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Climate Change, Carbon, and Forestry in Northwestern North America:

**Proceedings of a Workshop
November 14 - 15, 2001
Orcas Island, Washington**



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Climate Change, Carbon, and Forestry

in Northwestern North America: Proceedings of a Workshop

November 14 - 15, 2001

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Climate Change, Carbon, and Forestry

Forest resource issues have been on the front page of newspapers in northwestern North America for the past two decades. Superimposed on the complexity of managing ecosystems is growing concern about increasing temperatures and other aspects of changes in the atmospheric environment. Managers of public and private forestlands face increasing pressures to include climate change issues, particularly the disposition of carbon, in long-term management plans. Management, economic and policy approaches to carbon flows in natural resources are evolving rapidly.

The workshop on Climate Change, Carbon, and Forestry in Northwestern North America – convened on Orcas Island, Washington, November 13-15, 2001 – was an opportunity for scientists, resource managers, planners, and policy makers in the Northwest to learn about and discuss prominent issues related to climate change and carbon in forest ecosystems. Workshop participants developed a common understanding of the state of science, and developed approaches for incorporating carbon allocation in forest management and planning.

A summary of major conclusions and inferences developed by workshop participants is attached. Any comments or questions regarding this document may be directed to:

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Workshop Agenda

Wednesday, November 14, 2001

Welcome and introductions

Session 1: The Climate Change and Policy Context, Chair - David Spittlehouse

Best Guesses About Global and Regional Climate Change - Philip Mote

Beyond the Kyoto Protocol: Options and Strategies - Edward Miles

Panel Discussion

Session 2: Storing Carbon in Forests, Chair - Richard Bigley

Forest Management Strategies for Carbon Storage - Mark Harmon

Detecting Regional Trends in Carbon Storage - David Wallin

Economic Analysis of Carbon Storage Strategies - John Perez-Garcia

Panel Discussion

Adjourn - posters available for viewing

Thursday, November 15, 2001

Session 3: Techniques and Institutions for Managing and Storing Carbon, Chair - Robert Dick

Life Cycle Analysis of Wood Products and Carbon - Robert Kozak, Chris Gaston

An Institutional Framework for Carbon Credits and Trading Systems - Gary Bull, Ann Wong, and Zoe Harkin

A Model Forest Carbon Transaction: Principles and Policy Framework - Michelle Passero

How Do You Retire Forest Carbon Credits? Permanence and Leakage - Gordon Smith

Panel Discussion

Participating in a Marketplace for Carbon - Aldyen Donnelly

Linking Science, Planning and Technology with Policy - Ralph Alig

Panel Discussion

Summary Discussion, Chairs - John Innes, David Peterson

Adjourn

Contents

Proceedings Introduction: Managing Forests in a Greenhouse World – Context and Challenges <i>John L. Innes and David L. Peterson</i>	1
How and Why is Northwest Climate Changing? <i>Philip Mote</i>	11
Beyond the Kyoto/Marrakech Protocol: Options and Strategies <i>Edward L. Miles</i>	23
Economic Incentives for Carbon Storage in Western Washington’s Forested Riparian Management Areas <i>John Perez-Garcia, Jane Edelson, and Heather Rogers</i>	37
Life Cycle Analysis: A Wood Products Perspective <i>Robert Kozak and Christopher Gaston</i>	49
Carbon Accounting: Institutional Framework, Models, and Economics <i>G.Q. Bull, Z.E. Harkin, and A.Y. Wong</i>	61
Alternative Transaction Structures Allowing Permanent Retirement of Sink-based Emission Offsets <i>Gordon Smith</i>	81
The Use of Conservation Easements to Secure the Role of Private Forests in an Emerging Carbon Market <i>Laurie A. Wayburn and Michelle C. Passero</i>	91
Global Climate Change, Carbon, and Forestry: Decision-Making in a Complex World <i>Ralph Alig</i>	101
Final Workshop Summary and Scientific Conclusions: Climate Change, Carbon, and Forestry in Northwestern North America	117

Proceedings Introduction: Managing Forests in a Greenhouse World – Context and Challenges

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Abstract

Interactions between forests, climatic change and the Earth's carbon cycle are complex and represent a challenge for forest managers – they are integral to the sustainable management of forests. In this volume, a number of papers are presented that describe some of the complex relationships between climate, the global carbon cycle and forests. Research has demonstrated that these are closely connected, such that changes in one have an influence not only on the other two, but also on their linkages. Climatic change represents a considerable threat to forest management in the current static paradigm. However, carbon sequestration issues offer opportunities for new techniques and strategies, and those able to adapt their management to this changing situation are likely to benefit. Such changes are already underway in countries such as Australia and Costa Rica, but it will probably take much longer for the forestry sector in the Pacific Northwest region of North America (encompassing Oregon, Washington, Montana, Idaho, British Columbia and Alaska) to change their current practices.

Climatic Change

Climate is dynamic and is always changing. Around 15,000 years ago, much of the northern half of North America was covered by ice sheets; today only tiny remnants remain. Several sources of information, including both direct measurements and proxy evidence, have revealed that temperatures in the northwest of North America are increasing. Mote (this volume) reviews what we know about recent changes in the climate of the Northwest. During the 20th century, average annual temperature warmed by 0.6°C on the coast of British Columbia, 1.1°C in the interior and 1.7°C in the northern part of the province (Mote 2003). The temperature changes recorded in, for example, Fort St. James in British Columbia during the 20th century match very closely in pattern the changes in sea-surface temperatures recorded globally (Coulson 1997). These changes are reflected in the number of growing degree days, which increased by 16 percent in northeast British Columbia, by 13 percent on the Coast and in the southern interior, and by 5 percent in the central interior. Lakes and rivers are becoming ice-free earlier in the year, and the water temperatures of the Fraser River have increased. A number of glaciers in British Columbia (Brugman et al. 1997) and northern Washington (Granshaw 2002) have shrunk in size. Precipitation in southern British Columbia has been increasing by 2 to 4 percent per decade, primarily in the winter, and a 50 percent increase has been recorded in northeastern Washington and southwestern Montana during the 20th century.

By 2100, temperature increases of between 1.4°C and 5.8°C relative to 1990 are expected. Globally, the Intergovernmental Panel on Climate Change (IPCC 2001) predicted higher maximum temperatures (very likely), higher minimum temperatures (very likely), reduced diurnal temperature ranges (very likely), more intense precipitation (very likely, over many areas), and increased risk of drought (likely, in mid-latitude continental interiors). The actual nature of climatic change at a particular site will depend on a variety of local factors, and considerable efforts have gone into downscaling the results of global models to individual regions. Such downscaling is considerably more difficult in mountainous areas, with clear implications for northwestern North America.

Carbon and Climatic Change

Relationships between global atmospheric concentrations of carbon dioxide (CO₂) and various human activities have been examined in detail by IPCC (2001). Atmospheric concentrations of CO₂ have increased over the past 150 years, from a pre-industrial mean concentration of 280 ppmv to a mean concentration in 2000 of 367 ppmv, representing an increase of 176 Gt of carbon between 1850 and 1998. Between 1850 and 1998, ca. 270 Gt of carbon were released into the atmosphere from fossil fuel burning and cement production. An additional 136 Gt of carbon came from land-use change, mainly forest ecosystems. Thus, almost one third of the total increase in atmospheric CO₂ between 1850 and 1998 was the result of land-use change, mostly deforestation. To place these figures in perspective, natural emissions of CO₂ today amount annually to 50 Gt of carbon from vegetation, 60 Gt of carbon from soils, and 102 Gt of carbon from the oceans.

Evidence for the increase in CO₂ concentrations comes from the CO₂ concentrations in the air trapped in glaciers and ice sheets, together with detailed measurements carried out in Hawaii since the mid 19th century (Keeling et al. 1989). These measurements indicate that atmospheric concentrations of CO₂ are increasing steadily, which is why so much concern has been expressed about reducing or even halting the rate of increase.

There is a strong consensus among scientists that increased atmospheric CO₂ concentration is linked to climatic change. The IPCC states in its 2001 report that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." This consensus is based on a number of lines of evidence. CO₂ is a recognized greenhouse gas, meaning that molecules present in the atmosphere absorb heat. Other greenhouse gases are also present in the atmosphere (e.g., methane, chlorofluorocarbons, water vapor), and some of these are capable of absorbing more heat per unit mass than CO₂.

The impact of greenhouse gases on the atmosphere is measured using an index known as the Global Warming Potential (GWP), which relates the ability of the gas to absorb heat and its lifetime in the atmosphere. CO₂ has a GWP of 1, with most other gases having higher GWPs. For example, methane has a GWP of 21, whereas sulfur hexafluoride (SF₆), which is released in relatively small quantities, has a GWP of 23,900. Despite its low GWP score, the quantities of CO₂ present in the atmosphere make it by far the most important of the greenhouse gases, and responsible for 60 percent of the radiative forcing that occurred between 1750 and 2000. In British Columbia, 80 percent of greenhouse gas emissions consist of CO₂, with the next most important gas being methane (CH₄), representing 14 percent of emissions. Global models are increasingly successful at reproducing the observed trend in mean sea surface temperatures over the past 100 years, suggesting that the role of greenhouse gases has been adequately incorporated among the various forcing factors affecting global temperature.

Forests and Carbon

The rise of global concentrations of atmospheric CO₂ can be directly attributed to the burning of fossil fuels and to changes in land use. One ton of CO₂ contains 0.27 tons of carbon, and there are approximately 0.47 tons of carbon in a cubic meter of wood. One ton of carbon is equivalent to 3.7 tons of CO₂. Consequently, the burning of a cubic meter of wood will release ca. 1.7 tons of CO₂. While over the longer term (the last 150 years), a third of the total CO₂ emissions has come from land use change, more recently, the burning of fossil fuels has made an even greater contribution, with 75 percent of anthropogenic emissions of CO₂ over the last 20 years being from fossil fuels.

Land-use change is responsible for the release of between 1 and 2 Gt of carbon annually. This is about 25 percent of total emissions over the last 20 years. By 2050, more than 650 million ha of forest will be lost, resulting in emissions of >75 Gt of carbon. Some of these losses could be reduced, and a positive land management strategy aimed at increasing the amount of carbon stored in forests could have a significant effect on global CO₂ dynamics. For example, the 1995 report of IPCC (1996) stated that

forestry as a mitigation strategy could realistically reduce cumulative net anthropogenic emissions over the next 50 years by >70 Gt of carbon.

Recent simulation modeling results indicate that longer rotation length and other silvicultural practices may increase the potential for carbon sequestration in Northwest forests (Harmon and Marks 2002), although there are many uncertainties and assumptions involved in quantifying the long-term potential of forests to contribute to carbon storage (de Jong 2001). The greatest source of scientific disagreement is related to the *magnitude* of carbon storage on site, typically in older forests, woody debris, and soils, versus the *rate* of carbon uptake, which is typically much higher in productive young forests. Additional empirical data on Northwest forests and wood products are needed to quantify carbon pools in biomass and products, which will inform science-based management strategies and economic analyses (Alig et al. 2002).

Forests and Climatic Change

Forests respond to both short-term and longer-term variations in climate, and in northwestern North America, decadal variations in climate are strongly influenced by the Pacific Decadal Oscillation (PDO). Near the upper treeline, where trees are not typically constrained by summer moisture stress, growth is positively correlated with the PDO; positive PDO periods have lighter snowpack and an earlier start to the high-elevation growing season (Peterson and Peterson 2001, Peterson et al. 2002). However, at lower elevations where summer moisture stress limits productivity, growth is negatively correlated with PDO; warm dry winters and light snowpack associated with positive PDO increase summer drought stress.

A number of phenomena have already been observed that suggest that Canadian and southern Alaskan forests are responding to recent warming. These include increases in boreal forest productivity, accelerated seasonal development of some insects, changes in the distribution of insect pests, and provenances from slightly warmer areas out-competing local provenances.

Predicting future change in forest ecosystems is difficult because of the poor understanding of basic physiological mechanisms. We know that summer moisture stress is important throughout the region, at least at most lower elevation sites, but there is uncertainty over how the water-use efficiency of trees will change as a result of continuing CO₂ enrichment. This is so poorly understood that it is difficult to predict the direction of forest change (positive or negative) as a result of future warming. However, likely effects include changes in productivity, nutrient cycling, water quality, carbon storage, trace gas fluxes, tree composition, and biodiversity. Changes in the composition of forests are likely (Spittlehouse 1996, Zolbrod and Peterson 1999, Bachelet et al. 2001), with one impact being the disruption of the current forest classification systems in British Columbia (biogeoclimatic zones) and the northwestern United States (forest associations, series, and habitat types), the basis for much of the forest management in the region.

The ability of natural populations to adapt to new climatic conditions depends on the amount of genetic variation for traits under selection, rate of climatic change (selection intensity), generation length, and rate of population migration and gene flow. While high levels of genetic diversity in most tree species will support this process in the long term, there may be several generations of reduced productivity in the interim due to rapid rates of climatic change. There is also a question of resilience. Once established, stands may have substantial ability to buffer themselves against climatic variation, so structure and composition may not be directly affected. However, ecological disturbance, such as fire, insects and disease, may set back the forest to an establishment phase, when the trees appear to be most sensitive to adverse environmental conditions.

Climatic change could have a number of other impacts, including plantation failures due to poor adaptation, extreme climatic events, increased insect and disease problems, unacceptable levels of mortality, altered productivity, and loss of wood quality. Some of these factors interact – the increase in productivity of boreal forests that has already been recorded may be accompanied by a (so far unreported) decrease in the pulping qualities of the wood. The faster growth of forests could, in theory, increase the supply of wood, thereby depressing prices and making forestry in the region less

economically viable. Given that fire exclusion, selective removal of large trees, and intensive grazing have created a dense mixed forest overstocked with shade-tolerant pines and firs in some areas, the risks of major insect outbreaks, disease and large fires may become significant (McKenzie et al. 2004).

Responses in the Forestry Community

There have been a number of high-level policy initiatives that have taken into account the actual or potential effects of climatic change on forests. The background to the policy changes that have occurred are described by Miles (this volume).

The Montreal Process

As early as 1993, the importance of the maintenance of global carbon cycles was recognized as a criterion of sustainable forest management in the Montreal Process. Criterion 5 relates specifically to the maintenance of forest contribution to global carbon cycles. The Montreal Process and its ensuing Santiago Declaration (in 1995) cover 90 percent of the world's boreal and temperate forests, including those in Canada and the United States. These countries have stated their commitment to managing forests in a way that maintains the forests' contribution to global carbon cycles.

The Kyoto Protocol to the Framework Convention on Climate Change

Miles (this volume) describes the policy implications of the Kyoto Protocol. The Framework Convention on Climate Change (FCCC) was signed by 166 countries by June 1993, and came into force as of 21 March 1994. The aim of the Convention is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The stabilization level is not specified, but the Convention states that: "Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climatic change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." The way in which this stabilization will be achieved has been the subject of intense debate, and eventually, a new agreement known as the Kyoto Protocol suggested ways in which governments could act to reduce emissions of six greenhouse gases.

Article 3.3 of the Protocol states that "Certain activities that cause net changes in greenhouse gas (GHG) emissions through direct human induced land-use change and forestry, limited to afforestation, reforestation and deforestation, may be used in the calculation of emission targets." The type of land-use options that are considered include direct emissions reductions from deforestation, urbanization, and other land management practices; sink enhancements through expanding reservoirs of carbon stored in biomass, soils and wood products; and fossil fuel substitution through substituting biomass for fossil fuel-intensive energy and construction products. Some of the different systems are described by Smith (this volume).

In Canada, the forest products industry is responsible for 40 percent of energy consumed by the manufacturing sector but only 12 percent of CO₂ emissions (because CO₂ emissions from biofuels are not counted in greenhouse gas inventories). Most energy (90 percent) is used by the paper and related products industry. However, increased efficiency, replacing fossil fuel energy with biomass energy, and the use of less greenhouse gas intensive fuels (e.g., natural gas instead of bunker oil) have resulted in significant gains. For example, Avenor Inc. (British Columbia) in Gold River reduced emissions from 226 to 75 kt CO₂ yr⁻¹ (before the mill was closed down). Fletcher Challenge (also British Columbia) reduced emissions from 997 to 523 kt CO₂ eq yr⁻¹, and Canadian Forest Products reduced emissions from 530 to 498 kt CO₂ eq yr⁻¹ (equivalent to reducing emissions by 47 to 39 kt CO₂ eq 10⁻⁶ bdf).

Implications for Resource Managers

Although climatic change has profound implications for forestry, especially in northwestern North America, forest managers and policy makers have paid remarkably little attention to the phenomenon, reflecting a short-term view that is inconsistent with the sustainable management of forests. Failure to account for

climatic change in long-term management suggests that the majority of forests in Canada and the USA are not being managed sustainably. A large amount of information on climate and carbon is available, yet it is rarely used in the preparation of management plans.

One possible reason is the argument that climatic change is not considered a certainty. After the scientific fiasco of acid rain and forest decline in the 1980s in central Europe and eastern North America, forest managers are justifiably wary of predictions of impending ecological problems. However, the evidence of climatic change is overwhelming; it is the causes of these changes that are disputed. A more likely reason for the failure to account for climatic change is uncertainty over what actions to take, and a considerable degree of comfort in maintaining the status quo. This is particularly true in Canada, where forestry has yet to emerge fully from the paradigm of an extractive industry based on short-term revenues. In contrast, forestry on public holdings in the United States has changed considerably during the past 20 years, with relatively little timber now being cut on federal lands and a greater emphasis on habitat and other non-timber resources. This latter situation should be more compatible with implementation of carbon management strategies.

While presenting a threat to forest management, climatic change also presents opportunities. As discussed above, some jurisdictions have already taken advantage of the opportunities offered by carbon trading. However, the forestry sector in the Pacific Northwest has been slow to address the potential opportunities. Perez-Garcia et al. (this volume) provide details of how carbon storage could provide economic incentives for the maintenance of forest riparian management areas in Washington. This case study neatly illustrates the potential for managers to take advantage of financial opportunities. As Alig (this volume) points out, the amount of carbon released from forests could be reduced in a number of ways, including reducing the rate of conversion of forest land to other forms of land use, reducing the amount of biomass that is burned, and setting aside forested areas from harvesting. The amount of carbon stored in forests could be increased by afforestation of unforested lands, the use of short-rotation woody crops (particularly as a substitute for fossil fuels), and enhancing forest management.

In some countries, this has provided major incentives to change practices. For example, the Enocell Pulp Mill at Uimaharju in Finland produces excess heat by utilizing process wastes as fuel. Considerable interest has been shown in generating power from biomass, with the IGCC plant at Värnamo in Sweden being one of the first biomass gasification plants. While considerable advances have been made in Europe, similar advances in North America are less evident. However the Forest Forever Fund, run by the Pacific Forest Trust, provides an example of what is possible. This fund aims at "improving" forest management and has the objective of increasing carbon sequestration in a coast redwood stand in California by 65,400 tons of carbon by 2095. This is being achieved by increasing older age stands, reducing soil carbon losses, and restoring natural forest composition. The management goals are accomplished through the acquisition of restricted rights from an owner in the form of a conservation easement held by the Pacific Forest Trust. This easement guides forest management, and the project pays the opportunity costs of the foregone harvest. The potential role of conservation easements is examined by Wayburn and Passero (this volume).

Some of the most significant developments have occurred in Australia, where the concept of carbon trading has become particularly advanced. Many of the issues surrounding this are discussed by Bull et al. (this volume). Despite the uncertainties, steps have been taken in a number of jurisdictions to develop carbon trading. In June 1998, New South Wales State Forests together with Bankers' Trust and the New South Wales Treasury developed a forest-carbon investment memorandum for worldwide marketing. It provided an 8-10 percent return and carbon credits. Strategic agreements were established with Pacific Power and Delta Energy. Pacific Power purchased 4500 tons of carbon rights from 1000 ha of eucalyptus hardwood plantations established by New South Wales State Forests on former pasturelands. They have first right of refusal to extend to a cumulative total of 54,000 tons of carbon. Delta Energy entered into a Softwood Plantation Deed with State Forests, purchasing 5775 tons of carbon rights over 30 years. The project involved 41 ha of Monterey pine (*Pinus radiata*) plantations, planted and managed by State Forests on Delta Energy pasturelands. These developments are supported by research and monitoring efforts into proper carbon accounting (Keenan 2002) in a coordinated program that could usefully be emulated in the Pacific Northwest.

There are a number of practical considerations when looking at potential forest-related carbon sequestration projects. Proposed actions must be supplemental to what would have happened without the project. In other words, carbon credits are not awarded for continuing to manage a forest in the same way, even if there is substantial sequestration. The benefits from the project must be reliable and long term, and it must be possible to quantify, monitor, and verify the project's benefits accurately. There must also be significant co-benefits, such as conservation of biodiversity or the provision of employment. Most of these requirements are not usually a problem for forestry projects. However, one must determine if a particular project has sequestered carbon beyond what would have occurred without the project. An additional concern for forestry projects is known as leakage, in which gains in one area are essentially offset by losses in another. This means that the benefits could be reduced by indirect and feedback effects occurring outside the project's boundaries.

Future Management

There is growing recognition in northwestern North America that forested landscapes need to be managed for multiple services. One of the services that forests provide is carbon storage. The use of forests as a carbon sink has become embroiled in the politics surrounding the mechanisms by which countries can meet their commitments under the Kyoto Protocol. Environmental groups and many countries (particularly in Europe) argue that CO₂ emissions should be reduced, rather than forests being used to temporarily relieve the rate of increase in atmospheric CO₂ concentrations. However, these political considerations are of little direct concern to the individual forest manager, except if payment can be made for carbon credits. Instead, forest managers should consider carbon management as just one of a range of ecosystem services for which they can manage and from which they can potentially benefit. The problems this presents for decision makers is discussed by Alig (this volume).

There are a number of steps that a forest manager can take to reduce the potential impact of climatic change on forested landscapes, thereby managing carbon more effectively. A key concern is to avoid large-scale releases of carbon. These usually occur following major disturbances. Controls on the nature and distribution of clearcuts, along with restrictions on slash burning, mean that human-caused disturbances are now more likely to be medium scale than large scale. However, climatic change may be associated with an increase in large-scale disturbances. The recent outbreak of mountain pine beetles (*Dendroctonus frontalis*) in the interior of British Columbia is consistent with a warmer climate, combined with the poor management of the seral stage distribution of forests. The bark beetles are normally limited by extreme winter temperatures, a factor that has been alleviated by recent increases in minimum winter temperatures (Mote 2003).

Similarly, extreme fire seasons in western North America since 2000, associated with prolonged summer drought, are consistent with warmer, drier summers predicted for much of this area (McKenzie et al. 2004). Some of these fires may have been worsened by fuel accumulation following decades of fire exclusion. National parks in the United States pioneered widespread use of prescribed fire to reduce fuels, and similarly in Canada, the federal national parks are leading the way in prescribed fire. The USDA Forest Service is currently focusing on national strategies, such as the National Fire Plan, to address fuel accumulations and to develop science-based strategies for thinning and burning (Peterson et al., in press). However, the size of the land areas for which fuel reductions are needed is much larger than can be practically addressed under current regulatory constraints.

There are a number of steps that can be taken by forestry authorities and individual forest managers. These include increasing the distance of permitted seed transfers, allowing seed transfers from warmer to cooler environments. For example, the Red Rock provenance trial south of Prince George, British Columbia, is showing clear evidence that provenances from more southerly locations are out-competing local provenances, as are other trials. Long-term growth estimates need to be adjusted to take into account both climatic change and increasing CO₂ concentrations (which may have a temporary or long-term fertilizing effect).

Forest management at large spatial scales needs to more effectively account for large-scale disturbance (Lertzman and Fall 1998, Peterson and Parker 1998). Many areas are already planning “fire-safe” landscapes, a principle that could be extended more widely in the dry forests of northwestern North America. In intensively managed areas, there is a need to restore forest structure and composition, although reference conditions for restoration are uncertain, given the dynamic nature of forests. Individual stands need to be managed better to reduce drought stress and to reduce their susceptibility to fire and to insect infestation. This implies appropriate management of stand density to maintain high vigor.

Some steps taken by forest products companies to reduce emissions of CO₂ have been described above. However, it is also important to consider the fate of forest products. Kozak and Gaston (this volume) describe the importance of life cycle analyses of forest products. This technique enables the environmental costs of different products to be compared, and places each product in the correct context of the total amount of carbon used to generate it. It is clear that wood could be used in many more products than is currently the case. Aggressive marketing campaigns, combined with the inertia of the forest products sector in the Northwest, mean that it is difficult for new products and other innovations to be introduced to the market place. While changes to products could be made, the lack of investment in this sector limits market expansion. Similarly, low investment in research and development is hindering the development of new products, some of which might help the sector move out of its current depressed state.

Finding Ideas and Solutions in the Northwest

During the past 20 years or so, a substantial amount of ecological information on climatic change, carbon cycling, and forests has been published (e.g., Rosenberg et al. 1999, Karnosky et al. 2001, Lal 2001, Kimble et al. 2003). Most of the applications of this information in forest management are occurring in Europe and developing countries rather than in Canada and the United States. While implementation typically lags considerably behind scientific discovery, especially in natural resources, this problem appears to be particularly acute in the forestry sector. It is surprising that in the Pacific Northwest, the second most productive forest region in North America, opportunities for linking climatic change, carbon, and forest management have not been more assertively addressed.

In our experience, even progressive managers of forests and forest products industries are surprisingly uninformed on the scientific data about climatic change and forests, and are reticent to incorporate these data into management strategies. Their hesitation to use these data may stem in part from the perceived lack of economic incentives to do so, as well as the absence of policy imperatives that focus attention on climatic change. The forestry sector clearly has the potential to address this critical environmental issue, given the rapidity with which principles of sustainability and certification – once considered too constraining – are being incorporated on federal and commercial forest lands in Canada and the United States. One recent sign of change is in British Columbia, where foresters are now required to take more responsibility for their actions under the new Forest and Range Practices Act, with requirements for using recent scientific information. Similarly, the Washington Department of Natural Resources recently announced that it will include carbon sequestration as a component of broader objectives in management of state forests.

As a means of advancing the exchange of information and ideas on climatic change, carbon, and forestry in the Northwest, a group of scientists, forest managers, and agency personnel from British Columbia, Washington, and Oregon met in November 2001 on Orcas Island, Washington. Their discussions resulted in several state-of-science summaries and in recommendations for policy makers in northwestern North America. This proceedings document is the product of their deliberations. It is our hope that this work will result in increased focus on the role of the forestry sector in addressing climatic change and carbon management in northwestern North America.

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How and Why is Northwest Climate Changing?

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Abstract

A strong consensus among climate scientists has emerged on key aspects of global climate change: humans have unquestionably altered the composition of the atmosphere in significant ways, there has been an increase in global average temperature of $0.6^{\circ}\pm 0.2^{\circ}\text{C}$ in the past 100 years, and this increase in temperature is probably caused in part by the atmospheric changes wrought by humans. Global average precipitation has increased slightly. In the Pacific Northwest, changes in temperature ($+0.8^{\circ}\text{C}$) and precipitation (+14 percent) exceeded the global average in the 20th century. In the future, the accumulation of greenhouse gases is expected to lead to further globally averaged warming of $1.4\text{--}5.8^{\circ}\text{C}$ by 2100, with moderate (at the low end) to dramatic (at the high end) consequences for humans and global ecosystems. The uncertainty in this wide range of estimates stems about equally from uncertainty about natural feedbacks in the climate system and from estimates of future socioeconomic change. For the Northwest, eight climate models project a regional warming of $1.5\text{--}3.2^{\circ}\text{C}$ by the 2040s, with modest increases in winter precipitation. Climate change is expected to continue beyond the 2040s and probably even beyond 2100.

Introduction

Global climate change has received considerable attention recently owing to international efforts to reduce greenhouse gas emissions and to high-profile scientific advancements. This paper reviews the science of global climate change and the possible regional climate changes.

The “greenhouse effect” refers to a natural process in which certain gases (water vapor, CO_2 , and methane are the most important) allow the sun’s radiant energy to pass through the atmosphere, but absorb the radiant energy that Earth emits at lower wavelengths. This leads to a natural warming of the Earth. Fluctuations in the composition of the Earth’s atmosphere on geologic timescales have produced vastly different climates – 100 million years ago, Earth was so much warmer that alligators lived in what is now Siberia, and the CO_2 content of the atmosphere was probably four to eight times present levels (Kump et al. 1999, Prentice et al. 2001). Throughout Earth’s history, the natural warming of the greenhouse effect has kept the planet warm enough to sustain life. What is unusual now, however, is the rate at which CO_2 and other greenhouse gases are increasing.

In the last 150 years or so, humans have enhanced the natural greenhouse effect by increasing the quantities of key greenhouse gases. CO_2 has increased 32 percent because of burning fossil fuels and reducing forested area, and methane has increased by 151 percent through agriculture (chiefly cattle and rice paddies) and other human sources (Prentice et al. 2001). Other greenhouse gases have also increased, including some (CF_4 , C_2F_6 , and SF_6) whose human sources exceed natural sources by a factor of 1,000 or more, and some (e.g., the chlorofluorocarbons) that have no natural sources at all (Prather et al. 2001). In the global mean, CO_2 accounts for 60 percent of the radiative forcing by greenhouse gases, and methane 20 percent (Ramaswamy et al. 2001). Water vapor is also a greenhouse gas, but its influence is considered a response (positive feedback) of the climate system rather than as a separate forcing.

Observed Global Climate Change

Two key questions arise from the increase in greenhouse gases: (1) is the planet warming? and (2) can we rule out natural causes for recent climate change? These two questions are answered in this section, drawing heavily on the assessment reports by the Intergovernmental Panel on Climate Change, or IPCC. The IPCC was created in 1988 and has issued major reports in 1990, 1996, and 2001 (the first, second,

and third assessment reports). Much of what is presented below comes from the first volume of the IPCC's third assessment report. This comprehensive report was written by over 650 scientists who volunteered considerable time over a period of three years to write the report, and was reviewed by 300 additional scientists (IPCC 2001). The IPCC assessments constitute the most comprehensive, authoritative statement about the state of the science of climate change. The interested reader is strongly urged to consult the IPCC "Summary for Policymakers" (see literature cited).

The IPCC answered affirmatively to both of the questions posed in the previous paragraph.

Is the Planet Warming?

In answering yes to this question, the IPCC stated that "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system." Evidence marshaled included the following:

- Global average surface temperature has increased by $0.6^{\circ}\pm 0.2^{\circ}\text{C}$ during the 20th century;
- Snow cover has decreased by about 10 percent since the late 1960s;
- Most mountain glaciers retreated during the 20th century;
- Sea ice extent and thickness have decreased since the 1950s; and
- In addition (Cayan et al. 2001), since about 1950 the timing of spring, as marked by blooming or leafing-out dates of various plants, has advanced in much of North America.

The warming in the 20th century (figure 1a) did not proceed smoothly, but rather in two stages: one from 1910 to 1945 and one since 1976, with temperatures relatively constant at other times. This figure prompts a crucial question: was the warming natural or man-made?

Can We Rule Out Natural Causes?

Natural causes of climate change include solar variations, volcanic eruptions, and the redistribution of heat by the oceans. In answering this more complicated question about the cause of warming, scientists have taken different approaches. One approach is to examine past climate and determine whether the warming of the late 20th century is unusual. Scientists have carefully reconstructed temperatures in the Northern Hemisphere back to A.D. 1000 (figure 1b) from tree rings and corals and other "proxy" data (e.g., Mann et al. 1999), and two things about recent climate stand out: (1) the 20th century warming appears to be the largest of the millennium, and (2) the 1990s are likely the warmest decade of the millennium.

The second approach (Mitchell et al. 2001) is to simulate global temperatures (figure 2) with a climate model¹ while introducing various forcings, typically solar variations, volcanic eruptions, and human contributions (greenhouse gases and aerosols). When forced by natural causes alone (figure 2a), climate models can generally reproduce the warming from 1910 to 1945, but they cannot reproduce the warming since the mid-1970s. Only when the increase in greenhouse gas concentrations is included can the models reproduce the late-20th century warming. That human influence on climate would emerge later in the century is consistent with the observation that CO₂ and most other greenhouse gases have risen far more in the last 40 years than in the previous 100 years (Prentice et al. 2001, Prather et al. 2001).

Another approach (Mitchell et al. 2001, and references therein) is to compare the spatial pattern of warming as observed and as simulated by climate models with the observed increase of greenhouse gases. The pattern early in the century does not resemble the pattern expected from increasing greenhouse gases, and hence was probably natural. By contrast, the pattern of warming late in the century does resemble the pattern expected from increasing greenhouse gases. This underscores the

¹A climate model is an elaborate computer program that simulates the Earth's atmosphere and often its oceans, sea ice, and land processes as well. The goal of a climate model is to simulate correctly the statistics of weather (e.g., average high and low temperature) in some specified window of time (e.g., the decade of the 2020s).

difference between the (probably natural) early-century warming and the (probably unnatural) late-century warming. Taken together, these pieces of evidence support the view that “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.”

Variations of the Earth's surface temperature for:

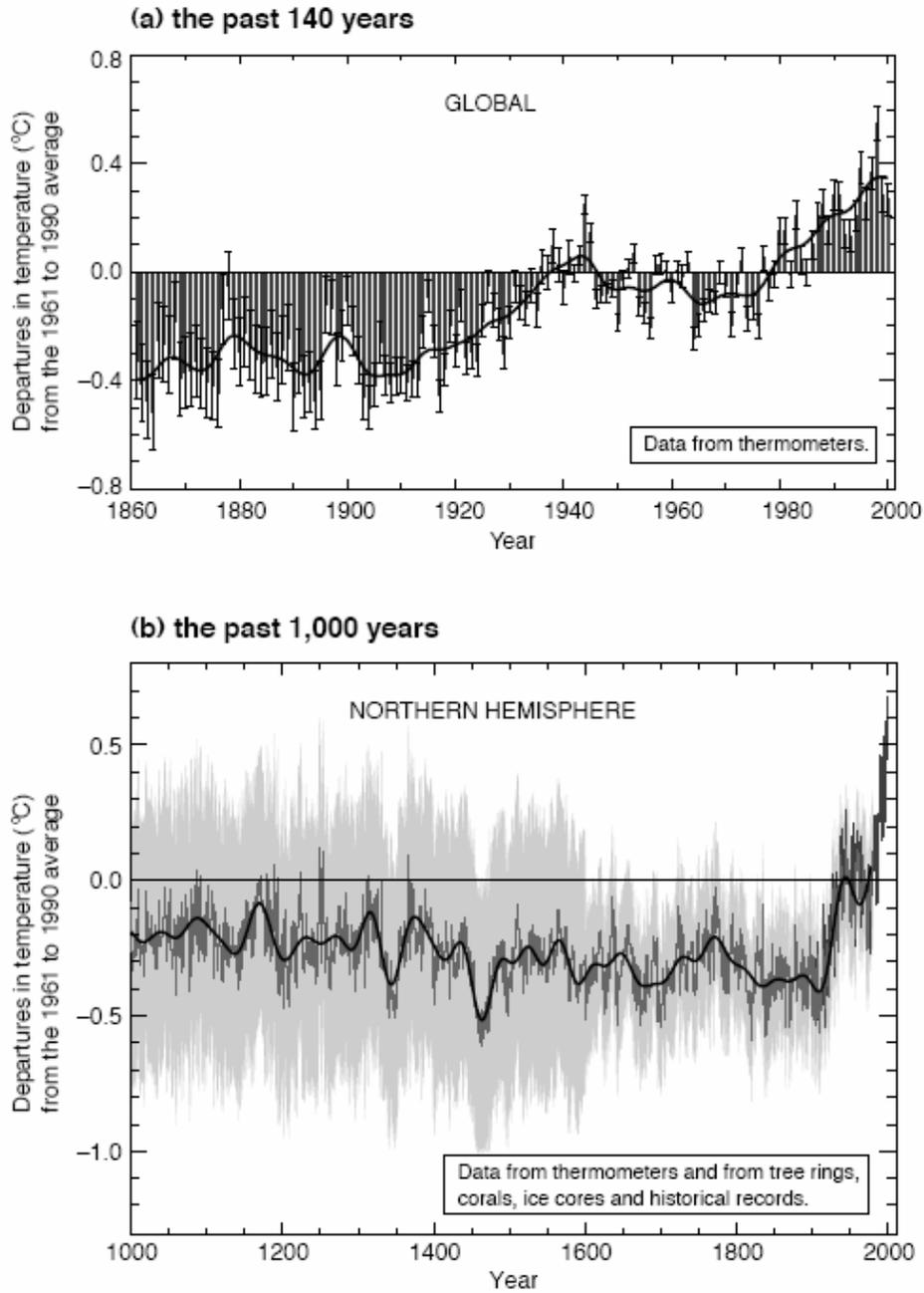


Figure 1—Average annual surface temperature of (a) the globe, from thermometer records, and (b) the Northern Hemisphere, from various sources. In the top (bottom) panel, year-to-year variations are 95 percent confidence range indicated by whisker bars (gray shading). From IPCC, used by permission

Global Climate Change – Future

The match between past climate as observed and as simulated with climate models (figure 2), along with other evidence presented in the IPCC report (McAvaney et al. 2001), supports the use of climate models for estimating future climate. Two factors influence the model-generated estimation of future climate: (1) future concentrations of major greenhouse gases and sulfate aerosols² and (2) the response of the climate system to a given concentration of greenhouse gases and sulfate aerosols. The first factor is provided by socioeconomic scenarios, which yield a variety of possible future development paths, each of which produce a different mix of greenhouse gases and aerosols. For example, IPCC scenarios for future CO₂ concentrations give values in 2100 ranging from twice the pre-industrial concentration to 3.5 times the pre-industrial concentration. In formulating these scenarios, the IPCC did not include possible international policy efforts, like the Kyoto Protocol, that would limit the growth of greenhouse gases. The second factor – the response of the climate system to a given concentration of greenhouse gases – can be estimated either from observations or from simulations with climate models. As in its first assessment report, the IPCC estimates that a doubling of CO₂ would eventually produce a global warming of 1.5–4.5°C (Cubasch et al. 2001).

Simulated annual global mean surface temperatures

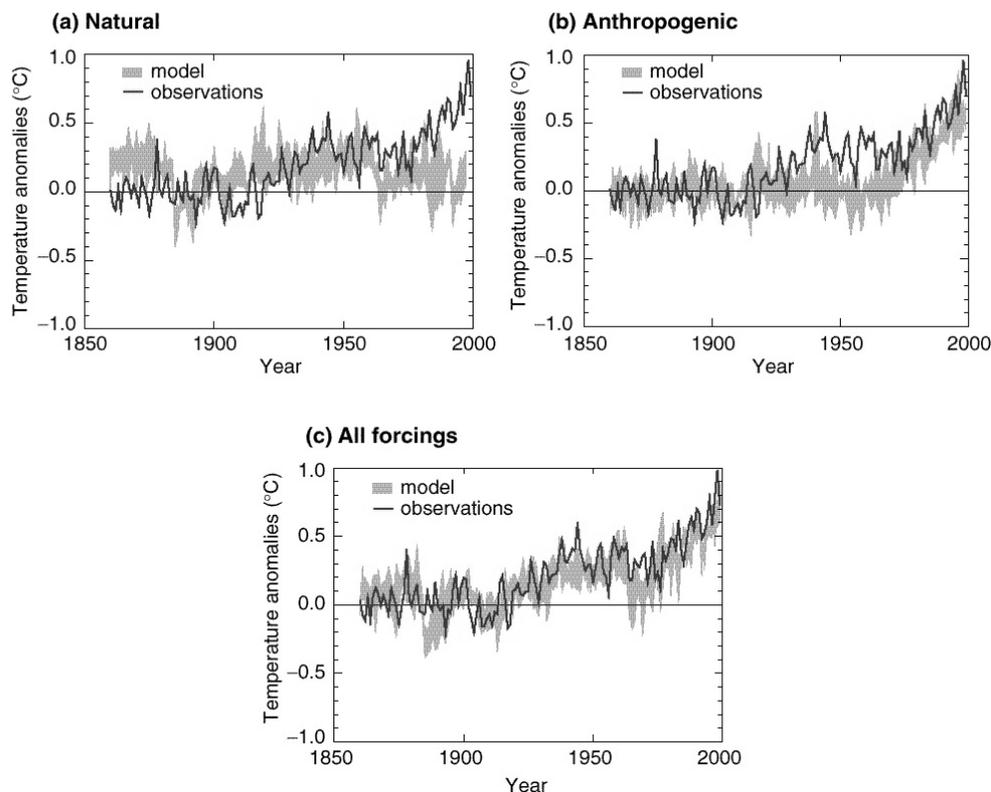


Figure 2—Global average temperature as observed (black) and as simulated using a climate model that was run with (a) natural (solar, volcanic) forcings; (b) anthropogenic (greenhouse gas, sulfate aerosol) forcings; and (c) all forcings. The results show human cause for the warming of the last 40 years, and the remarkable agreement between observations and model in panel c underscores the value and complexity of climate models. From IPCC, used by permission

²The influence of aerosols on climate is not well known, though it is generally accepted that they provide some regional cooling.

Putting together these two factors, the IPCC developed a range of warming rates: 0.8–2.6°C warmer than 1990 by 2050, and 1.4–5.8°C warmer by 2100 (Cubasch et al. 2001). The low bound results from a low estimate of climate sensitivity and a scenario in which global population peaks in mid-century and then declines, and a rapid transformation of the global economy away from manufacturing and toward service and information, with clean and resource-efficient technology. The upper bound results from a high estimate of climate sensitivity and a scenario with rapid global economic growth fueled by rapidly rising consumption of fossil fuels. Whatever the rate of warming, it is very likely that land areas will warm more than the oceans, especially at high latitudes in the Northern Hemisphere (Cubasch et al. 2001).

Other important aspects of global climate are likely to change as well. Precipitation is expected to increase at high latitudes, with extreme precipitation events becoming more common (Cubasch et al. 2001). Changes in the behavior of El Niño Southern Oscillation and other facets of the climate are likely. Furthermore, although projections tend to focus on the next 100 years, the long lifetime of CO₂ molecules in the atmosphere means that even after CO₂ concentrations are stabilized (a situation that occurs only in the lowest IPCC scenarios, and then not until 2100) climate will continue to change (Cubasch et al. 2001) and sea level will continue to rise. A warmer climate will persist for centuries, even long after any successful effort to reverse the changes.

Pacific Northwest Climate Change

Data

For this study we delineate the Pacific Northwest as the states of Washington, Oregon, Idaho, and the province of British Columbia south of 55° latitude. To examine trends in this region, we use station data from American and Canadian sources. Weather stations were not originally intended for monitoring long-term trends, and therefore these datasets attempt to correct for a variety of factors that can influence measurements, including changes in equipment or measuring technique (e.g., time of day), station moves, urbanization, and other factors. For Canada we use the Historical Canadian Climate Database (HCCD) (Vincent and Gullett 1999), which includes temperature data to 1999 for 32 stations and precipitation for 78 stations in the Pacific Northwest. For the US we use the Historical Climate Network (USHCN) (Peterson and Vose 1997), which has also been corrected and includes 113 temperature stations and 76 precipitation stations in the Pacific Northwest. We use data only between 1920 and 1997 and require that stations used in the analysis span this period of record.

Observed Changes

At most stations in the Northwest, the temperature trends (figure 3) have been positive over the 1920 to 1997 period of record (or any other period of analysis: Mote 2003b). In each of the three states, but not in British Columbia, a handful of stations have seen cooling trends. Most trends are between 0.5° and 2°C. Of the four political areas, Idaho has seen the smallest warming trends. Stations in and near urban areas have trends that are similar to those in rural areas, and in each of the three states the largest warming trend is in a rural area or near a small town. It is not trivial to combine these data into a single regionally averaged trend; Mote et al. (1999) did so for the U.S. Pacific Northwest by grouping stations into 28 climate divisions and then performing an area average. The result was a regional warming trend of 0.8°C over the 20th century, slightly greater than the global average (0.6°C).

A key question of relevance to forest resources is whether the observed trends (primarily at valley locations) are representative of trends at higher elevations. We group the stations by broad eco-zones (see dotted curves in figure 3): (1) coastal, which runs from the crest of the Cascades westward in the US and west of the coastal mountains in British Columbia; (2) Rocky Mountains, which includes most stations in Idaho plus the eastern stations in British Columbia; and (3) interior, consisting of eastern Oregon, eastern Washington, southwestern Idaho, and south-central British Columbia. Trends as a function of station elevation (figure 4) for each eco-zone reveal a general tendency for smaller trends with elevation except in the interior stations (+ symbols). (The highest-elevation station is at Crater Lake in the southern Cascades, categorized as a coastal station.)

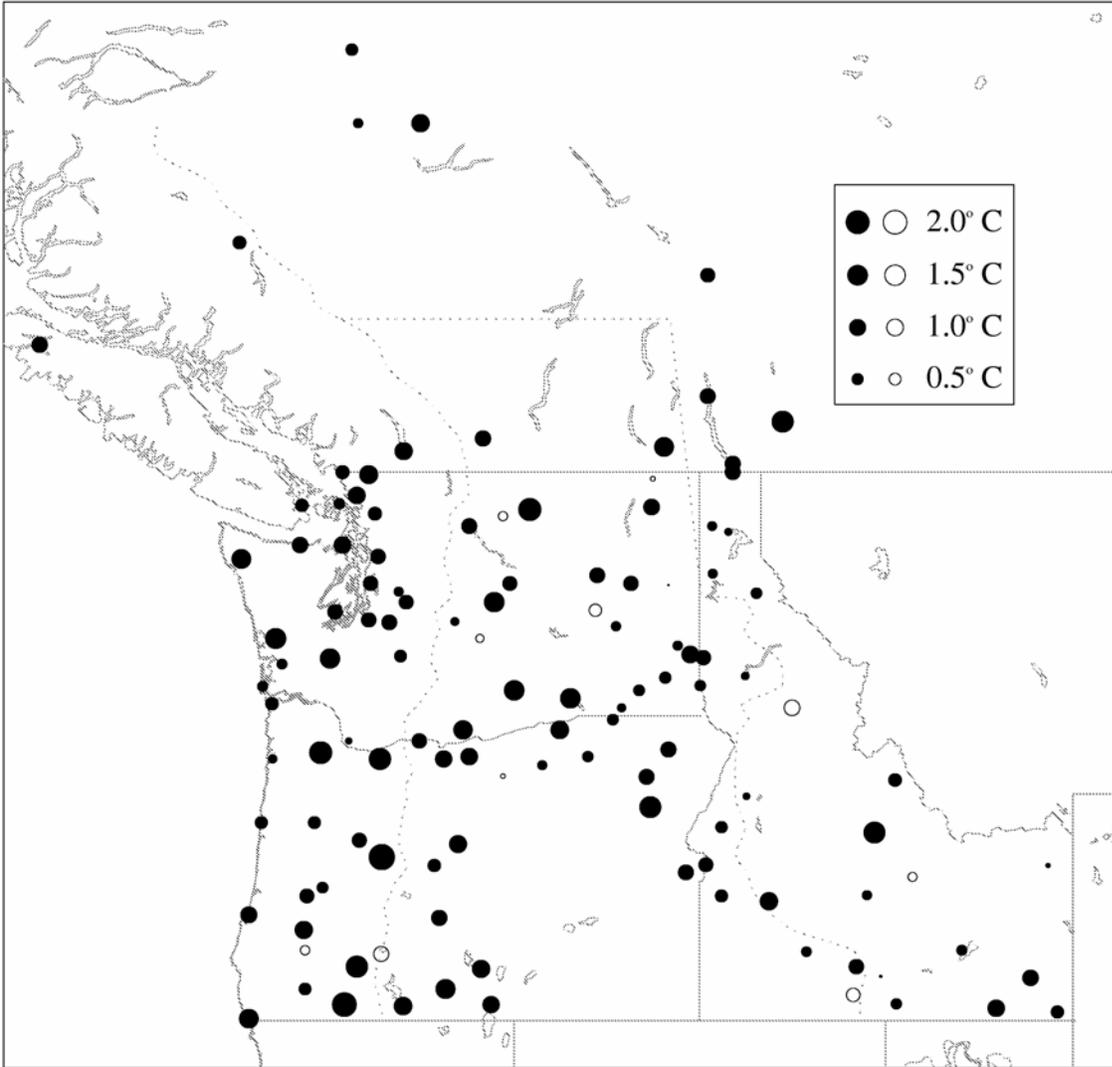


Figure 3—Trends (linear trends calculated from 1920 to 1997) in annual mean temperature ($^{\circ}\text{C}/\text{century}$) in the Pacific Northwest at stations with long, quality-controlled records. Filled circles indicate positive trends, open circles indicate negative trends, and the area of the circle indicates the magnitude of the trend according to the legend. Dotted lines delineate the three eco-zones used in the paper

The apparent tendency for high-elevation stations to exhibit weaker warming trends than lower-elevation stations stands in contrast to expectations from experiments with global (e.g., Fyfe and Flato 1999) and regional (Giorgi et al. 1997) climate models. In modeling experiments, the snow-albedo feedback, in which a slight warming near the snowline melts snow and allows the surface to absorb more solar radiation, drives substantial warming in winter and spring, and this warming is enhanced at higher levels. The observations presented here are not necessarily inconsistent with the modeling results; the climate stations at higher elevation are nearly all in mountain valleys rather than on locally higher ground, and it is possible (though in our view unlikely) that a much denser network of climate stations would have revealed different trends. Declines in spring snowpack in these mountains (Mote 2003a) are consistent with a warming that extends at least to altitudes of 1800 m.

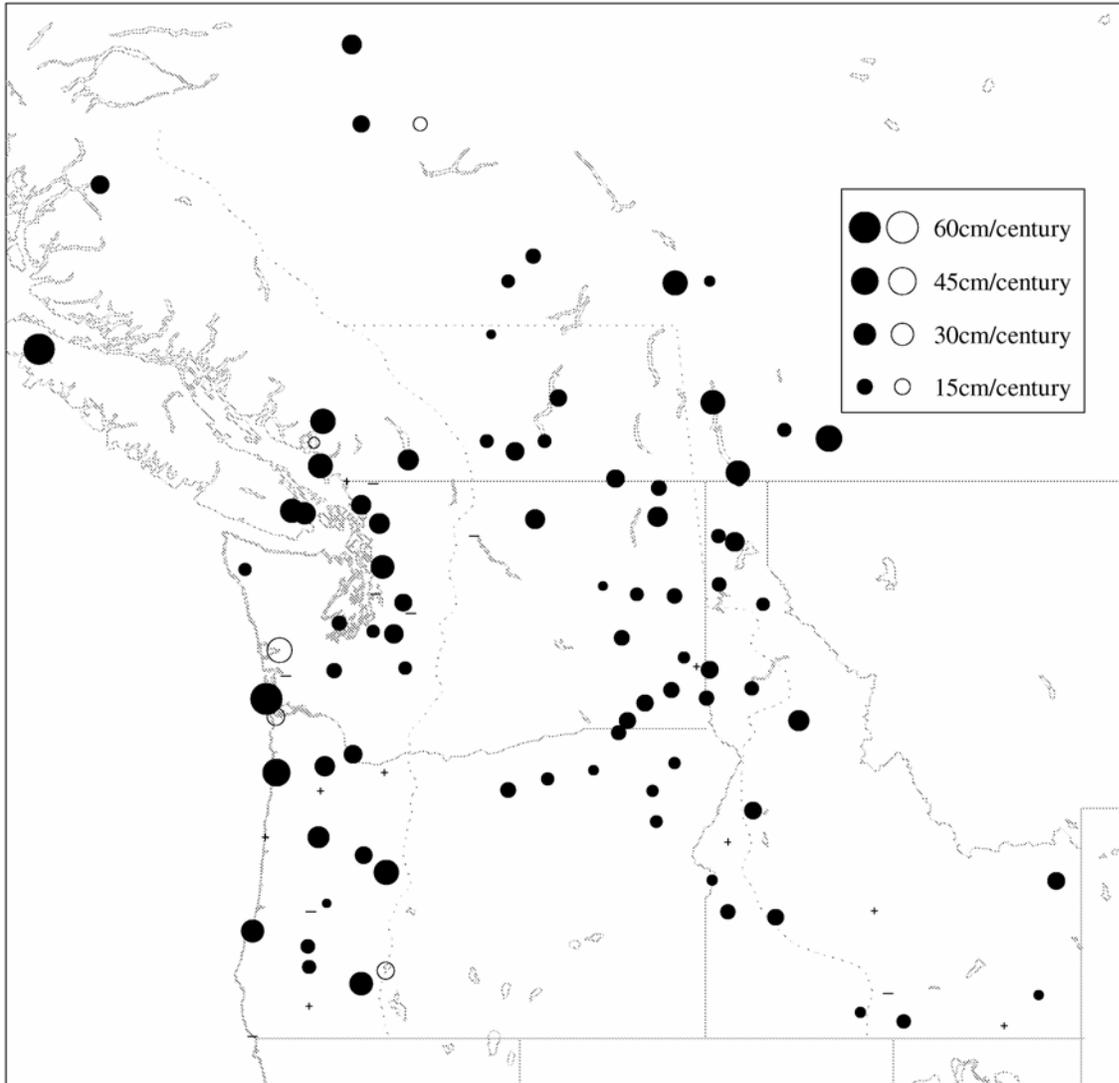


Figure 4— As in figure 3 but for trends in annual precipitation (in cm/century). Very small trends (less than 5 cm/century in absolute value) are shown as + or – symbols according to their signs

Trends in precipitation (figure 5) are also overwhelmingly positive, with some of the trends at wet coastal stations exceeding 50 cm/century. Some of the trends at drier interior stations (e.g., Conconully in north-central Washington and nearby stations in British Columbia) are very large relative to their meager annual precipitation, some in excess of 80 percent per century (Mote 2003b). Long-term precipitation measurements are more susceptible than temperature measurements to a variety of non-climatic factors like the growth or clearance of trees around a station, a point underscored by the five stations along the southwest Washington/northwest Oregon coast where two large negative trends are interspersed with three large positive trends over a distance of less than 150 km. Note too that there are fewer stations in the U.S. (especially in central and eastern Oregon) with good long-term records for precipitation than there were for temperature, while in Canada there are more stations with long precipitation records than long temperature records.

The elevation dependence of precipitation (figure 6) paints somewhat different pictures depending on whether trends are absolute (figure 6a) or relative (figure 6b). The truly coastal stations have the largest absolute trends, but it is the moderate-elevation (400-1000 m) stations, especially in the interior Northwest as noted above, that have the largest relative trends. Consequently, relative trends depend

little on altitude for any of the eco-zones. Absolute trends tend to decline with altitude for the coastal and Rocky Mountain zones.

Although it is possible to determine causes of temperature trends on the scale of continents (e.g., Stott and Tett 1998), it is not yet possible to do so for a region the size of the Pacific Northwest, in part because atmospheric circulation patterns can make one region warm and another cool without changing the global average. Nonetheless, the positive trends shown here for both temperature and precipitation are broadly in line with what 20th century trends might be expected given the changes in greenhouse gases that have been observed (Mote et al. 2003).

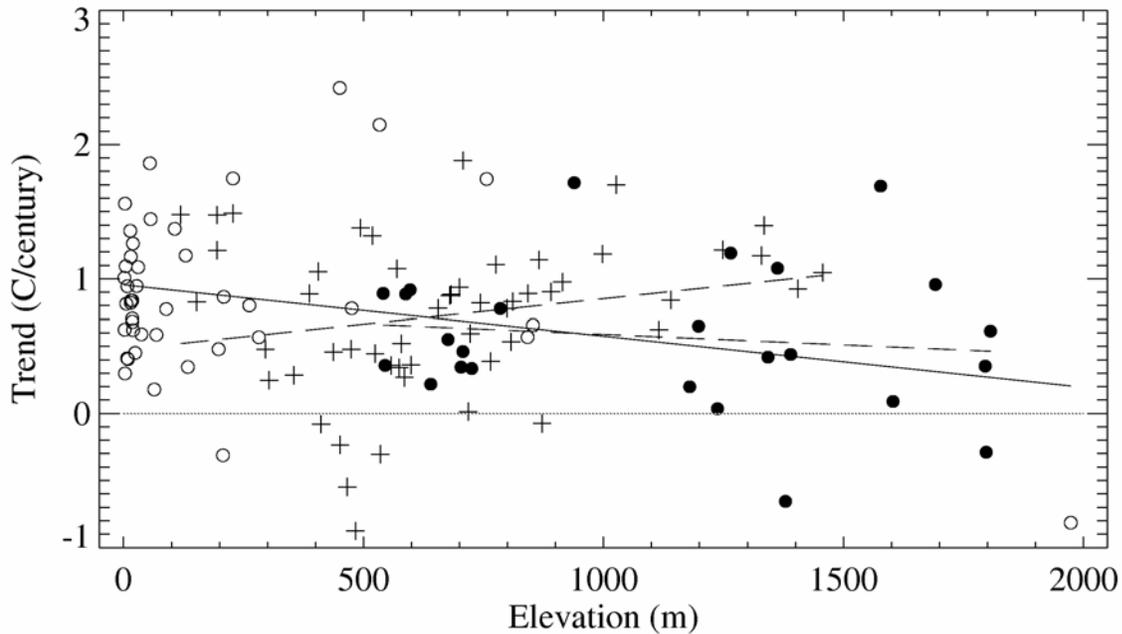


Figure 5—The linear trends shown in figure 3 are plotted as a function of station elevation and grouped according to broad eco-zone (open circles, coastal; + symbols, interior; and filled circles, Rocky Mountain). Straight lines show linear fit of trends to elevation; the decreasing trend with altitude at coastal stations (solid) is statistically significant, as is the increase at interior stations

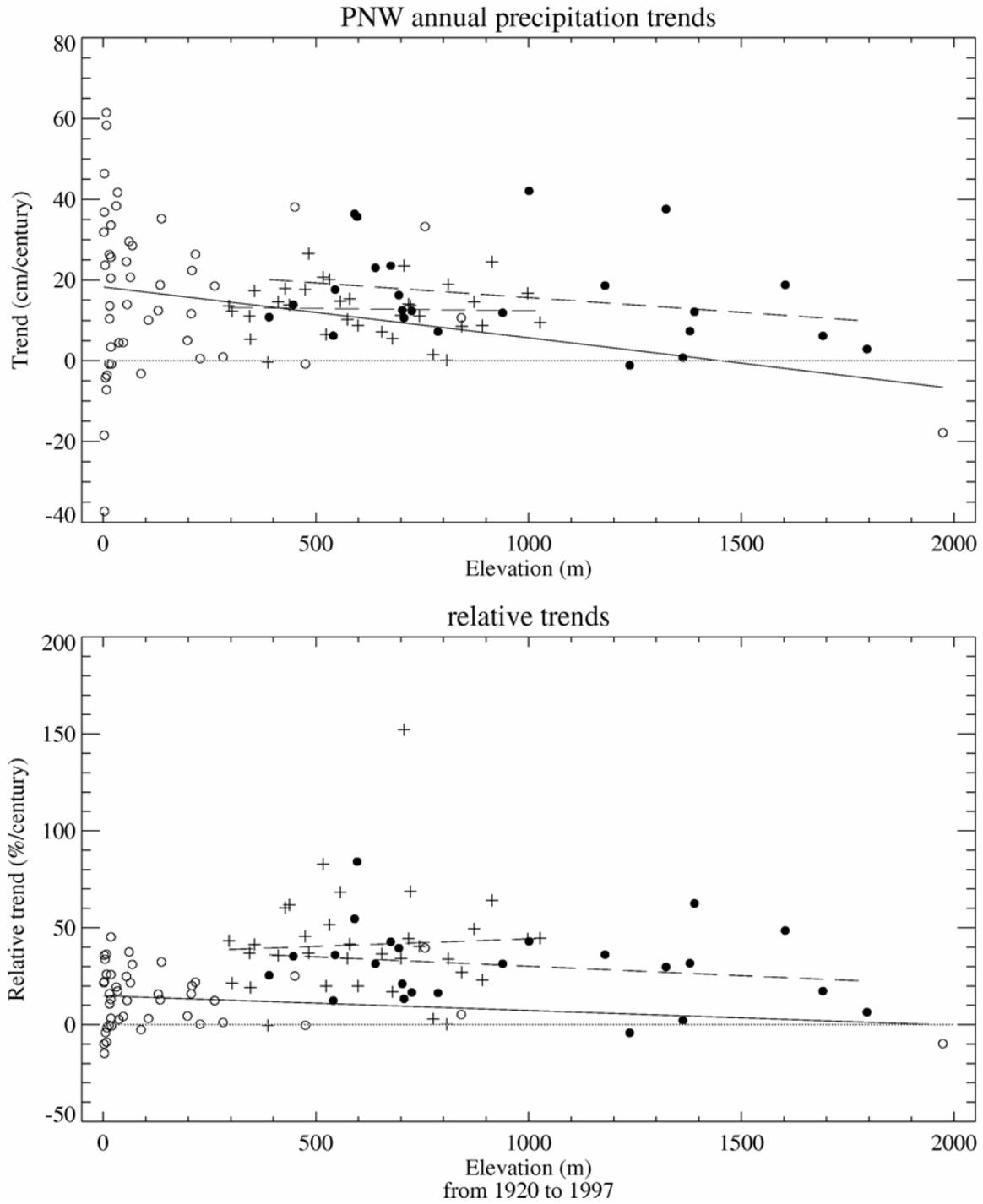


Figure 6—As in figure 5 but for precipitation, both absolute (top) and relative (bottom). Relative trends are calculated with respect to the linear fit to the 1920-1997 data, evaluated at 1920. The decreases with elevation of absolute precipitation at coastal (solid line) and Rocky Mountain (long dashed line) stations are statistically significant

Future

We have extracted changes in temperature and precipitation in the Pacific Northwest from a subset of the climate models discussed in section 3 that were used by the IPCC (Mote et al. 1999, with updates in Mote et al. 2003). These model simulations used a simpler projection of future greenhouse gases (1 percent/year CO₂ equivalent) than the IPCC SRES projections, but there is little difference in CO₂ concentrations before 2050: 508 (+38 percent) ppmv for IS92a, 488-532 ppmv (32-44 percent) for SRES scenarios. The average warming from these eight scenarios is 2.25°C from the 20th century to the 2040s (figure 7), with a range of 1.5 – 3.2°C. The models project changes in precipitation of roughly –5 percent to +20 percent in most months between November and May, with an average of about +10 percent, so the wet season is projected to get a bit wetter. Between June and October, some models show slight increases in precipitation and some show slight decreases; the average change is near zero. In summary, future Pacific Northwest climate is very likely to be warmer, with somewhat enhanced precipitation in winter. On the basis of the models' skill at simulating 20th century global climate variables, as summarized by the IPCC, we have more confidence in the temperature projections than in the projections of winter precipitation or (less still) summer precipitation.

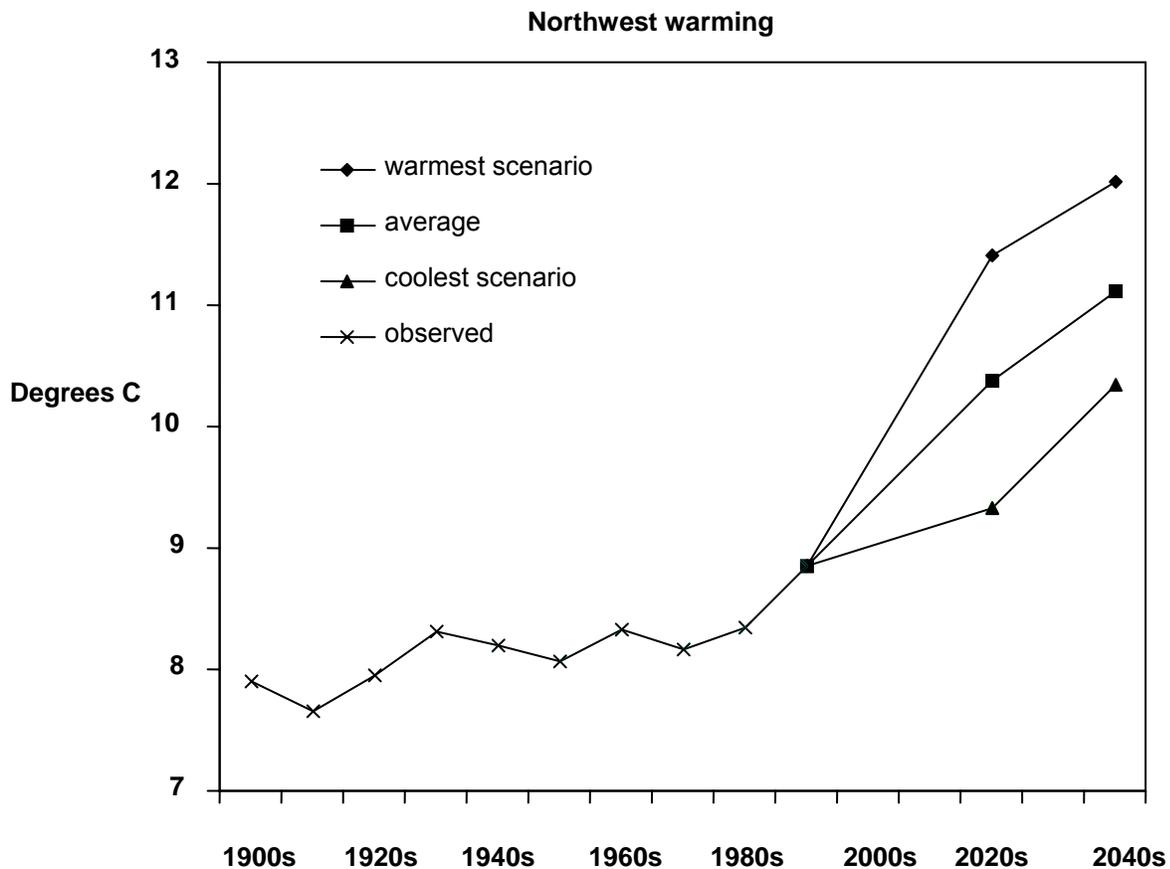


Figure 7—Past and future mean temperature in the Pacific Northwest. Observed (—x—) 10-year averages of Pacific Northwest temperatures show the 20th century warming of about 0.8°C. Eight climate models were used to construct regional change scenarios and these were applied to the 1990s temperatures. The average of the eight models is shown as (—■—) and corresponds to a warming rate of about 0.5°C/decade

Even with substantial increases in precipitation and the lowest rate of warming in figure 7, the warming that is projected will lead to substantial reductions in snowpack (Hamlet and Lettenmaier 1999). Climatic change will have important implications for Northwest forests: reduced snowpack will increase tree

growth and accelerate seedling establishment at higher elevations (e.g., for subalpine fir on wet sites) but in most locations and for most tree species, reduced snowpack and hotter summers will reduce tree growth and seedling survival (Mote et al. 2003).

Conclusions

An increase in Earth's average temperature of at least 1.4°C is, in the judgment of the world's climate scientists, virtually certain. Regional projections are somewhat less reliable, but the best available science points to a warming for the Northwest of about 0.45°C per decade, resulting in a gradual reduction in snow cover and summer soil moisture. There is some evidence that the Northwest is already on the path of regional warming.

These projections are by no means proven, but are sufficiently well grounded to warrant serious consideration in long-range plans. In our judgment, it is virtually certain that 21st century climate will be warmer than 20th century climate, and that notions of climate as "constant" (e.g., the 1971-2000 period currently used to define "normal climate") – what statisticians define as "stationary statistics" – will become obsolete. Consequently, definitions of "normal climate" based on the past should be used only with great caution in guiding future natural resource decisions.

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Beyond the Kyoto/Marrakech Protocol: Options and Strategies

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Abstract

This essay argues that the Kyoto Protocol was flawed not because it went too far in its objectives relative to mitigating the global warming problem, but because it did not go far enough. The rejection of the protocol by the United States is welcomed because it creates an opportunity for reappraisal of the problem and consideration of what suite of policies might make better sense in the circumstances. Given the long time scales over which trace gases are resident in the atmosphere, the author argues that a “buying time” strategy makes the most sense.

This perspective is justified by a combination of defining the policy problem comprehensively and showing, through a close reading of the history of the negotiations leading up to the Kyoto Protocol and the Marrakech implementation agreement, that such negotiations can lead only to “solutions” that fall far short of the mark. The objective of a “buying time” strategy is to push out the time horizon of irreversible impacts while the international community struggles to mount an effective response to the problem. This “buying time” strategy combines increasing efficiency via a carbon tax, emissions trading, revenue recycling, shifting out of coal to an emphasis on natural gas and nuclear power, and a serious evaluation of all options to sequester carbon.

Introduction

Prior to the resumption of international negotiations on the Kyoto Protocol to the Framework Convention on Climate Change which were scheduled to be held in Marrakech during October/November 2001, the Bush Administration decided to terminate United States (U.S.) participation in these proceedings. The Protocol was completed in Marrakech on November 10, 2001 (Revkin 2001) and is likely to come into force some time after Summer 2002 since all fifteen members of the European Union (EU) stated their intention to ratify the agreement en bloc (Environment News Service 2001). The EU ratified the Protocol on May 31, 2002 and Japan on June 4, thereby representing 35.4 percent of global emissions of CO₂ as of 1990. Fifty-five percent of global emissions of CO₂ as of 1990 is required for the Protocol to enter into force. In 1990 the U.S. accounted for 36.1 percent of global emissions of CO₂ (Showstack 2002).

Some, like the Bush Administration, opposed the draft Kyoto Protocol because they claim that its measures would hurt U.S. industry and society and, as such, the Protocol went too far. Others, like this author, argue that the Protocol was seriously flawed because it did not go far enough. Even so, the decision of the Bush Administration is to be welcomed because it gives the U.S. the opportunity to reappraise the problem and consider what suite of policies might make the most sense under the circumstances. This paper is an attempt to contribute to such a re-appraisal. Let us then go back to first principles.

Defining the Policy Problem Posed by Global Warming

The Intergovernmental Panel on Climate Change (IPCC) completed its Third Assessment in 2001. Among its major conclusions are the following points:

1. The global average surface temperature has increased over the 20th century by about 0.6°C.
2. Temperatures have risen during the past four decades in the lowest 8 kilometers of the atmosphere.
3. Snow cover and ice extent have decreased.
4. Global average sea level has risen and ocean heat content has increased.

5. Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities.
6. There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.
7. Human influences will continue to change atmospheric composition throughout the 21st century.
8. Anthropogenic climate change will persist for many centuries (IPCC 2001).

In response to this report, the White House requested that the National Academy of Sciences/National Research Council convene a panel of experts to vet the IPCC Report. This panel, entitled the Committee on the Science of Climate Change, issued its own report in 2001 (National Research Council 2001). Among its findings are the following two points:

1. Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability. Human-induced warming and associated sea level rises are expected to continue through the 21st century. Secondary effects are suggested by computer model simulations and basic physical reasoning. These include increases in rainfall rates and increased susceptibility of semi-arid regions to drought. The impacts of these changes will be critically dependent on the magnitude of the warming and the rate with which it occurs.
2. The committee generally agrees with the assessment of human-caused climate change presented in the IPCC Working Group 1 (WG1) scientific report, but seeks here to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them.

Now that it is clear that there is no significant scientific dissensus over the issue of whether the world is warming and will warm further we can see that the disagreements that do exist relate to the questions how much? When? And with what impacts? So let us begin this policy analysis by asking "What physical aspects of the global warming problem are most important initially for designing policy responses?"

Two aspects come readily to mind: the residence times of greenhouse gases in the atmosphere and the timescales of the global carbon cycle. These are shown in tables 1 and 2.

Table 1—Residence times of greenhouse gases in the atmosphere

GHG	Residence Times
Carbon dioxide (CO ₂)	50-200 Years (The range varies with sources and sinks and depends on the equilibration times between atmospheric CO ₂ and terrestrial and oceanic reserves.)
Methane (CH ₄)	12 years
Nitrous oxides (N ₂ O)	120 years
Chlorofluorocarbons	
CFC-11	50 years
HCFC-22	12 years
Perfluorocarbon (CF ₄)	50,000 years

Source: IPCC. 1990. Climate change: the scientific assessment, working group 1

The residence times of greenhouse gases in the atmosphere range from 12-200 years for the five most important gases and up to 50,000 years for a synthetic perfluorocarbon.

Table 2—Time scales of the global carbon cycle as determined by exchange between the atmosphere and the ocean

Mechanism	Time Required
Troposphere (lower atmosphere) mixing alone	1 year
Atmosphere to surface ocean layer	4 years
Surface ocean layer to intermediate layer below the thermocline	50-200 years
Venting from ocean above thermocline to atmosphere	100 years
Turnover time of deep ocean basins	1000 years

Source: IPCC. 1990. Climate change: the scientific assessment.

While there remains considerable uncertainty relating to the magnitude of terrestrial carbon storage, there is much less uncertainty over the magnitude of surface, intermediate and deep ocean storage of carbon (U.S. Global Change Research Program 1999). Annual fluxes between the atmosphere and the ocean and the atmosphere and the terrestrial biosphere vary widely, but there is no doubt that on decadal/interdecadal timescales the dominant influence on aggregate CO₂ concentrations in the atmosphere is the exchange of carbon between the atmosphere and the ocean. The lags in this exchange process are shown in table 2.

Why are these two sets of physical characteristics important for policy development? They demonstrate, first, that global climate change is a problem of long timescale and, secondly, that all policy measures will be indeterminate in their ultimate impacts. This combination, when linked to issues of costs, changing lifestyles, and distributive inequities creates large obstacles to significant policy action in the short run.

Scientists do not know and cannot say what thresholds of atmospheric concentrations of greenhouse gases are “harmful,” but we do know that human beings are modifying the planetary climate in ways that will render certain regions more or less vulnerable to the ensuing changes. We can therefore expect that all global intergovernmental attempts to develop policy relative to mitigation of and adaptation to global warming will be refracted through at least four major variables:

1. The dynamics of bureaucracy within national governments;
2. The rates and magnitudes of climate change experienced “on the ground”;
3. Perceptions of winners and losers; and
4. Societal capacity to learn.

We can also expect that, given the physical characteristics we have described, these problems will become critical in the 22nd century.

In the meantime, the data show that the U.S. accounts for a bit less than one quarter (22-24 percent depending on the year) of the carbon dioxide emitted into the atmosphere (NOAA 1997). This amount, which varies from 5.5 to 5.7 tonnes per capita, is currently twice the rate of non-OECD advanced industrial countries, more than twice the rate of OECD countries minus the U.S. (2.4 tonnes/year), a little more than five times the rate of China and India, and six times the rate of the rest of the world (Masood 1997). There is then no doubt that the U.S. stands out in the eyes of the world as the largest source of the problem by far. The corollary of that perception is that the U.S. bears the largest obligation to reduce its emissions of CO₂ in accord with international consensus.

There is therefore a very large gap between the ways in which the Bush Administration sees the problem (at least in 2001/2002) and the ways in which other advanced industrial countries see the problem. Moreover, most developing countries see the source of the problem as all advanced industrial countries, the governments of which bear the responsibility of doing something about the problem. The developing country coalition also insists that their development cannot be held hostage to a problem created by the advanced industrial world. However, a significant minority, calling themselves the Association of Small Island States (AOSIS), break from the majority on this point. Because their very physical existence is threatened by the consequences of global warming, they demand 20 percent cuts in aggregate emissions now. This lineup creates a very turbulent policy field and it implies that all attempts at international negotiation will be very difficult.

But the fact is that the world is now at an aggregate concentration level of 367 ppmv for CO₂, which is 31 percent higher than the pre-industrial ambient level of 280 ppmv (IPCC 2001). We know that if no mitigative actions are taken, we will double the 280 ppmv benchmark by the end of the 21st century and triple or even quadruple it by the end of the 22nd century. The problem is that increasing average global temperature has consequences in the form of climate impacts on natural and social systems (IPCC 2001). These consequences include:

- Increasing average global temperature in a range of 1.4 - 5.8°C by 2100;
- Dramatically decreasing the extent of snow cover and mountain glaciers;
- Increasing global average sea level as a function of thermal expansion;
- Intensification of precipitation as a function of increasing evapotranspiration; and
- Increasing the frequency and intensity of both floods and drought in different areas.

Data from ice cores and other paleoclimate indices indicate that the current level of CO₂ exceeds anything experienced over the last 420,000 years and maybe over the last 20 million years (IPCC 2001). The policy concern here is whether there are thresholds of change in impacts as the concentration is increased. The scientific community does not know the answer to that question and therefore cannot say.

We are faced then with a problem of long time scale which, at lower levels of concentration (i.e., doubling to tripling CO₂ levels) changes the distribution of costs and gains, that is, the Canadians and Russians “win” while the tropics “lose,” at the same time that it creates increased risks and costs for many natural and social systems in most regions of the world.

Uncertainties abound, but the outline of the risks as perceived to date justifies detailed planning to “buy some insurance.” But, because mitigation implies costs of a variety of kinds, and even lifestyle changes, governments balk at how big a bite on the problem they wish to take and what exactly they will do.

A reading of the relevant social science literature that can be brought to bear on managing environmental problems of long time scale yields the following assumptions (Lee and Miles 1991, Miles 1998):

1. Global environmental modifications originate in human activity, therefore social processes will be central to controlling, mitigating, and adapting to human impacts on the planet.
2. Societies learn via mass publics and organizations but governmental responses to perceived policy problems are always mediated through organizations.
3. Societal learning typically proceeds over long time scales (i.e. intergenerational). Major shifts in direction therefore take time. Governmental responses can shift markedly over much shorter time scales, particularly in times of crisis.
4. For long time scale problems, experience contains relevant lessons and permits predictions to be made.
5. The rate of change is crucial to whether and what type of learning occurs.

Developing the Policy, 1989-2001

Bodansky (1993) presents an overview of the evolution of the global warming issue from the time it emerged on the global agenda in the 1960's to the negotiation and successful conclusion of the Framework Convention on Climate Change in 1992. We will not repeat that history here but will focus only on some seminal events in the evolution of the issue.

We note that there was a large gap in time between the publication of the initial paper on CO₂ accumulations in the atmosphere by Revelle and Suess (1957) and the concerted moves of the international scientific community to alert governments to the implications which occurred in two conferences in 1985 (Villach) and 1987 (Bellagio). The mechanism which served to galvanize the scientists was Charles Keeling's continuous measurements of the atmospheric concentrations of CO₂ at the Mauna Loa laboratory in Hawaii (figure 1). Keeling's work was the immediate result of the Revelle and Suess paper.

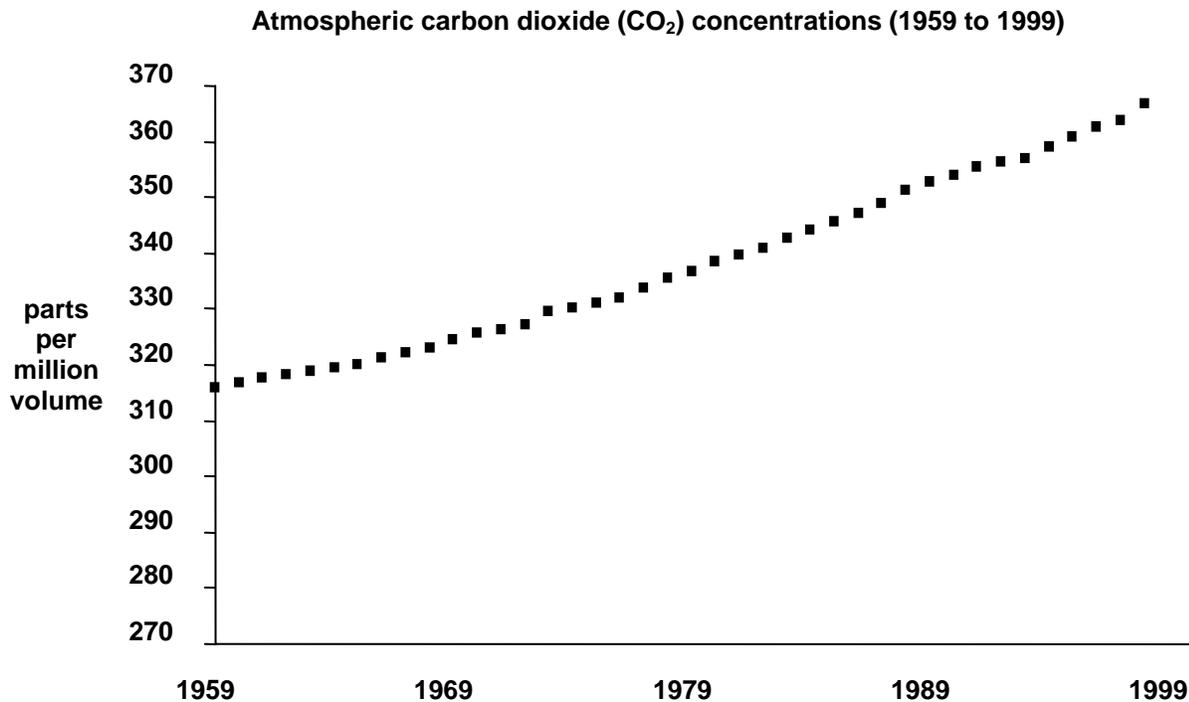


Figure 1—Atmospheric carbon dioxide (CO₂) concentrations (1959 to 1999). Data Source: C.D. Keeling and T.P. Whorf, Atmospheric CO₂ Concentrations (ppmv) derived from in situ air samples collected at Mauna Loa Observatory, Hawaii, Scripps Institute of Oceanography, August 1998. See <http://cdiac.esd.ornl.gov/trends/co2/contents.htm>.

At the 1985 and 1987 meetings, the scientists evolved into a full-fledged epistemic community (Haas 1992) since governmental and non-governmental scientists forged bonds to make governments aware of the dangers and to take action to mitigate the problem. Serendipitously, 1985-1987 was the point at which governments were earnestly negotiating the Vienna Convention (1985) and the Montreal Protocol (1987) to regulate the problem of the expanding ozone hole over Antarctica, which was itself discovered and reported thirteen years before in a paper by Rowland and Molina (1976).

Not surprisingly, the ozone experience captured the imaginations of both scientists and governments to the extent that ozone became the template for the design of the FCCC. These assumptions were explicitly stated by Prime Minister Margaret Thatcher in a speech to the UN General Assembly on November 8, 1989 (Thatcher 1989). Thatcher had by then emerged as the undisputed leader of the European coalition, in part because she was trained as an industrial chemist and the common language of the global warming problem is undoubtedly chemistry. In her speech, Thatcher said:

The most pressing task that faces us at the international level is to negotiate a framework convention on climate change – a sort of good conduct guide for all nations.

Fortunately we have a model in the action already taken to protect the ozone layer. The Vienna Convention in 1985 and the Montreal Protocol in 1987 established landmarks in international law. They aimed to prevent rather than just cure a global environmental problem.

I believe we should aim to have a Convention on global climate change ready by the time the World Conference on Environment and Development meets in 1992. That will be among the most important conferences the United Nations has ever held. I hope that we shall all accept a responsibility to meet this timetable.

In the face of this momentum, which had gathered significant speed in 1988 when the Prime Ministers of Canada and Norway had seized the initiative to convene the first non-governmental “governmental” conference combining scientists, policy makers, and non-governmental organizations (NGOs). The process at that time was still in the problem definition phase but significant divergence between the U.S. and its traditional European and North American Allies could already be seen. The U.S. pushed for institutionalizing the scientific epistemic community into what became the Intergovernmental Panel on Climate Change (IPCC) primarily seeking to slow down the push for economic regulation. The Europeans on the other hand wanted the IPCC to provide the scientific support for regulation. Thatcher, in her speech, explicitly called for prolonging the existence of IPCC beyond its expected 1990 assessment to perform such a role.

Additional divisions of great significance could also be detected at the time within the U.S. government as represented by the first Bush Administration. The Department of State took the problem seriously and was preparing for the FCCC negotiations under the leadership of Deputy Assistant Secretary of State for International Environmental Affairs William Nitze. In fact, at the opening ceremonies for the IPCC, Secretary of State James Baker (1989) himself represented the U.S. and in his speech made these important points:

1. Action should not be delayed until scientific uncertainties are resolved;
2. The immediate focus should be on steps that are justified on other grounds [i.e., “no-regrets” strategies];
3. Proposed solutions should be specific, cost-effective, and fair to all concerned.

These hopeful steps occurred on the cusp of a major internal revolution within the Administration in which certain high officials saw the global warming issue as involving highly sensitive issues with respect to the U.S. economy and the willingness of the public to accept strong regulation. The result was that the White House Domestic Policy Council wrested control of the issue from the Department of State under the dominant leadership of John Sununu, Chief of Staff to the President, and Richard Darman, then Deputy Secretary of the Treasury. The Domestic Council henceforth in the Bush Administration coordinated the Departments of Energy, Interior and Commerce, EPA, the Office of Management and Budget (OMB), and the Council of Economic Advisors. Nitze at State was fired and Secretary Baker was never heard to issue a public comment on the problem thereafter. While the U.S. did sign and ratify the FCCC, it did so with an explicit reservation against the binding target and timetable approach pushed by the Europeans which sought to stabilize emissions of CO₂ at 1990 levels by 2000.

While the FCCC negotiation process was successful, it gave hints nevertheless of how difficult negotiating implementing protocols would be. The process was simultaneously a three-level one occurring within the North (i.e., the advanced industrial countries [AICs]), the North vs the South (i.e., the lesser-developed countries [LDCs]), and within the South between OPEC countries, AOSIS countries, and the rest. Significant strains and conflicts were apparent at every level and some major conflict issues were dividing governments of AICs within their own countries, viz. the U.S. and Japan.

The regime that the FCCC creates (Bodansky 1993) contains basic institutions (the Conference of the Parties, the Subsidiary Body for Scientific and Technical Advice [SBSTA], and the Subsidiary Body for Implementation [SBI]); it enshrines the concept of differentiation of Parties based on their relative energy efficiency; weak obligations; and relatively strong reporting and review obligations which effectively provide for transparency. The latter is perhaps the most significant contribution of the FCCC, followed by avoiding intense politicization of the IPCC by creating SBSTA as a buffer.

Finally, the convention seeks to define a standard of performance as its major objective:

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow

ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

This objective is an admirable attempt to solve a very difficult problem. As such, it seeks to balance avoiding “dangerous anthropogenic interference with the climate system” with facilitating ecosystem adaptation, maintaining required levels of food production, and seeking to provide for sustainable levels of economic development. The only difficulty is that the standard is far in advance of what either the natural or social sciences can operationally establish. The standard therefore sets in train a comprehensive research program which can only be long-term. In the meantime, informally, the level referred to in Article 2 was taken to mean doubling the pre-industrial ambient CO₂ concentration to about 560 ppmv because preliminary analysis suggested the impacts would be manageable and global GNP would not be seriously affected.

However, given the long residence times of greenhouse gases, except for methane, in the atmosphere, the magnitude of present commitments and the difficulty of negotiation and implementing meaningful cuts in emissions in the short-term, it is a very serious question indeed whether any feasible mitigation policies can avoid doubling by 2100. Moreover, we have already made clear that the scientific community cannot now, and may never be able to, pronounce definitively on the issue of what specific concentration level constitutes dangerous interference with the climate system and where threshold effects may be.

Moving Toward Kyoto

1997 was a critical year in the attempt to negotiate the first binding Protocol to the FCCC. This was again a four-dimensional negotiating situation in which the fourth dimension was represented by the internal politics of the United States and Japan, with the former having a much bigger impact on the global negotiations. In the preparations leading up to what the States Parties hoped to be the final round of negotiations in Kyoto, Japan in December 1997, the original intent was to focus first on the AICs and only later seek to apply the provisions to the LDCs. This attempt to minimize the scope of the initial target was shot down by a Senate resolution which passed by a vote of 95-0 on July 25, 1997; it implied that the Kyoto Protocol would be “dead on arrival” if it did not include the LDCs (Mobile 1997).

A Republican-controlled Senate, with notably significant support from Democrats, was responding to great pressure from industry which argued that, while in 1995 AICs contributed almost 75 percent of global CO₂ emissions, by 2035 LDCs would be contributing 50 percent, with China as the world’s largest emitter (i.e., at 17 percent compared to 15 percent by the U.S.; down from 22 percent in 1995) (NOAA 1997). The effect of this letter, not surprisingly, was to galvanize the LDC coalition, the Group of 77(G77) into total opposition and to elevate this issue almost to the level of a conference-breaker. Internally, diplomats and others engaged in the process saw this letter as a most unhelpful move since the intent was to use 2010 as the cut-off date for the Kyoto provisions, at which time a successor Protocol would have to be negotiated and the LDC issue could be tackled then.

In addition to the LDC inclusion issue, there were eight other issues that were central to the Kyoto negotiations, six of the nine being very difficult indeed. These issues included the following:

Targets and timetable

The EU coalition proposed a 15 percent reduction below 1990 levels by 2010. The U.S., Japan, and Canada chose not to propose any target or timetable prior to negotiations, whereupon the EU refused to discuss any other issues until the U.S. disclosed its preferences for targets and timetables.

The EU “Bubble”

The “Bubble” was the idea proposed by the EU to permit EU compliance with the global standard as a collective unit, thereby allowing internal variation among its membership. More specifically, this proposal would allow the EU to present the global standard to its member states as a system of differentiated targets with internal emissions trading within the EU. This proposal was vigorously opposed by the U.S.,

Japan, and Australia, inter alios, as a scheme to give the EU an unfair advantage over other industrialized states.

Differentiation among AIC's

Japan, Australia, and Norway proposed that targets within the global standard be differentiated among AICs on the basis of their aggregate efficiency of energy use. On this issue the U.S. and the EU were united in opposition.

Emissions Trading

The U.S. was a strong supporter of this idea because its industries argued that the costs of compliance would be too high without the possibility of emission trading. They were supported by Australia, Canada, New Zealand and Russia. The EU and others were opposed on the grounds that the system would be too complicated. Moreover, it would be too favorable to Russia since its economy had collapsed. Russia's trading advantage later came to be referred to as "hot air."

Joint Implementation

This proposal was the initial idea that AICs could receive credit against their obligations by investing in "clean" energy projects in LDCs. The U.S. was a strong supporter along with the Central American countries, Canada, Australia, New Zealand, and Norway. The LDCs themselves and the EU objected. Later evolution would differentiate between joint implementation per se and the "clean development mechanism" available only for LDCs.

Policies and Measures

The EU, supported by Japan and Canada, pushed for harmonized and mandatory policies and measures. The U.S., preferring a voluntary approach, was strongly opposed.

Compensation

The oil-producing countries, members of OPEC demanded compensation for anticipated loss of income as a result of controls on petroleum hydrocarbons as a fuel. No other state supported such an idea.

Developing Country Actions

The U.S. proposed to advance LDC commitments immediately, but stopping short of specific targets and timetables. Emphasis was placed on the need for energy efficiency and the potential role of China. The G77 were adamantly opposed to being included.

Evolution

The U.S. argued that the LDCs must, in Kyoto, commit to participating in subsequent negotiations on binding targets and to a mechanism that allows for graduation from LDC status. In this instance the U.S. had China, India, and Brazil particularly in mind. Again, the G77 were adamantly opposed.

The outcome of the Kyoto negotiations, dramatically achieved at the eleventh hour, included inter alia the following provisions (UNFCCC 1997):

1. AICs were obligated as a group to achieve a 5.2 percent reduction from 1990 levels between 2008 and 2012. Contained within this provision was both a "Bubble" solution for the EU and the concept of differentiation among the AICs. Consequently, the required reductions for the major AICs differentiated between the EU as a group at -8 percent; the U.S. at -7 percent; Japan at -6 percent; and Canada at -6 percent.
2. There was to be demonstrable progress by 2005.

3. Three major provisions met the interests and demands of the U.S. explicitly:
 - a) A focus on net changes in greenhouse gas emissions from all sources and removal from such by including land use changes, afforestation, reforestation, and deforestation since 1990.
 - b) Rather than focus simply on CO₂, target a “basket” of greenhouse gases including CO₂, CH₄, N₂O, HFCs, PFC, and SF₆. The emphasis would be on their combined radiative forcing, a weighted sum.
 - c) Emissions trading and joint implementations.

Beyond these issues, strong provisions were included on reporting, independent review, and verification. There was no resolution on the enforcement issue and LDCs were not included.

The Inadequacies of the Kyoto Protocol

What then is the policy significance of the Kyoto outcomes in terms of finding solutions to the global warming problem? Objectively, Kyoto represents a very small step that cannot and will not prevent doubling of the CO₂ concentrations in the atmosphere by 2100. Supporters of the process will say that it was not meant to; that the fact of agreement in recognition of global warming as a major policy problem is the main message and that bigger bites of the problem must and will be taken in 2010 and beyond. The Economist (2000) clearly expressed this point of view:

The real significance of Kyoto was that rich countries had accepted that they should act to curb global warming, and that they should do it before requiring poor countries to do the same. They committed themselves to frequent updates and improvements of the treaty, the first substantive one of which is taking place in The Hague. And they agreed that cutting emissions might be so expensive that the treaty should allow countries innovative, flexible approaches to reduce compliance costs (<http://www.economist.com/printedition/displaystory.cfm?story>, p. 6).

This author’s view is different. The Kyoto Protocol undoubtedly contains policy ideas of significance, e.g., the market mechanisms (emissions trading, joint implementation, and the clean development mechanism) and the reporting, independent review, and verification provisions which facilitate transparency. But Kyoto demonstrates that there are severe problems in any attempt to negotiate a system based on targets and timetables (Victor 2001). The practical realities of implementing a global system of emissions trading are extremely difficult; the “basket” of differentially weighted greenhouse gases with sinks (forests and soils) as offsets underlying the targets contains provisions which are currently beyond our collective capabilities, and global coverage on the performance of forests and soils as sources and sinks of greenhouse gases is in its earliest stages. Moreover, the targets themselves represent the “law of the least ambitious program” (Underdal 1982) at work in this most difficult of collective action problems.

One month after the Kyoto Protocol as produced, Professor Bert Bolin, then Chairman of the IPCC, published a commentary on the technical implications of the agreement (Bolin 1998). He made five major points:

1. With respect to the “basket,” the increase of CO₂ alone would account for 70 percent of the total increase in radiative forcing of all greenhouse gases. Not many measures are currently available for decreasing methane and nitrous oxides and the other elements contribute only a few percent to radiative forcing.
2. Even if full compliance with the Protocol were achieved by 2010, AICs would still be contributing four times the CO₂ emissions of the LDCs to the atmosphere.
3. Even with full compliance, the accumulated emissions of CO₂ from 1990 to 2010 would amount to C.140 Gt of carbon, thereby implying an increase in atmospheric concentrations by about 29 ppmv to a total of 382 ppmv.
4. Therefore the Kyoto conference did not achieve much relative to limiting the buildup of greenhouse gases in the atmosphere.
5. Meeting the doubling standard (550 ppmv) by 2100 would require a 60 percent reduction in aggregate emission in two steps (30 percent reduction by 2050 and an additional 30 percent by 2100).

While the basic outlines of the Kyoto Protocol were achieved in December 1997, the job was certainly not done. Outstanding issues included coverage of the LDCs, and the details of measures of flexibility in the Protocol, particularly emissions trading, and compliance measures. Major conflicts arose in the AIC group on these issues between 2000-2001, particularly between the U.S. and the EU. The EU position was that the sanctity of the targets arrived at in Kyoto should be preserved at all costs and that Annex I Parties (the AICs) needed to reduce emissions domestically rather than by employing global accounting. The U.S. (Clinton Administration) position was that targets should be met in the most cost effective manner, even if all actions were non-domestic, that is, via offsets for forest and soil sinks plus emissions trading (“hot air”).

The reality was very different outside the negotiations. It was increasingly clear that of all the AICs, only Germany and the UK were on track to meet their 1990 targets and the U.S. was going in the opposite direction at a very rapid rate. The Energy Information Administration of the U.S. Department of Energy (Macilwain 1997) had published a report two months before the Kyoto negotiations which showed that the U.S. in 2000 would already be 18 percent above their 1990 emission levels and projected an additional increase of 16 percent by 2010. This report had a major impact on the position of U.S. industry which argued that Kyoto for them meant a 34 percent reduction, not 7 percent as the Protocol stated and this rate of reduction was unacceptably onerous. Thus the stage was set for the Bush Administration’s rejection of the whole Kyoto process in 2001.

Rejection stimulated a confrontation between an isolated U.S. and 178 states determined to prove that they could produce a Protocol nevertheless (Andrews 2001). But the price for “success” was high since it handed to the “laggards,” that is Japan, a club with which they could flog the “pushers,” that is the EU. The result was the Protocol was weakened significantly in two respects: a) enforcement was severely constrained since there was not legal liability for non-compliance; and b) obligations vis-à-vis the target could be offset from proven “sinks” which were limited to forests and agricultural soils only. Both of these provisions were adopted at the Seventh Session of the Conference of the Parties (COP7) held in Marrakech, Morocco from 29 October to 9 November, 2001. The result is that a much lower reduction from the original target is to be expected by 2010 (UNFCCC 2001). The changes to the Kyoto Protocol were negotiated at the sixth session of the conference of the parties held in Bonn in July 2001 and ratified at COP7 in Marrakech (UNFCCC 2001).

So what is the outcome? On the one hand, the Bush Administration has announced yet another voluntary program of controlling emissions by U.S. industry while the EU has enthusiastically ratified a severely flawed Kyoto Protocol (Revkin 2002). This means that the Kyoto Protocol has become a symbolic rallying point against potentially more effective alternative strategies as well as the Bush Administration’s voluntary controls idea. How do we get out of this bind?

Beyond Kyoto/Marrakech or Why We Have to Start Over

The point is neither Kyoto nor voluntary strategies. The point is cumulative atmospheric concentrations of greenhouse gases, most especially CO₂ and the fact that doubling the pre-industrial value seems to be inevitable by 2100. The real question then becomes whether or not we can put in place measures to avoid tripling the concentration or more between 2100 and 2200.

This is a significant question because the scientific community does not know where the thresholds of change lie and how quickly planetary-scale changes would occur in a warmer world. Schelling (2002), in a personal judgment after reading the available literature, suggests that that the range is probably between 600-1200 ppmv i.e., somewhere between doubling and quadrupling the pre-industrial atmospheric concentration. This range is probably correct but far too large to provide specific policy guidance and the chaos continues in the policy field.

Since neither targets and timetables nor voluntary controls will produce the necessary results, and the clock is definitely ticking, what can we do? I suggest that a “buying time” strategy makes sense, the objective of which is to push out the horizon of irreversible impacts (wherever that is), while the

international system struggles to mount an effective response. However, this strategy would still require U.S. leadership, albeit in a decentralized process. Given the immense scale of the problem we face, the strategy performance contains very large and difficult components.

The first component is increasing efficiency as a means of practicing conservation of fossil fuels. Our experience following the two OPEC "oil shocks" of the 1970's shows that conservation produces societal effects far in excess of personal virtue. In 1973, the time of the first oil shock, the nominal cost of a barrel of oil was approximately \$4.75 USD (OECD 1988). By 1979, the time of the second oil shock, the price per barrel was about \$12.00 USD and by 1981 the average market price of crude oil had shot up to \$32.00 USD (OECD 1988). At that time, consumers considered that the price was too high and they began to practice conservation. Consequently, by 1986, the price had declined to about \$13.00 USD a barrel before it started to climb again from 1987.

The moral of this story is that the market price of crude oil is a powerful lever for inducing conservation, and thereby for lowering emissions. The most immediate instrument for affecting the market price is a carbon tax (Grubb 1989, Nordhaus 1994, Cooper 1998) the purpose of which is to increase the market price of fossil fuels in proportion to carbon content. It is better to start modestly to avoid market dislocations but then ramp up over time. Such a tax would yield very large revenues which can be used for aiding coal mining communities and investing in energy research and development.

Internally within the U.S., the carbon tax could be combined with emissions trading and revenue recycling i.e. reducing taxes in other places. Emissions trading on the national level is far more manageable and is an aid to increasing efficiency without the distortions caused by large pools of "hot air" (Swift 1998). Expanding research and development investment also assumes a shift out of coal with emphasis on natural gas and nuclear power as transitional fuels for a century or so.

We need also to look very seriously at all options for sequestering carbon, e.g. forests and agriculture, iron fertilization of the surface ocean, sequestering in depleted hydrocarbon and salt reservoirs either on land or in the ocean, the possibility of deep ocean disposal of carbon, and potential biotechnology alternatives (U.S. Department of Energy 2000). All of the above components fall under the rubric of mitigation strategies. But, at the same time, because the planet is already committed to a substantial amount of warming, we need systematically to prepare for adapting to climate change and reducing the obvious vulnerabilities.

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Economic Incentives for Carbon Storage in Western Washington's Forested Riparian Management Areas

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Abstract

New practices for forested riparian areas reduce timber harvests and create carbon sinks. The study analyzes the size and value of these sinks and describes contractual agreements that can generate compensation for private landowners producing carbon sequestration. The average value of carbon sequestration is \$2 per ton. The size of a program that compensates landowners for sequestering carbon in western Washington riparian forests is \$230 million over a 50-year period. The projected carbon sequestered over the 50-year period is 110 million tons.

Introduction

The provision of forest goods and services by private ownerships can be promoted with contracts that compensate private land managers for public services that have equivalent private ownership values. For example, contractual agreements to maintain carbon can support recent changes to forest practices by compensating private landowners for the foregone timber production. The contracts can take advantage of interest in carbon sequestration, which when produced would also provide stream habitat improvement. This study examines a potential contractual mechanism to provide and sell carbon sequestration. It asks the question: If carbon can be sold to produce the positive externality of stream habitat improvement, can we take advantage of carbon market values to help compensate for the non-market values associated with stream habitat improvement?

Because recent regulations on forest practices have produced a greater burden on private landowners to provide for ecological services from their timberland, it makes sense to examine alternative sources of compensation that benefit private landowners and achieve social values. The new state regulations reduce the amount of potential timber that landowners can harvest on lands adjacent to streams. The newly preserved and alternatively managed areas protect stream habitat for salmon and other aquatic life forms and promote cleaner water. Other ecological benefits are also produced as externalities that complement improved stream habitat. One such benefit is carbon sequestered in biomass and soils that would have otherwise been converted to products or released to the atmosphere.

Compensation packages that provide some portion of the lost timber asset value to private landowners are taken from state revenues. Examining the carbon value can take advantage of recently established carbon markets as a source of revenues to fund compensation programs. The production of carbon as a spillover from stream habitat protection has not been quantified in any previous study of stream habitat preservation.

Our analysis estimates (i) the carbon that will be retained in the riparian management zones due to changes in land use practices and (ii) an equivalent economic compensation associated with the production of carbon sequestration services by private landowners. The value of carbon is derived by using timber values associated with riparian acres. The paper is developed as follows. First, we provide a background to the recent changes in forest practice rules in Washington state. The section is followed by a description of how we calculate carbon sequestered in riparian management areas, how we derive the monetary value of carbon sequestered and the data that we use to derive these values. Results are presented in the next section, with a discussion following it. We summarize our findings in a final section.

Background

In November 1997, in anticipation of the listing of several subspecies of Washington salmon as threatened or endangered, participants representing timber, fish and wildlife began negotiating a proposal for new forest practices rules. The goal of this proposal was to protect and restore riparian habitat on non-federal forestlands in compliance with the Endangered Species Act and the Clean Water Act, while maintaining the economic viability of Washington's timber industry. The process became known as the "Forest and Fish" negotiations and the stakeholders' recommendations became known as the "Forests and Fish Report," which is the foundation for the forestry module portion of the Washington State salmon recovery plan. While carbon sequestration was not mentioned explicitly in the report, one could argue that the report's recommendation implicitly would lead to new carbon sinks associated with riparian land management changes.

The new rules introduce changes to forest practices. The changes affect timber harvests, access to timber through road construction and maintenance and administrative setup cost. There are other aspects such as procedures for unstable slopes, multi-year permits, adaptive management plans and watershed analysis as well. In effect, these changes limit timber harvests and promote the establishment of late stage forest conditions. The result of the change in land use would be a new forest carbon sink.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (1998) provides rules that allow countries to remove carbon dioxide into living plants and use the sequestered carbon to offset some of their greenhouse gas emissions from other sources. While there is lively debate on the Protocol, its adoption by the international community and its effectiveness in reducing greenhouse gas concentrations in the atmosphere, it remains as the guiding framework for establishing a market for carbon. As such we analyze the newly established carbon sinks in Washington's riparian management areas as a potential credit that can be sold under an emissions trading scheme.

Methods

Our study takes data on parcels in western Washington used in the economic evaluation of the new forest practices rules under the Small Business Economic Impact Statement (SBEIS) (Perez-Garcia et al. 2000). The SBEIS uses a sample of forestland parcels to determine the value of the timber asset associated with areas under the new regulations to draw inferences on the effects of new rules on timber asset values in western and eastern Washington.

We determine the value of carbon associated with timberlands in riparian management areas using the timber asset values derived in the SBEIS and the amount of carbon associated with each acre in a parcel that is calculated below. Consideration is given to above and below ground carbon, as well as soil and organic matter carbon. The dollar value of carbon for newly regulated areas and total parcel acreage is determined by dividing the value of the timber asset by the volume of carbon. The resulting value is measured in dollars per ton, which can then be expressed in a carbon value per acre. This value per acre reflects the current volume on the acre and changes in the carbon value per acre as volume increases over time. We then proceed to determine the equivalent revenues required from selling carbon so as to produce the timber values lost due to new regulations to protect riparian habitat. Annual contracts are defined to reflect the additional carbon that would be sequestered over time under new riparian management schemes.

Data

The SBEIS data set contains spatial information for 92 sections in western Washington. Information for each section includes section boundaries, parcel information from the county's assessor's office, timber stand/land cover information from photo interpretation, buffer zones for new and current rules and valuation of the timber asset.

The timber stand/land cover information is classified into 10 categories based on earlier work by Department of Natural Resources (1997). Codes used for the forest-type are listed in parenthesis in table 1.

Table 1—Vegetation types with estimated rotation lengths

Reproduction (R)	5 - 15 years
Conifer Pole timber (CP)	15 - 30 years
Conifer Saw timber (CS)	30 - 100 years
Over Mature conifer timber (CL)	100 + years
Hardwood Pole timber (HP)	15 - 30 years
Hardwood Saw timber (HS)	30 - 60 years
Over Mature hardwood timber (HL)	60 + years
Mixed conifer/hardwood pole timber (MP)	(30% - 70%)
Mixed conifer/hardwood saw timber (MS)	(30% - 70%)
Mixed conifer/hardwood over mature timber (ML)	(30% - 70%)

Buffer zones were established using GIS techniques. Distances from stream centers are mapped according to regulation using stream maps that were inputted into a GIS software. Area under each buffer type is recorded for each parcel along with the timber stand/land cover information.

Timber values are the average value of timber sales per acre over the last three years aggregated for each county from the Department of Revenue (DOR). The average value of timber sales is total sales value divided by total acres for each sale, then aggregated by county to find an average county figure. This value is then matched to each parcel's county to be used as a proxy for timber values in each county. To be able to use the DOR values the SBEIS study assumed that the vegetation distribution for the average sale is similar to the vegetation distribution of riparian buffer acres and that the saw and mature timber stand types are harvestable. The advantage of using the value per acre parameter is that it permits calculating the timber asset value without introducing more complex assumptions on the volume distribution by species and their corresponding log or stumpage prices for each potential sale.

Table 2 illustrates the per acre values calculated for each county. We apply these values to the sum of acres in the pole timber type (CP, HP, MP, (where C = coniferous, H = hardwood and M = mixed stand; P = pole timber type)) saw timber type (CS, HS, MS) and over- mature timber type (CL, HL, ML). In western Washington, Kitsap County had the lowest per acre values followed by Jefferson and Mason counties.

Table 2—Per acre values based on Department of Revenue data on recent timber sales

Westside Counties	
County	Per acre value^a
Clallam	\$10,560.76
Clark	\$11,004.14
Cowlitz	\$12,659.27
Grays Harbor	\$14,592.31
Jefferson	\$6,238.56
King	\$12,742.27
Kitsap	\$3,721.30
Lewis	\$13,034.25
Mason	\$8,427.62
Pacific	\$13,420.28
Pierce	\$12,585.76
Skagit	\$10,863.43
Skamania	\$13,206.64
Snohomish	\$13,365.47
Thurston	\$12,798.15
Wahkiakum	\$13,047.26
Whatcom	\$11,459.97
Average	\$11,395.73

^a per acre average calculated using Department of Revenue timber sale data from July 1997 to March 2000.

Volume data were used to determine carbon in biomass. The volume of timber is taken from an earlier SBEIS on water typing (DNR 1997). Table 3 replicates the data for western Washington.

Table 3—Estimated volume of board feet for the various timber types

Timber Type	Western Washington
Non-Forest	0
Brush	n.a.
Reproduction	0
Conifer Pole	12,000
Conifer Saw	40,000
Conifer Large Saw	75,000
Hardwood Pole	5,000
Hardwood Saw	20,000
Hardwood Large Saw	35,000
Mixed pole	15,000
Mixed saw	30,000

Carbon was determined for above and below ground biomass associated with trees, soils and organic matter. Total tree carbon was estimated using a relationship of 4,400 pounds of carbon per thousand board feet of timber volume (Birdsey 1992). In addition, soil and organic matter carbon was factored in as

well. We assume that soil conditions are in equilibrium when calculating our soil carbon amount. These calculations produce carbon estimates for each parcel in the sample, differentiated by riparian and non-riparian buffer acres. With this data and information on timber values we calculate the value of carbon.

Results

The results of the carbon assessment indicate that on average, there are currently around 70 tons per acre of carbon sequestered in western Washington. There is slightly more carbon sequestered in riparian management zones. The average value of the carbon is \$7.80 per ton for the parcel and \$8.72 per ton within the riparian management area. Details of the results are presented below.

Figure 1 shows the current levels of carbon sequestered in parcels in western Washington. The range of per acre carbon estimates is from 65 tons to 90 tons. Differences in the estimate of carbon are related to the percentage of timber type in each parcel. A higher percentage of harvestable timber (categories CS, MS, HS, CL, HL, ML in table 1) leads to higher amounts of carbon captured in each parcel. The average carbon per acre for the sample is slightly over 70 tons per acre for all ownerships in western Washington.

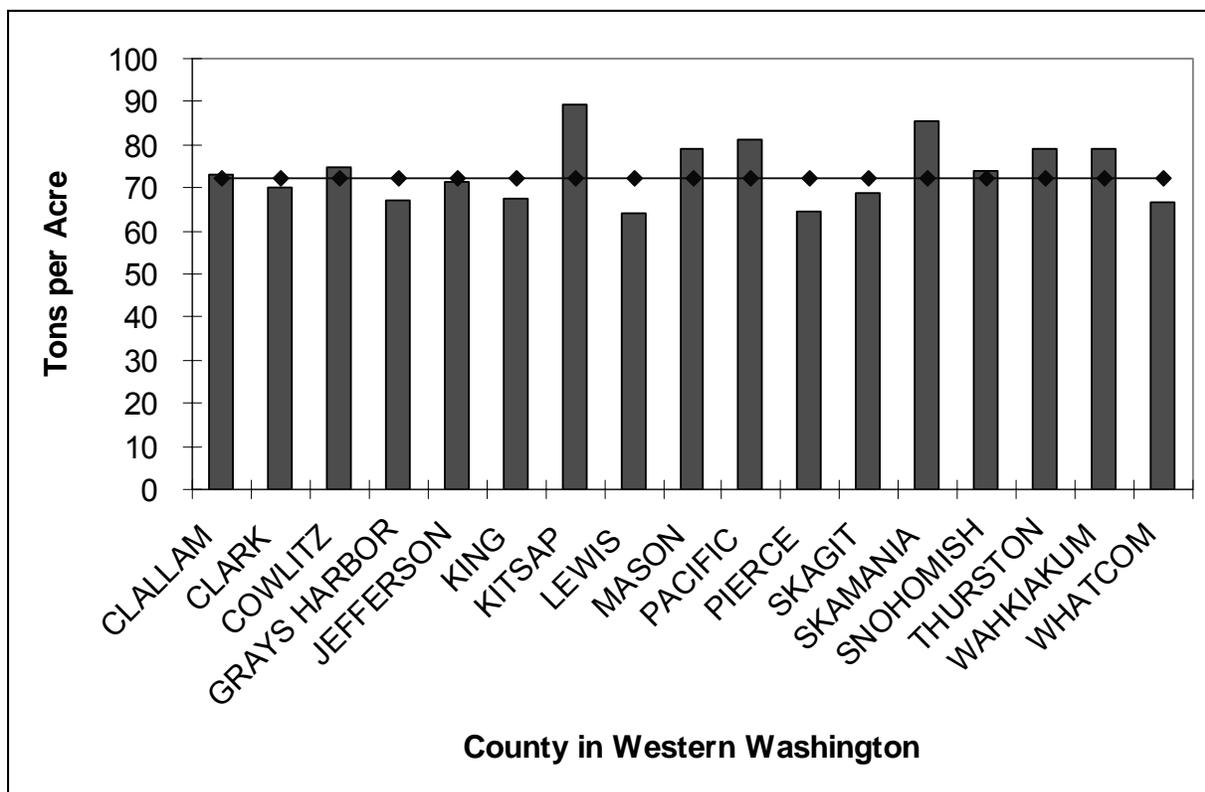


Figure 1—Carbon on forested acres

Figure 2 depicts the value of carbon for each parcel in the sample. The average value is \$7.80 with a variation between \$5 and \$14 per ton of carbon. Two factors affect the variation in the value of carbon. In addition to the percent of harvestable timber present in the parcel, the variation in the value of carbon is also influenced by the value of timber for each county (see table 2).

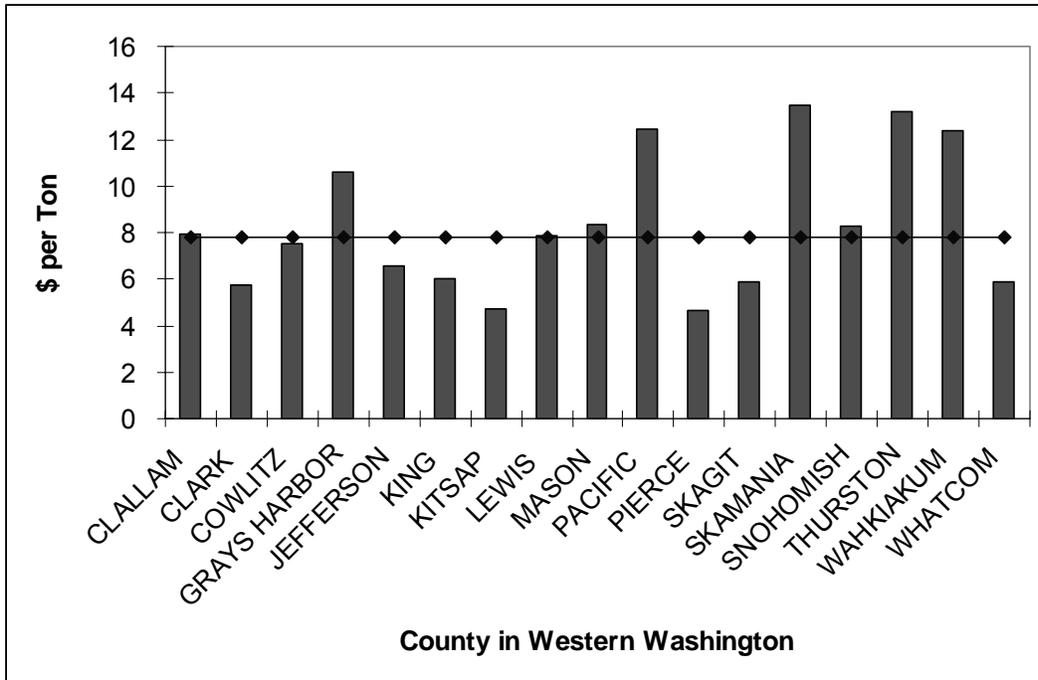


Figure 2—Value of carbon in parcels. The average value is \$7.80

Figure 3 illustrates the value of carbon for areas under new riparian buffers. The average value is \$8.72 per ton, higher than the average value of carbon for the parcel. The larger variance observed for the riparian management areas is due to differences in the amount of riparian areas by each parcel, in addition to the variation already noted above.

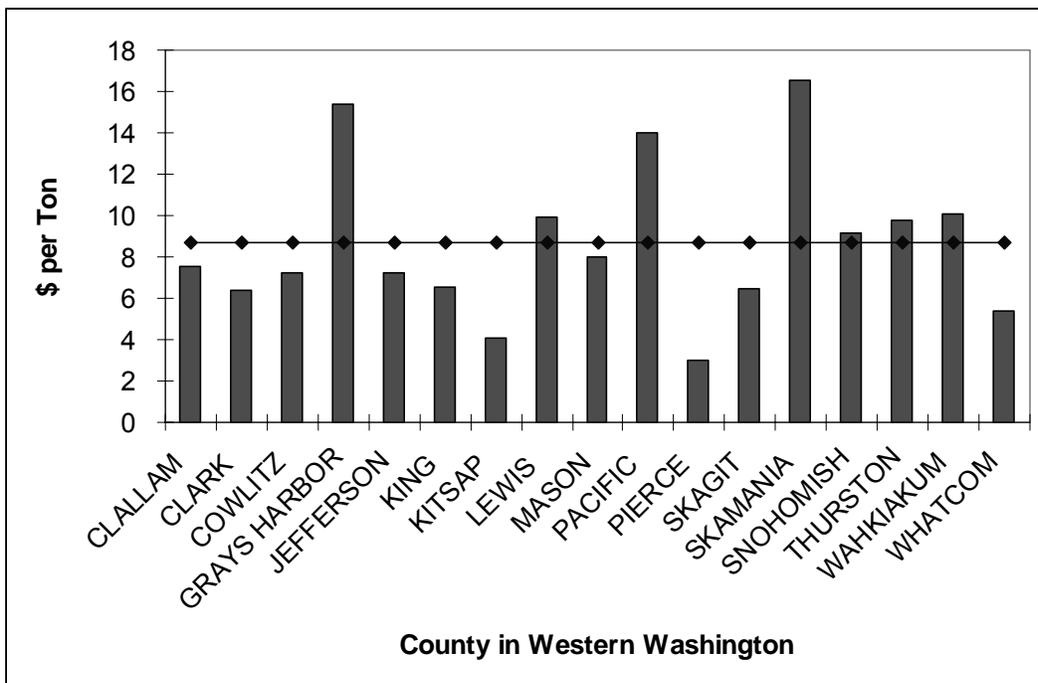


Figure 3—Value of carbon in buffers. The average value is \$8.72

The next step is to calculate a corresponding annual value that would equate revenues obtained under a timber production scheme with revenues obtained by selling carbon credits. For areas that are young or recently cut, the potential in sequestering carbon is larger than for those areas that already contain mature timber. On the other hand, harvestable timber represents a large stock of existing carbon, which would most likely have been harvested under past forest practices rules. Figure 4 shows the value of carbon given the current distribution of timber types in riparian management areas (dark bar) and the value of carbon assuming all acres are fully stocked (lighter bar). The potential growth in value attainable in riparian management areas is the difference between the two bars. It is equivalent to the growth in value if timber is allowed to reach a harvestable age.

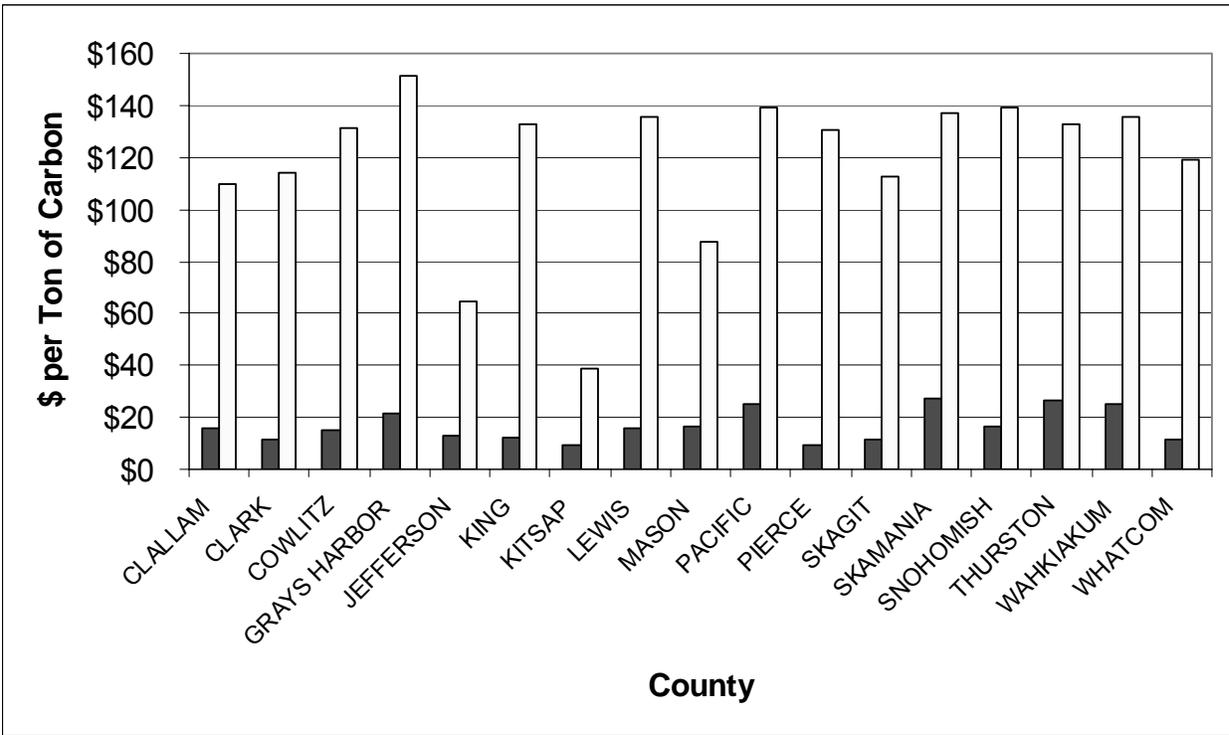


Figure 4—Value of carbon under current (dark bars) and fully (light bars) stocked acres

Table 4—Average carbon values for current and fully stock acres and their annual value

County	Average \$ / ton of C under current stocking	Average \$ / ton of C under fully mature timber	Difference between current and full stocking (\$)	Annual value (\$) using 50 years to get to full stocking
Clallam	15.90	109.72	93.82	1.88
Clark	11.51	114.33	102.82	2.06
Cowlitz	15.07	131.52	116.45	2.33
Grays Harbor	21.22	151.61	130.39	2.61
Jefferson	13.07	64.82	51.75	1.03
King	12.06	132.39	120.33	2.41
Kitsap	9.46	38.66	29.20	0.58
Lewis	15.79	135.42	119.63	2.39
Mason	16.63	87.56	70.93	1.42
Pacific	24.84	139.43	114.59	2.29
Pierce	9.31	130.76	121.45	2.43
Skagit	11.82	112.87	101.05	2.02
Skamania	27.00	137.21	110.21	2.20
Snohomish	16.49	138.86	122.37	2.45
Thurston	26.36	132.97	106.61	2.13
Wahkiakum	24.76	135.56	110.80	2.22
Whatcom	11.73	119.06	107.33	2.15
Average	16.65	118.40	101.75	2.03

Table 4 illustrates the values. The value of carbon under current stocking conditions is given in column 2. The value of carbon that is attainable allowing timber to continue growing is presented in column 3. The potential growth in value is shown in column 4. Column 5 divides the potential growth by 50 years to arrive at a simple arithmetic annual value per ton of carbon. The average annual value for each ton of additional carbon is slightly over \$2. In King County, the average dollar per ton of carbon for the current buffer stocking is \$12.06 per ton of carbon. Each additional year that the trees are maintained adds \$2.41 per ton in value. By the end of 50 years, the riparian management area would be fully stocked containing mature timber worth \$132.00 per ton of carbon (from figure 4 and table 4). The sum of payments received would be equivalent to a timber value of \$10,184.

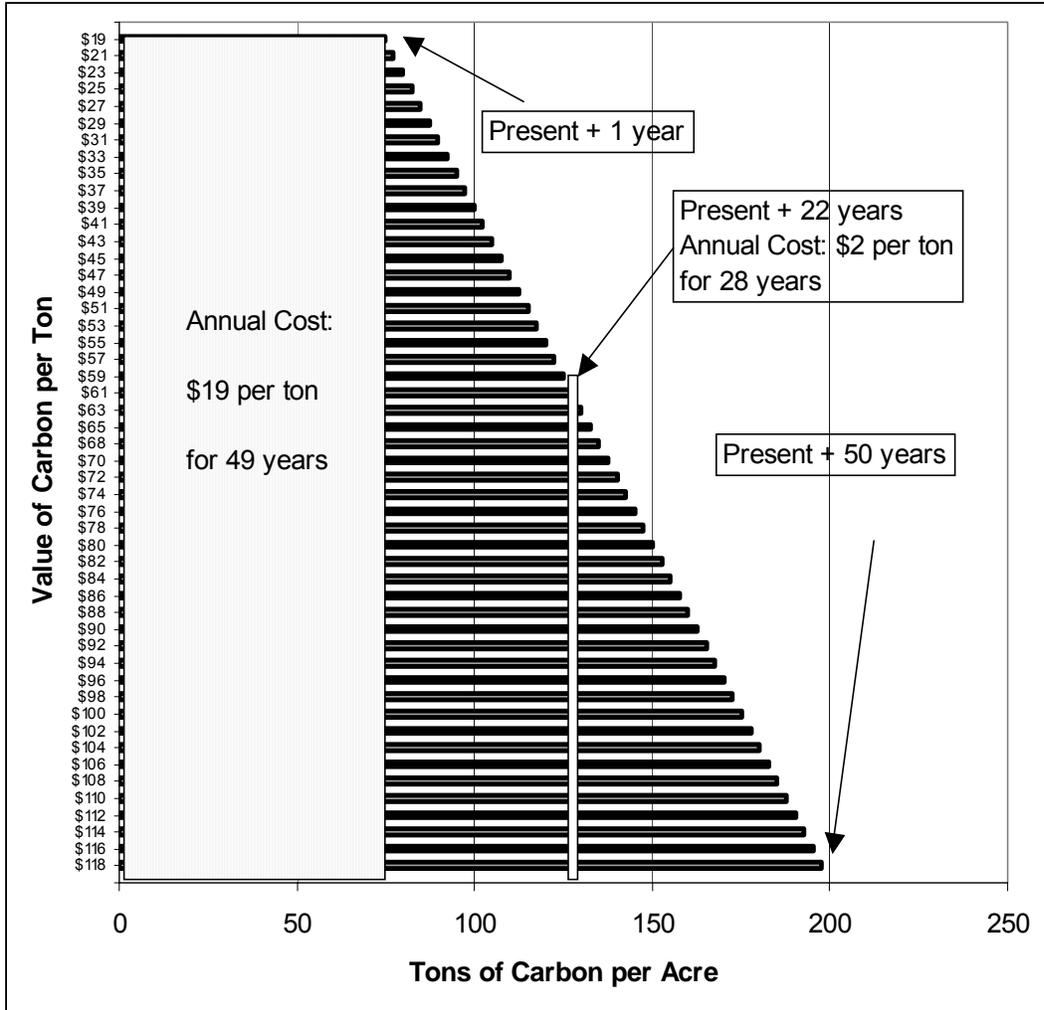


Figure 5—An example of annual contracts, their cost and length. The left rectangle is based on 14 percent mature timber. Additionality is the part of the bars to the right of the rectangle

Figure 5 depicts tons of carbon per acre and their value over a period of 50 years into the future. Current conditions for the average western Washington acre is nearly \$19 per ton (\$16.65 plus \$2.03 from table 4) and 72 tons per acre. A contract to sequester carbon would be valued at \$19 per ton, would be in effect for 49 years, and is represented by the larger rectangle in figure 5. There is a question of additionality associated with the carbon already in the ground under past forest practices rules under the Kyoto Protocol. Hence, only the part of bars to the right of this large rectangle can be considered additional carbon.

Annual contracts would be required each year after the initial contract. They would be needed to assure that the additional carbon sequestered by riparian management areas be sold to compensate for lost timber revenues. Scarcity in the carbon market would assure their marketability. The low cost per ton of carbon also helps marketability. Figure 5 presents an example in year 22 from present conditions. The annual cost of the contract would be \$2 per ton for the remaining 28 years. With an average 2.5 tons per acre per year sequestered, the total contract for that year would be worth \$143.

The additional carbon sequestered for the average acre is the difference between 197 tons and 72 tons or 125 tons. Region-wide (western Washington) the additional carbon sequestered amounts to over 2 million tons per year with an average cost of \$4.6 million annually (see table 5).

Table 5—Annual program size and carbon sequestered for western Washington

Year	Program Size (\$)	Carbon Credits (tons)	Year	Program Size (\$)	Carbon Credits (tons)
1	11,749,185	5,764,717	26	6,094,890	2,882,358
2	11,945,984	5,649,423	27	5,851,094	2,767,064
3	11,702,188	5,534,128	28	5,607,298	2,651,770
4	11,458,392	5,418,834	29	5,363,503	2,536,475
5	11,214,597	5,303,540	30	5,119,707	2,421,181
6	10,970,801	5,188,245	31	4,875,912	2,305,887
7	10,727,006	5,072,951	32	4,632,116	2,190,592
8	10,483,210	4,957,657	33	4,388,321	2,075,298
9	10,239,415	4,842,362	34	4,144,525	1,960,004
10	9,995,619	4,727,068	35	3,900,729	1,844,709
11	9,751,823	4,611,773	36	3,656,934	1,729,415
12	9,508,028	4,496,479	37	3,413,138	1,614,121
13	9,264,232	4,381,185	38	3,169,343	1,498,826
14	9,020,437	4,265,890	39	2,925,547	1,383,532
15	8,776,641	4,150,596	40	2,681,751	1,268,238
16	8,532,845	4,035,302	41	2,437,956	1,152,943
17	8,289,050	3,920,007	42	2,194,160	1,037,649
18	8,045,254	3,804,713	43	1,950,365	922,355
19	7,801,459	3,689,419	44	1,706,569	807,060
20	7,557,663	3,574,124	45	1,462,774	691,766
21	7,313,868	3,458,830	46	1,218,978	576,472
22	7,070,072	3,343,536	47	975,182	461,177
23	6,826,276	3,228,241	48	731,387	345,883
24	6,582,481	3,112,947	49	487,591	230,589
25	6,338,685	2,997,653	50	243,796	115,294
			Total	231,165,210	109,529,620
			Average	4,623,304	2,190,592

Discussion

The study presents carbon values that are estimated with current timber values to evaluate potential contracting mechanisms that would compensate private landowners for producing carbon sequestration. Currently landowners can be compensated for mature timber that is harvestable, but are not compensated for young stands that continue to grow. A carbon credit market provides an opportunity to raise revenues that can be used to compensate private landowners for foregone timber revenues associated with the implementation of new forest practice rules.

The value of carbon is based on the timber value that is given up to create the riparian forest. The equivalent values between carbon and timber results in a low price for carbon that can be sold in emerging carbon markets. The carbon values average around \$2 per ton of carbon for western Washington and may result in 110 million tons sequestered over a 50-year period. The revenues associated with such a program sum to \$230 million over the 50-year period.

The contractual program that is described in the present study results in contracts of various lengths and values. Only additional carbon stored as a result of the new regulation is considered in the study. The annual contracts are of various durations and values depending on the age of the riparian forests. This allows a variety of contracts to be offered over time.

The study does not consider the off-site carbon storage potential that is foregone through a reduction in harvests. Because Washington unilaterally imposes the regulations it is likely that the price effect from the reduction in harvest is minimal and likely to be made up in other regions. This would minimize the

negative effect of using more energy intensive materials that substitute for wood not harvested from riparian forests.

In summary, the study concludes that there is a substantial amount of carbon that would be created by new forest practices. The price of the carbon is relatively low and should be saleable in carbon markets. Contracts of various sizes and durations can be developed to reflect the additional carbon captured by forestland owners under new regulated management practices.

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Life Cycle Analysis: A Wood Products Perspective

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Introduction

End-users of building materials, such as steel, concrete and wood, are becoming more environmentally conscious. This paper investigates some of the pros and cons of alternative building materials in construction by introducing the concept of life cycle analysis, a “cradle to grave” analytical tool for quantifying the environmental impact of material choices. In particular, the positive aspects of wood – the only renewable building material – will be stressed, including tree growth’s ability to capture and store carbon.

The carbon cycle for wood products is complex, and many avenues to reduce CO₂ emissions exist. From the point of view of wood products researchers, perhaps the most obvious and appealing solution would be simply to extend the active service lives of wood products and systems in use. This solution is not only environmentally responsible, but over time it indirectly serves to reduce atmospheric CO₂. Wood products in use can and should last for hundreds of years – examples from around the world attest to this fact. However, in North America’s “disposable society”, wood products, systems and structures are more temporary in nature. As such, moving towards the creation of longer-lasting wood products, in many ways, represents a paradigm shift. That said, technological advancements in the areas of design, maintenance, preservation, and re cycling are making the notion of longer lasting wood products a reality.

Background

The vast majority of North Americans live in single or multi-family wood structures, with annual housing construction starts of approximately 2 million (Taylor 2000). The only other country in the world with such significant wood home construction is Japan, with annual wood starts of approximately 500,000 (Gaston et al. 2000), in addition to an even larger number of non-wood starts (high-rise apartment buildings suitable for their dense urban concentration). Western Europe is the third largest wood-use area, yet wood housing starts as a percent of total single-family starts is surprisingly small (Taylor 2000). Finally, it should be noted that, in all three of these regions, nonresidential buildings such as schools, stores and offices tend not to use wood structurally, with steel and concrete dominating as the principal structural materials (Kozak and Cohen 1999).

The affinity to wood homes in North America and Japan comes from a mix of tradition and economy. The North American “platform-frame” building (stick-frame construction using dimension lumber and structural sheathing) has evolved into perhaps the most efficient system anywhere, balancing the cost of production against performance (including energy efficiency, seismic safety, comfortable living environment, and so on). Even in Japan today, 15 percent of wood housing starts use this system over their traditional post and beam construction technique (Gaston et al. 2000). The economics of the platform-frame system is derived from a number of factors including North America’s abundant forest resource, successful sustainable forest regeneration (including plantations), and most recently, the advent of resource-minimizing engineered wood products and labor-saving building systems.

This evolution finds itself at a bit of a crossroads. Platform-frame homes (especially multi-family) have become more complicated in design and have, on occasion, failed to provide the performance of their simpler ancestors. A good example of this is the “envelope failures” (moisture damage) of condominiums in Vancouver (see next section). In addition, the introduction and spread of the damaging Formosan termite in the southern United States contributes to a potentially growing mistrust of wood as a structural

material. Worse still, home-buying consumers are being led to equate building a home with destroying a forest. This has largely been as a result of effective media campaigns by the steel industry (looking for market share in housing) and by various environmental non-government organizations (ENGOS). The evidence of this trend, while still small, is there. Today, steel studs and concrete systems have respectively captured approximately 5 percent of the United States home construction market, and these numbers continue to grow (Taylor 2000).

It is clear that consumers are becoming more environmentally conscious. But are the messages that they have been receiving based on facts or emotions? Some preliminary work that has been performed on this topic suggests that it is the latter (e.g., Canadian Wood Council 2002, Wood Promotion Network 2002). There is almost no scientific basis to the steel or concrete campaigns, and while many ENGOS seem determined to fight for a halt to virtually all logging, few alternatives are offered. Wood is the only renewable building material, and it has the advantage of being able to absorb carbon through tree growth and to store carbon as a wood product in service.

So who is right? Which building material is the most environmentally sound? How can we make sound decisions on this issue based on science as opposed to emotion? In this paper, the authors wish to introduce two areas of science that exist as tools to help address this complicated issue – life cycle analysis (or life cycle assessment) and, very much related, the carbon cycle.

Life Cycle Analysis

If one were to think about the entire cycle of a building material, from resource extraction to product manufacture to ultimate reuse / recycling / disposal, and consider comparative energy and water needs, global warming effects, and pollutants generated, we would be able to get an idea of the “environmental footprint” from using wood, concrete or steel. This is precisely what is involved in doing a Life Cycle Analysis (LCA). With databases on these structural materials (developed with input from all three industries consistent with ISO Life Cycle Assessment Standards), there exists the potential to have the science that we are looking for to develop a holistic tool that fairly compares the environmental consequences of using alternative building materials. This tool could be used by city planners, architects, engineers and other material specifiers. It could also help to enlighten homeowners and nonresidential building owners / occupiers – the ultimate consumers of building materials. In short, LCA represents a scientific and objective means of comparing the environmental merits of one building material over another from resource extraction to use to disposal and re-use.

Currently, there are many organizations globally involved in developing and implementing LCAs. Here in North America, many of these researchers have been brought together under the umbrella of the Consortium for Research on Renewable Industrial Materials, or CORRIM, a not-for-profit corporation of scientists from 15 member research organizations (Bowyer et al. 2001). To date, the focus of LCA research has been on the quantifiable aspects of the process, most notably, research on Life Cycle Inventories (LCI). Simply stated, measurable raw material inputs (resource, water, energy, etc.), products and co-products, and emissions to air, water and land are identified and quantified. Less quantifiable aspects, such as the impact of harvesting or mining on landscapes and ecosystems and carbon sequestration, are currently not part of any LCI, but must be considered in the context of a complete LCA (Bowyer et al. 2001).

In order to illustrate the LCA process in more detail, a graphical summary of the approach taken by the ATHENA™ Sustainable Materials Institute is offered in figure 1 (The ATHENA™ Sustainable Materials Institute 2002).

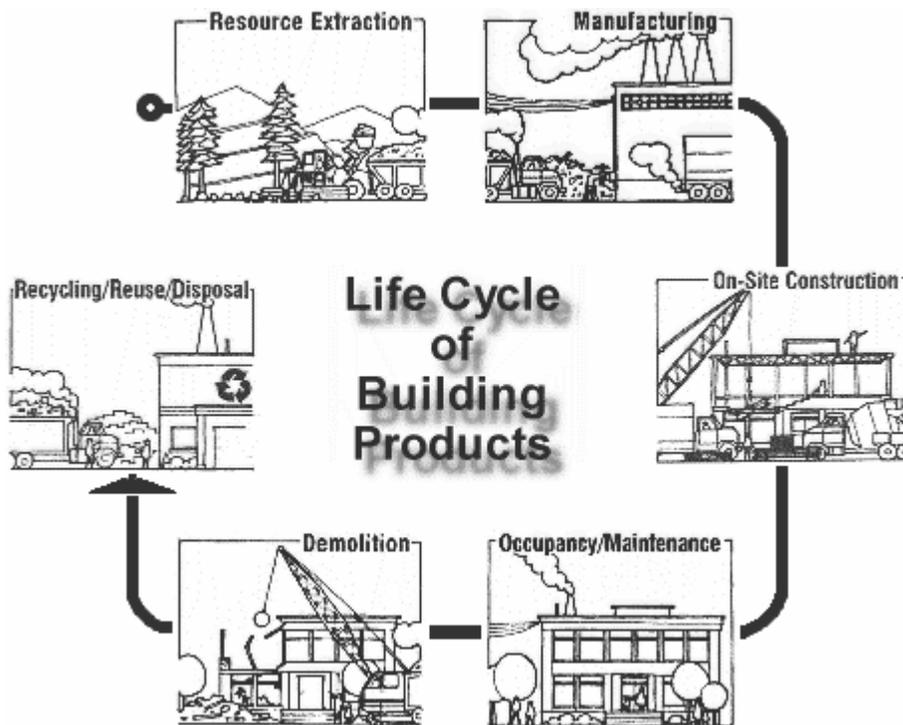


Figure 1—Component activities in a life cycle analysis (reprinted with permission from the ATHENA™ Sustainable Materials Institute, 2002)

To date, the focus of ATHENA™ has been on environmental impacts, from the resource extraction stage through to the occupancy and maintenance stages of products in use. All of the stages of LCA are discussed below, including resource extraction, manufacturing, on-site construction, occupancy / maintenance, demolition, and recycling / reuse / disposal. It should be noted that LCA is very much in its infancy, and that the lists of variables measured are by no means exhaustive.

Resource Extraction

Many activities are included for analysis at this stage. Since some of the variables are difficult to quantify, the focus of LCAs has been on the LCI measures, notably energy use and on-site waste:

- Harvesting, mining, and quarrying;
- Building access roads;
- Reforestation and reclamation;
- Transportation of raw resources; and
- Effects on biodiversity, soil stability, water quality, and ecological carrying capacity.

Manufacturing

Manufacturing is the stage that accounts for the largest proportion of embodied energy and emissions associated with the life cycle of a building product. Measured variables include:

- Raw material / energy use;
- Emissions (air / water / land); and
- Consistency with ISO Life Cycle Assessment Standards.

On-Site Construction

On-site construction includes additional manufacturing (individual products, components and sub-assemblies manufactured at the building site), transportation of products and sub-assemblies, and transportation of equipment. Measured variables include:

- Amount of waste generated;
- Energy use (transportation and on-site construction); and
- Emissions (air / water / land).

Occupancy / Maintenance

At this stage, activities such as heating, cooling, lighting and water use are identified. Also, the environmental impacts of products such as paints, stains, floor coverings and other interior finishes may be included. Finally, the possibility of a building remodel is introduced. Measured variables include:

- Heating, cooling, lighting (energy use);
- Water use; and
- Emissions (air / water / land).

Demolition

This stage recognizes that, while this may be the end of a building's life cycle, this is not necessarily the case for the construction materials used. Measured variables should include:

- Energy used in demolition; and
- Transportation energy.

Recycling / Reuse / Disposal

Clearly, there are benefits to be gained by using materials in several applications over time. However, there are also environmental impacts related to this decision. Measured variables should include:

- Environmental implications of land-filling or incineration; and
- Energy used in recycling and transportation of materials.

From the LCIs / LCAs that ATHENA™ have done to date, results suggest that wood emerges positively against either steel or concrete when used as the primary construction material in a building (The ATHENA™ Sustainable Materials Institute 2002). While their analyses and results are too expansive to report here, figure 2 illustrates this point, with sample results shown for resource use and waste, embodied energy, global warming potential, levels of air pollution, and levels of water pollution on three identically designed buildings made of wood, steel and concrete.

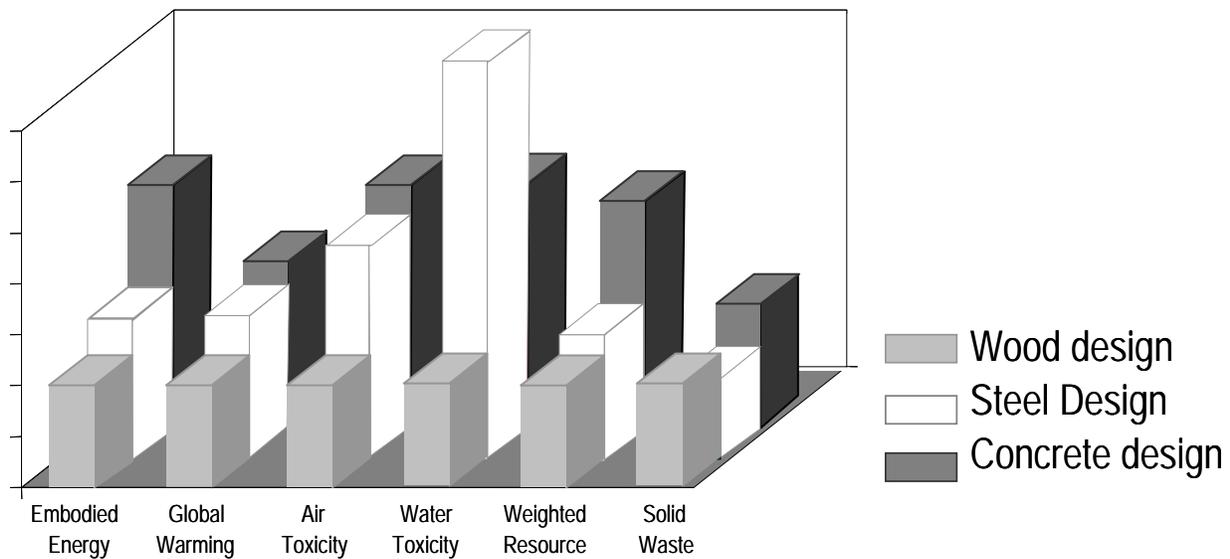


Figure 2—Generic example results from a life cycle analysis, showing relative magnitude of impacts (reprinted with permission from the ATHENA™ Sustainable Materials Institute, 2002)

It should be noted that the issue of global warming potential as an indicator in LCA is one area in which more work needs to be performed. Most notably, there is a need to better understand and quantify the relationship between carbon sequestration and the potential to reduce greenhouse gases within a LCA context. This is covered in following section, with a focus on strategies to extend the lives of wood products in use.

The Carbon Cycle

One very simple and obvious strategy for reducing greenhouse gases is simply to extend the active lives of wood products and systems in use. As we all know, atmospheric CO₂ contributes to global warming. In this context, it is useful to understand how carbon is cycled for various wood products.

The carbon cycle for a typical solid wood product is depicted in figure 3 (Augood 1997). In this model, the hatched lines represent CO₂ activity which directly either use or generate carbon dioxide. It should be noted that this model has been simplified in so much as it does not take into account the transportation and processing of goods, two obvious fossil-fuel users. However, the overarching theme in this cycle is that trees are a renewable resource. That said, atmospheric CO₂ is used in combination with water in the growth of trees through the process of photosynthesis. The trees are, in turn, extracted from the forest and manufactured into various wood products, most notably lumber. These wood products are put in use, however it is important to note that the process of manufacturing and constructing creates considerable waste byproducts. At the end of their useful service lives, wood products are typically either wasted or, in the case of larger structures like houses, demolished (Augood 1997).

Components of demolished structures are either wasted or recycled. Recycling can take on many forms, but generally post-service life wood products are mulched (which decomposes over time to create CO₂, partly in the form of methane), reclaimed or, increasingly, made into reconstituted panel products and engineered wood products – a relatively new and promising trend. These latter products are put back into service, usually in the form of construction components. The case of panels and engineered wood products (EWPs) is interesting, because much of the material for these products actually comes from waste byproducts generated in the manufacturing of primary wood products like lumber. This is especially true for products like particleboard, hardboard, and medium density fiberboard, which use sawdust and heavily refined wood fiber (Augood 1997).

Waste can also be incinerated for energy production, usually at wood processing facilities. Combustion CO₂ is released back into the atmosphere by the heat recovery process. The remainder of wood waste is landfilled, which in itself is an interesting and contentious topic. The general belief is that wood in landfills generally decomposes over time, creating CO₂ emissions. Some recent findings have shown that this depends largely on the presence of moisture in the landfill. A dry landfill, for example, may actually act as a carbon sink, taking CO₂ out of the atmosphere, and storing its carbon equivalent in the ground (Augood 1997).

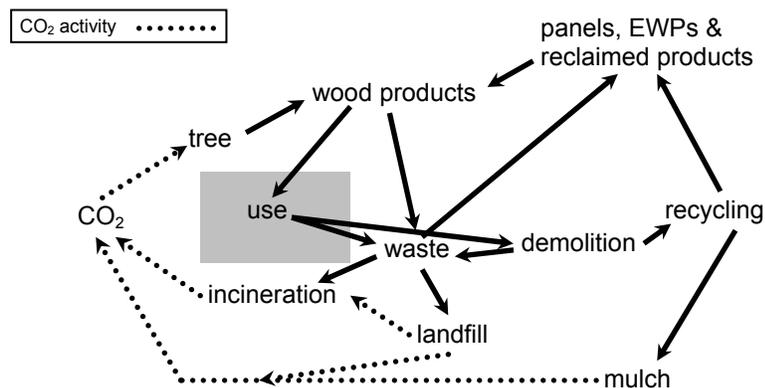


Figure 3—The carbon cycle for solid wood products (*adapted from Augood 1997*)

This model, while simplified, is useful in pointing to countless strategies available for reducing CO₂ emissions into the atmosphere, and thus, global warming. The focus of this paper, and the impetus for much of the current research in wood products and wood science, is on extending the service lives of wood products – in essence, sequestering carbon for longer periods of time. While this activity is not a direct CO₂ reducing activity, over time this strategy means that less wood will be extracted from the forest, which is a key concern especially as our population increases. Global warming aside, this is the environmentally and socially responsible thing to do.

Trees store carbon, but it is primarily the wood – the dead tissue – that is doing the bulk of the carbon storage. In other words, wood production and use equate to carbon sequestration. Perhaps more importantly, the longer that wood products are in service, the more carbon is sequestered. Strategies for extending the service lives of wood products, systems and structures in use include addressing the need for perceptual or attitudinal changes among designers and the public, proper design and maintenance of buildings, preservation and recycling. Each will be discussed in turn below.

Wood products, systems and structures can and should last a very long time. One need only look to the examples of stave churches in Norway, Egyptian tombs, and ancient temples and pagodas in Japan and China to see that wood structures can have life spans in excess of 1,000 years, far longer than the age of the trees from which they were built. Closer to home, it is not uncommon to see a 100-year-old house in the Pacific Northwest, virtually untouched and still durable.

Other more recent examples of wood building design have not been nearly as successful. The “leaky condo” fiasco in Vancouver, BC provides a useful illustration of this point. Essentially, there has been a rash of multiunit residential buildings that are failing because of “poorly performing building envelopes” (Ricketts 1999). Moisture is being trapped in air-tight buildings with limited overhangs and stucco siding, and the wood superstructures are decaying, with one article calling it, “the largest white collar crime recorded in Canadian history” (Kelln 2001).

Unnecessary demolitions are not restricted only to wooden buildings. The Seattle Kingdome is an example of a building with a large footprint that was perfectly structurally sound when it was imploded in early 2000. It was prematurely demolished, essentially as a result of the changing tastes of sports fans and team owners. However, this structure could have had many more years of use. The important point

is that many buildings currently in use are being gutted long before their time. This is occurring for a variety of reasons, but most relate to poor design decisions. Inappropriate design materials and methods were used in the case of Vancouver’s “leaky condos”. This is not true in the case of the Seattle Kingdome, for which insufficient forethought was given to the uses of the building, leading to an equally wasteful outcome.

Perceptual Changes

Perhaps one of the most fundamental problems related to the longevity of wood products in service relates to our perceptions of wood – specifically, the pervasive belief that wood is a temporary building material. While this attitude has suited our postmodern disposable society mentality in the past, it is simply no longer appropriate or sensible.

In 2001, a study was undertaken assessing the market potential for wood in nonresidential applications (Gaston et al. 2001). A survey was administered to architects and structural engineers across North America (in 1993 and 2000) and included the simple query, “how long do you think that structures made from wood, steel, concrete and masonry should last?”

The results, seen in figure 4, show that wood buildings are expected to last 20 to 40 years less than buildings made of other materials (statistically significant at $\alpha = 0.05$). This perception is simply untrue. Furthermore, it is a misconception that can be overcome only with a society-wide paradigm shift. As long as the design community feels that wood structures are more temporary in nature than steel, concrete and masonry buildings, they will be designed as such. As for larger, more permanent structures like nonresidential structures, wood products are hardly being used at all with some notable exceptions being restaurants, religious buildings, and offices (Kozak and Cohen 1999). From a global warming point of view, this is not a very prudent strategy, both in terms of the materials used in construction and the energy efficiency of the buildings in use.

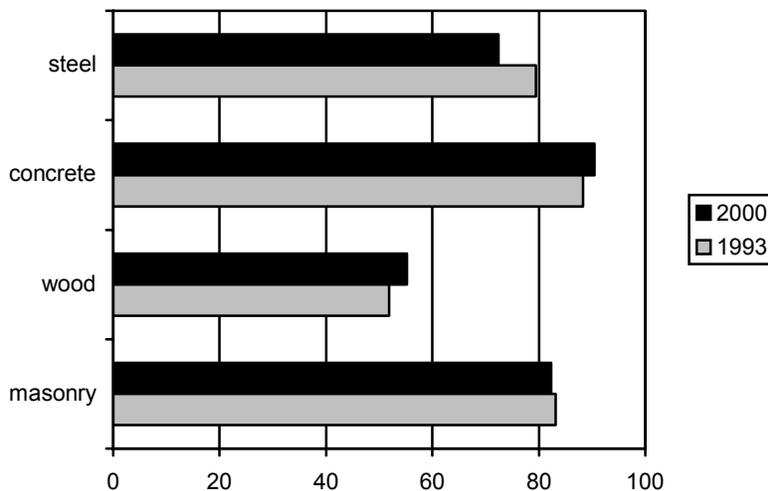


Figure 4—The perceived active service lives (in years) of buildings by structural material (source: Gaston et al. 2001)

Good Design

The key to longevity in buildings is good design. This vaguely esoteric notion is actually a very simple concept to grasp. When we design intrinsically beautiful buildings, they carry with them a high embodied value that, in and of itself, generally precludes unnecessary demolition. This is especially true for fairly robust buildings, which can be used for multiple functions over time.

At a more fundamental level, good design means little more than common sense. A badly designed steel or concrete building may last a few years longer than a badly designed wooden building, but not by many. Smulski (1999) recommends several design approaches for increasing the longevity of wooden structures, including:

- The use of proven products (the example of OSB siding and the subsequent class action lawsuits serves as a good example of this – siding is meant to act as a vapor barrier and OSB expands and loses its structural integrity when exposed to moisture);
- The use of watershedding features like overhangs and downspouts;
- The use of finishes on exterior wood products and primer on the ends of structural members to keep moisture out;
- The use of kiln-dried lumber (it is not uncommon in the Pacific Northwest to see green framing lumber used in the construction of new homes because it is less expensive, and unsuspecting homebuyers generally do not know any better);
- The use of caulking, sealants, and tapes to reduce air leakages;
- The correct use of vapor retardants to reduce the amount of moisture within a structure;
- Limiting moisture migration from the ground into basements;
- The use of venting and air exchange; and
- Good construction practices.

Maintenance

Not only is good design essential to long-lasting buildings, but so too is continual maintenance, which is required in any structure regardless of the building materials used. Fortunately, in North America, there exists a culture of repair and remodeling among homeowners – approximately one-quarter of the solid wood and panels that we use is for this purpose (Taylor 2000). However, there is room for improvement, especially in the nonresidential sector in which repair and remodeling are not yet commonplace.

This issue of maintenance also speaks to a need to build structures that are not highly “designed” per se. These buildings tend to be demolished as fashions and trends change. Rather, we need to be looking at more timeless and robust designs that can easily be retrofitted to suit our changing needs.

Preservation

Another very common approach to extending the life of wood long beyond its natural durability is with the use of preservatives – essentially chemicals that protect against insects, decay and other wood destroying organisms. In this light, preservatives can be thought of as a “vital contributor to the conservation of...forests” (Preston 1993). There are 3 major preservatives in use today (Preston 1993):

- Chromated copper arsenate (or CCA) is used in treated lumber products for residential applications like decking and fences;
- Creosote (or creos) is a preservative used in railway crossties, water pilings, marine structures and highway construction; and in some wooden siding applications in Europe; and
- Pentachlorophenol (or penta) is a preservative used primarily in utility poles.

The latter two are oilborn preservatives and together account for approximately 30 percent of the preservation market. CCA has been the dominant form of wood preservation, with approximately 15 million cubic meters produced annually in North America (Preston 2000). However, the future of CCA is very much in question because the United States Environmental Protection Agency has effectively banned the use of pressure-treated wood using arsenic in all residential applications by the end of 2003, citing that CCA treated wood “poses unreasonable [health] risks to the public” (Environmental Protection Agency 2002).

This move has led to the ramping up of research surrounding alternative wood preservatives that are safer for public consumption and more environmentally benign. In fact, most of the current research on

preservatives is not on life extension of wood products, but on developing environmentally friendly preservative products and processes like organic biocides, water-based emulsions, and modifying the wood substrate to be more resistant to decay (Preston 2000, Ruddick 1999).

Researchers are also working to find solutions to recycle and re-use preserved wood. Creosote and pentachloro, the two most toxic preservatives in use, are the most easily incinerated for energy conversion. This is not possible for CCA treated wood because of the hazardous metals contained in the resultant ash. Most of the CCA treated wood, which is a sizable volume, is currently landfilled, the reasons being that there are concerns with the reuse of preserved lumber in terms of safety to exposed workers and the efficacy of the preservatives over time (Preston 2000). Other possibilities currently being investigated include the production of alternative recycled products like wood-cement composites, panel products and miscellaneous reconstituted products like shingles (Cooper 1999).

Recycling

Recycling is fast becoming a realistic and effective means of extending the life cycles of wood products. This is not a life-extending strategy for wood structures in use per se, but rather it is a strategy for using wood products more efficiently and wisely through reclamation and re-use. This is a burgeoning area of interest to wood products researchers and may have a profound impact on reducing global warming if viable solutions can be uncovered.

The backdrop to recycling is that a huge amount of lumber has been used and wasted in North America alone (Burdock et al. 2001). The four major sources of solid wood waste are seen in table 1 (Falk 1997). Municipal solid waste refers to wood products that are thrown out in the form of refuse or yard trimmings. Estimates are that over half of this waste is recoverable, but currently only 10 percent is being used. Construction and demolition debris is also a major contributor to wood waste. It is estimated that, on average, over 1 metric tonne of wood is wasted per new home built, most of which could easily be re-used. In addition, approximately 23 million metric tonnes of waste wood is produced annually in the demolition of homes. The amount that is potentially recoverable from demolition is proportionately smaller as a result of wood waste typically being mixed in with other building materials during demolition. By far, the largest contributor to waste wood is the primary timber processing industries, which produce wood and bark residues as byproducts. Relatively small volumes are available for re-use, but it should be noted that the wood industry recycles byproducts to manufacture other products like pulp and paper, panels, mulch and fuel. The last category of waste wood is preserved wood. Approximately 4.7 million metric tonnes preserved woodwaste is generated every year, much of it ending up landfilled. However, the amount that can be recycled is currently unknown as researchers attempt to uncover safe reclamation uses (Falk 1997).

Table 1—The major sources of solid wood waste (source: Falk 1997)

	Currently Generated (millions metric tonnes)	Potentially Available (millions metric tonnes)
Municipal solid waste	39.6	19.4
Construction and demolition	29.2	12.5
Primary processing	106.8	6.2
Treated wood waste	4.7	uncertain

In the past, conventional uses for wood waste have been geared towards the production of products like pulp and paper, panelboards (e.g., particleboard), mulch and animal bedding, and fuel for heat and energy. Wood waste is also being used in reclaimed applications. For example, the United States military has buildings currently slated for demolition containing over 250 million board feet of lumber (Falk 1997). Recycled lumber, plank, and timber products from buildings like these are in high demand, creating high-end design niches for products like reclaimed flooring. A tremendous potential for woodfiber-plastic composites also exists – essentially wood-filled polymeric composites – in industrial markets like the window and door manufacturing sectors. Wood / inorganic-bonded products are

becoming more and more common. For example, wood fiber held together by Portland cement is being used in a variety of building applications for which fire and decay resistance is required (Falk 1997). Finally, reclaimed engineered wood products (I-beams, glulam posts and beams, etc.), while currently not a major concern, will be in the very near future as newer buildings containing these products are torn down.

According to Falk (1997), the successful and widespread adoption of recycled products depends on a number of factors including:

- The degree to which wood waste is free of contamination, especially in demolished buildings;
- The economics of recycling and specifically whether or not the costs of procuring, transporting and sorting through woodwaste can be offset by the price of developing and manufacturing new and competitive products;
- The variability of the resource being recycled with respect to species, size, quality, moisture content, etc. and the subsequent need for complex processing systems to aid in sorting; and
- The logistics of recycling in view of the fact that it is generally only feasible to recycle in large urban centers where high volumes of wastewood are readily available at present.

However, success also depends on our ability to think of “outside-of-the-box” solutions. Barkboard™, a product developed by Forintek Canada Corp. (not yet commercially available), provides a good illustration of this kind of thinking. In Canada alone, approximately 10 million tonnes of bark are generated as a byproduct from wood processing every year (Troughton 1996). It is simply infeasible to use all of this volume for hog fuel and mulch. One solution is to press the bark into a panel product. The high lignin content means that expensive resins are not required and the natural preservatives in the bark produce a panel that is resistant to decay and well suited to a number of housing applications.

Another example is to consider multiple uses over time from a single fiber source prior to a tree being harvested. Put another way, why do we automatically make lumber from a harvested tree? Perhaps it would be more prudent to keep the tree in its round form by first using it as a pole and then, over time, processing it into lumber, and finally, reclaiming the lumber for use in other wood products applications. This has never been attempted commercially and would effectively serve to increase the life span of wood in use. Admittedly, this model may be a bit simplistic, but nonetheless it does serve as a starting point for discussions on this topic. At the very least, we should begin to consider various end-use options when we harvest trees, rather than basing management decisions solely on rotation ages and the assumption that the production of commodity products is the most appropriate strategy.

Conclusions

In the final analysis, it is our belief that wood can and should be used in countless applications limited only by our collective imagination. History has decisively shown us that, in many instances, wood is the appropriate environmental choice. Now scientific inquiry, in the form of Life Cycle Analysis, is doing the same. This is especially true when our wood resource is used sustainably and responsibly with an eye to multiple applications over long periods of time. Seen in this light, wood use can have a positive impact on climate change – it is a renewable resource that sequesters carbon, both in the form of a tree and in the form of a wood product. The successful and enduring use of wood products is predicated upon the forethought with which we put products in use. This paper has shown that wood products, systems and buildings in service can last for hundreds of years without being landfilled. However, as an industry, we must do a better job of uncovering ways to extend the service lives of wood products in use and communicating this message to key decision makers, stakeholders, and consumers.

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Carbon Accounting: Institutional Framework, Models, and Economics

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Abstract

The development of forest carbon markets will require an appropriate institutional framework in which market participants can link efficiently with the regulators' requirements, and since it will be mostly a 'futures market', models will be required that are based on the best available science. Since decision makers will have to make financial and other monetary trade-offs, economics will also play a critical role in defining efficient market to regulator relationships and in selecting the most prudent and ethical modeling options. This paper explores the functions of various stakeholders in an institutional framework, a national carbon office, and roles and relationships to consider for market players and government regulators. It then reviews the various datasets and models used in a Canadian context and explains their relative roles in facilitating national greenhouse gas reporting and management-level carbon accounting by forest owners. To move forward, Canada and many other jurisdictions need to develop carbon accounting standards that can draw on existing data and models, and create an institutional framework that allows all market players and regulators to have efficient and effective information exchanges for various reporting requirements.

Introduction

It has been suggested that climate change is the most "complicated scientific, environmental, economic and political challenge in history..." (Wirth 1996). The nature of climate change will require an unprecedented level of collaboration between countries, and across language and geographical boundaries. The paper outlines an institutional framework to facilitate communication and data exchange between the key actors in the forestry, emissions trading and international climate change arenas. Solutions to climate change must be implemented at every institutional level, from the small family business to large corporations. A national carbon network is also needed to provide an efficient means of data exchange between individuals, communities, provinces and nations. At a more technical level, we will need more advanced forest modeling tools to process forest inventory data and ensure forest carbon inventory is conducted in a transparent and verifiable manner. We describe a number of forest carbon modeling tools available to the forest manager in British Columbia (BC). It is hoped that the tools and the national carbon framework might foster economic and environmental confidence in the integrity of forest-based emission offsets, so that we might promote sustainable forest management practices while preventing unacceptable levels of greenhouse gases (GHG's) in the atmosphere.

The National Carbon Network

"The Parties shall strive to implement policies and measures ... in such a way as to minimize adverse effects, including the adverse effects on climate change... and social, environmental and economic impacts..." (United Nations Framework Convention on Climate Change 1997)

It was with this goal in mind that provisions for domestic and international emissions trade were included within the Kyoto Protocol or other international climate change agreements.¹ The IPCC Working Group III report summarizes a number of studies that demonstrate that the cost of climate change adaptation is more than halved when global emissions trading is allowed (Hourcade and Shukla 2001). Likewise, the

¹The concepts presented in this paper are intended to be compatible with the Kyoto Protocol. At the time of writing, the U.S accounting rules and guidelines for carbon sequestration projects for its "Clear Skies Initiative" were not released. The institutional and modeling concepts presented in this paper are universal, however, and are assumed to be applicable to any international climate change agreement.

CO₂ absorption capability of forests was recognized within the Kyoto Protocol as a low cost means of emission reduction, as well as an opportunity to promote sustainable forestry practices (Articles 2.1a, 3.3 and 3.4). In their most recent investigation, the Intergovernmental Panel on Climate Change (IPCC) concluded that “Forests, agricultural lands and other terrestrial ecosystems offer significant carbon mitigation potential”, and could potentially offset up to 20 percent of total fossil fuel emissions by the year 2050 (IPCC 2001).

To maximize the economic and environmental benefits of emissions trading and forest carbon sinks requires an institutional framework to: 1) provide an effective means of recording forest carbon inventory data, and 2) enable tracking of carbon/emissions transactions between domestic and international markets.

The Kyoto Protocol, as well as the U.S. “Clear Skies Initiative”, include provisions to establish a national carbon registry to store and track carbon inventory data. A decision adopted at the fourth conference of the parties (COP) meeting in 1998 specified that “Each party in Annex B shall establish and maintain a national registry to ensure the accurate accounting of the issuance... holding, transfer, acquisition, cancellation and retirement of (one-ton equivalents of CO₂)” (FCCC/SB 2000).

Likewise, the U.S. Department of Energy is currently developing a GHG registry proposal under the “Clear Skies Initiative” (U.S. Environmental Protection Agency 2002).

The U.S. and Kyoto commitments towards development of GHG registries focus on tracking of carbon between large emitters and between countries. There has been little discussion on utilization of registries as a means linking operational to national level carbon inventories. In this paper, a formal methodology for scaling up operational level forest carbon inventory to a national level is proposed. We outline a “National Carbon Network” (NCN) as a means to measure, record, report, track and trade GHG’s. The NCN allocates responsibilities to each of the seven key actors in the forest and emissions trading sector in a way that is cost-effective, yet verifiable at an operational, national and international level. We use forestry as a case study to illustrate the operation of the NCN. However, the NCN could readily be adapted to other industries and environmental products as well.

The NCN, adapted from Australia’s “National Carbon Accounting System” (State Forests NSW 1998), is comprised of seven key components in the forestry, emissions trading and international climate change arenas:

1. National Carbon Office
2. Forest grower
3. Verification agency
4. Risk management agency
5. Emissions trading platform
6. UNFCCC/international trading partners
7. Non-governmental organizations (NGO’s)

Each of the key components has unique roles and responsibilities. The NCN is designed in order to best utilize the needs, skills and incentives of each actor for participation in the market for forest carbon. The relationship between each of these key actors in the NCN is illustrated in figure 1 below.

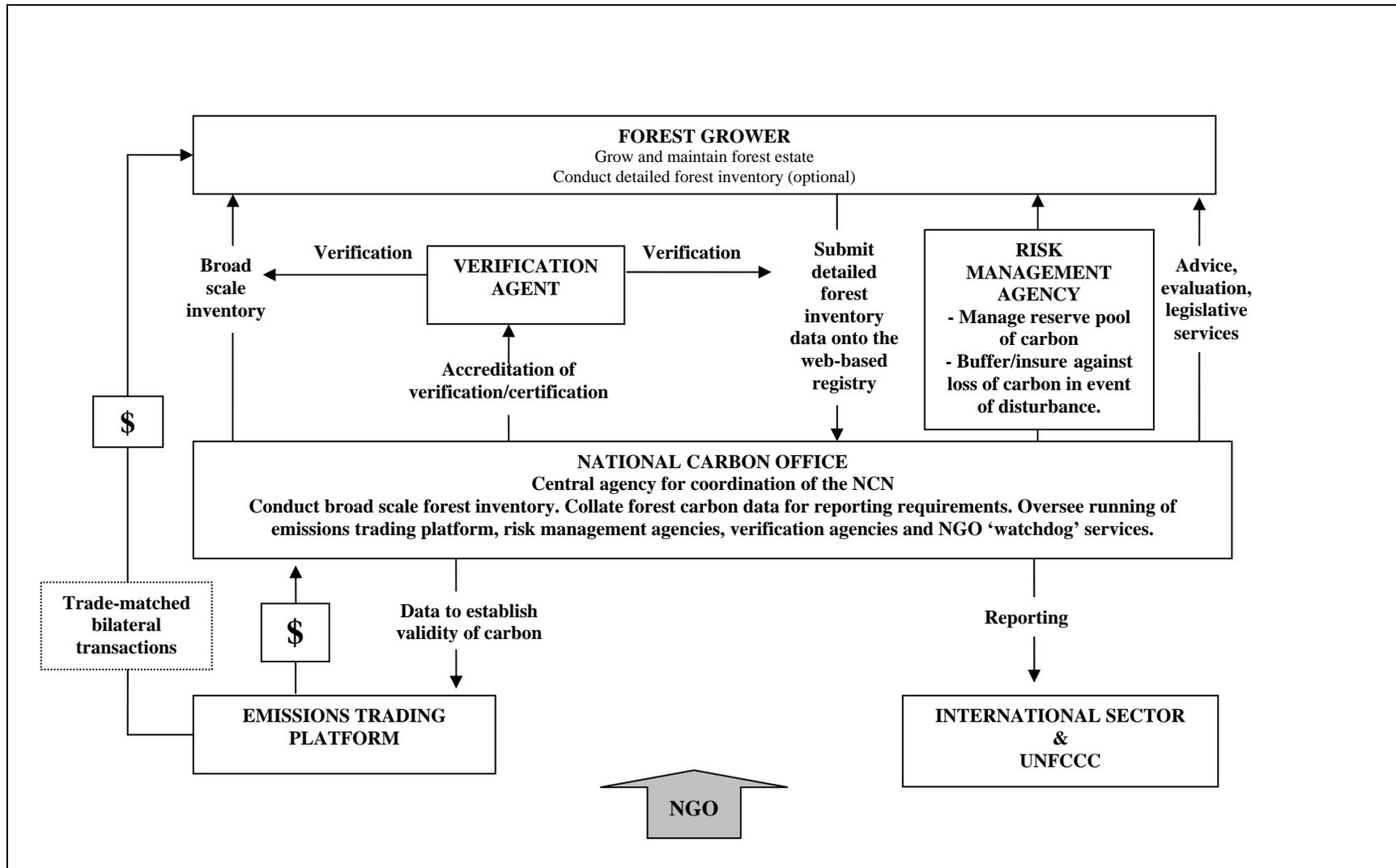


Figure 1—The National Carbon Network. The National Carbon Office liaises with six other key components (forest grower; verification agent; risk management agent; emissions trading platform, NGO and the UNFCCC) and performs six main roles

The roles and responsibilities of each of the key components in the NCN are outlined in the sections below.

The National Carbon Office

The National Carbon Office would be the chief agency responsible for coordinating the activities of the six other components in the NCN, and is therefore likely to be run by a government agency. The National Carbon Office would be divided into five departments, one for each of the following major roles performed by the office:

1. Public services
2. International trade relations
3. Inventory
4. Registry services
5. Accreditation and supervision of risk management agencies, verification agencies, emissions trading platforms and official NGO's.

The responsibilities of each of the departments are described below.

Public services department

Communication between the National Carbon Office and individual forest growers could occur via either of two mediums: 1) on-line information or feedback, or 2) a series of regional representatives employed by the National Carbon Office. The public services department is divided into four groups: project evaluation, management advice, legislative services, and public relations. The duties performed by each of these groups is outlined below.

Project evaluation group - main responsibility is to conduct on-site or on-line assessment of the following project components:

- Kyoto compatibility
- CDM compatibility, if applicable
- Economic feasibility
- Practicability
- Environmental impact assessment
- Impact on other forest values

On-line evaluation would occur via the web-based registry, which is described later in this paper. The forest grower would be required to submit basic project details such as project area, pre-project land-use, site location, species selection and proposed management regime. Based on these details, the evaluation group could assess the project against specified environmental and financial criteria. Alternatively, the forest grower could elect to have an on-site project evaluation conducted by one of the regional National Carbon Office representatives. This would involve a site visit by the representative, who would perform a soil and site productivity test, and conduct a personal interview regarding management intentions and temporal commitment of the grower and expected outcomes of the project (BRS 2000). The regional representative would then prepare an in-depth evaluation report for the forest grower and/or project investors.

Inventory and management advice group – their main responsibility is to publish an online inventory and management manual. This manual would provide forest growers as a first point of reference for detailed, easy to follow instructions on conducting a forest carbon inventory (BRS 2000). Support would also be provided by regional NCN representatives, who would be available for individual consultation and guidance regarding inventory and management advice.

Legislative services group - the Kyoto Protocol requires that once a forest is accounted for under Articles 3.3 or 3.4, then changes in carbon stocks must be accounted for in perpetuity (IISD 2001). To enable

perpetual accounting, liability for default on contract details must be legally established. In the absence of clear carbon ownership legislation,² a well written contract is invaluable. Therefore the key role of the legislative services group is to offer a legally binding on-line forest carbon-rights contract. The contract should delineate rights and responsibilities among key components in the NCN. It should specify definitions, objectives, plans, site boundaries, land ownership details, financing, insurance, and mechanisms for default and dispute resolution. A sample “forestry carbon offset agreement” is available in Davis (2000). NCN regional legislative representatives would also be available for personal legislative consultations.

Public relations group - a public relations program inherent within the National Carbon Office is necessary to provide education regarding the benefits of establishing a forest carbon project; forest carbon management techniques; and to overcome distrust of a government agency (BRS 2000). The public relations program of the National Carbon Office could comprise a number of initiatives, such as:

- An on-line promotional and informational package
- A series of regional seminars and workshops
- A network of regional contact persons, preferably local individuals who are approachable and well established in the community.
- Informational booklets and pamphlets distributed to educational institutions.

International trade relations department

In cooperation with the Emissions Trading Platform, the National Carbon Office will be responsible for facilitating the purchase of 1) certified emission reductions (CER's) in developing countries under the CDM, and 2) emission reduction units (ERU's) in other developed countries under joint implementation (JI) agreements. Companies that are interested in purchasing CER's or ERU's would be “trade-matched” with suitable projects in other countries, depending on preferred project type, duration and price of CER's/ERU's. The National Carbon Office will also be responsible for “screening” of CDM partners to assess ability to meet funding and technology transfer requirements. Upon successfully matching a CDM/JI project with a foreign partner, the National Carbon Office will facilitate transfer of CER's/ERU's via an accredited emission trading platform.

Inventory department

One of the challenges of any national forest carbon inventory program is to provide a means of linking operational and national-level carbon inventories. To maximize a country's forest sink potential, and to diversify income in small, isolated communities, participation of both small and large-scale forest growers should be encouraged. A two-stage national forest inventory system (i.e. broad-scale and detailed inventory) proposed under the NCN provides an incentive for small forest growers to submit detailed inventory information to the National Carbon Office. The forest growers' detailed forest inventory will supplement a broad scale forest inventory conducted by the National Carbon Office. In cases in which forest growers are unable to conduct their own inventory, they could ‘pay’ the National Carbon Office to conduct it for them. This system works as follows:

Broad scale forest inventory - broad-scale forest inventory would be conducted by the National Carbon Office on all forest land. This would be done using a combination of remote sensing and ground sampling techniques. The benefits of having a single broad-scale carbon inventory include: reduced per unit inventory costs; data consistency; and ability to capture sink benefits of forests where forest growers cannot conduct their own inventory, or where detailed ground-based inventory is not possible. The trade-off of broad-scale forest inventory is that areas of less than approximately 20 meters cannot be mapped accurately (Weir, personal communication 2000). A more detailed, operational level forest inventory is needed to capture the full carbon benefits of all forest carbon projects.

²At the time of writing, there has been little or no legislation to separate ownership of the carbon, forest and land in North America. The state of New South Wales in Australia established the world's first carbon ownership legislation in 1998.

Operational level forest inventory - the purpose of this inventory is to increase precision of inventory and enable measurement of small areas of forest by conducting ground-based forest measurement techniques. To provide incentive for individual forest growers to conduct their own detailed forest inventory, a 'carbon refund scheme' is proposed. The refund scheme would work in the following way:

1. To achieve official recognition and credit for additional forest carbon sequestration. The forest grower should electronically register their forest on the national web-based carbon registry.
2. Upon registration, a forest grower would enter into a compulsory "default" agreement with the National Carbon Office. In addition, the forest grower could enter into an optional 'detailed self-inventory agreement', committing them to undertake further inventory. The two agreements are described as follows:
 - a) The default agreement: contract requiring the forest grower to 'pay' the National Carbon Office for broad-scale forest inventory services. This "payment" would obligate the forest grower to forfeit a proportion of their forest carbon ownership to the National Carbon Office. Under the default agreement, the forest grower would also be required to allocated a proportion of forest carbon ownership to a "risk mitigation carbon pool", managed by the risk management agency (described later) (State Forests NSW 1998). The flow of forest carbon ownership between the forest grower, National Carbon Office, risk management agency and emissions trading platform is shown in figure 2.
 - b) Detailed self inventory agreement: an optional contract requiring the forest grower to conduct their own forest carbon inventory to supplement the broad forest inventory carried out by the National Carbon Office. Forest carbon inventory data would be submitted to the web-based carbon registry. Forest growers would be rewarded for additional inventory effort with a "carbon refund" of a proportion of their carbon ownership. The greater the precision of the inventory, the more carbon that would be refunded by the National Carbon Office.

There are two main advantages of this "variable precision carbon accounting system": 1) additional inventory costs are offset by revenue from the increase in trade eligible carbon (State Forests NSW 2000), and 2) forest growers are not locked in to achieving a specified level of inventory. Instead, forest growers can adjust the level of investment in forest inventory to relative to the price for carbon credits. This is important since small forest growers may find that only low levels of investment in forest inventory are economically feasible.

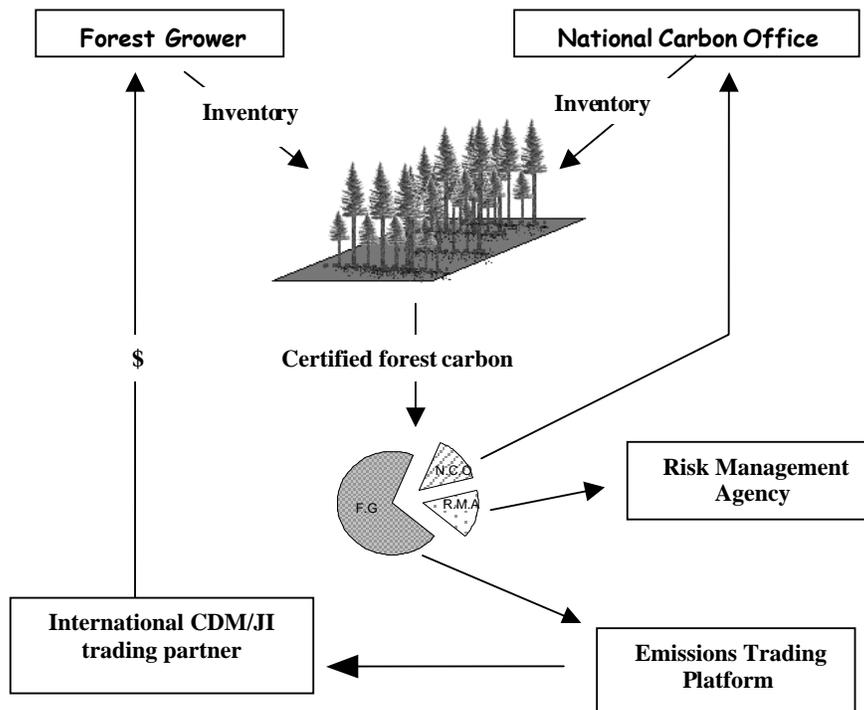


Figure 2—Flow of forest carbon ownership. The forest grower forfeits a proportion of forest carbon ownership to the National Carbon Office as 'payment' for inventory services. Some carbon is also allocated to a risk mitigation buffer, managed by the risk management agency. The residual carbon is sold to the CDM/JI trading partner as CERs/ERUs. Revenue from sale of CERs/ERUs returns to the forest grower.

Registry services department

Within the NCN framework, registration of a forest on the web-based national carbon registry is compulsory to obtain official recognition of forest carbon. The national carbon registry would be a user-friendly, multi-purpose, web-based computer program. Key features of the national carbon registry might include:

- Comprehensive tracking of carbon ownership: each ton of carbon could be traced back to the forest from which it originated.
- Full GIS rectification: all data within the national carbon registry would be spatially referenced and linked to a national GIS database (AGO 2000).
- Complete interface with emissions trading platform: real-time tracking of carbon trading transactions (Calman 1998).
- Incorporation of user-friendly spreadsheet-based statistical programs: allows the individual forest grower to calculate the carbon storage in their own forest. Aggregates all forest inventory data to calculate forest carbon on an operational, regional and national level (Richards 2001).
- Linkage with land tenure records.
- Recording of carbon contributions of each forest grower towards a carbon risk management pool.
- Storage of verification/certification information.
- Access to general information, references, links, contact details, evaluative, and management advice.

Accreditation and supervision department

Accreditation is the process of officially endorsing an agency by attesting that they have the necessary skills and resources in order to carry out their required task (Moura Costa et al. 2000). The National Carbon Office will be responsible for the accreditation of verification agents, risk management agencies, emission trading platforms and NGOs. Only officially accredited agencies will be allowed to work within the National Carbon Network. This will ensure that all service providers meet a baseline level of performance quality, thereby establishing the country as a reputable supplier of offsets. Following accreditation of service providers, the National Carbon Office function in a supervisory capacity and providing a means for dispute resolution.

Having described the major responsibilities of the National Carbon Office, we now shift our attention to the other key components in the NCN. The roles of the forest grower, verification agency, risk management agency, emissions trading platform, international trading partner, and NGOs are explained below.

The Forest Grower

The forest grower is responsible for a number of activities related to the establishment and management of the forestry project. Listed in order, there are two stages and nine steps required (Harkin and Bull 2000):

Stage One: Design and Evaluation of the Forest Sink Project

Design and evaluation of the forest carbon project will occur in consultation with the National Carbon Office's project evaluation department. This includes five main steps:

1. Develop project proposal

The project proposal should include the following considerations:

- a) Key objectives of the forest grower. Objectives might include purely carbon sequestration, timber production, biodiversity, and/or biomass production (Schlamadinger and Marland 2000).
- b) Intended nature of the project and investigation of management alternatives. This might include an outline of additional silvicultural activities and special harvesting/thinning requirements.
- c) Potential sources of leakage and a summary of all sources of carbon emissions associated with the project. NGOs can assist the forest grower in identifying potential sources of leakage.
- d) Temporal lifetime of the project, company, and project boundaries.
- e) Emissions/sequestration balance sheet.

2. Preliminary carbon yield projections

Using basic inventory data or regional biomass estimates, the forest grower should attempt to estimate the amount of carbon that is expected to be sequestered over the project lifetime.

3. Define and measure the "business-as-usual" baseline

A critical component of CDM/JI projects is that only carbon sequestration that is in excess of 'business-as-usual' is credible (UNFCCC 1997). This implies that the forest grower must determine what activities would have taken place in the absence of the CDM/JI project, and then estimate the amount of carbon that would have been sequestered or emitted over time in this baseline scenario. The "modalities and procedures" for defining and measurement of baselines are to be developed by an executive CDM board in June 2002 (Joint Implementation Quarterly 2002).

4. Project evaluation and registration

With the assistance of the on-line or on-site evaluation service provided by the National Carbon Office, the proposed project will be evaluated to determine whether it meets Kyoto eligibility criteria (or other criteria of other climate change mitigation programs). The project will also be assessed in terms of economic and environmental feasibility. If approved, the forest grower will be invited to register their forest on the national carbon registry. As described previously, this will require the forest grower to enter into a compulsory agreement with the National Carbon Office.

5. Locate buyer

The National Carbon Office in conjunction with the emissions trading platform, will attempt to match the forest sink project with a suitable buyer of forest carbon. The forest grower will agree to transfer ownership of forest carbon in exchange for financial reward, project funding and/or sustainable technology transfer.

Stage Two: Project Implementation: Inventory and Management

Stage two involves the design, implementation and submission of forest inventory data. This is mainly applicable if the forest grower decides to enter into the optional contract with the National Carbon Office, thereby agreeing to implement their own detailed forest inventory.

6. Establish and manage the forest carbon project

Management activities should be implemented according to the regime specified in the project proposal (Step 1).

7. Design sampling system

Prior to conducting forest carbon inventory, the forest grower should evaluate inventory design options. This should include the following considerations:

- a) Sampling and accounting objectives. One objective might be to achieve a specified inventory precision in order to receive a target carbon refund.
- b) Accounting methods. Some alternative accounting methods include the stock change, average carbon storage and ton-year carbon accounting methods (IPCC 2000).
- c) Economic constraints. One objective might be to achieve maximum sampling precision for a specified inventory budget (Brack 1999).

8. Conduct forest carbon inventory

The Kyoto Protocol requires that carbon should be measured in the following five pools: aboveground biomass, belowground biomass, litter, soils, and coarse wood debris (SBSTA 2000). Techniques for conducting a forest inventory would be outlined in the detailed forest inventory manual provided by the National Carbon Office.

9. Submit forest inventory data to the registry and schedule from an independent verification

Upon completion of forest inventory, the forest grower should submit inventory data to the national registry, using on-line spreadsheets provided within the national carbon registry. The forest grower will then schedule a verification agent to check the validity of inventory estimates and consult a risk management agency for options against carbon loss.

The Verification Agent

Verification is the process of checking the validity of inventory data (Moura Costa et al. 2000). To achieve official recognition of forest carbon sequestration, verification by an officially endorsed but independent verification agent is necessary. Once employed by a forest grower, a verification agent would have access to forest growers' records within the national carbon registry. The verification agent would then conduct a site visit to the forest in order to take a random sample of measurements. Forest inventory estimates recorded in the national carbon registry would be compared with the verification agents' own inventory. Precision of forest carbon inventory estimates would be reported in a verification report submitted to the National Carbon Office. Following verification, the National Carbon Office would certify the amount of carbon in the forest according to the precision of the inventory. For example, the National Carbon Office would certify 80 percent of total forest carbon for an inventory of 80 percent precision (State Forests NSW 2000). The National Carbon Office would then apportion the certified forest carbon between the "payment" to the Office, contribution to the risk management pool, and eligible for trade.

The Risk Management Agency

The Kyoto Protocol requires that once a forest is accounted for under Articles 3.3 or 3.4, then changes in carbon stocks must be accounted for in perpetuity (IISD 2001). An issue arises as to who might be responsible for refunding of offsets if carbon is re-emitted to the atmosphere via harvesting or natural disturbance (Harkin and Bull 2000). If the forest grower is responsible for refunding the cost of offsets, loss of forest carbon due to natural or anthropogenic disturbance could be financially devastating.

Risk management agencies will play a key role in providing insurance against loss of carbon from forests. The major role of the risk management agency would be to manage a national risk mitigation carbon pool. All forest growers would be expected to contribute a baseline amount of carbon to the national carbon pool as part of the default agreement with the NCN. In the event that the forest was destroyed by fire or insect attack, carbon losses would be covered by the reserve pool (State Forests NSW 1998). The pool could also be used to balance temporary carbon loss occurring during the harvest/regeneration cycle.

In order to determine the appropriate baseline contribution to the national carbon pool, the risk management agency would conduct a risk assessment of the project. This assessment would involve determination of the potential for natural disturbances, and assessment of socio-political, managerial and economic risk (Moura Costa et al. 2000). Following assessment, the project would be assigned a 'permanence rating', or likelihood of achieving permanent carbon storage. A permanence rating of '10' would imply that 10 percent of total forest carbon sequestration should be contributed towards the national carbon pool, while a permanence rating of '3' would imply a 3 percent baseline risk contribution. Forest growers may choose to contribute above the baseline amount in accordance in exchange for greater levels of risk protection. In the event of carbon loss, the risk management agency would be responsible for assessing appropriate compensation. Risk management agencies could also provide advice on other means of reducing risk associated with forest carbon projects. These might include portfolio diversification, or strengthening of insect and fire protection activities.

Emissions Trading Platform

An emissions trading platform would be responsible for facilitating the trade of carbon, functioning in much the same capacity as a stock exchange. To facilitate honest and reliable services, each emissions trading platform must be accredited by the National Carbon Office prior to commencing trade. Each emissions trading platform should have full access to registry data to determine the number of offsets for each forest grower. The intangible nature of emission offsets implies that transactions are conducive to online trade. To ensure real-time updates of carbon transactions, the online trading system should fully interface with the national carbon registry. To enable comprehensive tracking of carbon, each offset would be assigned a unique serial number, allowing both domestic and foreign investors instant access to information about the origin and nature of the offset (Beil 1999). For international transactions, the emissions trading platform will be responsible for adjustments between exchange rates and adhering to country specific trade restrictions and taxes. Each emissions trading platform should interface with all

other domestic and international emissions trading platforms and national registries. This will ensure that each transaction results in a simultaneous debiting of carbon from the seller's account, while the account of the buyer is credited. In other words, each company-level transaction should echo in national-level carbon accounts.

A number of emissions trading platforms have already emerged. Private on-line emissions trading platforms include CO2e.com, EmissionStrategies.com, ClimateRegistry.org, Ecoregistry.org and the Universal Carbon Exchange. Some countries, including the United Kingdom and Denmark, have also developed national carbon registries.

International Trading partners/UNFCCC

An international carbon transaction requires cooperation between two distinct partners: the host country and the foreign investor. In exchange for transfer of all or part ownership of offsets to the foreign buyer, the international trading partner must pay the host country an agreed price per ton equivalent of CO₂. For CDM projects, only afforestation or reforestation projects are allowed, and the project must add to the sustainable development of the host country (IISD 2001). The rules regarding definition of activities that constitute "sustainable development" under the CDM are due for clarification at the CDM executive board meeting in July this year (Joint Implementation Quarterly 2002). Pending these rules, however, it is assumed that forestry projects in developing countries must impart new knowledge (e.g. sophisticated institutional capacity such as the NCN; advanced forest inventory and management techniques); new technology (e.g., improved forest inventory and harvesting equipment) or foster the development of local communities (e.g., sustaining rural livelihoods through diversified income sources).

Regardless of whether the international trading partner is the host of the forestry project or buyer of forestry offsets, the international trading partner is responsible for ensuring that carbon transactions are reflected in national carbon inventories.

There are three main roles for the UNFCCC related within the framework of the NCN: 1) development of the final rules and modalities for carbon accounting and trade, and continued negotiation of climate change treaties in the future, 2) collation of national carbon inventories and administering of penalties for non-compliance, and 3) international dispute resolution.

Non-Governmental Organizations

Non-governmental organizations (NGOs) are privately run special interest groups whose voluntary role is to ensure that government and private companies conduct their operations in a way that does not conflict with the goals of their organization. The objectives of NGOs vary, but can include goals such as protection of environmental resources, sustainable development, and, income and gender equity. NGOs often assume an auditing or "watchdog" role in society: they utilize tactics to coerce companies to operate in a socially responsible manner, for example threats of defamation through public exposure, in addition to prosecution via the judiciary system. NGOs have proven remarkably effective in this watchdog role in the past. Their services could be officially recognized as part of the NCN framework, via accreditation and funding of NGOs as official "watchdog" organizations by the National Carbon Office. Official recognition of NGOs is consistent with Article 71 (Chapter 10) of the United Nations Charter (United Nations 1945). The Article establishes a process for NGO accreditation via the Economic and Social Council of NGOs (Department of Economical and Social Affairs NGO Section 2002). Within the NCN framework, NGOs would have two main responsibilities: 1) to ensure the roles and responsibilities of each of the key actors in the NCN are conducted honestly and competently, and 2) to monitor and record any leakage effects of forestry projects. This would enhance the efficiency of the entire NCN, and ensure that forest sink projects are carried out in a way that meets the socio-economic and environmental goals of a country.

National and Operational Carbon Accounting: Data and Models

To facilitate national greenhouse gas reporting in the NCN and the management-level carbon accounting by forest owners, certain tools and data must be in place. This section will investigate what data and models are available in Canada and provide an operational-level carbon accounting example in British Columbia.

Carbon Modeling by Government

A national carbon budget of forested and land use change areas is required for reporting to the United Nations Framework Convention on Climate Change.³ This would require an integration of data from the national forest inventory, remotely sensed data and other information pertaining to the carbon stocks in aboveground, belowground, soils, litter and dead wood pools. In Canada, there are two models that can estimate the national carbon budget, the integrated terrestrial ecosystem C-budget model (InTec) and the carbon budget model of the Canadian Forest Sector (CBM-CFS2).

The Canadian Centre for Remote Sensing and Intermap Technologies Ltd. developed InTEC which uses remote sensing techniques (Canada Centre for Remote Sensing 2000). InTEC estimates the carbon budgets of forests from atmospheric, climatic, and biotic factors including the effects of forest fire, insects-induced mortality, harvesting, planting, as well as changes in climate, atmospheric CO₂ concentration, and nitrogen deposition (Chen et al. 2000). InTEC also estimates soil carbon and net primary production in stands by using Farquhar's leaf photosynthesis model, the Century model, a net N mineralization model and age-net primary productivity relationship derived from forest inventory-based age-biomass relationships (Chen et al. 2000). Refinement in the relationship between stand age and net primary productivity is underway in addition to incorporating the effects of ozone, permafrost thaw, and drought stress.⁴ Simulation runs of carbon-offset potentials in Canada using InTEC have also been investigated for afforestation, reforestation, nitrogen fertilization, and substitution of fossil fuel with wood under different climatic and disturbance scenarios (Chen et al. 2000). The model is currently being applied to estimate the carbon budget for every km² of forested area in Canada (see footnote 4).

CBM-CFS is a national carbon model used by the Canadian Forest Service. Using forest inventories, ecosystem classifications, soils surveys, and other government and industry statistics, the CFM-CFS estimates carbon stocks and carbon flows in forest biomass, soils, and wood products (Kurz et al. 1992). Annual forest growth and soil decomposition are simulated using empirical relationships. The effects of wildfires, insect attacks, and harvesting on forest age-class structure and on C releases to the atmosphere and forest floor are calculated on a 5-year cycle (Price et al. 1997). The initial version of CBM-CFS estimated carbon pools and fluxes for a single year (Kurz et al. 1992). An updated model, CBM-CFS2, simulates the carbon budget for any time period between 1920-1989 (Kurz and Apps 1999). The CBM-CFS model is based on historical data on forest inventory, management, and disturbances; therefore, the model predicts the carbon budgets that would have occurred in the past, given the historic and present known information. However, assumptions about future forest management and forest processes have to be made and used to predict future carbon budgets. To date, the CBM-CFS model has been used only to forecast future forest carbon scenarios at the forest management level and not at the national level. A complementary model, the Canadian budget model of the Forest Product Sector (CBM-FPS) further tracks changes in carbon stocks in forest products pools (landfill, pulp and paper, solid wood products and fuel wood) till they are released into the atmosphere (Apps et al. 1999).

The CBM-CFS2 model has been applied at the regional level to estimate the carbon budget for the period of 1920-1989 for four ecoclimatic provinces in BC: Boreal, Cordilleran, Interior Cordilleran, and Pacific

³Each party included in Annex I shall have...a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases..." (United Nations Framework on Climate Change 1997).

⁴Chen, W. 2002. Application of InTEC for carbon reporting. Wenjun.Chen@CCRS.NRCan.gc.ca (17 April).

Cordilleran (Kurz et al. 1996). These ecoclimatic provinces range in size from 4.7 million ha to 32.8 million ha. A second approach has been to calculate the carbon budgets for each of the province's 14 biogeoclimatic zones (BEC)⁵ (Kurz et al. 2002). A comprehensive use of both tree biomass equations from the literature and the provincial growth and yield data from permanent and temporary sample plots by BEC zones have been used to determine both aboveground and belowground carbon, which are also the inputs for CBM-CFS2 to conduct further simulation on disturbance effects.

The results from the BEC zones has been filtered down to be used in BC's two different management units classified as a timber supply area (TSA) or a tree farm licence (TFL).⁶ There are 37 TSAs, which range in size from 76,751 ha to 13.4 million ha and 34 TFLs, which range in size from 8,366 ha to 804,000 ha.⁷ The CBM-CFS2 model has been used to forecast the carbon budget for the period of 2000-2032 for all TSAs and most of the TFLs with the assumptions in the timber supply review 2⁸ (Kurz et al. 2002). Within each TSA and TFL, land has also been categorized as timber harvest land base (THLB) and areas where no harvesting takes place (non-THLB). Therefore, carbon budgets based on THLB and non-THLB are also available for BC. Preliminary results find the THLB to be a source of 17.5 MT C/year and the non-THLB as a sink of 30.7 Mt C/year for the first commitment period (2008-2012) (Kurz et al. 2002). Depending on what areas are considered as "forest management" areas under the Kyoto Protocol, carbon reporting of just the THLB could result in BC being a carbon source whereas if the THLB and the non-THLB were included and subject to fire suppression, a carbon sink could be observed for the first commitment period (Kurz et al. 2002).

The CBM-CFS2 model has also been applied to the Foothills Model Forest located in Alberta (Price et al. 1997). Seventeen carbon budget scenarios that differ by the level of management, harvesting, protection from fires and insects, and natural disturbance cycle were compared for the simulation period, 1958-2238. With the experience gained from carbon budgets at the management level in BC and Alberta, the CFS is collaborating with the Canadian Model Forest Network to use the model forest as a testing ground for the development of a user friendly operational-level carbon accounting tool for forest growers across Canada.⁹

Carbon Modeling by Industry

In BC, some forest companies such as Canadian Forest Products Ltd., Lignum Ltd., Slocan Forest Products Ltd., and Lisaak Forest Resources Ltd., consider it important to calculate forest carbon contributions to the global carbon cycle as part of their environmental responsibility. There are many timber harvest regulation models used by forest companies that could be readily updated to predict forest carbon by incorporating appropriate carbon accounting assumptions and conversion factors. For example, Forest Ecosystem Solutions Ltd. has applied the volume-to-biomass conversion factors by Penner et al. (1997) to their forest simulation optimization system (FSOS) model and calculated carbon balances in wood products. The model developers are now incorporating predictions of belowground

⁵The Biogeoclimatic Ecosystem Classification (BEC) is a hierarchical system that uses climate, soil, and characteristic vegetation to group ecosystems at various levels, including regionally, locally, and chronologically (BC Ministry of Forests 2001).

⁶A timber supply area (TSA) is an area of Crown land defined in accordance with the *Forest Act*, primarily based on an established pattern of wood flow from the forest to the primary timber-using industries (BC Ministry of Forests 1999). A tree farm license (TFL) is an agreement entered into with the provincial government, which provides for the establishment, management, and harvesting of timber by a private interest on a defined area of Crown land in accordance with the *Forest Act* (BC Ministry of Forests 1999).

⁷Boyce, M. 2001. Request for information. Melanie.Boyce@gems1.gov.bc.ca (21 August)

⁸The timber supply review program updates and assesses the timber that may be available for harvesting over the short and long term for each TSA and TFL. By law in BC, the annual allowable cut must be predetermined at least once every five years (BC Ministry of Forests 1999). The assumptions in the Timber Supply Review 2 differ for each TSA and TFL. They encompass assumptions in growth and yield curves and management constraints due to factors such as biodiversity, water quality, and recreation.

⁹Kurz, W.A.. 2001. Telephone Interview. (17 August).

carbon, which represents an additional essential component for forest owners calculating a carbon budget. Carbon modeling using FSOS has been applied in two TSAs within BC.

Another model, FORECAST, is being applied in BC and Alberta (Kimmins et al. 1999; Seely et al. 1999; Seely et al. in press). It is a comprehensive ecosystem model of carbon and nitrogen cycling and net primary production in the forest. FORECAST includes carbon pools in aboveground, roots, soils, litter, and dead wood. Predetermined natural disturbance events can be modeled, as well as a range of management activities such as planting, fertilization, thinning, and silvicultural systems such as shelterwood and clearcutting. FORECAST is being used for the Arrow TSA and the Canadian Forest Products Ltd. TFL 48.

Because FORECAST is a stand-level model, it can simulate stand level carbon processes at quite a detailed level (i.e. carbon dynamics and assumptions are perceived to be less generalized than those of the regional-level carbon modelling). However, while addressing larger scale issues such as fire disturbances, wildlife corridors and beetle infestations, a landscape-level model is required. Links between stand-level and landscape-level models would therefore be valuable in balancing between a scale where reasonable carbon stocks may be estimated and verified on the ground and a scale where higher-level planning goals may be evaluated. Under the Lignum's Innovative Forest Practices Agreement, FSOS-FORECAST has been applied to an area in interior BC (near Williams Lake) to evaluate the future carbon budget. At present, a comparison between current management of fire suppression in the THLB and a fire suppression scenario in both the THLB and non-THLB has been made. A preliminary economic analysis of these two scenarios has shown that the most probable contract involving of 5-year purchase options would likely be economically viable, especially in the later years of the project. Evaluation of other forest management practices on total carbon in the Lignum area is underway. Because FSOS is a spatially explicit simulation-optimization model, carbon objectives can be assessed along with timber and biodiversity values across a landscape quantitatively and pictorially.

Additional Data / Research

Complete remote sensing coverage of Canada at 80-m resolution is available for every year since 1973, and at 30-m resolution for every year since 1984 (Kurz 1999). Remote sensing may be valuable in determining areas of land-use change, and areas disturbed by fire and insects, and for providing information in more isolated areas such as the Arctic. The national forest inventory (NFI) approach was revised in 1997 to provide more consistency among provinces, and additional data were to be collected for international initiatives such as the Kyoto Protocol, United Nations FAO Forest Resource Assessments and the Montreal Process (Canadian Forest Service 1999). The NFI is to be completed by 2005 and will include data on land use, ownership, conversion of forest land, areas and severity of insect attacks and fire, and total biomass by forest type, age, and succession stage. In 1996, BC started the Vegetation Resources Inventory (VRI) program to collect data on shrubs, herbs, and woody debris in addition to the traditional timber and soils data. Remote sensing data, the NFI and the VRI are important in providing the necessary data for carbon accounting.

Other research initiatives such as FLUXNET and CIDET could also contribute greatly to research gaps in carbon accounting. FLUXNET is a global network of over 150 micrometeorological tower sites that uses eddy covariance methods to measure the exchange of CO₂ between the forest ecosystem and the atmosphere (FLUXNET 2002). Canada has 15 towers, and three are in Campbell River, BC on a clearcut, young plantation and mature forest site. The Canadian intersite decomposition experiment (CIDET) is a cooperative study of researchers from the Canadian Forest Service, universities, and provincial ministries investigating the long-term rates of litter decomposition and nutrient mineralization in Canadian forests (Canadian Forest Service 2002). A number of additional biomass and carbon studies have also been undertaken in Canada (Bonner 1985, Penner et al. 1997, Siltanen et al. 1997, Stanek and State 1978). These research data can be used to improve and verify the national and operational-level models mentioned above.

Modeling Analysis

Carbon accounting and carbon processes in forest ecosystems are complex. There is still a considerable degree of uncertainty, particularly in belowground and dead woody debris pools; the dynamics between above and belowground with aging forests; the soil and future aboveground carbon after harvest, thinning, fertilization, and other silvicultural actions; and the effects of natural disturbances such as insects and fire on forest carbon. Furthermore, most carbon models have not been thoroughly tested or verified. This is a matter of difficulty and cost in measurement because the models are still rather new. However, if a forest carbon project were to be audited to gain carbon credits, then a field sampling system would be beneficial in measuring the “actual” carbon and would also aid in testing the sensitivity of the model. Ideally, a model should indicate a likely range of the amount of carbon predicted to be sequestered (with possibly some confidence level), which would help in determining the proportion a carbon owner may want to sell. Model comparisons would also be beneficial at least in part to demonstrate general trends (i.e., if an area is a sink, and if more or less carbon is stored with time), and the difference between models may give insight to the degree of uncertainty in carbon accounting. Comparisons between InTEC and CBM-CFS are in progress.¹⁰

At the national scale, the entire country is addressed. This allows for more generalized estimates including areas of less known data such as Arctic peatlands, and forest information for parks and other protected areas. The CBM-CFS2 can be used for national carbon budgets but improvements would be necessary for it to report a carbon budget according to the rules of the Kyoto Protocol. At the regional scale, it would have to be determined if regional estimates will be delineated by administrative boundaries as by provinces or by broad ecological zones as in the ecoclimatic classification system of Canada. An ecological-based regional carbon budget may be easier to estimate and perhaps even be used to compare the average carbon budgets of management unit areas within it; however, management assumptions such as those of the timber supply review may not be employed. Provinces are likely best suited to be responsible for the carbon reporting of its area in which case, there needs to be consistency and standards for carbon reporting. At the operational level, there is the CBM-CFS2 as well as other carbon landscape models. Because CBM-CFS2 has the potential to scale up to the national level, it would be ideal as a verification tool for those forest growers wishing to calculate their own carbon budget in their management area. Most forest companies have their own or are familiar with a certain timber supply planning tool that they use to make their timber and non-timber plans. Any required carbon analysis would likely have to be conducted in conjunction with their existing landscape planning tool so that all forest values can be evaluated. A model such as FSOS-FORECAST would be better able to address various forest concerns and objectives. Nonetheless, all the models, data sources and research initiatives discussed above will contribute to a better understanding of carbon accounting in the future. Canada has set a foundation for carbon accounting from the operational to the national scale.

Conclusions

There have been suggested guidelines but no standards developed on the methods of accounting, inventory, and monitoring of forest carbon at the international and Canadian level. Nonetheless, as discussed above, operational tools, data and models are in place for measuring, monitoring, and accounting of forest carbon. Currently, the Canadian government does not have a clear policy or plan detailing forest carbon accounting procedures that will link operational to national level reporting. However, as explained in the proposed national carbon framework, such integration is possible. This framework recommends that many components including the government, the forest growers, verification and accreditation agencies, international and non-governmental organizations be involved for a successful implementation of forest carbon projects and overall national forest carbon policies (when they are developed). The current operational tools and the national carbon framework could help foster economic and environmental certainty in forest-based emission offsets. Such offset projects could also promote sustainable forest management practices while preventing unacceptable levels of GHGs in the atmosphere.

¹⁰Kurz, W.A. 2002. CBM-CFS. wkurz@PFC.Forestry.CA. (17 April).

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Alternative Transaction Structures Allowing Permanent Retirement of Sink-based Emission Offsets

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Abstract

Carbon sequestration in forests can remove the greenhouse gas carbon dioxide from the atmosphere, thus offsetting the effects of greenhouse gases emitted elsewhere. For these sink-based offsets to be of value to emitters whose greenhouse gas emissions are capped, the emitters must be able to retire the offsets to reduce the emitter's net emissions. Retirement is permanent, but carbon stored in forests may be released at some time in the future. For emission tracking systems to have integrity they must account for any future loss of sinks. This chapter describes three mechanisms for transferring rights to offsets generated by carbon sequestration: regulating forests as emitters, renting offsets, and swapping offsets. Being regulated as emitters entails landowners accepting a perpetual obligation to maintain carbon stocks on their lands and, generally, landowners demand very high payments to voluntarily take on such obligations. Rental of offsets requires emitters to book an emission at the date of expiration of the rental contract when retiring a rented offset to net out a current emission. In a swap, the landowner creates and offset and transfers the offset to an emitter, who may permanently retire that offset to cancel out an equal amount of current emissions. At a specified later time, the emitter transfers a replacement offset back to the landowner. The landowner may retire the replacement offset to terminate the landowner's obligation to maintain a sink. The most robust type of replacement offset is an allowance. Payment for a swap can be estimated using present value calculations. Swapping offsets avoids the problem of the landowner accruing a permanent obligation as a regulated entity. Swaps also avoid the problem of the emitter having to book a future emission at the time the emitter retires a rented offset. Because swapping offsets avoids these problems it may be preferred over these other mechanisms for transferring sink-based offsets.

Introduction

Carbon sequestration in forests can remove the greenhouse gas carbon dioxide from the atmosphere, thus offsetting the effects of greenhouse gases emitted elsewhere. However, forest carbon sinks are not necessarily permanent. If emission tracking systems are to have integrity, this possible impermanence of sequestration must be tracked in emission accounts. This chapter presents alternative approaches to accounting for possible impermanence of sinks, and compares these approaches.

As of this writing, the United States (U.S.) does not have greenhouse gas emission caps or regulations about what counts as a regulated emission or creditable offset. Currently, in the U.S., greenhouse gas offsets are traded because buyers believe the offsets will be creditable under a future regulatory system, or for some non-regulatory purpose such as public relations. Some states within the U.S. and some other countries are developing greenhouse gas emission trading programs. Prominent among these entities are the European Union, Australia, California, New York, and Massachusetts. A significant proportion of the state efforts do not recognize offsets generated by terrestrial sinks. Under the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change, countries that agree to limit their greenhouse gas emissions are to make "demonstrable progress" toward implementing the Protocol by 2005. This deadline has been widely interpreted as meaning that countries that plan to use emission trading should have emission allowance allocations and trading – at least on a provisional basis – by 2005.

If nations or other levels of government choose to limit greenhouse gas emissions, a properly designed offset trading system can significantly reduce the cost of achieving any given level of emission reductions (Dudek et al. 1997). In order for emitters having capped emissions to be able to use offsets to comply with emission limits, those offsets must have attributes that allow the emitter and regulator to close the

emission account books on past accounting periods. Emitters and governments that set emission caps have little use for offsets that may vanish in a future period, leaving an emitter out of compliance with an emission cap in a prior period in which an offset was used. Even if a sink is not permanent, an emitter needs to be able to close the account books on past periods.

If a cap-and-trade system is created for greenhouse gas emissions, sinks and other offsets will have to meet a variety of requirements specifying what counts as a creditable offset. Requirements would define what emissions must be counted, what kinds of emissions and sinks may be counted, approaches to counting, whether third-party verification or auditing are required, whether offsets may be banked, and a variety of other things. Around the world, a variety of efforts are underway to develop methods to predict and measure carbon sequestration in forests and soils, including projects by the USDA Forest Service Northeastern Research Station, the Consortium for Agricultural Soils Mitigation of Greenhouse Gases, the Canadian Prairie Soil Carbon Balance Project, and Environmental Resources Trust. This chapter does not address how to measure sequestration or requirements for crediting particular sinks, but addresses how accounting may be structured to allow emitters to permanently close emission account books on periods where forest carbon sequestration is used to comply with emission caps.

Transactions of sink-based emission offsets could be structured in any of several different ways to provide accounting permanence to impermanent terrestrial sinks. Three different approaches are discussed here:

- Regulating forests as emitters
- Renting offsets
- Swapping offsets

This chapter focuses on offsets generated by sequestering carbon in forests. However, the concepts are applicable to other greenhouse gas sinks, such as sequestering carbon in agricultural soils by switching from conventional tillage to direct seeding.

Regardless of the accounting method used to achieve accounting permanence of a sink, the terms of the exchange will be spelled out by contract. These terms include usual elements of business contracts, including identification of the parties, definition of what is being exchanged, which party bears risks of various undesirable situations coming to pass, and remedies the parties may pursue if things do not go as planned.

Definitions

Several of the terms in this chapter are used with specific definitions. Key definitions follow.

Allowance. Permission from a regulator to emit a specified amount of a regulated substance during a specified period. May be permission for a one-time emission or a stream of emissions, such as permission to emit one ton per year.

Avoided emissions. A reduction in emissions to below what would have happened without a specified action taken to reduce emissions. This term applies to projects that do not have regulatory emission caps, and do not have allowances. In practice, often it is hard to document avoided emissions. Assuming that emissions are a side effect or producing something that people want, showing that emissions are avoided usually requires that demand for the pre-project amount of outputs is satisfied with lower gross emissions.

Banking. Holding an offset or allowance for retirement in a later accounting period.

Emission. Release of greenhouse gas into the atmosphere.

Gross emissions. The total amount emitted, before subtracting any offsets, for a specified accounting period.

Net emissions. Gross emissions minus offsets, for a specified accounting period.

Offset. Something that may be used to reduce gross emissions for the purposes of complying with a cap on emissions. Three main types of emission offsets are sinks, avoided emissions, and unused emission allowances. Not all sinks or avoided emissions count as offsets. For greenhouse gases, offsets are generally denominated in metric tons carbon dioxide equivalent.

Retirement. Applying an allowance or other offset to comply with a cap on emissions, during a specified accounting period. After an offset or allowance is retired it is considered used, and cannot be traded, re-used, or used to comply with a different emission cap. Retirement is permanent.

Sink. Removal of greenhouse gases from the atmosphere.

Emission caps and accounting may occur at various scales. Currently, caps and accounting requirements exist at company, local, state, national, and international scales. An example of corporate accounting is British Petroleum's self-imposed commitment to track greenhouse gas emissions resulting from corporate operations and reduce emission to 10 percent below 1990 levels by 2010, a cap that it met in 2002. An example of local-scale accounting is the requirement of the Seattle City Council that the city-owned electric utility reduce its greenhouse gas emissions. A state-level emission accounting program is Oregon's program in which certain new electricity generating facilities must meet a rigorous carbon dioxide emission standards and offset any emissions above the allowed amount. A prominent example of a national non-greenhouse emission cap is the U.S. sulfur dioxide emissions cap and trade program in which large emitters are required to reduce their net emissions over time. The Kyoto Protocol, negotiated in 1997 and not yet in force at the time of this writing, is an international plan for industrialized nations to achieve net annual emissions in the period 2008 through 2012, in aggregate, 5 percent below 1990 emissions.

Rules at one scale need not correspond to rules at other scales. For example, the Oregon program addresses only carbon dioxide from certain electric power generating facilities, whereas the Kyoto Protocol covers several greenhouse gases emitted from a wide variety of sources. Nations could offer domestic incentives that would not be creditable under the Kyoto Protocol to obtain net reductions in aggregate national emissions that the nation reports under the Protocol.

Regulating Forests as Emitters

Under a system in which large emitters of greenhouse gases-such as electricity generating plants powered by fossil fuel-have caps on their emissions, forest carbon sinks can be allowed as offsets for powerplant emissions. Offsets can be generated by forest sinks even if forest emissions are not capped. However, if forest emissions are not generally tracked, forest sinks will not create tradable offsets unless they are monitored and verified as continuing to exist as part of a sequestration project.

Consider the case of a regulated emitter planting trees on agricultural land, growing those trees, and maintaining the forest in perpetuity. The emitter may subtract the carbon dioxide sink from its capped emissions from burning fossil fuel and retire the offset to comply with a cap. By retiring an offset based on carbon sequestered by the growing forest, the regulated emitter creates an ongoing obligation to monitor the amount of carbon stored by the forest. If the emitter is not the landowner, this ongoing obligation would have to be accepted by the landowner in advance of retirement of the offsets. The commitment to ongoing monitoring expands the emission sources the emitter must monitor, from its fossil fuel use (and possibly other emissions sources) to forest land that previously was not monitored. The emitter could be creating this obligation to continue monitoring regardless of whether the emitter holds fee title to the land where sequestration occurs.

This obligation to monitor the forest sink forever occurs because the emitter has brought the forest land into the capped system, to use the sinks generated by the forest to meet a regulatory cap. The accounting system would not have integrity if the forest counted as a sink, but later emission of that sink

does not count as an emission. Because the emitter is the party who brings the forest land into the regulated system, the forest becomes a part of the emitter's regulated operations, and the emitter is the party responsible for any subsequent emission from that sink.

Alternatively, the forest landowner could be allowed to become a regulated emitter. The forest landowner would hold the obligation to continue to keep carbon sequestered. Unless the forest landowner is granted allowances by the regulatory program that limits emissions, the landowner is required to keep the carbon stored, or acquire offsets equal in amount to any emission. If the landowner releases stored carbon (such as by logging or wildfire), the landowner would be required to quantify the emissions, report the emissions, and acquire and retire an amount of offsets equal to the amount of emissions.

The sink becomes an entry in the holder's corporate balance sheet, similar to any asset or liability that is held on the books until disposed of. The holder of the sink obligation may be the emitter, the landowner, or another party that accepts the obligation. Unlike depreciable assets, which are removed from the balance sheet after their book value is depreciated, a sink would remain on the balance sheet until replaced with an allowance. Because these sinks appear of the corporate balance sheet, they must be priced. Multiple methods for pricing sinks (and their liabilities) are possible. One approach is to use the cash value of the purchase price. If a liquid market in allowances exists, it would be possible to "mark to market" the value sinks at the market price of allowances that could be used to replace those sinks. If a liquid market does not exist, accountants could estimate the fair market cost of replacing the sinks. The latter of these methods could result in substantial volatility in the value of sinks as entered on balance sheets. The U.S., the Internal Revenue Service, or the Financial Accounting Standards Board could issue guidelines addressing how to account for the value of sinks held on corporate balance sheets.

If at some future date the carbon in the sink is reconverted to atmospheric carbon dioxide, the entity with the liability for these emissions must count the emissions as a part of its regulated emissions. This is the case regardless of whether the landowner or emitter holds this liability. If the emitter holds the liability, to the degree that there is uncertainty that a sink will continue to exist, the emitter has risk of future emissions from sink offsets held by the emitter. This uncertainty may be small if the emitter holds a diverse portfolio of sinks, insures the sinks, or banks extra offsets or allowances as self-insurance.

Renting Offsets

In rental of forest carbon sequestration, an emitter contracts with a landowner to store a fixed amount of carbon for a specified period. In the case of a sink, the landowner would take a specified amount of carbon dioxide out of the air during a specified time period, and hold the carbon in the forest for a period of time specified by contract. After the contract expires, the landowner is no longer obligated to maintain the sink, and may choose to release the carbon back into the atmosphere. At the end of the contract, the emitter no longer has rights to the sink holding the emission offset. At that time the emitter must report the previously rented sequestration as an emission.

A contract for sale and transfer of greenhouse gas emission offsets specifies the rights and responsibilities of each party. Typically, the buyer of the offset purchases only the right to use the greenhouse gas emission offset, and does not purchase any right to own or remove timber from the land. The interests of the buyer may be secured by a timber deed, covenant, or easement, in addition to the security provided by the contract transferring rights to the offsets. The contract may give the buyer specified rights to intervene to protect sequestration, if the seller does not adhere to the terms of the contract. After expiration of a contract of finite duration, covenants or easements would expire, and the landowner would regain full rights to the timber, including the right to log the trees and sell the wood.

The net effect of a rental of sequestration is to defer an emission until the end of the rental period. A key point is that when a renter of offsets retires a rented sink, the party that retires the offset creates an emission in the future period when the rental contract expires (figure 1). Booking this later emission allows permanent retirement of the initial offset because the fate of the sink is tracked and recorded within the accounting system. Currently, under the Kyoto Protocol, moving emissions from the current emission

period to future periods is not allowed. A country outside the Kyoto process, such as the U.S., could institute an emission regulation system in which future emissions may be booked now.

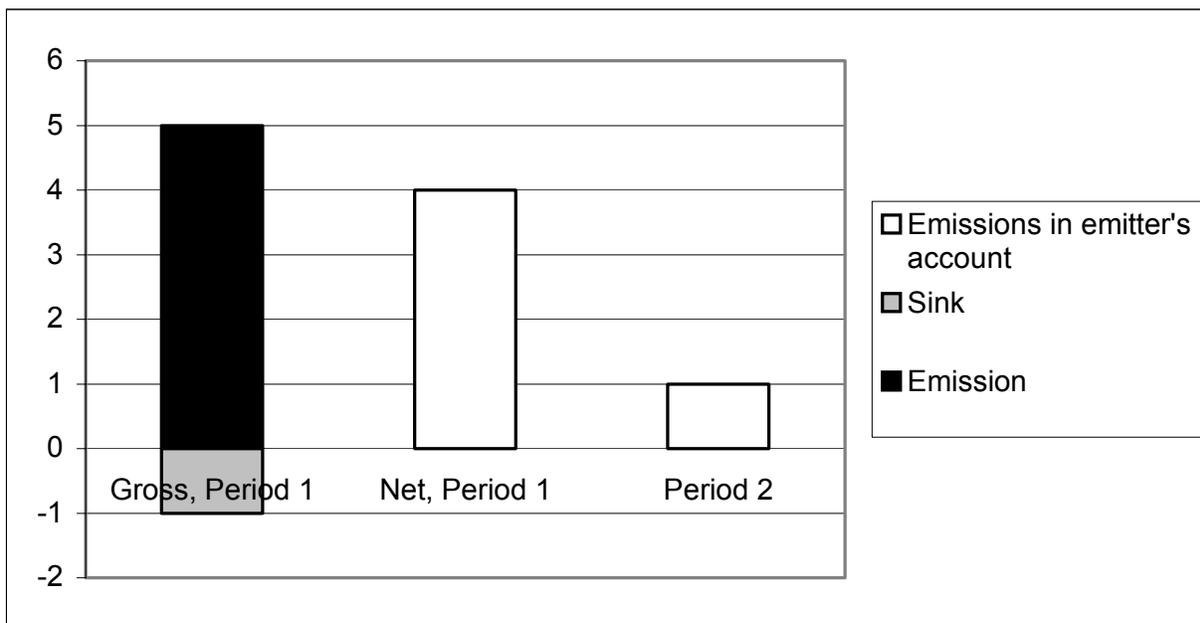


Figure 1—Sequestration rental illustration. An emitter has a gross emission of five units in period one, and acquires rights to a sink of one unit in period one, leaving a net emission of four units for the period. The rental contract expires in period two. As a result, at the time the emitter applies the sink to reduce offset emissions in period one, the emitter books an emission of one unit in period two. This emission in period two reflects that there is no further obligation to keep the sink after that time, and that the carbon in the sink may be emitted to the atmosphere

An emitter and landowner may choose to renew a sequestration rental contract. If the rental is extended the emitter may continue to defer the emission until the new end of the new rental contract (assuming that verification shows that the sink continues to exist).

Pricing rental of sinks is similar to pricing rental of use of money. The rental cost of money is the cost of taking out a loan. The starting point for determining the rental cost is the interest rate. For example, if the cost of a permanent offset is \$10 per metric ton carbon dioxide equivalent, and the annual interest rate is 6 percent, the starting point for determining rental cost of a one-ton offset is 6 percent of \$10, or \$0.60 for one year. The rental rate is adjusted for risks and responsibilities born by the parties, transaction costs, and other factors.

When starting a forest sequestration project in which offsets are generated by establishing and growing trees, annual rental payments start small. In early years of the project, relatively few tons have been sequestered. As the forest grows, it sequesters more carbon, and the number of tons of offsets increases, with proportional increase in the annual rental payment for sequestration. For example, assume a project establishes a stand that stores carbon at the constant rate of one new ton carbon dioxide equivalent each year, for 20 years. In the first year only one ton would be available for rent, while in the twentieth year 20 tons would be available for rent. Obviously, trees and stands do not grow and store carbon at a linear rate, and this simplifying assumption is used to make the example easier to understand.

This approach would require periodic measurement of the amount of carbon sequestered, with interpolation of amounts stored in years between measurements. Measuring more frequently gives more certainty about the carbon stock and sequestration, but each measurement typically costs tens of thousands of dollars. Higher quality projects to date have included a combination of measurements of

carbon stock change not more frequently than every decade, except sometimes as frequently as every five years near the beginning of projects. Between measurement times, inexpensive qualitative assessments are performed to determine whether the project appears to be developing as planned. For forest establishment projects, quantitative tree stocking surveys are generally performed annually until stands are declared free to grow. Projection of growth is done during project planning as a part of estimating yield of offsets, revenues, and costs. Determination of the amount of offsets achieved should be based on measurements performed over the life of the project, not modeling. Using periodic measurements to quantify the amount of carbon stored removes uncertainties resulting from the likelihood that stands will not develop as modeled.

Applying the example price of \$10 per ton to the growth example above, the revenue in the first year would be \$0.60 of one ton, and the revenue would rise each year and in the twentieth year would be \$12.00 for 20 tons. This example assumes that rental payments are made each year, for the sequestration service provided that year. Some existing transactions have had lump-sum payments near the beginning of the contract period. For simplicity, this example does not include adjustments to payment amounts that might be made to account for up-front payments for a stream of services that are provided over time.

In contrast to rising rental payments, annual revenues for rights to permanent offsets generated by forest carbon sequestration are much closer to constant. Continuing the example just given, assuming carbon is taken out of the atmosphere and stored at a constant rate, one ton is sequestered each year. Consequently, the annual revenue from selling permanent offsets as they are generated would be the price of offsets. In this example, in which one ton is generated each year and offsets are priced at \$10 per ton, the annual revenue would be constant at \$10 per year, until either the forest stopped increasing its carbon stock or until the sale is terminated.

Prices of rental of offsets are not determined simply by interest rates and prices of permanent offsets. If the buyer fears that the seller will not be able to deliver offsets, for any reason, the buyer will pay less. If the offset comes with other desirable attributes, such as creation of wildlife habitat, the buyer may be willing to pay extra. Many forest carbon sequestration transactions to date have involved payment near the start of time of the project, with tons being sequestered over decades. In this situation, the buyer is paying now for some tons that the buyer will not receive until many years in the future. Because of the time value of money, the buyer is likely to pay far less for a ton being delivered far in the future than for a ton being delivered now.

Expected future changes in the price of offsets can affect prices paid now. In the case of rentals, the buyer must acquire a new offset at the end of the rental period. If the buyer expects that the prices of offsets will be much higher at that future time, then the buyer expects to bear a large future cost as a result of engaging in the rental. Consequently, the rental is less attractive to the buyer and the buyer is likely to be willing to pay less than otherwise. Conversely, the buyer may expect the price of offsets to be lower in the future. In this case, deferring the offset avoids a higher cost now, and the buyer might be willing to pay a premium to rent an offset.

Swapping Offsets

An example of an offset swap involving forest carbon is the case in which a landowner generates an offset by sequestering carbon in forest, transfers the rights to this offset to another party, and then—at a specified later date—the other party transfers a different offset back to the landowner (figure 2). The original seller commits to maintaining the sequestration used to generate the original offset until the swap is completed. At the time of the completion of the swap, the original seller receives a replacement offset that may be applied to the original commitment to keep carbon sequestered, thus canceling the landowner's obligation to continue keeping the carbon sequestered. The original buyer may acquire the replacement offset from the market, and transfer that offset to the landowner. Alternatively, assuming the original buyer has allowances, the original buyer may transfer to the landowner an emission allowance valid at the time of delivery. For the period when this allowance is valid, the original buyer would have a lower net emission cap after the transfer.

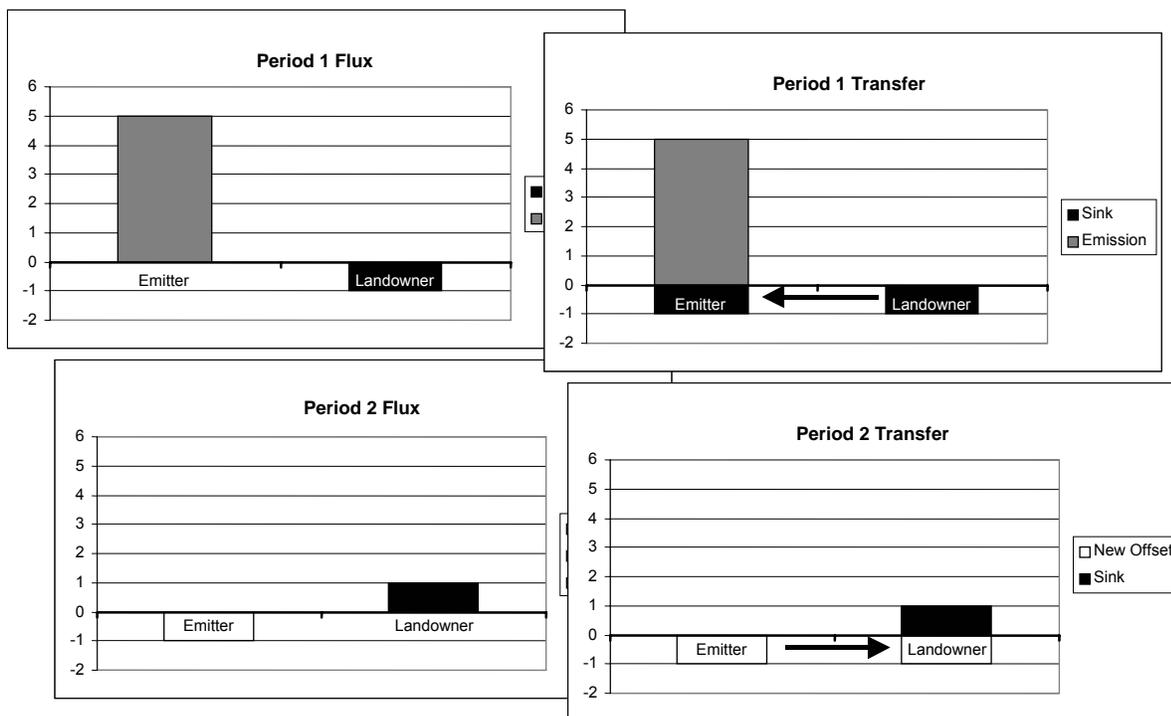


Figure 2—Offset swap illustration. In period one the emitter with gross emissions of five units acquires rights to a sink of one unit, resulting in a net emission of four units. In period two, the swap is completed. In period two the emitter must acquire an offset, which is transferred to the landowner who created the sink. The landowner may apply the offset to the sink, thus terminating obligations to maintain and monitor the sink

For example, Farmer Wood thinks that the combined revenue from future sale of timber, plus current revenue from swapping greenhouse gas emission offsets will be more than the farmer is currently earning by growing hay. As a result, Farmer Wood decides to take a field out of hay production and grow trees for the purpose of generating revenue from the sale of greenhouse gas emission offsets, and later, generating revenue from sale of timber. In 2004, Farmer Wood plants very fast growing trees that will be ready to harvest in 20 years. Farmer Wood hires a third party verifier to quantify the amount of carbon stored. In 2005, the seedlings do not store much carbon but they do store more than one metric ton carbon dioxide equivalent (ton CO₂e).

Big Coal Power Company has been recently regulated, and starting in 2004 the company will have to reduce its annual greenhouse gas emissions from 10 tons CO₂e to 9 tons CO₂e. Big Coal Power Company has existing electric power generation facilities that it needs to continue running to supply the power demands of its customers. As a part of the regulation capping the company's emissions, the government granted the company the right to emit 9 tons CO₂e per year. The company's power generation plant is getting old, and the company has plans to replace it in a few years with a new, more efficient natural gas fired plant that will serve the company's entire load while generating emissions of only 8 tons CO₂e per year. As a result, each year the new plant operates, the company will have an allowance it does not need. In 2005, Farmer Wood enters a contract with Big Coal Power Company to swap offsets. Under the contract, Farmer Wood generates an offset by storing one ton CO₂e of carbon in trees in 2005, and transfers the rights to this offset to Big Coal. In exchange, Big Coal promises that in 2025 it will deliver to Farmer Wood one of Big Coal's 2025 vintage allowances that allow the bearer to emit one ton CO₂e. The farmer and the power company agree to price both the 2005 offset generated by Farmer Wood and the replacement 2025 allowance provided by Big Coal at \$10 each.

In consideration of the fact that Farmer Wood will not get the replacement allowance for 20 years, the parties agree that reasonable compensation for the time value of Big Coal's use of farmer Wood's \$10 offset for 20 years is \$7 (reflecting roughly a 6 percent annual discount rate). As a result, the contract specifies that when farmer Wood delivers the offset in 2005, Big Coal will pay the farmer \$7. In 2005, Big Coal has gross emissions of 10 tons CO₂e, and submits to the greenhouse gas regulator the company's allowances for emission of nine tons CO₂e and the offset of one ton CO₂e generated by farmer Wood's trees. The regulator permanently retires all 10 tons CO₂e of offsets. In 2025, Big Coal receives allowances for emissions of 9 tons CO₂e for that year, retires 8 tons to cover its emissions from operations in 2025, and transfers 1 ton to Farmer Wood. Farmer Wood retires the allowance, thus terminating her requirement to maintain the carbon sequestration that was the basis of the 2005 contract and offset. After retiring the allowance, farmer Wood cuts the trees and sells the timber. Net emissions conform to the cap: 9 tons CO₂e in year 2005 and 9 tons CO₂e in year 2025.

The value in this exchange arises from the difference in time between the original delivery of an offset by the original seller, and the completion of the swap by the original buyer returning a different offset to the original seller. The original buyer gets use of the offset for the duration of the period between when the buyer gets the original offset and when the buyer delivers a replacement offset to the original seller. The second offset, provided by the buyer of the original offset to the seller of the original offset, may be a sink credit, emission reduction, or emission allowance. If the replacement offset is an emission allowance, that allowance may be retired, and thus eliminate the need for any additional monitoring of the maintenance of the sink.

As with any exchange, the contract specifies a variety benefits and obligations for each party. These benefits and obligations typically include the transfer of specified rights at specified times, criteria for what is an acceptable offset, an approach to verifying offsets, and amounts and timing of payments.

Payments for the original and replacement offsets can be made in various ways. In general, the buyer will pay the generator of the original offset for that offset at a point in time near the beginning of the period in which the swap contract is in force. The seller of the original offset may not wish to commit to expending cash several years in the future to buy a replacement offset. Also, the original buyer may not wish to take the risk that the original seller will have cash and be willing to expend that cash for a replacement offset at the end of the contract period. This problem can be avoided by having both payments occur at the same time, near the beginning of the contract period.

Assuming the price of offsets is constant over the contract period, then the buyer of the original offset is getting paid for the replacement offset several years (assuming the contract runs for several years) before the replacement offset is delivered. Consequently, it is reasonable to discount the value of this current payment for later delivery of an offset. The net payment to the original seller is the price of the offset, minus the discounted value of the replacement offset to be delivered in the future, plus or minus other adjustments. Essentially, the landowner providing the original offset is providing the buyer of the offset the use of an asset. The math works out that the payment to the landowner is the present value of the sum of annual interest payments on the value of the offsets, for the period of time between the two transfers that constitute the swap (table 1).

Table 1—Theoretical payment for an offset swap or rental, as a function of interest rate and length of time for which rights to use the offset are transferred, assuming the price of a permanent offset is \$10, without adjustment for risk, transaction costs, or other factors

Annual interest rate	Payment for 5-year contract	Payment for 10-year contract	Payment for 20-year contract	Payment for 40-year contract
20%	\$6.72	\$8.93	\$9.88	\$10.00
10%	\$4.10	\$6.51	\$8.78	\$9.85
5%	\$2.26	\$4.01	\$6.42	\$8.71
2.5%	\$1.19	\$2.24	\$3.97	\$6.37

Mathematically, the present value of something to be delivered in the future is the price minus the periodic interest rate, compounded for the number of periods. As time until delivery of the replacement offset increases, the discounted present value of that offset approaches zero. As a result, as the time between the delivery of the original and replacement offsets increases, the price paid to the provider of the original offset approaches the price of a permanent offset. As the periodic interest rate increases, the payment for a swap more quickly approaches the price of a permanent offset.

Standard financial discounting equations can be used to calculate the theoretical price of an offset swap or rental. The equation for calculating the theoretical price of a rental or swap of offsets is:

$$\$ = P * (1 - ((1 - r)^y))$$

where

$\$$ = the price per ton for the rental or swap

P = the price per ton for a permanent offset

r = the annual interest (discount) rate

y = the duration of the rental or swap, in years

The price paid in a specific transaction will vary from the theoretical price calculated using the time value of money. The buyer and seller will raise or lower the price at which they will be willing to participate in a deal depending on a variety of additional factors. These other factors include risk, expected future price changes, transaction costs, and the bargaining ability of the parties.

The swap would be very low risk for both buyer and seller if the swap were completed by the original buyer returning the original offset to the original seller. In this case, the original buyer would not face the risk that it might be difficult or expensive to acquire a replacement offset, and the buyer would not have risk that the replacement offset might not fully replace the original offset. However, when it is time to complete a swap, the original buyer is not likely to possess the original offset. This is because the original buyer probably acquired the original sink offset for compliance with an emission cap and retired the original offset, or the original buyer may have resold the offset for profit. Either way, when the time comes to complete the swap, the original buyer is not likely to possess the original offset.

If the original buyer no longer possesses the original offset, then the buyer must complete the swap by providing a different offset. The original seller would like to receive an offset with few attached conditions and future obligations. The most reliable of these replacement offsets is an emission allowance issued by the government regulator to which the original offset was retired.

Comparison of Alternative Transaction Structures

In summary, this chapter presents three possible ways to structure sales of greenhouse gas emission offsets generated by forest carbon sequestration such that the offsets may be permanently retired. One approach is that when a landowner sells an offset that landowner makes their land a regulated entity with a perpetual obligation to maintain the sink. This obligation could be discharged only by the landowner acquiring an offset, classifying the sequestered carbon as emitted, and retiring that offset to offset emission of the sequestered carbon. Another approach is rental of an offset in which the landowner commits only to maintaining a sink for a specified period of time, and the renter of the offset based on that sink defers the emission until the end of the rental period. In this case, the renter of the offset retires the offset to comply with a current emission cap. At that time the renter creates a future emission, occurring at the time of the expiration of the rental contract. A third approach is swapping offsets. With this approach, the landowner generates and sells one offset, and at a later date the buyer of the original offset completes the swap by delivering a replacement offset to the landowner. After receiving the replacement offset, the landowner may choose to count as emitted the sequestered carbon used to generate the original offset, and retire the replacement offset to terminate the commitment to maintain the sink.

Under all three of these ways of structuring exchanges of offsets, someone is responsible for loss of the sink used to generate an offset. When regulating forests as emitters and when swapping offsets, the forest landowners bears this responsibility. Many forest landowners are unwilling to accept such a

responsibility unless paid a price approaching the total value of their land. With an offset swap, the landowner is guaranteed to receive an offset that may be used to discharge this responsibility. With a rental of offsets, the buyer takes responsibility for future emissions. Presently, most countries (including the United States) do not have regulatory limits on greenhouse gas emissions. When jurisdictions establish caps on emissions, the jurisdiction determines whether or not regulated emitters may book future emissions resulting from rental of offsets.

Comparing these approaches to providing accounting permanence, landowners may be reluctant to commit to the ongoing obligations of making themselves regulated entities. Renting offsets would not be viable if future regulations do not allow regulated emitters to book emissions in future periods. Swapping offsets may avoid these problems. For these reasons, landowners and buyers of offsets may find swapping offsets a more attractive way to achieve accounting permanence than regulating forests as emitters or renting sequestration.

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The Use of Conservation Easements to Secure the Role of Private Forests in an Emerging Carbon Market

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Abstract

Private forests provide a wide range of public conservation good and services. Among these benefits is their ability to help mitigate global warming through their capacity to store and absorb carbon dioxide, a global warming gas. In spite of this capacity, the forest sector is currently the second largest global source of carbon dioxide emissions. However, this trend may be reversed. With increased conservation-based efforts, forests can help mitigate global warming.

The unique role of forests as both a carbon dioxide source and carbon reservoir is a focus of climate change discussions among policy makers as market-based approaches are developed to address global warming. Policy makers are considering how forests should participate in the evolving market-based approaches to global warming. Specifically, they are assessing the extent to which forests currently contribute to global warming and determining how they should contribute to its solution in a market context.

In the United States (U.S.), privately owned forestlands can play a significant role in a forest carbon market, as they represent the majority of forestland in the U.S. With the increased conservation and conservation-based management of these forestlands, these forests can help mitigate global warming and simultaneously achieve additional regional and national conservation benefits. However, in order to achieve such benefits, commonly accepted forest carbon accounting rules need to be established. While a regulatory structure that embodies such rules is evolving, there is an existing legal tool that can be used to implement these rules: conservation easements. Conservation easements are an available and effective legal mechanism that may be used to secure permanently carbon dioxide emissions reductions on private forestlands in a carbon market transaction.

Introduction

Forests, private as well as public, provide the public with a variety of conservation goods and services. They help maintain water quality, as forested watersheds catch and filter water, regulate flow and moderate flooding. They are a major destination for recreational activities such as camping, bird watching, backpacking and hiking. Furthermore, forests provide habitat for multiple species. For instance, in the U.S., forests host approximately 90 percent of the nation's amphibian, bird, and fish species and 80 percent of mammal and reptile species for at least part of their life cycles (U.S. Dept. of the Interior 1998). In fact, there are more endangered or threatened species listed for forests than for other land use types¹ (Best and Wayburn 2001).

Biodiversity is also an essential service that forests provide for species survival. Biodiversity encompasses all the interactions and processes of an ecosystem and includes not only the numbers of species (or richness) in an ecosystem, but other elements as well, including the diversity of species,

¹The terms threatened and endangered pertain to classifications under the U.S. Endangered Species Act (ESA). Pursuant to the ESA, the term "endangered species" means any species that is in danger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta determined by the Secretary to constitute a pest whose protection under the provisions of this chapter would present an overwhelming and overriding risk to man. The term "threatened species" means any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (ESA 1973).

structural stages and life cycles, life in functional and nutritional niches, and diversity of landscapes. The maintenance of diversity preserves options within a system, which in turn, provides greater resilience to disturbance. Thus, maintenance of options, or biodiversity, is critical to survival.

Moreover, forests play a critical role in climate stabilization, because they may be both a source of carbon dioxide as well as a carbon dioxide reservoir. As forests grow, they absorb carbon dioxide from the atmosphere. They convert the carbon dioxide into carbon and store the carbon in their leaves, roots, branches and boles. However, when forests are disturbed through events like deforestation or harvest, they release their carbon stores as carbon dioxide into the atmosphere.

At the global level, forests are the second largest source of carbon dioxide emissions. They comprise 23 percent of the world's total carbon dioxide emissions (U.S. Dept. of Energy 2001). The primary reasons for their emissions are forest loss due to conversion to agriculture and development, and harvest.

Role of U.S. Forests in Global Warming

Forests of the U.S. play a significant role in global climate change. They currently cover approximately one-third of the total U.S. land mass, comprising 747 million acres (EPA 2001). It is estimated that about 29 percent of U.S. forestland has been lost since 1630, with approximately 300 million converted to other uses, mainly agricultural (Smith et al. 2001). In recent decades, the amount of forest coverage has remained fairly constant (Smith et al. 2001).

From a carbon perspective, U.S. forests are currently a net carbon reserve. Recent statistics indicate that they sequestered 247 million metric tons of carbon equivalent (MMTCE) in 1999 (EPA 2001). However, while U.S. forests are currently a net carbon reserve, their sequestration capacity is declining. Between 1990 and 1999, carbon flux declined from 273 MMTCE to 247 MMTCE (EPA 2001). Much of this decline is attributed to land-use change, such as conversion to other uses and increased harvest (EPA 2001).²

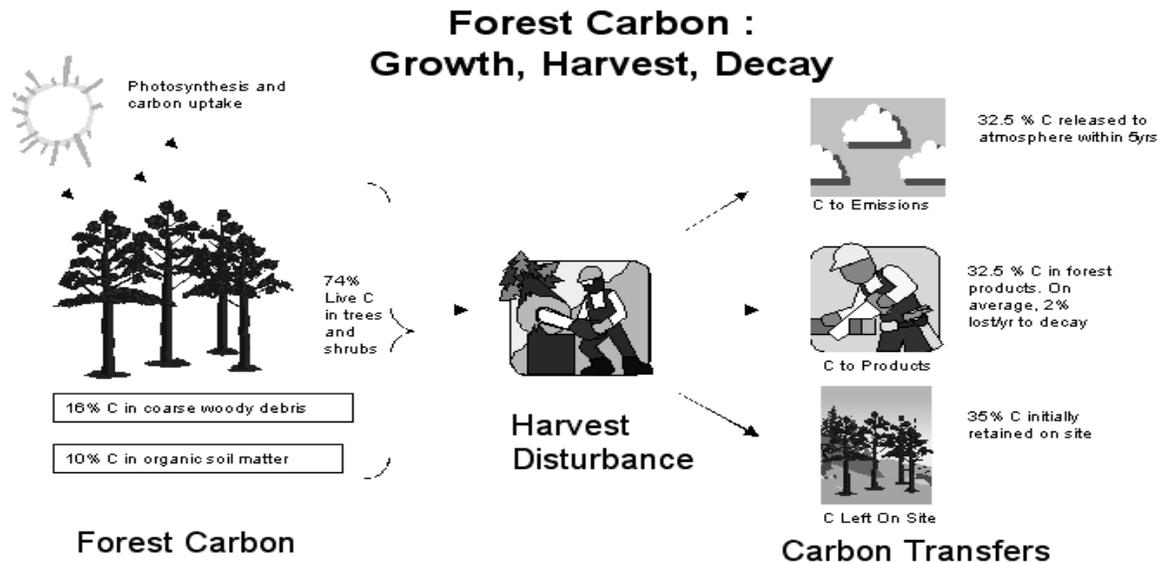
Privately owned forestlands contribute significantly to this decline. Because they comprise two-thirds of total U.S. forestland, their management and status have significant implications for U.S. total forest carbon stocks and carbon dioxide emissions (i.e. global warming). Conversion of private forestlands to other uses is increasing. Between 1992 and 1997, approximately one million acres of private forestland were lost each year to development, which is a 70 percent increase over the previous decade (NRCS 1999). This trend of loss is expected to continue, as the National Resource Council predicts a continued decline of 5 percent (20 million acres) by 2020 (Best and Wayburn 2001).

California and Washington are among the national leaders in terms of forest loss. Over the past decade, California's rate of forest loss to non-forest use has increased steadily. The State currently loses 60,000 acres of forestland annually, the majority of which is private (NRCS 1999). Coincidentally, statistics concerning California's inventory of greenhouse gases indicate that net carbon sequestration of California's forests and soils has declined by approximately 27 percent between 1990 and 1999 (Choate et al. 2002).

Statistics for Washington also portray a significant loss of carbon due to conversion. Between 1982 and 1997, 262,800 acres of private forestland in Washington were converted to non-forest uses (NRCS 1999). In 1990, over 4 million tons of carbon dioxide emissions in Washington were due to the conversion of forest to other uses, such as agriculture and development (Kerstetter 1994a). Similar emission rates are projected to continue through 2010 (Kerstetter 1994b). When forests are converted, not only are large amounts of carbon released to the atmosphere through burning and decay, but land development precludes realization of future carbon stores.

²While total acreage under forest coverage has remained fairly constant in recent times, underlying changes are occurring on private forestlands. Many older private forestlands are undergoing conversion while new younger plantations are replacing former agricultural lands (Wayburn et al. 2000, Best and Wayburn 2001).

Harvest on private forestlands also impacts total U.S. forest carbon stocks and emissions. In 1997, approximately 90 percent of the total U.S. timber harvest came from private forestland (Best and Wayburn 2001). Between 1991 and 1997, private harvest increased by 7 percent (1.02 billion cubic feet) and similar increases in harvest are projected to continue through 2020 (Best and Wayburn 2001). The carbon dioxide released into the atmosphere as a result of the harvest process is significant. In a typical harvest,³ one third of a forest's carbon stores is released into the atmosphere within five years of harvest (Harmon et al. 1996). The remaining two-thirds are almost completely lost over time due to decay and site preparation (figure 1). Ultimately, about 5 percent of the original forest carbon stores remain on site. While forest carbon may be stored for a term in forest products, the carbon is eventually released over time through decay.⁴



Sources: Harmon, M.E., S.L.Gamran, and W.K.Ferrell. 1996; Turner et al, "A carbon budget..." 1995; and Turner et al, "Carbon sequestration ..." 1995.

When forests are disturbed by harvest, 32.5% of the carbon is released to the atmosphere within 5 years. This increases to 62.5% over time as the majority of the 35% of carbon initially retained on site (in stumps, roots, and coarse woody debris) is released through decay over time through decay. 32.5% of carbon is transferred to the forest products pool where 2% of this carbon is released per year through decay.

Figure 1—Forest carbon: growth, harvest, decay

Some states have calculated the carbon dioxide emissions associated with the harvest process. Carbon dioxide emissions associated with harvest and forest products for the state of Washington amounted to 37,304,000 tons of carbon dioxide in 1990 (Kerstetter 1994a).⁵ Projections for 2010 show a slight increase in carbon dioxide emissions for this category in Washington at 38,683,442 tons (Kerstetter 1994b). Oregon attributed 8 percent (55.3 million tons) of its total carbon dioxide emissions in 1990 to old growth timber harvests (Oregon Dept. of Energy 1995).

The preceding information indicates that private U.S. forests certainly play a role in global warming, as they can either be sinks for or sources of carbon dioxide emissions, depending on how they are managed. At the same time, it also indicates that there is opportunity for these forests to be a part of the global warming solution. By mitigating or preventing private forestland conversion to non-forest uses, the carbon dioxide emissions associated with this loss can also be avoided or at least minimized. Likewise, changes in forest management practices can also lead to fewer carbon dioxide emissions from harvest

³For purposes of this example, the typical harvest is based on the national average.

⁴The average estimate of the decay rate for all forest products is 2 percent per year (Harmon et al. 1996).

⁵This statistic is a product of measuring CO₂ emissions from forest residue, long and short-term forest products, and slash burns.

and increased forest carbon sequestration,⁶ that is increased carbon dioxide removed from the atmosphere. This can be accomplished by extending rotations, retaining trees through one or more harvests, and rebuilding older age classes of forest on the landscape (Wayburn et al. 2000, Harmon et al. 1996).

Such conservation-based forest activities will not only maximize the potential of private forests to help mitigate global warming, but they will also maximize the multiple other conservation benefits that forests provide. Efforts to conserve carbon on private forestlands will help improve water quality, biodiversity and endangered species habitat. These benefits will also benefit recreational opportunities.

Thus, trends of private forestland management and loss in the U.S., whether from harvest or conversion to a non-forest use, demonstrate an opportunity for private forests to play a positive role in global warming. It will require private forestland owners to undertake conservation-based measures in forest management, such raising the average age of managed forests,⁷ restoring forests to former forestlands that have been converted to other uses, and/or preventing forestlands from being converted to non-forest uses (i.e., agriculture or development). Such actions will help prevent carbon dioxide emissions associated with forest loss and lead to increased forest carbon stocks. However, to catalyze these kinds of activities, forest landowners need an incentive. A forest carbon market that arises from market-based approaches to address global warming can provide such an incentive.

Conceptual Framework for Forest Carbon Market

In order for a forest carbon market to develop, there needs to be a demand for the carbon stored in forests. Such a demand could evolve from a regulatory system that caps greenhouse gas emissions – carbon dioxide in particular – from certain sectors whose emissions result from the combustion of fossil fuels (e.g. energy, transportation etc.). Similar to the emissions trading provisions of the federal Clean Air Act in the U.S., capped entities could be issued allowances (or permits) to emit a certain amount of carbon dioxide in a given year. If these entities emit less than their permitted amount, they would be able to sell (or trade) the remaining amount to another entity, perhaps one that is not able to meet its reduction goals on its own.

As a sector that both emits and sequesters carbon dioxide, forests would likely be integrated into such a market or trading system. Forest landowners (“sellers”) could receive credit for the additional carbon dioxide absorbed from the atmosphere and stored as carbon in their forests. These forest carbon “credits” could then be sold as emissions reductions to capped sectors/entities (“buyers”). Under such a scenario, the financial incentive to undertake forest carbon conservation would be created, as buyers would pay sellers to undertake such activities on their forestlands.

Elements of this market framework are evolving at the international, federal and state levels of government, as well as in the private sector. The Kyoto Protocol, while it has yet to enter into force, requires certain industrialized countries to reduce their greenhouse gas emissions to 1990 levels by 2012 and permits trading to achieve these goals. The Protocol also permits reforestation, afforestation and forest management as a means for countries to achieve emission reductions goals. States in the U.S., like Oregon and Massachusetts, have passed laws and regulations that limit carbon dioxide emissions from power plants and allow for at least some of the emissions reductions to be achieved through forest carbon projects.

Voluntary greenhouse gas registries and reporting protocols are also signals of an emerging forest carbon market. The U.S. government, as well as several states, have developed or are in the process of developing, protocols for the registration of carbon dioxide from the forest sector. For instance, the Climate Leaders program, recently established by the U.S. Environmental Protection Agency, is a federal voluntary greenhouse gas registry that allows for the registration of forest-produced emissions reductions.

⁶Reforestation is an additional means for sequestering carbon.

⁷For purposes of this article, managed forests are those that undergo harvest and regeneration.

Similarly, California has established a voluntary greenhouse gas registry that will include the registration of forests carbon stocks and emissions. Other private institutions, like the World Resources Institute and the Chicago Climate Exchange, are also creating guidelines and setting precedents for the role of the forest sector in a carbon market.

Rules for a forest carbon market

In order for forests to play a credible role in a market intended to reduce greenhouse gas emissions, forest-produced carbon dioxide emissions reductions need to achieve a real benefit for global warming. In addition, they should achieve local conservation benefits on the ground. In recognition of this reality, a set of principles to guide a forest carbon market policy has emerged and is gaining increasing acceptance. These principles will likely be incorporated in future forest carbon market policies, and they include the following:

Additionality and baselines

To produce real atmospheric carbon dioxide emissions reductions for buyers, marketable forest carbon stocks will need to result from activities that exceed “business as usual” (BAU) practices. These additional actions would cause additional carbon dioxide to be absorbed from the atmosphere and stored in forest biomass (i.e., sequestration) and/or prevent carbon dioxide emissions from being emitted from forests that would have otherwise occurred.

Under such a scenario, additional carbon gains will need to be measured against a baseline, which is based on BAU management practices (e.g. what is required by applicable land use laws/regulations). The baseline could be created in a given year through an inventory of current forest carbon stocks, which would serve as the initial point of measurement for additional carbon gains. Forest carbon models would then be used to predict BAU from fluctuations in carbon stocks over time, based on BAU management practices (e.g., harvest every 20 years with regeneration). The difference between the BAU baseline and actual increases in on-site carbon stocks over time would be the “additional” carbon stocks⁹ that would ultimately receive credit and be sold as carbon dioxide emissions reductions.

Permanence

In order to achieve long-term reductions of carbon dioxide in the atmosphere and simultaneously, enduring conservation benefits on the ground, additional forest carbon stocks should remain stored for the long-term or permanently. The calculation of this long-term or permanent storage should be based on average carbon stocks, so that there is the capacity to allow for harvest or tree removal in different areas over time.

Conservation benefits

A forest carbon market should foster the additional local conservation benefits that can be achieved through the conservation of forest carbon, such as improved water quality, biodiversity and species habitat, qualities that older, less disturbed forests promote. In addition, it should promote sustainable forest economies by rebuilding depleted forest timber inventories. Moreover, it should avoid encouraging or crediting perverse incentives such as the replacement of native forests or ecosystems with nonnative forests in order to generate carbon credits.

⁹If forestland is under an immediate threat of conversion to a non-forest use, the BAU carbon baseline could be adjusted to reflect the loss of carbon stocks that would have resulted from the conversion. Thus, this avoided loss of carbon dioxide could also be deemed “additional” and therefore marketable as emissions reductions.

Annual credit/debit accounting

As forests sequester carbon and emit carbon dioxide, both the annual gains and losses of on-site forest carbon stock should be accounted for. This is particularly important for managed forests as they gain and lose carbon stocks fairly regularly through harvest and regeneration. This type of information will become more important as a forest carbon crediting system evolves, since such a system will likely attribute credits for carbon gains and debits for losses of on-site carbon stock.

Third party verification

Third party verification (third party to the landowner/seller and buyer) of forest carbon gains and losses will be an integral part of the crediting process, to ensure that parties follow the same set of rules and real credible emissions reductions are achieved and maintained over time.

Practical application of these principles through a conservation easement

While a formal governing policy that incorporates these principles has yet to be established, there is an existing legal mechanism that may be used to implement these rules and facilitate a forest carbon transaction. This tool is a conservation easement. Similar legal tools exist and may be used in other countries to secure the same benefits.⁹ The Pacific Forest Trust (PFT) has successfully executed sales of carbon dioxide emissions reductions from privately owned forests with the use of conservation easements.¹⁰ The following explanations should provide practical insight regarding how such rules might be implemented on the ground in conjunction with a conservation easement.

A conservation easement is a voluntary legal agreement between a private landowner and qualified non-profit land trust or governmental agency. It is a perpetual deed restriction transferred to a third party that defines and limits development and land uses to protect public benefits such as habitat, water quality, open space and scenery. Multiple tax benefits, estate and income, are associated with conservation easements that meet the U.S. Internal Revenue Code requirements.¹¹ The financial value of conservation easements vary, as it depends on the rights (or a portion thereof) that are either donated or sold by the landowner (i.e. deed restrictions) and the value of those rights, which are dependent on variables such as development potential and timber value.¹² For managed forests, the easement will establish broad, long-term goals for consistent, conservation-based forest management, which allows the forestland land to stay in private ownership and productive use, including timber harvest. The land trust or other qualified governmental entity holds the easement and ensures, through monitoring and enforcement, that the terms of the easement are upheld in perpetuity.

In a forest carbon transaction, conservation easements can legally ensure the additionality of carbon dioxide emission reductions. Upon the development of an easement, a baseline description of the ecological condition for the covered area is created. This provides an overview of existing zoning and land use practices, infrastructure (e.g., roads, fences, bridges), conservation values, types and extent of

⁹Like conservation easements, conservation covenants in British Columbia serve as voluntary perpetual agreements that can secure carbon on private property. A covenant allows for identification of specific property and property use rights on a given ownership, and secures the permanent dedication of lands to specific purposes, particularly ecological purposes and in this case, carbon. At least 26 other countries have conservation easements or legal equivalent.

¹⁰The Pacific Forest Trust has completed two forest carbon transactions, selling emissions reductions based on conservation-based forest management from approximately 5,000 acres of forestland under easement to U.S.-based Green Mountain Energy and U.K. -based Future Forests.

¹¹See Internal Revenue Code, 26 U.S.C. 170(h)(4)(A) et seq.

¹²These values are determined through a standard, fair market appraisal process and qualified third party appraisal. Currently, carbon rights are not officially recognized or defined in the United States. Once this occurs, as it has in Australia, access to additional tax benefits, based on carbon conservation, may be possible.

vegetation, riparian zones, forests and soils and timber inventory. The baseline serves as the foundation for the monitoring of conservation easement terms, which outline the improved conservation-based management that will continue in perpetuity on that land area and will facilitate increased forest carbon stocks. It also serves as the basis for determining initial quantity of forest carbon stocks and projecting the carbon baseline over time, based on BAU practices, as a timber inventory is a main component for quantifying forest carbon stocks and sequestration.¹³ During easement monitoring, the land trust or governmental entity will use the baseline and conservation easement terms as a reference to ensure that the landowner is managing the property according to the improved management terms of the agreement and to assess that additional forest biomass (carbon stocks) is accumulating and being maintained over time, as planned.

The specific terms of the conservation easement may vary, depending on the type and condition of the forest and goals of the landowner. However, from a broad perspective, the terms should promote conservation-based practices by prohibiting or limiting subdivision and development, dedicating the property to permanent forest use, and improving the management of the property for conservation purposes, which can include carbon conservation. Examples of such terms can include maintaining native forest, limiting the amount of timber that may be removed from the property at any time, reforestation of certain areas, extending timber rotations, and increasing the size of riparian buffer strips. Essentially, the easement terms result in the increased average age of the forest (i.e., increased biomass), which in turn, results in increased, or additional, forest carbon stocks when compared to the baseline. Furthermore, the conservation easement, because it is perpetual, acts as a legal assurance that these additional forest carbon stocks will remain stored in perpetuity, as the conditions and management to create these stocks are perpetual. Such a legal guarantee is very attractive to buyers who are looking to buy emissions reductions with minimized risk of being emitted due to changes in forestland ownership, management and conversion to non-forest uses.

The terms of the conservation easement will also preserve forest conservation benefits on the ground, such as endangered species habitat, water quality and enhanced biodiversity. As mentioned earlier, conservation easements as defined pursuant to the Internal Revenue Code should be developed in accordance with one of the conservation purposes outlined in the Code. These purposes include: 1) the protection of open space (including farmland and forest land) for the scenic enjoyment of the general public or pursuant to government conservation policy that significantly benefits the public, and 2) the protection of relatively natural habitat of fish, wildlife or plants (or similar ecosystem) (IRC 1986).¹⁴ The specifics of these requirements become a part of the permanent easement agreement, which then provides the legal guarantee that these benefits will be achieved and maintained. These conservation benefits are not only beneficial for the general public but also for the buyers who are looking for emissions reductions that have the added tangible benefits of local conservation. Thus, forest-based emissions reductions secured by conservation easements can have additional value in a forest carbon market due to these required local benefits.

The monitoring process associated with conservation easements is also a convenient arrangement for annual credit/debit carbon accounting. Typically, land trusts monitor easement properties on a regular basis to ensure that forestland is being managed and maintained in accordance with the easement terms. A qualified land trust, while conducting this regular monitoring, can also account for the forest carbon gains and losses (i.e. credits and debits), as it can monitor gains and losses of forest biomass that result from harvest, tree removal or natural causes. The carbon stock values can be extrapolated easily from the forest biomass and reported in a central registry, from which credits and debits can ultimately be determined.

¹³Carbon stocks can be determined through the use of standard algorithms for tree bole volume and extrapolations for roots, branches, litter and decay pools (Birdsey 1996).

¹⁴Other purposes include 1) “the preservation of an historically important land area or a certified historic structure” and 2) “the preservation of land areas for outdoor recreation by, or the education of, the general public” (IRC 1986).

In addition, the conservation easement monitoring process can provide the added security of third party verification. In the event of a sale of emissions reductions from a forest landowner to an interested buyer, the land trust (or qualified governmental entity) may play the role of third party verifier, since it would be a third party to the purchase and sale transaction. Through the monitoring process, it may verify, among other things, the maintenance and accumulation of additional carbon stocks that would be purchased as emissions reductions by the buyer.

Thus, conservation easements are a tool that may currently be used in the practical application of evolving forest carbon market rules. They provide a financial incentive, independent of the emerging values of forest-based emissions reductions, that is needed to encourage landowners to undertake additional conservation efforts on their forestlands, which lead to real climatic benefits and other valued local conservation benefits. Conservation easements are attractive to the buyers in a carbon market, as the easements provide a perpetual legal assurance of additionality, permanence, and conservation benefits. In addition, they provide the basis for third party certification and annual debit/credit accounting through the monitoring process.

Conclusion

Private forests of the United States can play a significant and positive role in emerging market-based solutions to global warming. The financial incentive created by a market for forest carbon can help reverse the trend of private forest loss and their associated carbon dioxide emissions. For the same reason, a forest carbon market can also encourage more forest conservation and conservation-based management practices, which will increase the amount of carbon dioxide absorbed and stored by these forests. Such practices will help mitigate global warming and simultaneously achieve other significant local conservation benefits, such as improved water quality, species habitat and biodiversity.

Commonly accepted rules that govern the role of forests in a carbon market are emerging. These rules require additionality, permanence, local conservation benefits, credit/debit accounting and third party certification. While a specific policy that reflects these rules has yet to be established, conservation easements are existing accepted legal mechanisms that are also financial incentives in their own right that can be used to effectively implement these rules and secure permanent gains for the climate and local conservation.

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Global Climate Change, Carbon, and Forestry: Decision-Making in a Complex World

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Abstract

Global climate change from a build-up of greenhouse gases has raised questions about physical, ecological, economic, and social issues. Potential technologies for reducing net greenhouse gas emissions include a wide variety of actions involving sinks and sources. Land managers and policy makers require scientific information to aid in the multiple facets of the decision-making process: an understanding of the overall system and key components and linkages; development of management or policy options; how much attention to devote to adaptation versus mitigation actions; and estimation of the likely effects and outcomes of adaptation and management actions and policies. Science pertaining to the linked aspects of climate, ecological effects, economic impacts, and social concerns has evolved substantially over the last decade. Future choices pertaining to adaptation and mitigation should be assessed with consideration of dynamic interactions among climate, ecological, and socio-economic systems and attendant effects on agriculture, forestry, and natural resources. Science-based assessments can support analyses of environmental, social, and economic costs and benefits, and implications of these interactions for integrating climate-change response strategies in an equitable manner into broad sustainable development strategies. Unintended consequences of policies should be considered, given previous experiences with other government programs. Just as lifestyle choices result in unintended consequences at times, public policies sometimes can have unintended results, including effects across sectors (e.g., leakage possibilities), in addition to planned outcomes.

Introduction

Global climate change from a build-up of greenhouse gases (GHG) has raised questions about physical, ecological, economic, and social issues. Potential actions for reducing net greenhouse gas emissions involve a wide variety of sinks and sources. A wide range of strategies can increase the storage of carbon in forests and forest products (Sedjo 1989, Hair et al. 1996, IPCC 1996, Birdsey et al. 2000, Kauppi et al. 2001), however, costs would vary notably across strategies. The mix of winners and losers would also vary significantly across strategies. These strategies include reducing carbon emissions from forests by reducing the conversion of forests to developed uses, farmland, and other uses (i.e., reducing deforestation), setting aside existing forests from harvest, and reducing biomass burning. Strategies for increasing carbon build-up in forests are: converting marginal agricultural land to forests (carbon plantations, forest product plantations, short-rotation woody crops (e.g., Alig et al. 2000) or joint product plantations), and enhancing forest management (e.g., Plantinga and Birdsey 1993). Other strategies include substituting wood products for more energy-intensive products (Skog et al. 1996, Skog and Nicholson 1998), and planting trees in urban and suburban areas to affect urban climate by shading, reducing wind, and reducing evapotranspiration (McPherson and Rowntree 1993, Nowak 1993, U.S. EPA 1995).

Choices involving strategies will need to be made, and with finite resources, will involve trade-offs among societal priorities. I will provide examples of broad-scale considerations for this decision making. These selected examples include the current forest resource situation, markets, and unintended consequences of policy. Given that climate change is a global concern, policy makers need to consider interrelationships between sectors of the economy and other countries. These interrelationships affect whether forests can play a major role in the global effort to slow the accumulation of atmospheric carbon dioxide. In its review of evidence from past studies in the rapidly evolving topic area of carbon sequestration, this paper complements earlier reviews (e.g., Sedjo et al. 1995). Although numerous

studies have investigated adaptation⁷ and mitigation throughout the world (e.g., Hoen and Solberg 1994), this review focuses mainly on research conducted in the United States (U.S.). One reason is the significant effort in the U.S. to link ecological models to economic models in order to assess adaptation to climate change. In addition, most U.S. ecosystems are dominated by humans, and understanding how humans adapt in these ecosystems is crucially important for understanding potential impacts on industrial wood markets, as well as biodiversity, carbon storage, and other services from forests.

Current Forest Resource and Ownership Situation

The U.S. has approximately 747 million acres of forestland, with about two-thirds (504 million acres) classified as timberland that meet productivity standards and are available for timber management and harvests (Smith et al. 2001). Despite major historical transfers of land to agriculture, the United States still has a very large forested area, roughly two-thirds of the land that was forested in 1600 (Powell et al. 1993). Since 1952, the area of U.S. forestland has declined about 4 percent, with the largest net losses to developed uses (Alig et al. 2002a).

Many biological and economic opportunities exist to increase forest growth on the sizable U.S. timberland base, many of which would increase carbon stores (e.g., Hair et al. 1996, Vasievich and Alig 1996). Tree planting on marginal agricultural land has been suggested numerous times as one strategy for increasing terrestrial carbon stores (e.g., Moulton and Richards 1990, Adams et al. 1999). Currently, less than 10 percent of U.S. timberland is planted. The majority of the planting is in the South, predominantly conifer species on private lands.

Although the planting of trees to create forest plantations has emerged as a major activity in recent decades, about 90 percent of U.S. forestland area has naturally regenerated stands. Major U.S. forest regions have widely different potentials to attract private investments in tree planting and in forest production more generally (Alig et al. 2001). Rapid tree growth generally translates into higher potential economic returns to investors; tree growth is fastest in the South and high-rainfall areas of the Pacific Northwest.

The South, comprised of 13 states, accounts for about 80 percent of U.S. tree planting. The region has large areas of marginal agricultural land that could be planted to trees, and is near major wood-processing facilities that are relatively close to the large concentration of the population in the East. In 1998, 10 states in the South each planted more than 100 thousand acres and collectively planted more than two million acres in 1998, 77 percent of the U.S. total (Moulton 1999). In the remainder of the United States in 1998, the West had 16 percent of the nation's tree planting while the North had 4 percent.

The South is the leading tree planting area in the U.S. for a number of reasons, including a favorable climate (long growing season and generally abundant precipitation), excellent markets for wood due to the heavy concentration of forest industry in the region, and comparatively less competition for land from agriculture. The South does have an important and diversified agricultural sector, based largely on fruits and vegetables (citrus, onions, peaches, and other truck crops), rice, tobacco, cotton, poultry, hogs, and other meats. The South is not a significant producer of major field crops like corn and wheat, which in some other regions require large amounts of area.

Potential for further expansion of tree planting is largely in line with past trends. With tens of millions of acres of non-forest land in the U.S. that potentially could be converted to forests, a majority of such afforestation opportunities are in the South and on private land. Afforestation of such marginal

⁷Adaptation to climate change by affected systems can include autonomous responses by both natural and human systems. In the case of a natural system, plants or animals may migrate to a new location. Humans can change behavior, such as changing planting dates or planting varieties. Such adaptations are in response to an observed impact of climate change, and the actors make the adaptation on their own. Socio-economic factors (e.g., per capita income, education) tend to affect the ability of the system to absorb (robustness) or respond to climate change (resiliency) (IPCC 2001).

agricultural land could economically and substantially increase forest growth and carbon sequestration (e.g., Vasievich and Alig 1996, Alig et al. 1997, Birdsey et al. 2000). An example of how much carbon could be stored is provided by the range of estimates for a hypothetical program to afforest 23-45 million acres of marginal cropland and pastureland (Birdsey et al. 2000, table 8.3). That program would be phased in over a 10-year period and could effect a change in carbon storage of 50 Tg C/yr, at an annual cost of \$350-770 million, with 20-30 years to achieve the program's target.

The South enjoys a cost advantage in that Southern pine seedlings (e.g., loblolly pine and slash pine) need only be grown in nurseries for one year before they are ready for field planting. Currently, high quality, genetically improved Southern pines are available in the South for about US\$35 per thousand seedlings. In contrast, conifer seedlings in the North (white pine, red pine and spruces) and West (Douglas-fir, ponderosa pine) cost US\$150-300 per thousand in the late 1990s. They are typically grown for two to three years, and may have to be transplanted within the nursery.

The U.S. South is a key supplier of fiber for papermaking and contains about two-thirds of the fast-growing coniferous plantations in the world, equal in 1997 to about 30 million acres of Southern pine plantations (Smith et al. 2001). Planted pine area in the South increased more than 10-fold since 1952, evidence of how quickly some changes in the forest resource can occur. The area of planted pine in the South is projected to increase by more than 40 percent over the next 50 years (Alig et al. 2002a).

The projected increase in planted pine area is largely on private lands. Overall, a large majority of U.S. tree planting is by private land owners. Within the South, a proportionately larger amount of forest industry (FI) timberland (32 percent) is planted—as opposed to naturally regenerated—compared to nonindustrial private forest timberland (6 percent), with about 12 percent of the total southern timberland covered by plantations.

Changing forest product market and policy conditions in recent years have been accompanied by marked intensification of timber management on some private lands in the U.S. and with an increasing share of total harvest being derived from private lands. Between 1986 and 1996, the share of U.S. softwood timber harvests from public forests dropped by more than half, from 26 to 12 percent. In the wake of these shifts, rising timber prices induced private investment to enhance timber yields, primarily through the use of improved planting stock. One source of information on such trends is the Resources Planning Act Assessment, which documents current resource conditions and trends, and projects future trends (e.g., USDA Forest Service 2001, 2003). This information helps to establish benchmarks and future milestones for long-term performance indicators, and the Timber Assessment utilizes 50 years of historical data, and makes projections 50 years into the future. The Assessment draws upon more than 70,000 permanent data plots across the U.S. The Assessment considers the broad workings of the economy, such as continuing increase in recycling and efficiency in paper production.

Expansion of U.S. plantation area is consistent with broad trends in other key timber growing regions of the world, where plantations increasingly are the source of industrial wood. Plantations in many cases offer timber supply advantages in terms of location, accessibility, operability, wood type, and wood quality. The vast majority of tree planting on private timberland consists of softwood species, mainly because softwoods have long fibers that are desirable in papermaking and because they produce larger volumes of higher value sawtimber in less time, relative to hardwoods.

From a timber production perspective, planted forests are highly productive on average, compared to naturally regenerated forests. Planted forests are projected to provide a majority of the U.S. softwood timber harvest by 2050, although plantations will only occupy less than one-quarter of the U.S. timberland base (Alig et al. 2002a). The forest landscape of the new millennium may have increasing areas of naturally regenerated forests that will not be managed primarily for timber and could contribute a declining percentage of the nation's timber harvest. Analyses of carbon sequestration potential will need to account for both the fate of carbon in naturally regenerated and planted stands, as well as the carbon storage in products from harvested forests. Minimum cost strategies for sequestering carbon in forests should consider the hundreds of millions of acres of naturally-regenerated U.S. hardwood forests. For example, the North's large concentrations of hardwood forests provide opportunities to increase carbon

stores in hardwood stands (Adams et al. 1999). Hardwood and softwood species grow at different rates and sequester different amounts of carbon, and also have different decomposition rates. Thus, the choice of species mix over time is a further potential tool in meeting certain carbon storage targets.

The extent of the U.S. timberland base and its many forest types provide multiple options for responding to climate-induced changes. Mitigation strategies will be discussed further in the next section, and here I note that the potential of forests to contribute will be affected by any climate change that is occurring. Potential effects of global climate change on the U.S. forest sector, including impacts on forest carbon inventories, may include modifications of growth and geographic distribution of forests. Alig et al. (2002b) examined global change scenarios from the National Climate Change Assessment (U.S. Forest Sector Team 2000), based on a combination of global circulation (Canadian and Hadley) and ecological process (Century, Terrestrial Ecosystem Model) models. The analyses used an equilibrium climate scenario based on transient Canadian and transient Hadley scenarios, with a baseline scenario using average climate for the 1961-1990 period. The climate change scenario was the average of the projected climate for 2070 to 2100. Results indicate the likelihood of an overall increase in forest productivity in the United States, leading to an increase in long-term timber inventory (Irland et al. 2001).

With more forest inventory, timber harvests in most scenarios rise over the next 100 years, lowering timber prices, and reducing costs of wood and paper products. Total economic welfare is higher than in the base case for all climate change scenarios, due to overall higher forest productivity. Adjustments related to market-based incentives include interregional migration of timber production, substitution in timber consumption, altered forest stand management (e.g., change in timber rotation length), salvage of dead or dying trees, shifts in planting stock, and changes in fertilization and thinning regimes. Aggregate welfare effects of climate change for the forest sector are relatively small, consistent with McCarl's et al. (2000) findings that they are relatively limited even under extreme scenarios.

The estimates of increased forest productivity by the ecological process models are consistent with the direction of change indicated by Nemani et al. (2003) in that the Earth has been greening over the past 20 years. Plants have flourished in some places where climatic conditions previously limited growth. Nemani et al. constructed a global map of the net primary production (NPP) of plants from climate and satellite data of vegetation greenness and solar radiation absorption. NPP is the difference between the carbon dioxide (CO₂) absorbed by plants during photosynthesis, and CO₂ lost by plants during respiration. NPP globally increased on average by 6 percent from 1982 to 1999. Ecosystems in tropical zones and in the high latitudes of the Northern Hemisphere accounted for 80 percent of the increase. NPP increased significantly over 25 percent of the global vegetated area, but decreased over 7 percent of the area, illustrating how plants respond differently depending on regional climatic conditions. Some conjecture that a saturation point for the greening may be reached in the future, with much uncertainty surrounding those predictions.

Counter to the opportunities discussed above for sequestering more carbon in forests and wood products, land use changes are likely to result in more deforestation to provide housing and infrastructure. This will decrease the land base on which carbon is stored in vegetation, with recent projections indicating a 3 percent decline in U.S. timberland area by 2050 (Alig et al. 2002a). Prospective land use changes are particularly important for the South, which has been experiencing above-average growth in population (Alig et al. 2002a, Wear and Greis 2002). More than 90 percent of nonfederal land in the United States is in forests, crops, pasture, or range (USDA NRCS 2001). Where climate and physiography permit, these rural uses can compete for the same land, especially in the South, and are also subject to conversion to developed uses.

Markets

The U.S. has a market-based economy, which is an important consideration in assessing potential roles for forestry in reducing the build-up of greenhouse gases, particularly CO₂. Markets reflect the aggregation of individual decisions by sellers and buyers. The decisions of sellers determine the market supply of land and of forest products and services. On the demand side, each buyer determines how many units she or he is willing to buy at each specific price. Aggregation of these individual decisions

determines the market demand. In the marketplace, these supply and demand schedules determine the market price, where the quantity demanded equals the quantity supplied. Prices convey information in markets. Hypothetically, a relatively high market price for forest carbon resulting from a high demand for forest carbon would provide an incentive for producers to supply more forest carbon.

Changing supply and demand conditions can cause changes in forest carbon, leading to changes in carbon sequestration. A number of factors influence supply and demand conditions. These include changing consumer demand for goods and services produced on the land containing carbon stocks and for direct consumption of land, e.g., deforestation through housing developments. Other factors are increases in population size and personal income levels that lead to an increase in demand for agricultural and forest products, potentially affecting the joint production of carbon. In addition to rural land use shifts between agricultural production and forest production, technological improvements affect yields per acre, and increases in aggregate yields can put downward pressure on market prices and alter opportunity costs of carbon storage.

Birdsey et al. (2000) suggest that afforestation and forest management can potentially provide the most additional carbon sequestration in the U.S. over the next 10 – 30 years. Within the market-based U.S. economy, forest carbon management programs would have some key variables: geographic scope, subset of forestry practices and suitable land for each practice, treatment costs and land costs for each practice, and annual carbon yield for each practice in a specific geographic area. Accomplishments of the carbon program would be evaluated against a baseline. Even in the absence of any incentives or explicit programs to encourage carbon sequestration, the nation is sequestering carbon in its forests, and in baseline projections is expected to continue to do so over the next several decades (e.g., Birdsey et al. 2000).

Estimates of costs for carbon programs differ notably across some studies, in part because of differences in scope and underlying assumptions built into the analyses. This includes whether opportunity costs of the land and market effects on land and resource prices are incorporated, causing estimates of carbon sequestration to rise. For example, Birdsey et al. (2000) indicate a broad range of U.S. cost estimates, and Kauppi et al. (2001) show a wide range across regions of the world. In general, higher costs are associated with high opportunity costs for land. In regions that have low opportunity costs for land, including many subtropical regions, the costs tend to remain relatively low (Kauppi et al. 2001).

In a market-based economy, values for carbon can affect incentives and management of our wealth of timberland and timber stocks. How forest carbon relates to such decisions is discussed by Sohngen et al. (2002). An example is the potential effects of forest carbon dynamics on forest rotation lengths. If forest carbon dynamics influence marginal decisions to harvest forests, there could be large changes in overall storage. For instance, if forest carbon releases are large at harvest time, and carbon subsidies or payments exist, landowners may have an incentive to hold trees for longer periods of time (i.e., longer timber rotation) to accumulate carbon payments. This could affect both above-ground and soil carbon storage.

Landowners are unlikely to manage their forest resources for carbon sequestration alone, and in the absence of financial incentives, any carbon sequestration will likely be incidental (Kauppi et al. 2001). Different payment mechanisms have been proposed in the literature to provide incentives for landowners to sequester carbon in forestland. Some payment mechanisms may be adapted more easily than others to include forest carbon. These mechanisms include renting land (as in the current USDA Conservation Reserve Program), paying only for land-use change, renting carbon directly, and other methods. See Sohngen et al. (2002) for a discussion of the relative efficiency of a number of different payment proposals in terms of their potential to maximize forest carbon sequestration.

A question regarding afforestation practices and landowner incentives is how landowners will retain forest practices, especially tree plantings on former agricultural land. Research indicates that owners tend to retain a large majority of government-subsidized plantations well beyond the program date (e.g., Alig et al. 1980, Kurtz et al. 1996). The plantations also generally are well stocked with trees, and are often regenerated back to forest after harvest.

Unintended Consequences of Policies

Institutions for managing and storing carbon have increasingly been discussed but no national institution serving this purpose exists currently in the U.S. Policies and technological changes can contribute to forest carbon changes within our market-based economy. To date, studies have mostly examined hypothetical policies or institutions, and the following literature review reflects that situation. For example, Alig et al. (1997) examine market effects of targeted hypothetical tree planting on agricultural land, to see if leakage² with respect to policy aims was significant if the amount of tree planting was large enough.

Case of Longer Rotations

Recent policy proposals aimed at increasing carbon sequestration have included those that lengthen timber rotations to maintain larger areas of older stands. The extending of rotations for softwood stands would increase the carbon sequestered by U.S. forests in the first projection decade by 17 percent compared to a base case (Alig et al. 1998). However, the forest carbon addition under the policy is less than under the base case for the subsequent two decades.

Carbon-related changes for the longer-rotation case compared to the baseline are influenced by intertemporal shifts in timber harvest when the policy alters market signals. Longer rotations would concentrate some beneficial forest carbon storage and ecological effects in the first projection decade, but the economic impacts could subsequently include disincentives for landowners if enough other owners decide to participate. If enough owners delay harvest of their timber, timber prices could rise in the short term, prompting some owners of other timber stands to harvest in the near term. Prices could drop in subsequent years if enough owners with older timber decided to harvest in the same period.

On the biological side, dynamics of harvest, timber processing, decomposition, and forest regeneration affect the intertemporal path of forest-related carbon amounts relative to the base case. Because large amounts of carbon are sequestered in parts of the forest sector other than tree boles, and because solid forest products generally decay slowly and release carbon gradually after harvest, projected carbon levels can continue to rise even after the total merchantable bole volume has stabilized or begun to fall. Different classes of forest products have markedly different patterns of carbon storage and release in consumption (Harmon et al. 1990, Kershaw et al. 1993).

Empirical investigation of the impacts of extended timber rotations by Alig et al. (1998) focused on private timberlands, which provide more than three-quarters of current U.S. timber harvest. Their study examined longer forest rotations for softwood types only on private timberland, using 10 years in the South and 20 years elsewhere in the U.S. In terms of environmental changes, the extended rotation scenario results in substantially more land use change in the first projection decade than in a base case used as a comparator. The extended rotation policy leads to higher timber product prices that boost land rents in forestry. This causes more land to come into forestry, with the amount of land use changes more than double that under the base case. In particular, most of the land reallocation would be in the eastern U.S.

Environmental impacts of the extended rotation include an increase in the area of hardwood forest types relative to the base case. Overall, an increase in hardwood area could benefit those wildlife species dependent on hardwoods for habitat and food. Areas of planted softwoods would increase in the near-term, but decrease in the long term as softwood timber supplies increase when the older stands reach the extended harvest age. That is, the extended rotation policy could result in a build-up of softwood inventory relative to the base case and lead to a longer-term moderation of softwood accretion relative to

²Leakage in general involves projects or policies having offsetting effects elsewhere, and can originate with a number of land use and management activities (e.g., afforestation, timber harvest, reforestation). Leakage can happen, for example, when market forces at relatively large scales include price changes in land markets that lead to less net tree planting than envisioned by program planners (Alig et al. 1997).

the base case. Longer-term levels of higher timber volumes at the extended rotation age lessen the need for softwood plantations. The extended rotation scenario produces age class distributions with more trees in older age classes and fewer in younger classes, thereby altering forest structures accordingly. Unintended consequences can be positive or negative, and forest managers need to consider all costs and benefits - of which carbon is one component - of different alternatives. For example, additional or accompanying co-benefits of a carbon sequestration-oriented policy may include changes in wildlife habitat.

Major market effects of the extended rotations are concentrated in the first several decades of the projection. In effect, the scenario forces postponement of harvest of some timber that was financially mature in the first few decades of the projection. The policy would exacerbate conditions of limited merchantable private timber inventory in the U.S. during the first several projection decades. Projected prices in these decades are more than 50 percent higher than in the base case. When the associated acres move above the higher age minimums, their volumes are larger and consumption and prices return quickly to the base levels. The extended timber rotation policy would also affect agricultural commodity prices, as the grain price index is 3 percent higher for the first projection decade than under the base.

In sum, an extended forest rotation policy would have consequences for the environment that are not directly associated with the goals of more forest carbon sequestration (e.g., changes in forest cover type areas). The policy would also have economic impacts on both the forest and agricultural sectors.

Other examples of unintended consequences of policies related to global warming mitigation are given by Alig et al. (1997) and Alig (2001). Forests can provide cost-effective means for obtaining sizable near-term increments in stored carbon (e.g., Adams et al. 1999). Regardless of carbon flux target, cost effective policies may involve both the expansion of forest area and modifications in the management of forests. Leakage via unintended (and unregulated) adjustments in land use between forest and agricultural sectors in response to a sequestration policy can be substantial. Sequestering substantial additional amounts of carbon via afforestation of agricultural lands may have only modest economic welfare impacts on the agriculture sector. Efforts to increase forest carbon could have a different geographic and species focus than previous studies suggest. Policy simulations show that forest sector mitigation options can be an economically effective short-intermediate term strategy. Permanence issues include whether current sequestration is followed by future releases. Policy design can greatly affect the amount of leakage. Synergies between climate change productivity, carbon prices, and sequestration rates are substantial.

Considerations in Decision-Making

Those involved with natural resources who may need to make decisions concerning climate change represent a broad and varied set of people, whether individual or in groups. Such decisions in some cases will be part of a larger set of everyday decisions. The potential role of forests in reducing greenhouse gases increasingly involves complex tradeoffs among biophysical, economic, ecological, and societal values. Knowledge regarding the value of GHG reduction to different groups and methods with which to evaluate the biophysical, economic, ecological, and social tradeoffs associated with allocating limited resources among competing uses is vital to devising appropriate and effective forest carbon policies.

Next, I summarize selected findings from the literature that may aid in developing carbon management strategies that are ecologically sound, economically efficient, and socially acceptable.

1. Demand for scientific information about climate change for use by land managers and policy makers involves several parts of the decision-making process: an understanding of the overall system and key component and linkages; development of management or policy options; and estimation of the likely effects and outcomes of management actions and policies. Science pertaining to the linked aspects of climate, ecological effects, economic impacts, and social concerns has evolved substantially over the last decade. To help in informing decision makers, future choices pertaining to adaptation and mitigation should be assessed with consideration of dynamic interactions among

climate, ecological, and socio-economic systems and attendant effects on agriculture, forestry, and natural resources. Science-based assessments can support analyses of environmental, social, and economic costs and benefits, and implications of these interactions for integrating climate change response strategies in an equitable manner into broad sustainable development strategies. Joint consideration of ecological, economic, and social aspects of forest carbon sequestration requires a broad systems view.

The broad systems view would help promote an effective linking or coordination of related policies. Forests produce multiple goods and services, and climate change strategies can affect biodiversity and other environmental elements. In the case of afforestation as one policy tool, one possible biodiversity advantage could be in the form of enhanced populations of forest-dependent species. One example is neotropical birds, many species of which are declining in numbers. Matthews et al. (2002) show that assessment of the biological consequences of afforestation for carbon sequestration must consider both current land cover and the distributional patterns of organisms as well as the policy's conversion goal. In addition to carbon credits, biodiversity-related credits could be earned if financial incentives were offered for such ecosystem services.

Activities on both public and private forestland should be jointly assessed, given differences in average frequencies of timber harvest and other disturbances that affect carbon stores on the land and in products. Policies should be developed with the multiple environmental attributes in mind, with consideration given to coordinated policies. For example, integrated policies might address both forest fragmentation and forest carbon storage. Integrating climate change response strategies into broad sustainable development strategies could enhance multiple benefits of forest carbon sequestration, across biophysical, economic, ecological, and social facets.

The systems view includes policy considerations at both temporal and geographic scales. Changes at both scales involve a human ecology portion that includes physical patterns observed on a landscape. The economics portion involves consideration of private versus social viewpoints, in that some effects are external to private producers' and consumers' outcomes. The bulk of research examining possible impacts from global warming has been biophysical in nature (e.g., Neilson and Marks 1994). Forest strategies to sequester more carbon have multi-dimensional environmental attributes, involving biophysical, ecological, and economic facets. Although there has been some cooperative work across disciplines (e.g., Sohngen et al. 1998, Krankina et al. 2001), more integrated research involving both biophysical and socio-economic aspects is needed. On the dynamic socioeconomic side, the world population is projected to grow from six billion to nine billion by 2050. At the same time, national population is projected to grow by 126 million people by 2050, a 40 percent increase. More than half of the U.S. population lives on 17 percent of the area in coastal zones. Growth in population, along with increasing incomes, will affect ecosystem stewardship in the face of global warming, while at the same time we strive for desired levels of human welfare.

2. Analyzing the efficacy of climate change strategies involves considering possible impacts of mitigation practices as well as how to entice landowners to undertake such practices. In addition to engineering estimates of costs of forest carbon sequestration, policy makers need to consider the behavioral aspect and how that may affect actual costs of mitigation practices. For example, what incentives will be required to motivate landowners to get involved and to stay involved in forestry practices that sequester carbon? A wide range of forestry or wood product practices could be used to store more carbon, including converting marginal agricultural land to forests, short-rotation woody crops, enhancing forest management, and substituting wood products for more energy-intensive products. Linkage between forestry practices and storage in wood products warrants attention, as likelihood of replanting after harvest can affect carbon storage totals. Evidence from studies of landowners' tendencies to plant trees can aid in guiding mitigation strategies, in that upfront costs tend to overshadow the more time-distant revenues from timber harvests (e.g., Lee et al. 1992, Kline et al. 2002). This suggests that cost subsidy programs may be necessary to entice additional tree planting by nonindustrial landowners for carbon sequestration purposes. Studies also suggest that such tree plantings tend to be retained for relatively long periods (e.g., Alig et al. 1980). In addition to tree

planting subsidies, possible responses to other incentives, such as taxes (e.g., van Kooten et al. 1995), are also worthy of examination.

The traditional approach to addressing environmental problems has been command-and-control. However, solutions to environmental problems have increasingly taken a variety of institutional forms that are better suited to landowner behavioral tendencies. In the U.S. the current trend is to encourage adoption of trading and related incentive-based instruments (Randall and Taylor 2001). In the case of regulation, theory suggests that incentive-based instruments reduce compliance costs by encouraging efficient resource allocation and innovation in environmental technology. In the GHG case, the future may see more carbon trading, with trading institutions involving tradable permit markets. This may be accompanied by more incentives for landowners to modify land use and management practices to store more carbon. Yet, costs and complexity of administering an otherwise ideal plan may preclude its use. However, there have been many examples of programs that have attempted to induce land use changes through various subsidies (Alig et al. 1990), such as the Conservation Reserve Program that shifted about 40 million acres of U.S. cropland to alternative cover crops (Plantinga et al. 2001). Whether other aspects of forest management, such as rotation age, can be influenced similarly is open to question.

3. Unintended consequences of climate change policies should be considered, given previous experiences with other government programs. Just as lifestyle choices can result in unintended consequences at times, public policies sometimes can have unintended results in addition to planned outcomes, including effects across sectors (e.g., leakage possibilities). For example, if leakage is a serious issue at larger scales (Alig et al. 1997), then governments could invest large sums of money in subsidies or other incentives with relatively little net gain in forest carbon or secondary benefits.
4. Studies of costs of carbon sequestration in forests (e.g., Moulton and Richards 1990) have provided a wide range of estimates; however, the estimates are comparable to, and in some cases lower than, costs of alternative mitigation and abatement approaches. Forests play an important role in the global carbon cycle, and land-use changes have been suggested as important mitigation options. However, two unresolved issues pertain to accounting for costs and benefits and appear to have counteracting impacts regarding the efficiency of forests' potential contribution to global warming mitigation (Richards and Stokes 2002). The first issue is that secondary benefits or co-benefits of converting agricultural land to forests may be as great as the costs. Secondary benefits include reductions in sediment, nitrogen runoff, and soil erosion; improvements in hunting and biodiversity; and other non-consumption benefits. This could lead to forestry as a no-regrets strategy. The second issue is leakage through markets (e.g., Alig et al. 1997). Whether these two countervailing effects will tend to offset is unknown.

Costs of carbon sequestration in forest ecosystems in the future may also be impacted by a wide variety of other factors in our economy. Examples of factors with potentially opposite impacts are conversion of forest land to developed uses and increasing productivity of existing forestland. The rate of conversion of rural land to developed uses increased in the 1990s, and future increases are projected to be substantial due to U.S. population growth (USDA Natural Resources Conservation Service 2001, Alig et al. 2003). This can affect costs of forest carbon sequestration in two ways. First, it can reduce the total supply of carbon in forests because of deforestation. Second, it can cause land prices for rural lands to rise in land markets, as they become scarcer due to conversion to developed uses. This can increase the costs of storing carbon in forests. As an opposing factor to offset increases in costs of forest carbon sequestration, an expanding area of faster growing private forests (e.g., pine plantations in the U.S. South) (Alig and Butler 2003) will supply more of the nation's timber needs and may allow forests in other parts of the country to be used more for other purposes (USDA Forest Service 2003), which can include increased carbon sequestration.

5. Transaction costs may be significant when considering implementation of strategies and operational climate change mitigation activities. Without a broadly established carbon market, components of mitigation activities for which costs are currently not well known are: measuring forest and soil carbon at different scales, monitoring, cooperatives or marketing groups to allow economies of scale in carbon

supplies, estimating additions to “baselines,” and carbon reporting. Land ownership can also change relatively frequently. If carbon “banking” becomes a reality, there may be legal implications for changes in land ownership or changes in land management practices such as converting forests back to agriculture land during a carbon rotation. Other institutional developments that may arise are carbon trading (e.g., utilities paying for carbon sequestration in private forests), and transaction cost estimates are not well-known for such endeavors.

6. A central forestry-related finding is that there will be a greater reliance in the future on managed forests, private forests, plantations, and recovered fiber; processing capacity will change in line with these trends. There will also be a greater reliance on smaller diameter and more uniform wood raw material (USDA Forest Service 2001, 2003). Concurrently, processing capacity to handle larger logs will decline, which may affect prices received for larger logs in the future.³ Landowners will want to recognize this, given that larger logs would be produced by longer rotations under carbon-related policies to mitigate global warming. Technological changes will continue to alter processing capacities, in addition to how timber is grown and other forest benefits are provided (e.g., storage of forest carbon).
7. Scale is important in that adaptation may sometimes be more of a local response, while mitigation actions or policies may typically be formulated at broader geographical scales. However, market-based responses at higher geographical scales can also lead to adaptation. For example, the forestry and agriculture sectors may undertake adaptive market-related adjustment to climatic shifts, including changing mixes of products produced, land-use shifts between the sectors, and alteration of the intensity of management among forest owners and across regions. Adaptation may be part of the “baseline” and it is difficult a priori to estimate what may occur in the absence of global warming mitigation activities. Economic considerations are important for defining appropriate measures of global change at different scales, determining implications, and identifying appropriate and efficient technological and policy responses. Interdependencies in the economy lead to concerns at larger scales about the extent to which climate change policies would affect other activities in the economy and also how they would interact with other government policies.

During the past 15 years, links among forests, human activity, and potential climate change have been heavily researched. Studies on adaptation have focused mostly on exploring the relationship between the ecological impacts of climate change and timber markets (e.g., Binkley 1988). Given that recent assessments suggest that “adaptation options for ecosystems are limited, and their effectiveness is uncertain” (Watson et al. 1998), a closer examination of existing economic studies may provide additional insights into adaptation processes at different scales. Mitigation represents one of the most important links among humans, forests, and climate change through potential effects on the global carbon cycle (Sohnngen and Alig 2000).

Those designing climate change policies need to consider how the interaction of natural and human systems may lead to changes outside the historical range of behavior. Land-use and land-cover changes can be a driver of environmental and climatic changes. For example, at a larger scale, land use change, such as farming or urban sprawl, has been reported as a major factor contributing to climate change (Cai and Kalnay 2003). Until now, policy makers have focused mainly on how heat-trapping gases such as CO₂ are contributing to global warming. However, land surface changes caused by humans may redistribute heat regionally and globally within the atmosphere and may actually have a significant impact on climate. Cai and Kalnay (2003) estimate that about half of U.S. climate warming is due to land use changes. Urbanization and the growth of industrial agriculture are responsible for more of the rise in temperature across the United States than previously thought.

8. Interactions of humans and natural resources are likely to expand. The specter of global climate change has reinforced the understanding that humans can significantly impact natural systems, at a broad range of scales. At the same time, what people do, what they know and care about, and what

³Changes in processing capacity for larger logs are being investigated currently by Oregon State University; personal communication, Eric Hansen, Dept. of Forest Products, May 7, 2002.

values and perceptions they hold affect natural resources and are affected by natural resource management. In a changing socio-economic context, scientists are recognizing that interactions between humans and natural resources at multiple temporal and spatial scales can be quite complex. Interactions include both targeted and other effects. Targeted interactions include those under the Kyoto Protocol that is primarily designed to reduce GHG emissions, which some countries have adopted but for which the ultimate climate benefits are uncertain at present. Ultimate impacts of carbon mitigation policies under the Kyoto Protocol on the economy will be determined by complex interactions between elements of aggregate supply and demand, in conjunction with monetary and fiscal policy decisions.

Other institutional structures, such as international trade agreements (e.g., Softwood Lumber Agreement for Canada and the U.S.), reflect socio-political interventions in market economies. Such arrangements warrant consideration when society considers how to address global climate change. For example, a majority of Canada's forest product exports go to the U.S. and any changes in trade agreements may affect forest resource conditions and prices in both countries, thereby altering prospective costs of forest carbon storage in North America. Adams (2003) reports that recent imposition of another import tariff on Canadian softwood lumber found support both as a means to offset alleged unfair Canadian cost advantages and to force reductions in Canadian old-growth harvest. His analysis provides estimates of the traditional market impacts associated with this policy, plus the less commonly considered resource tradeoffs. Under a tariff, the cross-border harvest trade-offs include that most of the Canadian forest inventory savings would be in older forests, while most of the U.S. inventory reduction would also be in older stands. That is, timber harvest will decline in Canada due to the tariff but rise on private lands in the U.S., lowering U.S. softwood inventories. Given smaller volumes per unit area in Canada forests, the land area unharvested because of the tariff would likely be larger than the expanded harvest area in the U.S.

9. Climate change decision making must deal with uncertainties (Winnett 1998), including the risk of non-linear and/or irreversible changes, and requires balancing the risks of either insufficient or excessive action. Risk studies could analyze sensitivity, effects of gradual versus abrupt climate change, and imperfect information and models. Feedback effects also need to be considered, using an integrated resource modeling system that has biophysical, ecological, and socio-economic components. Within a broader context, this can include examination of precautionary principles, changing social values, and equity issues (e.g., who gains or loses when resources are reallocated). Forest management questions increasingly require use of human-related sciences to address policy and management issues, and to clarify social issues related to public policies. The lens through which we view—and judge—transformations can change from generation to generation. Currently, “forest sustainability” emphasizes maintaining integrity of ecological systems while providing goods and services. Future efforts to promote forest sustainability will be impacted by what happens to the Kyoto Protocol under The Framework Convention on Climate Change, and by significant uncertainty that surrounds social aspects of global climate change.

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Final Workshop Summary and Scientific Conclusions

Climate Change, Carbon, and Forestry in Northwestern North America

The workshop brought together scientists, practitioners and policy makers from a variety of different backgrounds in northwestern North America. It started with the premise, accepted by the Intergovernmental Panel on Climate Change, that “the balance of evidence suggests that there is a discernible human influence on global climate” (IPCC 1996) and that “there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities” (IPCC 2001). While there is uncertainty over the extent of the warming that can be attributed to human activities over the past 150 years, much of the warming over the past 50 years can be linked with some confidence to greenhouse gas emissions. The effects of this warming will vary regionally, being beneficial in some areas and disruptive elsewhere.

Forestry has a role to play in reducing the extent of warming caused by greenhouse gases, particularly carbon dioxide (CO₂). First, increased carbon sequestration by trees and forest ecosystems can temporarily reduce the rate of increase in atmospheric CO₂ concentrations, providing time for other control measures to be brought into effect. Second, the use of biofuels as a substitute for fossil fuels such as oil and coal will help to reduce overall CO₂ emissions. Finally, wood products can be substituted for other materials that are produced through fossil fuel emissions (such as steel, cement, and plastics).

Much of the landscape in the Northwest is currently in a “regrowth” phase with younger forest stands. Active management for sequestration of carbon in living trees and wood products may be able to account for up to 30 percent of current levels of CO₂ production in the region. This means that forest management can significantly reduce net emissions to the atmosphere, but is only a partial solution to reducing total greenhouse gas emissions.

Forest Management Strategies

Several potential forest management strategies for sequestering carbon exist. These strategies present risks to forest managers, but maintaining the status quo is also risky given our knowledge about the extent of climate change over the past century and the predicted changes in climate in future decades. In order to increase carbon sequestration, the following strategies could be adopted: increased rotation lengths, increased residual material left in the forest after harvesting, and use of the most productive land for the most intensive forestry practices. The first two of these have a number of secondary benefits, including the conservation of biological diversity. The third strategy has a number of advantages, including the potential to set aside reserves of old-growth forest, given that forest productivity elsewhere is being increased. This latter strategy is of particular importance in areas where significant areas of old-growth forest remain.

Wood Utilization Strategies

There are a number of ways in which wood utilization could be altered in order to increase the amount of carbon stored. First and foremost, the increased use of wood in buildings and other structures would be a major benefit. There are various means by which the lifetime of this wood could be extended, but these have not been fully exploited. During the manufacturing process, the amount of wood waste could be reduced, with the added benefit that the recovered wood waste, once processed, has an economic value. Finally, the amount of wood that is recycled could be dramatically increased given recent advances in wood processing and the construction of composite materials.

Institutional Arrangements

Encouraging forest management and wood utilization that sequester more carbon requires a viable economic framework. This is perhaps the biggest challenge to creating real change in the status quo,

especially in areas where forest owners and manufacturers are struggling financially. Trading of greenhouse gas emission credits (carbon credits) is in its infancy, there is no stable marketplace, and business guidelines are limited. The current value of carbon credits is low, although this value could increase considerably in the future. In some cases, carbon credits may be a viable option for smaller landowners who join in cooperative ventures. International trading may also be possible. In order to stimulate a carbon marketplace with less risk for investors, governmental institutions at all levels would need to develop a structure conducive to broad-based participation by forest landowners.

Regulations

While it would be possible to use regulatory mechanisms to encourage the integration of carbon sequestration strategies in forest management, such an approach is against the prevailing philosophy of the governments in the region. If a regulatory mechanism were to be adopted, it would require an integrated approach that includes both the biophysical and economic components of the system. In addition, other forest values would need to be considered, such that carbon sequestration was balanced against all forest functions. The sequestration and accounting would need to be effective across all scales. While these seem like stringent requirements, there are already systems in place in a number of areas (e.g., Australia) that could be used as a model for North America. Regardless of whether regulations are developed, economic incentives (a viable carbon marketplace and/or subsidies) would likely be needed to ensure long-time participation.

Contribution of the Private Sector

The private and public sectors will likely play different roles in how forest management addresses climate change and carbon sequestration. While the private sector has a major role to play (particularly in the US), it lacks incentives to participate in sequestration efforts. These incentives are particularly important on industrial private forest land with short rotations for timber harvest. On nonindustrial private forest land, other values (e.g., wildlife, aesthetics) are more compatible with longer rotations and long-term carbon storage. Although regulation could provide such an incentive, government regulation and control are not always compatible with innovation. Nongovernmental organizations can play a major role in this issue through facilitation, education and other means.

Grass Roots Efforts

In Europe, Agenda 21 (a document developed at the 1992 United Nations Conference on Environment and Development) provides the basis for local action on sustainability. The document recommends action at the local level, with consumer behavior playing an important role in the development of sustainability strategies. This approach of local and community action can have an enormous impact when replicated at many locations. Most people in North America are not yet ready for the sort of lifestyle changes that are needed to significantly reduce greenhouse gas emissions. However, if any region of North America is likely to change, it will be the Northwest, where environmental values and community-based social activity are important to many of the residents. Cooperative efforts among stakeholders at the local level could be especially effective in addressing issues of carbon sequestration.

Conclusion

Many North Americans are only now beginning to realize the potential significance of climate change. At present, the United States does not support the current structure of the Kyoto Protocol to the Framework Convention on Climate Change, while Canada has supported it. Regardless of the current policy environment, forestry provides one means by which carbon sequestration can be achieved while concurrently producing a number of other benefits. Management of carbon in forests, essentially a new resource target, provides an attractive means by which policy makers can achieve a number of environmental, economic, and social benefits.

Over a century of timber harvest in the Northwest has contributed large amounts of CO₂ to the atmosphere. But now forests are regrowing and being managed for longer-term objectives and sustainable resource production. Including carbon sequestration as a discrete management objective throughout the cycles of forest growth and use of wood products is a great opportunity to address the global issue of greenhouse gas emissions at both the regional and local levels.

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