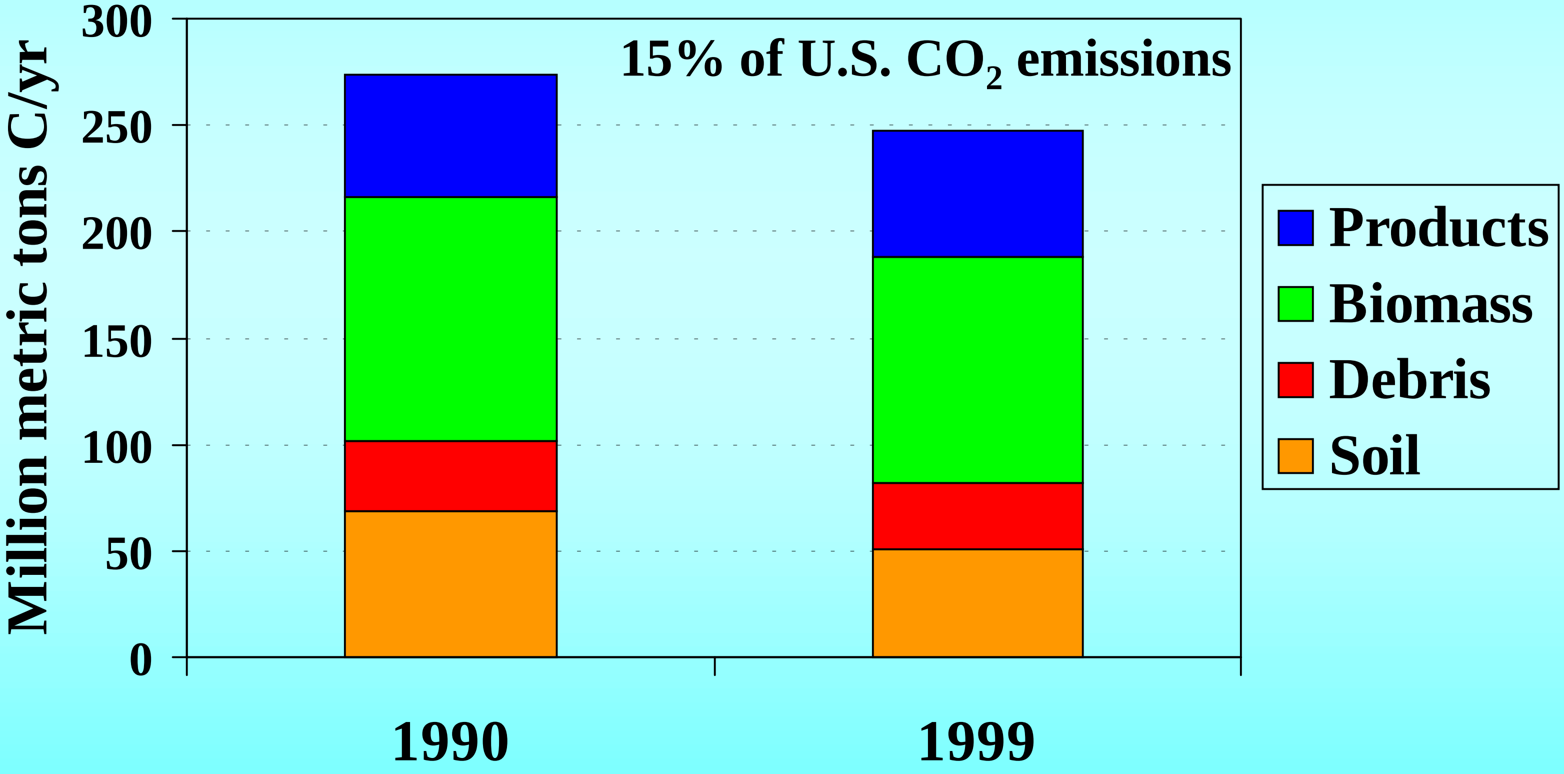
Intergovernmental Panel on Climate Change

Key Definitions

- Forest
- Afforestation
- Reforestation
- Deforestation

- Activity →
- Baseline →

Measuring the Baseline: Carbon Sequestration by the U.S. Forest Sector



Heath 2001, reported in EPA GHG Inventory

Groups of Carbon Accounting Variables and Ability to Monitor at Regional Scale in the U.S.

Live biomass	Good
Woody debris and litter	Fair
Soil organic matter	Poor
Wood Products	Fair

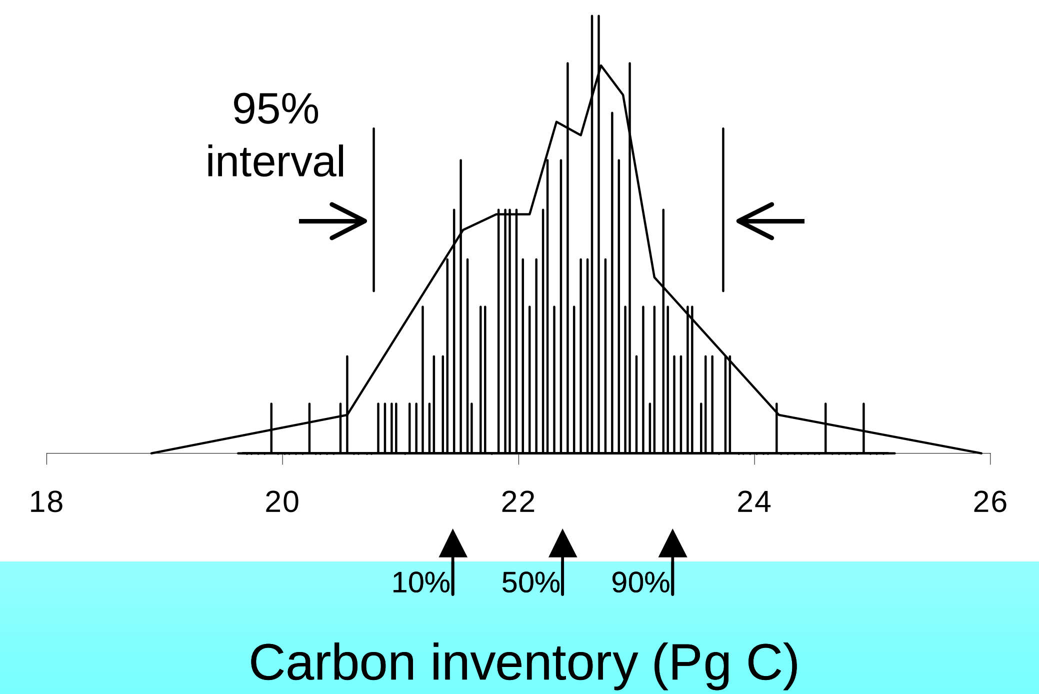
- ***Research needs***: efficient protocols for extensive monitoring; enhanced network of long-term intensive study sites; improved models and analysis
- ***Implementation need***: not all forest lands are monitored effectively for changes in ecosystem C

Measurement Issues (1)

- Monitoring system design
  - Frequency
  - Sampling vs. enumeration
  - Gaps and overlaps in coverage
  - Uncertainty →

Sources of Uncertainty

- Sampling and estimation errors
- Surprises (wildfire, climate change)
- Economic activity
- Uncertainty can be quantified →



Heath and Smith 2000

Measurement Issues (2)

- Biomass
  - Adequacy of equations
  - Coarse roots
- Coarse woody debris and litter
  - Methods available – needs implementation
- Soils
  - Need efficient indicators and sampling protocols
  - Account for “legacy effects” of past land use
- Wood products and landfills
  - New products and changes in technology
  - Imports and exports

Accounting Issues

- What activities count? →
- Additionality →
  - What is the baseline? Does baseline = BAU?
- What carbon stocks count?
- Land-based or activity-based?
- Separate direct from indirect causes? →
- Attribution of debits and credits?
- Transparent and verifiable?
  - Accuracy and precision

Accounting issues are closely linked to measurement issues

Activities to Increase C Sequestration Above Baseline

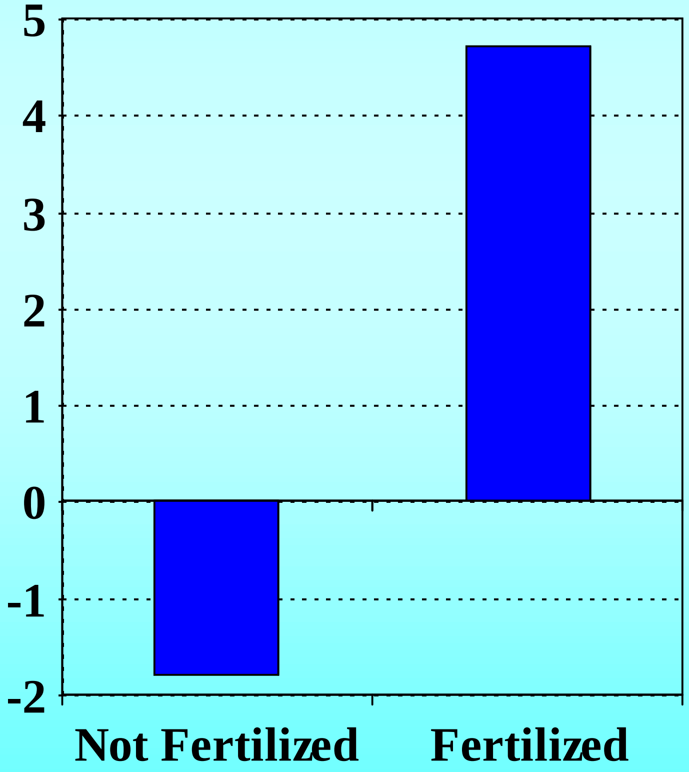
- **Increase Sequestration**
  - Afforest marginal cropland and pasture
  - Reduce conversion of forestland to nonforest use
  - Improve forest management →
  - Reduce harvest
  - Increase agroforestry on cropland or pasture
- **Increase Sequestration Plus Reduce Emissions**
  - Substitute renewable biomass for fossil fuel energy
  - More efficient use of raw material
  - Increase paper and wood recycling
  - Plant trees in urban and suburban areas
- **Reduce Emissions**
  - wildfire management
  - energy efficiency in wood production
  - product substitution to wood

Birdsey et al. 2000

Forest Management Practices to Increase Productivity

- Regeneration
- Weed control
- Fertilization →
- Genetic improvement
- Site management
- Stocking control
- Harvest methods
- Utilization of logging debris
- Low-impact harvesting

Net ecosystem production (tC/ha/yr) – 11 year old loblolly pine plantation



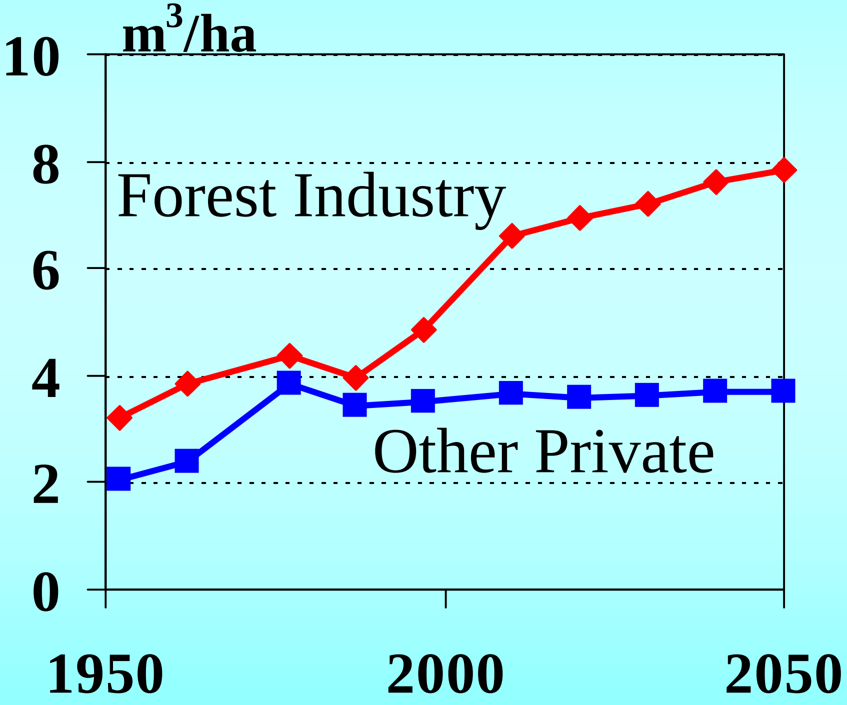
Sampson and Hair 1996

Johnson et al. 2001

What is the Baseline? Does Baseline = BAU?

Net Annual Growth in the South

- Forest industry lands are managed more intensively
- Average site quality better on forest industry lands
- Long-term trend toward more intensive management
- Opportunity to increase management intensity on other private lands



NOTE: units are volume not mass

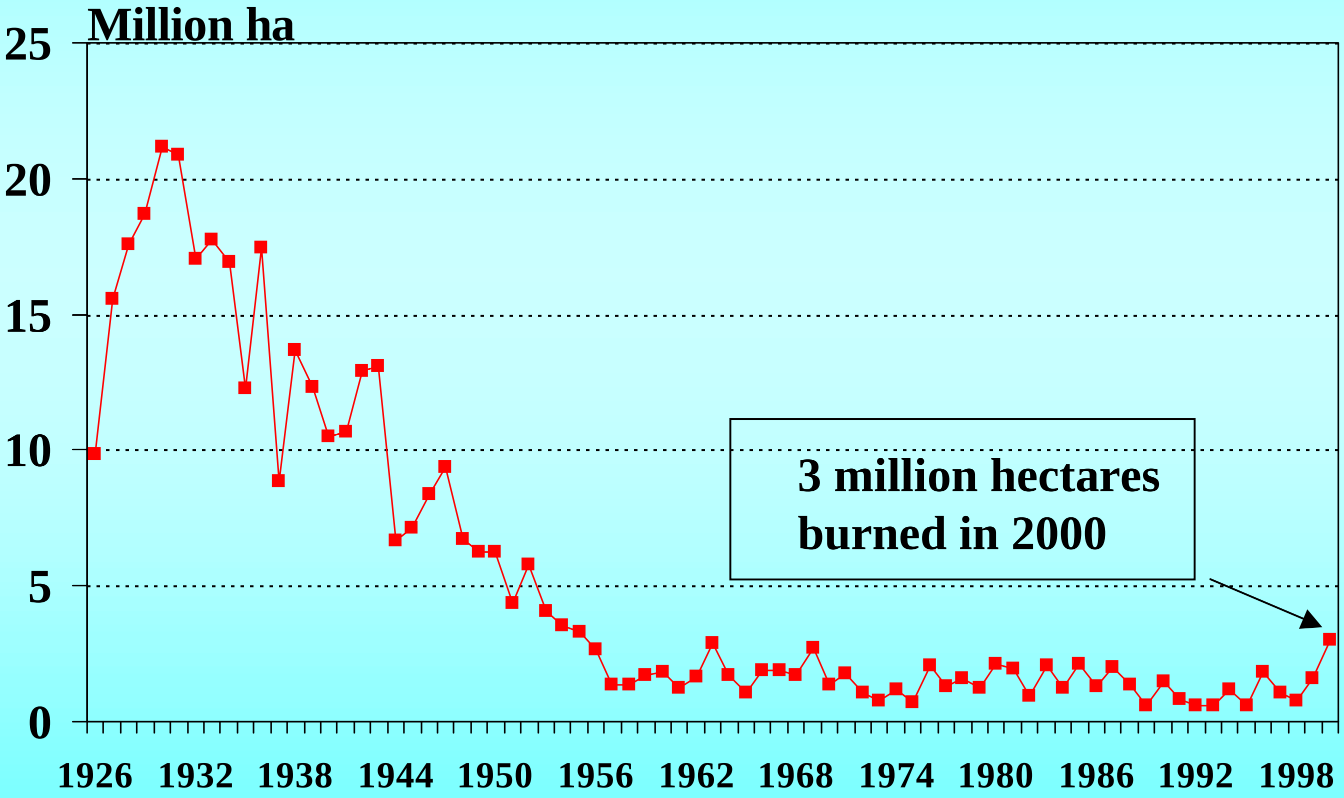
Separating Direct from Indirect Causes of Carbon Stock Changes

- **How to attribute effect …**
  - – Change in carbon stocks
- **…to causes**
  - – Natural (indirect): CO_2, N deposition, climate
  - – Human (direct): land use, land management

Permanence of Carbon Stocks

- Longevity and stability of stocks
  - Large tree boles and soil stocks (*Nature* 22 March 2001, “Carbon sinks for a century…”)
- Natural disturbances →
  - Risk to permanence
  - Accounting for anomalies during reporting periods (fires, hurricanes, climate, etc.)

U.S. Forest Land Damaged By Wildfire, 1926-2000

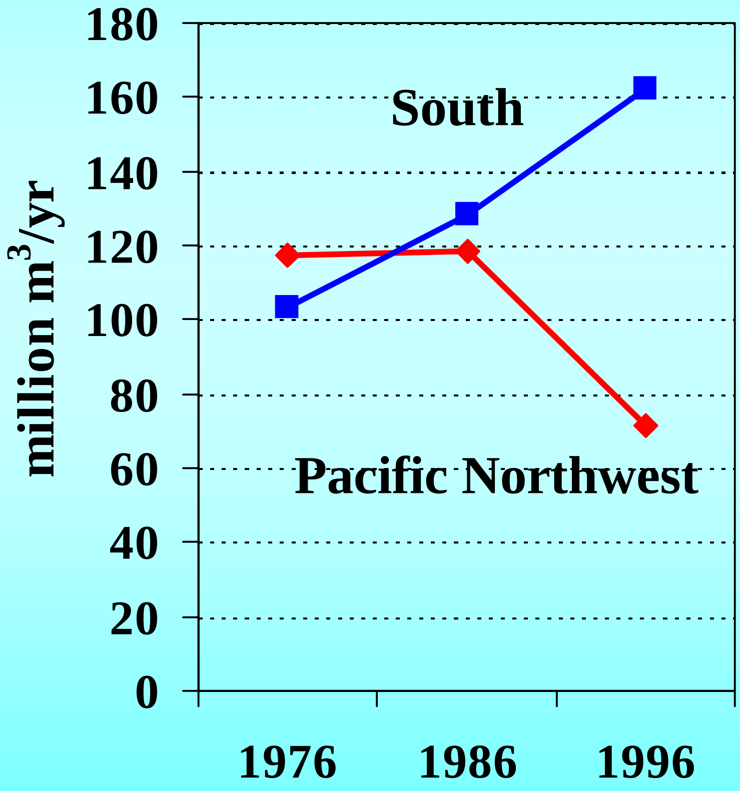


3 million hectares burned in 2000

Leakage Issues

- Direct substitution effects →
- Indirect effects
  - Increased planting for sequestration may offset plans to plant for timber production
- Difficult to measure

Removals of growing stock – U.S.



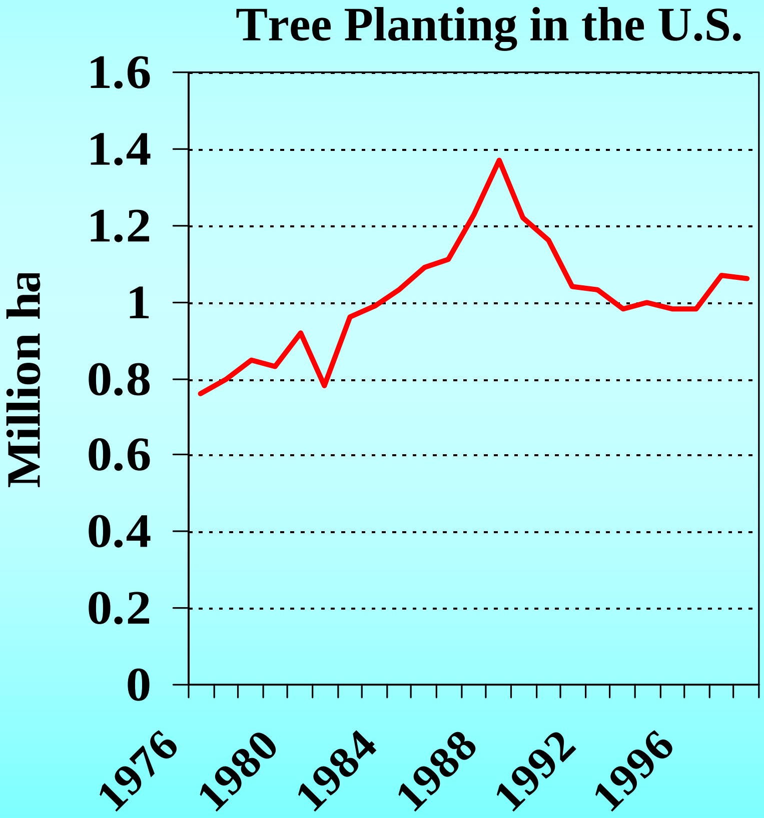
NOTE: units are volume not mass

Considerations for Implementing a Forest Carbon Sequestration Program

- Define roles of public agencies, private sector
- Landowner objectives – is increased carbon sequestration compatible with other objectives?
- A *suite* of practices may be effective
- Practices must be tailored to specific forest ecosystems which are highly diverse
- Knowledge of specific practices to apply in different situations is lacking
- Experience with programs suggests that incentives are required to engage landowners

Barriers to Increasing Forest Carbon Sequestration

- Infrastructure may be lacking (e.g. nurseries to produce tree seedlings)
- Lack complete knowledge of how forest practices affect ecosystem carbon pools
- Landowner assistance programs specific to carbon sequestration must be developed
- May be incompatible with other policy goals



USDA Forest Service

Monitoring Considerations in the U.S.

- Existing national inventory programs are speeding up and expanding coverage
  - Goal is 5-year cycle nationwide
  - “Wall-to-wall” sampling is envisioned
  - Filling gaps in ecosystem carbon pools
- Project-level monitoring feasible but not as part of National strategic monitoring
- International context regarding C accounting:
  - Accounting components and methods not yet defined
  - Methods must be transparent and verifiable
  - Possible need to separate direct from indirect causes
- Techniques research is ongoing
  - Part of mission of various research programs

Forest Carbon Research Needs

- Improve accuracy and precision in understanding, monitoring and predicting carbon storage and release
- Develop comprehensive carbon accounting models
- Predict carbon storage and dynamics based on conditions and management
- Develop and demonstrate management systems for increased productivity and carbon sequestration
- Develop cost-effective, low-impact forest operations systems
- Increase the durability, quality, and uses of wood products

A Pool Paradigm: Monitoring and Verification of Carbon in Vegetation Using Inventory and Remote Sensing Information

Pekka E. Kauppi

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A Pool Paradigm: Monitoring and Verification of Carbon in Vegetation Using Inventory and Remote Sensing Information

Pekka E. Kauppi*

Introduction

The objective of the UN Framework Convention on Climate Change is to stabilize atmospheric concentrations of greenhouse gases (GHG) at levels that do not cause harmful effects. I have earlier suggested that this goal may be too ambitious (Kauppi 1995); nevertheless, stabilizing the concentrations at the lowest possible levels appears important and reasonable. This paper deals only with carbon dioxide, omitting other GHGs. Carbon dioxide is probably the hardest gas to control. The policy objective considered here is the stabilization of the carbon dioxide concentration at the lowest possible level.

As the volume of the atmosphere can be assumed constant, concentration can be expressed as the pool of carbon in the atmosphere. This pool, measured in gigatons (Gt), has increased as follows (Siegenthaler and Sarmiento, 1993; ORNL CDIAC 2000):

1800	600 Gt
1980–1989	750
2000	789

Since our policy objective is to minimize this number (the pool and, hence, the concentration), the lower the pool at any given time, the better. Analysis and debate are needed on variants of this goal over different time spans. Given the momentum of the world energy and land use system, it will not be possible to stabilize the carbon pool of the atmosphere in, say, the next 30 years. But is it desirable to minimize the pool in the next 50, 100, or 150 years?

Sink policies need to be integrated into the control of fossil fuel emissions. Sinks can make an additional and incremental contribution to climate policy, reinforcing the effect of emissions reductions. One can wonder, though, whether the approach of the Kyoto Protocol, which puts fossil fuel emissions and sinks in the same basket, is optimal.

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Here I suggest an independent and separate regulatory policy addressing the *rates* of fossil fuel emissions, with a complementary policy for the sinks. The sink issues could be treated by focusing not on the rates but on the *pools*. The carbon pool in the vegetation and soils of the global land ecosystems is 1,000 to 2,000 Gt (IPCC 2000)—much larger than the current pool of carbon in the atmosphere (790 Gt). "Pool paradigm" implies that maximizing the carbon pool in land ecosystem is a tool for minimizing the pool in the atmosphere.

What about *substitution*—that is, using renewable biomass to substitute the use of fossil fuel reserves? I suggest considering substitution as an instrument for reducing fossil fuel emissions. By definition, substitution has an impact on the rates of fossil fuel emissions. If the regulatory policies for the emissions were separate from those for the sinks, substitution would be treated as an element of emissions policies.That would reduce the scope of sink policies to the relatively feasible task of maximizing the carbon pool in land ecosystems at, for example, a national level.

The objective of this paper has been to introduce the pool paradigm for consideration in the policy dabate. If the pool paradigm is adopted, monitoring, modeling, verifying, and predicting changes in the carbon pools of vegetation and soils appear critical. Referring to two submitted manuscripts, I present the latest methodologies and preliminary findings on carbon pools, and the changes of carbon pool in the forest vegetation of the boreal and temperate zones.

Methods

First, Liski et al. (2001) collected and assessed the latest information describing the carbon pool in forest vegetation over large geographic areas. The data came from a recent international study (ECE/FAO 2000). Liski et al. (2001) essentially updates the results of Dixon et al. (1994), though only for about half of the global forest area (forests in the temperate and boreal regions). The ECE/FAO 2000 observations are six to eight years more recent than those reported in Dixon et al. (1994). In some cases the new data are more reliable because the methods have improved.

Second, Myneni et al. (2001) have combined remote sensing observations with the ECE/FAO data and produced estimates of the carbon pool in vegetation on a grid of 8×8 km for North America and Eurasia. The latter study, in particular, adopted the pool paradigm, and flux data on growth rates, removals, and mortality rates were not needed.

Results and Discussion

Both studies showed a larger carbon sink in the forest vegetation of the study region than the one reported seven years earlier (Dixon et al. 1994). Liski et al. (2001) showed that the net annual increment (NAI) has increased in all regions and has enhanced the vegetation carbon pool, because annual fellings have either increased less than NAI or decreased, as in the case of Russia (Figure 1). Myneni et al. (2001) observed similar general patterns, showed larger geographic details, and used a consistent methodology for all countries, unlike ECE/FAO (2000), in which inventory methods vary from country to country. For verification purposes, the method in Myneni et al. (2001) appears promising because field verification can be organized in grid cells of 8×8 km. However, the method must be further tested and evaluated.

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Siegenthaler, U., and J.L. Sarmiento. 1993. Atmospheric carbon dioxide and the ocean. *Nature* 365:119–25.

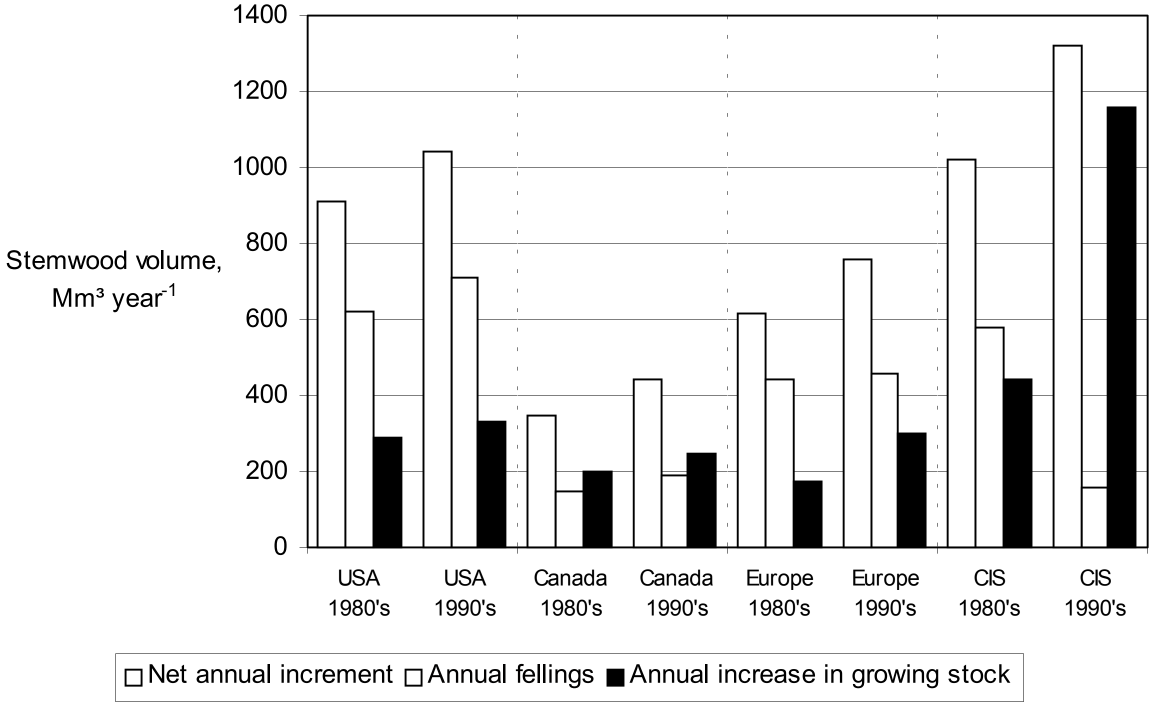

Figure 1. Net annual increment, annual fellings, and annual increase in growing stock, the latter calculated as the difference between the former two, of trees in temperate and boreal forests in the 1980s and the 1990s. Inventories labeled "1980s" were taken in some countries in the late 1970s. Net annual increment is the gross stemwood volume increment less the stemwood volume of trees or stands that die naturally from fire, insects, disease, etc. Growing stock is the stemwood volume of living standing trees. Reproduced from Liski et al. (2001) with the permission of the authors.

Making Sinks Operational In the Kyoto Protocol

Ian Noble

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Making Sinks Operational in the Kyoto Protocol

Ian Noble[*]

Introduction

Sinks—uptakes to or reductions in emissions from terrestrial ecosystems—can make a significant contribution in slowing the rate of buildup of greenhouse gases (GHG) in the atmosphere. However, there are two significant threats to establishing an international regime whereby sink activities will be encouraged: first, that international negotiations will not fully recognize their contribution, and second, that the uncertainties and costs of trading sink sequestrations may damage market confidence in them and thus lose the capital flow that is essential.

Clearly, it is essential that the Kyoto Protocol—a variant or an entirely new version—be ratified if sinks are to have any reality. The prevailing view is that this largely depends on reengaging the United States and the European Union (EU) in productive discussions. This paper is written with the assumption that such a reengagement will be achieved, and that individual parties' attitudes toward sinks are largely determined by the relative advantage or disadvantage to be realized from their inclusion in the protocol.

Reengaging the United States

I suggest that the United States will not move to ratification of any protocol unless this country will clearly be able to comply in the first commitment period(s). Currently, U.S. emissions are roughly 300 million tons of carbon (MtC) per year over its assigned amount, although significant reductions to emissions can be made via energy efficiencies and the increased application of current technology before the first commitment period. However, sinks

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play a pivotal role in the U.S. position, both in credits that may be gained from internal actions and in a reduced price of carbon if substantial sink opportunities are included in the flexibility mechanisms.

Land Use Interpretations

The proposal put forward by the United States before the Conference of the Parties 6 (COP 6) sought to claim just over 300 MtC/yr from a radically different interpretation of Article 3.4. It sought credit for carbon accumulating in forests, rangelands, and croplands. The proposal is consistent with the "broad land-based approach" to accounting outlined in the Special Report on Land Use, Land-Use Change and Forestry issued by the Intergovernmental Panel on Climate Change in 2000 (IPCC Special Report). However, the U.S. proposal has been criticized on two grounds.

First, it seeks credit for processes initiated long before 1990 but maintained by continuing management action (or inaction) since then. It also would capture some of the "free ride" that arose from the increased uptake of carbon by terrestrial ecosystems due to increased CO_2 concentrations, nitrogen inputs, and warming. The United States said it was proposing a "comprehensive approach would best account for the full range of natural and human activities that could affect the global climate system," an approach it said was "also consistent with the nature of the agreement struck at Kyoto, which was intended to include [land use, land use change, and forestry, or LULUCF] in a manner that would result in significant additions in the first commitment period to the assigned amount of countries that are sequestering large amounts of carbon (including the United States)."

Was there a clear understanding at Kyoto that credit would be given only for actions to reduce emissions or increase uptakes taken since the beginning of 1990? Much of the text of the protocol suggests this, including the 1990 baselines for nonsink emissions and the post-1990 requirement for activities for Article 3.3 and similarly for Article 3.4 in the first commitment period. President Pronk has recently confirmed his view on this in "New Proposals by the President of COP 6" (April 9, 2001). The argument is that the Kyoto Protocol is an attempt to make a significant change in the buildup of greenhouse gases in the atmosphere, and thus changes that were already in chain before the negotiations leading up to the protocol (taken as January 1, 1990) should not be credited.

But there have always been different interpretations of Article 3.4 about the validity of including activities that began before 1990 and were maintained after that date. Similar questions could be raised about the decision to shift from coal to gas in the United Kingdom, or when the decision was made to move toward reunification of Germany and the revival of the East German industries. The United States might claim that ongoing uptake from land management decisions made many decades before the Kyoto Protocol but maintained by active decisions up to 1997 and since is equivalent to the above cases. If that is true, then was that fully understood by all parties at Kyoto? My interpretation was that it was not, and I find it surprising that the United States waited so long to clarify its understanding.

The second criticism of the U.S. proposal is that the country would gain credit for processes that many see as not being human induced. The best estimates of the dynamics of the global carbon budget indicate that a net 2.3 gigatons of carbon (GtC) per year are being taken up by terrestrial ecosystems mainly a result of CO_2 fertilization, warming, and nitrogen deposition, but also including the increase of biomass in forests and woodlands as a result of changes in management practices over past decades (IPCC Special Report). A rough estimate suggests that at least 1 GtC/yr of the worldwide 2.3 GtC/yr is being taken up in industrialized, Annex 1 countries. This is more than enough to reduce emissions below business-as-usual projections to meet the emissions reduction targets defined at Kyoto. The United States has argued that the vast majority of the estimated land-based uptakes are attributable to changes in past management regimes rather than “greenhouse” effects. However, it recognized that some of the claims might be contentious by noting in that some discounting might be necessary.

Renegotiating the Protocol

A common complaint about the Kyoto Protocol is that the targets were set before the costs were known. There could be a reorientation of the current protocol and possibly a renegotiation of the differentiated targets, or the process could use an entirely different basis. McKibbin and Willcoxen[1] of the Brookings Institute have made one such proposal (see Appendix 1), which seems to encompass the use of sinks within national boundaries to achieve compliance, but only if they are available for less than their base price of $10 per tonne of carbon for emissions permits.

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[1] Web address http://www.brookings.org/comm/policybriefs/pb066/pb66.htm

The European Union's Skeptical Position

The EU has taken a much more skeptical approach to sinks than many other nations. Most EU parties have less to gain from the comprehensive inclusion of sinks in a protocol than do their trading partners. Their criticisms have been wide-ranging, and I will deal with some of them below, under "Threats to Sinks." Other criticisms relate to the inclusion of sinks in the CDM.

It is often implied by commentators, nongovernmental organizations, and sometimes delegates to the negotiations that there is something suspicious about the so-called Australia Clause, the second sentence of Article 3.7. I have argued elsewhere (Noble and Scholes 2000, and see Appendix 3) that this clause is an essential component of a gross-net accounting system. It is clear that without it Australia may well not have even become a signatory to the protocol. The effect of the clause, coupled with Australia's "generous" target of 108%, means that Australia can achieve compliance in the first commitment period despite an almost 2% annual increase in emissions from fossil fuels and industrial processes. However, it does require that Australia significantly reduce its land clearing—no simple task in a federation of states where land management is a state matter. Australia faces continuing uncertainty about the amount of carbon uptake due to the invasion of woody plants into areas that were grasslands or open woodlands under indigenous land management. The operation of Article 3.7 in Australia depends upon on the precise amount of invasion and clearing of such areas, and there is a debate about whether the process is human induced. The issue of "woody weeds," as this invasion is often called, is likely to be contentious in future negotiations over sinks, as woody weeds appear to constitute a significant part of the U.S. claim under Article 3.4.

Loss of Market Trust in Sinks

Another threat to sinks in the protocol is the loss of market trust that sinks can be measured with sufficient accuracy and at reasonable cost so that they can be incorporated in a trading system. Another threat, still rarely discussed, is the variability of the emissions and uptakes from sinks over time spans of a year to five years.

Overcoming the Threats

Accounting Standards

There seems to be a view in some quarters that it is necessary to account for every tonne of carbon. Doing so will bring with it enormous costs, and I do not believe that this is necessary. What is important is that any omission or miscount err on the side of the atmosphere; that is, that accounting during a commitment period overestimate emissions and underestimate uptakes. This leaves entities free to choose measurement and accounting systems most appropriate to their particular cost-benefit analysis.

What Error Is Tolerable?

It is difficult to conceive of an emissions trading system in which the credits are not fully fungible. Thus, it is essential that all credits appearing on the market convey with them the same minimum level of greenhouse gas reduction and surety that this will persist. However, questions have been raised as to whether it is possible to measure some important carbon pools—particularly soil carbon—with sufficient accuracy.

Every measurement of greenhouse gas fluxes or changes in stocks has some element of uncertainty. This is particularly a problem using a stock change method, as recommended under Article 3.3. Simple calculations quantify the error in calculating the incremental loss or gain of carbon in a pool when the pool is measured at the beginning and end of a commitment period:

$$\text{95\% confidence limits of the change in stocks} = \frac{2.8 * \text{Sampling error}}{\text{Proportional change} * \sqrt{n}}$$

where *sampling error* refers to the inherent error in the measurement (here, the ratio of the standard deviation to the mean of any soil carbon), *proportional change* is the change in soil carbon being measured, and *n* is the number of independent samples of the change made at a site. This implies that unless the error associated with the measurement technique is at least an order of magnitude smaller than the proportional increment being estimated, large numbers of samples will need to be taken at each site. For example, if the increment in soil carbon over the commitment period is 1% but the error of the sampling procedure is also ±1%, then about 100 samples will need to be taken to reduce the 95% confidence limits of the estimate of the change in stocks to ±14% of the mean estimate. Thus, although it is technically feasible to estimate small changes in stocks with relatively insensitive methods, the number of samples required increases dramatically, and along with it, the costs.

Impermanence

Expiring CERsThe Colombian proposal for expiring CERs is a commonsense approach to the permanence issue in sink projects. While the CERs survive, via either the original contract or any renewal, they should be regularly monitored, just like any other sequestration or emissions reduction, to ensure their validity. But once the CERs are allowed to expire, it is assumed that the CO_2 is immediately returned to the atmosphere.

Obviously, liability for replacing the CERs, whether by extending the existing project, with new expiring CERs, or with more permanent credits, remains with the buyer. I suggest that liability should also rest with the buyer if the CERs expire early because of a breakdown in the original contract. The buyer may wish to negotiate insurance, penalty clauses, or lower prices to buffer losses of this kind.

Annual Variability in Sinks

There has been little consideration of the effect of climatic and other environmental variability on the uptake of carbon by sinks. At national scales the annual fluxes vary with weather patterns over the year. For large nations there tends to be a spatial averaging, as some regions experience better growing conditions and others, poorer. However, large-scale weather patterns, such as El Niño, do cause significant variation in the global uptake.

Annual variability becomes particularly acute in emissions trading associated with projects confined to a geographical location. Appendix 2 shows some calculations for a proposed trading scheme in which the validity of the traded certificates was guaranteed by allowing sellers to sell only a proportion of the best estimate of the sequestration expected from a project during the first commitment period. Simple calculations show that even if relatively risky positions are taken (e.g., in two of three projects, the predicted sequestration will be met or exceeded), only 70% of the best estimate of that sequestration should be traded. With a more conservative approach, the figure drops to 50%—a significant discount in the value of carbon sequestration in land-based sinks. Managing a pool of projects over a wider geographical range can reduce the overall risk; however, other forms of risk, such as losses due to disturbances, also need to be taken into account.

Fires

Current accounting systems do not deal adequately with fire. The IPCC guidelines (1996) for national accounting under the Framework Convention on Climate Change recommend that the emissions of non-CO_2 greenhouse gases from savanna and agricultural burning be accounted for, but CO_2 emissions are not included. The global emissions of GHG from burning each year are significant but in the long term are balanced by increased uptake of carbon during regeneration following fire. However, this approximation breaks down when applied to accounting under the Kyoto Protocol.

Changes in the fire regime can lead to significant changes in carbon stocks. For example, Houghton et al. (2000) estimate that from 1950 to 1990 the policy of fire prevention, introduced early in the century, led to the accumulation of more than 200 MtC/yr. This is a significant component of the uptakes claimed by the United States under its interpretation of Article 3.4 in the leadup to COP6. There are other hidden errors in national accounts. For example, Australia bases the uptake by managed forests for its 1990 baseline on the age structure of the forest types and their associated growth rates. A significant component of these growth rates is the contribution of fast-growing forests recovering from fire. However, the calculations do not include the losses due to fires, as these are assumed to be balanced by the enhanced uptakes. Thus, the accounting is unbalanced.

Those errors are subtle and probably not important compared with the quantities of emissions involved in the negotiations of the differentiated targets. However, the problem of fires arises again in emissions trading. If an area subject to traded CERs or ERUs is burned, it might be expected that the carbon losses will be made up by the selling party though either a backup site (i.e., underselling their stock of accumulated carbon) or insurance. However, under IPCC guidelines this will not be reflected in the national accounts.

In summary, very little thought has been given to the whole area of year-by-year variability and in particular to the role of disturbances, especially fires, in the accounting and trading system. I believe that the issues are complex but nevertheless soluble.

Can Sinks Make a Difference without the CDM?

I have avoided any significant discussion of sinks in the Clean Development Mechanism (CDM) in deference to the greater expertise of other speakers. However, I wish to conclude by arguing that terrestrial sinks provide an opportunity to buy time while technological change and innovation occur. The global capacity is significant but ultimately limited. The goal of any agreement on reducing greenhouse gases in the atmosphere should be to encourage the use of all sink opportunities that are cost effective and whose social or environmental effects do not outweigh their benefits. Any protocol should provide incentives to create new sinks or emissions reductions and no disincentives for those already in place from either “natural” or human-induced processes.

The IPCC Special Report shows that the greatest sink opportunities are in the developing world. The restriction of sinks to Annex 1 countries and to Article 3.3 and a narrow interpretation of Article 3.4 would buy very little time. It would also have a major impact on the price of carbon credits in the first commitment period, as many studies have shown.

Some European commentators have expressed the view that sinks are an unnecessary complication to the Kyoto Protocol and are largely the reason for the current impasse (see, for example, the comments by Svend Auken, Danish Minister of Environment and Energy, at the Pew Center, April 18, 2001[2]). If credits for sink activities are restricted to Annex 1 countries, or if loopholes allow preexisting uptakes to be counted, that view will be largely true. However, I think it is important that a way to operationalize sinks in their widest context be found, thereby allowing time for the social and technological changes to a society less dependent on fossil fuel emissions.

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[2] See www.pewclimate.org/events/auken.cfm

Appendix 1

Key Elements of the McKibbin-Wicoxen Proposal

All countries create two assets:

1. an emissions permit, which is required by fossil fuel industries to supply a unit of carbon annually; and
2. an emissions endowment, which gives the owner an emissions permit every year forever.

All countries create two domestic markets:

3. a domestic emissions permit trading system with a fixed price of $US10 per ton of carbon in Annex 1 countries and a cap price of $US10 in non-Annex 1 countries; and
4. a domestic emissions endowment trading system with a flexible price.

In 2000, all countries are allowed to make a once-only allocation of emissions endowments domestically based on Kyoto targets for Annex 1 countries and current emissions plus a percentage to be determined for non-Annex 1 countries. Trading in both markets begins January 2001.

Permits must be reconciled against production or imports of carbon on an annual basis at the top of the carbon production chain (coal mines, oil refineries, gas refiners). Production that is exported is exempted.

Every decade there is a meeting of the Conference of the Parties to the UNFCCC to evaluate the extent of abatement and the state of climate science, and to negotiate new prices for permits.

Appendix 2

Uncertainty in Trading Sinks

The commodity to be traded is the amount of carbon sequestered from the start of 2008 to the end of 2012 on land falling under Article 3.3 (often interpreted as deliberately established forest on land that was not forested in 1990). There may be opportunities to trade carbon sequestered in other circumstances, but this discussion is limited to the above.

In forecasting this amount, the following information is required:

- An estimate of the area of forest (A).
- An estimate of the carbon at the start of 2008.
- An estimate of the increment in carbon through the end of 2012.

Projecting forest growth is a standard part of forest practice used in management, planning, and forecasting future harvests and sales. Usually, yield tables and models are used to forecast the cubic volume of timber. To covert such estimates to carbon, three factors are needed:

5. A conversion of the volume of log to carbon content. This can be calculated by multiplying by wood density and the carbon content of wood.
6. An expansion factor to allow for the nonlog biomass (and carbon) in branches, bark, and leaves.
7. A similar conversion factor to allow for below-ground carbon.

Each of the above estimates is subject to uncertainties, which will vary by species, growing conditions, individuals, and stand age.

Here we assume that below-ground carbon changes little, and thus item 3 is ignored. Separate rules will be required to exclude stands in which this assumption about soils may not be true, or more particularly, where root and soil carbon may be lost.

Items 1 and 2 above can be combined into a single conversion factor (E) that converts forecasted log volume to above-ground carbon for that site.

Thus, the final equation for estimating the tradeable carbon is:

Carbon =

Area * Log volume per ha at the start of 2008* proportional growth increment of that log volume over commitment period (2008 through 2012) * E
or $C = A * L * G * E$

The equation is expressed in the form of the product of four largely independent variables, and in this form the uncertainty of the overall result can be calculated from a simple equation using the uncertainties associated with each of the variables[3]:

$$U_C = \sqrt{(U_A^2 + U_L^2 + U_G^2 + U_E^2)}$$

Here U is the ratio of the standard deviation to the mean for each variable.

Once we have calculated U_C, a conservative estimate of the amount of carbon to be traded can be made. For example, nine of ten forest stands will have a tradable carbon content of greater than:

$$C * (1 – p * U_C)$$

where $p = 1.65$. If a less conservative approach to trading is used, the value of p would be lower (eg. 1.28 for four of five stands, and 0.97 for two of three).

Rough Estimates of the Uncertainties

U_A can usually be measured with high certainty. For example, sd/mean = 0.02 and maybe up to 0.05.

U_L depends on a number of factors, but by using 2000 data as a starting point, we require projections of growth over the next seven years. Climatic variability sets a lower limit to the uncertainty (i.e., a minimum value for sd/mean). If variation in annual rainfall is taken as a guide to the effect of climatic variability on growth, then most forestry areas have a sd/mean for annual rainfall of about 0.24 with higher values in drier areas. Variation from year to year is approximately independent[4], and thus variation in the growth over seven years would be reduced by approximately $1/\sqrt{7}$. These estimates are very approximate and fail to take into account the uncertainty of the growth behavior of stands. They can, however, be determined more directly by

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[3] See standard texts or IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories available at http://www.ipcc.ch/

[4] El Niño and similar phenomena lead to autocorrelation in annual weather patterns

reference to forest plots, growth rings, etc. They can also be partly estimated from models such as CO2FIX, CAMFOR etc[5]. Preliminary runs with CAMFOR suggest that the uncertainty introduced by uncertainty in parameterization is only about 0.07, although I suspect that this estimate is low. However, models that are derived from particular species and silvicultural practices should have a low uncertainty. There is also an uncertainty associated with the estimate of the starting log volume in 2000, but this should be of the order of sd/mean = 0.05, as it can be directly measured. Combining these uncertainties gives a minimum uncertainty of:

$U_L = \sqrt{}(0.24^2/\sqrt{}7 + 0.07^2 + 0.05^2) = 0.17$

A similar limit to certainty due to climatic variation applies to the estimate of U_G. In this case estimates are over five years of growth, which means that the minimum values for sd/mean are 0.24 divided by √5—that is, 0.11—and the full uncertainty is:

$U_G = \sqrt{}(0.24^2/\sqrt{}5 + 0.07^2) = 0.18$

U_E is more difficult to estimate and probably has the greatest uncertainty. It is most likely that sd/mean is of the order 0.20 or higher. It may be lower for stands of well-known species growing in well-known locations.

These rough estimates show that the minimum estimate of U_C is:

$U_C = \sqrt{}(0.02^2 + 0.17^2 + 0.18^2 + 0.20^2) = \sqrt{}0.1002 = 0.32$

This would mean that if a rule that nine of the ten forest stands entering an estate had to be above the traded carbon content, then the maximum proportion of the best estimate of carbon content that could be traded is about 50%. However, this result is strongly affected by the value for U_E. If the value is reduced to 0.1, then the proportion that could be traded rises to 60%. If in addition the rule is reduced to two of three, the proportion that could be traded increases again to 70%.

The above calculations represent a very rough investigation of the nature of the problem. Each of the steps needs to be dealt with in more detail by reference to forest datasets and evaluation of the actual yield projection models being used.

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[5] These models are usually not responsive to year by year climatic variations, and thus can be used only to assess the uncertainties that may be inherent in parameterising the growth projection model per se.

The message from the rough analysis is that without more detailed analyses, trading more than 50% to 60% of the estimated carbon content even on the best-estimated stands would be risky. If the tradable proportion is to be increased, then the uncertainty about the conversion factor (essentially, stand volume to stand carbon) must be reduced. The inherent uncertainty due to climatic variation also needs to be checked, although even if the sensitivity to climate were half that estimated above, then the tradable proportions would be increased by only 5% to 10%.

Appendix 3

(From Noble and Scoles 2000, *Climate Policy,* Volume 1)

The "gross-net" issue and Article 3.7

The Kyoto Protocol specifies what is called the "gross-net" approach to accounting for carbon. That is, the 1990 baseline used for setting assigned amounts is based on aggregate anthropogenic CO_2 emissions of greenhouse gases listed in Annex A of the Protocol. Annex A includes emissions from the energy, industrial processes, solvent and other product use, agriculture, and waste sectors ("industrial sectors"). A land-use change and forestry (LUCF) sector, which includes both emissions and sinks, was excluded late in the course of the negotiations. However, many parties felt that some of the opportunities for increased uptake in sinks should be counted and that Articles 3.3 and 3.4 should allow a limited set of LUCF-sector emissions and sinks to contribute to compliance during commitment periods. Hence the accounting model is often referred to as a gross-net system. That is, assigned amounts are based on gross (but not fully inclusive) emissions, and compliance includes some additional activities where net emissions (emissions minus sinks) are calculated.

Articles 3.3 and 3.4 also limit the sources and sinks to be counted in the first commitment period to those resulting from activities since 1990. If this qualification had not been added, then all nations with a net sink in the allowed LUCF activities would have received an amount equivalent to that net sink as a windfall toward compliance (compare country A under Rules 3 and 4 in Appendix Table 2a).

In contrast, countries with significant land-clearing and consequently net emissions from LUCF activities would be penalized by a gross-net accounting system (compare countries A and C under Rule 4). Article 3.7 (Rule 5) helps redress this problem by allowing countries "for whom land use change and forestry constituted a net source of greenhouse gas emissions in 1990" (the "trigger") to include net emissions from "land-use change for the purposes of calculating their assigned amount."

There have been many queries as to why the trigger for Article 3.7 is "land use change *and forestry*" but only land use change is included in calculating the assigned amount. Also, some have noted that a country's situation changes significantly according to whether it is just above or below the trigger (see countries D and E under Rule5).

A common suggestion is that forestry be included in calculating the assigned amount (see Rule 6), but this defeats the purpose of Article 3.7, since it reintroduces a penalty for forestry sinks, as in Rule 3. A better rule would have been to omit forestry from the trigger clause (Rule 7); however, this would mean that any nation with significant land use change and especially land clearing would have come under Article 3.7. Rule 7 is a symmetric accounting of greenhouse gases, in that the assigned amount is based on emissions, and compliance is based on that same set of emissions with the additional incentive to increase sinks in Kyoto lands.

There have been suggestions that the trigger component of Article 3.7 be removed and the adjustment to the assigned amount be applied to all countries. Forestry could be included or excluded in calculating the assigned amount (Rules 8 and 9). In either case the outcome is equitable to all countries, in that the required reductions in emissions from the industrial sectors are about the same. If forestry is included in calculating the assigned amount, then all countries are penalized, and thus Rule 8 would be unlikely to gain favor.

		Country		A	B	C	D	E	
				Base	Declining forest uptake	With stable land-clearing	Just above the trigger	Just below the trigger	
	Industrial emissions 1990	I		100	100	100	100	100	
	Forest sinks 1990	F90		-10	-10	-10	-10	-10	
	Land-clearing emissions 1990	C90		0	0	20	11	9	
	Forest sinks 2010	F10		-8	-3	-8	-8	-8	
	Kyoto forest sinks 2010	K		-2	-2	-2	-2	-2	
	Land-clearing emissions 2010	C10		0	0	20	11	9	
	QELRO	Q		0.9	0.9	0.9	0.9	0.9	
	2010 Target for industrial emissions	IT (negative is a required reduction in emissions)							
Rule									
1	**Net-net**	A = Q * (I + F90 + C90)	A	81	81	99	91	89	**1**
	All carbon sources and sinks	A - (I + F10 + K + C10)	IT	-9	-14	-11	-10	-10	
2	**Gross-gross**	A = Q * I	A	90	90	90	90	90	**2**
	Only "industrial" emissions	A - I	IT	-10	-10	-10	-10	-10	
3	**Gross-net**	A = Q * I	A	90	90	90	90	90	**3**
	Full inclusion of "sinks" in compliance	A - (I + F10 + K + C10)	IT	0	-5	-20	-11	-9	
4	**Gross-net as in Kyoto Protocol but no 3.7**	A = Q * I	A	90	90	90	90	90	**4**
	"Sinks" limited to post 1990 activities	A - (I + C10 + K)	IT	-8	-8	-28	-19	-17	
5	**Gross-net Kyoto & A3.7 as in Protocol**	if (F90 + C90) > 0 then A = Q * (I + C90) else A = Q * I	A	90	90	108	100	90	**5**
	Strict Kyoto Protocol	A - (I + C10 + K)	IT	-8	-8	-10	-9	-17	
6	**Gross-net Kyoto & modified A3.7**	if (F90 + C90) > 0 then A = Q * (I + F90 + C90) else A = Q * I	A	90	90	99	91	90	**6**
	Forestry included in assigned amount	A - (I + C10 + K)	IT	-8	-8	-19	-18	-17	
7	**Gross-net Kyoto & modified A3.7**	if (C90) > 0 then A = Q * (I + C90) else A = Q * I	A	90	90	108	100	98	**7**
	Trigger and assigned amount exclude forestry	A - (I + C10 + K)	IT	-8	-8	-10	-9	-9	
8	**Gross-net Kyoto & modified A3.7**	A = Q * (I+F90+C90)	A	81	81	99	91	89	**8**
	A3.7 applied to all parties	A - (I + C10 + K)	IT	-17	-17	-19	-18	-18	
9	**Gross-net Kyoto & modified A3.7**	A = Q * (I+C90)	A	90	90	108	100	98	**9**
	A3.7 applied to all parties; forestry excluded	A - (I + C10 + K)	IT	-8	-8	-10	-9	-9	

Appendix Table 3a.

The outcome of applying nine accounting rules to five hypothetical countries (A to E). Each country has the same emissions from its fossil fuel and industrial sectors but different emissions and sinks associated with its land use change and forestry sectors. The table shows the assigned amounts (A) and the change required in the fossil fuel emissions and industrial sectors (IT) to allow each country to meet its assigned amount in the first commitment period. Negative numbers represent sinks or reductions in emissions. The IT rows give an indication of the difficulties that the industrial sectors in each country would face in compliance. Negative numbers in this column represent required emissions reductions.

From Noble and Scholes (2000).

Measuring and Monitoring Carbon Benefits for Forest-Based Projects: Experience from Pilot Projects

Sandra Brown

Can Carbon Sinks Be Operational?
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Measuring and Monitoring Carbon Benefits for Forest-Based Projects: Experience from Pilot Projects

Sandra Brown*

Introduction

Many forest-based climate mitigation projects have been developed and are currently providing experience in measuring, monitoring, and accounting for carbon benefits. Focusing on carbon simplifies the task because the problem is reduced to calculating the net differences between carbon stocks with and without the project on the same piece of land over a specified time. The challenge is to identify which carbon stocks need to be quantified, measure them accurately to a known and often predetermined level of precision, and monitor them over the length of the project.

The initial carbon inventory is distinguished from subsequent monitoring. In the initial inventory, the relevant carbon pools are measured; in subsequent monitoring, only selected pools may need to be measured, and even indicators can be used, depending upon the type of forestry project. For example, for a forest restoration project where the carbon credits are generated from growing forests, it would be prudent to monitor the changes in carbon stocks on a regular basis, perhaps every five years. However, for a mature forest protection project, routine monitoring might involve only remotely sensing that the forest is indeed not being cut, and the carbon pools may need monitoring only at much longer intervals.

Which Carbon Pools to Measure?

Land use change and forestry (LUCF) projects are generally easier to quantify and monitor than national inventories because they have clearly defined boundaries, can be stratified relatively easily, and offer a choice of carbon pools to measure (Brown et al. 2000b). Criteria for selecting the carbon pools to inventory and monitor are type of project; size of the pool and its rate and direction of change; availability of appropriate methods; cost of measurement; and

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attainable accuracy and precision (MacDicken 1997a, b). The carbon credits from a project for all pools measured (pools 1 to n) are as follows:

$= \sum_{1}^{n}$ (carbon in pool$_1$ for with-project case – carbon in pool$_1$ for without-project case)

It is clear that for some pools the difference will be positive. For example, lengthening forest cutting cycles (“rotations”) or stopping deforestation (with-project) will, on average, leave more carbon in trees than more frequent logging or the conversion of forests to agriculture (without-project). For other pools, the difference will be negative. For example, the deadwood pool in a reduced-impact logging project will be less than the deadwood pool in a conventional logging practice. Basically, a selective or partial accounting system can be used that includes all pools expected to decrease (i.e., those pools that are smaller with-project than without-project) and choice of pools expected to increase (i.e., those pools that are larger with-project than without-project) as a result of the project. Only pools that are measured (or estimated from a measured parameter) and monitored are incorporated into the calculation of carbon benefits.

The major carbon pools in forestry projects are live biomass, dead biomass, soil, and wood products (Table 1). How decisions about choosing the pools to measure and monitor may be made for different types of LUCF projects is illustrated in Table 1. Carbon in trees should be measured for practically all project types, since this is the source of most carbon benefits. Measuring the understory is recommended where this is a significant component, as in agroforests or open woodlands; dead wood should be measured in all forest-based projects—and must be measured in projects related to stopping or changing harvesting practices. LUCF projects have often been criticized because of the difficulty of measuring changes in soil carbon pools. However, for most forestry projects, soil need not be measured if no loss of soil carbon will result. And in fact, projects aimed at protection of threatened forests, improved management of timber harvests, forest restoration, or longer-rotation plantations will not cause soil carbon to be lost; rather, they will maintain or increase carbon in soil.

The decision matrix presented in Table 1 implies that one design does not fit all projects—that measuring and monitoring designs will vary by project type and the available resources.

Techniques for Measuring Carbon in LUCF Projects

Experience with pilot projects has shown that an initial assessment of the area, including collecting as much relevant data as possible, is a time- and cost-efficient activity. Relevant information would include a ground-truthed land-cover and land use map of the project area;

identification of pressures on the land and its resources; a history of land use in the project area; identification of without-project proxy areas for future monitoring; climate (particularly temperature and rainfall), soil types, and topography; and socioeconomic activities (e.g., forestry and agricultural practices). Such information is useful to delineate relatively homogeneous land-cover strata (e.g., by forest, soil type, topography, land use, etc.) for designing the inventorying and monitoring sampling scheme, improving baseline projections, and developing guidelines for leakage avoidance. Preliminary sampling of the identified strata is also recommended to determine their variability in carbon stocks—information that is then used to develop the sampling design.

Techniques and methods for sampling design and for accurately and precisely measuring individual carbon pools in forestry projects exist and are based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys (Pinard and Putz 1996, 1997; MacDicken 1997a, b; Post et al. 1999; Winrock International 1999; Brown et al. 2000a; Hamburg 2000). The specialized field of forestry called mensuration develops methods for sampling and measuring forest trees—the component that provides the most carbon benefits in most LUCF projects. Foresters have been sampling and measuring forests for merchantable volume and tree growth for decades, and their techniques are well developed and accepted. Winrock's methodology (MacDicken 1997a) incorporates these mensuration techniques for inventorying and monitoring LUCF projects for carbon. For inventorying forest carbon, the use of fixed-area permanent plots (using a series of nested plots where forests are composed of small- to large-diameter classes) and tagging of all trees are recommended; this approach is generally considered statistically superior for evaluating changes in forest characteristics, including carbon pools. Within these plots, all the carbon pools can be measured or estimated, with the exception of wood products. Accepted methods exist for determining the number, size, and distribution of permanent plots (i.e., sampling design) for maximizing precision at a given cost (MacDicken 1997a).

To estimate live tree biomass, diameters of all trees are measured and converted to biomass and carbon estimates (carbon = 50% of biomass), generally using allometric biomass regression equations. Such equations exist for practically all forests of the world; some are species-specific and others, particularly in the tropics, are more generic (e.g., Alves et al. 1997; Brown 1997; Schroeder et al. 1997). Sampling a sufficient number of trees to represent the size and species distribution in a forest to generate local allometric regression equations with high precision, particularly in complex tropical forests, is extremely time consuming and costly and generally beyond the means of most projects. But experience with generic equations, for both tropical and temperate forests, has shown that measurements of diameter at breast height (dbh), as is typical for trees, explains more than 95% of the variation in tree biomass. The advantage of using generic equations, stratified by, for example, ecological zones or species group (broadleaf or conifer), is that they tend to be based on a large number of trees (Brown 1997) and span a wider range of diameters; this increases the accuracy and precision of the equations. It is very important that the database for regression equations contain large-diameter trees, as these tend to account for more than 30% of the above-ground biomass in mature tropical forests (Brown and Lugo 1992; Pinard and Putz 1996). A disadvantage is that the generic equations may not accurately reflect the true biomass of the trees in the project. However, field measurements (e.g., diameter and height relationships of the large trees) or the harvest of two or three representative large trees can be used to check the validity of the generic equations. For plantation projects, developing or acquiring local biomass regression equations is less problematic, as much work has been done on plantation species (Lugo 1997).

Dead wood, both lying and standing, is an important carbon pool in forests and should be measured in many forestry projects (Table 1). Methods developed for this component have been tested in many forest types and generally require no more effort than measuring live trees (Harmon and Sexton 1996). Total root biomass is another important carbon pool and can represent up to 40% of total biomass (Cairns et al. 1997). However, quantifying this pool can be expensive, and no practical standard field techniques yet exist. Instead, recent reviews of the literature based on research studies of all examples of the world forests are available for estimating root biomass carbon based on above-ground biomass carbon (e.g., Cairns et al. 1997).

Although soil carbon pools are a source of contention in forestry projects, there are well-established methods and documentation for their measurement (Post et al. 1999). Measuring change in soil carbon over relatively short periods is more problematic, but as shown in Table 1, this pool need not be measured in most projects. In cases where changes in soil carbon are included, rates of soil oxidation under different land uses are available in the literature (e.g., summarized in the land use and forestry sector of the Intergovernmental Panel on Climate Change [IPCC] Guidelines for National Greenhouse Gas Inventories; Houghton et al. 1997). Promising technologies for measuring carbon both directly and indirectly, in some cases with modeling and remote sensing, are on the horizon (Post et al. 1999).

The long-term effectiveness of carbon storage in wood products depends on the product. In projects that reduce output of harvested wood by improving forest management or preventing logging (and deforestation if some of the wood cut during deforestation entered the wood products market), the change in the wood products pool would be negative because the with-project production is less. This negative change in the wood products pool reduces some of the carbon benefits from the project and must be accounted for. In plantation projects, wood that goes into long- to medium-term products (e.g., sawtimber for housing, particle board, paper) represents additional carbon storage. Several methods exist for accounting for the storage of long-lived wood products (Winjum et al. 1998). A recent report by an expert group for the land-use and forestry sector of the IPCC guidelines describes and evaluates the approaches available for estimating carbon emissions or removals for forest harvesting and wood products (Brown et al. 1999; Lim et al. 1999). A decision on the methodology to be used in the guidelines is pending from the Subsidiary Body for Scientific and Technical Advice (SBSTA).

Techniques for Ongoing Project Monitoring

Monitoring is the ongoing measurement of carbon pools. Permanent sample plots, as often used in the initial carbon inventory, are generally considered the statistically superior and cost- and time-efficient means for evaluating changes in forest carbon pools (MacDicken 1997a). Methods are well established and tested for determining the number, size, and distribution of permanent plots (i.e., the sampling design) at various levels of precision or cost. Moreover, only a random selection of the permanent plots may be measured in a monitoring program: Not all the initial carbon pools need be measured at every interval in some projects, and if judiciously selected, some pools can serve as indicators.

The frequency and intensity of monitoring depend to a large extent on the nature of the project. Projects designed to avoid emissions through arresting deforestation or logging need to establish that no trees are removed or clearings made, and that the carbon is remaining constant or increasing. In projects designed to sequester carbon by protecting secondary forests or establishing new forests, on the other hand, changes in all carbon stocks being claimed need to be remeasured periodically.

Remote sensing technology may be useful for monitoring LUCF projects, though to date it has hardly been used. Satellite imagery has been used mostly for producing land use maps of project areas and for estimating rates of land use change or deforestation in the project formulation phase. However, remote sensing technology clearly has potential for monitoring forest protection projects and trends in plantation or agroforestry establishment at the subnational to national scales. Monitoring improved forest management or secondary forests, particularly in the tropics, is difficult with the current suite of satellites, but future development and launching of new satellites may overcome this problem.

Not all remotely sensed monitoring activities need to use data from satellites. Because LUCF projects have well-defined boundaries and are relatively small in area (several thousand to hundreds of thousand hectares, ha), remotely sensed data from low-flying airplanes can be used. A promising advance in this area couples dual-camera digital videos (wide-angle and zoom) with a pulse laser profiler, data recorders, and a differential global positioning system (DGPS) mounted on a single-engine plane (Slaymaker 2000; EPRI 2001). This system is able to determine crown area, tree height (from the pulse laser), and number of stems per unit area, a combination of which has been shown to correlate highly with above-ground forest biomass.

In some circumstances, models can complement monitoring activities for LUCF projects by estimating changes in carbon pools over short periods for which direct measurements fall below detectable levels, followed by direct measurements over longer intervals to verify model projections (MacDicken 1997a; Post et al. 1999; Vine et al. 1999). Process-based models are particularly useful for projecting slow changes in soil carbon pools (Paustian et al. 1997; Post et al. 1999). Likewise, process-based models for the vegetation component of secondary forests and plantations (e.g., Maclaren 1996; Schlamadinger and Marland 1996) could be used in conjunction with direct field measurements.

Pilot Project Experience

In this section I discuss two designs for measuring and monitoring carbon benefits and show how the initial measurements of carbon pools are used to estimate the carbon benefits for two pilot projects.

The Noel Kempff Climate Action Project, Bolivia

In 1996, the Government of Bolivia, the Bolivian organization Fundación Amigos de la Naturaleza (FAN), American Electric Power and The Nature Conservancy designed a forest-based pilot project to allow the expansion of Noel Kempff Mercado National Park. PacifiCorp and British Petroleum America (now BP Amoco) joined the project in 1997. The duration of this $9.5 million project is 30 years. This is the largest pilot LUCF project to date to be implemented in terms of area, funds invested, and projected carbon offsets. Further details of this project are given in Brown et al. (2000a).

Noel Kempff Mercado National Park is in northeastern Bolivia in the Department of Santa Cruz. The project area of approximately 634,000 ha is within a 1996 addition to the western region of the park (latitude 14.775°S to 13.485°S and longitude 61.850°-W to 60.640°

W). The park is bounded on one side by the Bolivia-Brazil border, formed by the Itenez River, which drains into the Amazon Basin. For about 15 years before the Noel Kempff Climate Action Project began, the forest in the expansion area had been high-graded—that is, the best trees of several commercial species were cut—by three concessionaires. The forests in the expansion area are made up of six strata (from interpretation of Landsat TM satellite data). The elevation of the project area is about 200 m or less with gentle to flat topography, with a mean annual rainfall of about 1,500 mm and a dry season (< 50 mm/mo) of about two to three months.

The project obtains carbon benefits from two main activities:

1. Averted logging
    - Removal of commercial timber has been halted.
    - Associated damage to unharvested trees has been eliminated.
2. Averted conversion of forested lands to agricultural uses
    - Loss of carbon in forest biomass has been halted.
    - Loss of carbon from soil because of cultivation has been eliminated.

Inventory of carbon pools: The project design for inventorying and monitoring carbon pools is based on the methodology and protocols in MacDicken (1997a). The carbon inventory of the area was based on data collected from a network of 625 permanent plots, located using a differential global positioning system. The plots were established across the project area, with the number of plots sampled in a given strata based on the variance of an initial sample of plots in each strata, the area of the strata, and the desired precision level (±10%) with 95% confidence (Table 2). A fixed-area, nested-plot design was used (4 m radius plot for trees with dbh of ≥ 5–20 cm, and 14 m radius for trees with dbh ≥ 20 cm), and the following carbon pools were measured for each plot: all trees with dbh ≥ 5 cm, understory, fine litter, standing and lying dead wood, and soil to 30 cm depth (Table 2). Tree biomass was estimated from a general biomass regression equation for moist tropical trees (Brown 1997); the validity of this equation was confirmed with the destructive harvest of two large-diameter trees. Biomass regression equations for early-colonizing tree species and palms were developed by destructive harvesting of a sample of individuals of such species. Root biomass was estimated from root-to-shoot ratios given in Cairns et al. (1997).

The total amount of carbon in the project area was about 115 million tons (tC), most of which was in above-ground biomass of trees (60%), followed by soil to 30 cm depth (18%), roots (12%), and dead wood (7%); the understory and fine litter accounted for about 3% of the total. The 95% confidence interval of the total carbon stock was ± 4-%, based on sampling error only; regression and measurement error were not included. Inclusion of the error due to regression and measurement is likely to increase the total error by no more than double, as the sampling error has been shown to be the largest source of total error (up to 80% or more) in measuring carbon stocks (Phillips et al. 2000).

In this pilot project, encompassing several strata of a complex tropical forest, the measurement of carbon stocks can be accomplished with a high degree of accuracy and precision: The key is to establish the required number of plots to reach the targeted precision levels. The cost of measuring the 115 million tons of carbon was less than 1 cent a ton.

Estimating the carbon benefits: Estimates of the changes in major carbon stocks due to logging practices—if logging had been allowed to continue over the project life—were developed to generate the without-project baseline. The main carbon pools considered are above-ground tree biomass, dead biomass, and wood products. Data included estimates of how much land would be logged and the likely timber extraction rates, plus information on the minimum diameter classes of harvested trees and the frequency of reharvesting, The estimates, based on analyses developed by an independent team of Bolivian foresters, in some cases using information from logging concessionaires' management plans, were projected over the life of the project.

To determine the change in carbon stocks from logging activities, measurements are made in a nearby proxy forest concession (about 80 km from the western edge of the project area) whose forest types closely resemble those in the project area and whose practices are in compliance with recently enacted forestry laws. Paired permanent plots (logged and unlogged) have been established to measure the amount of dead biomass produced during the felling of a tree and associated activities, such as yarding and skidding, as well as the rate of regrowth after harvesting and without harvesting. Dead biomass results from the crown of the felled timber tree and damage to other trees (which may be broken or uprooted or lose large branches). Total production of dead biomass carbon per unit of harvested biomass carbon is determined from these plots. Results show that for every 1 tC in a harvested log, 2.95 tC (95% confidence interval = 0.3, n = 102) of dead wood are produced (S. Brown, M. Delaney, and R. Vaca, unpublished data).

$$\text{C benefits from averted logging} = \Delta\text{live biomass C} + \Delta\text{dead biomass C} + \Delta\text{wood product C}$$

where Δ is the difference between with- and without-project C stocks. The annual benefits are calculated from a carbon accounting model that tracks all the changes in these pools from a scenario based on the annual area logged, log extraction rates, and logging damage. The approach described here for estimating the carbon benefits is based on "change detection" methods—that is, measuring the change in carbon stocks directly rather than measuring the stocks at two different times and subtracting them.

<u>Δlive biomass C</u> = (biomass C from logging damage + C in timber extracted) × growth factor

To estimate the change in live biomass, one could measure the live biomass in the proxy concession before and after an area is logged; the difference would give the change in the live biomass C. However, in this approach two large carbon stocks are being subtracted, and although the error on each stock might be small, the error on the difference, expressed as a percent, will be much larger. To overcome this problem, the change in live biomass is being measured directly. The change in live biomass between the with- and without-project cases is a result of the extraction of timber and damage of residual trees from the logging activities (the quantity in parentheses). The quantity in parentheses, expressed on an area basis, multiplied by the area logged per year gives the total change in live biomass without adjustment for logging effects on growth of the residual stand (the growth factor in the above expression). It is not clear whether harvesting stimulates or reduces regrowth in recently logged areas. The logging of large trees and the damage to residual trees may be enough to *reduce* net biomass growth of the stand per unit area for a number of years after logging, rather than stimulate it. For projects that prevent or modify logging, this effect of logging on growth of the residual trees must be determined. Monitoring of paired permanent plots in logged and unlogged areas of the proxy concession is under way to establish the sign and magnitude of the growth factor over the length of the project.

<u>Δdead biomass C</u> = (dead biomass from logging damage × decomposition factor)

In projects that prevent or reduce logging, dead wood cannot be ignored because it is a long-lived pool that logging increases. Stopping logging has the effect of reducing the dead biomass carbon stock, and the dead biomass carbon in the with-project case is therefore less. However, the change in the dead biomass pool has to be corrected for decomposition. At present, estimates of the decomposition correction factor are taken from the literature (Delaney et al. 1998), but field measurements are under way for improving this factor. Note that no measurement of the existing dead wood pool is needed in this method—only the amount of dead wood produced by logging.

$\underline{\Delta\text{wood products C}}$ = (timber extracted × proportion converted to long-lived products)

When forests in Santa Cruz are logged, some of the wood ends up in long-term storage as wood products. Stopping logging does not prevent all the biomass carbon going into the atmosphere, and the fraction that ends up in long-term storage must be accounted for. In the Noel Kempff project, the proportion of harvested roundwood (i.e., logs and bolts) that goes into long-term wood products was obtained from literature sources for Brazil (Winjum et al. 1998). The project assumed that wood waste generated at each stage of the conversion of timber to products (50% was converted to sawdust in the first milling stage) was oxidized in the year of harvest.

All told, with the project there is more carbon in the live biomass pool and less carbon in the dead biomass and wood products pools than in the without-project case.

Carbon benefits from averted deforestation: The carbon benefits from stopping deforestation result from eliminating the loss of carbon in forest biomass and soil. The without-project baseline for this component was established using projected human demographics in the region adjacent to the project area. The two factors affecting conversion of forestland to cropland are increasing human populations and the resulting demand for farmland. In constructing the deforestation scenario, it was assumed that migration into the area would fuel a continued demand for agricultural land, as has been seen in other nearby areas.

C benefits from averted forest conversion = Δtotal biomass C + Δsoil C

Carbon loss from change in biomass is calculated as the product of the projected area cleared and the difference between weighted average carbon in forest biomass (sum of trees, understory, litter, dead wood, and roots; Table 2) and agriculture crop biomass. Change~~s~~ in soil carbon is estimated as the product of area cleared, weighted average forest soil carbon (Table 2), and an average soil oxidation rate for converted tropical forest soils obtained from Detwiler (1986).

Future monitoring: For the averted deforestation component, very little additional carbon monitoring is planned because it is expected that carbon in the existing forest will increase only slowly. The key component of this activity is to ensure that the forest is not being cleared; monitoring efforts will usethe dual-camera videography technology that Winrock is developing.

For the averted logging, monitoring plans call for remeasurement at five-year intervals of the paired plots in the nearby proxy concession to determine any delayed mortality and differences in carbon accumulation rates between logged and unlogged plots. These data will be used to revise the carbon benefits if necessary. After two remeasurements, an additional set of paired plots in another harvested block will be established to determine whether logging practices are changing.

The Guaraqueçaba Climate Action Project, Brazil

The Guaraqueçaba Climate Action Project in the Atlantic forest in Paraná, Brazil, is being developed by Central and South West Services (now AEP), The Nature Conservancy, and SPVS. The project area is within the Guaraqueçaba Environmental Protection Area, a federal reserve of 775,000 ha. Of the 4,500 ha in the existing project area, about 15% is in pasture, 20% is in young to very young secondary forests, and 65% is in late secondary forests; all the forests have been disturbed or cleared in the past. The project involves purchasing water buffalo ranches, protecting all remaining forests, reforesting some of the pastureland with native species, allowing the remaining pasture to regenerate naturally, and allowing regrowth in the secondary forests over the 40-year project life.

The carbon benefits of this project result from emissions avoidance (protection from deforestation) and carbon sequestration (reforestation and natural regeneration of areas with pasture, enrichment plantings, and recovery of successional forests). In the absence of the project, it is expected that the lowland areas would continue to be deforested and upland forests would continue to be degraded. With the project, lands that were threatened with deforestation are being protected and degraded lands reforested.

Inventory of carbon pools: The approach taken for this project is generally the same as that described above for the Noel Kempff project. Using a combination of remote sensing data and on-the-ground measurements, the project area has been classified into four forest strata (based on disturbance and successional stage) and three nonforest strata (based on the presence or absence of shrubs), upon which the carbon benefits from this project will be estimated. The initial inventory involved 168 plots, a number based on initial field measurements in each strata as described above for the Noel Kempff project. Using the same criteria, the main carbon pools included in this project were live trees (to a minimum diameter of 2.5 cm), dead wood, roots, soil (to 30 cm depth), and litter and understory in the younger forest strata.

In the initial inventory, the total carbon pool (excluding soil) in the forest strata is estimated to be about 446,000 tC with a precision level of 6% of the mean at 95% confidence (Table 3). The overall weighted mean carbon content of forests is 112 tC/ha (Table 3), of which 78% is in the live, above-ground woody biomass, 13% is in roots, 7% is in dead wood, and about

2% is in litter and understory combined (S. Brown and M. Delaney, unpublished data). Litter and understory were not measured in the altered mature forest, because these were assumed to be an insignificant component and not worth the time and cost to measure (even in the advanced-medium stratum, litter and understory represented less than 2% of the total vegetation pool).

Soil carbon (in the top 30 cm) was measured in the two young forest strata only because these are the only strata likely to produce measurable changes over the project life, and a baseline value needed to be established. The total carbon in the soil of these two strata is 59,377 t with a 95% confidence interval of 13% of the mean. Additional plots in these two young strata are planned for 2001, to decrease the variation in the vegetation and soil carbon pools.

Future monitoring: The baseline carbon content of the pasture-shrub strata has been estimated. As these areas are restored with native tree species and undergo succession, permanent plots will be established and remeasured at five-year intervals over the length of the project. The number of plots to be established will be based on the variance of the lowland advanced- to medium-successional forests, as this will be the target forest and its variance will reflect the variance of the restored forest.

Because significant carbon benefits are expected from protecting the forests from further degradation, the plots established during the initial inventory will be remeasured at five-year intervals during the length of the project. These permanent plots have tagged trees and mapped dead wood, and therefore the changes in carbon stocks can be measured directly; this will result in smaller errors.

Other Measuring and Monitoring Issues

Future monitoring tools: Although the above projects call for ongoing monitoring of carbon stocks by revisiting the permanent plots, technological advances are likely to produce systems that can monitor carbon stocks remotely, after some initial calibration. The dual-camera videography system described above is one such advance that is showing high promise for accomplishing this task (EPRI 2001). A test of the system in the Noel Kempff project showed that using its measures of crown area and tree height for one stratum of trees in 1-ha plots, with appropriate regression equations, yielded average carbon stocks well within the 95% confidence limit obtained from the field plots (Slaymaker 2000).

Data quality and archiving: A reliable baseline and measurement and monitoring plans for both the initial and the future assessment of carbon-offset projects require steps to control for errors in sampling and analysis. Furthermore, the credibility of the estimates of the carbon sequestered and retained necessitates a quality assurance and quality control (QA/QC) plan. This plan should include formal procedures to verify the methods to collect field data and the techniques to enter and analyze data. A set of standard operating procedures (SOPs) for all aspects of the field and laboratory activities should be part of the project's documents. To ensure continuity, it is also important that the same procedures be used during the project life and are archived using standards acceptable to all partners involved in the project. Adhering to the procedures will ensure project integrity despite changes in personnel, as well as consistent information whenever questions arise about any aspect of the project.

Carbon-offset projects of the type described here are still in their infancy and must stand up to the scrutiny of the scientific community as well as outside organizations that will ultimately verify the carbon offsets resulting from project activities. The QA/QC plan must be part of the project's set of documents available for review and inspection. The QA/QC plan and SOPs should be updated as necessary when new field equipment or procedures become available.

Because of the relatively long-term nature of these projects, data archiving will be an important component of the work. Original field sheets, laboratory analyses, data analyses, reports, models, and assumptions should all be maintained in original hard copies as well as in electronic media, and everything stored in a dedicated and safe place—preferably in more than one place. Because of the rapid pace at which software and hardware are changing, all data should be stored in a form that can be retrieved and migrated to new systems.

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Table 1. A decision matrix of main carbon pools for examples of land-use and forestry projects to illustrate the selection of pools to quantify and monitor. Y = yes and indicates that the change in this pool is likely to be large and should be measured. R = recommended and indicates that the change in the pool could be significant but measuring costs to achieve desired levels of precision could be high. N = no and indicates that the change is likely small to none and thus it is not necessary to measure this pool. M = maybe and indicates that the change in this pool may need to be measured depending upon the forest type and/or management intensity of the project.

Project type	**Carbon pools**						
	Live biomass			Dead biomass			
	Trees	Herbaceous	Roots	Fine	Coarse	Soil	Wood products
Avoid emissions							
•Stop deforestation	Y	M	R	M	Y	R	M
•Reduced impact logging	Y	M	R	M	Y	M	N
•Improved forest management	Y	M	R	M	Y	M	Y
Sequester carbon							
•Plantations	Y	N	R	M	M	R	Y
•Agroforestry	Y	Y	M	N	N	R	M
•Soil carbon management	N	M	M	M	N	Y	N

Table 2. Estimates of carbon stocks in tons of carbon per hectare (tC/ha) in the forests of the Noel Kempff Climate Action Project (from Delaney et al. 2000).

Strata (#plots)	Area (ha)	Above-ground woody biomass	Palm biomass	Standing dead biomass	Lying dead biomass	Understory	Litter	Below-ground biomass	Soil	Mean
Tall evergreen(171)	226,827	129	0.5	4.1	11.0	2.0	3.6	25.8	26.9	203
Liana (131)	95,564	56	0.5	2.3	4.7	3.8	4.0	11.1	39.9	122
Flood Tall (64)	99,316	132	1.1	3.2	11.3	1.9	3.1	26.4	44.8	224
Flood Short (35)	49,625	112	0.2	3.0	9.6	2.1	2.9	22.3	55.5	207
Mixed L. (218)	159,471	90	1.5	4.4	7.7	2.6	4.3	17.9	24.4	152
Burned (6)	3,483	57	0.2	1.6	4.9	0.9	4.2	11.4	36.0	116
Weighted mean	634,286	106.7	0.8	3.6	9.1	2.4	3.7	21.3	33.3	181
Statistics										
95% CI, % of mean					4.2					
Project total carbon content (tons)					114,852,218					
Confidence interval (minimum)					110,074,406					
Confidence interval (maximum)					119,630,030					

Table 3. Total carbon content (including trees, roots, understory, dead wood and litter, but excluding soils) in the forest strata of the Guaraqueçaba Climate Action Project, Brazil (from S. Brown and M. Delaney, unpublished data).

Strata	Mature Altered (7DM)	Medium/ Advanced (7M)	Young (7Y)	Very Young (7VY)
n=	69	46	13	12
Area	763.0	2,269.6	583.9	363.8
Mean	153.5	113.5	96.5	40.3
Min	73.6	65.1	41.1	5.7
Max	398.7	197.4	203.7	73.2
Variance	2638.6	952.4	2280.7	414.7
Standard Deviation	51.4	30.9	47.8	20.4
Standard Error	6.2	4.6	13.2	5.9
C.V. (%)	34	27	50	51
Mean (t C/ha ±95% CI)	111.9 ± 6.8			
Total (t C ±95% CI)	445,464 ± 27,247			
95% CI (% of mean)	6.1			

Seeing the Forest and Saving the Trees: Tropical Land Use Change and Global Climate Policy

Suzi Kerr

Can Carbon Sinks Be Operational?
RFF Workshop Proceedings – April 30, 2001

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Seeing the Forest and Saving the Trees: Tropical Land Use Change and Global Climate Policy

Suzi Kerr*

Introduction

Tropical forests are potentially large stores of carbon that can be used to reduce atmospheric concentrations of greenhouse gases (GHG). However, their incorporation in global climate change policy is fraught with uncertainty because of the difficulties of designing policies to protect and enhance forests in developing countries. This paper tackles the issues of international climate and land use policy design. It provides an overview for the contribution to policy design of the subsequent articles, which deal in detail with remote sensing, ecology data needs, ecological modeling, economic modeling of land use, and the implications of uncertainty.

Land use and land use change play a significant role in the global carbon cycle and offer important potential to mitigate climate change in both industrialized and developing countries. According to the Intergovernmental Panel on Climate Change (IPCC 2000), from 1989 to 1998 net emissions from land use change, primarily from the tropics, amounted to 1.6 ± 0.8 gigatons of carbon (GtC) per year, which is roughly 25% of emissions from the fossil fuel and cement sectors (6.3 ± 0.6 GtC/yr). However, these deforestation emissions were offset by a terrestrial sink of 2.3 ± 1.3 GtC/yr, resulting in net uptake in the land use, land-use change, and forestry sector of 0.7 ± 1.0 GtC/yr.

IPCC (2000) projects that under business-as-usual, global deforestation is expected to lead to emissions of 1 to 2 GtC per year during the first commitment period. More than half of this is likely to occur in tropical forests, which make up 1.8 billion of earth’s 4.2 billion hectares

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[*] Motu, New Zealand, and MIT Joint Center for Global Change; suzi.kerr@motu.org.nz This paper was developed during discussions with Catherine Leining at the Center for Clean Air Policy. Some sections draw on Leining and Kerr (2001). Many of the ideas were developed in the context of the Costa Rica Carbon Sequestration Project and particularly discussions with Alex Pfaff, Arturo Sanchez, Flint Hughes, Shuguang Liu and Boone Kauffman. I would like to acknowledge funding from the National Science Foundation, the Center for Clean Air Policy, and Resources for the Future. Thank you to participants at the RFF symposium, “Can Carbon Sinks Be Operational?” and particularly to Gregg Marland for helpful discussant comments. All opinions expressed are my own and I am responsible for all errors and omissions.

(ha) of forests. Some portion of this deforestation and significant emissions could be avoided through conservation projects and changes in the underlying factors that drive deforestation. Estimates suggest that reforestation could sequester 1.1 to 1.6 GtC per year, with 70% in tropical forests.[2] Additional carbon benefits could be realized through forest management activities to enhance existing sinks. Undertaking projects in developing countries to prevent deforestation and degradation, increase reforestation, and improve forest management could produce important greenhouse gas benefits. Environmentally, these benefits are just as valuable as reductions in GHG from energy use. The science suggests that it is important to find a way to incorporate tropical land use in the global climate mitigation effort.

Another advantage of including tropical forests in the climate mitigation effort is the considerable benefit that some developing countries could realize from programs like the Clean Development Mechanism (CDM). This mechanism potentially advances the process of sustainable development in those countries and also gives benefits to the poorest countries, which may not benefit much from energy sector activities. Enhancing participation of a wider group of countries could encourage them, in the longer term, as they become wealthier or the agreement develops, to become more heavily involved. In the words of Robert Stavins, it helps allow developing countries to "catch the train but not pay for the tickets."[3]

Land-use activities in developing countries may produce GHG benefits at a relatively low cost per ton of CO_2 reduced, thereby lowering the overall cost to Annex I Parties (industrialized nations) of compliance with the Kyoto Protocol. They could also provide GHG benefits quite quickly. In particular, avoiding deforestation of forests with high carbon stocks could yield large short-term gains. Land-use projects require relatively unsophisticated technology, even though they may require institutional and political changes to be truly effective in some countries. Investments in conservation and reforestation in the tropics could essentially buy time for the parties to develop GHG mitigation technologies in other sectors and replace the capital stock in Annex I gradually. Allowing emissions reductions to occur as capital is replaced and technology advances is much more efficient than trying to achieve it very quickly.

To effectively incorporate tropical land-use activities in any climate mitigation effort, we need to identify environmental additionality in every period and provide land users and

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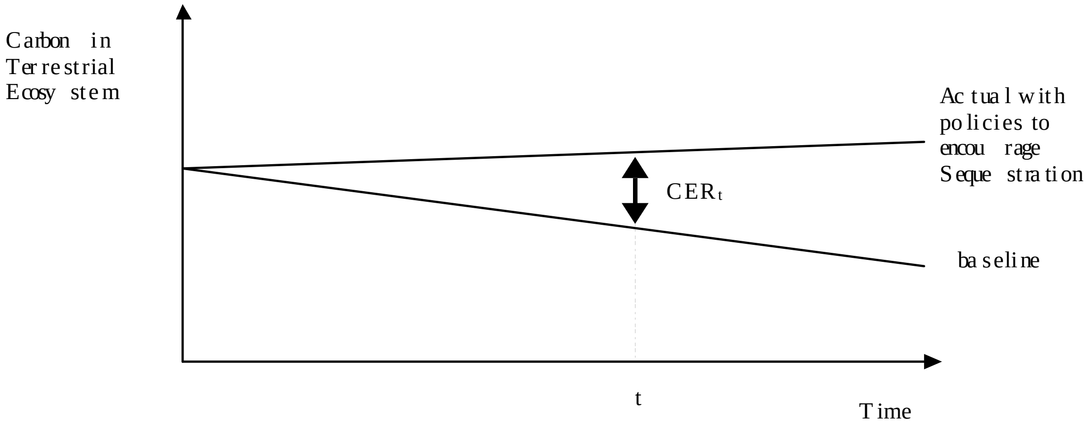
[2] In this paper I use "reforestation" to cover both reforestation and afforestation.

[3] *Boston Globe* Op Ed, April, 2001.

regulators in developing countries with incentives that reflect those environmental benefits. Figure 1 shows how additional environmental benefit is defined as the difference between actual carbon stored and carbon that would have been stored in the baseline. The key principles that we apply to assess possible approaches are environmental integrity, economic efficiency, and simplicity.

Figure 1. Definition of Additional Emissions Reduction



Environmental Integrity

Sequestration of carbon in sinks in developing countries (non-Annex I Parties) needs to have the same atmospheric effect as the emissions reductions that it would replace.[4] The credits given for sink enhancement should depend only on the additional carbon that is removed from the atmosphere (or not put in) and when the carbon is removed.

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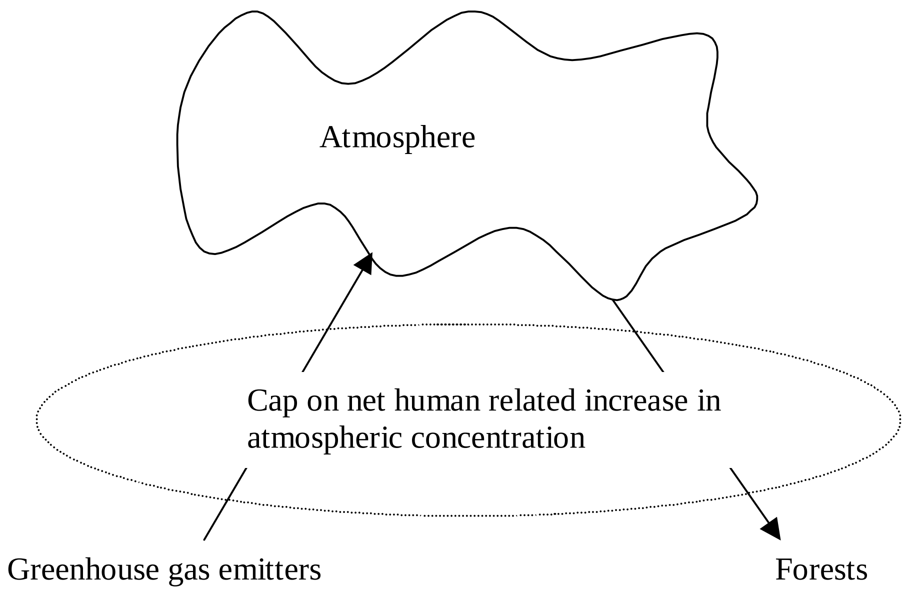
[4] For convenience I use the word “sink” loosely to mean anywhere that carbon is stored temporarily or permanently outside of the atmosphere in the terrestrial ecosystem. The ocean is also a sink.



Why does it matter *when* GHGs are removed from the atmosphere, given the long lifetime of CO_2? It is important for credibility (whether the reductions actually occur) and efficiency under fixed targets (reductions today are worth more than reductions tomorrow with a binding cap today). We cannot borrow in an unrestricted way from banks on the basis of a simple promise to repay; nor should we borrow from the environment when our ability to repay is highly uncertain. As long as we base other climate regulation on caps on net emissions during a specified period (as Kyoto does), net sink emissions should be treated equivalently so that the credits created are fungible.

Economic Efficiency

Efficiency has two aspects. First, incentives should match environmental benefits. Clean Development Mechanism credits or equivalent credits under any post-Kyoto system should be given only for activities that produce additional environmental improvements. Since we want as many actors as possible to internalize the environmental implications of their actions, we need to translate these environmental implications into prices. Cheap credits are not more efficient if they don't have equivalent environmental impacts. Subject to the requirement to maintain environmental integrity, the rules should allow as much flexibility as possible to facilitate innovation, experimentation, and a wide range of approaches.

Uncertainty makes the matching of benefits to rewards more complex, but the simplest rule is that we should reward efforts based on their expected impact. As long as people cannot manipulate the rules, this will, on average, lead to environmental equivalency with programs that involve certain credit. We discuss the issue of uncertainty in more depth below.

Second, we need to minimize the administrative and transaction costs associated with the program. If we can use cheaper ways to certify and monitor projects that maintain environmental quality, we should. If we can remove bureaucratic hurdles that are unnecessary for environmental integrity, we should. Below, we discuss the trade-off that arises when cost effectiveness requires some loss of environmental certainty.

Simplicity

First, the people who need to implement climate policies relating to tropical forests are, as a rule, not highly technically trained. The rules need to be as simple as possible to reduce the gap between the intentions of policymakers and actual implementation. A complex policy may appear to address problems but may actually create more because people cannot understand it and implement something different from what was intended.

Second, because these tropical forest policies are part of an international cooperative agreement, transparency is critical. People have to be able to observe what others are doing, both to build trust and to provide informal mechanisms that assist and pressure people to comply. If the rules are complex, it will be difficult to determine whether a project is really in compliance. The rules need to be designed to minimize the potential for manipulation and the perception of manipulation.

Sinks and the Clean Development Mechanism

Many parties have questioned the use of land-use activities for climate change mitigation through the CDM. Some of these concerns arise in developed countries, but others are unique to the developing world. Considerable work is needed to address these concerns. The benefits from land use sequestration vary considerably across countries. This creates political difficulties because some countries will receive no direct benefits and hence are not very interested in finding ways to overcome these problems.

In the context of Kyoto, the issue has been made more complex by the unusual way that land use has been included for developed, Annex I countries. Because of poor projections of business-as-usual GHG changes attributable to land use change, countries have found that simply including changes in net sinks in Annex I would provide a significant loosening of expected targets. This is particularly true for the U.S. targets. To address this, a number of complex rules have been proposed that would limit the land use counted for compliance to areas where people have deliberately enhanced sinks.[5] The obvious solution—altering the overall commitments to reflect the shift in position—is not available because it would require renegotiating the targets and timetables, a process many countries are not willing to risk. This issue does not arise for developing countries because baselines are not yet set. Much of the discussion of sinks in Annex I countries is not helpful for understanding how to include them in the context of developing countries.

An issue unique to developing countries is the impermanence of GHGs in land use. If Annex I faces a series of contiguous commitment periods that take net sinks into account, any loss of a sink will be automatically accounted for. For developing countries we need to create this compensation mechanism.

Some developing countries are concerned that hosting land use projects under the CDM will threaten their sovereignty over their long-term land-use and sustainable development priorities. The international rules need to allow developing countries to maintain control over their resources. Assistance may be needed to develop domestic regulatory systems that both protect the country’s sovereignty and enhance sustainable development.

Leakage is also a larger issue in developing countries because small projects are possible and not all developing countries will participate. Leakage results when land-use activities are simply displaced from the project area to another area, and the project benefits are offset. Any land use project that reduces the supply of a valued resource, such as agricultural land or timber, without also reducing demand will likely be subject to leakage. A land use reforestation project that increases the supply of plantation timber may crowd out other commercial plantations. Leakage can occur within countries and across borders (although within Annex I, the only leakage of concern is to countries outside Annex I). If developing countries cannot include land-

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[5] Under Article 3.3, Annex I Parties must account for carbon fluxes from land use change activities (afforestation or reforestation, and deforestation) that occur after the base year of 1990. The carbon credits or debits are calculated on the basis of the change in carbon stocks from these activities between 2008 and 2012. These restrictions impose a kind of additionality requirement on the land use, land use change, and forestry (LULUCF) credits claimed under Article 3.3. That is, Parties are to claim credits only for activities involving a change in land use after 1990. Under Article 3.4, Annex I Parties have the option to expand eligible LULUCF activities to potentially include such activities as forest management, cropland and grazing land management, and revegetation. This expansion could potentially apply to the first commitment period.

use projects, leakage from Annex I countries to developing countries will be exacerbated, but leakage within and among developing countries would be avoided.

Because non-Annex I countries do not have binding commitments, the additionality of tropical sequestration must be determined by comparing a project's land-use activities with a baseline representing business-as-usual projections for land-use and associated changes in carbon stocks. Carbon sinks, sources, and reservoirs are expected to change with economic development, and this change should not be penalized or rewarded. The creation of baselines is discussed in greater depth below.

Finally, developing countries are inherently different because they have different levels of institutional and commercial capability. For example, it is much harder to reliably monitor forest management in a developing country. Defining "forest" simply and monitoring forests by remote sensing might therefore be a sensible way to measure land use even though it misses the subtlety of different qualities of forested landscapes. Another implication may be allowing some countries with limited capability to carry out very small projects. These projects will have little global environmental impact but may facilitate learning and provide local benefits as well as strengthening the global cooperative agreement.

International Rules vs. Domestic Rules

In this paper we address the design of international rules only. How developing countries can effectively create programs under those rules is a critical question. Developing countries will face significant challenges in implementing policies to take advantage of the international opportunities while also protecting their sovereignty and their own environmental interests to enhance sustainable development. This design problem needs to be the subject of future research. We believe that clarifying the requirements at an international level is a prerequisite for productive research on these domestic policies because they must respond to international institutional structures. We also believe that despite the importance of domestic sustainable development, domestic policies to promote sustainability can be addressed separately and do not need to affect international policy.

Domestic systems can look quite different from the international system. Measurement approaches and definitions of "projects" don't have to be the same at both levels. Individual countries can be allowed flexibility in how they implement sinks policy as long as they receive certified emissions reductions (CERs, the tradable credits created by the Clean Development Mechanism) according to international rules. Developing countries vary enormously in economic condition, land use, political structure, existing regulations, and concerns about sovereignty; their approaches to land use and climate policy should also be allowed to vary as long as international environmental integrity is maintained.

For example, a government could give landowners very generous baselines to ensure high levels of participation in sink enhancement, even though the international baseline for the project that includes this land is not generous. The government would simply be subsidizing the project. A second example could be a domestic tax incentive for forestry. To claim international credit, the government would use the international measurement rules to work out the net additional effect of this policy and claim CDM credits. The value of these credits might offset the cost of the tax credits. Third, a large corporation might implement ecofriendly policies in the rain forest in an attempt to reduce deforestation over a wide area. These policies could include providing seed and technologies for more intensive agriculture, helping farmers gain legal title and hence increase tenure security, replanting areas where roads are cut for oil access, and protecting particularly sensitive areas. The government could approve the project and allow the company, together with local people, to claim CDM credits assessed under the international measurement rules.

Structure of Paper

This paper considers only part of the issue of land-use and climate change—forests and carbon dioxide. Other land uses and gases are important but secondary in overall climate impact. We take a long view rather than focus on the specific short-run issues related to the Kyoto negotiations, but we offer some pragmatic short-run options as well. Our focus is almost exclusively on developing country issues; the relationship to similar issues in Annex I, where relevant, is pointed out in footnotes.

We begin by addressing two issues that are technically solvable in a simple way: permanence and temporal risk. We also discuss the effects of this solution on concerns about sovereignty. We briefly address the effects of carbon fertilization and show that this should not be a concern in the CDM. We then consider the more complex problems of monitoring land use, measuring carbon, and predicting baselines. We have no perfect solutions to these problems but suggest some ways forward. We discuss ways to think about the trade-off between reducing uncertainty and the costs of living with uncertainty. We also consider the benefits of larger projects and ultimately national-level projects to effectively incorporate tropical sinks. The following section takes a shorter-run perspective and proposes alternative ways to deal with the problems that may threaten the integrity of sinks in the short run and lead to their exclusion from international climate mitigation efforts. We consider the sources of risk and different short-run approaches to minimize and limit risk. These alternatives aim as much as possible to provide short-run environmental integrity and efficiency while also facilitating a transition toward the optimal system in the long run.

Solvable Problems

Permanence and risk[6]

The GHG benefits from land-use change can be lost or reversed over time, unlike the GHG benefits from projects in other sectors.[7] This difference necessitates a different set of rules for CERs from land use activities and CERs from other sectors.

When choosing among possible rules, we need to consider how they satisfy various criteria. First, the rule should ensure that land use credits have the same environmental impact as any other CER, assigned amount unit (AAU, Annex I emissions units), or emissions reduction unit (ERU, created in Annex I Joint Implementation). These different units are all fungible under the cap. The crediting systems should be compared in terms of how they reflect atmospheric GHG levels at every point in time. This principle of environmental integrity means that any risk from reversibility should be borne by the buyer and/or seller (as determined in the project contract), not by the international community. Second, subject to achieving environmental integrity, the rule should maintain maximum flexibility in how the credits are created and hence achieve maximum economic efficiency in climate mitigation. If two rules are environmentally and economically equivalent but one is simpler than the other, the simpler rule would be preferred.

An effective permanence rule should be designed to reflect the following equivalencies:

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[6] This section draws heavily on Kerr and Leining (2000).

[7] Some people argue that not emitting fossil fuels is simply delaying emissions, on the assumption that all fossil fuel stocks will eventually be used. However, even if this were true and the long-run level of exploration and exploitation did not fall, the reversal of the reduction would occur extremely slowly through a marginally lower long-run price path. In contrast sink emissions can be rapidly reversed.

- One ton of permanent sequestration or storage from land use activities is directly equivalent to one ton of avoided fossil fuel emissions (e.g., a wind farm).
- The release of one ton of emissions from land use activities (e.g., burning forest) is directly equivalent to one ton of emissions from fossil fuel.

Illustration: Wind Farm Project vs. Avoided Deforestation Project

Consider a land use project that permanently avoids deforestation of one hectare and hence reduces atmospheric CO_2 by 100 tons. The Annex I Party that acquires those credits can then emit 100 tons of CO_2 from fossil fuel use. Over time, the project continues to store the carbon, thereby maintaining a lower CO_2 concentration in the atmosphere. In contrast, the Annex I emissions from fossil fuel use are gradually removed from the atmosphere through the global carbon cycle, so the project yields a net benefit as long as the carbon storage continues.

Note that this is identical to the following non-land-use situation:

A wind farm project in a developing country avoids 100 tons of CO_2 emissions. The Annex I Party that acquires those credits can then emit 100 tons of CO_2 emissions from fossil fuel use. As time passes, the 100 tons of avoided emissions from the wind farm project are not returned to the atmosphere, so the project continues to maintain a lower atmospheric CO_2 concentration. As in the previous case, the 100 tons of Annex I fossil fuel emissions are gradually removed from the atmosphere, so the wind farm yields a net benefit.

The implication is that if the land use project yields permanent benefits, it should be treated identically to the wind farm project.

Some people have argued that the decay of emissions should mean that the amount of land use carbon needed to offset a one-time emission would fall over time. If this were true, it would also be true of all other emissions reductions. Therefore, all credits would convey not only the immediate right to emit an equivalent amount but also the right to continue to emit as the initial emissions were removed from the atmosphere. If we do not treat wind farm credits this way, then we should not treat land use credits this way, either. In each year of a land use project, the project’s level of carbon stocks changes relative to the baseline. Under an optimal system, if the difference in carbon stocks between the project and the baseline increased, the CDM would reward the project with more CERs. If it decreased, CERs would be retired. If the forest and therefore the CERs were temporary, a CER still would have value, just as money borrowed from a bank has value. Annex I countries are willing to pay to delay at least part of their need to reduce emissions. Under a system where CERs are retired when project benefits are lost or reversed, environmental integrity can be maintained without requiring that CERs be permanent or that a forest be protected forever.

Our first recommendation is for the project's credited GHG benefits to be verified and adjusted (if necessary) at regular intervals.[8] These intervals could be equal to or shorter than the period over which caps are defined and emissions are assessed, or the "commitment period." The contract between buyer and seller could permit more regular monitoring and hence evaluation and adjustment.[9] A net increase in carbon stocks relative to the baseline during each crediting period would be awarded CERs. These CERs would be identified as specific to the project and could be maintained in a registry or used by the buyer to achieve compliance. During each crediting period, any net loss of previously credited carbon stocks would require payback of the CERs by the buyer.[10] If project monitoring stopped for any reason, the buyer would pay back all net accrued CERs. As long as no carbon release occurred and monitoring continued, the CERs would remain valid. Allowing indefinite projects would require that long-term baselines (or at least a clear process for extending a baseline) be defined in advance. This would be needed in any case if projects were to be renewed.

The second recommendation is that the obligation to repay expired CERs should be passed on with ownership of the project-specific CERs if the CERs are traded internationally. If a CER is surrendered for compliance, the party that surrendered it should ultimately be responsible for repayment when the CER expires. Where multiple parties hold CERs from a project and not all CERs need to be repaid, the parties should bear proportionate liability to repay the CERs.

Note that here we support buyer liability. This contrasts with our earlier arguments in the context of Annex I trading.[11] The difference is that the seller party is not in Annex I and so does not have binding commitments under the protocol and is less able to be held liable by the international community. Because seller liability would be extremely weak in this case, the costs

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[8] This is equivalent to the stock-change approach discussed in the IPCC report (2000). Very similar conclusions have been reached separately by Don Goldberg at the Center for International Environmental Law and Ken Chomitz at the World Bank.

[9] The increased monitoring burden may be economically justified for large projects.

[10] In the case where a buyer Party had surrendered the CERs specific to the project for compliance, payback would consist of subtracting the equivalent number of credits (CERs or AAUs) from that Party's registry. If the CERs were still in the buyer Party's registry, payback would consist of the subtraction of those CERs from the registry.

[11] See Kerr (2000).

of buyer liability would be outweighed by the benefits. To ensure environmental integrity, the ultimate liability at the international level for payback of land use CERs must be held by Annex I Parties, who will be legally bound by their protocol commitments and will face penalties for noncompliance. For efficiency, risk should be borne by those who can control it (i.e., those involved in the project, not the international community), and beyond that, by those who have low risk aversion or high ability to absorb shocks (perhaps investors rather than developing country partners).[12] However, Annex I Parties could still choose how to distribute the burden of that liability domestically through specific regulations between the Annex I Parties and their legal entities or the specific contracts between buyer and seller. If the buyer is concerned about moral hazard on the part of the seller if the seller is not responsible, the contract could make the seller responsible under domestic law even though the buyer is internationally liable. Under the terms of the contract, the seller might agree to compensate the buyer if the credits are lost.

The proportionate liability for repaying expired CERs would not be necessary if all CERs from a project were ultimately surrendered by one actor or if all the carbon were released at the end of the project. With the secondary market and with projects of significant size, the involvement of multiple parties and partial losses of CERs will likely occur.

We recommend that the permanence rule for land use CERs have the following characteristics:

- As sequestration or avoided release occurs, CERs are generated and can be sold. The buyer party adds the CERs to its adjusted assigned amount.
- CERs should be verified at least once per commitment period, with mandatory payback of CERs by the CER holder during the commitment period when credited carbon stocks are lost or monitoring ceases, whichever comes first.
- Liability for payback of CERs should be carried with ownership of the specific CER when it is traded and shared proportionately among the CER holders when partial payback is required.

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[12] These issues are discussed in Kerr (1998) in the context of risk to the international community from noncompliance. In that paper and here I propose putting that risk onto the project organizers.

Sovereignty over Land Use

The primary concern with sovereignty is that if a land use project is permanent, the country cedes permanent control over the use of that land. The issue is identical to concerns about other forms of foreign ownership of resources.[13] If projects are not required to be permanent, a country could agree to conserve an area for five years but every five years would have the option of ending the contract and developing the area. There will be no penalty for reversing the sequestration—it is not a breach of contract. The country can gain the benefits of investment in land-use projects while maintaining control of its resources. If it wants to engage in a long-term contract, it can, but it is not required to. Thus, the solution to the permanence problem largely addresses the sovereignty problem as well.

CO_2 Fertilization and Other Changes in Carbon Stocks Related to Climate Change Itself

Emissions of carbon and nitrous oxides can actually lead to higher levels of land-use sequestration—that is, the pollution itself acts as a fertilizer and creates sequestration. Some parties have expressed concern that Annex I parties might be rewarded for their own emissions if they are able to claim more land use credits as a result of this sequestration. This is an issue in Annex I because the fertilization does not alter the commitment levels against which compliance is assessed and was not considered when the commitment levels were initially chosen. This should not be a concern in developing countries, however. Land use credits in developing countries are given only for the difference between actual sequestration and the baseline. Where land use does not change, fertilization affects both actual and baseline sequestration equally, and no credits are created. Where land use does change, those who deforest less (or reforest more) than the baseline should—and will—be rewarded more because the environmental effect of avoiding deforestation is greater than the benefits of sequestration without fertilization. Efficiency requires that credits reflect the true additional environmental impact, which includes the effect of fertilization. Equity is not an issue here because those who benefit from the credits are developing countries that are not historically responsible for the bulk of emissions.

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[13] Other aspects of the sovereignty issue may relate to foreign investment per se or to issues of bargaining and contracting ability.

Harder-to-Solve Problems: Current Knowledge and Limitations

To maintain environmental integrity, we need to know the net reduction of carbon in the atmosphere attributable to the CDM project. This requires reliably measuring actual carbon in terrestrial stocks and comparing it with counterfactual carbon levels. Three measurements are required: the area in each land use, the carbon stock in each land use, and the area of predicted land uses in the counterfactual case. The same measurements of carbon can be used to assess total actual and total counterfactual carbon.

$$\text{Environmental benefit} = \sum_i (\text{actual} - \text{counterfactual land use}) \times \text{carbon in land use } i$$

Monitoring Actual Land Cover

The first question is what land covers we want to monitor and how to define them. The most accurate definition would include all types of vegetation and uses, as well as the way the vegetation is managed. Although this would encourage all forms of sequestration as well as protect environmental integrity, it is infeasible, especially in developing countries. We need to trade off potential bias in aggregate measures of carbon stock, incentives to preserve and sequester carbon efficiently, and our ability to monitor.

The answers to the definitional questions will be different for Annex I Parties because of differences in countries’ capabilities. Moreover, the definitions of “forest,” “reforestation,” and other terms could compensate for what some see as overgenerous Annex I baselines for land use. The CDM lets us consider the appropriate definition purely on the basis of feasibility and efficient, full-carbon accounting.

For carbon sequestration the essential difference is between forest and nonforest, but there are also important differences among forests. Young, regenerating forests contain much less carbon than mature forests; forests that have been logged or degraded by pests contain much less carbon than more pristine forests. Forests also vary greatly by their ecological characteristics, but this can be measured in different ways (see section on measuring carbon, below).

Currently, monitoring can be done in two basic ways: ground-based measurement and remote sensing. Remote sensing covers large areas and can be externally verified. It is good for large projects or large numbers of projects and can relatively easily distinguish mature forests from nonforest areas (with the notable exception of dry forests). The quality of interpretation is still very important, especially where forests are highly fragmented. New satellites and techniques allow much finer classification of land cover but are currently too expensive, available only in a few areas, and require an extremely high level of skill to interpret.

If remote sensing is chosen for monitoring, several questions need to be answered.[14] What level of canopy cover is classified as forest? Should this be the same across continents? Should remote sensing be used to establish the age of regenerating forests? What is the appropriate level of resolution? Higher resolution is more accurate but also more expensive. Whatever resolution is chosen, it should be the same for the counterfactual baseline prediction and the actual forest to ensure consistency, but it could vary across projects and time as we learn more and costs fall.

Other questions arise as well. What images are actually available from which satellites? Are cloud-free images available for the regions we are interested in? Will satellites continue to provide these data? Reforestation can take many years to be identified; if remote sensing is used, reforestation projects may not receive any credit until the trees are tall enough to be recognized, at which point they would receive full credit for “forest” unless the history of land use is used to identify their age.

Ground-based reporting is the alternative. This is more intensive but may be more accurate for small areas. A domestic program that rewards foresters and farmers directly may need this approach. And if a country uses ground-based reporting and the system is sound and reliable at the level of each farm, the aggregate measurements based on this will be sound for international purposes. The results could be checked with remote sensing, despite the inevitable differences between the two approaches.

A short-term approach would be to define forest as land cover with a certain canopy density that is easily distinguished by remote sensing. We could use the land-use history to distinguish age where possible. Because this approach will not pick up degradation, we might need to use a conservative carbon number and assume an average level of degradation. Small projects could be allowed to use ground-based reporting but with estimates that were more conservative than those shown by remote sensing. In the long run, a move to remote sensing

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[14] Arturo Sanchez-Azofeifa, Benoit Rivard, and Armond Joyce are exploring the use of remote sensing for the CDM. They are all associated with the National Science Foundation project on land use and carbon sequestration in Costa Rica.

should probably be encouraged because of its low cost for large areas and because it can be replicated by outsiders if measurements are challenged.

Monitoring should probably be required every five years, particularly if the CERs are seen as temporary, as discussed above. Project managers could choose to monitor more frequently if they wanted to collect higher CERs earlier. Periodic monitoring could lead to small amounts of strategic behavior—for example, forest clearing immediately after monitoring—but this would be limited.

Estimation of Carbon and Nitrous Oxides Associated with Different Land Cover and Ecological Conditions

We need measures of carbon in biomass and soils for a range of ecological conditions and the land covers we choose to monitor (e.g., forest and nonforest).[15] In Annex I countries, a combination of remote sensing, on-the-ground measurement, and modeling of carbon dynamics is used to produce estimates of carbon fluxes from different land uses. Reasonably good carbon models exist in many Annex I countries and have been calibrated to a range of ecological conditions using actual data (e.g., CENTURY). However, a large amount of uncertainty still exists, particularly for fluxes in biomass and soil carbon on land where management practices change without an overall change in land use.

Uncertainty regarding biomass and soil carbon fluxes is greater in developing countries, where ecological knowledge about carbon in natural forests is limited. More is known about carbon stocks in commercial forestry because carbon is directly related to the volume of commercially valuable timber, but even here, little is known about soil carbon, below-ground biomass, understory, and litter. In tropical countries, conditions are extremely heterogeneous, and levels of carbon vary dramatically. Relatively little systematic research has been done on carbon stocks across a range of ecological conditions. Within our National Science Foundation project we are currently sampling more than 100 sites in Costa Rica in six “life zones” to provide a consistent dataset that, together with geographic information system (GIS) databases of physical conditions, we will use to calibrate CENTURY to Costa Rican conditions.

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[15] Boone Kauffman, Shuguang Liu, and Flint Hughes are working on this issue in the context of Costa Rica, which has ecological conditions representative of about 75% of the tropics. They are all funded through the National Science Foundation project on land use and carbon sequestration in Costa Rica.

At the project level, a developer can relatively easily sample the tree component of carbon stock within each project but cannot easily sample other components—roots, leaf litter, soil, and small vegetation—that may vary significantly between forest types and can change significantly as forest is cleared.

Our long-run goal is to produce a "carbon map" of the world so that project developers do not need to measure on-site carbon. Their reward would be based purely on their location (its climate and physical characteristics) and the mapped predictions of carbon in different land covers in that location. This would simplify the process and make claims for CERs easily verifiable. Data should be continually collected to improve the accuracy of the carbon map and allow us to make finer distinctions among land uses.

Simple Illustration

Step 1: Monitor actual land cover in project area.

	Forest (million ha.)	Pasture (million ha.)
Actual use in 2002	2	3

Step 2: Translate the actual land use into levels of carbon in the terrestrial ecosystem for different land uses and ecological conditions.

	Forest	Pasture
Carbon per hectare	100 tons	5 tons

These two combine to give the level of actual carbon in sinks each year.

	Forest	Pasture
Actual use in 2002	2 (million ha.)	3 (million ha.)
Carbon per hectare	100 tons	5 tons
Total Carbon	200 million	15 million ton.

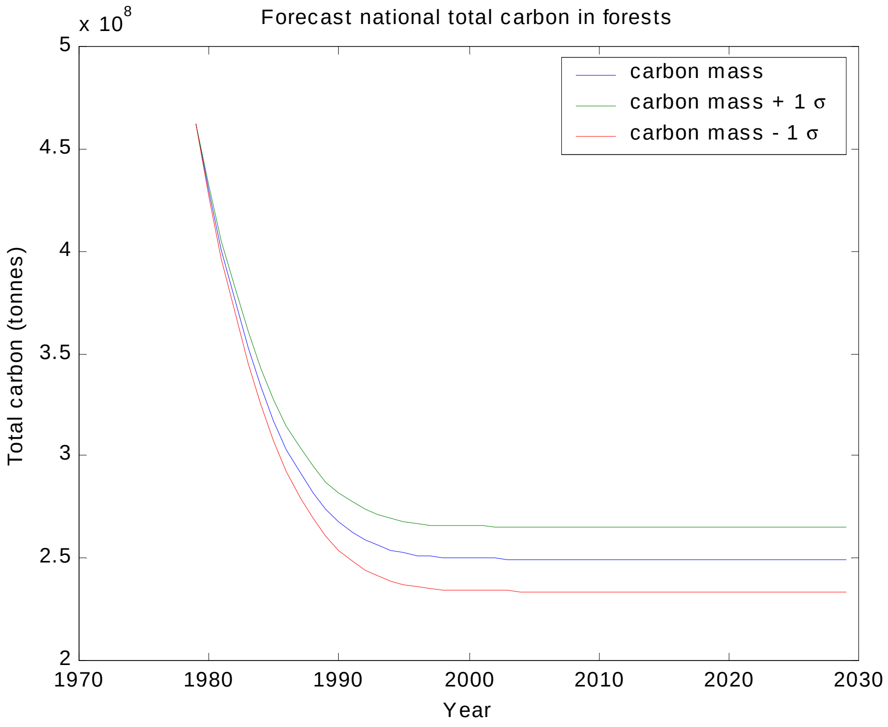
Counterfactual Baseline Predictions

A baseline attempts to capture what would have happened if there had been no effort to protect or enhance sinks. We do not know what land use would actually have been chosen and will never observe it; we are able only to predict it.

Predictions can be based on a combination of extrapolation of past deforestation or reforestation trends and known socioeconomic factors, such as roads, population density, level of development (e.g., gross domestic product per capita or urbanization), value of agricultural output, value of timber, and agricultural productivity of the land. Accurate prediction is extremely difficult, particularly for small areas. In large areas, idiosyncrasies tend to average out. The further into the future the prediction, the less accurate it is likely to be.

Deforestation Baselines

Figure 2. Baseline Prediction of Carbon Level in Costa Rica with Uncertainty



Our baseline prediction of the carbon level in forests for Costa Rica over 50 years from 1980 (Figure 2, from Kerr et al. 2001c) uses all the factors discussed above. The middle line is the best guess; the upper and lower lines indicate a likely range. The actual forest cover in both 1986 and 1997 lies in the expected range, so changes in carbon levels are probably similarly accurate.

This baseline forecast was constructed using data for the whole of Costa Rica. Details of the process for constructing the baseline are given in Appendix 1. It assumes no reforestation. Baseline projections are made for 436 districts and then combined into a national forecast. Each of the individual district-level projections will be much more uncertain than the national pattern. The same approach could be applied to any area where similar data could be found.

In this model the level of carbon loss flattens out after the early 1990s for three reasons. First, within Costa Rica, the highest-quality land had all been cleared by the mid-1980s, so clearing additional land for agriculture was unattractive. Remaining land tends to be high in the mountains, steeply sloped, or on poor soils. Second, Costa Rica is beginning the transition from an agricultural economy to an industrialized country, and increasingly people are working in sectors such as computer chip manufacture rather than clearing more land to farm. Third, the Costa Rica government (and some private citizens) have been very active in protecting forests over the last 20 years. Much of the remaining forest is in national parks or other reserves.

Reforestation Baselines

People often assume it is easier to establish a baseline for a reforestation project than for a deforestation project. This is unlikely to be true. Over very short periods it may be credible to suggest that many areas of land would not otherwise be reforested, but over the long periods that we need to consider for climate change, reforestation is hard to predict. As an example, consider the history of forest cover in the United States. In the early 1900s the eastern United States was almost completely deforested and used for farming. Today it is heavily forested and there is almost no agricultural land. This happened not because of deliberate policies but as a natural result of economic development. The development of railways and other forms of transportation made it possible to ship food cheaply from the Midwest, and east coast farmers who had poor soils could not compete.

Similarly, in Costa Rica in the last decade, reforestation through land abandonment and natural regeneration has become significant, particularly in areas of lower agricultural productivity. In the tropics as a whole, even in the absence of climate policy, as natural sources of timber are depleted and internal infrastructure improves, allowing logs to be transported cheaply, plantation forestry will become more profitable and larger areas will be put into plantations.

Although such changes will likely promote reforestation, they are no easier to predict than the processes that drive *de*forestation. In some ways they are harder to predict because we have less experience with reforestation in developing countries. We have tried to analyze reforestation in Costa Rica (using similar data as in our deforestation study) but have so far had little success in explaining the pattern.

In the short run, reforestation may affect relatively small areas, but if the experience of the United States or New Zealand is repeated in the developing world, large areas of land and hence large amounts of carbon may be affected.

Updating of Baselines

In general, predictions of land use should cover long periods to provide investor certainty and discourage strategic behavior to try to influence future baselines. That said, predictions far into the future are inherently very uncertain. Baselines could be updated with care. More accurate baselines would improve environmental integrity over time and actually increase investor certainty (in contrast to IPCC assertions). Updating the baseline takes out uncontrollable changes in underlying conditions and ensures that the rewards for doing the project reflect more closely the real effects of the developer’s activities. The developers will not be held responsible for things beyond their control. Baselines might be increased or decreased depending on the shocks that actually occur. Updating removes some of the risk involved in what is essentially a property rights allocation. The stakes are very high because this property is potentially very valuable. Establishing an updating process may make all parties happier about creating these property rights in the first place.

As a general rule in updating, factors that the people affected by the baseline can alter should not be taken into account. For example, if the baseline covers a country as a whole, a new road or a change in policy that encourages agricultural expansion should not lead to a change in the baseline level of forecast deforestation even if it does increase deforestation. In particular, changes in the observed level of deforestation relative to the baseline should not lead to changes in the baseline.

In contrast, factors that are outside the control of actors could be used to update the baseline. For example, Central American countries are strongly affected by the international prices of coffee and beef but have little control over them. A rise in the price of beef will likely increase deforestation and could lead to an increase in baseline deforestation. Global or even national economic development could be considered a factor that governments do not directly control as part of climate policy. Thus, baselines could be tied to gross domestic product (GDP) and updated as it changes.[16] (See, for example, studies of the relationship between deforestation and population in Cropper and Griffiths 1994, and between deforestation and GDP in Kerr et al. 2001). Increased biomass as a result of CO_2 fertilization should also lead to an updating of baseline carbon stocks.

Alternative Approaches to Baselines for Small Areas

Although knowledge about local institutions and players as well as detailed information about local economic conditions might make prediction for a small area more accurate, the problem of leakage makes unbiased baseline prediction difficult. It is very difficult to ensure that the sum of baselines for small areas will be consistent with an unbiased national prediction. One approach to ensuring consistency is offered below in the discussion of small vs. large projects.

Anthropogenic Change vs. Natural Change

A well-defined baseline separates natural changes from human-induced change. The only activities that are credited above the baseline are human-induced changes that occur because of climate-related policies. In the CDM we do not need to define human-induced changes on a project-by-project basis.[17]

Errors in Baseline Forecasts

From an international perspective, environmental integrity roughly requires that the baselines be right for the average plot of land covered by a project and that no leakage occur outside the project. The baseline does not have to be correct for every hectare, however. What is

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[16] This is similar to the concept of growth baselines.

[17] This is an issue in Annex I because of unhappiness in how the commitments were set for sinks. Some negotiators intended the commitments to require a certain level of real emissions reduction from business as usual.. Because they underestimated the net sinks in some Annex I countries (particularly the United States), the commitments are more generous than intended. The discussions about limiting sink credits to ones that are directly human induced are essentially attempts to correct this “mistake.”

needed here is methods that avoid bias and are perceived as fair (and produce results comparable to results in other sectors if the emissions reductions are supposed to be fungible across sectors). Because no prediction method will always be correct, the process may be as important as the outcome.

Table 1 shows several examples that illustrate the environmental and efficiency effects of errors in baselines. The first line shows the correct baseline where no CERs are received if no carbon is sequestered and every extra unit of sequestration is rewarded with one CER.

The second line illustrates a case where the baseline predicts more deforestation (less reforestation) than would actually have occurred. Without doing anything, this project can claim 20 CERs—an environmental loss because it does not relate to any sequestration but does allow more fossil fuel emissions. If a project is implemented, however, any additional sequestration is rewarded with the correct number of additional CERs, so project developers have incentives to create projects.

In the third case the baseline predicts very high levels of forest (little deforestation or lots of reforestation). Assuming that the developing country would not be forced to take losses of CERs when it achieves less than the baseline, the country does nothing: It neither creates a project nor claims CERs, and there is no environmental impact. However, there is an efficiency loss: A project developer who manages to sequester 10 extra units of carbon will still not be rewarded because the actual forest level will still be below the baseline level, and projects that could create real sequestration will therefore not be done.

Table 1: Effects of Incorrect Baselines

	True baseline	*Estimated baseline*	*CERs if do nothing = environmental loss*	*CERs if do small project that sequesters 10*	*True additional sequestration*	*Additional CERs awarded*
	100	100	0	10	10	10
	100	80	20	30	10	10
	100	110	0 Will not make claim because would be negative	0 No point in doing project	10	0
				Large project that sequesters 50		
	100	110	0	40 Project may be worthwhile even with less than total credit	50	40

If our concern is to encourage developing countries to use their land in appropriate ways, it would be better to err on the side of making the baseline overgenerous and compensating for any environmental loss by reducing total AAUs through more stringent Annex I targets.

Leakage

Leakage is defined in the IPCC Special Report as “the unanticipated decrease or increase of GHG benefits outside of the project’s accounting boundary (the boundary defined for the purposes of estimating the project’s net GHG impact) as a result of project activities.” In the context of land use projects under the CDM, leakage could occur if the land uses being altered by the project are merely displaced to other areas instead of being replaced altogether. Failing to account for leakage (i.e., increases in emissions outside of the project area caused by activities undertaken by the project) would result in the overestimation of project benefits. Consider the example of a project to conserve primary forest that would otherwise be cleared for agriculture. If the project does not address the unmet demand for agricultural land, then the population that needs the land will simply clear forests in other areas, and the project benefits will be offset. Because leakage can occur at the regional, national, and international levels, it can be very difficult to predict or measure.

The IPCC proposes a range of approaches to reduce or account for leakage. The most obvious, and least restrictive of project design, is to increase the project boundaries so that side effects occur within the boundary. This is considered below, in the discussion of the merits of larger projects. As an alternative, without increasing the size of the project, the area monitored could be increased. This would capture leakage into the area surrounding the project but clearly increases the risk to the project developers, who become responsible for activities in areas outside their control. This option is similar to the option of multiple projects within national or regional baseline, discussed below.

Project design can help reduce the potential for leakage. For example, a developer can evaluate the likely impacts of the project on the existing supply of and demand for goods and services, and seek to change this supply-demand equation or address it through alternative actions (e.g., agricultural intensification or alternative employment nearby). Alternatively, the developer could require that funds freed up from harmful activity not be invested elsewhere (e.g., logging company investments).

The developer can attempt to predict where leakage is likely, monitor leakage impacts over time (possibly by monitoring indicators of demand for land, such as demand for fuel, timber, or agricultural products), and adjust the estimate of project benefits accordingly. Another solution is the development of leakage coefficients by project type and region that can be used to adjust the estimate of project benefits in a more standardized way (IPCC 2000).

Finally, the parties could set conservative baselines to account for leakage by, for example, restricting project eligibility to those activities that address the demand for land-related resources, such as agricultural intensification projects that enable afforestation, reforestation, or forest conservation as a cobenefit. Such a project would have less leakage than one that simply restricts the supply of agricultural land without addressing demand.

Long-Term Solutions

These problems are complex and we will never find perfect solutions. We need to search for simple, standardized, externally replicable methodologies that will lead to unbiased outcomes even if they do not reward all actions efficiently and accurately. In the short run, land cover could be estimated using low-resolution remote sensing with simple classifications. Rather than measure carbon directly on each plot where C sequestration is being rewarded—a very costly process—carbon numbers would ideally be based on the climatic and ecological conditions in the project area and the land-use history, all of which can be known from GIS databases. Baselines could also be derived from a series of historical GIS and other databases that include some socioeconomic information. Then baseline forecasts and carbon estimates could be made from anywhere in the world and crosschecked by other analysts without the need for site visits.

Large projects, ultimately at national level, are more likely to lead to unbiased estimates of land cover, carbon, and baselines and hence are more likely to support environmental integrity. In the long run, these problems will be reduced only by additional research, by learning by doing, and by evaluating our efforts at all stages.

What are the costs of using these simpler measures of land cover, carbon, and baselines? What level of accuracy is necessary and desirable?

Uncertainty and Climate Policy Efficiency: Costs and Benefits from More Accurate Measurement and Prediction[18]

If simplified forest area and carbon stock estimates were compared with very accurate estimates, we would observe forecasting and measurement errors. The land-use baseline predictions will also be incorrect relative to true counterfactuals, even though these cannot be observed. By definition, we cannot observe what would have happened without the reward if the land managers did in fact receive the reward. Thus, when land managers are rewarded for carbon sequestration, their rewards will be incorrect by an unobservable amount. These errors in baseline predictions and carbon measurement have real social costs, even when we cannot observe them. What is the nature of these costs and how do they compare with the benefits of low costs and easy auditing of rewards (such as those available if a model like the one we create for Costa Rica is used)?

If rewards are based on incorrect measures and forecasts, the errors create three costs. First, the inaccurate rewards will lead to aggregate environmental outcomes that differ from those desired. Overstated measurements of sequestration would lead to real increases in emissions when the sequestration credits are sold to a developed country. Aggregate net emissions would rise. What matters here is the error in aggregate additional sequestration relative

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[18] Much of this material draws on Pfaff et al. (2000) and Kerr et al. (2000).

to baseline for the whole country (or even the globe). The cost will depend on how far the aggregate actual additional sequestration under the inaccurate rewards differs from the aggregate credits generated for sale. The global cost of each excess credit could be measured as marginal environmental damage minus avoided marginal abatement cost. Producing too many credits is likely to be perceived as a greater cost than producing too few, though if global targets were chosen efficiently, both would be concerns.

Second, land managers would have inappropriate and hence inefficient incentives to sequester carbon. The cost of the sequestration that did occur would be higher than necessary. Some managers will sequester too much, and others, too little. Our model can estimate these costs in dollar terms. Third, land managers who sequester equal amounts of carbon will be rewarded differently, creating equity concerns. This could affect the acceptability of the system. Unacceptability is not measurable, but the marginal costs will increase with the size of errors, whether positive or negative. Both of these costs depend on errors in plot level rewards. Efficiency costs simply depend on errors relative to reality. Equity costs depend on how forecasts vary across plots that are really identical. Even if the forecasts correctly credit aggregate sequestration, inefficiency and inequity could be problems.

Costs of Reducing Uncertainty

The gains from reduced uncertainty need to be contrasted with the qualitative values of greater simplicity, which translates to lower costs of participation in trading and lower potential corruption through greater transparency and verifiability in the application of crediting rules.

A first obvious cost of increasing accuracy is an increase in direct costs of the analyses (in pilot sequestration projects, generating acceptable C measures has been a significant cost). In developing countries with low capacity, the skilled people needed to do high-quality remote sensing, baseline development, or carbon measurement may be unavailable or better employed elsewhere. Second, both direct costs and uncertainty about the outcome of the certification process will discourage potentially valuable projects. Fewer C trades will take place, so some gains from trade will be lost.

The third cost of using more data and more complex computations is an increased scope for manipulation. Complex rules may become nontransparent black boxes. This makes decisions ambiguous and difficult to challenge. Unlike the pilot phase of activities implemented jointly, the CDM would involve real financial gain. Project developers and managers would have a financial incentive to bias their estimates in their own favor, and these biases may be difficult for outsiders to identify or challenge. If the analysis uses specific local information, outsiders cannot replicate and check it without a large cost. Because more complex rules involve more costly data collection, third-party monitoring to check the claims by CER producers may be reduced. Ironically, then, increased effort and complexity to reduce some errors may in fact lead to others.

Clearly, if it costs nothing to increase certainty, we should. However, attempts to reduce uncertainty could actually increase it—and also disproportionately reduce the possible benefits from sinks.

Costs and Benefits of Small and Large Projects

To date, most land use projects have been relatively small compared with the nations that submit them. To realize the full potential of sinks, we probably need to move toward more comprehensive projects that cover large areas. The scale of the climate problem is large, and numerous small projects, each with a high fixed cost for organizing, monitoring, and so forth, are probably unwieldy. Although larger projects have large organizational costs, there are almost certainly economies of scale.

National or regional projects can assume a wide range of forms and look quite different from most of the current projects. Including a very wide area allows rewards for policy efforts whose effects are diffuse but important when summed over large areas. National efforts can include not only familiar projects, such as those to create or protect national parks, but also policies that may not even be recognized as climate policies: reducing subsidies for pasture, improving security of tenure, facilitating the diffusion of technology and access to capital that allow intensive agriculture, tax incentives for commercial forestry, strategic location of roads, population control, and industrial development that will draw forest users into other employment. These policies are not easily rewarded in the context of projects that cover small areas but may be the most important in the long run.

In this section we first explore the advantages of large projects, as well as the benefits from small projects. Then we discuss ways that some benefits of small projects could be realized while gaining the international benefits from national baselines and monitoring. Finally, we discuss the effects that large projects might have on the negotiating process itself.

Advantages of Large Projects

1. Averaging out heterogeneity and idiosyncrasy over large areas

Most processes for prediction of baselines, remote sensing of forests, and estimation of carbon stocks in an ecosystem will make random errors on each individual site because people and ecological systems are heterogeneous. For example, for reasons that we cannot easily observe, some people clear poor-quality land that we would not expect to be cleared, while others preserve forest cover on high-quality land. Some land happens to have unusual soil characteristics and can store much more or much less carbon than the average site with the same rainfall and temperature. Remote sensing at low resolution cannot observe small cleared areas or pieces of forest, but with an appropriate rule for interpreting the data, the gaps and fragments that are missed should balance each other out.

Careful statistical work can make sure that the processes are not biased over large samples and that these errors will average out to give very precise estimates over large areas. In small areas these errors cannot be avoided without enormous effort, and estimates generated using the same methods will tend to be inaccurate.

2. Preventing environmental bias because of project selection

Suppose there are two areas in a country. The same baseline approach—one that generates unbiased accurate national baselines—is used for both. It creates a favorable baseline for one area (low level of forest expected) and an unfavorable baseline for the other simply because of errors in the baseline process that average out at the national level. If a project developer can observe factors that are not included in the baseline calculation and hence knows that the baselines are incorrect, she will choose to do a project in the area with the favorable baseline. She will gain credits not only for the real sequestration the project achieves but also for the difference between the calculated baseline and the true baseline.

If only that one area is used for a project, environmental integrity will be lost. If one larger project covered both areas, however, the favorable baseline in one area would be offset by the unfavorable one in the other, and environmental integrity would be ensured.

3. Reducing problems with leakage

Leakage is likely to be less of a problem with large projects because it can occur only outside the project. As more areas are included in a project, more side effects are automatically included in the project monitoring.

Figure 3. Leakage and Project Size

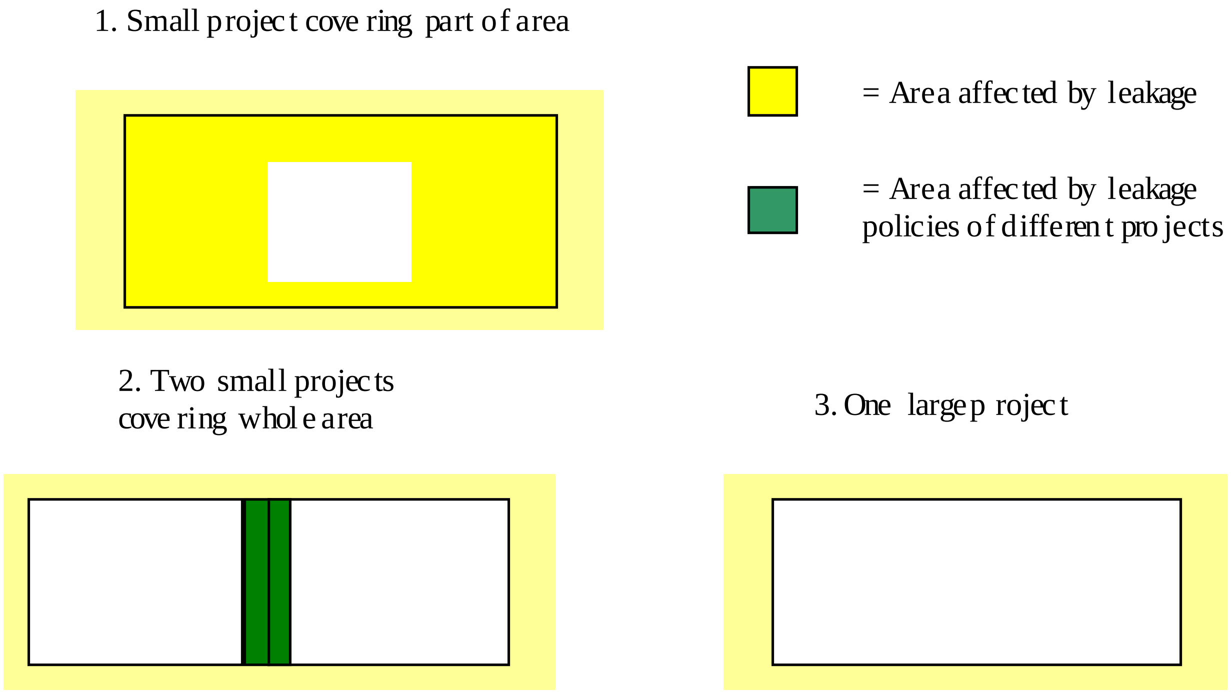


Figure 3 shows some leakage implications of different sizes of project. The dark line indicates the regional or national boundary across which leakage is likely to be reduced. The first example has potential for a lot of leakage, which must be built into its baseline and the scope of the area monitored (see discussion below of ways to address leakage in small projects). The second example has no major leakage outside the project area (all leakage is into other countries or regions) because one project or the other is responsible for all carbon outcomes. This could require some coordination among projects if one project precedes another. If leakage is taken into account in the first project, it will reduce the obligations of the second project or lead to net environmental overcompliance. The third example is the simplest case: leakage occurs only outside the region.

In any case we need to define the project boundaries carefully so that most of the side effects are contained within the project and do not just cross the border. Leakage probably decreases with distance. Ideally, land uses outside the project border will be relatively unaffected by the project. If the project has little effect, leakage will also be small. For example, because deforestation often increases near roads, using a road for the boundary will simply shift deforestation to the other side of the road, creating significant leakage. Leakage across a national border is likely to be weaker than leakage within a country because of market barriers and reduced labor mobility across frontiers.

4. Costs of organizing and monitoring projects

Every project, regardless of size, requires the same basic components. The costs per hectare of monitoring forest, estimating carbon levels, and predicting baselines all diminish as project size increases. Large projects cost the international community less but provide the same amount of additional sequestration.

Advantages of Smaller Projects

1. Potentially higher accuracy

With small projects a very different approach can be taken to monitoring, estimating, and predicting. Measurements for a small project could involve much more specific information and hence could be more accurate on a hectare-by-hectare basis. This could provide more efficient incentives to land users.

2. Potentially fewer errors

As discussed above, the costs of errors probably increase with the total amount of errors. For example, the damage from small levels of inequity or manipulation is probably small but may grow rapidly with the size of gains by particular groups until it is perceived as unacceptable. Similarly, small deviations in aggregate environmental benefit are insignificant, but large deviations may reduce confidence in the agreement as a whole. If each CER is systematically biased to produce less true sequestration than is credited, a project that creates a large number of CERs will lead to a large bias.

Small projects produce fewer CERs, so even if they are more risky per ton, the total risk is lower. Furthermore, no one associated with a small project can make a very large illicit gain.

3. Lower total cost of organization and monitoring

Greater total resources are needed for setting up a large project even if the average cost per unit of sequestration is small. If the project is experimental and must be subsidized, it is much cheaper to subsidize if it is small. If the project is profitable, the relevant cost is the average cost of organization and monitoring.

4. Relative ease of coordinating

In the short run, small projects may be essential if we want the least-developed countries to participate. Such nations face an acute shortage of the entrepreneurial and managerial capability necessary to design and implement large, sound projects at the national level. Large projects would therefore need to be organized through governments, which are sometimes unstable and always focused on more pressing issues. In contrast, nongovernmental organizations (NGOs) or foreign companies, with the support of local communities, could facilitate small projects.

5. Independence from government

Another advantage of small projects is that they require only the host country's approval, not its active participation. When NGOs and companies or subnational domestic organizations in communities or states organize the projects, the potential problems of government-level corruption are reduced. In contrast, national-level programs almost inevitably involve government in a significant role.

6. Equitable distribution of side benefits from participation

Often, those who do projects with foreign investors receive nonmonetary benefits, such as technology transfer, foreign exchange, and access to additional capital. In less-developed countries these benefits can be hard to access directly. If the least-developed countries cannot organize large projects, they therefore may not realize these side benefits. Thus, rules that ensure that every country can have at least some projects would be equitable.

Making small projects more feasible is one approach. This is part of the rationale behind the Pronk proposal to give preferential treatment to small projects. However, this will advantage all small projects, not simply those in countries that would otherwise have difficulty participating. Alternatively, if the goal is to help less-developed countries and those who have no experience with projects participate in the CDM, these groups could be targeted directly with international programs to help them build capacity to create projects.

Part of the motivation for the concern about equity is the expectation that CDM will be somehow capped in total. Under a cap on total CERs (or those from sinks), it might be expected that the largest, most efficient projects would be done and the small, least efficient projects would not compete. This would not be a concern if small projects were efficient. If there is no cap, any project where the costs are lower than the value of the CERs created will be feasible and will find a buyer. We discuss below the reasons for and against a temporary cap on CERs from sinks.

7. Learning

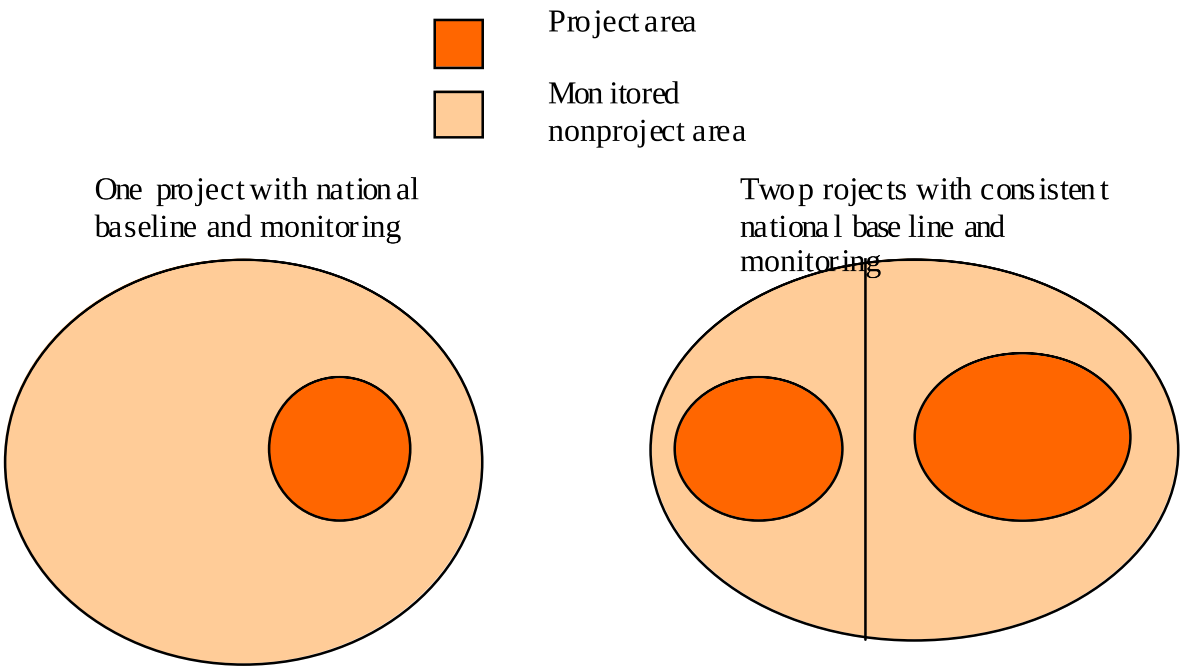
Probably the most important argument for allowing small projects, despite the risk they create, is the contribution they can make to learning—by the project developers, the host government, and the international community. Because total risks and total organization costs are lower for small projects, we could afford to experiment with a range of project designs at little cost.

Individual Projects within a Nationally or Regionally Consistent Baseline and Monitoring System

An alternative approach that allows subnational projects while gaining the international advantages of national or regional projects would be to establish "national" baselines and monitor on a national level but have the national project broken in several projects that are jointly consistent with the national monitoring but can be considered separately for compliance.

The same methodology would be used to create baselines for the project area and the nation or region. Monitoring of land use and estimation of carbon changes would be done at a national or regional level. For assigning credits, the international rules would assume that all the area outside the project is at baseline level and hence allocate all CERs generated in the nation or region as a whole to the project. Two or more projects would have to have a prior agreement on how to share credits. A logical approach might be to assign all the area outside the projects to specific projects, as illustrated in Figure 4.

Figure 4. Alternative Method of Creating Baselines for Small Projects



Effects of Regional or National Baselines on Future Commitments

Creating regional or national baselines has some clear advantages for reducing leakage and reducing the uncertainty in land use projects. Some developing countries have expressed concern, however, that creating such baselines would disadvantage them in future negotiations.

At the same time there are high international costs from the uncertainty about how the developing countries' commitments will be established in the future. As long as the basis for future commitments is not clear, it will be difficult for developing countries to create appropriate policies to address growth in their greenhouse gas emissions. Developing countries have strong incentives to behave strategically because their current actions are likely to affect their future obligations. Ideally, all countries—both developing nations and Annex I Parties—would now begin to behave as though they face a price for the use of carbon. They would consider the global implications in every decision about land use. Taking on a regional or national baseline would facilitate this because the CDM would reward all efforts to sequester additional carbon.

If, however, developing countries believe that future emissions targets will depend on future emissions levels, they would have incentive to increase their rate of deforestation or defer reforestation and resist regional or national baselines—and in fact, the CDM as a whole.. This is the opposite of what is ideal. Developing countries may also resist regional and national baselines if they want to avoid commitments altogether. Baseline estimates would provide an obvious focus on which to base commitments. If baselines have been calculated and accepted by the developing country, it will be harder to delay commitments by stretching out the negotiation over levels of commitment.

Will future commitments depend on future emissions? Will doing CDM projects on a large scale affect future bargaining? Unfortunately, they may: In Annex I, emissions were clearly the basis for negotiations, and although 1990 emissions were used as the standard, the differentiation around that depended in part on the growth in emissions between 1990 and Kyoto in 1997. Changes in emissions since Kyoto have led to attempts to alter commitments.

Essentially, negotiations tend toward finding outcomes that impose similar costs on similar people. If a country carries out a lot of CDM projects and has an efficient system with a regional or national baseline between now and 2012, it will be able to control emissions at lower cost after 2012. In contrast, a comparable country that does not do anything about climate change will face much higher costs of achieving similar emissions levels after 2012. The country that engaged in CDM and took on regional or national baselines will tend to face higher commitments.

Can Adverse Effects Be Prevented?

The adverse effects could be prevented by a clear agreement that future commitments will not be based on future emissions and hence will not penalize developing countries that act early. For example, language in the agreement could state that future commitments will not be based in any way on levels of actual emissions after 2000. Commitments could still depend on factors that influence emissions, such as economic growth or population growth.

Straw-Man Proposal for Incorporating Tropical Forests in Climate Mitigation Efforts

Land use CERs should be credited as sequestration occurs and tracked so that if the sequestration is reversed in the future, they (or equivalent AAUs) expire. This solves the problems of deliberate or accidental loss of sequestration as well as providing sovereign control over the long-term use of land in developing countries.

To avoid concern that current efforts to control emissions will backfire on countries, leading them to face more stringent pressures in the future, we can explicitly state that commitments for developing countries will not be determined on the basis of any measure of emissions or sequestration after 2000.

On the more difficult issues of monitoring land cover, measuring carbon, and predicting baselines we propose one possible solution as a starting point for discussion. The details are incomplete but we believe the overall structure is appropriate.

We propose two sets of rules. The first is for national or regional projects, where estimates will tend to be more accurate because the projects are wide in scope and do not have problems with strategic selection of project locations or with leakage. The second is for small projects, recognizing that at least in the short run there are reasons why national or regional projects will be impractical and inappropriate for some actors and some countries.

Proposed National or Regional Project Rules

Monitoring Land Cover

- Monitor only forest versus nonforest.
- Distinguish forest from nonforest with a fixed canopy cover rule (e.g., 50%), for reliability and consistency of remote sensing.

- Set resolution of remote sensing to a given level (e.g., 3 ha or 1 km) with a “majority rule” to account for forest fragmentation.
- For reforestation, monitor the age of the forest (using historical remote sensing data) as well as the canopy cover. Reforestation projects would not receive credit until they passed the canopy cover level.

Refinements could allow more levels of forest (different levels of canopy cover) and choices about the level of resolution. Higher resolution would necessitate different majority rules to maintain average forest cover estimates for the same forest.

Measuring Carbon

- Use temperature and precipitation (or other readily observable factors) to identify different zones in each country.
- Estimate the average carbon per hectare for forest with more than the required canopy cover in each zone globally.
- Estimate nonforest carbon per hectare for each zone (if it varies significantly; otherwise use one number).
- Set the carbon number for nonforest areas at the high end of the likely range.
- For deforestation, set the carbon number for forest at the low end of the range.
- For reforestation, credit only the increase in carbon in above-ground biomass. Use the lower end of estimates of annual sequestration rates.

Refinements could allow nation-specific carbon numbers to account for factors other than temperature and precipitation. This would be particularly important if variation in soil carbon was included.

Predicting Baselines

Deforestation Baselines

- Calculate past deforestation rates by the temperature-precipitation zone.
- For least-developed countries, assume that this rate continues within each zone.
- Decrease this rate by a proportion for higher-income countries. For example, the rate for countries with per capita annual income above US$3,000 would be reduced by 20%, and above US$6,000, by 50%.

Reforestation Baselines

- Assume a positive percentage of cleared agricultural land (this could be further refined to cover land not used for permanent crops).
- Increase this percentage as per capita GDP rises.

Proposed Rules for Small Projects

Monitoring Land Cover

- Use the same canopy rules as for national and regional projects.
- Allow ground-based monitoring as an alternative.
- Use higher-resolution remote sensing.

Measuring Carbon

- Use the same rules as for national and regional projects but discount the difference between forest and nonforest to account for problems of strategic site selection.
- Allow local measurements as an alternative but discount them if the measurements are not easily replicated.

Predicting Baselines

Deforestation:

- Use local historical deforestation rate for the temperature-precipitation zone but discount it to account for strategic site selection.

Reforestation Baselines:

- Use the same assumptions as for national and regional projects but discount them to account for strategic site selection.

Leakage

- Either discount all CERs (by a decreasing amount as project size increases); or
- require active antileakage policies; or
- create baselines and monitor forest cover on an area larger than the project and reduce credits by the measured leakage outside.

Short-Run Solutions to Risk

The environmental integrity risks associated with including land use activities in CDM are real and significant. They arise from problems with monitoring land cover and leakage, with measuring and estimating carbon stocks on land, and with predicting baselines. These risks will probably decrease over time with improved knowledge, but in the short run, if we want to include these activities, we need to think about ways to reduce the risk.

We are concerned about risk for two basic reasons. First, the environmental integrity of the agreement as a whole may be endangered such that global emissions do not fall as far as planned. There is a concern that land use projects would be systematically biased toward providing more CERs than they really sequester additional carbon. Second, even if the aggregate effect on environmental integrity is small, inequity could be a concern. Large differences in the CERs given to projects that in reality have similar environmental impacts will create concern among those who feel they are disadvantaged. If these differences were caused by deliberate manipulation by those who gained more CERs, the sense of unfairness would be exacerbated. If the concerns were only about real changes in environmental outcomes, the risks would have to be quite large before they had a global impact, but because they involve perceptions of lack of integrity or inequity, even small risks may have large impacts.

The disadvantage of policies to reduce risk is losing real opportunities for environmental and economic gain, as well as the collateral benefits of CDM projects, such as technology transfer and capital access. Opportunities for learning, and hence long-term risk reduction may be lost as well. If policies to reduce risk were implemented, it would be important to ensure that these disadvantages do not affect some groups disproportionately. Different countries should have similar opportunities to benefit from the CDM and to make the investments that will allow them to participate fully in the longer term.

Thus, the challenge is to reduce risk and the perception of risk while, as far as possible, maintaining some benefits from sinks and encouraging learning that will facilitate a transition to the optimal system in the long run.

Delay Inclusion of Sinks

One extreme response to the risks involved in CDM projects is to simply delay the inclusion of sinks in the CDM until a later conference of the parties. This avoids the risk of creating bad precedents with bad rules that are hard to change. It also eliminates any interim gains. Given the time that afforestation and reforestation projects require to create significant credits, delaying the decision until a later conference would effectively remove any gains from these projects even if land use activities become eligible by the time of the first commitment period. Investors are unlikely to develop significant projects until the rules are clear. Learning could still occur through research and through pilot projects that may not be credited, but it would be limited to the type of learning that occurred under the pilot phase of activities implemented jointly.

Limit Risk

A risk-reducing strategy should trade off reductions in risk against the lost real sequestration and loss of opportunities to learn. Before deciding how to limit land use projects under the CDM to reduce risk, we need to consider where the risks come from and where they are likely to be higher and lower. We should aim not only to reduce total risk but also to reduce average risk per ton of carbon benefit. If average risk falls, we can gain more benefits for the same level of total risk.

The risk can be thought of in terms of risk per ton of CERs claimed and the number of total tons potentially involved. The risk per ton depends on the accuracy of land cover monitoring, the accuracy of carbon measurements, and the accuracy of the baseline. The number of tons depends on the cost of avoiding deforestation and encouraging reforestation over large areas. It could depend on such factors as the area of forest, the value of additional agricultural land or timber (and hence the level of threat to the forest), the ease with which the threat can be avoided, and the area that might be available for reforestation and the cost of reforestation. A large risk that affects a small number of tons of CERs may not be that important.

Total risk = risk per ton × number of tons

Different types of projects will have different risks per ton of credit created. Conservation projects tend to lead to more total risk simply because large amounts of avoided release are involved. Mature forests contain much more carbon than growing forests (ten times or more in the early years of reforestation). In addition, the areas of existing forest that are threatened and hence could be conserved are much larger than the areas likely to be reforested in the short run. Thus, even small risks per ton in conservation projects blow up into large total risks. At the same time, the large amounts of avoided release also mean that the potential benefits from conservation projects are very high.

It is not necessarily true, however, that conservation projects face more risk per ton of credit created. It is arguably easier to predict baselines for deforestation than for reforestation (see earlier discussion). Levels of carbon in tropical mature forests are better understood than levels in forests that are growing (except for plantation tree crops, which have been well studied). The extent of mature forest is also easier to monitor by remote sensing.

Large projects may face less risk per ton of carbon than small ones because many of the uncertainties in measurement and prediction average out over large areas. Large projects also avoid concerns that project developers have strategically chosen sites that have favorable baselines. Larger projects face fewer problems with leakage. Projects that create large amounts of credit per hectare could probably create at least a small amount of credit per hectare with very little risk. However, the total scale magnifies any risks on a large project.

Average risks do not necessarily increase as a particular country produces more CERs (or decrease as the number of CERs declines) because there is no reason why less risky projects would be done first. Concerns about inequity, however, could be a function of the amount of risk created by each country. If all countries impose similar risks and receive similar benefits, the concerns may not be so great as if some countries benefit disproportionately from biases in the CDM system.

Two basic strategies could be used to control risk—indirectly, by capping risk per ton, and directly, by capping total credits. These could also be used in combination.

Indirect Limits on Risk

The first possible approach is to reduce the risk on every CER created. This approach would not limit total risk directly but, by lowering the risk on every ton and reducing the number of profitable projects, would reduce total risk as well. This could be done in two ways: conservative rules for CER creation and exclusion of risky activities.

Conservative Rules for CERs

Making the rules for monitoring, measurement, and prediction extremely conservative would ensure that on average, fewer CERs are created than additional sequestration is achieved. That is, conservative rules create a positive environmental bias.

Within the proposed policy rules discussed in section 3.5 are a number of opportunities to systematically create fewer CERs for every unit of sequestration. For example, nonforest carbon numbers can be set high and forest carbon numbers low relative to the range of international estimates. The rules might allow only a fraction of past deforestation rates as the baseline deforestation rate. For example, a country with 2% annual deforestation over the past decade might be allowed to claim only 0.5% deforestation as a baseline for the next decade. Small projects could have their credits highly discounted to reflect their higher average risk.

Imposing these types of restrictions would probably result in the loss of some good projects, but most projects lost should be marginal ones, which are probably also more risky. The restrictions would lower (or conceivably even remove) the average risk per project as well as reduce the total number of profitable projects—both of which will reduce total risk. Conservative rules will not, however, completely block any particular country or any project that could have potential. They will facilitate learning while controlling risk. If the rules were based on what we think optimal rules will look like, they can gradually be made less conservative as information improves and risk diminishes.

Exclusion of Some Activities

Some parties have proposed excluding activities that are perceived as having a higher risk. For example, several proposals (including the Pronk Presidency Paper, April 9, 2001) would make natural forest conservation (or regeneration) ineligible for CDM projects. What would be the implications for the environment? First, as discussed above, it is not clear that this would lower average risk. Conservation projects may actually have a lower risk per ton of carbon sequestered. It is clear that such a policy would reduce total risk because a large amount of potential carbon sequestration (and hence a lot of aggregate risk) relates to avoided deforestation.

Excluding conservation projects could, however, have some unfavorable side effects. If actors can cut natural forest, replace it with plantations, and receive a reward for the plantations, the level of carbon in the atmosphere will rise. This would be hard to avoid in the long run because land use baselines have not been set in developing countries. In terms of efficiency, not including natural forests would miss a major opportunity to sequester carbon. Natural forests in the tropics contain very high levels of carbon that are lost almost immediately when they are cleared. In contrast, carbon is sequestered relatively slowly in new forests, particularly when the land has been cleared for a long period and the soil has consequently been degraded. Other implications of excluding natural forests would be the loss of opportunities to gain cobenefits, such as conserving biodiversity, maintaining the cultures of indigenous peoples, protecting watersheds, and preventing floods. Any policy that excludes some types of projects would limit total risk but would not necessarily lower average risk, and it would not facilitate learning about how to deal with excluded projects.

Direct Limits on Total Sink Credits

The simplest approach to limiting total risk while allowing some CDM land use activity is to limit the total number of land use CERs. This would put an upper bound on total risk at the maximum risk per ton × the CER cap. Because land use CERs can be temporary, any limit should be on the land use credits created net of land use credits that have expired during the commitment period.

A cap makes CERs scarce and valuable. A key question is who will get to create the limited number of profitable CERs and what quality those CERs will be. The worst possible thing that could happen under a cap is that, because the least environmentally sound projects are the cheapest to create, they will be the first—and only—projects. Each of these CERs will generate profit. Once a CER has been created, it is "gold plated" and will sell at the international price even though it may have cost little to produce. Buyers do not benefit from credits' being created more cheaply—only the sellers (creators) do.

Any fixed cap requires some type of rationing system. This could be done in four ways:

- A process-based rationing system controlled by the CDM executive board.
- A previously agreed-upon cap on each seller country.
- First-in first-served: Projects would receive credit until the cap is reached.
- A previously agreed-upon cap on each buyer country.

A rationing system operated by the CDM executive board would need to be based on a set of agreed-upon criteria. It would likely mimic a combination of a country cap, first-in first-served, and the type of indirect limits discussed in the following section. Direct caps at a country level tend to lead to government control because there needs to be rationing within each country. Government control can reduce innovation and also lead to corruption because of the power it gives bureaucrats. Under first-in first-served, projects would have to be accepted before sequestration begins to provide some certainty to developers. As projects are accepted, the credits they anticipate creating would need to be saved by the executive board so that as the project progresses, the credits can be given out. First-in first-served with a strongly binding cap will tend to disadvantage the least-developed countries and concentrate activity in a few countries and maybe a few large projects.

It would be hard to find fair rules for distributing a limited and strongly binding cap either under the CDM executive board or through seller caps. Caps on buyers do not inherently relate to the way the benefits under the cap are distributed because sellers receive the benefits.

The easiest way to make a cap function as a total limit on risk would be to combine it with conservative rules on the creation of CERs. These conservative rules would automatically reduce the total number of CERs and hence make the cap less binding. With a weakly binding (or nonbinding) cap the benefits from being able to sell CERs would be small, and therefore equity would be less of an issue and we could just use first-in first-served to allocate the cap. In addition, the conservative rules would raise the average quality of CERs and reduce risk even further.

Conservative rules may discourage some countries, particularly the least-developed countries, from creating viable projects. This equity and learning concern could be addressed through use of the adaptation fund. Projects could be subsidized through technical and practical assistance so that even under the strict rules, they would qualify and bring benefits to their host countries. If the conservative rules inhibit certain types of learning, individual countries, companies, or the UN could subsidize the necessary expertise as part of a research and learning program.

Conclusion

I conclude that it is possible to incorporate sequestration and storage in tropical forests in the CDM or a similar instrument. The problem of lack of permanence of sink credits is easily solvable with a requirement that the buyer pay back credits when sinks are removed. This solution also gives the sellers more control over their land use and hence reduces problems related to sovereignty. CO_2 fertilization is not an issue in the context of developing countries because, handled correctly, it affects baselines as well as actual sequestration.

The measurement of land use and carbon is not so easily solvable, but bias and manipulation could be avoided by using standardized rules that can be cross-checked. For example, the definition of forest could be chosen so that the forest area claimed can be verified by remote sensing. Carbon numbers for forest and nonforest areas could be standardized, and the numbers for highly uncertain carbon stocks, such as soil carbon, could be deliberately conservative.

Baseline prediction is probably the most difficult issue. Creating baselines is similar to allocating property rights. The high level of uncertainty about the true business-as-usual path means that updating baselines to reflect exogenous changes that affect land use will benefit both project developers and the international community. Baselines are probably easier to predict for large areas simply because the greater variability in historical data allows key coefficients to be estimated. Reforestation baselines are similar in difficulty to deforestation.

By the law of large numbers, estimates of land use, carbon, and baselines are likely to be more precise when they are made on a larger scale. Thus, larger projects will have lower risk per unit of credit. Larger projects also face less leakage because many of the side effects occur within the area of the project. In addition, if a project encompasses a large area, its developers cannot strategically choose to site it where the rules are most favorable to them. Large projects are less likely to create bias and excessive credit creation. Nevertheless, during the period of experimentation, small projects may need to be facilitated to enhance participation of the least-developed countries. In small projects the rules may need to be more conservative to account for concerns about bias, and credits could be discounted to account for leakage unless this can be directly addressed in the project design.

Overall, simplicity, consistency across projects, and replicability will yield good results in the face of uncertainty. The rules need to avoid upward bias in the creation of credits and need to be perceived as fair. In the short run, to minimize total risk, we might want to deliberately bias the rules to make them more conservative to guarantee net environmental gains from the inclusion of sinks. These rules could be relaxed as we learn more and perceptions of risk fall. Because of short-run perceptions of high risk, the total amount of sinks could also be capped. If this were done at a level unlikely to be binding, with conservative rules well applied, a cap would not limit the market too much or require a complex rationing system.

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Appendix 1. Generating Land Cover Baselines on a Large Spatial and Temporal Scale

The baseline example given in the text was developed by an interdisciplinary research project led by Alex Pfaff (Columbia University) and Suzi Kerr (Motu) and funded by the U.S. National Science Foundation. The details of the derivation are given in Kerr et al. (2001c), and the project as a whole is described in Pfaff et al. (2000).

The goal in creating this baseline deforestation forecast was to find a way to generate long-run, unbiased projections that cover broad areas while using relatively few data. The forecast is done based on a model for the whole country, so we can realistically assume that most causes of deforestation are derived within this area, most market interactions occur within the area, and institutional structures are reasonably common across the area. We would not expect significant leakage from Costa Rica to neighboring countries. We did not study reforestation because it has occurred only recently and would be more complex to model (see discussion in text). With improved data we hope to add analysis of reforestation.

To forecast deforestation, we begin by trying to understand why people clear forests. In Costa Rica the primary cause is agricultural extension rather than logging (in which only the high-quality timber is removed). If we want to forecast for long periods, we need to understand the causes of deforestation. Short-term patterns may continue for a while, but they are unlikely to persist over 20 years or more as conditions change.

Our model of human choices is based on individual decisionmaking. We assume that humans do the best they can for themselves and their families within constraints on their ability to borrow (either for investment or to cover short-term needs, such as education or medical help) and their access to information. We do not assume that we can perfectly predict their behavior. Because human behavior is complex, we want to model average observed behavior rather than build a model of specific parts of human behavior that we can study even if they yield a biased total picture. By studying past human behavior under a range of different conditions, however, we have some ability to predict the direction of response to new conditions and whether the response will be large or small. For example, if a new road is built—and in the past people have always cleared land near roads—they are likely to do so again.

Data

Our basic data are from remote sensing coverage of all of Costa Rica: the early 1960s, 1979, 1984, 1986, and 1997. These data distinguish forest and nonforest in all years and in 1997 distinguish reforested areas from existing forest. For the current study the data are aggregated to the level of 436 districts. These data allow us to identify the patterns of deforestation across space and a long period of time.

To explain these patterns, we use a range of variables. At a national level we use GDP per capita and population growth. We expect that as people become better off, at first they will use more land to produce more but later they will start to move toward producing services (e.g., tourism) and industrial goods (e.g., computer chips) that demand less land. In addition, as people become wealthier, they begin to value the environment more, and their government gains more capacity to protect it. Thus GDP growth will initially raise deforestation pressure but in the long run will reduce it. As a second measure of the development of the economy, recognizing that this varies significantly between regions, we use the percentage of population that is urbanized in each district. Temperature and precipitation in the district are summarized through the use of life zones that characterize different ecological conditions. These and measures of soil quality affect the likely agricultural productivity of the land.

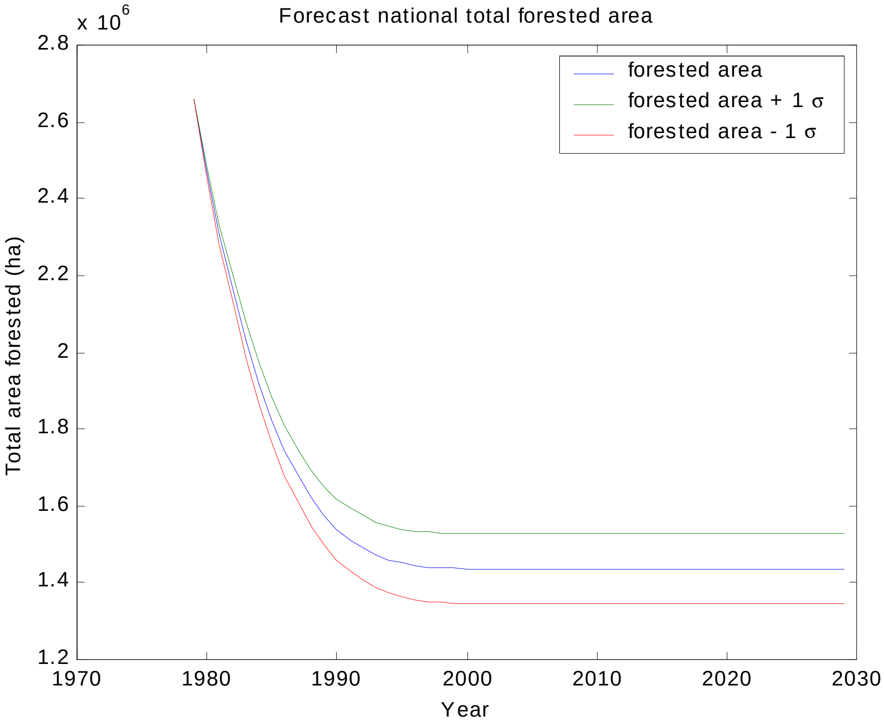
We also directly estimate the likely profitability of crops that can be grown in the area. As another measure of the quality of land that has not yet been deforested—and also the overall level of development of the district—we use the percentage of land in the district that has already been cleared. For example, we expect that flat land will be cleared first, so remaining forest land is more likely to be on steep slopes and hence less attractive. We use the deforestation rate in the last period to account for ongoing development toward the region’s potential (this is the basis of models that simply extrapolate past deforestation rates) and the effects of existing deforestation on access for clearing more land. Finally, we use distances to key locations (cities and ports) and the density of roads in a district to indicate the ease of access of farmers in the area to local, national, and international markets.

Method

To relate the history of deforestation to the behavior of individuals who cause it, we use regression techniques (Grouped logit). We aggregate the implications of individual decisions to the district level and then relate observed changes in land use with the characteristics of those districts.

The results of this statistical analysis allow us to create a forecasting model that predicts future forest levels in each district (these are aggregated to the national level in Figure 5. We then use ecological data on the amount of carbon in different types of forests to translate levels of forest into levels of carbon to give the baseline carbon forecast in the text.

Figure 5. Predicting forest levels from 1979



Generalizability

These results cannot be directly applied to countries that have different ecological and economic characteristics. The *method* we developed, however, is broadly applicable. Understanding the important characteristics that drive deforestation and the nature of changes as development occurs would allow us to develop reasonable forecasts with considerably less data and work than was required for this first analysis. Most countries have at least one year of remote sensing coverage, many have life-zone maps and soil data, all have GDP and population data, and many of the other variables can be easily generated with a map. All our analysis could be replicated from anywhere in the world.

Although this analysis requires some data and skill, the work involved is considerably less than that required to collect local data and do other onsite work to predict baselines. Locally generated baselines may be appropriate for small areas but are not feasible on a broad spatial scale. In particular, use of local knowledge may be more appropriate for domestic policies where aggregate environmental integrity is not so critical (because it is already ensured at the international level by international rules) but local equity is crucial. Such baselines will tend to be more precise on a site-by-site basis but are probably biased in aggregate.

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The Role of Woody Debris in Forest Management for Carbon

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Introduction

Carbon (C) sequestration is among the recent additions to the set of forest management objectives. It gives a new twist to several aspects of forest management. For example, it makes longer rotations (harvesting cycles) more attractive, and it provides an additional incentive for afforestation efforts and for enhancement of tree growth through various silvicultural practices (Binkley et al. 1997). However, these are incremental and predictable changes because such measures are already widely accepted as good and responsible forest management (e.g., Sampson et al. 2000); the monetary value of carbon merely provides additional support. On the contrary, the established management paradigm regarding tree mortality, logging residues ("slash"), and other woody debris has to be entirely reconsidered if the forest is managed for C. From the point of view of C sequestration, it does not matter in what ecosystem component the accumulation occurs, and therefore, C accumulation in woody debris may be just as valuable as C accumulation in live trees. This represents a reversal of the established negative view of woody debris as waste and indication of poor management.

At the dawn of forestry, timber was the main objective of forest management, and the forestry practices focused on minimizing tree mortality and logging waste. An extensive set of practices was developed to achieve this goal, including thinning, choice of appropriate plantation density and species, fertilization, genetic improvement of planting stock, optimizing harvest rotation, disturbance control, and other techniques. A large body of research shows that many of these techniques are useful for increasing C stores in forest ecosystems. When concerns about biodiversity emerged and the need for retention of coarse woody debris (CWD) in forests became clear, it was seen as a sacrifice of productivity for the sake of wildlife. For that reason the transfer of material from live to dead wood is practiced at the minimal level needed to maintain wildlife habitat. Only in the context of forest management for carbon does woody debris become equal in importance and value to live wood. The role of woody debris thus

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represents a cardinal difference between managing forests for carbon and for any other objective. This difference is also frequently overlooked with major consequences for estimated effects of forest management practices on C stores.

The role of woody debris is substantially different from that of fine litter and soils because management practices directly affect the input of material into the woody detritus pool. Timber harvest not only transfers live biomass into the forest products pool, it also produces a large, instant flux of material into the CWD pool and reduces future inputs into this pool from tree mortality. This input reduction naturally leads to long-term reduction in CWD mass, and very few models to date include this link. The difference between various management options is in effect the difference in quality, quantity, and timing of material flow into the forest products and woody detritus pools. To optimize the distribution of material flow for greater overall C storage, it is necessary to compare the fate of C in these two pools (Binkley et al. 1997). This paper shows why in most cases the adequate estimation of woody debris is a vital component of efforts to make C sinks operational and how it can be done.

Can We Ignore CWD?

In the past, estimation of C stores in forest ecosystems was performed in the context of scientific research. The transition from academic research on C pools and fluxes to operationally robust techniques for quantifying changes in C stocks is an ongoing process (Hamburg 2000; Boscolo et al. 2000). CWD is often among the first ecosystem components to be dropped in an effort to simplify C accounting. The argument is that counting dead trees as “committed C emissions” simply ignores some of C accumulation on the site and therefore provides conservative estimates with respect to C credited. Although this may be true for projects designed to sequester C through afforestation, in other types of C-offset projects, ignoring dead trees can lead to unrealistic projections of C benefits. For example, when the effect of protecting forests from logging is estimated, emissions from the logged forest form a baseline. The assumption that the biomass of all logged trees is instantly released into the atmosphere vastly exaggerates estimates of C losses in the near term and therefore the short-term benefits of a conservation project. On the other hand, long-term benefits of a conservation project may be underestimated when CWD is ignored. CWD plays a large role in C accumulation of old forests (Harmon et al. 1986, 2001). In rare cases where live biomass approaches equilibrium, accumulation of CWD may continue for many decades, even centuries.

It is also important to include CWD in estimating the effects of substitution. In regions where natural disturbance regimes are replaced by rotation forestry, the forest is maintained so that harvest equals net growth. The premise is that the forest can both be a source of wood products and still retain the captured C (Karjalainen et al. 1998). Thus, a considerable pool of carbon is permanently stored in the steady-state biomass while wood products continue to be generated with each timber crop, in a cumulative manner, substituting for fossil fuels. Although this approach is perfectly valid, it overlooks the management option that appears to be the most effective in increasing C stored within the next 100 years or so, namely forgoing timber harvest and allowing the forest to grow (Figure 1; Schlamadinger and Marland 1996). Accepting the "opportunity curve" as a baseline leads to the conclusion that sustainable forestry actually causes losses of C for the next 100 years even if forest products and fuel substitution are accounted for. Biomass accumulation beyond the age of harvest is certainly the major reason, but the growth of CWD stores also plays a role. Excluding CWD from consideration would clearly diminish the benefits of forgoing timber harvest, especially over longer time frames (beyond those shown in Figure 1).

Timber harvest, whether by thinning or clearcut, has two major impacts on the CWD pool: It generates an instant flux of material into that pool, but more importantly it causes long-term reduction in tree mortality—that is, future input into the CWD pool. Unfortunately, few existing models reflect this connection between forest products and the CWD pool. Replacing mortality with harvest is a clear and unequivocal benefit from the point of view of traditional forestry, and this is exactly the point where traditional forestry and C forestry diverge. To find out whether diverting material from mortality creates additional C stores, we have to compare the retention of C in CWD and in forest products, including the production pipeline (Figure 2). C sequestration in forest products can be a valid strategy, but only when the forest products pool provides more effective C storage than woody debris (measured as decomposition rate or average residence life) (Binkley et al. 1997). Model simulation of C accumulation in CWD and in forest products assuming common decomposition rates for the boreal and temperate zones (Figure 2) indicates that converting wood to short-lived products leads to significant losses of C. In other words, greater C sequestration can be achieved if trees are left in the forest than if they are converted to short-lived products. Medium-lived products store C more effectively than the dead wood of fast-decomposing species. Here again, treating dead trees as "committed emissions" would lead to projecting C benefits where there may be none. This probably represents the most significant omission in C accounting brought about by ignoring CWD.

Another example of overestimation of C benefit due to inadequate quantification of CWD involves measures to reduce the rate of natural disturbance. Fire control is often considered a measure to increase C stores in undeveloped boreal forests, such as those in Canada and in Russia. However, disturbances generally do not cause an instant loss of the entire C store. Instant releases following fire seldom exceed 10% of biomass; other types of disturbance release even less C. The transfer of live forest biomass to woody detritus actually provides longer-term retention of C than the majority of forest products because of the low decomposition rates of CWD in boreal zone.

Many C-offset projects cause changes in species composition. Examples include plantations and an increased proportion of late successional species in landscapes where disturbance is controlled or nonclearcut harvest methods are practiced. Species that occur within the same region can have quite different decomposition rates and therefore different levels of C stocks in CWD for the same input rate (Figure 2). Other factors being equal, planting species with slower decomposition rates will produce higher C stores in CWD. Slow-decomposing species are in many cases late-successional ones. Conservation projects, which promote those species, will have an added C store in CWD relative to faster-decomposing species. Even for the moderate difference in decomposition rates shown in Figure 2, the difference in C stores can be substantial: For each unit of input into the CWD pool, the added equilibrium C storage is more than 15 units.

Adequate accounting for CWD is important for many aspects of planning C-offset projects, such as selecting a time frame, addressing leakage, and designing a monitoring system. For example, excluding CWD from C accounting may result in invalid estimates of the role of young forests when trees are planted on a previously harvested site. Even when the removal of bole biomass from the site is very thorough, stumps remain, and so do the roots and usually branches. This material constitutes more than 20% of the live biomass of a mature forest (Cairns et al. 1997) and takes a very long time to decompose (Table 1). The amount of C lost in the process exceeds C accumulation in young trees for significant periods of time. Some studies estimate that it takes 30 years for C uptake in live biomass of young trees to balance the C release from slash (Cohen et al. 1996).

Overlooking CWD in C accounting is unfortunately quite common. In fact, most of the recently published reports on operational C-offset projects do not include the CWD component (Brown et al. 2000a). One reason that incorporating CWD into C accounting has been slow is that the general public and even some professionals find it difficult to accept dead wood as a sink of C. Forestry tradition has certainly contributed to the strictly negative attitude toward dead trees. Including biodiversity and C into the set of management goals can be expected to facilitate the recognition of the significance and value of CWD and, perhaps, an eventual change in public attitude.

Methods and Techniques for Operational Quantification of CWD

A major reason for ignoring CWD is the perceived difficulty of quantifying it. CWD stores may be difficult to assess because they vary significantly over succession and do not necessarily parallel the dynamics of live biomass. The amount of CWD is strongly influenced by disturbance (natural and anthropogenic) and characteristics of the previous generation of trees on a given site (Harmon et al. 1986; Clark et al. 1998; Krankina et al. in review). The existing experience with measuring CWD is certainly not as extensive and standardized as measurement of live wood. Nevertheless, methods are available and academic studies of dead wood have increased dramatically in the last two decades following the recognition of the importance of CWD for many aspects of ecosystem functioning (Harmon et al. 1986). Based on this research, operational techniques for estimating CWD are being developed and tested (Fridman and Walheim 2000; Krankina et al. in press; S. Brown pers. comm.). These and other studies of CWD have generated the data and expertise needed to include CWD into C accounting. Developing an operational system for quantifying CWD in the context of C-offset projects was not the intended purpose of our recent study of CWD in several major forest regions of Russia (Krankina et al. in review). However, we did an extensive study of CWD for all the major forest tree species across the full range of climatic conditions and disturbance regimes (Figure 3). The resulting dataset provides an opportunity to explore different options for simplification of estimation procedures for CWD.

As for other biomass components, the goal is to measure change in CWD stocks over time. Protocols for field measurements of CWD have been developed (Harmon and Sexton 1996), and there is significant experience in application of these field methods. Our study in Russia integrates three types of field data: (1) measurements of the bulk density of CWD on sample trees (Table 2), (2) CWD and live tree inventories in sample plots, and (3) forest inventory data. The first two types of data are examined below to identify strategies for developing cost-effective procedures to quantify CWD. The use of Russian forest inventory data for large-scale assessments is published elsewhere (Krankina et al. in review).

Our primary goal in collecting data from individual dead trees was to establish a system of decay classes that associate a complex of visual characteristics of logs and snags (standing dead trees) with bulk density values. We sampled 922 dead trees, representing major tree species in all the regions examined, for bulk density of wood and bark (Table 2). Sample trees were selected from five decay classes that covered all the stages of decomposition from nearly sound wood (class 1) to the most advanced stages of decomposition, when CWD material is soft and friable (class 5). Twenty visual characteristics of dead trees (e.g., extent of bark loss, moss cover) were recorded:

Percent of bark cover on bole
Presence or absence of needles or leaves
Presence or absence of twigs
Presence or absence of branches
Presence or absence of bark on branches
Presence or absence of bark on bole
Sapwood sloughing
Log is collapsing (unable to support its weight)
Log’s cross section is elliptical
Presence or absence of conks on bole
Presence or absence of moss on bole
Presence or absence of lichens on bole
Presence or absence of carpenter ants
Presence or absence of bark beetles or galleries
Presence or absence of brown rot
Presence or absence of white rot
Sapwood can be crushed by hand
Heartwood can be crushed by hand
Log surface is hard but center is soft
Branch stubs can be moved
Presence or absence of wood borers or galleries

Samples were taken from four cross sections 2 to 5 cm thick located systematically along the length of each log or snag examined. The bulk density of each sampled log or snag was calculated as the weighted average, then the sample trees were grouped by species and decay class within each region, and mean densities were calculated for each grouping (Table 3a). These mean densities were used to compute masses of each CWD piece measured recorded in sample plots.

The variation of density within each decay class was substantial, with the coefficient of variation (CV) ranging from 11% to 17% in decay class 1 and 20% to 48% in decay class 5. The differences between classes were not always significant (Table 3a). The five-class system—designed for academic research and intended to reflect changes of a whole host of variables over the process of decomposition—probably resulted in collecting some field data that were redundant for purposes of density sampling. To quantify CWD stores, the system should focus exclusively on density; the statistically effective system of density classes might then be limited to fewer classes (Yatskov 2000). Analysis of the visual characteristics of our five decay classes showed that visual distinction of three classes might be more appropriate (Figure 4). The presence of bark, branches, and twigs is a good indicator of decay classes 1 and 2, for example, and friable and sloughing sapwood and heartwood and log collapse would distinguish the advanced decay classes (4 and 5). Overall, the most effective visual characteristics are associated directly or indirectly with wood mechanical strength, which is known to be linked to wood density. By pooling data from classes 1 and 2 into a single class and classes 4 and 5 into another pool, a three-class system was developed (Table 3b).

CWD was measured in 1,044 sample plots ranging in size from 0.1 to 1 hectare (ha). These plots represent the dominant tree species and different successional stages (recently disturbed forests and young to old-growth forest stands) in all seven regions examined (Table 2). To inventory dead wood in plots, we used our system of five decay classes. Measurements in plots included the end diameters, the middle diameter, and length of each piece of dead wood >10 cm in diameter and >1 m in length. All forms of CWD were inventoried, including snags, logs (dead and downed), and stumps (cut by harvest). Species and decay class of each piece were recorded and the mass of each piece was calculated by multiplying the computed volume by the average bulk density of CWD for a given species and decay class. An alternative and perhaps more cost-effective method is to use line transects to determine the volume of CWD in plots by species and decay class.

It is important to include all types of CWD in plot inventories. In natural forests two types of CWD occur, logs and snags. In managed forests stumps form a third major type. The role of stumps can be substantial: In the mature, intensively managed forests of the St. Petersburg region, stumps represent up to a third of the total CWD store, and their biomass is between 2 and 17 Mg/ha. The mass of logs is generally greater than the mass of snags, but the role of different types of CWD (logs, snags, and stumps) varies greatly.

Can we estimate woody debris from live biomass, wood mass, or wood volume or other stand variables? In general the answer is no, because of the large variation in live biomass to CWD ratios. In our plots CWD constituted 2% to 96% of total above-ground biomass. However, grouping plots by region, species, and age groups allowed us to calculate significant ratios of CWD to live wood volume for middle-aged and mature forests (Table 4). In young forests the ratio varied widely, and this precluded the calculation of a meaningful number. We attributed this to the fact that dead wood found in young forest stands came from the previous (predisturbance) generation of trees, and consequently the amount of CWD did not correlate with the current volume of young trees in plots. For young forests, the mean volumes of logs and snags per unit area were calculated, and these volumes varied greatly among regions. In two western regions where managed forests prevail (St. Petersburg and Central), the stores of CWD were low, as in other regions where the prevailing disturbance type is clearcut harvest (Fridman and Walheim 2000). In contrast, natural disturbance, including fire and insect outbreaks, is a major cause of stand initiation in the eastern part of Russia, where young stands inherit large amounts of material from the previous forest stand (Table 4).

Once the initial store of CWD is estimated, the change in this store over time can be either quantified by remeasurement (for monitoring purposes) or modeled (when changes are projected into the future). Models can use information on inputs through tree mortality and losses through decomposition. A global review of measured decomposition rates for many forest regions and species has been published recently (Harmon et al. 2001), but additional measurements are required, especially for the tropics. Inputs through tree mortality can be easily estimated when the forest is disturbed; however, background mortality in many forest types is still poorly studied.

Detecting change in CWD stores may be accurate when these stores change rapidly (e.g., following harvest or natural disturbance). However, gradual changes (e.g., accumulation in older forests) may be more difficult to detect because of large variability of CWD stores within stands and landscapes. The number of observations required to detect this change within a decadal time frame may be cost-prohibitive. It was found that in soils, change in C content of less than 15% is virtually impossible to detect, and in most cases changes less than 30% are difficult to measure with any degree of accuracy (Homann et al., in review). Because variability in CWD C stores is generally similar to that in soils, monitoring C stores by repeated measurements is unlikely to produce reliable results when changes are expected to be small.

Yet another method of quantifying change in CWD stores is estimation based on the ratio of CWD to live biomass. The system of ratio estimators should be carefully set up with disturbance regime, stand age, and species group as primary design variables. Then, changes in CWD are estimated based on changes in live biomass and the transition of forest land from one category into another. Because it is well established that CWD does not generally correlate with live biomass, it is important to make the system of estimator ratios detailed enough to reflect, for example, the loss over time in CWD stores of young stands (which occurs while live biomass is increasing). It is also essential to apply these ratios only to the forests stands that were statistically sampled. Using these ratios outside these limits is clearly not acceptable.

Conclusions

Full consideration of woody debris dynamics is needed for a comprehensive assessment of C sinks in forest ecosystems and the effects of forest management practices on C stocks. Ignoring CWD may be acceptable in some cases, but it can undermine the integrity of many C-offset projects.

Operational measurement and monitoring methods for estimating C stocks in CWD are available or being established, and research data on processes that control C dynamics in CWD exist for many major forest regions. However, models and other operational estimation and analysis techniques have been slow to incorporate research results.

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Table 1. The range of decomposition time (years) for each decay class and species (Yatskov 2000).

Decay classes	Species					
	Betula costata	*Betula pendula*	*Larix* spp.	*Pinus sylvestris*	*P. siberica/ koraiensis*	*Picea* spp.
1	1–8	0–7	0–11	0–9	0 - 8	0 - 8
2	11–12	2–15	4–25	1–19	7 - 65	2 - 15
3	13–22	5–33	13–104	8–40	21 - 77	5 - 71
4	22–77	11–33	30–104	17–70	39 - 160	16 - 77
5	77	24–73	90–110	40–70	65 - 135	30 - 77

Table 2. Field data overview: Sampling of CWD density and inventory of coarse woody debris and live wood in sample plots (Krankina et al. in review).

Regions	CWD density		CWD and live wood volume inventory	
	Species	Sample trees	Age group	Sample plots[a]
Northwest:	*Pinus sylvestris*	55	young	43
St. Petersburg oblast	*Picea abies*	30	middle age	211
	Betula pendula	28	mature and older	125
	Populus tremula	12		
Central [b]	*Populus tremula*	20	young	15
			middle age	38
			mature and older	30
West Siberia:	*Abies sibirica*	20	young	3
Khanty-Mansi okrug	*Betula pendula*	35	middle age	19
Novosibirsk oblast	*Pinus sylvestris*	20	mature and older	185
East Siberia:	*Abies sibirica*	23	young	12
Krasnoyarsk krai	*Betula pendula*	99	middle age	66
Irkutsk oblast	*Larix sibirica*	113	mature and older	161
	Picea obovata	63		
	Pinus sibirica	57		
	Pinus sylvestris	130		
Far East	*Betula costata*	30	young	5
Khabarovsk krai	*Betula pendula*	28	middle age	30
	Larix dahurica	63	mature and older	101
	Picea ajanensis	67		
	Pinus koraiensis	49		
Total		922		1044

[a] An additional 20 plots were set up in disturbed forests (including burned stands, wind-throw areas, and clearcuts) across all regions.

[b] Central region includes the following administrative units: Briansk oblast, Vladimir oblast, Ivanov oblast, Tver oblast, Kaluga oblast, Kostroma oblast, Moscow oblast, Oriol oblast, Riazan oblast, Smolensk oblast, Tula oblast, Yaroslav oblast, Nizhnii Novgorod oblast, Kirov oblast, Republic Mari El, Republic Mordovia, Republic Chuvashia.

Table 3a. Mean densities (g/cm^3 + SE) of CWD by decay class and species for major tree species of Russia. Values marked by the same letter are not significantly different (ANOVA with the Tukey pairwise mean comparison test, p<0.05 (SAS Institute 1990)).

Decay classes	Species					
	Betula costata	*Betula pendula*	*Larix* spp.	*Pinus sylvestris*	*Pinus siberica/ koraiensis*	*Picea* spp.
1	0.516 ± 0.007	0.474 ± 0.005	0.455 ± 0.007	0.362 ± 0.005	0.336 ± 0.006	0.358 ± 0.006
2	0.333 ± 0.037	0.370 ± 0.009	0.424 ± 0.009	0.338 ± 0.006	0.322 ± 0.006	0.335 ± 0.010
3	0.194 ± 0.012	0.237 ± 0.014	0.368 ± 0.013	0.269 ± 0.009	0.252 ± 0.011	0.236 ± 0.010
4	0.120 ± 0.005 D	0.148 ± 0.012	0.162 ± 0.008	0.172 ± 0.012	0.146 ± 0.008	0.139 ± 0.010
5	0.084 ± 0.003	0.108 ± 0.010	0.109 ± 0.008	0.122 ± 0.006	0.109 ± 0.007	0.108 ± 0.006

Table 3b. Mean densities (g/cm^3 ± SE) of CWD by decay class and species for major tree species of Russia utilizing three-decay class system.

Decay classes	Species					
	Betula costata	*Betula pendula*	*Larix* spp.	*Pinus sylvestris*	*Pinus siberica/ koraiensis*	*Picea* spp.
1	0.482 ± 0.020	0.421 ± 0.008	0.439 ± 0.006	0.349 ± 0.004	0.329 ± 0.005	0.347 ± 0.006
2	0.194 ± 0.012 C	0.237 ± 0.014	0.368 ± 0.013	0.269 ± 0.009	0.252 ± 0.011	0.236 ± 0.010
3	0.102 ± 0.011	0.132 ± 0.009	0.138 ± 0.007	0.148 ± 0.008	0.129 ± 0.007	0.128 ± 0.007

Table 4. Parameters for estimating CWD volume in forest stands with no CWD reported in the forest inventory database: Volume of dead wood in young forests and CWD:live wood volume ratio in middle-aged and older forests (mean ± standard error).

Region[a]	Species group	Young[b] (m^3/ha)		Middle age (%)		Mature and old (%)	
		Logs	Snags	Logs	Snags	Logs	Snags
Northwest	Hardwoods	9±2	2±1	2.5±0.9	1.2±0.3	5.7±2.0	4.0±1.4
	Conifers			6.7±0.9	4.4±1.1	12.1±1.6	3.0±0.4
Central	Hardwoods	8±2	2±1	4.4±0.4	2.1±0.3	7.9±2.0	3.0±0.4
	Conifers			3.9±0.5	1.5±0.3	7.8±2.7	2.9±0.5
West Siberia	Hardwoods	6±1	5±2	7.0±4.7	8.5±4.6	5.5±1.5	1.3±0.2
	Conifers			2.0±0.4	1.5±0.5	4.4±0.5	1.9±0.2
East Siberia	Hardwoods	37±11	22±10	7.4±1.4	3.7±0.9	10.9±2.1	4.1±1.0
	Conifers			8.4±2.3	3.4±0.9	7.6±0.9	1.9±0.3
	Larch			9.0±3.7	6.2±1.5	11.2±3.6	2.9±0.9
Far East	Hardwoods	92±19	30±6	4.1±3.6	1.4±0.3	24.8±5.8	7.3±1.7
	Conifers			21.6±3.6	9.1±3.4	11.8±2.9	9.1±2.0
	Larch			18.0±7.3	4.6±1.8	12.8±2.9	7.1±1.6

[a] Administrative units within each region as in Table 1.

[b] In young forests mean volume of logs and snags was calculated for a combined set of plots that included all species groups.

Cumulative carbon-stock changes for a scenario involving afforestation and harvest. These are net changes in that, for example, the diagram shows savings in fossil fuel emissions with respect to an alternate scenario that uses fossil fuels and alternative, more energy-intensive products to provide the same services. (Adapted from Marland and Schlamadinger, 1999).

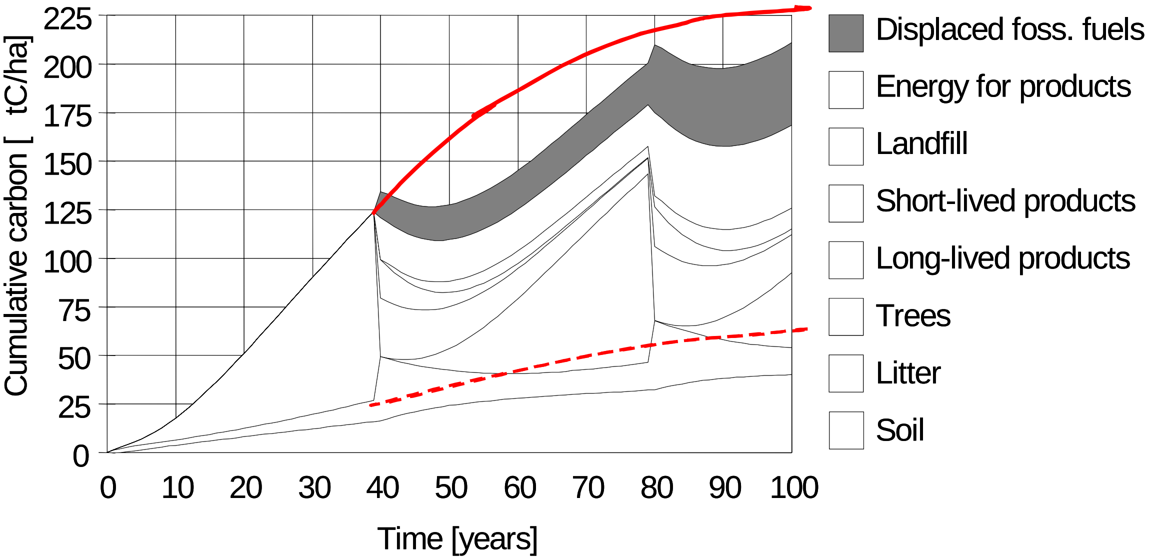


Figure 1. The "opportunity curve" in red shows C accumulation for a scenario without timber harvest.

Figure 2.

Decomposition control on C accumulation in CWD and forest products.

Curves 1 and 2 represent C accumulation in CWD for a constant mortality input of 1 Mg/ha/year (average for natural mortality in Eastern US (Brown and Schroeder 1999)) and decomposition rate constants 3.3% and 7 %.

Curves 3 and 4 represent C accumulation in forest products, long-lived and short lived forest products. Higher decomposition rates reduce the steady-state pool and the time it takes to achieve equilibrium.

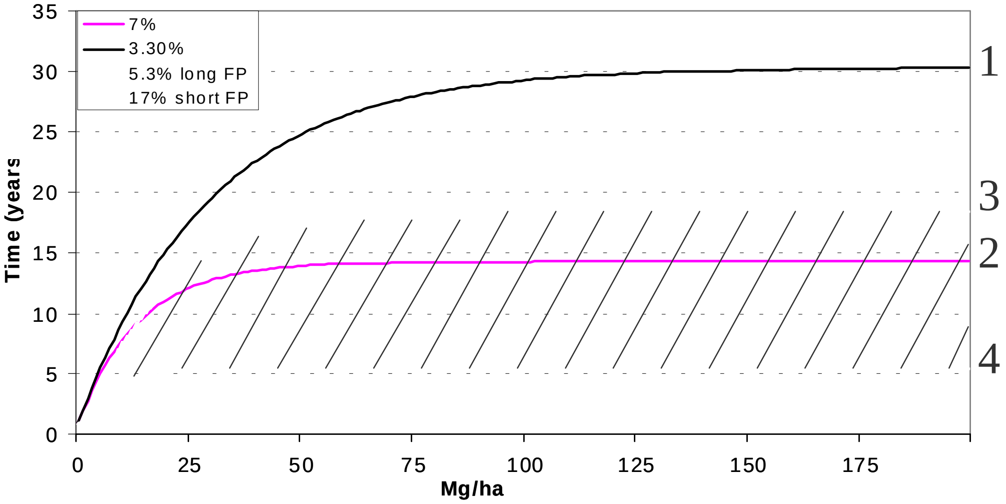
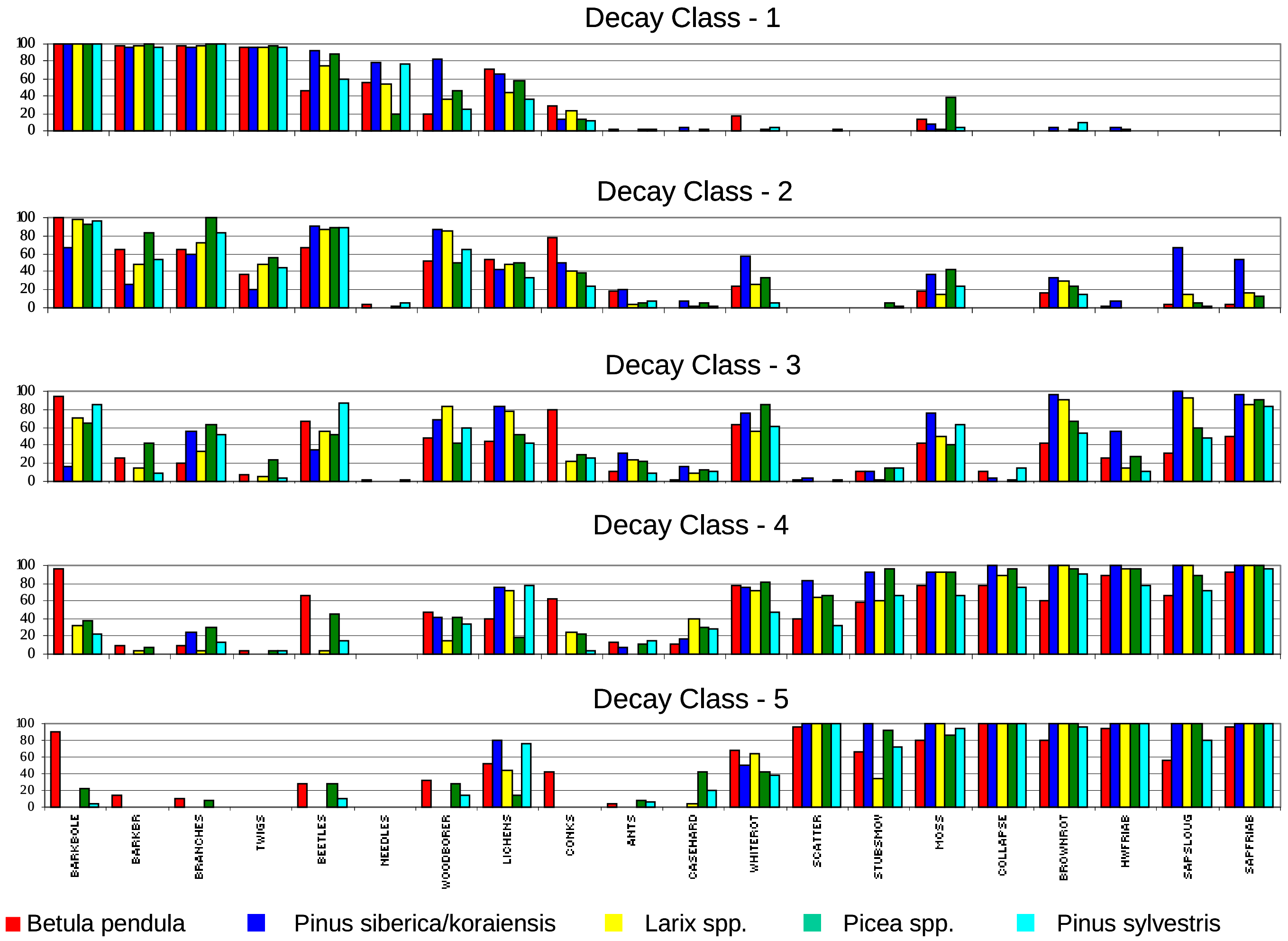


Figure 3. Schematic of forest regions where CWD stores were estimated: 1, St. Petersburg oblast; 2, Central region (see footnote to Table 1 for complete list of administrative units); 3, Khanty-Mansi okrug; 4, Novosibirsk oblast; 5, Krasnoyarsk krai; 6, Irkutsk oblast; 7, Khabarovsk krai (Krankina et al. in review).

Figure 4.

Frequency (%) of Indicator Presence in CWD



Elements of a Certification System for Forestry-Based Greenhouse Gas Mitigation Projects

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Elements of a Certification System for Forestry-Based Greenhouse Gas Mitigation Projects

Pedro Moura-Costa*

1. Introduction

During the last ten years, a variety of forestry projects have been established with the objective of sequestering, storing, or preventing the release of CO_2 to the atmosphere to offset emissions taking place elsewhere (see, e.g., Moura-Costa and Stuart 1998 for a list). The number of greenhouse gas (GHG) mitigation projects[1] is expected to increase after international agreement is reached on the use of forestry as a means to achieve the objectives of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC).

Although there is still uncertainty about which modalities of forestry will be accepted for implementation of the Kyoto Protocol, the protocol is explicit about the need for verification and, in the case of the Clean Development Mechanism (CDM, Article 12), certification of project activities. This requirement for verification and certification is not yet specified in any official set of rules, regulations, or guidelines.

In this interim phase, rules and regulations have been created by national GHG regulatory bodies (e.g., USIJI 1994; JIRC 1997) for the evaluation of projects under the activities implemented jointly (AIJ) pilot phase; specialized institutions (private sector, nongovernmental organizations, academic institutions) have developed their own methods for the quantification of the performance of GHG mitigation projects. It is likely that these early experiences will provide inputs for the formulation of internationally agreed-upon guidelines for verification and certification of carbon offsets. This paper describes the author's views of the steps required for

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[1] A variety of terms have been used to refer to different project-level climate change mitigation mechanisms (Joint Implementation, JI, Activities Implemented Jointly, AIJ, Clean Development Mechanism, CDM) and their outputs: carbon offsets, carbon credits, emission reduction units (ERUs), certified emission reductions (CERs). This paper will use the generic terms '*carbon offsets*' and '*GHG mitigation offset projects*' to refer to all different technical formulations, with specific terminology used only as and when appropriate.

certification of forestry-based GHG mitigation projects. These steps also form the basis of the carbon offset verification service used by the international monitoring and verification firm Société Générale de Surveillance (SGS) (Moura-Costa et al. 1997), which has been already applied to more than 15 projects in Africa, Latin America, and Europe.

2. Institutional Requirements for Certification

In this paper, *verification* is defined as the activity of checking the validity of the claims of a project, usually based on the data gathered by the project's internal monitoring program. If a project fulfills all regulatory requirements, verification may lead to certification.

Essential components of a verification-certification system include a published standard, an accreditation body, and certification agencies accredited to use the standard. The standard used for certification must be adopted by an independent standard-setting organization and must be accepted by the parties concerned. In the case of the standards developed by the International Organization for Standardization (ISO, the major worldwide standard-setting organization), technical committees work within the ISO framework (Upton and Bass 1995). In forestry, the Forest Stewardship Council (FSC, an organization that certifies sustainable forest management) has established generic principles and criteria, and country-specific standards based on these are being set up by national working groups (Higman et al. 1999). But there is no universally accepted standard for certification of GHG mitigation projects. To address this issue, the organizations currently verifying the carbon offset claims of existing projects have used compilations of criteria from the project selection requirements of GHG regulatory bodies and carbon investment entities worldwide (e.g., the USIJI, the Canadian JII, the Australian AIJ Pilot Initiative, the Netherlands JIRC, the German AIJ Pilot Phase Programme, the World Bank Prototype Carbon Fund, and the Emission Reduction Units purchase tender of the Dutch Government).

Certification agencies must be independent of the standard-setting body and the organizations seeking certification and must have well-defined procedures, guidelines, and training (Upton and Bass 1995). In the language of the protocol, certification companies have been referred to as operational units.

To ensure credibility, the certification process must be overseen by an accreditation body independent from certification companies, ensuring consistency and compliance with the standard and certification procedures (Higman et al. 1999). In essence, accreditation bodies "certify the certifiers." For certification of GHG mitigation projects, no accreditation body has yet been established. It is likely that this role will be filled by some accreditation body selected by the Conference of Parties to the UNFCCC, possibly linked to the Intergovernmental Panel on Climate Change (IPCC, the scientific advisory body to the UNFCCC). In the absence of an official accreditation body, verifiers have submitted their evaluation reports for peer review by internationally recognized experts.

As the negotiation process stands, the verification of GHG mitigation projects has been divided into two phases: validation of project design, and verification and certification of the project's achievements. These phases are further discussed below. It has been proposed that these activities be performed by separate operational entities to create a process of self-control by the verifiers themselves. Others suggest that this may burden the system and argue that the integrity of the system should be maintained by the accreditation bodies.

3. Validation of Project Design

The process of validation of project design can be divided into two phases related to the requirements of the Kyoto Protocol. First, a qualitative analysis must be performed to verify the suitability of the project according to eligibility criteria required by UNFCCC, the Kyoto Protocol, and GHG regulatory agencies. In particular, the Kyoto Protocol requires that projects "promote sustainable development" (Article 2) and result in benefits "additional to any that would otherwise occur"—that is, they must fulfill the additionality requirement (Articles 6.1b and 12.5c). Other requirements relate to host country approval and project externalities, both related to GHG (leakage) and unrelated to GHG (social, economic, and environmental impacts).

Second, the GHG benefits of a project must be quantifiable in a "transparent and verifiable" manner. Consequently, the validation process must include a verification of the data and methods that will be used to quantify carbon offsets, determination of a "without project" baseline, and the projection of carbon benefits expected from the project. Inevitably, this initial analysis would be based on assumptions and projections and could not provide anything more than a forecast of the likely benefits.

The initial validation should lead to the acceptance or rejection of the project as a valid GHG mitigation project. Additionally, from a developer or investor's point of view, the assessment increases the credibility of the project and reduces risk to investors, especially if combined with a risk analysis. Certification, however, is accomplished only after an *ex post* analysis of project is conducted, based on real accomplishments.

4. *Ex post* Verification and Certification

This stage of the process cannot take place until project activities have been implemented: It is not possible to verify something that has not yet occurred. Verification of a project requires a field visit. The frequency of such visits can vary and should be determined by the needs of the project developers or investors. During the field visits, certification companies (operational entities) must carry out the following activities:

- Determine whether the assumptions adopted for the project baseline remain valid, as political, social, economic, or environmental situations may change. In some cases, verification of the baseline is done through the establishment of control plots where the intervention is not implemented and business continues as usual.
- Verify the actual project activities (e.g., area planted). This can be achieved through satellite imagery, aerial photography, or field visits, depending on the scale of the project.
- Verify the project's monitoring activities. Although quantification itself is not part of the verification process, certifiers must verify that the project's internal monitoring program consistently utilizes appropriate data collection and quantification methodologies, as described in the validated project document. Methodologies may vary depending on data availability, project circumstance and design, and technology used, but some key elements must be addressed, as described elsewhere (e.g., MacDicken 1996; IPCC 1995; Greenhouse Challenge Office 1998). Verification should ensure that the data used for quantification are consistent with the project's data records, and that the records match observations in the field. The data collected by the project staff need to be verified by book inspections and field sampling.
- Check the quantification methodologies.
- Adjust the results to account for uncertainty and measurement errors (see Section 5 below).

If satisfied with the results of the verification, the certification company then issues a certificate stating the amount of certified carbon offsets achieved by the project to date, completing the certification process. It is still being discussed who will have the authority to issue the actual carbon credits—the certified emission reductions (CERs) and emission reduction units (ERUs). Suggestions include the operational entities themselves, the host country, the Clean Development Mechanism's executive board, and the Conference of the Parties (COP).

Practitioners in this field would prefer a simple and expeditious process to avoid the delays of further deliberations.

5. Treatment of Risk and Uncertainty

Once the carbon benefits of a project have been verified, it is necessary to estimate the uncertainties and risks affecting such estimates. In the context of GHG mitigation projects, uncertainty can be classified as mensuration error and counterfactual uncertainty. Mensuration error relates to the degree of uncertainty attached to a measurement, expressed as a standard error, or standard deviation of means. The amount of carbon credits to be authorized for use should, perhaps, deduct an amount for the anticipated error attached to the measurements. Counterfactual uncertainty relates to factors that cannot be statistically quantified, as in estimating the baseline. At the outset of the project, counterfactual uncertainty could be addressed by estimating the effect of uncertainty assumptions on the baseline during project implementation, and adopting a conservative scenario.

Risk differs from the uncertainties described above because it relates to project implementation rather than to quantification of project benefits. Risks are particularly important in the case of forestry projects because they can lead to the “reversal” of carbon credits that may already have been issued. Risk relates to the likelihood and significance of particular events that may or may not happen, such as natural catastrophes (e.g., fire, floods, droughts, pests, diseases), anthropogenic interventions (e.g., encroachment, theft, fire); and sociopolitical, economic, financial, and market problems (e.g., nonenforcement of contracts, noncompliance with guarantees, expropriation, uncertain property rights, changes in costs and prices).

A possible way to deal with risks is to create a carbon offset reserve that is kept for self-insurance purposes during the project implementation phase. This approach was first used in the certification of the national program of the Costa Rican Office for Joint Implementation, which placed 40% of the project’s offsets in a self-insurance buffer reserve (SGS 1998). Another way to reduce risks of reversal of GHG benefits is to allow crediting only after a predetermined period of storage, or to provide credits yearly according to a ton-year factor (Moura-Costa and Wilson 1999). The ton-year approach has two advantages: It allows for carbon storage to be credited according to the time frame over which this service is provided, and it reduces the need for long-term guarantees and hence the risks associated with long time frames. If the project’s forests are damaged, carbon credits can be cancelled, and the amount of credits lost can be more easily calculated.

6. Conclusions and Recommendations

A wide range of methods, approaches, and criteria have been developed and field tested for the evaluation and quantification of the carbon offset benefits of forestry projects. Nevertheless, current lack of policy related to methods and guidelines to be used for certification of carbon offsets has resulted in large discrepancies between the claims of different projects. This, in turn, leads to uncertainty, discrediting forestry as a greenhouse gas mitigation option. There is therefore an urgent need for standardized procedures for project analysis to ensure consistent results and comparability between projects. In particular, agreement is needed on the protocols for determining baselines and additionality, the precision levels required for quantification, the treatment of uncertainty and mensuration error, methods for calculating project benefits, and the time frame used for project analysis.

Independent verification and certification are a tool to increase credibility and transparency of project claims. As in any trading system, independent certification facilitates transactions by removing a layer of uncertainty and risk for a relatively small fraction of the overall transaction costs. In the case of GHG mitigation projects, it could enhance the legitimacy of the projects, and thus increase the comfort level of regulatory bodies, investors, and other interested parties.

For certification to succeed, however, some components must be put in place. First, an internationally accepted standard must be adopted by the UNFCCC. Second, clear and objective guidelines for project analysis and quantification of project benefits must be defined. Finally, the UNFCCC must elect an accreditation body to certify and oversee the activities of the certifiers, adding a layer of transparency, credibility, and legitimacy to the system.

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