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Introduction

Human-induced climate change is an important environmental issue worldwide, as scientific studies increasingly demonstrate that human activities are changing the Earth's climate. For more than 420,000 years the CO_2 abundance in the atmosphere was bounded, oscillating between about 180 and 280 parts per million (ppm) over the glacial and interglacial periods. However, since the Industrial Revolution, the CO_2 abundance has risen to 375 ppm and continues to rise according to the Intergovernmental Panel on Climate Change (IPCC, 2001). Research suggests that most of the observed global warming of the past 50 years, including the increase in atmospheric CO_2, can be attributed to human activities (IPCC, 2001; see Box 1-1). Even if dramatic reductions in emissions were made today, some human-induced changes are likely to persist beyond the 21st century because of the slow response of the climate system caused by the long residence times of many greenhouse gases in the atmosphere, the large heat capacity of the oceans, and the dynamics of other components such as ice sheets and the biosphere. Nevertheless, current research indicates that taking measures to limit CO_2 emissions in the atmosphere can mitigate these impacts (IPCC, 2001). Considerable attention has focused on measures that could be taken by the energy sector, but land use, land use change, and forestry activities have also been proposed as a means of moderating the effects of climate change, either by increasing the removal of greenhouse gases from the atmosphere or by reducing emissions.

BOX 1-1
Background on the Carbon Cycle

William Schlesinger, Duke University, provided an overview of the global carbon cycle to provide background to the discussion of direct and indirect effects on carbon fluxes. The abiotic elements of the carbon cycle include volcanic emissions, carbonate and silicate rock weathering, and air-sea exchange, (see Figure 1-1), although carbon fluxes expand substantially with the addition of biotic processes (see Figure 1-2). For the mid-1990s, Schlesinger noted that the exchange in and out of the terrestrial biota was more than 100 Pg C/yr. Much of this carbon is either respired within the terrestrial biosphere or is emitted by decomposers or fires. A rough balance exists between the natural exchange of terrestrial inputs and outputs of carbon, with only a small amount escaping decomposition and moving into the soil pool.

The human impact on the carbon cycle is twofold. First, humans are converting forests to agricultural lands and thus releasing carbon from forest stands and soil reservoirs, particularly in the tropics. The burning of fossil fuels also serves as a very large source of carbon in the atmosphere. The amount of atmospheric carbon released from fossil fuel emissions is four or five times larger than estimates of carbon emissions from net vegetation destruction. When comparing the sum of these net human-induced atmospheric emissions with estimated carbon sinks, Schlesinger highlighted the residual sink, which illustrates the current incomplete understanding of carbon uptake. The residual sink (previously called the "missing sink") represents the apparent imbalance in global CO_2 accounting:

Atmospheric increase = Fossil fuel emissions + Net emissions from land use – Ocean uptake – Residual sink.

It has been estimated (by difference) at 2.9 Pg C/yr for the 1990s (Houghton, 2003). Robert Watson of the World Bank noted that the residual carbon sink appears to be increasing, up from 1.9 Pg C/yr in the 1980s. Schlesinger proposed several explanations for this residual sink, including carbon accumulation in the undisturbed terrestrial biosphere due to CO_2 fertilization. Forests may also be growing back on previously deforested land or changing their distribution on the landscape in a way that replaces low carbon sinks with high carbon sinks. Research has shown that the Earth's biota have a strong effect on the global carbon cycle through seasonal fluctuations in CO_2 (e.g., Keeling and Whorf, 2004; see Figure 1-3). Because the residual sink is thought to originate from terrestrial processes, the net terrestrial flux can be calculated as follows:

Box 1-1 (continued)

Net terrestrial flux = Net emissions from land use – Residual sink.

Schlesinger stated that the origin of this residual sink has significant implications and opportunities for policy makers. If the sink exists in forested or agricultural land and policy makers are concerned about global warming, the function of that portion of the biosphere (removing CO_2 from the atmosphere) would merit preservation. Schlesinger noted that if this sink were lost, atmospheric CO_2 concentration could rise much faster. However, he noted that a policy intended to absorb much of the nation's emissions, let alone much of the industrialized world's emissions, through land use and forestry would be unrealistic. Schlesinger's rough calculations based on typical sequestration rates suggest that it would take extremely large areas of forest lands (Schlesinger calculated 2.2 million miles^2 or nearly 10 times the area of Texas) to offset annual U.S. carbon emissions.

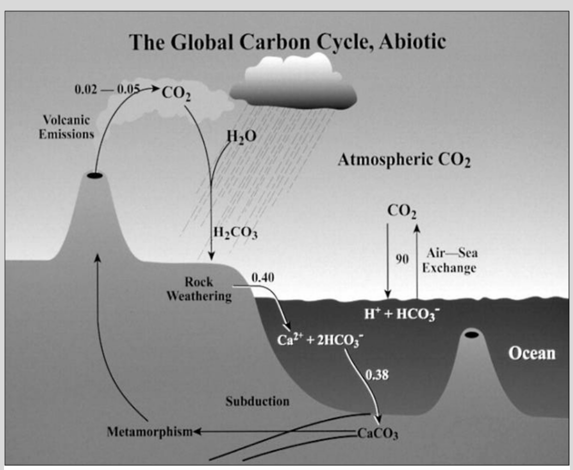

FIGURE 1-1 The global carbon cycle on a lifeless earth. All units in petagrams of carbon per year. Source: Schlesinger (2003)

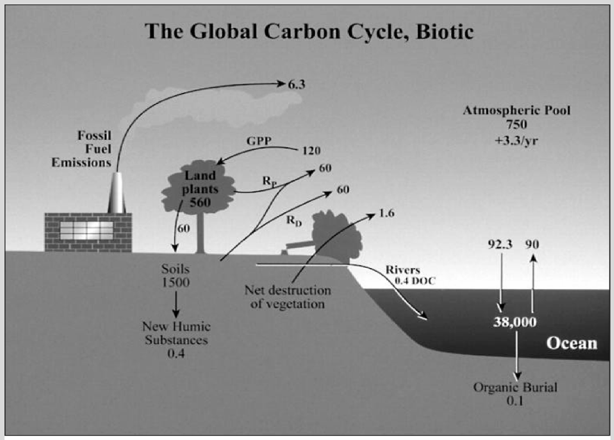

FIGURE 1-2 The global biotic carbon cycle. All units in petagrams of carbon per year. Source: Schlesinger (2003.)

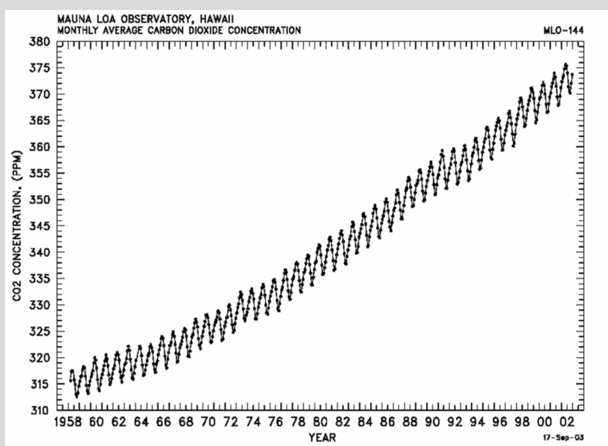

FIGURE 1-3 CO_2 measured at Mauna Loa Observatory. Source: Keeling and Whorf (2004)

DIRECT AND INDIRECT HUMAN-INDUCED EFFECTS ON GREENHOUSE GASES

The United Nations Framework Convention on Climate Change and the Kyoto Protocol (see Box 1-2) both call for emissions reporting that separates human activities directly affecting atmospheric concentrations of greenhouse gases from those caused by indirect and natural factors. Examples of direct influences on greenhouse gas fluxes are the burning of fossil fuels and management actions such as reforestation, agricultural practices, and fire suppression. Examples of indirect influences include CO_2 fertilization, nitrogen deposition, acidic deposition, temperature and precipitation changes, invasive species, and tropospheric ozone. Natural effects on greenhouse gas fluxes could occur due to climate variability, pests, or changes in fire frequency and intensity (not including human efforts at fire suppression).

At the workshop, Christopher Field noted that the main motivation for factoring out direct and indirect effects in any carbon management scheme is to provide credit for something that requires an investment for purposeful action. By separating direct and indirect effects, countries are not punished or provided credit for an accident of nature, such as the fact that a country's forests happen to be sensitive to CO_2 fertilization. Accordingly, countries are not given credit for actions in the past, such as regrowth in a previously harvested forest. The Intergovernmental Panel on Climate Change (2000b) reports that approximately 2.2 petagrams[1] of carbon per year (Pg C/yr) is sequestered globally by terrestrial

BOX 1-2
International Response to Rising Greenhouse Gas Emissions

The international community is addressing the issue of rising greenhouse gas levels through the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The UNFCCC articulates the long-term objective as follows: stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human-induced interference with the climate system, with a specific focus on food security, ecological systems, and sustainable economic development. The Kyoto Protocol aims to supplement and strengthen the UNFCCC by setting legally binding emissions targets and including steps for implementation, accounting, reporting, and review. Specifically, the Kyoto Protocol requires most industrialized countries to reduce emissions by 2012 to 5 to 8 percent below those emitted in 1990. The UNFCC and Kyoto Protocol provide the context for climate change research.

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[1] Petagrams are equivalent to 10^{15}grams or 1 gigaton (Gt).

ecosystems through biomass growth resulting from CO_2 and nutrient fertilization and changing climate and regrowth resulting from natural regeneration.

The definitions of indirect and direct effects were one focus of discussion at the workshop. Although Michael J. Prather emphasized that the definitions of direct and indirect effects are ultimately negotiated by global policy makers and the workshop participants agreed not to debate this, the discussion is presented here to illuminate some of the participants' concerns. For context a recent IPCC discussion of direct and indirect effects is presented in Box 1-3. Indirect human-induced effects were generally considered by workshop participants to result from environmental changes that could affect rates of photosynthesis, respiration, growth, and decay, such as elevated atmospheric CO_2 concentrations, increased deposition of nitrogen, or changing weather patterns that result from human-induced climate change. Direct effects were generally viewed as management influences that produce a change in greenhouse gas fluxes. However, there was some discussion as to whether a manager also needed to have the intent to influence carbon fluxes to classify the effect as direct. For example, can CO_2 fertilization be considered a direct effect if the decision was made to abandon cropland to forest knowing that CO_2 fertilization would add to the carbon uptake?

BOX 1-3
Direct and Indirect Activities in the Kyoto Protocol

The following description from IPCC (2000b) highlights potential interpretations of direct and indirect activities in the Kyoto Protocol:

The Kyoto Protocol distinguishes between direct and indirect human-induced land use change and forestry activities. The word "direct" precedes the phrase "human-induced" in Article 3.3 but not in Article 3.4. Temporal and spatial immediacy may indicate directness; the closer in time and space the activity is to the impact, the more direct it is. Intent and foreseeability also might be relevant in determining directness.

One of the most significant distinctions between direct activities and indirect influences relates to the effects of CO_2 fertilization and nitrogen deposition. CO_2 fertilization and nitrogen deposition are indirect because the removals are not geographically immediate—that is, they may occur thousands of miles from the site of the emissions. The fact that enhanced growth of biota is a completely unintended consequence of the polluting activity also argues in favor of treating it as an indirect activity. Moreover, CO_2 fertilization and nitrogen deposition cannot reasonably be described as land use change or forestry activities.

Workshop participants also discussed how much of the residual carbon sink can be attributed to indirect effects. Ian Roy Noble commented that there is an assumption that the amount of carbon out of equilibrium can mostly be considered the indirect effect, and both Eric Sundquist and Prather agreed that the residual sink could be considered equal to the indirect effect. However, Richard A. Houghton and Rattan Lal pointed out that current estimates of carbon flux from landuse change are probably incomplete, thus underestimating the current carbon sink attributed to land use change and overestimating the residual sink. For example, a forest's recovery from disturbance 20 years ago may in fact be a past management effect, but it would appear in the carbon budget as part of the residual sink. Houghton noted that if the influence of past management changes on carbon fluxes could be accurately estimated, the indirect effects might appear insignificant. Several workshop participants asserted that current global estimates of the processes contributing to direct effects are too uncertain to determine how much of the current residual sink is determined by indirect effects, while Kimble and Ruth DeFries expressed concern about the large uncertainty associated with the current estimate of the residual carbon sink.

WORKSHOP GOALS

William Hohenstein of the U.S. Department of Agriculture's Global Change Program Office, sponsor of the workshop, emphasized the need for scientific advice to decision makers on the subject of direct and indirect human contributions to terrestrial carbon fluxes. He stated that the role of forests will be a key consideration in greenhouse gas mitigation, given that 30 percent of the current increase in atmospheric CO_2 is attributed to land use and land use change. Policy makers want to understand the role of indirect effects, such as CO_2 fertilization, nitrogen deposition, acidic deposition, temperature and precipitation changes, and tropospheric ozone and whether they have the potential to change the timing or the magnitude of changes in atmospheric carbon concentrations. Hohenstein noted that even though the United States has not signed the Kyoto Protocol, efforts to determine the human influences on land use systems are necessary in the context of reporting CO_2 emissions to the United Nations.

Hohenstein highlighted several issues that motivated the development of the workshop on direct and indirect human contributions to Terrestrial Greenhouse Gas Fluxes. The risks of climate change, such as higher temperatures, changes in precipitation, increased climate variability, and extreme weather events, can result in significant impacts on agricultural and forestry activities; however, agricultural and forestry activities provide an opportunity to mitigate carbon fluxes through targeted land management.

Characterization of these direct and indirect contributions to carbon fluxes will influence decisions on implementation of mitigation and adaptation strategies for agricultural and forestry activities.

Additionally, Hohenstein noted that the need for guidance on direct and indirect effects from land use and land use change activities on national greenhouse gas inventory reporting. Indirect effects of human activities may alter carbon storage on forested and agricultural lands affecting the national greenhouse gas inventory. These indirect human-induced effects on carbon fluxes in forests, for example, could alter the timing of carbon sequestration (i.e., faster growth with trees reaching maturity earlier), the magnitude of carbon sequestration (i.e., increased growth with trees maturing at a larger size), or a combination of both.

Hohenstein specifically presented a number of questions on which policy makers are asking the scientific community for guidance:

- Do indirect human influences affect the timing or magnitude of emissions and removals, or both?
- Can a reasonable "baseline" be established?
- How large are indirect human influences, now and in the future?
- Is it practical to separate direct and indirect human influences?
- How might factoring out indirect human influences change the costs of reporting?
- Can defaults be established? Can rules of thumb be used?
- How should emissions from carbon sequestered by indirect human influences be treated?
- What are the implications for the functioning of the inventory system if indirect human influences are factored out?

Hohenstein commented that advice on these topics was needed in the context of the 10-year strategic plan for the Climate Change Science Program (http://www.climatescience.gov/Library/stratplan2003/default.htm), which focuses not only on understanding the carbon cycle but on decision support and management issues as well.

Therefore, the National Academies convened a workshop on September 23 and 24, 2003, to discuss the current state of scientific understanding on issues related to quantifying the direct human-induced changes in terrestrial carbon stocks and related changes in greenhouse gas emissions and distinguishing these changes from those caused by indirect human effects, natural effects, and past practices on forested or agricultural lands (see Box 1-4).

BOX 1-4
Workshop Goals

The National Academies convened a workshop to discuss the current state of scientific understanding on issues related to quantifying the direct human-induced changes in terrestrial carbon stocks and related changes in greenhouse gas emissions, distinguishing these changes from those caused by indirect human-induced effects, natural effects, and effects due to past practices in forests and current or former agricultural lands. The workshop goals were to examine the following five topics:

1. Methods for quantifying, characterizing, and cross-checking terrestrial carbon stocks over differing timescales and spatial scales.

2. How terrestrial carbon stocks and related greenhouse gas emissions change over time as a function of direct human-induced changes in land use, forestry (afforestation, reforestation, deforestation, and forest management,), and other practices (such as cropland and grazing land management).

3. How terrestrial carbon stocks and related greenhouse gas emissions change over time as a function of indirect human-induced effects (such as CO_2 fertilization, nitrogen deposition, and climate change), natural effects (such as fire frequency and intensity, pests, and climate variability), and past practices in forests and current or former agricultural lands (such as land succession from historical agricultural lands to forests).

4. Methods to distinguish direct human-induced changes in terrestrial carbon stocks and related greenhouse gas emissions from those caused by indirect human-induced effects, natural effects, and effects due to past practices in forests and current or former agricultural lands. Particular attention was to be paid to the following issues:

- the scientific feasibility of partitioning direct human-induced changes from other effects;
- whether it is possible to identify characteristic observations that would distinguish direct human-induced changes from other effects over different spatial scales;
- areas where improved scientific understanding is most needed;
- the costs and technical requirements of applying such methods as part of a national greenhouse gas inventory system; and
- the potential implications for accounting procedures for indirect and natural effects on national and international greenhouse gas inventories, including near-term and longer-term impacts.

5. Efficacy and longevity of varying carbon storage practices and technology.

WORKSHOP SUMMARY

This report summarizes the key technical issues from presentations and discussions that occurred at the workshop. This workshop summary is intended for informed scientists and policy makers as well as interested parties who are well versed on the issue of greenhouse gases, but it covers a range of technical material and thus is not intended as an introduction to the topic of carbon fluxes. This summary is intended to illuminate issues, not resolve them. By its nature, any workshop is necessarily incomplete, and a workshop summary can report only on what was said. With the exception of a few boxes and some cited references that are provided for context and background information, all of the information reported here emerged from presentations and discussions during the workshop. This summary is intended to reflect the variety of opinions expressed by the speakers.

Following this introduction, which describes the context, motivation, and goals for the workshop, Chapter 2 provides a summary of three policy perspectives, focused on national and international activities related to quantifying and reporting direct and indirect human-induced effects on carbon fluxes. Chapter 3 summarizes the science base regarding direct, indirect, and natural effects on carbon fluxes. The workshop speakers provided detailed discussions of the state of knowledge with regard to direct and indirect human-inducted effects, natural effects, and historical land use, reflecting both forestry and agricultural practices. The speakers also presented approaches for partitioning direct from indirect and natural effects. Chapter 3 also summarizes several presentations highlighting data and research needs in this field. Finally, Chapter 4 presents a synopsis of the ideas presented at the workshop, organized according to the five workshop goals presented in Box 1-4.