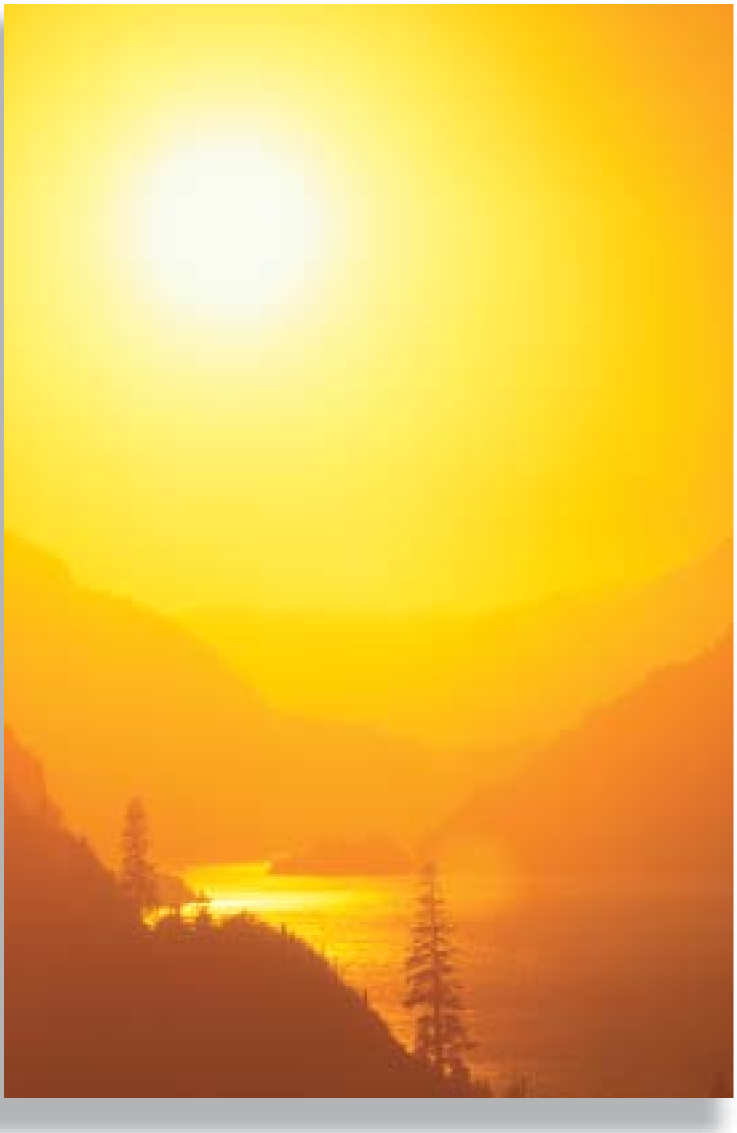
Forests, Carbon and Climate Change

A Synthesis of Science Findings



Forests, Carbon and Climate Change

A SYNTHESIS OF SCIENCE FINDINGS

A project of

The Oregon Forest Resources Institute
Oregon State University College of Forestry
Oregon Department of Forestry

TABLE OF CONTENTS

Contributing Authors

Gail Achterman
Director, Institute for Natural Resources
Oregon State University
210 Strand Agriculture Hall
Corvallis, OR 97331

Dominique Bachelet, Ph.D.
Associate Professor
Department of Biological and Ecological Engineering
Oregon State University
Corvallis, OR 97331

Mike Burnett
Executive Director
The Climate Trust
65 SW Yamhill St., Suite 400
Portland, OR 97204

Jim Cathcart, Ph.D.
Acting Forest Health & Monitoring Manager
Oregon Department of Forestry
2600 State St.
Salem, OR 97310

Matt Delaney
Forester
Delaney Forestry Services
1216 Calapooia St.
Albany, OR 97321

Raymond J. Drapek, Ph.D.
Ecosystem Modeler/GIS Scientist
U.S. Forest Service
PNW Station
Corvallis, OR 97331

Mark Harmon, Ph.D.
Richardson Chair and Professor of Forest Science
Oregon State University
Department of Forest Science
321 Richardson Hall
Corvallis, OR 97331

Jeffrey D. Kline, Ph.D.
Research Forester
Pacific Northwest Research Station
3200 SW Jefferson Way
Corvallis, OR 97331

Olga N. Krankina, Ph.D.
Assistant Professor, Senior Research
Department of Forest Science
Oregon State University
202 Richardson Hall
Corvallis, OR 97331

James M. Lenihan, Ph.D.
Research Scientist
USDA Forest Service
3200 SW Jefferson Way
Corvallis, OR 97331

Connie Millar, Ph.D.
Research Paleoecologist
Sierra Nevada Research Center
PSW Research Station, USDA Forest Service
800 Buchanan St.
Albany, CA 94710

Ronald P. Neilson, Ph.D.
Bioclimatologist
USDA Forest Service
3200 SW Jefferson Way
Corvallis, OR 997331

Hal Salwasser, Ph.D.
Dean, College of Forestry
Oregon State University
Corvallis, OR 97331

George Taylor
State Climatologist
Oregon Climate Service
326 Strand Ag Hall
Corvallis, OR 97331

Bettina von Hagen
V.P., Forestry and Natural Capital Fund
Ecotrust
721 NW 9th St.
Portland, OR 97209

Jim Wilson, Ph.D.
Professor Emeritus
Department of Wood Science and Engineering
Oregon State University
Corvallis, OR 97331,
Vice President,
CORRIM, www.corrim.org.

Preface

The Oregon Forest Resources Institute (OFRI) commissioned this book, a synthesis of science findings on the relationships between forests, atmospheric carbon and climate change. While there is not scientific consensus about all the causes and implications of global climate change and the role of human activities, there is agreement that the relationships between forests and carbon, carbon and climate, and climate and forests are important and need to be better understood. It is also clear that Oregon is a forest-rich state, poised with opportunities for forests, forestry and forest product enterprises to contribute toward maintaining a livable climate.

As we might remember from school, carbon is **the** essential element of life. Plants convert atmospheric carbon from CO2 into sugars through photosynthesis. Animals eat plants and give off CO2 to the atmosphere through respiration. And all organisms give off carbon when they respire, die and decay.

We now know that there is a relationship between temperature and the amount of carbon in the atmosphere. Of the five greenhouse gases (those in the atmosphere that warm the earth because they let in light but do not let out heat), CO2 is the most prevalent. Recent research has enabled scientists to determine historic CO2 atmospheric levels as well as rates of increase and decrease, and these data have helped put the situation today in historical perspective.

We know that forests contribute to clean air and water and to wildlife habitat while providing wood products and recreation. We know that forests are dynamic and have changed both in location and species composition through cooling and warming periods over the last several million years. We know that climate sets the stage for livability on earth. And, we know that forests play an important role in maintaining a livable climate.

Beginning around 8,000 to 10,000 years ago, humans initiated massive losses of forest due to agriculture and, subsequently, urban and industrial development. While forest conversion has largely been reversed in North America and Europe, we still face big challenges to keeping the world's remaining 9.6 billion forest acres in forest use.

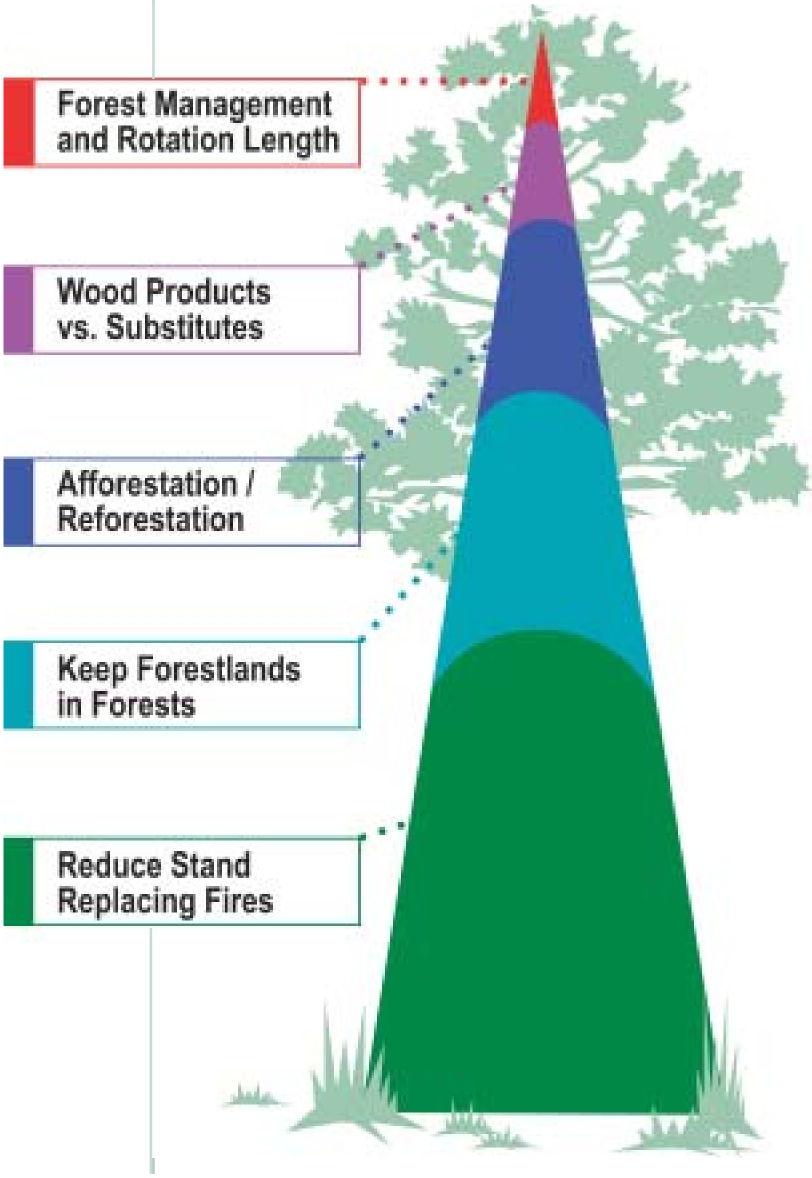
During the past 300 years of the industrial age, humans have accelerated the transfer of carbon from long-term stores in fossil fuels and forests into the atmospheric pool. The current level and rate of increase in both temperature and atmospheric carbon may exceed conditions over the past 650,000 years, with forests responding in complex ways.

Since forests play an important role in storing carbon, having more forest cover is a positive force in lowering atmospheric carbon levels. Conversion of lands currently in other uses to forests (afforestation), reforesting quickly and aggressively after harvest or natural disturbance, keeping forestland in forest use and managing forests for fire resilience all have obvious positive effects. Beyond that, recent research by forest scientists has confirmed that wood products continue to store carbon.

For Oregon and the other Northwest states that are rich in forest resources, the role forestry can play in reducing atmospheric carbon has been of key interest. This is evidenced even on the policy front, where California, Oregon and Washington have stepped ahead of the federal government in addressing the issue. Forests contain about 75 percent of the earth's biomass, so in a state like Oregon, with its highly productive forests, the per-acre potential for carbon storage is among the highest in the world.

Forest scientists have been studying the interactions of forests and climate for some time, and while there is, as might be expected, some complexity and contradiction, there are forest management strategies that can help in sequestering carbon or reducing its emission into the atmosphere. These techniques include:

- reducing forest densities to keep trees healthy and minimize the risk of stand-replacing fires and insect problems (for example, the 2002 Biscuit Fire in southwestern Oregon released about a fourth as much carbon into the atmosphere that year as was emitted statewide by the burning of fossil fuels);
- keeping forestland in forest use (this means ensuring that private forestlands can be managed profitably as forests);
- afforesting former forestlands that have been converted to non-forest uses and reforesting quickly and aggressively after harvest or natural disturbance;
- using wood products and energy generated from wood in lieu of using fossil fuel-intensive products such as steel and concrete and energy generated from fossil fuels; and
- changing forest management strategies to sequester carbon through thinning, increasing rotation lengths and other techniques can provide forest landowners an opportunity to profit from the sale of carbon offsets.



This “carbon sequestration tree” demonstrates my personal understanding of the relative importance of these strategies in affecting climate change. Moving up the tree from the bottom to the top, we have a series of management strategies that can help reduce the carbon in our atmosphere.

OFRI’s board of directors and staff appreciate the thorough and professional work done by the authors and reviewers of the various chapters in this book. We especially appreciate the leadership of Hal Salwasser, dean of the OSU College of Forestry, in conceiving this idea and helping bring it to fruition. We are grateful for the fine work of our editor, Donna Matrazzo of the Writing Works, who worked tirelessly with our authors and reviewers to pull this project together and translate scientific and technical jargon into language the rest of us can understand. Finally, we want to thank Mary Gorton, graphic designer with Oregon State Printing, for a masterful job of laying out this book.

We hope you enjoy this book and are stimulated by these ideas.

Mike Cloughesy
Director of Forestry
Oregon Forest Resources Institute

CHAPTER ONE

HIGHLIGHTS:

ATMOSPHERIC CARBON DIOXIDE

INTRODUCTION: FORESTS, CARBON AND CLIMATE — CONTINUAL CHANGE AND MANY POSSIBILITIES

WHY SHOULD WE CARE ABOUT FORESTS, CARBON AND CLIMATE?

- People benefit greatly from forests: quality water, native species, wood, recreation.
- Climate sets the stage for livability; carbon links forests and climate.
- Our climate is warming rapidly; climate affects forests, forests affect climate.

How have Forests Changed over Time and Space?

- Forests are dynamic and have changed both in location and species composition through cooling and warming periods over geologic time.

Working with Half the Forest

- Human activities have reduced 50% of Earth's post-glacial forest cover.
- We face large challenges perpetuating the remaining 9.6 billion forest acres as forest.

How have Carbon and Climate Changed over Time and Space?

- Levels of atmospheric carbon correlate over time with ice ages and warm periods.
- Current level of atmospheric CO_2 exceeds levels estimated over the past 650,000 years; rate of change highest since Last Glacial Maximum about 18,000 years ago.
- During the past 300 years of the industrial age, humans have transferred carbon from long-term stores in forests and fossil fuels into atmospheric and oceanic pools.

What does the Future Look Like From Here?

- Climate oscillation and change are expected to continue, with forests responding in complex ways: longer growing seasons, warmer winters, more drought stress and fires.

What can We do to Influence Future Climate through Forest Resource Management?

- Increase forested land area; forests are better at storing carbon than other land cover.
- Manage forests and protect from fire, insects to store more carbon per acre.
- Capture more carbon in wood products.
- Use mill waste, woody biomass for bio-based, renewable energy.
- Use wood products instead of more energy-demanding materials.
- Reward forestland owners for ecosystem services, other public values; helps keep forestland in forest use.

The Future for Oregon/Final Comments

- Oregon is a forest-rich state, poised with opportunities for forests, forestry and forest product enterprises to profit from positive roles in maintaining a livable climate.

CHAPTER ONE

INTRODUCTION: FORESTS, CARBON AND CLIMATE — CONTINUAL CHANGE AND MANY POSSIBILITIES

Hal Salwasser

WHY SHOULD WE CARE ABOUT FORESTS, CARBON AND CLIMATE?

This is a book about forests, carbon, and climate and how they interact. Forests are vital to our quality of life and well being. They protect our watersheds, harbor native plant and animal species, provide wood and fiber-based products used daily by nearly everyone, and are settings for varied recreational and cultural activities. Forest management and conservation and forest products enterprises also support many communities and drive a major part of Oregon's economy.

Climate, of course, sets the context for livability. It affects the means by which all organisms pursue their existence. It also affects the kinds of forests that occur in different places and at different times across the land surface of our planet. And, as we are increasingly aware, not only does climate affect forests, but forests affect climate. Carbon is one of the prime linkages between forests and climate, along with water and oxygen.

Carbon is a key component of all life's fundamental building blocks, including fats, carbohydrates, and proteins. In fact, about half of the dry mass of all living things is composed of carbon. Plants take carbon from the atmosphere in the form of carbon dioxide gas (CO_2) and use water and the sun's energy to make a new compound, glucose ($C_6H_{12}O_6$), composed of carbon, hydrogen, and oxygen. Some of the glucose is converted by the plant to cellulose and ends up as one of the main structural compounds in wood in the case of trees. Through this process, called photosynthesis, carbon is removed from the atmospheric pool. About half the carbon absorbed through photosynthesis is later released by plants as they use their own energy to grow. The rest is either stored in the plant, transferred to the soil where it may persist for a very long time in the form of organic matter, or transported through the food chain to support other forms of terrestrial life.

When plants die and decompose, or when we burn biomass or its ancient remains in the form of fossil fuels, the original captured and stored carbon is released back to the atmosphere as CO_2 and other carbon-based gases. In addition, when forests or other terrestrial ecosystems are disturbed through harvesting, conversion, or natural events such as fires, some of the carbon stored in the soils and organic matter, such as stumps, snags, and slash, is oxidized and released back to the atmospheric pool as CO_2. The amount released varies, depending on subsequent land use and probably rarely is more than 50% of the original soil store.

At the global scale, if more carbon is released through decomposition or burning than is captured and stored through photosynthesis or oceanic processes, the concentration of carbon dioxide (CO_2) builds in the atmospheric pool. Why is this important? Because CO_2 is a greenhouse gas, as are methane (CH_4) and nitrous oxide (NO_2). Like a car windshield on a sunny day, these gases let short wavelength sunlight energy pass through the atmosphere to the earth's surface, but do not let an equivalent amount of longer wavelength heat energy pass back out to the universe. Oceans also absorb and store—or sequester—large amounts of carbon through the accumulation of unoxidized products of photosynthesis, as well as through other chemical processes (IPCC 2001).

Carbon dioxide levels in the atmosphere correlate with the earth's mean annual surface temperature, and global surface temperatures affect processes such as glaciation. From the geologic record, it appears that glacial periods coincide with atmospheric levels of around 200 parts per million (0.02%) CO_2. Interglacials (the periods of time between glacial epochs) have generally coincided with levels approaching, but not exceeding 300 parts per million (0.03%)—that is, until the past 100 years (Siegenthaler et al. 2005). Earth's atmosphere currently includes around 380 parts per million (0.038%) of CO_2, the highest detected or inferred level over the past 650,000 years. The current concentration of atmospheric CO_2 is about 30% higher than at the start of the industrial era, with a rate of change unprecedented since the last glacial maximum.

It is important to note that global temperature and CO_2 relationships are correlations. They may not necessarily result from a direct cause and effect relationship. Scientists are still not certain about the degree to which increasing carbon dioxide in the atmosphere causes warming or the degree to which warming causes increasing atmospheric carbon dioxide levels. Mean global surface temperatures during the most recent glacial period are estimated to have been around 10° F colder than present (IPCC 2001). Scientific evidence is clear that both temperature and CO_2 levels have increased over the past 100 years, reversing a prior cooling trend in the climate (IPCC 2001, NRC 2006), and human activity is strongly implicated.

The Intergovernmental Panel on Climate Change (IPCC) estimated about 0.25° F sensitivity in mean annual global temperature with each change of 10 parts per million in the level of atmospheric CO_2. This would amount to a global climate about 2.5° F warmer than 100 years ago, if CO_2 alone explained all climate change. But the climate warmed by only about 1.0° F over the past century, mostly during two periods: 1910-1945 and 1976-2000 (IPCC 2001). The difficulty in elucidating cause and effect between atmospheric carbon dioxide and climate results from lags in process responses and complex feedbacks among climate factors that are not completely understood at this time (Boisvenue and Running 2006). Major aspects of climate change are also driven by mechanisms unrelated to greenhouse gases, such as the shape of the earth's orbit, tilt of the polar axis, and solar and volcanic activity. Nevertheless, recent scientific evidence points to human-caused additions of greenhouse gases to the atmosphere as *very likely* (90%-99% probability) factors in recent warming trends over the past century (IPCC 2001, NRC 2006).

Forests play important roles in climate through other mechanisms in addition to carbon exchange. These mechanisms may be as or more important than that of carbon exchange. The massive amounts of water transpired by forests ultimately change the global distribution of energy in the atmosphere, affecting rainfall patterns, cloudiness, and storms. Even the optical or reflective properties of forests differ from those of most other objects; forests absorb 85%-95% of incoming shortwave solar energy. Evergreen conifers in the boreal region thus warm the atmosphere by holding solar energy, while boreal deciduous forests with snow on the ground in the winter reflect more incoming radiation away from the earth, as do deserts.

There is currently much public concern and scientific dialogue about the impacts of human-caused additions of CO_2 and other greenhouse gases to the atmosphere. Cycles of warming and cooling periods in our geologic history have greatly affected where certain organisms could thrive, including lately, humans. Thus the ability of plants and animals to move and adapt in response to climate change has been vital to the persistence of those lineages that have not gone extinct (Williams 2006). Some tree species, for example, have shifted in elevation as much as 3,000 feet or in latitudes as much as 1,000 miles in response to climate changes since the last glacial retreat around 10,000 years ago. In the past, species had the time and physical ability to make such adjustments.

Some studies suggest that the rate of climate change today is unparalleled in the geologic past, certainly in the past 1,000 years (NRC 2006). Other evidence indicates that climate changes may have been even more rapid and abrupt during previous glacial periods, associated with large releases of methane from the ocean floor, and that the interglacial period of the past 10,000 years may actually be a more stable climate than characterized much of the previous 2.5 million years, except perhaps for the past 100 years when the rate of change has been very steep (IPCC 2001, NRC 2006).

Irrespective of the rate of climate change currently underway, the landscape in many parts of the world is now filled with artifacts of human occupancy that present barriers to the free movement of many species, such as fenced highways, valley bottoms full of houses and farms, and dams on major river systems. Today's diverse assemblage of species has neither the luxury of time nor the freedom to move unimpeded by physical barriers or fragmented landscapes.

If human-caused additions of carbon dioxide and other greenhouse gases to the atmospheric pool are driving the rapid rate of climate change, then we have major reason for concern. Forests are affected. Hydrologic cycles are affected. Agriculture is affected. And ultimately our quality of life is affected. But we need not sit back and just let it all unfold. Some even say we have a moral imperative to act quickly and boldly to change human impacts on climate (Gore 2006). Options are many but lag effects of greenhouse gases already in the atmosphere appear to commit the planet to continued warming for many decades (Pacala and Socolow 2004). If we want diverse, productive and resilient future forests, we need to prepare them for a warmer future. And we need to look for ways forest resources can mitigate or ameliorate undesired climate change.

We can take actions to reduce the effects of human activities on climate, but not immediately reverse impacts already made. The most significant action to reduce human-caused atmospheric carbon is to use less fossil fuel energy to support our life needs. To reverse trends will require finding energy substitutes for fossil fuels at the global scale. These points cannot be overemphasized because without taking these actions soon the planet is going to get a lot warmer than it has been for at least several million years.

Annual per capita CO_2 emissions vary widely among nations: estimated at 22 US tons emitted per person per annum in the U.S., about 11 tons per person in European Union countries, about 3.3 tons in China and slightly over 1 ton for India (United Nations 2005). With the economies of India and China growing rapidly based on fossil fuel energy, principally coal-fired power plants, their per capita consumption rates are bound to increase; combined those nations already have nearly eight times the human population as does the U.S. Combined per capita carbon emissions in India and China need only rise to around 2.8 tons per person to equal the total CO_2 emissions of the U.S. at our current population and consumption. They may well reach this level of total emissions in the early 21st century. Unlike some local or regional environmental impacts, adding pollutants from anywhere to the atmosphere eventually effects the entire planet.

We can partially influence how much human-caused carbon dioxide is added to or sequestered from the atmosphere through how we manage and conserve forests and forest products. Major options include reducing deforestation which reduces carbon release, storing more carbon in existing forest ecosystems, accelerating afforestation which sequesters more carbon as the trees grow, and encouraging greater use of wood-based materials that store more carbon and use less energy in manufacture in place of more energy-demanding products such as steel, concrete, and plastics. These actions could also have significant co-benefits beyond their impacts on climate.

We can also influence future forest ecosystems so they are better able to accommodate the warmer climates they are likely to encounter. Westerling *et al.,* (2006) suggest that climate warming is a significant factor in the intensity of forest fire seasons in recent decades and that restoring resilience to fire in some forest types may reduce future impacts of even warmer temperatures on forest fires. Given that climate is warming, even if we do not understand all the driving factors, preparing forests to handle a future much different than the past makes sense. As the saying goes, "One cannot navigate the future by only looking in the rear-view mirror."

Forests, forestry, and forest products cannot collectively solve the entire "climate problem," but they are essential pieces to a comprehensive climate strategy (Pacala and Socolow 2004). The chapters in this book show that how we use, manage, and conserve forests and forest products can make a difference for future climates if we begin to bring carbon and climate into forest policies and decision-making.

How have Forests Changed over Time and Space?

So, what can we learn from the past that will help us navigate into the future regarding forests and climate? Satellite imagery has been used to show the kinds of vegetation or lack thereof currently covering the earth's land surface. If such imagery could have been obtained for prior times we would see much change in land cover. Over the past 2.5 million years we would see around 40 cycles of glacial and interglacial periods, sea levels rising and falling by 300-400 feet, and forests moving and changing not only in location but also in species composition. Over hundreds of millions of years we would see entire continents moving across the surface of the earth, isolating or reassembling their biotas in the process. ***Lesson 1:*** whatever we might consider as forest today, even without human actions it has never been stable or in the same place for all time.

Regardless of age, structure, or species composition, all forests are created and maintained by interactions among their constituent species and between those species and their physical environments, including the prevailing climate for the region. Forests are also affected by disturbance events such as fires, storms, droughts, landslides, volcanoes, floods, and human actions. While a given forest may look stable or seem in equilibrium to a casual observer on an annual or even decadal time scale, all forests are highly dynamic on multiple temporal and spatial scales with both species composition and structure changing over time and space. Some animal species move in and out of particular forest areas on a daily or seasonal basis. Hourly measures of carbon exchange between forests and the atmosphere show that large changes occur over the course of a day. ***Lesson 2:*** any perspective on forests must be taken with multi-scale dynamics in mind, especially change we can affect over decadal and centuries time scales at stand, landscape and regional geographic scales.

Prior to around a million years ago, the land surface cover we would see over most of the world if we had the satellite imagery would consist of whatever nature delivered in the absence of human beings. But with the emergence of early humans (*Homo erectus*) and their eventual diaspora out of Africa into Europe and Asia around 0.5 to 1 million years ago, nature without humans ceased being the only driver of change (Williams 2003, Wade 2005). Human influence on forests through use of fire, hunting, and gathering would most likely have been slight and localized at first, then spreading and more pervasive as behaviorally modern humans (*Homo sapiens*) subsequently evolved in Africa then dispersed across Eurasia an estimated 80,000 to 50,000 years ago. In some places they replaced earlier hominids, *Homo erectus*, and in others, such as Australia and the Americas, they were the first humans to show up. People arrived in the Americas perhaps as early as 15,000 to 20,000 years ago (Shreeve 2006), though the most credible earliest reliable dates so far recorded are closer to 12,000 years ago (see review by Roosevelt *et al.,* 2002). At the height of the Last Glacial Maximum approximately 18,000 years ago, sea levels were an estimated 300-400 feet lower than current (Lambeck and Chappell

2001), continental ice sheets covered vast areas of North America's middle to higher latitudes, and glaciers occurred even at low elevations, ca. 3,000 feet, in the Southern Sierra Nevada in California. By 12,000 years ago, continental and montane glacial ice was in retreat but sea levels were still nearly 200 feet lower than current. It is plausible that some of the first Americans lived in places now under coastal oceans and used watercraft and coastline resources (Erlandson 2002) in their rapid dispersal to South America, reaching present day Chile an estimated 12,500 years ago (Dillehay 2000).

The key point here is that whenever and wherever humans arrived, they did not encounter forests or any other ecosystem types in the same places or of the same species composition that we do today. When humans first arrived in what is now Oregon, as hunters and gatherers who also used fire, it marked the beginning of a new force of ecosystem change in our state—human action. ***Lesson 3:*** one must envision forests in periods prior to human occupancy—not just prior to Euro-American settlement—to get a sense of what a pristine forest unaffected by human activity might have been and that forest will never occur in exactly that form or place again.

Human influences on forests increased dramatically in scope and magnitude following the most recent glacial period. Sometime around 20,000 years ago in Southeast Asia, Hoa Binh people appear to have learned how to cultivate food plants to augment their hunter-gatherer existence. Around 8,000 to 10,000 years ago, perhaps earlier, humans began practicing agriculture in the near East (Mesopotamia), Indus River Valley, and Far East (China) and Mesoamerica. Farming enabled people to augment then replace small-band nomadic and hunter-gatherer lifestyles with more stable, larger communities based on sedentary rather than shifting agriculture and a larger, more consistent food supply. The early post-glacial domestication and selective breeding of cereal grains, maize, fruits, and vegetables entailed purposeful transformation of native plant communities, including areas of forest, to farm plots or the interplanting of food crops into native plant communities. With new, more stable food supplies, the total human population was able to grow from around 5-10 million prior to agriculture to perhaps on the order of 100 million as cultivating cultures spread and multiplied. It also enabled the evolution of social hierarchies, complex cultures, and the trappings of what we would eventually call civilizations, including highly organized warfare.

It is likely that early farmers grew their first crops in forest or woodland openings, on floodplains or on terraces near water but above flood zones. Grassland sods would likely have been difficult to cultivate with primitive tools but their large-scale conversion to farms would eventually come beginning 3,000 to 5,000 years ago with metal tools, draft animals and, in the last 100 years, motorized machines. As the global human population grew, reaching an estimated 500 million prior to the start of the industrial era, its need for forest soils for crops, water for irrigation, and wood for fuel, farm implements, building materials, metallurgy, and conducting trade and war impacted forests farther and farther from the early communities (Perlin 1991). As Perlin (1991) compellingly documented, most Euro-Asian civilizations were enabled by wood and other forest resources. Many of those civilizations, in turn, dramatically transformed forests and forest soils, often to the long-term degradation of the land and the cultures they at one time supported (Marsh 1874, Perlin 1991, Williams 2003). The reader should note that what I am describing here is not forestry as we know it today; it was unsustainable resource exploitation, land degradation and land-use conversion. Forestry emerged as a "solution" to these unsustainable human land and resource use practices.

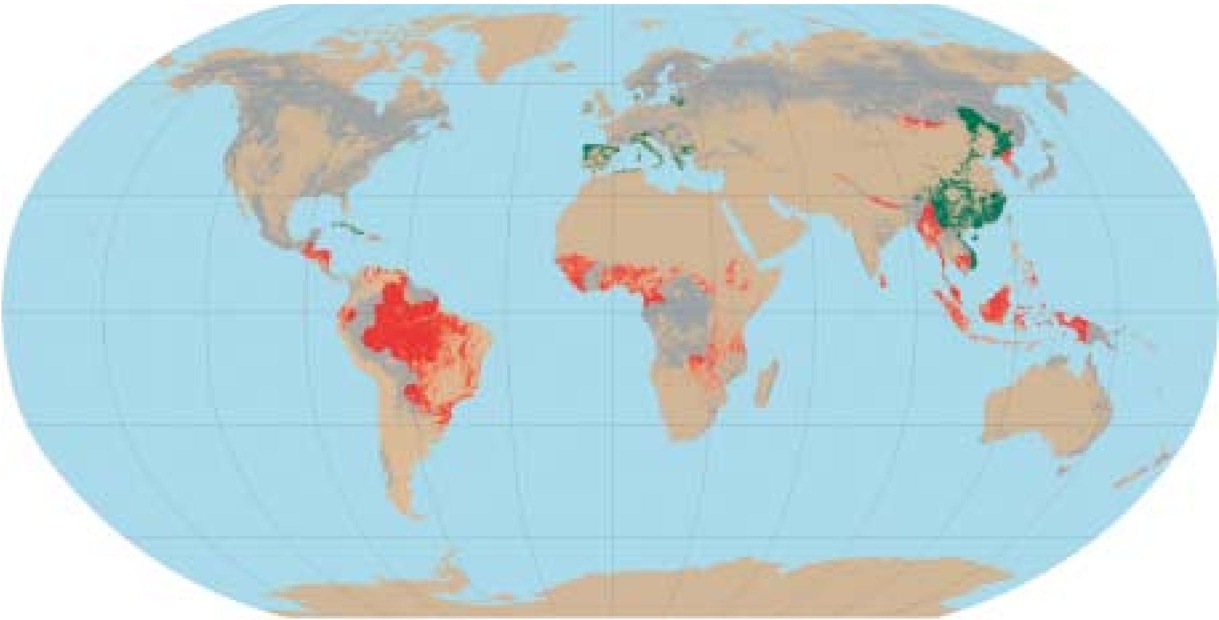
Sedentary agriculture and associated high densities of people arrived or emerged at different times in various places around the world. But whenever and wherever it did, it inevitably entailed human-caused land use change. These changes, in the most recent 2,000 years, include massive conversion of forests to agriculture and, prior to widespread use of fossil fuels, massive amounts of wood used for cooking, heating, shelter, tools and ships (Perlin 1991, Williams 2003). Forest trees provided the fuels that allowed prehistoric stone-age humans to begin smelting bronze beginning about 5,500 years before present and later iron beginning around 3,200 years before present. Both of these metals require very energy-demanding processes, i.e., lots of wood or charcoal to fuel the furnaces. New metal tools then enabled even more productive agriculture and more land conversion to farms and towns. While IPCC (2001) suggests relatively little human impact on climate prior to the industrial era, other evidence suggests potentially significant pre-industrial impacts (Perlin 1991, Ruddiman 2003, Williams 2003). ***Lesson 4:*** while it is commonly believed that most global forest loss and its associated climate impact occurred during and after the industrial era began in the mid to late-1700s, it is quite plausible that very early uses of forest resources and forest transformations actually began the era of human-aided climate change thousands, not just hundreds of years ago.

Ruddiman (2003) points to a divergence in the actual level of atmospheric carbon from that predicted by current global climate models—without human additions, atmospheric carbon dioxide levels based on Earth's physical processes should have declined, while actual levels estimated from proxy indicators increased. CO_2 release from widespread deforestation, burning of wood and forests, rise of paddy rice cultivation, and growing herds of domestic livestock are cited by Ruddiman as reasons why the climate at northern latitudes is now an estimated 3.6° F warmer than it otherwise might have been without human-caused additions of atmospheric carbon dioxide that started well prior to the industrial era. He posits that had it not been for pre-industrial age additions of carbon dioxide and methane to the atmosphere, Earth would have begun returning to the early stages of the next glacial period nearly 6,000 to 4,000 years ago. Broecker (2006) rebuts Ruddiman's explanation and claims that the past 8,000-year record of atmospheric CO_2 can be explained by non-human factors. If Broecker is right, pre-industrial era impacts of human action on climate may not be of significant concern, though the recent and current roles certainly are. However, if Ruddiman is right, the roles of human action and forest loss in climate change over thousands of years would be even more substantial than we might currently think and would compel consideration in better understanding current impacts. At this point science is still debating and collecting data and running models. But it certainly is intriguing as we ponder the effects of climate warming to think about Ruddiman's hypotheses and whether or not the human enterprise has unintendedly postponed the next period of glacial advance.

Deforestation and fire create the second largest source of human-caused CO_2 emissions to the atmosphere, following fossil fuel burning. Future forest losses if deforestation is not halted could lead to something on the order of 25% of total future CO_2 emissions still coming from forest conversion. This is why the human-caused climate impacts of the last 150 years, the current rapid rate of human-influenced climate change, and further changes projected for the next 100 years are of prime concern now and for the foreseeable future and why forests and forest resources must be part of any comprehensive strategy to ameliorate undesired changes. ***Lesson 5:*** the rates of climate change since 1850 and projected for the next 100 years are extreme compared to most of the past and they will have profound consequences for our quality of life that will be compounded if we do not start taking actions to ameliorate them.

Working with Half the Forest

Why is this historical perspective on forests, carbon, and climate included in the introductory chapter? Because understanding the past is useful in knowing how to journey into the future. Human population growth, expansion, and land transformation have likely resulted in the more-or-less permanent loss of about 50% of the forest cover that existed 8,000 years ago, and much though certainly not all of this loss has occurred within the past 300 years (Figure 9.1, Williams 2003). (I say more or less permanent because if or when the earth's biodiversity no longer includes humans, forests may eventually return to those places where climate and soils support their species.) Some forests long ago converted to farms returned to forest when people abandoned areas of occupancy or decided to plant trees rather than food crops, while deforestation continues in other places to this day. Not all of the originally converted forests would have been old-growth full of stored carbon, since nature and human activities create and maintain mosaics of successional stages. But some or much of the original forest must have been old-growth or late-successional forest that stored maximal amounts of carbon for the forest type and geographic location.



🟥 **> 0.5% Decrease per year**

🟩 **> 0.5% Increase per year**

▨ **Change rate below 0.5% per year**

Figure 1

Source: Williams, Michael. 2003. *Deforesting the Earth: From Prehistory to Global Crisis.* ©University of Chicago Press.

The main point here is that whatever the developmental stage of the world's forests prior to the advent of agriculture or prior to the industrial era post 1750, approximately half of it is not forest of any kind anymore. It has been converted to agricultural use, or more permanently changed by multiple forms of human development. It has long ago given up its above-ground stored carbon to the atmospheric or oceanic pools or to temporary storage in durable wood products and some—probably less than 50%—of its below-ground carbon as well. How much total carbon? We can only estimate the answer. A plausible amount might be that something on the order of between 25% and 37% of the carbon once stored in forests has been released since about half the carbon stored in global forests is in the soils and between 50% to 100% of an equivalent to the original soil carbon pool may still be intact or subsequently replenished. By now, oceans have probably absorbed most of the CO_2 released from forests centuries to millennia ago and they may be turning more acidic as a result with undesired consequences to marine life (Kleypas *et al.* 2006).

Beyond knowing we are now working with about half the forest that might have been possible had the human enterprise not evolved as it has, we must also consider that much of the remaining half has been impacted by harvests and reforestation, afforestation after agricultural abandonment, or alterations in species composition resulting from "agroforestry" or introduction of non-native species. Hence, their ecological condition and carbon storage capacity are much different from that of pristine forests prior to human intervention. And humanity is not a mere 500 million souls anymore, but nearly 6.5 billion, heading for perhaps 8 to 10 billion by mid-century. This is on the order of 1,000 times more people than are thought to have existed at the advent of agriculture.

Global forests currently store just over half of the carbon residing in terrestrial ecosystems (FAO 2001). The total biosphere carbon pool is estimated at 2,190 Pg (a petagram is 1.1 billion U.S. tons) of carbon. Of this, approximately 1,000 Pg is in forests. How significant is that? It is roughly 50% more carbon than now resides in the atmospheric pool and about 20%-25% of the carbon pool stored in remaining, accessible fossil fuels, estimated at 4,000-5,000 Pg. This means the original forest prior to human impacts may have stored up to 40% as much carbon as the current pool in fossil fuels, or that deforestation may have already released an amount of carbon equal to up to 15% of the carbon currently stored in the fossil fuel pool. Far greater carbon pools are in deep oceans (38,000 Pg) and carbonaceous rocks (65,000,000 Pg), but contrary to forests, these pools do not turn over quickly.

Cumulative carbon losses due to changes in land use from 1850 to 2000 are an estimated 156 Pg of terrestrial carbon (Houghton 2003), 90% of which may be from deforestation alone (IPCC 2001). Emissions from burning fossil fuels and making cement during this same period are estimated at 275 Pg of carbon (Houghton 2003). Thus, carbon emissions from historical land use change could be equal to 56% of historical fossil fuel emissions making land use change, most especially deforestation and afforestation, a significant factor in atmospheric carbon accumulation and in any comprehensive climate strategy.

Throughout the industrial era, most though not all forest clearing occurred in temperate regions. Now most deforestation is occurring in tropical regions and global temperate forested area is relatively stable (or increasing though afforestation). However, much new temperate forest is quite different in composition and carbon storage capacity than the original forest it replaced and it is also quite different than primary tropical forest (FAO 2005). Temperate forest area stability, while true for many regions, is not true for certain U.S. regions, such as Washington, California, New England, the South, and Midwest, where forests are still being converted to residential uses.

Deforestation remains the primary source of carbon emissions from terrestrial ecosystems globally, amounting to net of about 2 Pg per year (FAO 2001). Releases from burning fossil fuels add more than 6 Pg per year. FAO (2001) estimates that reducing deforestation by 50%, combined with agroforestry and afforestation/reforestation over and above what is currently occurring could maximally offset about 1.5 Pg of the fossil fuel additions to the atmospheric pool. This is significant and should be considered in any comprehensive climate policy. But even if all global forests were managed for maximum carbon sequestration, they alone cannot completely offset CO_2 emissions from current rates of burning fossil fuels.

Humans are not through transforming land, particularly forests. And we're not through burning fossil fuels. Starting with only half the forestland that might have been possible absent humans, we face large challenges to retain even the remaining 9.6 billion acres of global forest *as* forest. Only by keeping or increasing forestland in forest uses, storing more carbon in those forests, using forest products in place of energy-demanding substitutes, or by lengthening the life of forest products can forests contribute to the amelioration of current climate trends. Doing all these things would maximize forest opportunities to contribute to desired climate outcomes.

How have Carbon and Climate Changed over Time and Space?

Absent the presence and impacts of humans, climate and atmospheric carbon continually change in cyclical patterns due to physical factors associated with the shape and position of Earth's orbit relative to the sun, tilt of the polar axis, solar activity, volcanoes, and ocean currents. There are also complex feedbacks between the reflectance of various land covers and climate trends. Ice sheets reflect more of the sun's energy than forests so when a glacial period starts it accelerates as the ice advances and vice versa. These climate processes have been at work for almost as long as Earth has existed and they will continue to cause climate change in the future. Thus the issues at hand are: what are the effects of human activities in modifying climate change and what can we do about those we do not wish to experience? These are the main points of contention among climate scientists.

Most climate scientists do not argue about climate change, they argue about how current change relates to past change, the magnitude of human impacts on climate, and how those impacts might be interacting with non-human factors that drive climate change (IPCC 2001, Ruddiman 2003, Broecker 2006, NRC 2006). The principal human activities that add carbon to the atmosphere are burning fossil fuels, manufacturing cement which consumes energy to heat limestone, converting ecosystems with high carbon stores (such as forests) to ecosystems with lower carbon stores (such as agricultural lands or residential areas), certain agricultural practices such as paddy rice cultivation which emits methane, and maintaining large populations of domestic livestock that also produce methane. Much of the estimated 50% loss of forests to other land uses over the past 8,000 years has occurred during the most recent 300 years of the industrial age, augmenting the additions of carbon to the atmosphere from other human activities.

The past 300 years are also significant in several other ways. The massive conversion of forests during this period coincided with burning wood harvested from those forests, and then burning fossil fuels. Used for smelting metals, making bricks and cement, and eventually fueling motorized transportation, fossils fuels helped enable dramatic increases in economic activity in certain nations, along with accelerated global trade. The industrial age has thus witnessed the transfer of large amounts of carbon from two of its long-term stores into the atmospheric and oceanic pools—from forests converted to other land uses and from wood and fossil fuels burned to drive economic development. The atmospheric carbon in excess of what nature's processes would otherwise deliver will eventually be taken back up by oceans, but not as quickly as we are delivering carbon to the atmosphere, and not all of it until human actions release only as much carbon as terrestrial and aquatic ecosystems are capable of sequestering.

Scientists are still working to understand more precisely how industrial-era carbon releases have impacted global climate. Relationships between carbon and climate are not simple. Nor are they linear, direct cause and effect. During this 400-year period of adding carbon dioxide to the atmosphere, Earth also experienced what is referred to as the Little Ice Age, a cooling period that ended during the latter half of the nineteenth century. Remnant glaciers have been receding since the late 1800s, dramatically so in recent decades. Did the addition of carbon dioxide from industrial era forest conversion coupled with burning fossil fuels bring the Little Ice Age to a premature end? Ruddiman (2003) thinks it plausible. Or did long-term cyclical factors that drive climate override whatever impacts human activities might have had? Probably not (IPCC 2001, NRC 2006).

What does the Future Look Like From Here?

To a degree, what we know from the past tells us what we might expect in the future. Climate oscillates, it cycles at multiple scales, it often changes abruptly, and forests respond to climate change in complex ways. We should not expect any of these principles to be different in the future.

The transition time to any potential future climate equilibration—estimated to be at least a century from now, perhaps longer and then only if we boldly change course on emissions and sequestration soon—means that we and our grandchildren will live through warmer climates for many decades. Will the current levels of CO_2 in the atmosphere, and projected additions from future human activities, be enough to alter any non-human climate cooling forces? Or will they exacerbate non-human warming factors? We don't know for sure yet. We have only models to give us ranges of possible futures and the main scenarios examined point to a warmer, not cooler, future (IPCC 2001). These scenarios suggest future mean annual global temperature increases that range from a low of about 2 times the amount of increase over the past 100 years to a high of about 11 times the rate of increase during the twentieth century (IPCC 2001). Thus, the heightened concern about carbon and climate and what we can do about them.

What might these estimated future global mean temperatures mean for us? IPCC (2001) estimates the following as *very likely:* higher maximum temperatures and more hot days over nearly all land areas, higher minimum temperatures, fewer cold days and more frost-free days over nearly all land areas, and more intense precipitation events. They rate as *likely,* increased summer continental drying and associated risk of drought for most mid-latitude continental interiors. The U.S. south of the Canadian border is a mid-latitude region.

Using the best state-of-the-art models and databases, scientists describe what we might expect for climate and forests in Oregon—not a single future but a range of possible futures based on current trends and assumptions about their continuation. Most future climate scenarios for the Pacific Northwest show increases in mean annual temperature of from about 3.5 to 7.0° F by the end of the twenty-first century. Recall that global mean annual temperature rose by only about 1.0° F during the twentieth century. Regional precipitation may change little, perhaps become slightly wetter or slightly drier. But with a warmer climate more precipitation will come as rain than snow and growing seasons may be extended, leading to higher biomass accumulations and lower summer stream flows.

Woody vegetation is likely to increase in the dry ecosystems east of the Cascade crest and in southwestern Oregon, while alpine vegetation may be reduced as the upper treeline moves up in elevation — right off the top of the mountain in some cases. Projected warmer winter temperatures could open some Oregon forests to species that do not tolerate hard winter frost, changing the assemblage of species in our forests. It could also change the nature of insect and disease outbreaks, as cold winters are one of nature's checks and balances on their populations. In the past, plant and animal species were able to move freely across the landscape in response to climate change if it was tolerable and slow enough. But the current faster pace of change, along with extensive human infrastructure such as roads and developments throughout many landscapes, will hamper the natural ability of some species to adapt by changing location.

Perhaps the most significant implications of future climate scenarios for the Pacific Northwest are the potential impacts on fish and fire. Warmer temperatures, longer growing seasons, earlier snow melt, and more droughts mean earlier peak stream and river flows and lower summer flows. These are bound to impact native fish populations, including wild salmon runs. Forests in the future will be even more vulnerable to insect epidemics and uncharacteristically intense, large fires.

Westerling et al. (2006) document data and model results suggesting that climate warming has made fire seasons since the 1980s more severe, regardless of fuel conditions or past forest management. Running (2006) suggests future fire seasons will even be more severe.

These changes in fire seasons will require either more resources dedicated to fire suppression, which will only make the eventual fires more severe, or a policy change to allow fires to burn where they do not endanger other's property or homes. With a declining federal discretionary budget, the latter may end up being the default option. Another option would be to purposefully ignite fires when forest and weather conditions are likely to lead to acceptable and more controllable fire intensity and area of burn. This may require rethinking how air, water, and endangered species laws are implemented, accepting some short-term risk to air and water quality and at-risk species to reduce long-term cumulative risk (Mealey *et al.* 2005).

Whether future forest fires will add more CO_2 to the atmospheric pool than is removed by forests accumulating more biomass in a warming climate with longer growing seasons is not universally clear. It depends on the geographic scale and the severity of fires, as well as the forest type. It also depends on what happens after the fire in terms of burned trees and reforestation. In some cases the most positive effect on climate may entail harvesting fire-killed trees, turning them into durable products, and then actively reforesting the burned area as proposed by Sessions et al. (2004). But this also depends on how much fossil fuel would be consumed through harvest, transport, milling, and reforestation. In others the most positive effect may entail letting nature alone decompose the fire-killed trees and revegetate the landscape (Law *et al.* 2004). The issue of how best to respond following major forest disturbance events is currently receiving much attention in scientific and policy areas.

What can We do to Influence Future Climate through Forest Resource Management?

Scientists, among others, have suggested worst case scenarios for future climate and forests. But we are not doomed to worst-case scenarios on either climate or forests unless we do nothing to change course. There are significant actions that can be employed to mitigate the worst case, and help reduce net human-caused additions of carbon to the atmosphere, what Princeton scientists Steven Pacala and Robert Socolow (2004) call the Wedge Strategy to close the gap between worst case and possibly tolerable case. West Coast governors have agreed to work together to reduce CO_2 emissions. California has established a state-backed and third-party verified carbon registry that includes forest conservation and management for storing additional carbon beyond "business as usual." There are many actions the field of forestry can employ.

The U.S. Environmental Protection Agency (2005) estimated that forest and agricultural land in the U.S. is currently an annual "sink" of about .225 Pg of carbon equivalent. (Carbon equivalent represents all greenhouse gas effects expressed as the net effect of that amount of carbon dioxide. A sink is a carbon pool that is gaining carbon, such as a forest that is growing). Annual removal of CO_2 through carbon sequestration, i.e., the rate of carbon removals, in terrestrial ecosystems is greater than CO_2 emissions from forest harvests, land-use conversions, or fire—and 90% of this sink activity occurs on forest lands. U.S. forests currently offset about 12% of annual U.S. greenhouse gas emissions from all sectors. If fossil fuel use increases, the offset percentage may go down. If fossil fuel use stabilizes or declines and if forests and forest products are better used as sequestration mechanisms, it could go up. But the U.S. continues to lose forests to development at the rate of about 1 million acres per year in the 1990s declining slightly since then but with projected net losses of up to 23 million acres by 2050 (Stein *et al.* 2005, Alig *et al.* 2003). This trend needs to be reversed if forests are to play positive roles in carbon storage and climate.

Forests could play more positive roles in atmospheric carbon and future climate if we manage and conserve them with their roles in carbon cycles in mind—as both long-term storage pools and active sinks—and use durable wood-based materials instead of higher energy consuming substitutes such as steel and concrete.

Land Use Strategies

The Food and Agriculture Organization of the United Nations (FAO 2005) estimates global net forest loss at about 45 million acres per year: about 79 million acres of forest lost in the tropics, offset by about 35 million acres of forest gained in temperate areas each year. But these are not one-for-one offsets. An acre of native forest in the tropics doesn't equal an acre of new forest in temperate zones for carbon or biodiversity for that matter. The two most positive impacts on global climate the forest sector can make are land-use strategies that reduce forest conversion to other uses—i.e., keep forestland in forest uses—and the creation of additional forests on soils capable of supporting forest trees but were not in forest use. Managing for and perpetuating high-carbon-storage older forests are also part of landscape-scale solutions. But this will require new thinking about what old forest conservation means in the face of a continually warming climate with more droughts, insects, and fire; it may not mean passive preservation with no human intervention.

Starting points are significant in determining a given forest's contribution to global atmospheric carbon. Afforestation of abandoned agricultural land that is suitable for tree growing will have a net positive effect, removing more carbon than is being released. Reforestation of recently cut old or mature forests would have negative net effects until such time as the new trees capture and store more in-forest carbon than was released through harvest and processing, as well as that released from on-site decomposition. Also, determining the net effect of forestry on carbon sequestration is not a stand-scale problem; it requires landscape-scale and inter-regional assessments over periods of time. Storing more carbon in domestic old growth or secondary forests will do little to increase the global rate of carbon sequestration if primary forests in other regions of the world are harvested to produce the wood products we consume but do not produce (Shifley 2006). This is a real and timely concern as the U.S. now imports nearly 40% of softwood timber products used annually (Howard 2006), much of it from boreal primary forests in Canada at present. Between 1965 and 2005 softwood lumber consumption in the U.S. – our largest use of wood products — rose by 93% while the portion of consumption supplied by imports rose by 400%. Domestic strategies for using forests to sequester and store carbon must be considered in the global context of how much wood the U.S. is using and where it is coming from.

Forest Management Strategies

Beyond avoiding deforestation and creating new forests on suitable lands, there are multi-pronged management strategies that can be employed for existing forests. For example, more carbon can be stored per acre of land by accelerating reforestation and tree growth after disturbance, whatever the cause. On forests managed for timber production, extending the length of time trees grow prior to harvest along with protection against fires and insects, would increase in-forest carbon storage and reduce vulnerability to carbon loss at the landscape scale. In fire-prone forests this might mean favoring a diversity of tree species rather than a single species, and keeping stocking levels lower than full-site occupancy for maximum productivity, i.e., reducing vulnerability to drought stress, insects, and fire. Lower stocking and diverse species tend to reduce fire severity resulting in more trees surviving the fire and hence more carbon stored than if a fire kills most or all standing trees.

Perpetuating old growth forests in a warming climate subject to more fire may require landscape-scale strategies to reduce fire hazards within reserves and buffer surrounding areas from high severity burns. In interior lower elevation forests, it may mean active management to restore stand and landscape conditions that support low severity sub-lethal fires as opposed to stand replacing fires. In wood production forests, growing trees on shorter rotations and turning the young trees into durable products then returning a fast-growing forest composed of species or provenances suited to the changing climate (St. Clair and Howe submitted) may also be part of a comprehensive solution if combined with use of wood products offsetting use of more energy demanding materials (Perez-Garcia et al. 2005). Paying sharper attention to the carbon impacts of forest management activities that consume fossil fuels, such as reducing the use of fuel inefficient machines, petroleum-based chemicals, and long-distance transport of logs and biomass to processing facilities, could also have some positive impacts.

Some of these options have co-benefits beyond carbon storage. Longer rotations, for example, generally provide habitats for a wider diversity of wildlife species and have the potential to generate higher value wood products. Restoring forest resilience to extreme disturbance events through thinning to reduce stocking levels can generate wood-based products or biomass energy as byproducts of forest treatments while decreasing the likelihood that large-scale future disturbances would create both immediate and long-term carbon releases through fire or decomposition. Rapid regeneration of forests after large disturbance events, especially if it entails transfer of significant portions of the carbon in damaged trees into durable wood-based products, may accelerate the return of a net carbon sink for the landscape so affected. But full accounting must consider carbon consumed in harvest, transport, manufacturing and reforestation relative to carbon transferred from the forest pool to the product pool.

Forest Product Management Strategies

Once trees with their stored carbon leave the forest, what happens next as wood products can provide additional opportunities for carbon sequestration. Forest products carbon is a transfer of carbon from one pool to another, not a new pool or stock of carbon. In the mill, carbon capture in manufactured wood products is typically about 50 percent of the carbon in the log as it entered the mill, and perhaps one third of what was in the forest carbon pool. In modern mills the capture may be higher. Also in the mill, biomass not suited for wood-based products is increasingly being used to generate energy, offsetting the burning of fossil fuels for that amount of energy. The role of wood-based products in global carbon could be significant if those products are durable and store carbon for very long periods. Even wood products in landfills continue to store carbon. Technological advances in the manufacturing sector have resulted in significant improvements in biomass capture into products since the 1950s. More may be possible. Durable wood-based products are additionally valuable for carbon storage when they are used in place of substitute materials such as steel, concrete, and plastics that have higher fossil fuel needs in their manufacture.

Forest Profitability from Carbon Markets

The Kyoto Protocol arose from an international treaty on climate change negotiated in 1997 and came into force in 2005. The protocol does not embrace all potential roles for forests and forest products in carbon sequestration, however, due to resistance from some environmental groups. They were and perhaps still are concerned that fully crediting carbon sequestered and stored in forests and forest products would be used to justify continued fossil fuels emissions. The U.S., Australia, India, and China have chosen to not participate in Kyoto. Rather, they are working with Japan, South Korea, and other members of an Asian-Pacific partnership on a non-binding plan to cooperate on development and transfer of technologies that would enable greenhouse gas reductions, including better use of forests and forest products. Collectively, these non-Kyoto nations account for around 50 percent of global greenhouse gas emissions, energy consumption, gross domestic product and population. But they are still talking about what to do, without taking significant action yet.

In the meantime, California is developing carbon offset markets to generate revenue streams for forestland owners who go beyond "business as usual" to store additional carbon in their forests. On September 27, 2006, Governor Arnold Schwarzenegger signed into law Assembly Bill 32, making California the first state in the nation to direct its Air Resources Board to establish a state greenhouse gas emissions cap by 2012. Oregon-based The Climate Trust is working on the state's Carbon Dioxide Standard and creating a voluntary carbon offset market. Under the offset concept, forestland owners receive payments for the amount of carbon they store that (1) cancels out other emissions, (2) are recorded in a registry, and (3) work as if the emission had not occurred. Offsets, in essence, are compensations based on the promise that the additional carbon storage would have the same atmospheric effect as if the emissions being offset had never occurred in the first place. The potential emitters pay the entity making the promise to store a particular amount of carbon for a certain period of time.

The U.S. has rudimentary carbon markets, mainly starting to develop at state or regional levels. While there is much attention to and interest in carbon markets and how they might add streams of revenues to forestland owners, there is also much uncertainty in how those markets would function and how the carbon benefits would be measured and accounted for. Some states and entities are creating regulations that set emission reduction standards.

A recent study cited in this book shows the potential for carbon markets to augment revenue streams over and above those from traditional forest management. The potential to deliver internal rates of return competitive with short rotation, industrial forestry are possible through extended rotation lengths that store additional carbon, if accompanied by a small premium for higher value logs, sale of carbon sequestration offsets, sale of conservation easements, and New Market Tax Credits. There remain significant uncertainties in this possibility, but these are all possibilities for those who choose to participate in emerging markets. The power in this concept comes from finding ways to value and price the public benefits of private forests, in turn creating streams of revenues for forest ecosystem services beyond those that currently have markets, such as wood, recreation, and some aspects of biodiversity conservation. Stavins and Richards (2005) document that forests can play a significant and economically valuable role in future climate policy.

To date, carbon markets look at rewarding landowners for storing additional carbon beyond "business as usual." This is the reference point used in the Kyoto Protocol. But an alternative reference point could be "beyond alternative land uses." Where pressures to convert forest to other land uses or where regulatory costs of forestry are high, landowners may see business as usual as sell the land for development or high value agriculture such as wine grapes or specialty orchards (Alig et al. 2003). Treating existing forestry practices under state forest protection laws as the reference for additionality fails to reward landowners for keeping their land in forest uses in the first place. This coupled with the potential impacts on timber supply of compensating landowners for storing more carbon in their trees rather than sending them to mills (Im *et al.* in process) could be among the contentious issues as state or federal forest-carbon policy takes shape.

The Future for Oregon

Can any of this happen in Oregon? Yes, it can and likely will. Oregon is poised to be a player in carbon markets. Our forests have relatively high productive capacity, i.e., high potential for carbon storage, and a wide diversity of values that are compatible with and may even be enhanced by "stacking" streams of revenues from all forest ecosystem services, including sustainable wood production. This potential warrants serious policy consideration as the state explores its forest futures.

So, where do we sit on the policy front? California has a carbon registry and a new law to set emissions caps. Oregon's governor has a Global Warming Initiative. Oregon is also teaming with California and Washington to develop regional and state strategies for reducing contributions of greenhouse gases. The forestland parts of the strategies include reducing wildfire risk by creating markets for woody biomass, considering greenhouse gas effects in farm and forest land use decisions, and increasing afforestation on under-producing lands. These are good first steps and all journeys start with first steps. But they just get us started on the possibilities. What is significant about Oregon's first steps is they have an Executive level mandate.

Final Comments

This introduction has attempted to set a global and temporal context for the material covered in this book. I have brought in some information that is not covered by other chapters to help describe long-term relationships between forests, carbon, climate and people and what is possible for forest roles in carbon and climate. The chapters you are about to read tell part of the story of forests, carbon, and climate—a story that is also only partially revealed to date. We still have a lot of learning to do. But we already know enough to get started.

What we know so far is that our climate is rapidly getting warmer due to human activities. This will affect our quality of life for many decades, perhaps longer. Forests can play vital roles in ameliorating some of future climate change because they are significant carbon sinks and carbon pools. They could be managed to be even more significant in the future. Forests are also very responsive to climate change. They will exist in a warmer climate with more severe disturbance events than at any time since the last glacial maximum, perhaps even longer. This needs to be considered in revising conservation and management plans that were not developed with climate change in mind. We know that how we conserve and manage forests and how we produce and use wood products have potential to ameliorate some of the carbon being added to the atmospheric pool through other human activities. We know that managing forests for carbon storage, as well as for wood and other ecosystem services, has co-benefits that generally improve our quality of life. We know that carbon markets have the potential to add streams of revenue to forestland owners, perhaps significant enough to help conserve forests from conversion to other uses less beneficial to the climate. Finally, we know that forests managed and conserved to sustain a multitude of values, uses, products, and services also help maintain economic and community vitality in our state.

These are some of the major reasons we should all care about forests, carbon, and climate. Because Oregon is such a forest-rich state, the future is indeed bright with many possibilities for Oregon forests, forestry, and forest products enterprises to play positive roles in maintaining a livable climate.

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CHAPTER TWO
HIGHLIGHTS:
ATMOSPHERIC CARBON DIOXIDE

Introduction

- Carbon dioxide plays a critical role in regulating earth's surface temperature.
- Human activities that release carbon dioxide have resulted in increasing concentrations sufficient to increase the earth's surface temperature above natural cycles.
- Current concentrations and recent increase rates exceed that of the last 420,000 years.

Carbon Dioxide as a Greenhouse Gas

- Carbon dioxide is one of five main greenhouse gases, which retain heat by allowing short-wave radiation (light) to pass through, but act as a barrier to long-wave radiation (heat).
- Next to water vapor, carbon dioxide is the most prevalent greenhouse gas.
- Arrhenius in 1896 hypothesized that carbon from burning fossil fuels could increase the earth's surface temperature; Keeling since 1958 showed the trend in increasing concentrations.

The Global Carbon Cycle

- **Carbon Pools.** Carbon is stored in geologic, biologic and atmospheric "depositories."
- **Carbon Cycle and Time Scales.** The geologic cycle is examined over millions of years. The biologic cycle, from less than a year to hundreds of years, is more relevant to managing atmospheric carbon dioxide in the next 100-200 years.
- **Human Effects on the Carbon Cycle.** Processes that remove carbon dioxide from the atmosphere are not increasing enough to remove all the carbon added by humans.

Measurements of Atmospheric Carbon Dioxide

- A global network of 40 stations measures current concentrations.
- Precise historical measurements were derived recently from snow and ice in glacial deposits
- Current levels are higher than any time in last 420,000 years; unprecedented rate of increase.

Historical Changes in Atmospheric Concentrations of Carbon Dioxide

- Great fluctuations in the past were caused by natural sources such as volcanoes.
- Human release since 1850 increased carbon dioxide more than 90 times that of past cycles.
- Human inputs are currently so high that natural processes cannot change the increases.

Future Trends

- Ocean and land capacity to store carbon is expected to remain about the same.
- Humans have the potential to enhance carbon sequestration.
- Management actions on forestland are limited, but not to be ignored.
- Pattern of atmospheric carbon dioxide increase is strongly dependent on speed of use of alternative energy.
- Overall outlook is one of increased carbon concentrations for foreseeable future.

CHAPTER TWO
ATMOSPHERIC CARBON DIOXIDE

Mark E. Harmon

Introduction

Carbon is not particularly abundant on earth (of all elements, it ranks 50th), yet it is a key component of all living organisms. As part of several greenhouse gases, such as carbon dioxide, carbon monoxide, and methane, it also plays a critical role in regulating the surface temperature on earth. With the release of carbon dioxide through the burning of fossil fuels, cement production, and changing land use, humans have been increasing the concentration of this gas in the atmosphere for over 150 years. Although these concentrations are still relatively small, they are sufficient to warm the earth's surface temperature. Carbon dioxide is a natural part of the atmosphere. However, both the current concentrations, and rate of increase observed in recent decades, exceed that observed in the past 420,000 years.

This chapter reviews what is generally known about carbon dioxide in the atmosphere, how it is measured, and how it is changing.

Carbon Dioxide as a Greenhouse Gas

Although carbon dioxide can be deadly to animals at high concentrations, the current atmospheric levels of 0.037% (or 370 parts per million) are far below lethal levels. The current concern about rising carbon dioxide concentration stems from the ability of carbon dioxide to act as a greenhouse gas. These gases enhance the retention of heat by allowing short-wave radiation (light) to pass through, but acting as a barrier to long-wave radiation (heat). There are five main greenhouse gases: carbon dioxide, methane, nitrogen oxide and water vapor (all naturally occurring) and chlorofluorocarbons (man-made). While carbon dioxide is not the strongest greenhouse gas (methane is 30 times more effective), next to water vapor it is by far the most prevalent.

Greenhouse gases have different strengths and life spans. They are not static; they are formed and then they break down. To analyze the effect of the release of a greenhouse gas, its "instantaneous," or initial, strength, and the rate that the gas breaks down, are averaged over time. Because of carbon dioxide's prevalence, it is often used to indicate the overall greenhouse forcing (or effect) on climate. Thus, the effect of all other greenhouse gases, is expressed in carbon dioxide units. (Ramanathan *et al.*, 1985, Lashof and Ahuja 1990).

The ability of carbon dioxide to act as a greenhouse gas has been known for over 100 years and can be readily determined in a laboratory. Indeed, in 1896 the Swedish scientist Arrhenius used this knowledge to predict the warming effect of greenhouse gases on earth's temperature compared to a planet without these gases. Performing thousands of calculations by hand, he was able to predict the earth's temperature remarkably well (Arrhenius 1896, Hayden 1998). It was also Arrhenius who hypothesized that the release of carbonic acid (or carbon dioxide) from the burning of fossil fuels might increase the temperature of the earth's surface. Charles Keeling's measurements of concentrations of carbon dioxide in the atmosphere during and after the 1957-1958 International Geophysical Year showed an increasing trend in concentrations, renewing interest in Arrhenius's hypothesis (Keeling 1960, Baes *et al.* 1977).

The Global Carbon Cycle

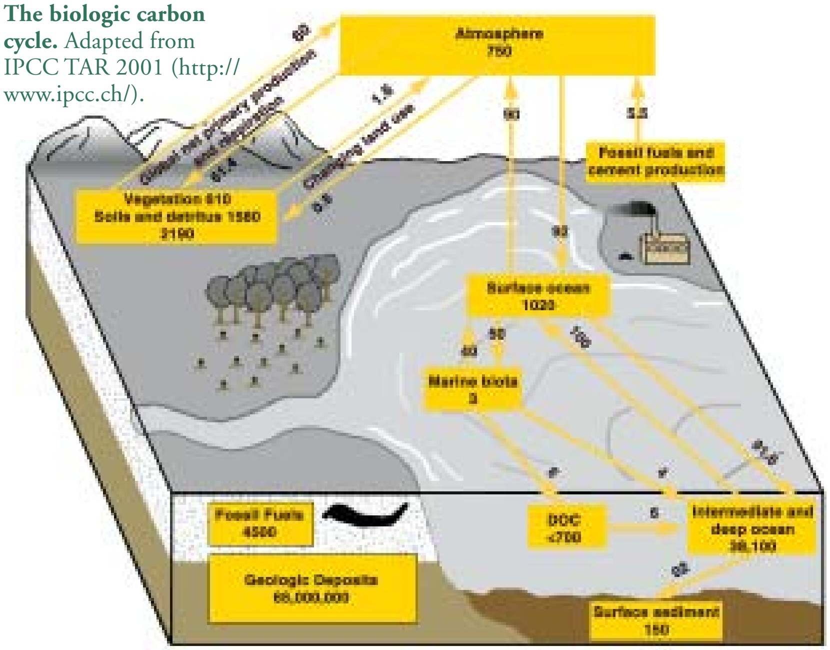
Carbon Pools

Carbon is stored on Earth in several major "pools" (depositories) — geologic, biologic and atmospheric.

Geologic carbon stores are by far the largest. Geologic deposits such as calcium carbonate hold approximately 65,000,000 Pg (a petagram is 1.1 billion U.S. tons) of carbon. There is also a concentrated store in fossil fuels of 4,000 to 5,000 Pg, but the majority of fossil carbon (15,000,000 Pg) is stored in very dilute concentrations within geologic strata in a form of carbon known as kerogen. (As an aside, kerogen plays another significant role in the dynamics of the atmosphere. Comprised of plants that photosynthesized millions of years but did not fully decompose, leaving an excess of oxygen in the atmosphere, kerogen has led to the current high level of oxygen in the atmosphere. Interestingly, this means the oceans and tropical forests are not the source of most of the atmosphere's current oxygen, as popularly envisioned.) Biologic carbon stores are less, but significant. The largest biologically-related store of carbon is in the oceans. Deeper zones of the ocean hold 38,100 Pg of carbon, surface ocean holds 1020 Pg and sediments contain 150 Pg. Marine biota are a particularly trivial store of carbon (3 Pg), but play a critical role as a biological pump, removing carbon dioxide from the surface ocean. Carbon is also stored terrestrially. Non-living organic matter such as dead wood, soils and peat store at least 1,580 Pg of carbon, and plants hold 610 Pg. *(Figure 1)*

Figure 1

The biologic carbon cycle. Adapted from IPCC TAR 2001 (http://www.ipcc.ch/).



The atmosphere, by comparison, currently stores 750 Pg of carbon. Relative to the other pools, the atmosphere stores little carbon, so small changes in those other pools can have a profound effect on the carbon in the atmosphere and therefore its effect on climate.

To illustrate this: Imagine that all the terrestrial stores were instantaneously consumed in a fire. This would lead to 292% increase in carbon concentrations of the atmosphere. Suppose all this carbon was then absorbed by the oceans. The store in that pool would only increase by 6%. While neither scenario is realistic, these calculations demonstrate how sensitive atmospheric carbon concentrations are to changes in the other pools.

Carbon Cycle and Time Scales

The carbon cycle is studied at two very different time scales, depending on whether geologic processes or biologic processes are dominating the processes in the cycle. Neither the geologic or biologic carbon cycles are purely geologic or purely biologic.

The geologic carbon cycle is examined over millions of years. It involves the formation of carbonate deposits, as well as the weathering of carbonate and aluminum-silicate minerals, and the release of carbon to the atmosphere via volcanism (Berner and Lasaga 1989). At this time scale, volcanic activity has a high correlation with atmospheric carbon dioxide concentrations. But while it is called the geologic carbon cycle, biology plays a role. The cycle is largely thought of as controlled by abiotic processes (i.e., the absence of living organisms), yet the weathering of carbonates and minerals does involve living organisms to a significant degree.

The biological carbon cycle is typically examined over time periods from less than a year to hundreds of years (Post et al. 1990). The primary processes involve photosynthesis in removing carbon dioxide from the atmosphere, and respiration in releasing carbon dioxide back again. While the biological carbon cycle is dominated by biological processes, a number of abiotic geologic and physical processes are ongoing, and control some of the fluxes. These include fires, river and ocean transport, and turbulent mixing of ocean waters by waves, diffusion and a host of other processes.

While the geologic and biologic cycles are occurring simultaneously, the biological carbon cycle is the one most relevant to management of atmospheric carbon dioxide in the next 100 to 200 years. Thus, while it is probably true that much of the carbon released by humans will eventually be absorbed by the oceans, this process is likely to take thousands of years.

Human Effects on the Carbon Cycle

Humans release carbon dioxide through burning fossil fuels, manufacturing cement (i.e., carbon dioxide released as limestone is heated to form cement), and converting land cover types with high carbon stores (forest) to those with lower stores (agricultural land). For thousands of years before the industrial revolution, humans were clearing forests for agriculture (Williams 2003), but at a rate that could generally be absorbed by other carbon pools. At the start of the industrial revolution, changes in land use comprised the major human-related release of carbon dioxide to the atmosphere (0.5 Pg/year). Although land use-related releases have quadrupled to a current value of approximately 2 Pg/year, release from fossil fuels and other industrial uses has increased from virtually zero to over 6.5 Pg/year in the same time period. Carbon dioxide release from fossil fuels currently amounts to 75 % of the total, which places some rough limits on how much future alteration of land use could offset future releases.

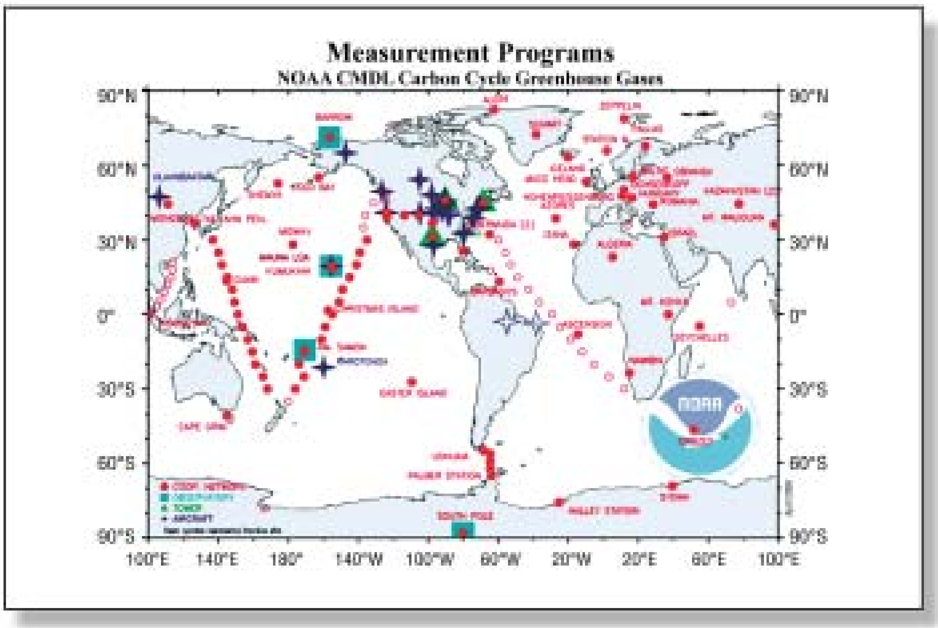
Approximately 50% of the carbon that has been released by these human-related activities has accumulated in the atmosphere; the remainder has been either "absorbed" by the oceans or stored terrestrially. The proportion going to each of these "sinks" has been the subject of ongoing debate and highly dependent on the time period being considered. In the past, given the size of the oceanic pool, it was difficult to directly measure increases in carbon stores. Now, increases are large enough that this is becoming possible. Models of current ocean uptake indicate that approximately 1.5-2 Pg of carbon is annually "absorbed" by oceans. Although this process is too slow to keep up with the current increase of atmospheric carbon dioxide, the oceans are potentially capable of removing much of the carbon dioxide added by humans once emissions from fossil fuels end. It is anticipated that either fossil fuel reserves will be depleted in the next 200 years (depending on the rate of use) or policies will be implemented to decrease use before that time. Either way, the ocean will gradually remove the human-released carbon dioxide but very slowly; it will potentially take many thousands of years (Archer 2005). There is estimated to be a net terrestrial sink of 2 to 3 Pg per year, which is slowing the rate of atmospheric increases, but cannot at this time eliminate it (Houghton 2003). This is why changes in land use management are not the ultimate solution for eliminating atmospheric carbon dioxide concentrations.

Thus, these sinks absorb approximately 3.5 to 5 Pg of carbon per year, while human activities are releasing approximately 8.5 Pg per year. By releasing carbon tied up in fossil fuels, humans are, in a sense, speeding up the geologic cycle and making it interact with the biologic cycle. While warmer temperatures and longer growing seasons may enhance photosynthesis, which removes carbon dioxide from the atmosphere, this process is currently not increasing quickly enough to remove all the carbon added by humans.

Measurements of Atmospheric Carbon Dioxide

Starting with the observations of Charles Keeling in 1957, there has been a concerted effort to measure concentrations of carbon dioxide and other greenhouse gases in the atmosphere. A ground-based global network of over 40 stations now exists to periodically measure these concentrations, as well as gases that can be used to determine global atmospheric circulation patterns (*Figure 2*). These observations are primarily made at sites where well-mixed air samples can be taken, often locations on islands or on the margins of continents. Additional measurements are also taken from ascending balloons, tall towers, aircraft, and oceangoing vessels.

Figure 2



Location of atmospheric sampling stations to determine concentrations of carbon dioxide and other greenhouse gases. Source: http://www.ogp.noaa.gov/mpe/gcc/2000/tans.html.

While it is possible to directly measure current atmospheric concentrations (often referred to as the mixing ratio) of carbon dioxide, determining past concentrations has involved a good deal of ingenuity. When Charles Keeling began to observe increases in atmospheric carbon dioxide, the concentration at the start of the industrial revolution was not clear. Attempts were initially made to sample gas trapped in items created in the past, including—of all things—metal buttons. Other efforts sought to deduce past atmospheric concentrations using proxies, such as the density of stomata on leaves.

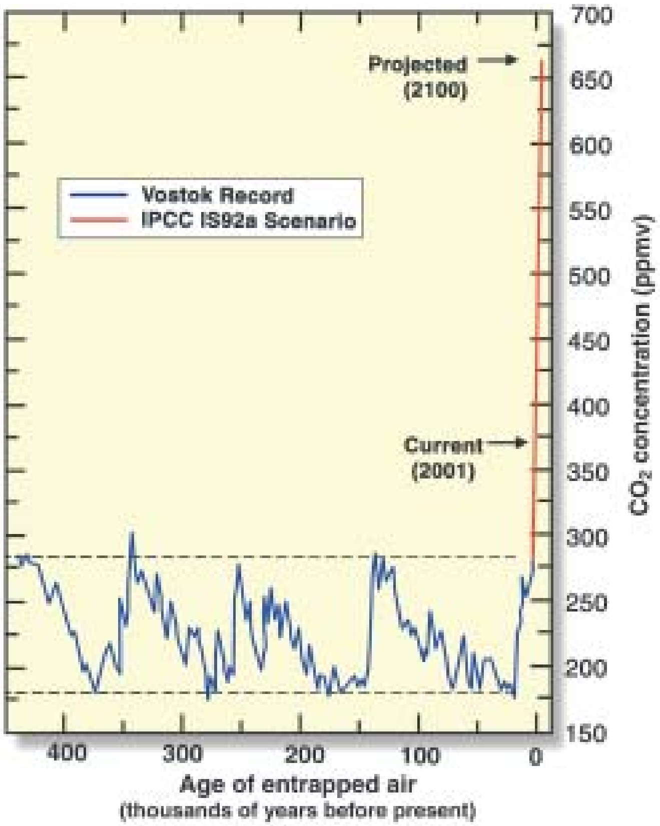
More recently, measurement of gases trapped in snow and ice in glacial deposits have yielded very precise and accurate measures of past carbon dioxide concentrations going back over 420,000 years. These measurements provide very certain evidence that while atmospheric concentrations of carbon dioxide have fluctuated, the current levels are higher than have occurred at any time in the past 420,000 years, and are increasing at an unprecedented rate (*Figure 3*).

Historical Changes in Atmospheric Concentrations of Carbon Dioxide

Concentrations of carbon dioxide in the atmosphere have fluctuated greatly in the past. It is thought that in the Paleozoic and Mesozoic eras, 50 to 500 million years ago, concentrations ranged between 1,200 and 4,000 ppm (parts per million).

Figure 3

Changes in atmospheric carbon dioxide concentrations in the past 450 thousand years as indicated by gases trapped in ice at Vostok. Source: http://www.ipcc.ch/



In large part, the greater concentrations were caused by a higher level of volcanic release of carbon dioxide than in recent times. These levels were far above today's level of 370 ppm. However, temperatures were considerably higher, with strong evidence that sea surface temperatures in the tropical latitudes averaged 89 to 97°F, or 9 to 14 degrees higher than today (Schouten *et al.*, 2003).

In the past 420,000 years, carbon dioxide concentration has cycled between 175 and 300 ppm with approximately 100,000 years between the peaks in cycles. The cycles are thought to be associated with glacial activity, with lower concentrations occurring during the height of glacial advances. Starting in approximately 1850, clearing of forests by humans and release of fossil fuel-related carbon have caused an upward increase in carbon dioxide concentrations from 285 ppm to 370 ppm today — a 30 percent increase. This concentration is 70 ppm higher than the cycle peaks in the recent geologic past and is increasing at greater than 90 times the rate observed in past cycles.

In addition to these long-term trends, recent observations show a seasonal cycle of carbon dioxide concentrations. Fifty years of measurement at Mauna Loa in Hawaii illustrate a fluctuation through the seasons averaging 5.7 ppm (*Figure 4a*). Globally, the range of such a fluctuation varies, depending on the latitude where the measurements are made. It tends to be higher near the northern pole, as measured at Point Barrow, Alaska, with an average fluctuation of 17 ppm. At the southern pole it is lower, an average of 2.2 ppm (*Figure 4b*). For all observation stations, carbon dioxide concentration is higher in winter and lower in summer due to the seasonal cycles of respiration and photosynthesis.

Figure 4a

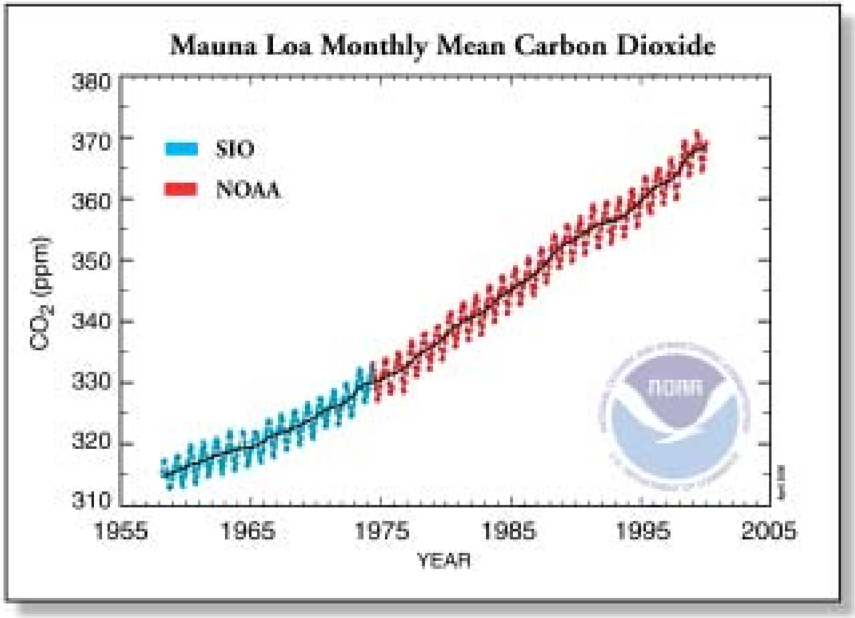
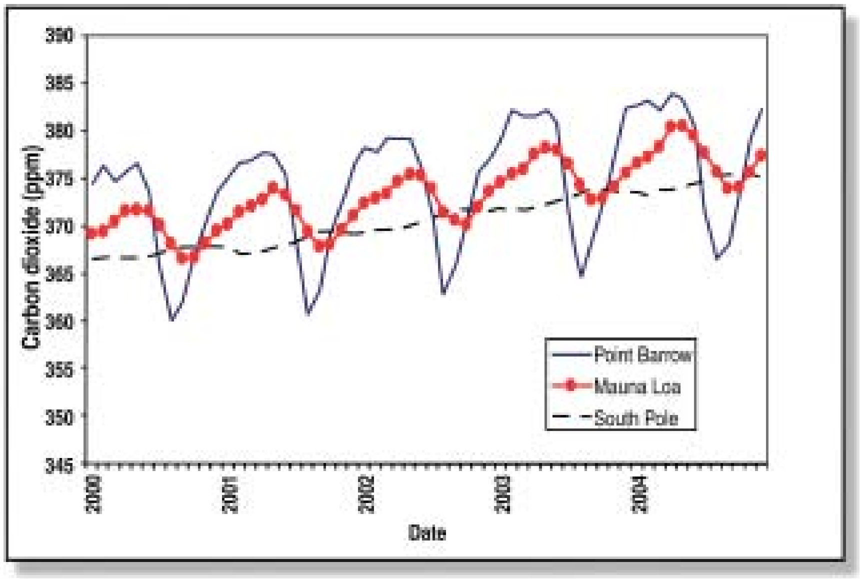


Figure 4b



Observed recent change in atmospheric carbon dioxide concentrations. (a) Long-term record at Mauna Loa; (b) typical seasonal cycles at Point Barrow, AK; Mauna Loa, HI; and South Pole observatory stations. Source: Keeling and Whorf (2003).

This latitudinal variation and rate of increase of carbon dioxide have been used to identify possible areas that are absorbing carbon, using a technique known as "inverse modeling." Spatial and temporal patterns of carbon dioxide concentrations are combined with modeled patterns of human release, plant production, ecosystem respiration, and atmospheric circulation patterns to infer the location of possible carbon sinks. These studies have generally suggested a terrestrial sink in northern latitudes (Tans *et al.* 1990), although other locations, such as tropical forests and the southern Pacific Ocean, may also be sinks. Attempts have also been made to infer longitudinal sinks (for example, North America versus Eurasia), but given the limited density and distribution of measurement stations and the uncertainties of modeling atmospheric circulation, the results are far less definitive.

The rate of increase of carbon dioxide has not been constant from year to year. As more data are gathered, the role of short-term climatic cycles such as El Niño is becoming clearer. For example, drier years in the tropics associated with El Niño can lead to increased incidence of fire in that region, resulting in larger-than-average increases in atmospheric carbon dioxide concentrations (Jones et al. 2004). On the other hand, some years there is a slower rate of increase, which might be explained by two possible factors, both arising from volcanic activity. First, volcanic activity releases dust and sulfur dioxides that lead to the formation of aerosols that increase light scattering, which leads to greater diffuse radiation, and cooler temperatures. A greater proportion of diffuse radiation is hypothesized to enhance the photosynthesis, which increases uptake from terrestrial plants lowering the rate of increase (Gu et al. 2003). The other mechanism is that cooler temperatures create a lower rate of respiration, which also leads to slower rates of release from plants and soils.

Finally, despite the presence of these very interesting changes in the rate of increase, it should be noted that human-related inputs of carbon dioxide are so high at this point that these natural cycles cannot change the resulting overall increase in atmospheric concentrations.

Future Trends

Predictions, by their very nature, are uncertain. It is therefore most useful to present a "prediction envelope," or a specific range. For future carbon dioxide concentrations, uncertainties stem from imperfect knowledge about the system and the human potential to alter it, depending on the policies adopted.

The oceans' capacity to store carbon is expected to remain about the same. Increases in atmospheric carbon dioxide concentrations are likely to increase the net rate that the carbon dioxide is diffused onto the ocean surface and absorbed. On the other hand, increases of carbon dioxide concentration in the deep ocean are likely to cause the dissolving of the calcium carbonate shells associated with small organisms, such as plankton. Currently the shells of these organisms fall to the ocean floor when they die, so their dissolution may decrease amount of carbonate-rich sediments building up on the ocean floor. As a result, upwelling of deeper waters may release more carbon dioxide back into the atmosphere. If climate does change, it is likely to alter oceanic circulation patterns, and this may also alter the net rate of oceanic uptake.

Enhanced rates of uptake by the terrestrial system are possible, but limited in amount and duration. Laboratory and field research have produced differing results. Laboratory experiments have shown that when carbon dioxide concentrations are increased to twice the current level, some plants exhibit enhanced photosynthesis and net uptake of carbon. However, field studies near caves in limestone regions, where carbon dioxide concentrations are naturally higher than average, indicate that plant growth is not necessarily enhanced, in part because plants physiologically "down regulate" when carbon dioxide is more abundant (Tognetti et al. 2000). In at least one terrestrial experiment in forests where carbon dioxide concentrations were doubled in a free-air carbon dioxide enhancement (i.e., FACE) experiment, indicators pointed to other factors like nitrogen that can limit forest response (Oren et al. 2001, Schlesinger and Lichter 2001). While the carbon dioxide fertilization effect is not completely understood for all forests, the median response of four such doubling-carbon-dioxide experiments in the temperature zone was a 23% increase in plant uptake of carbon (Norby et al. 2005).

Regardless of the amount of increase in plant uptake with higher carbon dioxide concentration, if there is an associated warming of climate, then an increase in plant and soil respiration will occur,

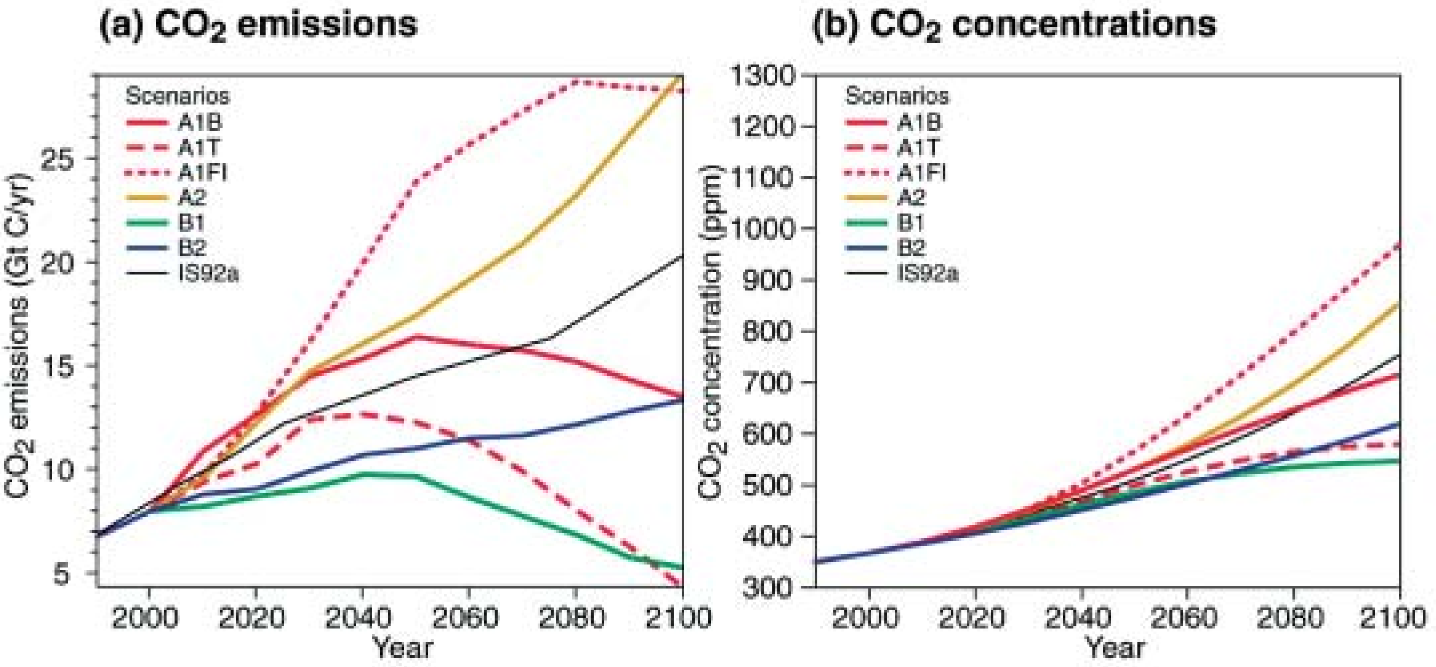


Figure 5

Projected trends in fossil fuel use and atmospheric carbon dioxide concentrations from 2000 to 2100. Source: IPCC TAR 2001. http://www.ipcc.ch/

which is more than likely to offset many of the gains in plant uptake.

While all these factors introduce uncertainty, they are unlikely to change the overall pattern set by human activities. Humans have the potential to influence the rate fossil fuels are released, and to alter land use to enhance carbon sequestration (see Chapter 5). Because all biological systems tend to saturate in terms of carbon uptake (i.e., eventually carbon uptake approaches the rate of carbon release), the ability of management actions on forest and agricultural lands is limited, but not to be ignored. Moreover, while carbon storage would increase at the time of management change, those increases would decline over time unless additional changes are made to increase carbon uptake.

Reducing future concentrations depends on how quickly fossil fuel use is curtailed. For example, in one "high" scenario (A1F1, *Figure 5a*), if carbon dioxide emissions increase at the current rate until the year 2050, then slow to eventually stabilize at 28 Pg/year in 2075, carbon dioxide concentration could reach 960 ppm by 2100 (A1F1, *Figure 5b*). This would represent more than a tripling of concentrations since the industrial revolution began. In a contrasting scenario (B1, *Figure 5a*), if the rate the of CO2 emissions eventually peaks at 10 Pg/year in 2050 and decreases to zero by 2100, then atmospheric concentration could be as low as 520 ppm by 2100 (B1, *Figure 5b*). This very optimistic scenario still reflects an increase of 40 percent over today's level of 370 ppm, and 73 percent over the 300 ppm level at the beginning of the industrial revolution. An intermediate scenario of carbon dioxide emissions (B2, *Figure 5a*) assumes an increase to a rate of 16.5 Pg/year until 2050 and a decrease to 14 Pg/year in 2100. This more realistic scenario leads to a predicted carbon dioxide concentration in 2100 of 660 ppm — over twice that before the industrial revolution.

While the future range of atmospheric carbon dioxide concentration is high, from 520 to 960 ppm, and the pattern of increase is strongly dependent on how quickly alternative energy sources are used, the overall outlook is one of increased carbon dioxide concentrations for the foreseeable future.

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CHAPTER THREE

HIGHLIGHTS:

CLIMATE CHANGE AT MULTIPLE SCALES

Introduction

- Climate change is a key driver of historic vegetation change.
- Understanding climate change is important to the stewardship of forests.

The Natural Climate System — Overview

- New tools, computing capacity and research have revealed much about past climate.
- Climate naturally cycles, with major warm and cold periods, and shorter nested cycles.
- Climate often changes abruptly, and often vegetation response is dramatic.

The Natural Climate System — A Primer on Past Climates

- The earth has experienced more than 40 warm and cold cycles during the Quaternary Period, i.e., the past 2.5 million years ago.
- Climate changes in multiple cycles, from multi-millennial to those that last a few years or decades, and worldwide evidence shows life on earth has responded on each scale.

Implications of Natural Climate Change for Vegetation Ecology

- Ecological conditions constantly change in response to climate, and species shift even in the absence of human influence.
- Currently, species ranges and demographics are expected to be highly unstable.

The Human-Dominated Climate System

- Recent global average temperature is higher than the past 1,000 years.
- Trends since 1975 can only be explained by non-natural forces.
- Future scenarios depict increases of approximately 2.7 to 10.4 °F by 2100 and an increase in carbon dioxide concentrations of 575-1000 parts per million.
- Even with CO_2 decreases, atmosphere would not stabilize for 100 to 300 years.

Potential Impacts of Climate Change on Oregon Ecosystems

- Most scenarios show temperature increases from about 7 to 8 °F from the present time to the end of the 21st century.
- The growing season could lengthen at least four to six weeks.
- In models, precipitation decreases 10-40% in summer; in winter has a range from 10% decrease to 24% increase.
- Biomes could change dramatically; shrubland/grassland could disappear.
- Vegetation distribution could have significant decreases and expansions.
- Wet maritime forests would lose carbon, while dry ecosystems gain carbon.
- Suppression of fire vs. uncontrolled fires greatly alters all the scenarios.

Summary

- Even with the latest techniques, projections about future climates are difficult to forecast.

CHAPTER THREE

CLIMATE CHANGE AT MULTIPLE SCALES

Constance Millar, Ron Neilson,
Dominique Bachelet, Ray Drapek and Jim Lenihan

Introduction

Concepts about the natural world influence approaches to forest management. In the popular press, *climate change* inevitably refers to global warming, greenhouse gas impacts, novel anthropogenic (human-induced) threats, and international politics. There is, however, a larger context that informs our understanding of changes that are occurring – that is, Earth's natural climate system and its variability.

Climate change is a central focus of paleoecology, the study of past vegetation dynamics. Climate looms large because it is a key driver of historic vegetation change at multiple spatial and temporal scales, the force that sends species migrating up and down mountain ranges, expanding across basins, or contracting into fragmented populations. Large climate changes over thousands of years have triggered speciations (lineage-splitting events that produce two or more species), and the evolution of major adaptations among and within species. On scales of decades and centuries, smaller climate changes have driven mixing and re-mixing of plant communities and catalyzed shifts in population size. Much as we have come to terms in vegetation ecology with the concepts of dynamism, such as the roles of fire, flood, and insects, we tend to view these successional changes against a static background. Significant historic climate changes are often considered events of the past with little relevance to the present or future. To the contrary, climate changes, often abrupt and extreme, characterize the ongoing stream of natural climate.

Without understanding these natural climate processes and the ways in which forest species are adapted to climate changes, decisions may be made that are counter-productive to the forests we wish to steward. Further, greater awareness of the natural climate system can put in perspective the specific effects of human-induced climate changes. In the past decade, scientists have recognized that a new, human-dominated climate system has emerged that diverges in significant ways from the natural system (IPCC 2001). This brings additional challenges to forest management beyond coping with natural changes in climate. Because of the long residence time of carbon dioxide in the atmosphere, the human influences on the current trajectory appear to be irreversible for decades to centuries, even with mitigation. Thus, given the dynamics of the natural climate system and the superimposed changes humans are causing, the 21st century is an important transitional time for undertaking both mitigation and adaptation actions.

Given this, what can forest and resource managers of private and public forest lands do to address these challenges responsibly? While we begin here to outline new management strategies for a climate context, detailed case studies and demonstrations haven't yet been fully developed. These will be wrought from collaborative discussion among colleagues – scientists, resource managers, planners, and the public – and they will be case-, location-, and project-specific. While general principles will emerge, the best preparation is for managers and planners to remain informed about the emerging climate science in their region, and to use that knowledge to shape effective local solutions. The goal of this paper is to outline natural climate patterns and mechanisms as important context for understanding current and future changes. Further, we provide an update on conditions of the human-dominated climate system, especially in the Pacific Northwest, and finally, briefly introduce five general principles for vegetation management in the face of the climate change.

The Natural Climate System — Overview

Changes in weather are familiar features of Earth's surface, readily recognizable as daily variations, seasonal cycles, and annual differences that irregularly include extremes of drought, wet, heat, and cold. All forms of life are influenced by this variability in how and where they live, and mitigate adverse weather effects through conditioned responses and evolved adaptations. Until recently our knowledge of climate processes over longer time frames, however, was rudimentary. Understanding came mostly from interpreting indirect effects of climate on the earth's surface – e.g., glacial moraines as evidence of past ice ages, coastal terraces as clues to former sea levels – and these gave a view of slow change over time. Without direct methods for understanding past climate variability, there was no reason to believe that the past climate was relevant to the present. All this changed with the advent of new methods.

Climate Oscillates

In the past two decades, new tools with high precision and resolution, new theory based on high-speed computing capacity, and a critical mass of empirical research have revolutionized understanding of earth's climate system. Historic climate is now understood as being far more variable and complex than previously imagined (Bradley 1999, Cronin 1999, Ruddiman 2001). Several key insights have emerged. First, climate naturally *changes* over time and the changes *cycle*, or *oscillate*, rather than wander randomly or follow pervasive linear trends (*Figure 1*). So, it is important when considering human-dominated climate change to recognize that change itself is natural and precedented, and to use this natural variability as a reference for evaluation. Because climate is cyclic, distant periods in the past may be more similar to the present than the immediate or recent past. Similarly, past variability may give better insight into the future than do current conditions. For instance, the 20th century and especially the middle of the 20th century (when many of us grew up) were the least variable and wettest decades in the past 1000 years (Graumlich 1993), and thus may inform us poorly about future variability and potential for drought.

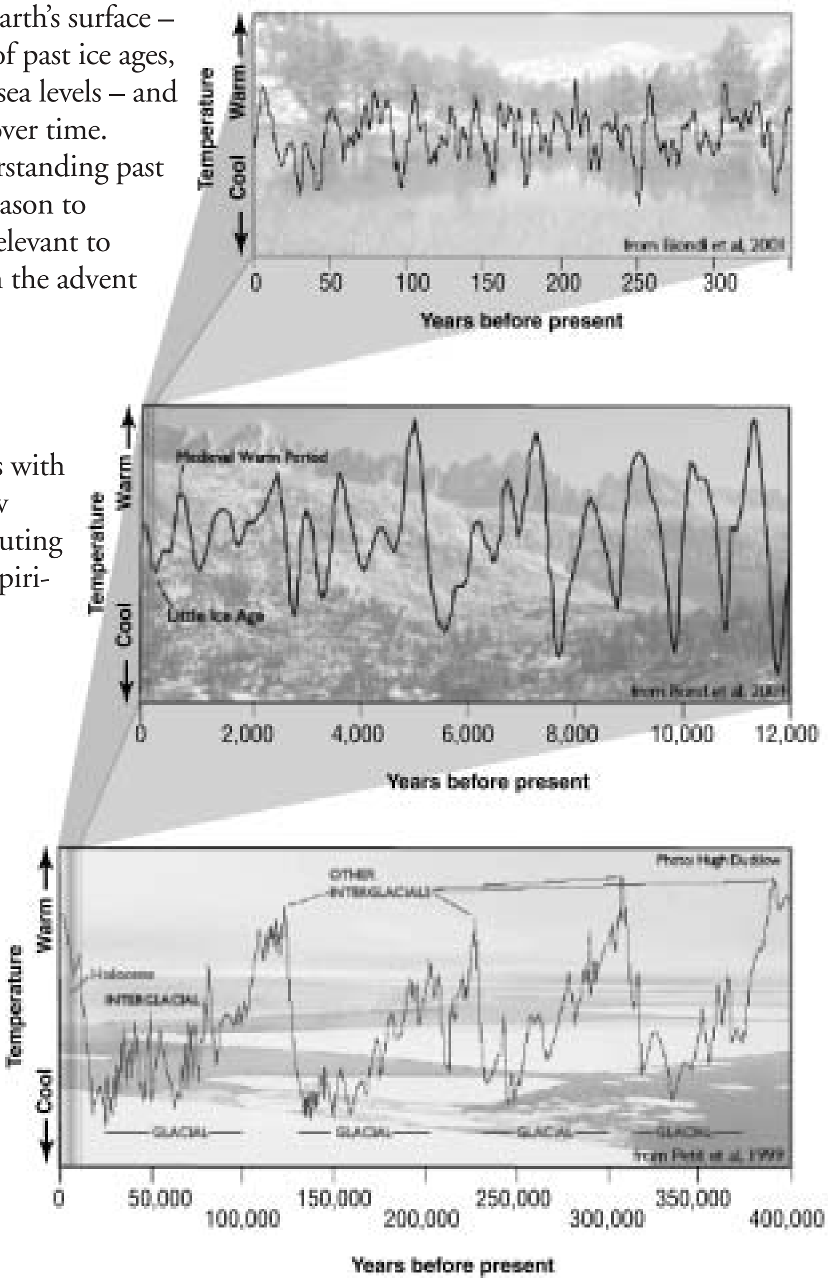


Figure 1

Global temperature cycles. a) Decadal cycles driven by ocean circulation and sea temperatures, b) Century cycles driven by solar variability, c) Millennial cycles driven by changes in earth's orbit around the sun. These and other cycles interact continually and, in combination, result in ongoing gradual and abrupt changes in earth's natural climate system. Source: Millar, 2003.

Climate Cycles at Multiple Scales

A second major insight is that climate has varied simultaneously at *multiple and nested scales*, operating at multi-millennial, millennial, century, decadal, and interannual scales (*Figure 1*), and which are caused by independent physical mechanisms. Major interglacial (warm) and glacial (cold) periods cycle on multi-millennial scales. These are caused by oscillations in earth's orbit around the sun, which in turn, control significant temperature changes. At the century scale, recurring variations in the sun's activity drive cycles of about 1200-year periods. The now familiar El-Niño/La Niña cycle (called ENSO, for El-Niño Southern Oscillation) is an example of changes at the interannual scale, and a similar 30 to 40 year oscillating pattern in the Pacific Decadal Oscillation (PDO) affects the west coast of North America. These shorter cycles result from mechanisms internal to earth, that is, the cyclic patterns of ocean circulation and ocean temperature. The separate mechanisms of these various cycles interact and feed back to one another, creating gradual as well as abrupt changes. Climate at any one time is the cumulative expression of all mechanisms operating together.

Climate Often Changes Abruptly

Third, the science of past climate informs us that major and minor transitions in climate state often occur *abruptly* (a few years to decades). Climate states are highly sensitive, catalyzed by threshold and feedback events, triggered by random effects, and especially vulnerable during times of high variability such as the present (NRC 2002). For example, although glacial/interglacial periods are long, changes between states can be abrupt, with switches to glacial climates occurring in only a few decades. A recent example at a different scale is the western North America regime shift at 1975-1976. Abrupt, coincidental changes in the climate of the previous two decades occurred in many variables, including surface air temperature, precipitation, snowpack, and ocean temperature to conditions that have characterized western U.S. since the mid 1970s (Ebbesmeyer *et al.,* 1991).

Vegetation Responds Complexly to Climate Change

Finally, *ecological and physical systems respond to climate change* at each scale. Temperature and precipitation directly affect water availability in the form of rain, snow, ice, and glacier, resulting in changes in streamflow, groundwater, aquifers, soil moisture, and erosion. Plants and animals react to climate and changes in the hydrologic system with shifts, often dramatic, in population size, range distributions, and community compositions and dominances. These are often accompanied by changes in fire regimes and insect/pathogen relations.

In the following sections, we give additional details on basic principles of natural climate variability.

The Natural Climate System – A Primer on Past Climates

The most widely applied new method for understanding past climates — studying core samples — was first derived from long ice cores drilled into polar ice caps (Cuffey *et al.* 1995). Gases and atmospheric particles trapped in ice faithfully record atmospheric conditions at the time of deposition. Due to annual layering and the ability to date layers accurately, analysis of thin sections at regular intervals yields high-resolution historic climate data in a continuous time series. Cores drilled to the bottom of continental ice sheets (e.g., Greenland) have yielded high-resolution information on more than 40 climate variables that extend over 200,000 years (Lorius et al., 1990). The most important are isotopes of oxygen. Ratios of heavy to normal oxygen isotopes (^{18}O) quantify the relative amount of oxygen stored in land ice relative to seawater, and provide strong indicators of surface air temperature at the time the isotopes were trapped in the ice. Analysis of these and other climate-related isotopes are now routinely extracted from other situations where undisturbed deposition occurs, such as lake beds, coral reefs, and sea floor sediments. Depending on the depth of the deposition and the time interval between sections analyzed, such sediment cores yield detailed climate information at multi-millennial to interannual scales, as we summarize below.

Multi-Millennial Climate Cycles

Taken together, these long records collectively document the repeating, cyclic nature of climate during the Quaternary, or past 2.5 million years (*Figure 2*, Wright 1989; Raymo and Ruddiman 1992). Unlike earlier assumptions of persistent ice ages, oxygen-isotope records show a repeating pattern of over 40 glacial (cold) /interglacial (warm) cycles, with global temperature differences between cycles averaging 11 to 15°F (Petit *et al.* 1999). A startling insight revealed by the oxygen-isotope records is the overall similarity of our past 10,000 years to similar warm interglacial periods throughout the Quaternary. Recent climate cycles are not wholly novel after all.

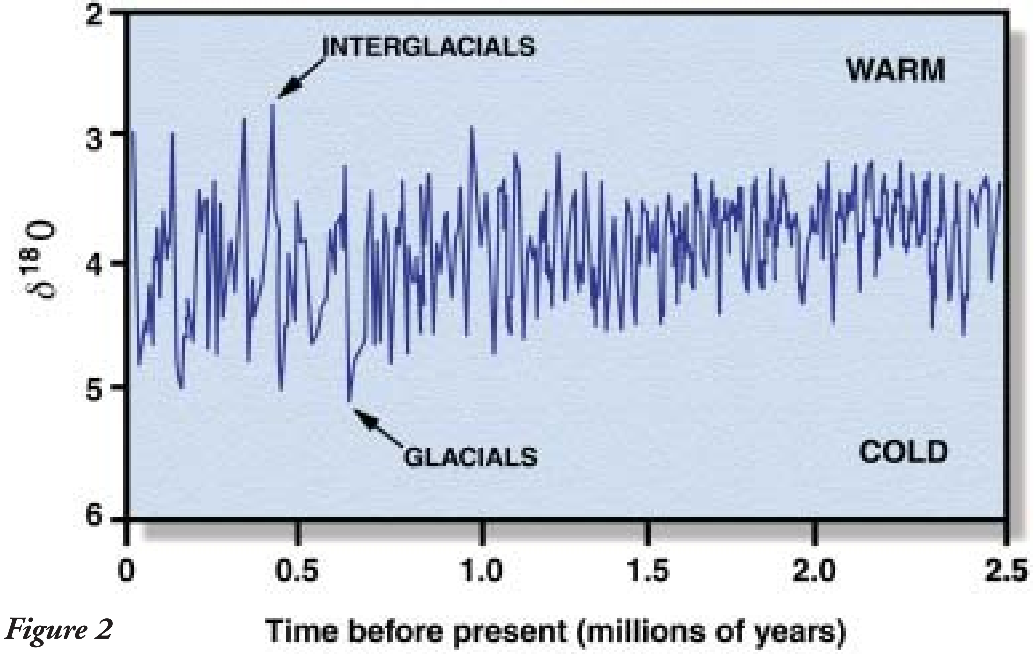


Figure 2

Temperature fluctuations between glacial and interglacial periods of the past 2.5 million years. Derived from oxygen-isotope analysis of ice cores from the Greenland ice sheet. Current interglacial period (Holocene) is at the far left, from 0-10,000 years ago. From Wright, 1989.

The oxygen-isotope data further reveal a repeating structure of climate variability *within* glacial and interglacial phases (Lorius *et al.,* 1990). Extensive cold glacial periods were interrupted by warm periods. A pattern emerged: interglacials began abruptly, peaked in temperature in early to middle cycle, and ended in a series of steps, each with abrupt transitions, into the cold of another glacial period. The cumulative effect is a sawtooth pattern typical of Quaternary climate records around the world (Figures 1, 2).

Importantly, the pattern of historic temperature change synchronizes with changes in carbon dioxide and methane. Concentrations of carbon dioxide (CO_2) during previous warm interglacial periods were about the same as the peak natural levels of the Holocene (the past 10,000 years), about 300 ppm, while during cold glacial periods, concentrations lowered to 190-200 ppm. The tightly synchronous changes in temperature and greenhouse gases suggest a mechanistic relationship. Although variable CO_2 concentrations are not the primary cause of cold – warm cycles, it is thought that they played a role. There were times when changes in CO_2 concentration preceded changes in temperature and vice versa.

The leading theory is that as glaciers advance, the CO_2 concentration is reduced through increased carbon sequestration in the oceans and ocean sediments, creating a negative feedback inducing further cooling. However, when the planet begins to warm, CO_2 is released from the oceans, creating a positive feedback and increasing the rate of warming. It is estimated that about half of the glacial – interglacial temperature change is due to the greenhouse gas feedbacks (Petit *et al.*, 1999). This may help explain the asymmetry observed in glacial – interglacial cycles, with slow cooling and rapid warming. The potential CO_2 increase through the 21st century may be sufficient (at the upper end of the uncertainty bounds) to induce a temperature increase that is of the magnitude of a full glacial – interglacial cycle (IPCC 2001).

A mechanistic cause for the overall glacial/interglacial climatic oscillations was proposed by Serbian mathematician Milatun Milankovitch (Milankovitch 1941) long before detailed past-climate variability had been documented. Milankovitch integrated knowledge about earth's orbit around the sun into a unified theory of climate oscillations. This has been revised subsequently into a modern orbital theory that is widely accepted as the mechanism that controls the ice ages (Imbrie *et al.,* 1992, 1993).

Three major cycles of orbital variability recur over time (*Figure 3*, Hays et al. 1976): (1) change in the shape of earth's orbit around the sun from elliptical to circular (100,000 years), (2) change in the angle of earth's tilt on its axis (41,000 years), and, (3) change in time of year when the earth is closest to the sun (23,000 years). The amount of heat from the sun reaching the earth at any point in time varies with the earth's position in each cycle. Integrating the three cycles mathematically results in a curve over time of predicted temperature on earth that corresponds to the observed changes in oxygen-isotope concentration, and thus the sawtooth pattern of periods of warm and cold. (e.g., Figures 1, 2).

Century- to Millennial-Scale Climate Cycles

Within these cycles that extend over tens to hundreds of thousands of years are shorter, orbitally-driven climate cycles or "events" — extremely cold or warm intervals — that last from one hundred to a thousand years. These climate events are increasingly understood as part of a pervasive oscillation pattern, now called "Bond cycles," documented for at least the last 130,000 years (Bond *et al.*, 1997). Bond cycles average 1300-1500 years, meaning that each warm or cold phase lasts about 700 years, and the peak warm and cold phases last about 350 to 450 years (*Figure 4*). Climate intervals during the Holocene that exemplify Bond cycles include the Little Ice Age, a significant ice advance and global cold period from 1450-1920 (Grove 1988; Overpeck et al. 1997); the Medieval Climate Anomaly, a warm, dry interval from 900-1350 (Hughes and Diaz 1994, Stine 1994, Esper *et al.*, 2002); and the so-called 8200 year (ago) cold event (Alley *et al.*, 1997).

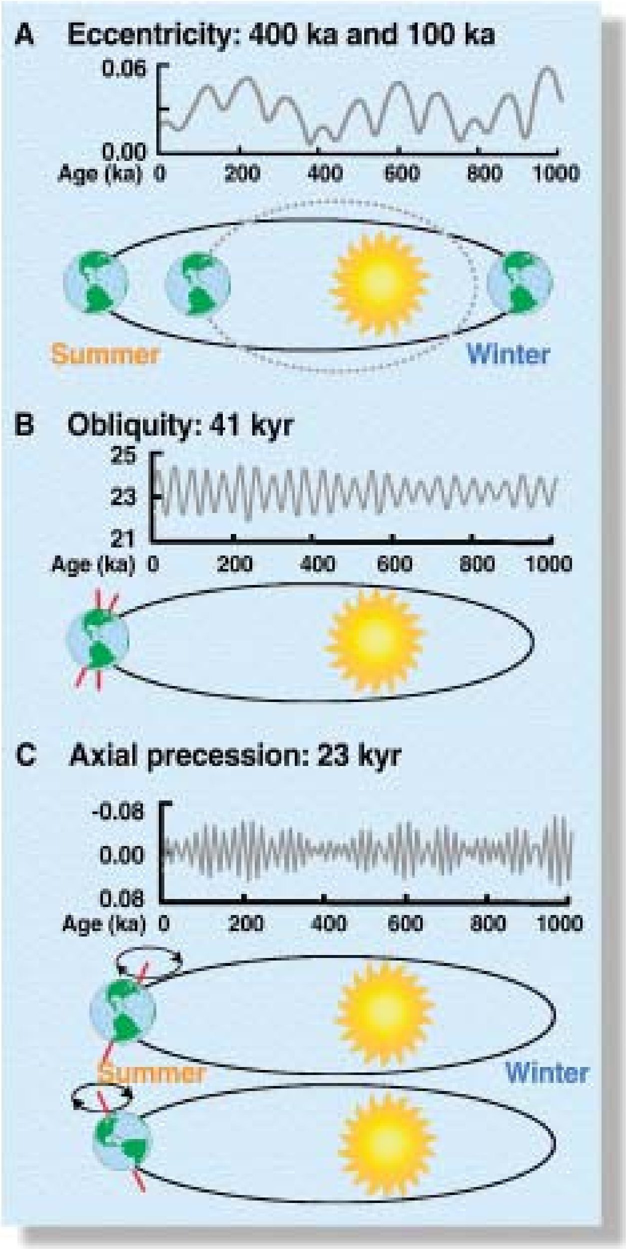


Figure 3

Primary orbita cycles of the earth. The fundamental mechanism for oscillating climates of the past 2.5 millio years. Temperatures on earth vary depending on how much heat from the sun (solar insolation) reaches earth's surface. This i turn varies depending on the exact position of eart within each of three orbital cycles. Mathematical integration of the three curve produces a grap of temperature over time that closes matches temperature reconstructions from ^{18}O, e.g., Figure 1. Data source: *Science, Variations in th Earth's Orvit: Pacemaker of th Ice Ages. 1976.*

Painstaking analysis at high resolution of several well-known Bond intervals has documented that oscillations often begin and end extremely abruptly. For example, a study of the major collapse of ice at the end of the Younger Dryas cold event (11,500-12,500 years ago) revealed that a 27°F warming occurred in two 10-year periods separated by a 20-year plateau of no detectable temperature change (White *et al.*, 2001).

Of particular interest at this time scale is the warming of the 20th century. During the Little Ice Age (1450-1920) temperatures in western North

America were on average 2°F colder than present; glaciers in many western North American mountain ranges were at their greatest extent since the end of the Pleistocene over 10,000 years ago (Clark and Gillespie 1997). Warming since the late 1800s has been about 1.3 °F globally (IPCC 2001). Increases in the early part of the century are now widely accepted as natural climate forcing, whereas continued warming since mid-20th century can be explained only from recent human-induced greenhouse gases (IPCC 2001, and see section below).

The natural mechanisms driving climate oscillations at the 100 to 1,000 year scale are a topic of current interest. The relationship of extremely cold intervals within glacial periods to sudden surges of polar ice into high-latitude oceans, and resulting abrupt changes in global ocean salinity, first led climatologists to believe these intervals were driven by ice and ocean-circulation dynamics (Broecker *et al.*, 1990, Clark *et al.*, 2001). Recently, however, millennial cycles in the sun's intensity have also been shown to match the timing of the Bond cycles over the last 130,000 years with high precision (Figure 4, Bond *et al.*, 2001). This has led climatologists to speculate that a trigger for 100 to 1,000 year climate changes comes from outside the earth – that is, changes in the sun – and subsequent changes in ocean circulation and temperature.

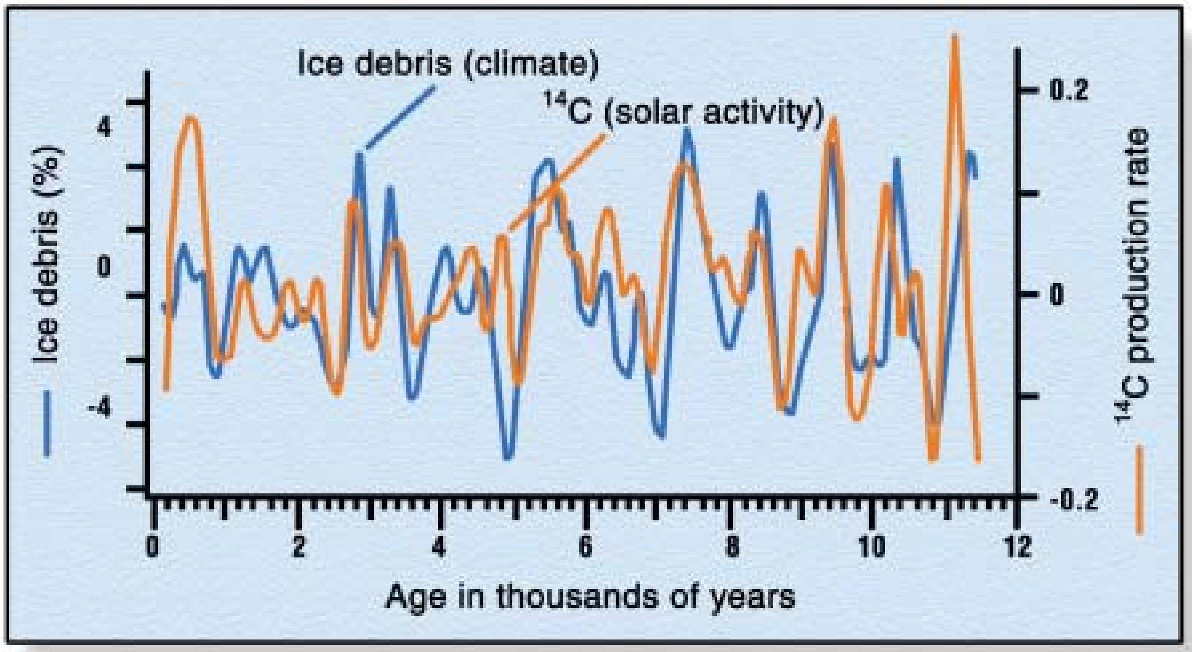
Interannual- to Decadal-Scale Climate Change

In recent years, climatologists have defined high-frequency climate cycles from a few years to several decades. The best known of these is the El-Niño/La Niña pattern (ENSO; Diaz and Markgraf 2000). Every several years, hemispheric trade winds that typically blow warm tropical ocean water westward across the Pacific Ocean stall and instead, warm water accumulates in the eastern Pacific Ocean. This leads to the presence of unusual water temperatures offshore from North and South America. Each year there is some degree of El Niño or its opposite effect, La Niña. Extreme events cycle on a 2 to 8 year basis (*Figure 5*). El Niño events bring different conditions to different parts of the world. For instance, they portend unusually cold and dry weather in the Pacific Northwest but unusually warm and wet fall and winters in central and southern California. The reverse occurs during La Niña events.

Climate oscillations on multi-decadal (20 to 60 year) periods have also been described recently. Like ENSO, these act regionally but have effects on distant locations. The Pacific Decadal Oscillation

Figure 4

100-1,000 year oscillations. Bond cycles have been pervasive at least through the Holocene and last major glacial age. Individual events have long been recognized, such as the Little Ice Age (1450-1900 CE) and the Younger Dryas (11.5-12.5 ka). From Bond *et al.*, 1997, 2001.



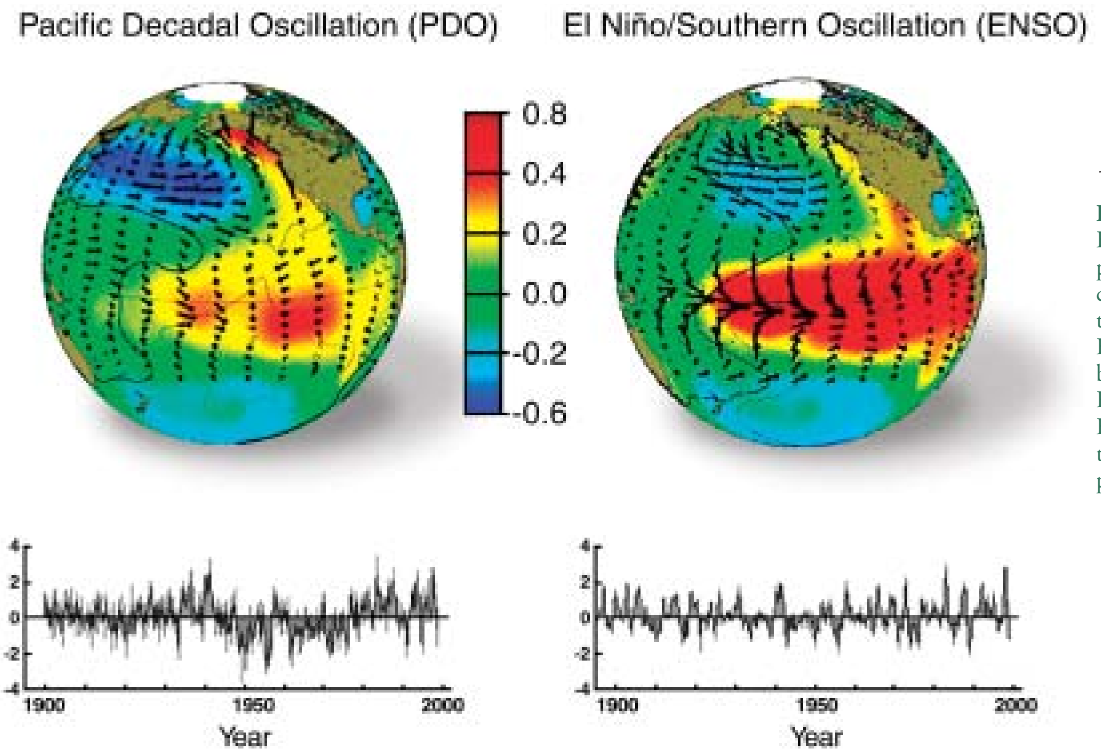


Figure 5

PDO and ENSO. Positive ENSO (El-Niño)and PDO periods bring warm, wet conditions to certain parts of the world, while negative ENSO (La Niña) and PDO bring cool, dry conditions. From Mantua et al., 1997 and ENSO website: http://tao.atmos.washington.edu/pdo/

(PDO, *Figure 5*) affects western North America. It appears to be regulated by decadal changes in ocean circulation patterns in the high-latitude Pacific Ocean (as opposed to ENSO's tropical locus), and yields climate effects and regional patterns similar to extended ENSO effects (Mantua *et al.*, 1997, Zhang *et al.*, 1997). Warm (or positive) phases are extensive periods (10 to 25 years) of El Niño-like conditions that alternate with cool (or negative) phases of La Niña-like conditions. Other such multi-decade, ocean-mediated patterns affect other parts of the world (Cronin 1999).

Climate as a Force of Ecological Change

Abundant evidence worldwide indicates that life on earth has responded to climate change at each of these scales. Changes in biota over time can be measured in many ways, such as from sediment cores taken from wet areas including meadows, bogs, lakes, and ocean bottoms. In dry environments, packrat middens preserve macrofossils, while in temperate forests, tree-ring records archive annual tree growth.

At *multimillennial* scales, ecological records of the past collectively document that, at any one place, compositions of species changed significantly in correspondence with major climate phases. Often, changes showed complete species turnover. In relatively flat terrain, such as in northeastern United States, eastern Canada, parts of Scandinavia, and northern Asia, species shifted north and south hundreds of miles, as modeled, for example, for spruce (Picea) in eastern North America (*Figure 6*, Jackson *et al.*, 1987). By contrast, in mountainous regions, plant species

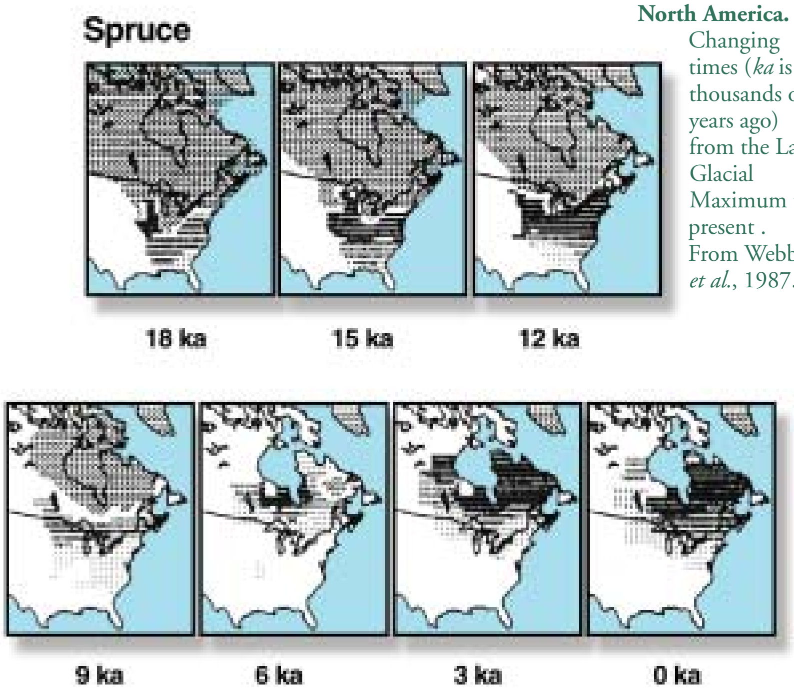


Figure 6

Shift in ranges of spruce (*Picea*) forests in eastern North America. Changing times (*ka* is thousands of years ago) from the Last Glacial Maximum to present . From Webb *et al.*, 1987.

responded primarily by moving in elevation, as indicated by conifers of the Great Basin and southwestern desert region, which shifted as much as 4500 ft (*Figure 7*, Thompson 1988, 1990, Grayson 1993). Before temperature proxies such as oxygen isotopes provided independent measures of historic climate, millennial-scale abrupt climate events were inferred from changes in flora and fauna. For instance, the Younger Dryas cold interval was known from changes in abundance of the arctic tundra plant *Dryas octopetala* (Jensen 1935).

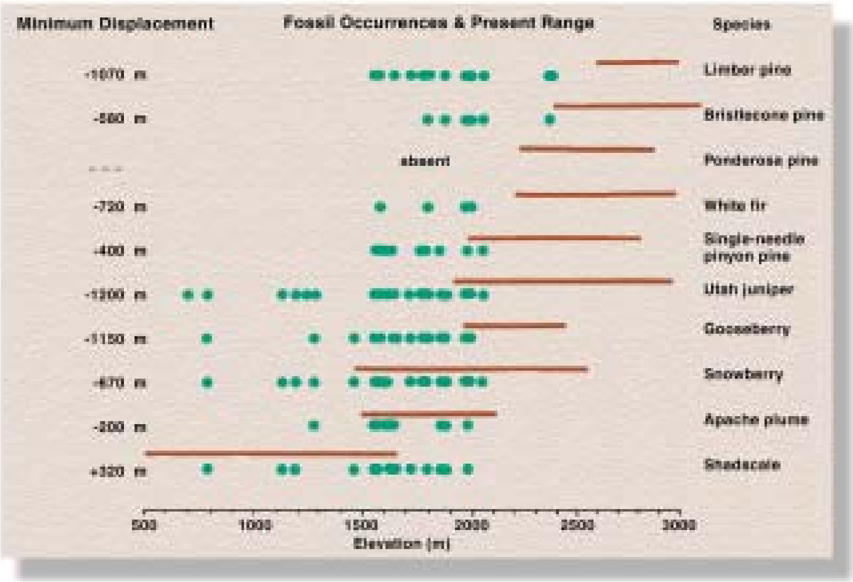


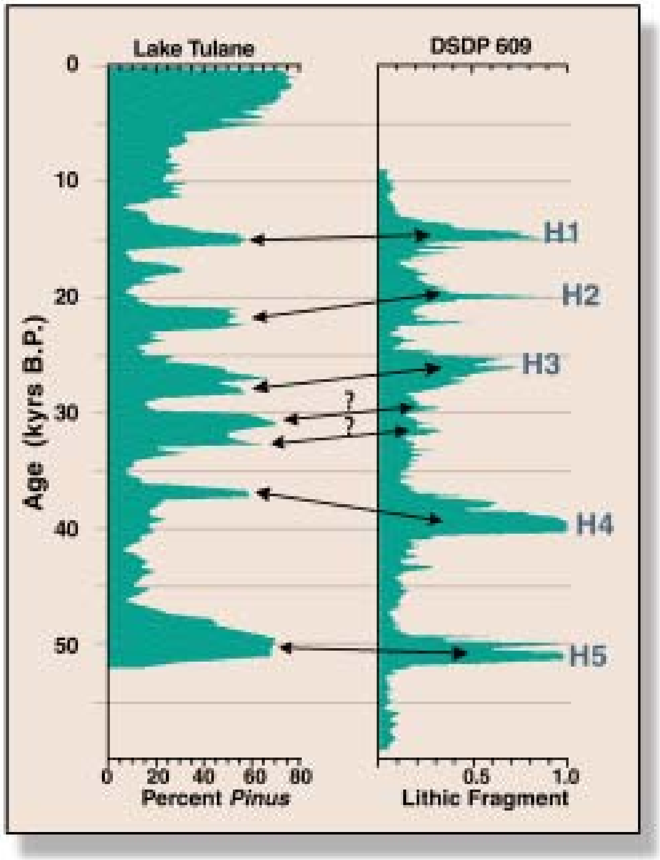
Figure 7

Glacial/interglacial shifts in elevation for plant species of the Sheep Range, southern Nevada. Current (solid line) and past (dots) elevation limits, and individualistic responses of species. From Thompson, 1990.

Significant and rapid response of vegetation to *century* scale climate change is also well-documented, although elevation shifts are lower and migration distances smaller than for longer time scales. Many examples now show fluctuating changes of vegetation corresponding to Bond cycles, which average 1300-1500 years. An illustrative example is the abrupt change in pine versus oak vegetation in southern Florida that corresponds to Heinrich events (extremely cold intervals 100 to 1,000 years ago) (*Figure 8*, Grimm *et al*., 1993). In California, abrupt changes in the dominance of oak versus juniper corresponded to rapid climate oscillations of the last 160,000 years (Heusser 2000). In the Great Basin of North America, major changes in population size and extent of pinyon pine (*P. monophylla*) correspond to Bond-scale cycles (Tausch et al. 2004). Whereas recurring patterns emerge at coarse scales, species responses are individualistic, lags are common, and nonlinear patterns frequent, so that population increases or decreases may not appear to be "in synch" with climate change, especially when climate changes are extreme and abrupt (Jackson and Overpeck 2000)

Vegetation responds also to *interannual and decadal* variability. At the ENSO scale, changes occur primarily in plant productivity and abundance within populations. The oscillations contribute to regional fire regimes, where fuel loads build during wet years and burn during dry years (Swetnam and Baisan 2003). These lead to mid-scale vegetation changes as ENSO itself cycles, and thus fire regimes change over time (Swetnam and Betancourt 1998, Kitzberger *et al*., 2001). Decadal climate and vegetation oscillations have been well-docu-

Figure 8



Abundance of pine from Lake Tulane, Florida (indicated by pollen %, left panel) correlates with millennial scale cold, or Heinrich, events of the last glacial period (indicated by % lithics, or ice-rafted rock debris, right panel). Data from Grimm *et al*., 1993.

mented in secondary growth of trees, such as recurring droughts over the past 2,000 years that led to reduced ring-widths in ponderosa pine in New Mexico (Grissino-Mayer 1996). Other examples are the recurring pattern of ring-widths in bigcone Douglas-fir (*Pseudotsuga macrocarpa*; Biondi *et al.*, 2001), mountain hemlock (*Tsuga mertensiana*; Peterson and Peterson 2001) and subalpine fir (Abies lasiocarpa; Peterson et al. 2002) that correlate with PDO for up to 400 years in the past. Vegetation-type conversions from meadow to forest, changes in species growth rates and crown morphology, and changes in forest density were associated with PDO cycles in conifer forests of the Sierra Nevada, California (Millar *et al.*, 2004).

In perspective, a key characteristic of Quaternary paleoecology for the past million years is that each plant species responds to specific climatic cues with its own unique rate and sensitivity. Individual species follow their own ecological trajectories as climates cycle, leading to changes in community compositions that themselves form, dissolve, and may reform over time. Often non-analog communities (that is, species combinations that do not exist currently) have formed. From this perspective, plant communities exist as transient assemblages; species move individually through time and space following favorable climates and environments.

Implications of Natural Climate Change for Vegetation Ecology

This brief background of natural climate cycling and its effects on vegetation provides insights into concepts of forest dynamics and vegetation ecology. We offer a few examples below.

Sustainability

Ecological sustainability is a dominant operating paradigm for forest management. It implies the endurance of species, communities, and ecosystems over time, and is often used as implicit or explicit forest management and restoration goals (e.g., Jordon *et al.*, 1990, Lele and Norgaard 1996). In practice, sustainability has been difficult to describe or to recognize. Generally, it is accepted to exist when natural species diversity is maintained, species are abundantly distributed throughout their recent historic native range, community associations are maintained, natural processes occur at reference intervals and conditions, and human disturbance is minimized (Lackey 1995, Hunter 1996).

The complex and recurring cycles of ecological change in response to climate cycling challenge this interpretation of ecological sustainability. Species ranges have, and will — even in the absence of human influence — shift naturally and individualistically over small to large distances as species follow, and attempt to equilibrate with, changes in climate. In the course of adjustment, plant demography, dominance and abundance levels change, as do the relationships of plant and animal species in local communities.

A major conclusion from past records is that, at scales from years to millennia, ecological conditions are not in equilibrium, do not remain stable, nor are they sustained, but, by contrast, are in ongoing state of change (Jackson and Overpeck 2000). Paleorecords challenge interpretations of ecological sustainability that have emphasized persistence of species and stability of communities within current ranges. As widely used, such concepts of sustainability do not adequately accommodate natural dynamics, and promote misinterpretations about the behavior of natural systems.

It is important to note that the time scales under discussion are short relative to the lifespans of most existing plant species. Many native North American plant species originated 20 to 40 million years ago, and thus have been subjected to the demands of shifting climates, at both large scales and small, throughout their histories. This implies that adaptation to abrupt climate changes has had many opportunities to evolve. Resilience and sustainability, at least in terms of species persistence, appear to have been met through the capacity of plants to track favorable environments as they shift over time, and through adjustment in range distribution, habitat, associates, and population characteristics.

Population Size, Population Abundance, and Native Species Range

Changes in population size and abundance, and in overall range – observed through monitoring or other measures – are often assumed to be human-induced, whereas these may be natural species responses to climate change. For instance, species of oak (*Quercus*) and juniper (*Juniperus*) expand and contract in complementary fashion: oak population and range distribution expanded repeatedly during warm climates and contracted during cool climates while the opposite occurred for juniper species (Adam and West 1983, Heusser 1995). Although oaks in general are widespread and common in southern Oregon and California now, during repeated long glacial periods they were rare in the region. Although these changes are most obvious between long-term glacial and interglacial times, significant changes in abundance occur at climate scales as short as a decade (Heusser and Sirocko 1997).

This perspective of vegetation dynamics over the past million years compels us to evaluate causes for changes in population size, abundance, and native range more carefully. Rather than interpreting change as resulting from undesired human-induced threat, we might investigate instead whether these are natural species adaptations. For instance, *Juniperus* expanding in Great Basin rangelands has been considered an exotic invasive, and measures have been taken to remove plants. However, this expansion appears to be an adaptive response to climate change (Nowak *et al*., 1994). Other things being equal, an ecologically-informed resource management action might be to encourage and not thwart juniper expansion.

Although changes in population size and distribution may be natural responses to climate change, causes are often difficult to discern in practice. Lags in adjustment and other imbalances between population distributions and climate mean that population changes may not be synchronous with climate change, especially when rapid climate changes occur over short times, making the search for mechanistic causes difficult (Jackson and Overpeck 2000). Because individual plants, unlike animals, cannot "pick up and move," they migrate by dying in some areas while expanding in others. These may appear poorly segregated on the landscape – with patchiness and irregularity characteristic – making the effects difficult to evaluate while they're happening. Causes may be attributed readily to other proximal factors, such as to insects and pathogens, or human-induced effects such as fire suppression, even where climate is the underlying, ultimate factor.

A challenging question for vegetation ecology becomes, "what is the native range of a species?" The native range is the basis for monitoring its condition, understanding favorable habitat and ecological interactions, diagnosing threats and risks, determining restoration targets, and indicting species as "exotic" (Jackson 1997). Viewed against historic changes in distribution and natural flux, the native range of a species must be considered a transient and dynamic process itself, readily capable of moving in space as climate shifts over the landscape.

Population abundances and species' distribution ranges may be relatively stable whenever climate is in a more stable phase, or if the environment of a species offers considerable local diversity (Thompson 1988, Jackson and Overpeck 2000). In these cases, shifts in climate may be tracked with relatively minor overall geographic changes.

By contrast, in situations that are sensitive to change, for instance landscapes with little topographic diversity, even small shifts in climate may bring large changes in population condition. Given that the 20th and 21st centuries are undergoing rapid change in climate with high variability, we would expect population demographics and species ranges to be now highly unstable.

Reference Conditions and Restoration Targets

"Pre-disturbance" or "pre-EuroAmerican impact" conditions are used routinely as reference models and descriptions of desired targets for ecological restoration. This assumes, however, that climate hasn't changed between the historic target time and the present.

In western North America, the disturbance period is regularly assumed to start at European/Asian contact with native peoples and their landscape, about 1840-1860, and the centuries prior are used as pre-disturbance reference conditions. As that period coincides with the coldest part of the Little Ice Age, however, it makes a poor model for 21st century restoration. Even in eastern North America, where European contact with the landscape was several centuries earlier, the dominant climate was Little Ice Age, with ecological conditions very different from present. Although "pre-modern contact" times differ around the world, the point remains: because of climate change, historic conditions are likely to be very different from present, and thus poor models for forest management or restoration.

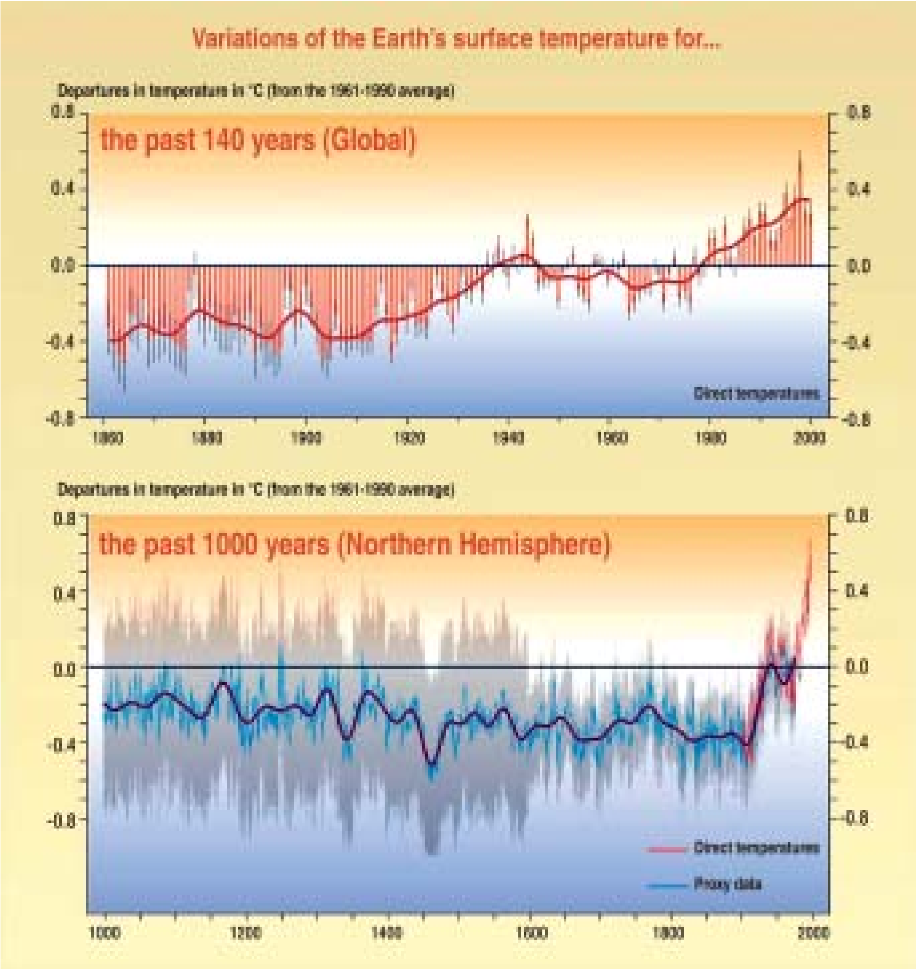


Figure 9

Global mean surface air temperature changes (°C) over the past 140 and 1000 years. From IPCC, 2001.

The Human–Dominated Climate System

Given the dynamics of the natural climate system in the past, it is not surprising that climate would be changing now as well. Considering the past 1,000 years, the amplitude of natural temperature cycles has been about +/- 2°F from the average of the mid-20th century. It was warmer by this amount during the Medieval centuries and colder during the Little Ice Age. The natural mechanisms that led to the Little Ice Age reversed in the late 1800s, and by 1900, temperatures again began warming. So where do humans begin to influence the climate system and global warming?

The Global Perspective

In 1988, the World Meteorological Organization and the United Nations Environment Programme formed the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess on a comprehensive, objective, open, and transparent basis the scientific, technical and socio-economic information relevant to understanding the risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC's Scientific Assessment Reports, issued in 1990, 1995, 2001, with a fourth anticipated for 2007, are widely accepted as representing a synthesis of the world's scientific consensus on recent climate change.

A key question the IPCC addresses is: *how has global temperature changed over the last 100 years, and how has this compared to the past 1,000 years?* Answers to the first question came from compilations of instrumental data across earth's surface and indicate a temperature increase of 1.3°F over the 20th century (*Figure 9,* IPCC 2001). Temperature increase relative to the past 1,000 years has resulted in a number of interpretations depending on the nature of the climate indicator (such as tree rings, corals, ice cores, etc.) and the statistical interpretation. The global average temperature in the late 20th century was higher than global averages over the last 1,000 years, although some regions experienced significantly warmer conditions. Regardless of relative change in the earlier centuries, the trend of increasing temperature late in the 20th century is clear in all interpretations.

Another key question for the IPCC analyses is: *are globally observed 20th-century warming trends the result of natural processes or human influences via greenhouse gas emissions?* This question is now answered with high confidence: the trends in global climate since about 1975 can only be explained by non-natural forces. Without human influence, the models indicate that the natural climate systems would be cooling slightly, as a result of solar activity and atmospheric dimming from volcanic aerosols. The observed warming trends are duplicated in models only when human-induced greenhouse gas emissions (carbon dioxide, methane and others), and their feedback effects, are added to the models (IPCC 2001).

The IPCC also has been charged to generate models of future climates, called scenarios, which rely on an increasing array of General Circulation Models. Diverse models are used to generate a range of results that derive from different approaches, as well as starting assumptions. These include, for instance, different emissions conditions, such as "business as usual" (no change from current practices), doubled, and tripled CO_2 levels. The ensemble of scenarios depict a global average temperature increase of approximately 2.7 to 10.4°F by 2100 (*Figure 10*) and a range in CO_2 concentrations of 575 to 1000 ppm. Considering the extreme values in these ranges, the last time global temperature was this warm was during the last interglacial period, about 120,000 years ago, and the last time CO_2 concentrations were this high was about 120 million years ago when earth was in a radically different atmospheric, tectonic, and environmental condition than present (Berner 1990).

Elevated levels of atmospheric CO_2 have direct effects on ecosystems in addition to influencing climate. Some of these are likely to be detrimental, such as affecting the success of unwanted invasive species (Ziaska 2003), and increasing acidification of oceans with cascading effects on ocean biota. The role of increased efficiency of photosynthesis by plants has been touted as beneficial for the fertilizing effect on tree growth and changes in water-use efficiency. Increasingly, studies show this is not a universal effect, and that the additional photosynthate is not always stored in wood nor does it necessarily result in accelerated growth. Depending on species, age, and time since exposure, CO_2 may be stored in

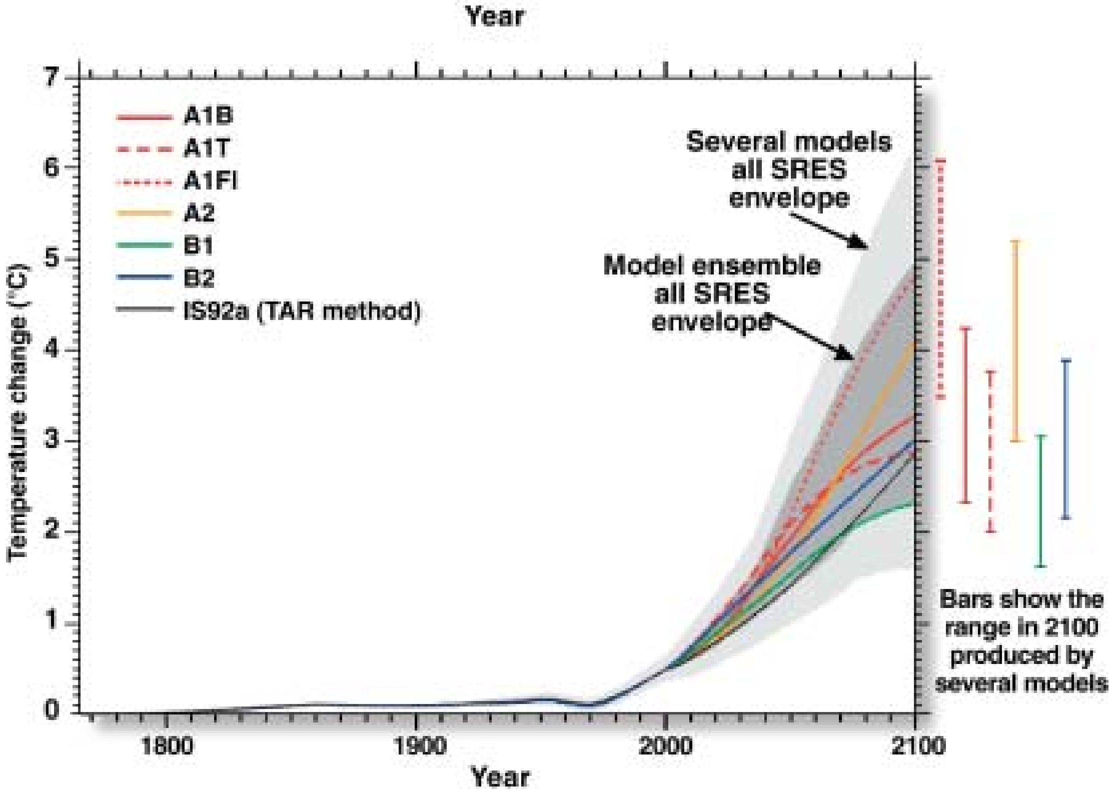


Figure 10 **Global mean surface air temperatures (°C) projected for the 21st century** and plotted with the observed temperature trend prior to 2001. Multiple lines after 2100 indicate different results from climate models; bars show ranges for each model. From IPCC, 2001.

stems, roots, or fruits. Old-growth forests may respond less than young trees, and all forests studied show a capacity to acclimate to the high levels of CO_2 such that growth increases initially, then declines (Körner *et al.*, 2005).

Cascading environmental effects from a continually warming world are already widely documented and projected to accelerate. These include decreased arctic ice cover (down 23% since first monitored in 1979); increasing sea level as sea ice and ice caps melt (CCSP 2005); changes in earth surface albedo (surface reflectance) as bare ground is exposed in the Arctic, and especially as shrubs invade (Chapin *et al.*, 2005); worldwide retreat of mountain glaciers and ice caps (averaging approximately 50% decline over the western U.S. during the 20th century, Mennis and Fountain 2001); decreased snowpack accumulation and associated decreases in streamflow (Dettinger and Cayan 1995); increases in amplitude of extreme weather events (hurricanes, drought, flood, CCSP 2005); "greening up" (i.e., increases in density) of temperate lowland and montane forests, followed by "browning down" (mortality) as a result of epic forest dieback and uncharacteristically severe wildfires (Westerling *et al.*, 2003, Breshears *et al.*, 2005); and loss of alpine ecosystems as high-elevations species move upward off the tops of peaks (Pauli *et al.*, 2003).

An important take-home message from the IPCC analyses is the time required for the climate system to equilibrate reductions in CO_2. Assuming greenhouse gas emissions peak and could be restored to early 20th-century levels within the next 50 years, the residence time of CO_2 in the atmosphere is such that it would not stabilize for 100 to 300 years, and temperature would not stabilize for the same amount of time (IPCC, 2001). Thus, the scenarios for the 21st century show best-case assumptions for greenhouse gas emissions; if they are not controlled, climate changes will be significantly amplified. The effects of human-caused emissions on climate, combined with land-use changes that affect climate, give rise to the recognition that a human-dominated climate system is characteristic of the new millennium.

Potential Impacts of Climate Change on Oregon Ecosystems

The potential future impacts of climate change on ecosystems in the Northwest have been estimated using a variety of climate and vegetation models. Following are new estimates that build upon earlier work that contributed to a National Assessment of the potential impacts of climate change, which was sponsored by the U.S. Global Change Research Program (Bachelet *et al.*, 2001).

Temperature and Precipitation

The future climate scenarios presented here use three general circulation models, coupled with dynamic ocean models, each simulating two IPCC greenhouse gas emissions scenarios through the 21st century, moderately high (A2) and moderately low (B2).[1] The three global climate models were developed in Canada (CGCM2), the United Kingdom (HADCM3), and Australia (CSIRO).

The scenarios show temperature across Oregon increasing from the present time to the end of the 21st century from about 7 to 8 °F, which can lengthen the growing season by at least four to six weeks (*Figure 11*). For precipitation, the scenarios show a range in winter of 10% decrease to 24% increase, but decreases of 10 to 40 % in summer (a relatively small amount since summers are generally dry). The potential winter decrease is important because previous studies had shown significant *increases* in Northwest precipitation (NAST 2000).

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[1] *Intergovernmental Panel on Climate Change, Special Report on Emissions Scenarios, IPCC SRES A2 and B2 were used in a new and ongoing assessment of the impacts of climate change over North America (Price et al., 2004).*

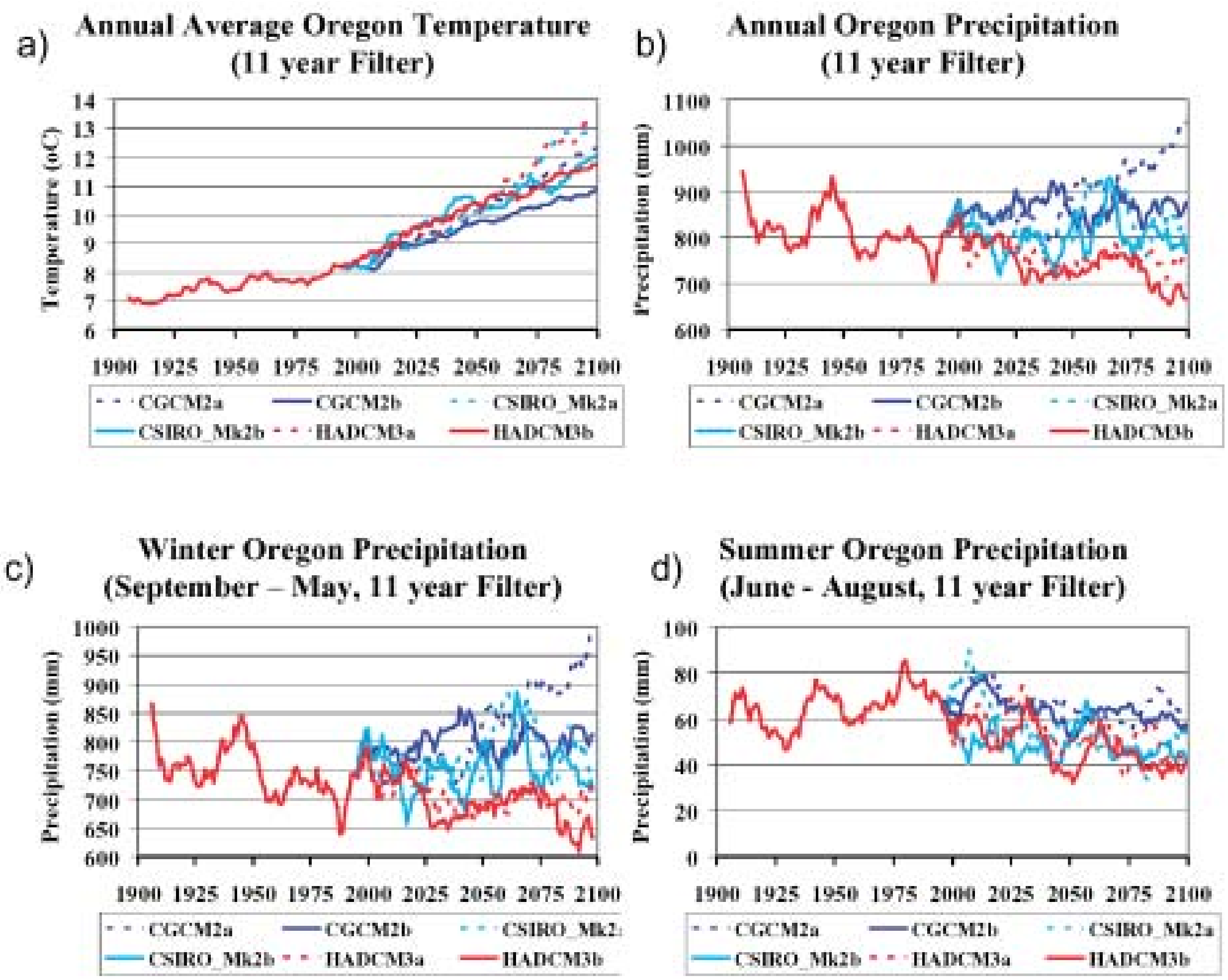

Figure 11

Historical and simulated future trends in temperature and precipitation over Oregon. The scenarios were produced from three global climate models (GCM), the Australian Climate Center (CSIRO), the Canadian Climate Center (CGCM2) and the Hadley Center of the United Kingdom Meteorological Office (HADCM3). Each GCM was run with two different assumed trajectories of greenhouse gas emissions, a moderately high scenario (A2) and a moderately low scenario (B2). The emissions scenarios are designated with 'a' for A2 or 'b' for B2, coupled with the GCM designation to distinguish each of the six scenarios. *See text for additional explanation of scenarios.*

The VINCERA Project

A new class of ecosystem model called DGVMs, or *Dynamic General Vegetation Models*, combines additional types of data for improved forecasts of projected climate changes on natural ecosystems. These new models combine two traditionally separate fields within ecology — the distribution of vegetation, and biogeochemical cycling (how nutrient cycling affects plant productivity). In addition, DGVMs also include a third element, wildfire simulation, which can be a large component of the flux of carbon back to the atmosphere.

Three Dynamic General Vegetation Models — simulating changes in vegetation distribution, carbon balance, and disturbances from drought and fire — were analyzed more broadly in a project known as VINCERA, *Vulnerability and Impacts of North American Forests to Climate Change: Ecosystem Responses and Adaptation.* Results from one of these vegetation models, MC1 (MAPSS-CENTURY, version 1), are presented here.

a. Impacts of Climate on Future Distribution of Vegetation

Figure 12 shows Observed (current) vegetation for the Northwest, compared with two simulations under Historical Climate (1961 to 1990, with and without fire suppression) and six scenarios of Future Vegetation Distribution simulated for the end of the 21st century (2070 to 2099). This figure depicts six future climate scenarios developed by the three climate modeling groups, each using two different assumptions of future greenhouse gas emissions (A2, medium high; B2, medium low).

The two historical simulations are reasonable renditions of the observed current natural vegetation distribution. The apparent overabundance of boreal forest (blue) is not a major problem, since the boreal trees are functionally very similar to the temperate conifer forest shown in the observed map. The historical simulations demonstrate the effect of fire suppression, implemented in the model in 1950, on the expansion of woodlands and savannas (juniper and ponderosa pine) into the sagebrush vegetation in eastern Oregon in recent decades. This is a well-described phenomenon and is currently threatening numerous sagebrush habitats for wildlife.

The simulations of future vegetation distribution include no fire suppression and yet in all scenarios, the interior shrublands/grasslands are overtaken by expansion of woodlands (e.g. juniper), savannas (e.g. Ponderosa pine), or continental conifer forests (e.g. Douglas-fir), due to increases in precipitation, enhanced water use efficiency from elevated CO_2 and a lengthened growing season. The maritime forests along the wet coastal regions are displaced in many future climate scenarios by the "warm temperate-subtropical mixed forest," or the interior conifer forests. Overall, there is an increase in broadleaf vegetation amidst the conifer forests, both along the coast and inland, suggesting expansions of species such as alder, maple, madrone, oak, pines and other Klamath region and California species.

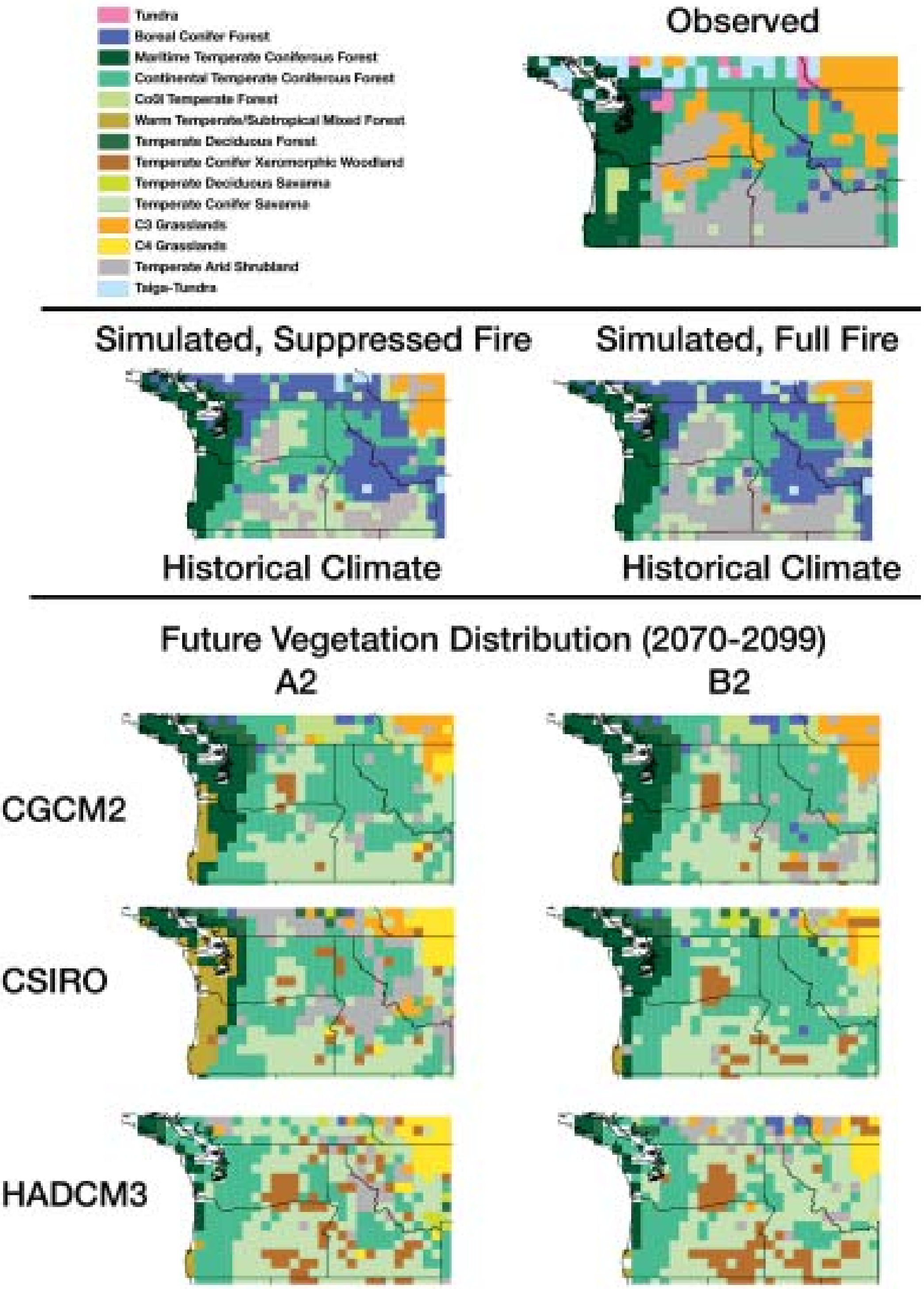

Figure 12

Vegetation distribution. Observed, simulated historical and future vegetation distribution. The two historical simulations (with and without fire suppression) show a reasonable comparison to the 'observed' current vegetation distribution. The primary features to note are the maritime forests along the wet coastal regions (dark green) and the interior, dry sagebrush regions (gray). The maritime forests are displaced in many future climate scenarios by the 'Warm Temperate-Subtropical Mixed forest', or the interior conifer forests. In all scenarios, the interior shrublands/grasslands are overtaken by expansion of woodlands (e.g. Juniper), savannas (e.g. Ponderosa Pine), or continental conifer forests (e.g. Douglas-fir). *See text for further details.*

b. Impacts of Fire on Future Distribution of Vegetation

Figure 13 shows future climate scenarios with percent change in biome area in Oregon, without (13a) and with (13b) fire suppression.

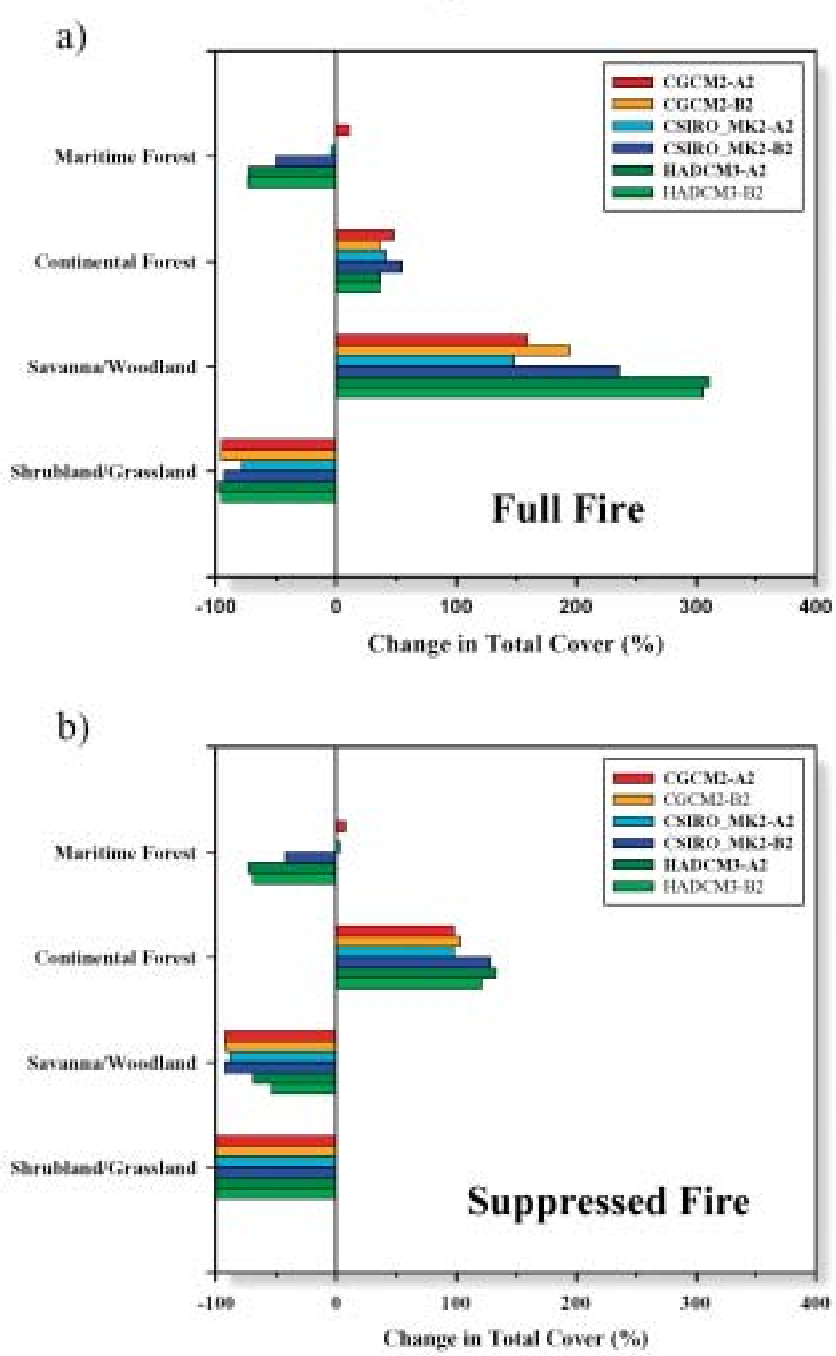

Figure 13 **Percent change in biome area in Oregon**, without and with fire suppression, under six future climate scenarios, comparing (2070 – 2099) with (1961 – 1990). The 14 different vegetation classes shown in Figure 12 have been aggregated to four major biome types. See Table 1 for definitions of biomes.

The fourteen vegetation types shown in *Figure 12* were aggregated into four vegetation classes (*Table 1*).

With **Full Fire** across all six scenarios (*Figure 13a*), **maritime forest** either increased in area slightly by about 12%, or showed a range of decreases in area from nil to over 70%. The maritime forests were displaced either by the warm temperate/subtropical mixed forest or the continental temperate forest. The former carries more broadleaf species such as oak and madrone whereas the latter is typified more by Douglas-fir and both types are accustomed to more fire. With suppressed fire **continental forest** increased in area by about 40% to nearly 60%; while, **savanna/woodland** increased by about 150% to over 300%, as they both encroached upon the drier shrub and grasslands. Shrubland/grassland showed decreases in area from about 80% to over 90%. (*Figure 13a*).

In contrast, with **Suppressed Fire** (***Figure 13b***), **continental forest** increased even more, as it took over the role of **savanna/woodland** in displacing **shrubland/grassland**, which disappeared entirely, being largely replaced by the continental forest.

The simulated future distribution of vegetation, shows a significant increase in woody vegetation in the interior dry ecosystems (*Figure 12*). With increases in temperature, there would be significant reductions in alpine vegetation, as the upper treeline moves upward in elevation, as shown in previous higher resolution simulations (Bachelet *et al.*, 2001). The simulations show some increase in warm temperate/subtropical mixed forest in the coastal mountains of both Oregon and Washington. This implies an increase in broadleaf deciduous and evergreen species, perhaps such as present in the Klamath region with madrone, tanoak and other oak species in the drier sites, and maple and alder in the wetter sites. More southerly conifers could also be favored, such as possibly redwood or

Table 1.

MC1 vegetation type aggregation scheme and regional examples of the vegetation classes

Vegetation Class	Vegetation Type	Regional Examples
Maritime Forest	Maritime Temperate Conifer Forest Cool Temperate Mixed Forest Warm Temperate/Subtropical Mixed Forest Temperate Deciduous Forest	Sitka Spruce – Western Red Cedar – Western Hemlock - Douglas-fir Forest Alder – Maple – Oak Forests Mixed Conifer Forest Ponderosa Pine Forest Tanoak–Madrone–Oak Forest Coastal Redwood Forest
Continental Forest	Tundra Boreal Forest Continental Temperate Coniferous Forest	Alpine Meadows Aspen Subalpine Forest – True firs – Mountain Hemlock Douglas-fir – Western Hemlock Forest
Savanna / Woodland	Temperate Conifer Savanna Temperate Conifer Xeromorphic Woodland	Yellow Pine Savanna Douglas-fir–Tanoak Savanna Mixed Conifer Savanna
Shrubland / Grassland	Temperate Arid Shrubland C3 Grassland C4 Grassland	Sagebrush Steppe Palouse

even some pines. However, slow migratory rates of southerly (California) species would likely limit their presence in Oregon through the 21st century (Neilson *et al.*, 2005). The drier interior vegetation shows a large increase in savanna/woodland types, suggesting possibly juniper and yellow pine species range expansions. Also, if winter temperatures warm sufficiently, then hard frosts could become less frequent and open the door to an entire flora of frost-sensitive species from the Southwest potentially displacing many native eastern Oregon species over the course of decades to centuries (Neilson *et al.*, in press).

Hotter temperatures would enhance evaporative demand, tending to drought-stress the vegetation. However, that is somewhat countered, or even reversed, if it is also accompanied by increases in precipitation, as well as the increased water use efficiency of the vegetation from elevated CO_2 concentrations.

Decreases in summer precipitation, accompanied by a longer growing season, would tend to increase the drought stress. However, the future scenarios show an increase in winter precipitation. There is speculation that as global oceans warm, the world could shift into a more positive PDO regime, similar to an extended El Niño (Mote *et al.*, 2003). These conditions often shift storms away from the Northwest, creating dry conditions.

Fire increases significantly in the coast range and Willamette Valley in Oregon in the absence

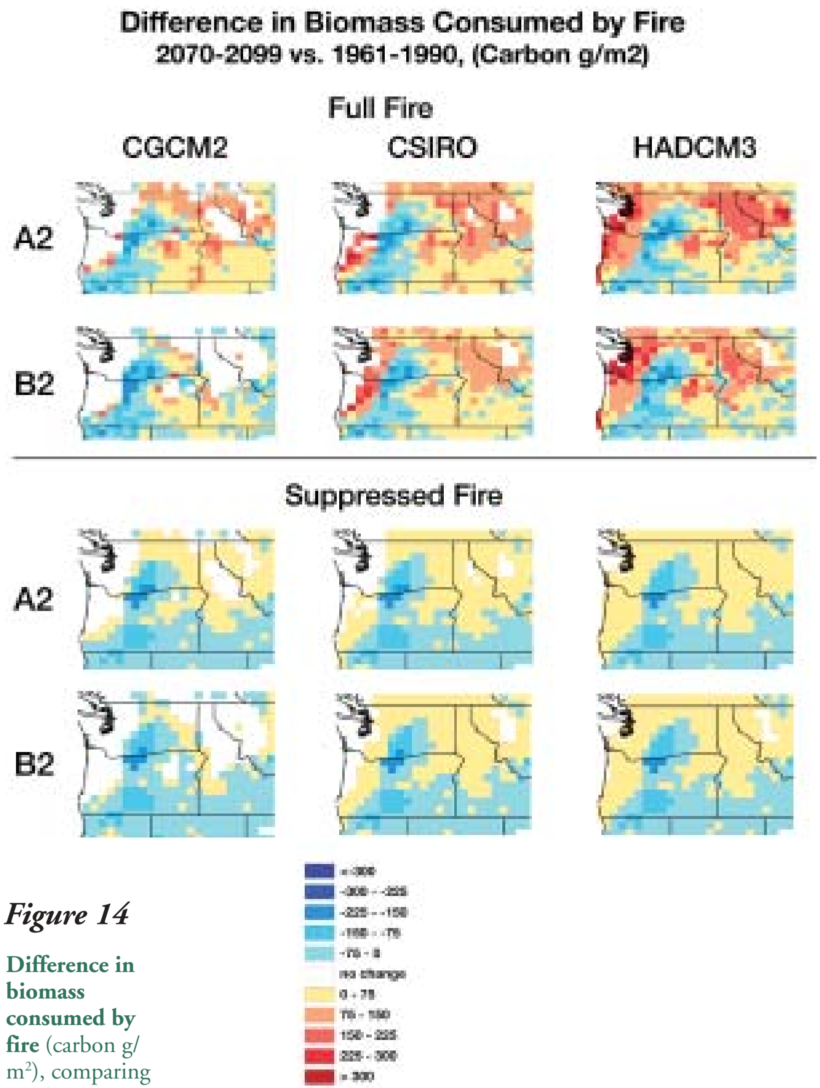

Figure 14

Difference in biomass consumed by fire (carbon g/m²), comparing the future average ecosystem biomass consumed by fire (2070 – 2099) with the current (1961 – 1990) biomass consumed, without fire suppression (upper panel) and with fire suppression (lower panel). The six future scenarios are arrayed by GCM (columns) and emissions scenarios (rows). The GCM definitions are as in Figure 11.

of fire suppression in all scenarios, especially the drier Hadley (HADCM3) and Australian (CSIRO) scenarios (*Figure 15*). The Willamette Valley and east slopes of the coast range appear to be most at risk of increased fire. Much of this increase in fire can be mitigated by fire suppression, but would likely require significant mobilization of fire fighting resources above current levels

However, the coastal forests are heavily managed and have a very complex harvest history and age-class structure. Much of the region is recovering from clear-cut logging and is likely still below the water-limited carrying capacity and may yet be in a position to benefit from the warmer winters and elevated CO_2. These younger ecosystems, with lower stature and less "rough" canopies, may use less water and be less likely to experience drought stress followed by fire.

c. Extended Growing Season

The increases in temperature would advance the onset of spring growth, bringing it closer in line with the spring precipitation peak that is characteristic of the Northwest. Most of the vegetation growth is accomplished in the spring, before the long, dry summer. However, Northwest vegetation, particularly in the drier interior, tends to be deeply rooted and can take advantage of the winter rains for persistence throughout the summer, due to the winter and spring recharge of the deep soil layers.

Even though the percentage decreases in summer rainfall are large, the summers are generally dry in any case, so the absolute magnitude of the change is not as great as it seems. The effects of increased summer temperatures on evaporative demand are likely of greater importance. However, since the growing season would be longer on both spring and fall ends, the vegetation would demand more water overall, unless the impact of elevated CO_2 concentrations on water use efficiency and the increased winter precipitation are sufficient to offset the demand.

It is not easy to anticipate whether, for example, the sagebrush ecosystem would increase or decrease in certain domains in the Northwest, as illustrated in Figure 12, since there are so many counter-acting forces. The overall changes in area of the different aggregated ecosystems, specifically for Oregon, simplify the complex changes expressed in the maps and are shown in *Figure 13*. The shrubland/grassland vegetation type decreases due to woody encroachment. The lengthening of the growing season is especially important in the interior dry ecosystems, where the traditionally very cold winters prevent significant photosynthesis until late spring when the rains are typically waning. Thus, even with the drier scenarios, the interior vegetation can much more effectively utilize the winter precipitation.

The greater the effectiveness of fire suppression, the greater will be the woody expansion, even moving toward a closed canopy in many regions of the interior (*Figure 13*). The effect of the delicate balance between all the contrasting forces can best be observed in the changes in vegetation and ecosystem carbon and on whether fire consumes more or less biomass.

d) Change in Vegetation Carbon

With climate change, the wet maritime forests tend to lose carbon, even under scenarios with increased precipitation, (Figure 15). Interior dry ecosystems tend to gain carbon. The interior conifer forests lose carbon without fire suppression, but gain carbon with fire suppression. The wet maritime forests are unique among Northwest ecosystems in that the historical fire return interval is sufficiently long that the simulated ecosystems have grown up to their water-limited carrying capacity. Thus, the increases in temperature lengthen the effective growing season of the maritime forest, as well as produce a much higher evaporative demand. The result is that the trees, with their current leaf area, withdraw more water during the hot summer than is available in the soil. Therefore, the leaf area is reduced via dieback of leaves, branches and trees, augmented in some cases by increases in fire With a lower leaf area, implying a less dense forest (as shown by the reduced vegetation carbon), the forest is again able to maintain a positive water balance throughout the summer.

The interior forests show an increase in leaf area under the future climate, due to a more favorable synchrony between their growing season and the precipitation, and are also normally maintained by fire at a lower leaf area than could be maintained by the water balance. The increase in the vegetation density in these interior ecosystems is also driven by increases in winter precipitation and enhanced water use efficiency from elevated CO_2. The interior savanna/woodland ecosystems are able to put on more biomass even with an increase in fire and without fire suppression. However, the presence or absence of fire suppression serves to modulate whether the interior conifer forest ecosystems become carbon sources or sinks (*Figures 14, 15*).

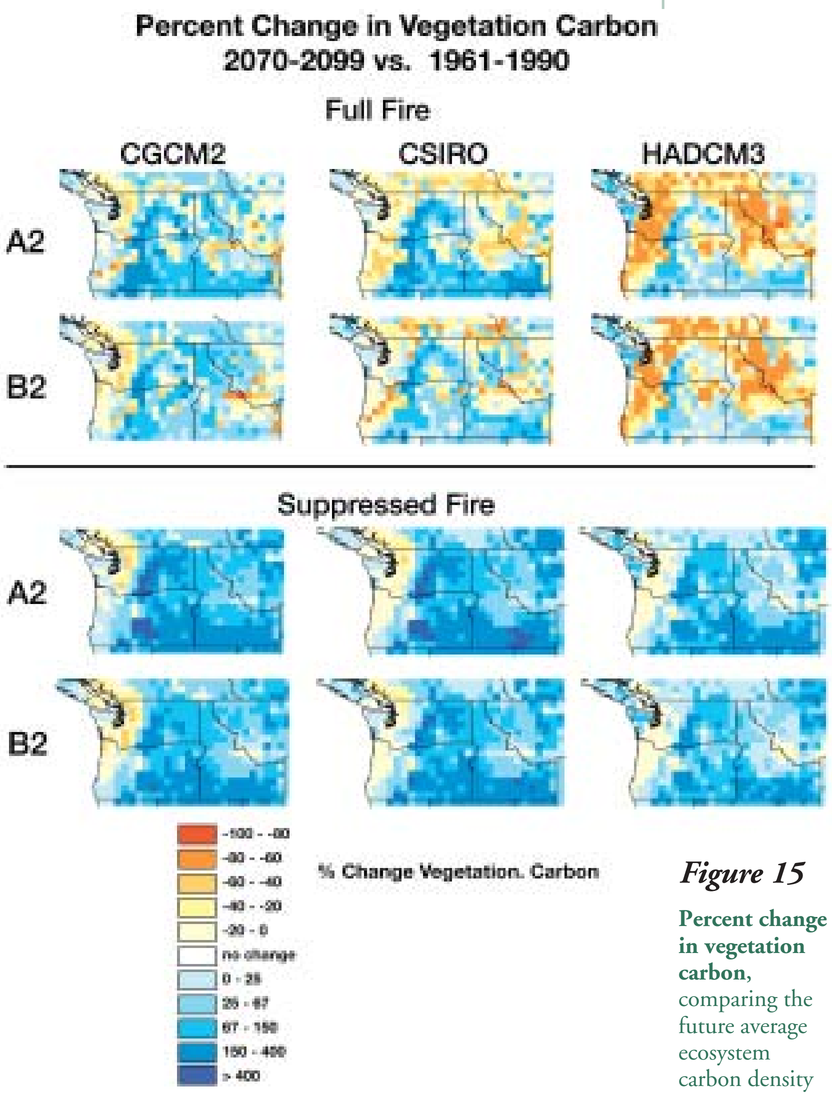

Figure 15

Percent change in vegetation carbon, comparing the future average ecosystem carbon density (2070 – 2099) with current (1961 – 1990) carbon density, without fire suppression (upper panel) and with fire suppression (lower panel). The six future scenarios are arrayed by GCM (columns) and emissions scenarios (rows). The GCM definitions are as in Figure 11.

Summary

With climate change, all ecosystems in the Northwest show significant changes in species composition, fire disturbance and carbon balance. The complexities and nuances of counteracting forces cannot be minimized. Even with the newest modeling techniques, the balances in the real world are difficult to forecast. However, colder ecosystems (alpine) will be threatened while warmer ecosystems will increase. Fire is likely to increase, even in wet coastal ecosystems. Ecosystem carbon gains and losses will be mixed, but fire suppression or exclusion could have a profound positive influence on ecosystem carbon sequestration.

Forest Management in the Face of Changing Climates

In the context of changing climates and increasing atmospheric carbon, basic concepts and overall strategies frame the discussion. These can be categorized as *mitigation, adaptation*, and *conservation.* Mitigation practices aim to reduce emissions of new greenhouse gases, as well as to remove existing CO_2 from the atmosphere. Adaptation practices include actions to increase the capacity of forests, ecosystems, and society to function productively under changing climates and greenhouse atmospheres. Conservation practices include all those actions that reduce energy use and dependence on fossil-fuels, and thereby relieve stress on forests, ecosystems, and ecosystem services. For forest management to meet these three principles, we outline five decision-making strategies. They are *Reduce* Greenhouse Gases, *Resist* Change, Create *Resilience* After Disturbance, *Respond* to Change, and Conduct *Triage* (Millar 2006). While these guidelines pertain to many situations, the discussion here addresses production forest management on private and public lands. For similar discussion specific to restoration ecology, conservation practices, and lands managed primarily for biodiversity, see Millar and Brubaker 2006.

(1) Reduce Greenhouse Gases.

To date, discussion in western forestry and land-management circles regarding climate has focused on adaptation to anticipated changes. A priority, however, must be to contribute actively to mitigation of human-induced climate and atmospheric effects by reducing greenhouse gas emissions. The forestry sector is especially called to action because the potential for positive effects through deliberate forest management is large, and, conversely, there is great potential for negative impacts when forests are mis-managed or carbon issues ignored. While the U.S. has fallen far behind other countries in developing stringent federal standards and emissions caps, many U.S. states including Oregon are taking steps to establish standards that compare to Kyoto-protocol countries. These fall under the category of sequestering greenhouses gases, reducing unnecessary emissions, and maintaining a “house in order.”

Sequester Greenhouse Gases. Plants remove CO_2 from the atmosphere during the process of photosynthesis, and, with water, convert carbon to wood and other plant parts. Under natural conditions, carbon is stored in plant parts above- and below-ground until it is returned to the atmosphere via burning (combustion) or decomposition, or further stored in the soil. Carbon is stored, or sequestered, in live plant tissues as stems, leaves, and roots, in dead tissue as stems and litter, and in soil pools in diverse forms. This process can be exploited as a mitigation strategy.

Forest management practices designed to achieve goals of removing and storing CO_2 are diverse. A recent study on carbon sequestration options identified that “afforestation provides the biggest terrestrial sequestration opportunity in Oregon, Washington, and California,” (Kadyszewski et al. 2005). Afforestation involves converting non-forest land into forested condition, either restoring native forests (e.g., forest that had been cleared) or establishing plantations on land that was not previously forested. Other approaches to sequestering carbon duplicate long-recognized best forest management practices where the goals are to maintain healthy, vigorous growing stock, keep sites fully occupied with minimal spatial or temporal gaps in non-forest conditions, and minimize disturbance by fire, insects, and disease. Responsible sequestration practices delay return of CO_2 to the atmosphere, both in situ (in the forest or plantation) and post-harvest.

Once fiber is removed from the forest or plantation, its path through the utilization cycle continues to affect its carbon emissions status. Options include storing carbon in wood and fiber form as buildings, paper, fiberboard, etc., or used for biomass to fuel electricity production.

The latter provides a tremendous opportunity for the future, as wood removed from the forest not only reduces greenhouse gas emissions by reducing fire vulnerabilities but provides alternative energy to replace fossil-fuel and other high greenhouse gas-emitting forms of energy.

Reduce Unnecessary Emissions. Wildfire and extensive forest mortality as a result of insect and disease are primary sources of unintentional carbon emissions from forests in western U.S., and represent catastrophic loss of decades to centuries worth of carbon storage. This situation is likely to be worsening, in the near term at least, in that forest growth has increased during the 20th century due to warming and wetter climates as well as decades of fire suppression ("green-up"), priming overdense stands for wildfire during dry years and droughty periods (Lenihan *et al.*, 2005, Westerling and Bryant 2005, Westerling *et al.*, 2003). This effect will exacerbate in coming decades under continued warming, with increasing catastrophic fire years leading to what has been modeled as widespread "browndowns" for many western and eastern forest types (Ron Neilson, results in prep).

Management practices that lower forest vulnerabilities to wildfire and non-fire mortality should be widely implemented. On public forest lands, while there is support for fuel and fire reduction, there has been public pressure to minimize harvest (thinning) and to use managed fires instead. While this may be important for ecological values, from a carbon-accounting standpoint it is less desirable. Removing trees (thinning or chipping) from dense or dead stands is appropriate where this practice lessens fire risk, and especially if the fiber is subsequently used as biomass to fuel energy co-generation or stored longterm.

Maintain House in Order. While not directly related to vegetation management, energy conservation and reduction of emissions from resource-related activities should be a priority for forestry and environmental institutions. For example, based on a 2005 Presidential Memorandum, the Chief of the U.S. Forest Service issued a directive on energy and fuel conservation that requires 10% agency-wide reductions in energy use, travel, and use of gas-fueled vehicles. He further proposed changes in agency fleets to include hybrid and other clean-fueled transportation, and outlined employee incentives to telecommute, use public transportation, etc. (Bosworth 2005). Many state and utility programs offer rebates and incentives to install solar panels, wind-generators, and to reduce gas and electricity usage. Energy audits are readily performed and many types of carbon calculators are available online. Green tag programs, such as that run by the Bonneville Environmental Foundation, encourage trading of energy debt (paid by individuals to offset greenhouse gas emissions) to entities that provide clean energy sources. Many other businesses and organizations (e.g., Carbon Neutral Company, TerraPass) have been developed with missions to mitigate climate effects by promoting positive and practical actions to reduce emissions.

(2) Resist Effects of Climate Change.

On the adaptation side of management options, one approach is to resist the influence of climate change on forest resources. From high-value plantation investments near rotation to rare species with limited available habitat, maintaining the status quo may be the only option. In Oregon, this will almost always involve protecting resources from fire, insect, and disease. Options include traditional fuel breaks, strategically placed area treatments, defensible fuel profile zones, group selection, and individual tree removal. Intensive and complete fuel breaks may be necessary around highest risk areas, such as wildland-urban interfaces and valuable plantations, while mixed approaches may best protect habitat for biodiversity.

Abrupt invasions, changes in behavior, and long-distance movements of non-native species are expected in response to changing climates.

Monitoring non-native species and taking early actions to remove and block invasions are important. This applies to invasive plants, animals (vertebrate and invertebrates), and pathogens. Aggressive early resistance is critical.

Resisting climate change influences on natural forests and vegetation may require additional investments, intensive management, and a recognition that one is "paddling upstream" against nature. For instance, climate change in some places will drive site conversion so that site capacities shift from favoring one species to another. Maintaining prior species may require significant extra and repeated efforts to supply needed nutrients and water, remove competing understory, fertilize young plantations, develop a cover species, thin, and prune.

(3) Create Resilient Vegetation.

Resilient forests and plantations are those that not only resist change but resile (*verb:* to return to a prior condition) after disturbance. Resiliency of vegetation can be increased by management practices similar to those described for resisting change. These include practices to reduce fire risk, and also aggressive actions to encourage return of the site to desired species post-disturbance. Given that the plant establishment phase tends to be most sensitive to climate-induced changes in site potential, intensive management at young ages may enable retention of the site by a commercially desired species, even if the site is no longer optimal for it. Practices include intensive site preparation, replanting with high-quality stock, diligent stand improvement practices, and minimizing invasion by non-native species. Unfortunately many examples are accumulating where resilience is declining in natural forests, and retaining resiliency will become more difficult as changes in climate accelerate.

(4) Respond to Climate Change.

Another adaptation option for management is to anticipate the effects of projected future climate on vegetation and plan protective and opportunistic measures in response. For this to be useful requires that climate and response models yield useful projections. While regional modeling is becoming increasingly sophisticated, outcomes should be considered highly uncertain at the local spatial and temporal scales used in forest management. This is partly because large uncertainties exist at global climate scales that translate and amplify as models are downscaled to regional levels. Rather than viewing models as forecasts or predictions of the future, they are better used for attaining insight into the nature of potential process and about generalized trends. Focusing on results that are similar across diverse models should indicate areas of greater likelihood. Ecological response (including fire and insect/disease) to climate is even more difficult than climate to model accurately at local scales because threshold and non-linear responses, lags and reversals, individualistic behaviors, and stochastic and catastrophic events are common. Models typically rely on directional shifts following equilibrium dynamics of entire plant communities, whereas especially in mountainous regions, patchy environments increase the likelihood of complex individualistic responses. Once a forest manager obtains regional information about future climate scenarios, either from sophisticated modeling or qualitative extrapolations, options for managing resources in response to anticipated change can be developed. Depending on management goals and the environmental context, different approaches may be taken. A sample of these includes the following:

Follow Climate Change. Use coupled and downscaled climate and vegetation models to anticipate future regional conditions and project future forest stands and plantations into new habitat and climate space.

Anticipate and Plan for Indirect Effects. Evaluate potential for indirect effects, such as changes in fire regimes and exotic insects and pathogen responses, and plan management accordingly.

Increase Redundancy. While some situations may implicate "putting your eggs in one basket" and trusting that climate and vegetation models accurately project the future, for other situations, bet-hedging practices may be a better choice. Essentially this group of actions plans for uncertainty in the future rather than a certain (modeled) scenario, and promotes decisions that spread risk rather than concentrating it.

Expand Genetic Diversity Guidelines. While in the past several decades, genetic guidelines for reforestation have been increasingly refined to favor local germplasm and close adaptation, relaxing these guidelines may be appropriate under changing climates as another bet-hedging practice.

Establish "Neo-native" Locations. Information from historic species ranges and responses to climate change offers a different kind of insight into the future than modeling studies might. For instance, areas that supported species in the past under similar conditions to those projected for the future might be considered sites for new plantations or "neo-native" stands of the species (Millar, 1998).

Experiment with Refugia. Plant ecologists and paleoecologists recognize that some environments appear more buffered against climate and short-term disturbances while others are sensitive. If such environments can be identified locally, they could be considered sites for longterm retention of plants, or even for new plantations.

Promote Porous Landscapes. A capacity to move in response to changing climates is key to adaptation and long-term survival of plants in natural ecosystems. Plants migrate, or "shift ranges," by dying in unfavorable sites and colonizing favorable edges including internal margins. Capacity to do this is aided by porous landscapes, that is, landscapes that contain continuous habitat with few physical or biotic restrictions, and through which plants can move readily (recruit and establish). Promoting large forested landscape units with flexible management goals that can be modified as conditions change will encourage species to respond naturally to changing climates and enable managers to work with rather than against the flow of change.

(5) Conduct Triage.

Species, plant communities, regional vegetation, and plantations will respond to changing climates individualistically. Some species and situations will be sensitive and vulnerable. Depending on their value or risk level, these may be targeted either for aggressive intervention, or, conversely, intentionally relinquished to their fates. By contrast, there will be other species and situations that are buffered, at least initially, from effects of climate changes or resilient to climate-influenced disturbances. These may need little attention or minimal modifications of management plans, at least in the near future. Decision-support tools that help managers weigh risk levels, project expected benefits or impacts from intervention, evaluate priorities, and develop simple management alternatives must be developed.

Conclusions

Change is a natural and ongoing aspect of earth's complex climate system, and forms the context against which current human effects on climate can be evaluated. Natural cycles in climates occur at millennial, century, decadal, and interannual time frames. Climate states may shift abruptly over times as short as years or decades. Over historic time, species have adapted to climate changes by shifting ranges and (over long time spans) adapting through genetic change. Since the 1970s, the interaction of climate-driving mechanisms has shifted to become dominated by anthropogenic influence, predominantly greenhouse gas emissions. As a result, climate of the 21st century and beyond will react in different ways than in the past, and will increasingly extend beyond relevant historic ranges of variation. Direct effects of CO_2 on plants will have both detrimental and beneficial effects, depending on species and context. Current projections for Oregon's climate future suggest warming temperatures by 7 to 8.5°F and somewhat wetter. If these result, more precipitation will fall as rain rather than snow, mountain snowpacks will be greatly reduced, winters will be shorter, streamflows will decline, and the already extensive summer drought will be longer and more severe. Significant shifts in forest, shrub, and grasslands, as well as fire regimes, are anticipated.

Perhaps most importantly, regardless of historic precedence, rapid changes in climate, increasing temperatures, and increases in extreme events are much more difficult for modern society (including the forestry sector) to cope with than in times when human population was smaller and more adaptable Our dependence on stable and predictable conditions has led to situations where even historically natural levels of climate variability will have increasingly serious health and economic consequences worldwide. Global political opinion, with some exceptions, is in agreement that the next 50 to 100 years must be a period when greenhouse gas emissions and atmospheric concentrations are brought into control. Managing carbon and coping with climate changes will be the tacit context for vegetation management in the coming century.

In the face of these changes, forest managers can help to mitigate ongoing climate changes and greenhouse gas emissions, plan strategies to adapt to change, and take actions to conserve energy use and relieve stress on ecosystems.

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CHAPTER FOUR

HIGHLIGHTS:

GLOBAL WARMING: A SKEPTIC'S VIEW

Is There Global Warming?

- The world has warmed within the last 100 years, but probably not over the last 5,000 years.
- Over a millennial time scale, current conditions are comparable to and even cooler than past temperatures.
- There is a human influence on climate, but natural variations may be the most dominant factors.

Scientific Consensus

- Organizations that have issued policy statements may be representing a small working group without input from the broader membership.
- Consensus may be wrong. Recent theories about Continental Divide, El Niño and the Missoula Floods were ridiculed and later proven correct.

Glaciers

- Glaciers are often considered good indicators of climate change.
- At Glacier National Park, most of the glacial reduction occurred prior to modern greenhouse gas buildup and must be due to natural effects.

Polar Regions

- Arctic climate changes have regional differences. Alaska temperatures have remained steady since 1976 and Greenland temperatures have generally cooled.
- Antarctic ice is growing and the overall trend is positive, with considerable year-to-year variation.

Climate of Oregon and the Pacific Northwest

- Current temperatures are cooler than the 1930s.
- Snowpack has declined since 1950, but the 1950s were exceptionally snowy.
- Sea level is rising on the central and northern coast and lowering on the southern coast; both may be due to geologic factors.
- Other decadal-scale variability like El Niño may explain most of Oregon's warming and cooling.

Summary

- While the world is warming, it has been warmer in the past.
- There remain strong climate influences that we do not yet understand.

CHAPTER FOUR

GLOBAL WARMING: A SKEPTIC'S VIEW

George Taylor

Introduction

I have worked as Oregon's State Climatologist since 1991. During that time, I have studied long-term climate trends as well as climate "forcings" — factors which cause climate to change. In particular, I have focused on Oregon and the Northwest, but since global climate patterns affect Oregon, I have spent considerable time studying larger-scale factors as well.

The opinions expressed here are my own and do not necessarily represent those of the State of Oregon or Oregon State University, where I am employed.

Is There Global Warming?

There are three questions we should be asking: (1) Is the world warming? (2) Are we seeing unprecedented conditions? (3) Are humans influencing climate?

1. Is the world warming?

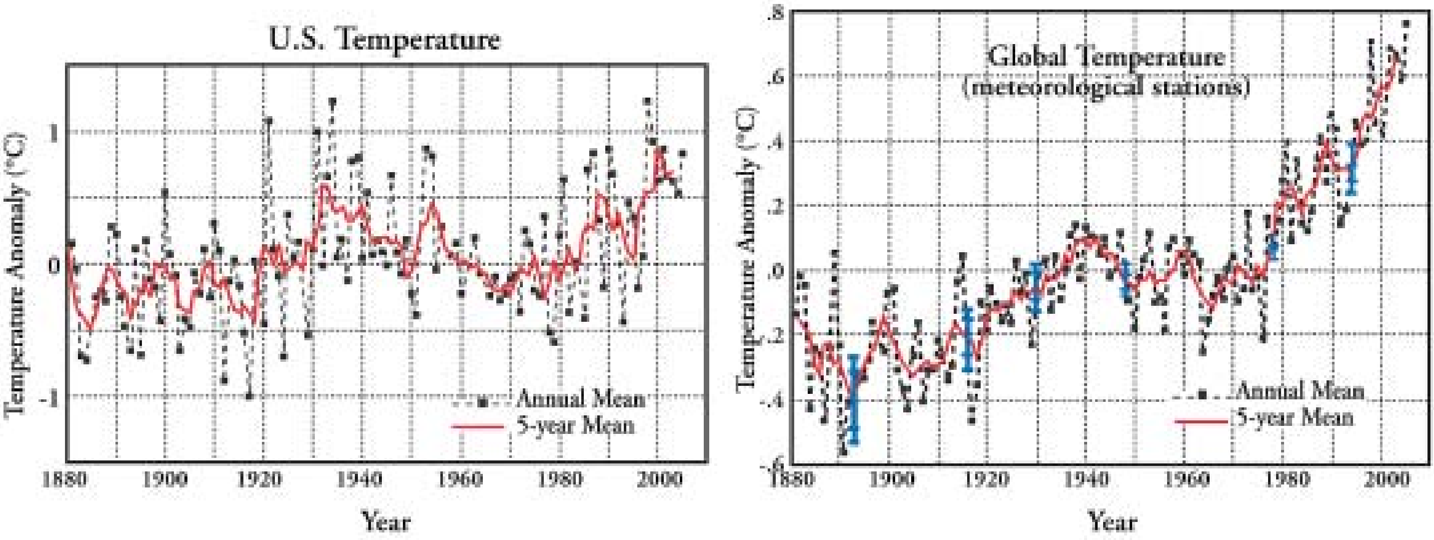
The answer depends largely on the starting and ending points analyzed. In the past 30 years, the world has probably gotten warmer. Maybe it's warmer than the last 70 years. It's definitely warmer than that past 100, or the past 300 years. But looking back further than that, to 1,000 years, it's not so clear. And the earth is probably not warmer than it was 5,000 years ago.

Has the world warmed in the last 30, 70, 100 years? YES.

The Intergovernmental Panel on Climate Change (IPCC 2001) says that global average surface temperatures have increased over the 20th century by about 1°F. Globally, IPCC says it is very likely that the 1990s was the warmest decade and 1998 the warmest year. But the record shows a great deal of variability, rather than a steady rise; for example, most of the warming occurred during two periods, 1910 to 1945 and 1976 to 2000. In between those periods, there was widespread cooling; this is especially notable in data for the U.S. and for Oregon.

Figure 1 shows estimated annual temperatures from 1880 to 2000 for the U.S. (left) and world (right). The U.S. graph shows

Figure 1



warm conditions in the 1930s-40s, cooler before and after, and recent warming. The warmest decades in the last 100 years in the U.S. were the 1930s and the 1990s and the warmest years were 1934 and 1998. In the global chart the recent temperature rise is higher.

Has the world warmed in the last 300 years? YES.

Three hundred years ago the Little Ice Age marked a time of very low temperatures, certainly much cooler than modern conditions.

Has the world warmed in the last 1,000 years? MAYBE.

The thermometer was invented about 300 years ago. Since we have no direct measurements of temperatures 1,000 years ago, earlier conditions are estimated based on inferences from "proxy" data – measurable parameters that approximate or mimic temperature. These include such things as tree rings, sediments, ice cores and isotope measurements. *Figure 2* (IPCC 1990) is an example of the "accepted" history of temperatures of the last millennium, which depicts the Medieval Warm Period. Histories such as this suggest that earlier temperatures were as warm as, or warmer than, those observed in recent times.

Goosse *et al.*, (2005) studied the climate history of the last millennium and compared estimated data with model simulations. Their assessment is that "the Medieval Warm Period was a hemispheric-scale phenomenon, at least, since the temperature averaged over the northern hemisphere was generally higher during the period 1000-1200 AD than during the following centuries," and that "this is the consequence of a global forcing, external to the climate system itself." This suggests that changes in sunlight, for example, led to the changes in climate.

Refereed journals offer insights into historical climate. Some articles have suggested that current temperatures are unique – higher than any since the last ice age. Others differ. For example, according to Soon and Baliunas (2003), "the assemblage of local representation of climate establishes both the Little Ice Age and Medieval Warm Period as climatic anomalies with worldwide imprints, extending earlier results by Bryson *et al.*, (1963), Lamb (1965), and numerous intervening research efforts." In addition, they find that "across the world, many records reveal that

Figure 2

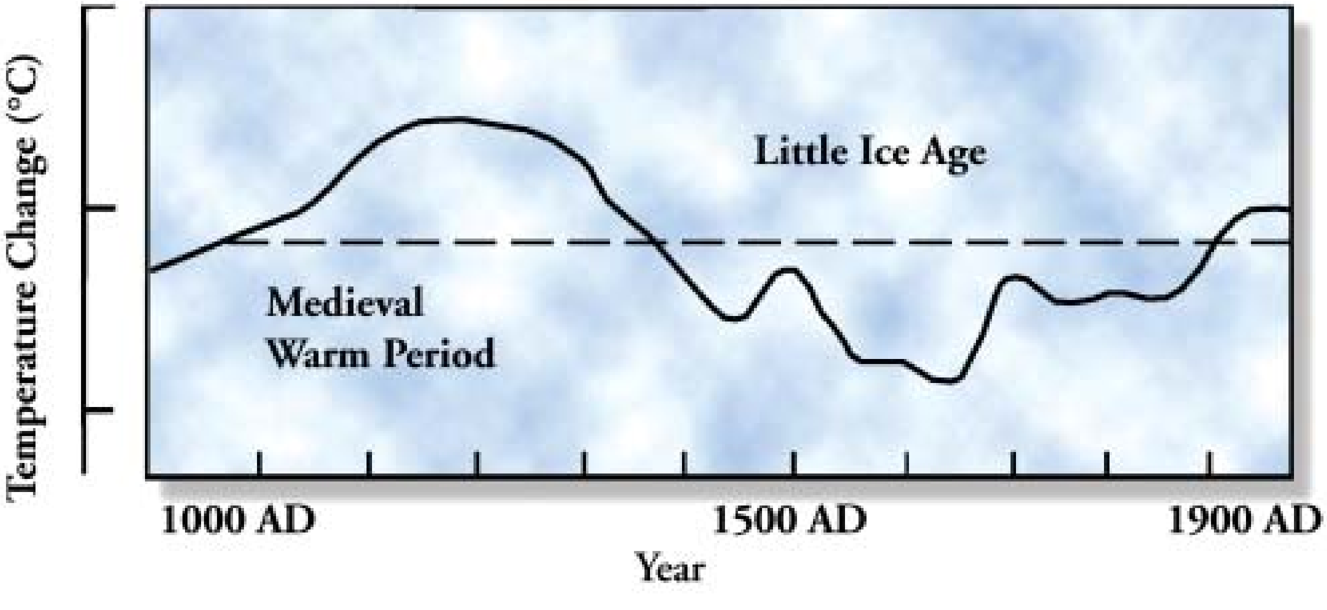
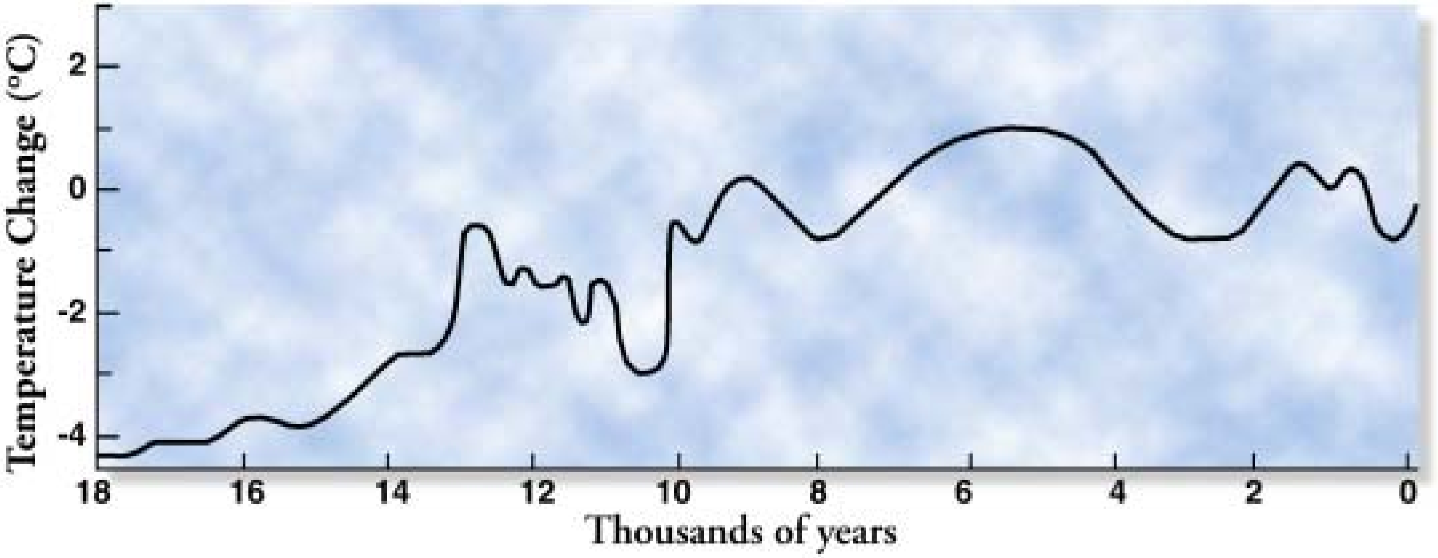


Figure 3



the 20th century is probably not the warmest nor a uniquely extreme climatic period of the last millennium." This would imply that current temperatures may be due in large part to natural climate variations.

Has the world warmed in the last 5,000 years? PROBABLY NOT.

During the period between 4,000 and 7,000 years ago, a period often referred to as the Holocene Maximum, global temperatures reached as high as 3.6°F warmer than at present. *Figure 3* above, from IPCC (1990), shows the approximate temperature history of the Holocene. Recent journal articles, such as Levac (2001), Kaplan, et al. (2002), and Mayewski et al. (2004), confirm the warmer temperatures during that epoch.

Thus, to answer the original question, "Is the world warming?" the answer is "It depends on the starting point." Looking at the last 100 years, there has been global warming, but when the starting point for analysis is 5,000 years, the answer is not so definitive.

2. **Are we seeing unprecedented conditions?**

To predict the future, one must understand the past. Climate history helps us define cause and effect relationships pertaining to climate, and also to place today's conditions in historical perspective.

Mayewski et al. (2004) identify six periods of "Rapid Climate Change" during the Holocene: calendar years BP [before present] 9000-8000, 6000-5000, 4200-3800, 3500-2500, 1200-1000 and 600-150, the last two of which intervals are, in fact, the "globally distributed" Medieval Warm Period and Little Ice Age, respectively. In speaking further of these two periods, they say that "the short-lived 1200-1000 BP Rapid Change Climate event coincided with the drought-related collapse of Maya civilization and was accompanied by a loss of several million lives, while the collapse of Greenland's Norse colonies at approximately 600 years ago coincides with a period of polar cooling."

They go on to state, "of all the potential climate forcing mechanisms, solar variability superimposed on long-term changes in insolation (exposure to the sun's rays) seems to be the most likely important forcing mechanism." In addition, they note that "negligible forcing roles are played by CH_4 and CO_2," and that "changes in the concentrations of CO_2 and CH_4 appear to have been more the result than the cause of the rapid climate changes."

Are today's temperatures unprecedented? Compared to conditions over the last several hundred years, temperatures have increased. But in the longer viewpoint (millennial time scale), current conditions are comparable to and even cooler than global temperatures in the past.

3. **Are humans influencing climate?**

The issue is not "do humans affect climate?" Clearly there is a human influence. The question is, "how much?" In my opinion, natural variations have dominated the climate system, and continue to do so.

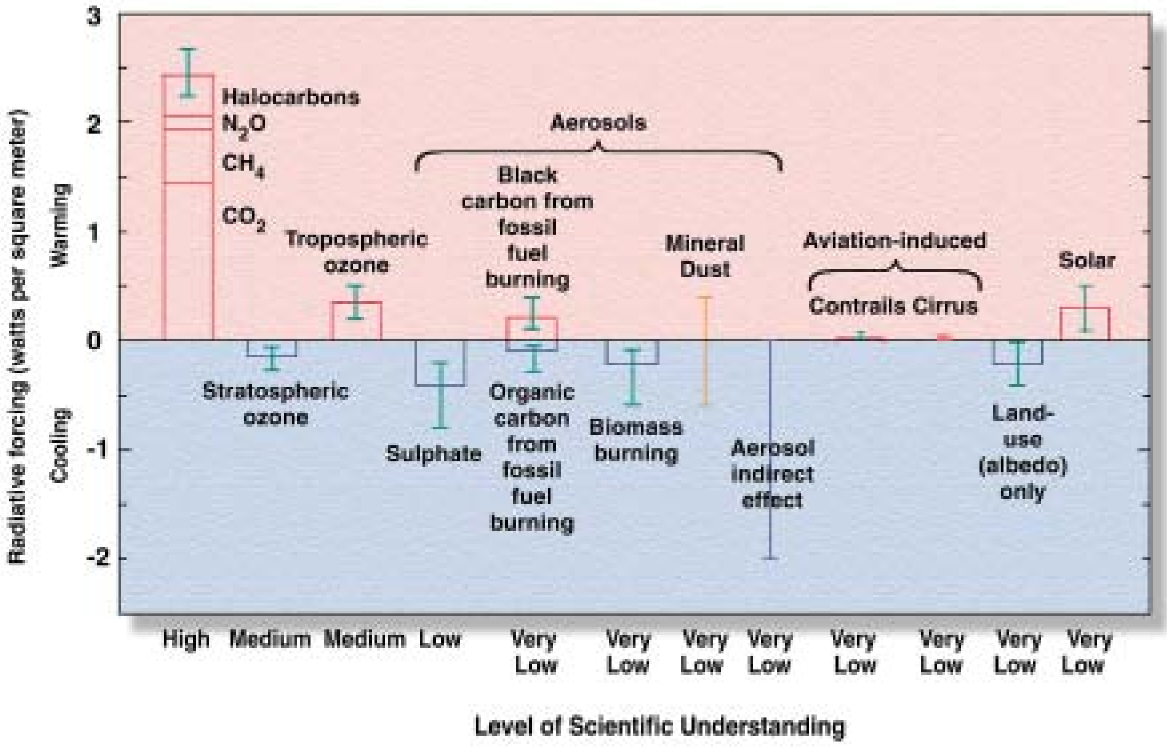
Modeling the earth's climate is not an exact science. General Circulation Models (GCMs) vary by a factor of three in their forecasts; they require arbitrary adjustments and they cannot properly simulate clouds. Their forecasts of substantial warming depend on a positive feedback from atmospheric water vapor. Many of the natural variations, such as sunlight, El Niño, volcanoes, and so on, cannot be predicted with any skill in the future.

The argument that "since 1975 the warming is best explained by human-caused changes in greenhouse gases" (Governor's Task Force 2005) is based on climate simulations using climate models. GCMs suggest that temperatures in the next century will rise significantly, mostly due to greenhouse gas increases. However, there are many variables known to affect climate which global climate models are unable to adequately simulate — for example black carbon from fossil fuel burning, or stratospheric ozone. For most of these variables, as illustrated below, there is a "very low" degree of scientific certainty.

Figure 4 (IPCC 2001) shows the level of scientific understanding of variables known to affect climate. The level of understanding of the effects of greenhouse gases (CO_2, CH_4, N_20, Halocarbons) on climate are listed as "high." Stratospheric and tropospheric ozone effects are at a "medium" level of understanding. The remaining nine factors are understood at a "low" or "very low" level.

It is my belief that factors other than greenhouse gases have been, and will continue to be, the primary influence on climate change. According to the National Research Council (2005), there are at least 12 significant short-term influences ("forcings") on climate, including changes in land use and land cover and the effects of aerosols.

Figure 4 **The global mean radiative forcing of the climate system for the year 2000, relative to 1750**



> Finally, a significant (though very intermittent) influence on temperatures involves major volcanic eruptions. Mount Pinatubo in the early 1990s caused global cooling for many months.
>
> Are humans influencing climate? Yes, I believe that they are, to a degree. But I believe that natural variations have dominated climate change in the past. Attributing climate change mainly to human causes is incorrect, in my opinion. Doubtless there remain strong influences on climate that we as yet do not understand.

Scientific Consensus

Several organizations, including The National Academy of Science, the American Meteorological Society (AMS), and the American Geophysical Association have issued policy statements that address human-induced global warming. The following is an excerpt from the statement of the AMS (of which I am a member):

"Human activities have become a major source of environmental change. Of great urgency are the climate consequences of the increasing atmospheric abundance of greenhouse gases and other trace constituents resulting primarily from energy use, agriculture, and land clearing. These radiatively active gases and trace constituents interact strongly with the Earth's energy balance, resulting in the prospect of significant global warming."[1]

The document referenced above was created by a small working group without input from the broader society membership. The statement drew a response from some members who questioned whether it reflected the consensus of AMS members.

Is there really a consensus?

European climate scientists Stehr and von Storch (2005) stated that "a significant number of climatologists are by no means convinced that the underlying issues have been adequately addressed. Last year, for example, a survey of climate researchers from all over the world revealed that a quarter of respondents still question whether human activity is responsible for the most recent climatic changes."

That survey (Bray 2004) involved responses from 530 scientists worldwide. They were asked: "To what extent do you agree or disagree that climate change is mostly the result of anthropogenic causes?" Only 9.4% strongly agreed, while 9.7% strongly disagreed. Another 19.3% were in general disagreement.

But even if there actually *was* a consensus on this issue, it may very well be wrong. In the 1600s, Galileo was imprisoned for espousing that the earth revolved around the sun. In more recent times, three examples are Alfred Wegener (Continental Drift), Gilbert Walker (El Niño), and J. Harlan Bretz (Missoula Floods). None is well-known now among members of the public, and all of them were ridiculed, rejected, and marginalized by the "consensus" scientists. Each of the three was later proven to be correct, and the consensus wrong.

Wegener suggested that the continents were all connected at one time but had drifted apart, a phenomenon we now call continental drift. Among his critics was Dr. Rollin T. Chamberlin of the University of Chicago who said, "Wegener's hypothesis in general is of the footloose type, in that it takes considerable liberty with our globe, and is less bound by restrictions or tied down by awkward, ugly facts than most of its rival theories" (UCMP n.d.). Chamberlin also said "Can geology still call itself a science, when it is possible for such a

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[1] *Climate Change Research: Issues for the Atmospheric and Related Sciences. Adopted by AMS Council on 9 February 2003.* ***Bull. Amer. Met. Soc*** *., 84, 508 —515*

theory as this to run wild?" (NMNH n.d.). In time, though well after his death, Wegener's "footloose" theory became dominant.

Walker was chided for his belief that climatic conditions over widely separated regions of the globe could be linked, and that fluctuations in the tropical Pacific affected the Indian Monsoon and other climatic features. We now call those Pacific fluctuations the "El Niño-Southern Oscillation," and recognize that it has a profound effect on world weather.

Bretz postulated that massive floods had transformed the landscape of the Pacific Northwest at some time in the past. Geologists, who believed in slow, uniform processes, called Bretz a "catastrophist" because he believed in large-scale events not currently seen. Bretz engaged in "flaunting catastrophe too vividly in the face of the uniformity that had lent scientific dignity to interpretation of the history of the earth," according to one fellow scientist (Allen and Burns, 1991). Decades after his research began, it was shown that post-ice age floods had indeed scoured the landscape, and that Bretz's theories were correct.

Is there a consensus among scientists regarding global warming? Perhaps – it depends on how that is measured, and by whom. But does this tell us much about the truth of human influence on climate? I suggest that it does not. In the words of Brian David Josephson, Nobel Laureate in Physics, "if scientists as a whole denounce an idea this should not necessarily be taken as proof that the said idea is absurd: rather, one should examine carefully the alleged grounds for such opinions and judge how well these stand up to detailed scrutiny." (Josephson n.d.)

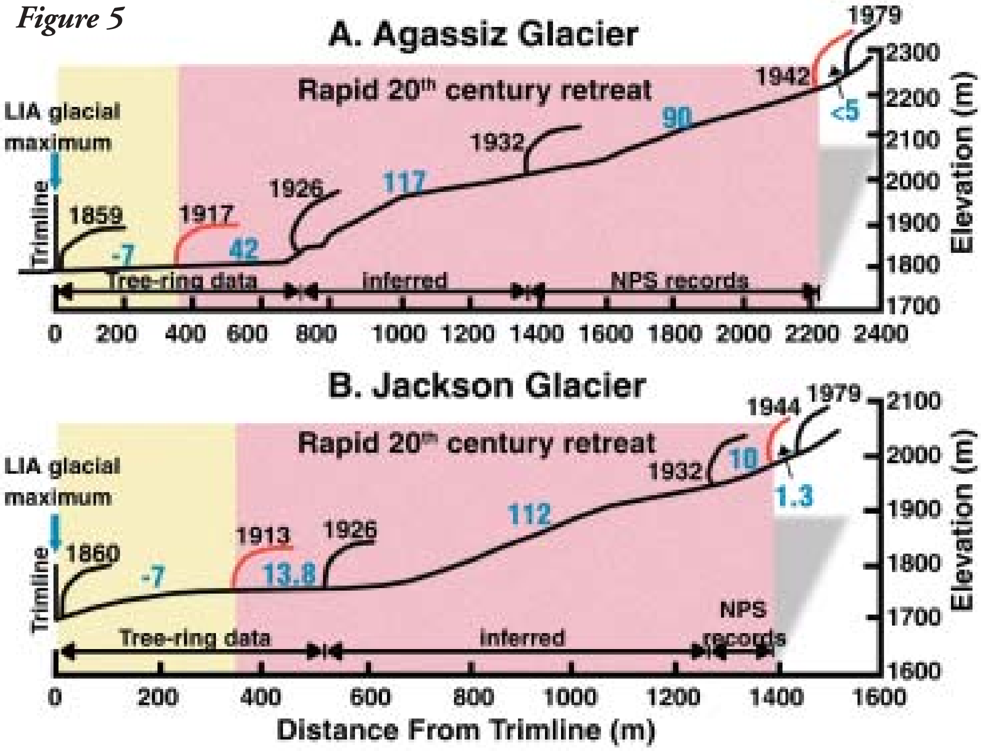
Glaciers

Glaciers are often considered as good indicators of climate change. According to IPCC (2001), "Work on glacier recession has considerable potential to support or qualify the instrumental record of temperature change and to cast further light on regional or worldwide temperature changes before the instrumental era."

Glacier dynamics are quite complex. Glaciers are affected by changes in precipitation as well as temperature; temperatures during the warm "melt" season are especially critical. Some scientists have suggested that global warming will cause significant influences on glaciers in the future, based on observed changes in the past. Aptly-named Glacier National Park (GNP) may be moving toward "not so aptly named" if the glaciers continue to shrink. According to the U.S. Environmental Protection Agency (EPA n.d.):

> "The area of [GNP] covered by glaciers declined by 73 percent from 1850-1993. The cause? A regional warming trend that some scientists believe may be related to global climate change. If scientists' predictions are accurate, Grinnell and all of the park's other glaciers will disappear entirely within the next 30 years."[2]

Figure 5



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[2] *http://yosemite.epa.gov/oar/globalwarming.nsf/content/ImpactsMountainsWesternMountains.html*

In a journal article, four Montana scientists attempted to understand the history of glacier behavior in GNP over the last several hundred years (Pederson et al. 2004). While their report acknowledges that glaciers are shrinking, they note that the dynamics of glacier changes may be poorly understood, and that the glacial shrinkage may reflect regional climate variations. For example:

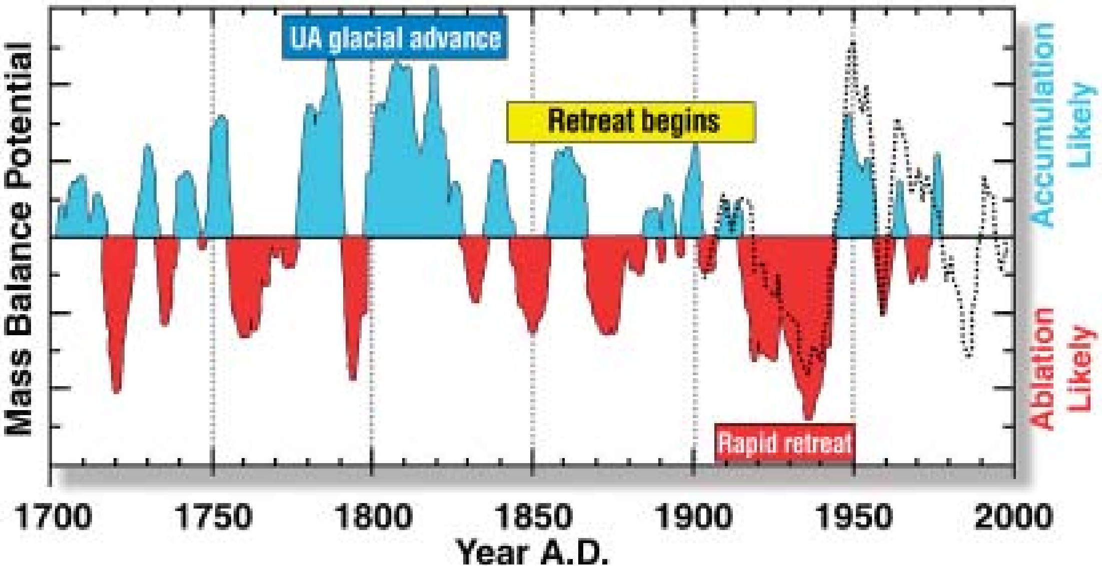


Figure 6

> "Little Ice Age (14th–19th centuries AD) glacial maxima and 20th century retreat have been well documented in Glacier National Park, Montana, U.S. However, the influence of regional and Pacific Basin driven climate variability on these events is poorly understood. We use tree-ring reconstructions of North Pacific surface temperature anomalies and summer drought as proxies for winter glacial accumulation and summer ablation (reduction in size) respectively, over the past three centuries."
>
> "These records show that the 1850s glacial maximum was likely produced by 70 years of cool/wet summers coupled with high snowpack. Post 1850, glacial retreat coincides with an extended period (approximately 50 years) of summer drought and low snowpack culminating in the exceptional events of 1917 to 1941 when retreat rates for some glaciers exceeded 100 m/yr."

In commenting on glacier histories since the 1850s, the authors say:

> "The maximum glacial advance of the LIA (Little Ice Age) coincides with a sustained period of positive MBP (Mass Balance Potential) that began in the mid-1700s and was interrupted by only one brief ablation phase (approximately 1790s) prior to the 1830s,"
>
> after which they report that "the mid-19th century retreat of the Jackson and Agassiz glaciers (*Figure 5*) then coincides with a period marked by strong negative MBP."

Glacier became the country's tenth national park in 1910 and the glaciers remained approximately the same size, with a modest retreat (approximately 3 to 14 meters/year) until 1917. For the next 25 years, glaciers retreated at a rate of greater than 100 meters/year, the period of greatest glacial retreat in recent centuries. From the mid-1940s through the 1970s, the glaciers began to advance, but after that, from the late 1970s through the 1990s, warmer conditions resulted in a "continuous, modest retreat" of the glaciers (Pederson *et al.*, 2004).

Pederson *et al.*, suggest that the primary reason for the variability is a combination of the Pacific Decadal Oscillation (PDO), which affects both temperature and precipitation during winter, and Mean Summer Deficit (MSD) from tree rings. PDO is a term for multidecadal shifts in North Pacific Ocean temperatures, while MSD is an index relating to annual precipitation conditions. The observed PDO for the last century is shown in 5A., and a reconstructed PDO in 5B.

Figure 6 from their report shows estimated GMP (glacier mass potential, an index that represents the growth or shrinkage of glaciers) since 1700 using a combination of PDO and MSD. The 1917-

1940 ablation period is clearly the largest in the last 300 years, while the greatest accumulation periods were in the late 18th and early 19th centuries. While glaciers have shrunk since the 1850s, most of the reduction occurred prior to the modern greenhouse gas buildup and thus must be due primarily to natural effects.

Polar Regions

Global climate models suggest that polar regions should warm more quickly than temperate or tropical regions in a greenhouse-enhanced world for several reasons: (1) water vapor dominates the global greenhouse effect, but there is much less water vapor in the cold, dry polar regions than in warmer regions, so the relative effect of CO_2 and other greenhouse gases is higher near the poles; (2) there is an ice-albedo feedback mechanism in which warming leads to a reduction of ice and snow coverage, decreasing albedo (reflectivity), resulting in further snow and sea ice retreat. The low amounts of water vapor, the most significant greenhouse gas, cause the relative effects of other gases, notably carbon dioxide, to be greater. Thus climate change caused by an increase in the latter should be most evident in the polar regions.

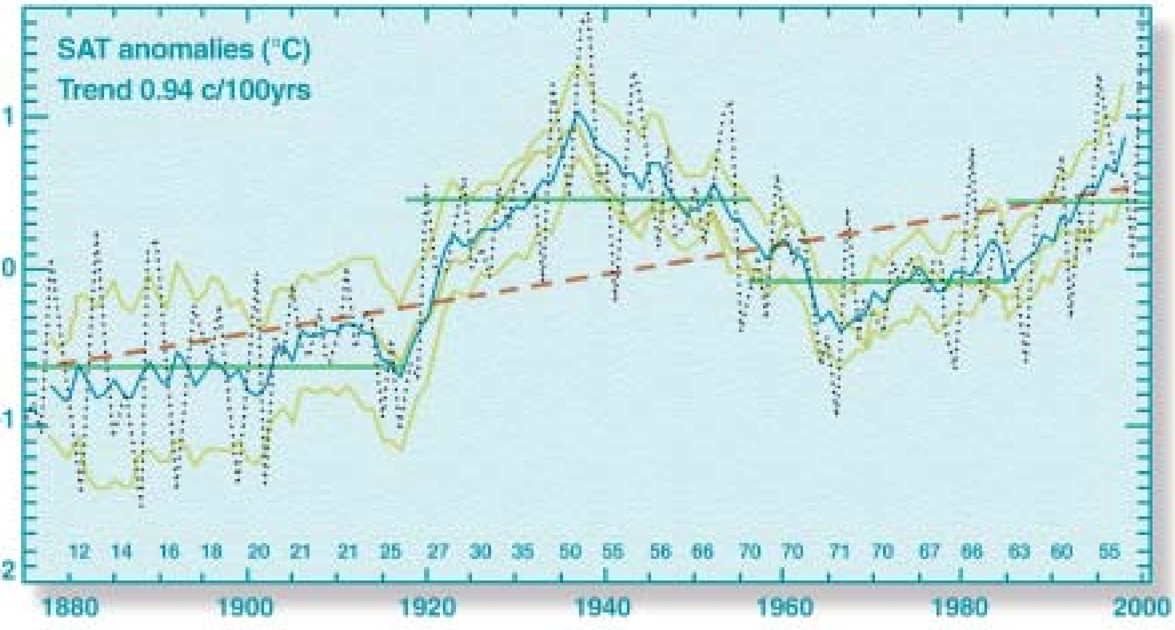
According to IPCC (2001), "Climate change in polar regions is expected to be among the largest and most rapid of any region on the earth. Once triggered, [it] may continue for centuries, long after greenhouse gas concentrations are stabilized, and cause irreversible impacts on ice sheets, global ocean circulation, and sea-level rise."

Arctic

Granted, temperatures have changed in most of the world in the last several decades. The 1960s and 1970s were generally cool decades. However, for the Arctic and elsewhere, they were preceded by a much warmer period — the 1930s and 1940s. *Figure 7* shows a graph of annual average temperatures in the Arctic, based on temperature measurements. Note the very warm period, the 1930s and early 1940s, which exceeded recent temperatures.

Figure 8 shows temperatures in Alaska from 1949 to 2003. On the one hand, temperatures are considerably higher at present than they were at the beginning of the periods shown. On the other hand, this was the result of a one-year step in temperatures at the time of the now-famous Pacific Climate Shift of 1976-77, when a significant ocean atmosphere regime shift occurred in the Pacific. According to Hartmann and Wendler (2005), "Shifts and multiyear anomalies result in temperature trends over periods that can differ substantially (even in sign) from the trend of the full time period. The cooling trend throughout much of Alaska since 1977, though not statistically significant, is in contrast to some theories regarding the atmospheric

Figure 7



Courtesy of American Meteorological Society

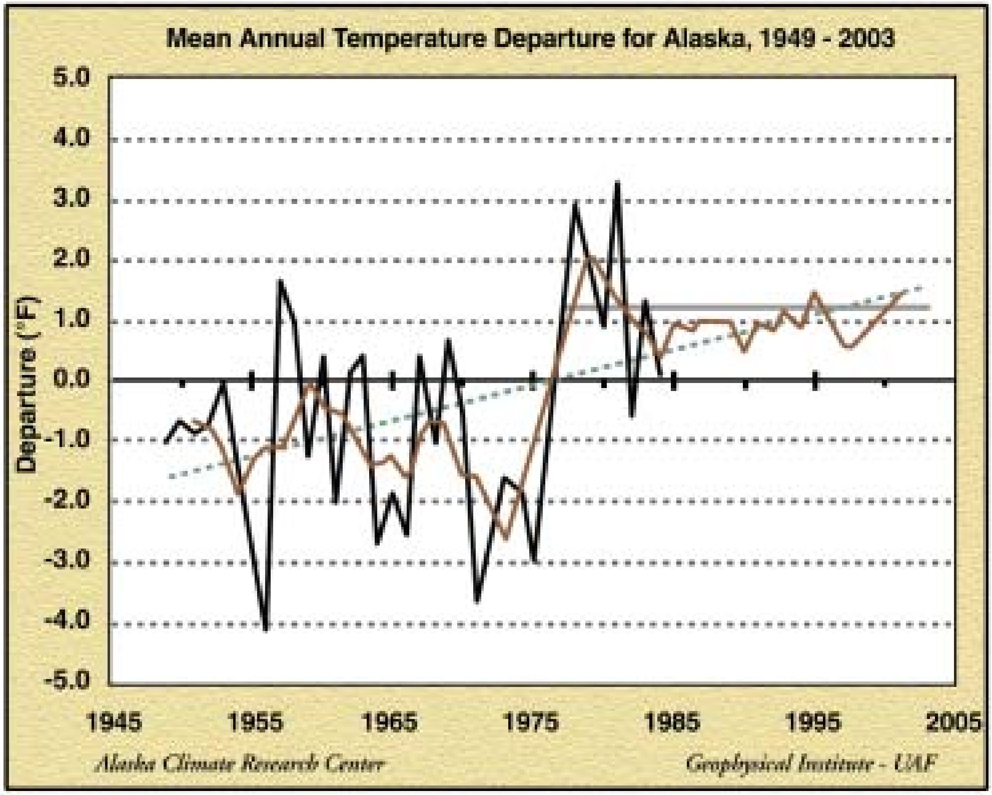


Figure 8

warming in an increasing greenhouse gas environment." Though current temperatures are higher than they were 35 years ago, all of the increase occurred in a one-year period attributable to a large-scale climate shift unrelated to greenhouse gas forcing. Further, since the 1976-77 shift, temperatures have actually declined.

In Greenland, according to Chylek *et al.*, (2004),

> "The Greenland surface air temperature trends over the past 50 years do not show persistent warming, in contrast to global average surface air temperatures. The Greenland coastal stations' temperature trends over the second half of the past century generally exhibit a cooling tendency with superimposed decadal scale oscillations related to the NAO [North Atlantic Oscillation]. At the Greenland ice sheet summit, the temperature record shows a decrease in the summer average temperature at the rate of about 2.2 C/decade, suggesting that the Greenland ice sheet at high elevations does not follow the global warming trend either."

A significant and rapid temperature increase was observed at all Greenland stations between 1920 and 1930. The average annual temperature rose between 2.6 and 7.2°F in less than ten years. Since the change in anthropogenic production of greenhouses gases at that time was considerably lower than today, this rapid temperature increase suggests a large natural variability of the regional climate.

In summary, high-latitude northern hemisphere data show a slight increase in temperatures in the last several decades, but with regional differences: Alaskan temperatures since 1976 have remained steady (in some areas increased and in others decreased); Greenland temperatures have generally cooled; and data suggest that the 1930s-40s was a warmer period than currently.

Antarctic

Figure 9 shows the ice extent around Antarctica through 2005 (NSIDC, 2006). While there is considerable year-to-year variation, the overall trend (diagonal line) is positive: Antarctic ice is growing.

Doran *et al.*, (2002) conducted a study of temperatures and ecosystem response in Antarctica's dry valleys. They acknowledge that "climate models generally predict amplified warming in polar regions," which would suggest that Antarctic temperatures should have warmed in response to increases in greenhouse gases.

However, "although previous reports suggest slight recent continental warming," they declare that "our spatial analysis of Antarctic meteorological data" demonstrated "a net cooling over the entire

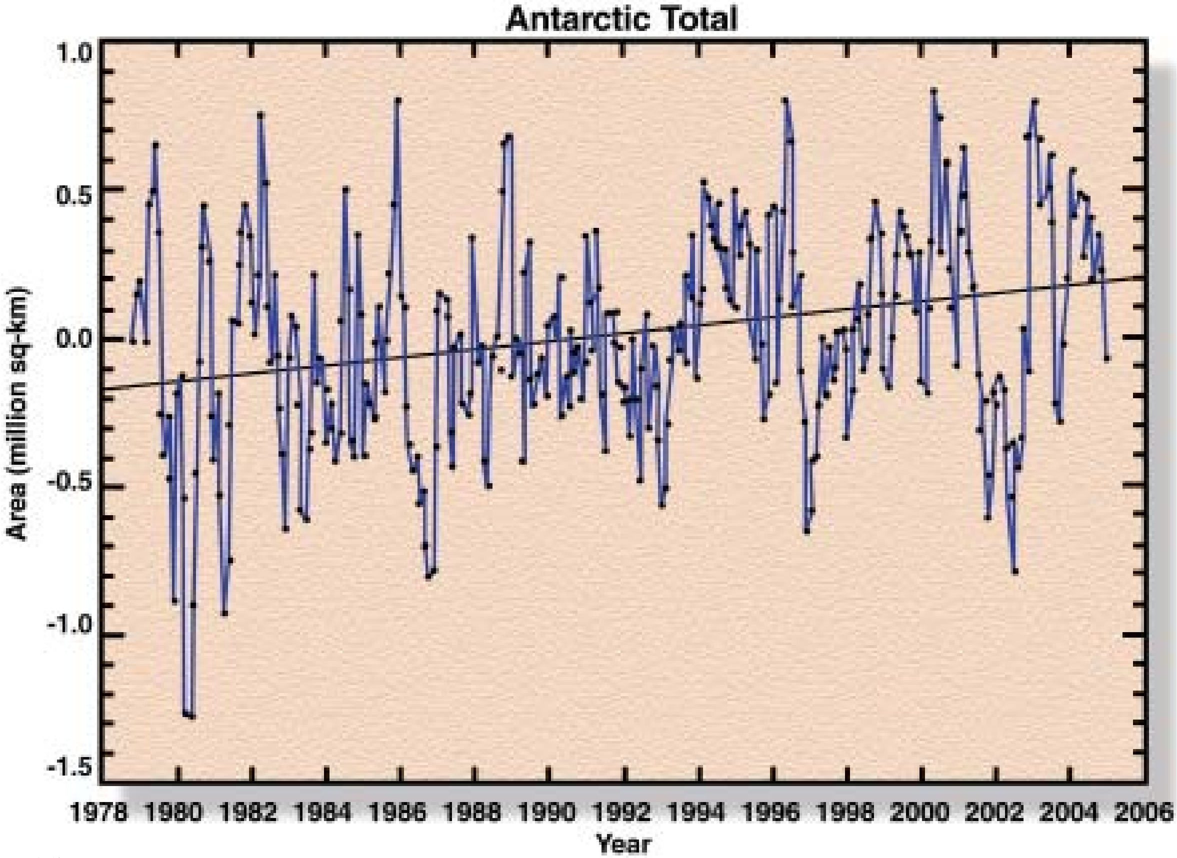


Figure 9

Antarctic continent between 1966 and 2000, particularly during summer and autumn," when ice melt would be most likely to occur. A study of temperatures and ecosystem response in the McMurdo Dry Valleys indicated a cooling of 1.26°F per decade between 1986 and 2000.

Antarctic ecosystems show clear evidence of cooling, suggesting that the temperature measurements reported by Doran *et al.*, are occurring widely. Among those effects are "decreased primary productivity of lakes (6-9% per year) and declining numbers of soil invertebrates (more than 10% per year). The authors conclude by saying, "continental Antarctic cooling, especially the seasonality of cooling, poses challenges to models of climate and ecosystem change."

Climate of Oregon and the Pacific Northwest

Oregon climate history goes back to the 19th century, but early records are sparse and discontinuous. Over the last 100 years or so, we have long-term data from several dozen weather stations. The highest-quality stations have become part of NOAA's Historical Climate Network (HCN).

Temperature

In Oregon there are many long-term temperature stations. Forty-one of them are among the HCN data set, a high-quality data set of monthly averaged maximum, minimum, and mean temperature, and total monthly precipitation, developed to assist in the detection of regional climate change. For most of the Oregon HCN stations, the warmest decade of the last 100 years was the 1930s, and 1934 was generally the warmest year of that decade. Although most HCN stations are in rural areas, some of them are in areas which have undergone significant land use change. For example, *Figure 10* shows two charts of mean annual temperatures from HCN stations. Corvallis is and has always been a rural station, and shows the common "warmer in the thirties than currently" trend. The other site shown, Forest Grove, is in a growing suburb of Portland, Oregon and shows a very different trend, with the highest temperatures in recent years.

The difference between the Corvallis and Forest Grove trends is almost certainly due to land use differences. Hale *et al.*, (2006) studied long-term climate stations which had seen land use land cover (LULC) changes nearby. They concluded that temperature trends were "mostly insignificant" prior to LULC change, but that this “contrasted sharply with trends in temperature after periods of dominant LULC change, when 95% or more of the stations that exhibited significant trends in minimum, maximum, or mean temperature exhibited a warming trend.”

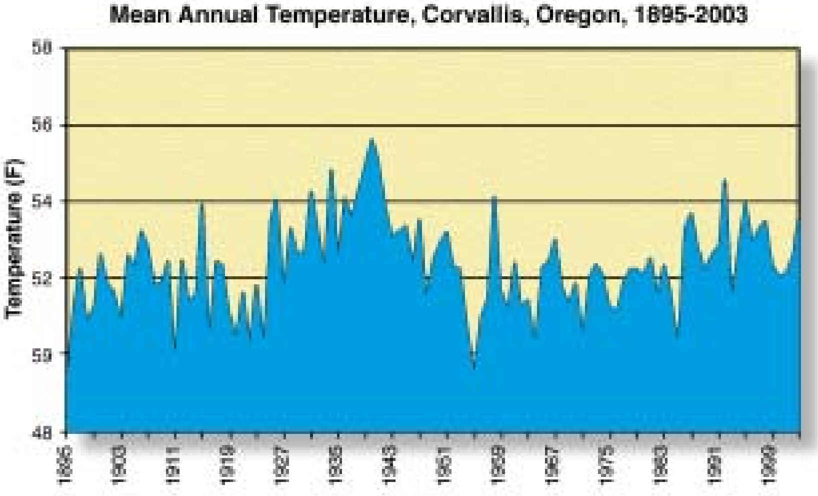
It is very difficult to correct for the “data contamination” caused by LULC change. The only reliable way to assess long-term climate trends due to large-scale climate change is to use rural stations. And in Oregon, at nearly every rural station, the trends are similar: the warmest decade was the 1930s, the 1950s through early 1970s were cooler, and since the mid-1970s there has been a warming trend, but current temperatures remain below those observed 70 years ago.

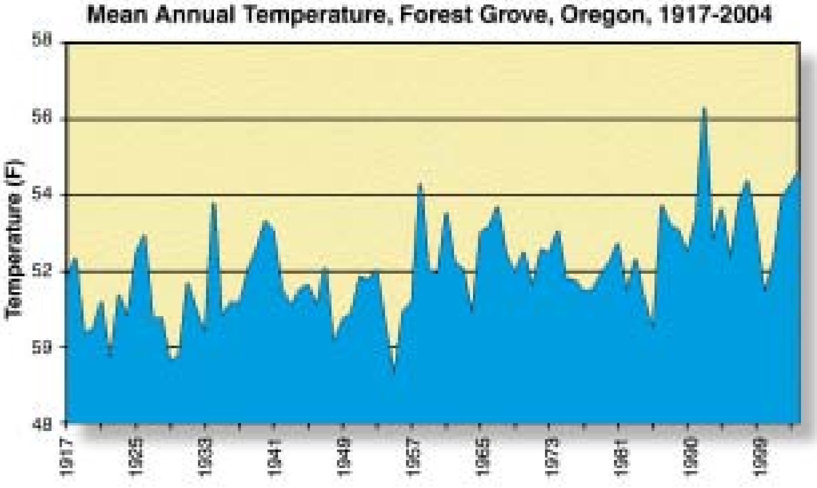
Snowfall

According to the Governor’s Task Force on Global Warming (2004),

> “Between 1950 and 2000, the April 1 snowpack declined. In the Cascades, the cumulative downward trend in snow-water equivalent is approximately 50% for the period 1950–1995. Timing of the peak snowpack has moved earlier in the year, increasing March streamflows and reducing June streamflows. Snowpack at low-to-mid elevations is the most sensitive to warming temperatures.”

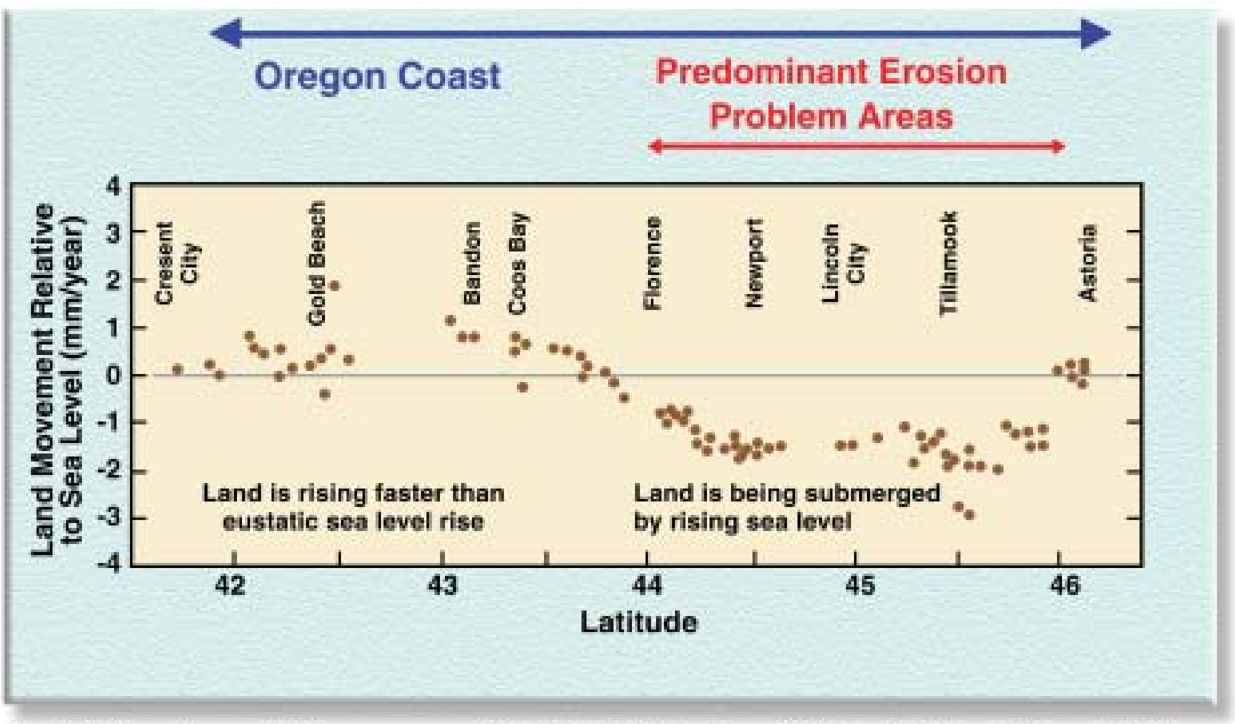
Figure 10





An examination of snowpack data for Oregon (and for limited areas in Washington) suggests that the declines described are at least partly a function of the period of record studied. What is true for a 30- or 50-year period may be very different if a longer period of data is examined. The early 1950s were an exceptionally snowy period in Oregon and the Pacific Northwest. The 1930s and 1940s had much less snow. Including those earlier decades in trend analyses produces much different results; for example, the 1935-2000 trend is rather flat in much of Oregon, in contrast to the 1950-2000 trend which shows big declines.

Figure 11



Geodetic leveling and tide gage records (–1930-95) *Data from Weldon (1991) and Komar (1997)*

Sea Level

Sea level rise is often mentioned as an adverse consequence of global warming, due to a combination of thermal expansion of seawater and melting of glaciers and icecaps. Some say that sea level rise to due global warming has already begun. According to the Governor's Task Force on Global Warming (2004),

> "Land on the central and northern Oregon coast (from Florence to Astoria) is being submerged by rising sea level at an average rate of 0.06 – 0.08 inches (1.5–2 mm) annually, as inferred from data for the period 1930–1995."

There are three long-term sea level measurement sites along the Northwest coast: Neah Bay, Washington; Astoria, Oregon; and Crescent City, California. None of them has shown sea level rises over that period; however, according to the Institute of Natural Resources (INR, 2006) some areas of Oregon are seeing relative rises in sea level.

Figure 11 shows the effects of uneven "geodetic leveling" along the Oregon coast. On the north coast, the land is moving downward relative to sea level, while on the south coast it is rising.

According to White and Church (2005), global climate models "show an increase in the rate of global average sea level rise during the 20th century." However, they note that for Oregon, the apparent rise in sea level on the northern Oregon coast is due to large-scale sea level rise, while the lowering of sea level on the south coast results from tectonic uplift. In general, they state that there is "no significant increase in the rate of sea level rise during this 51-year period."

Decadal-scale variability

In the Northwest and around the Pacific Rim, there are two natural long-term effects that influence climate, called the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). These are warming or cooling trends involving sea surface temperatures, wind patterns, and moisture that occur annually

(ENSO) , or by decade (PDO), that vary from the average climate temperatures. Precipitation is also affected. Records show that the years the Pacific Decadal Oscillation has been positive occur in conjunction with warm and dry periods in Oregon, while negative PDO occurs with (and probably helps cause) the cooler and wetter decades.

Gedalof and Smith (2001) compiled a transect of six tree ring-width chronologies from stands of mountain hemlock growing near the treeline that extends from southern Oregon to the Kenai Peninsula, Alaska, from 1599-1983. Their comment:

> "Much of the pre-instrumental record in the Pacific Northwest region of North America is characterized by alternating regimes of relatively warmer and cooler SST [sea surface temperature] in the North Pacific, punctuated by abrupt shifts in the mean background state," which were found to be "relatively common occurrences." From their study it would appear that PDO-type effects are a fixture of Northwest climate."

In fact, PDO trends explain most of the warming and cooling in Oregon in the last century. The 1920-1945 period, a very warm one, was characterized by positive PDO conditions; the 1945-1975 years, with generally negative PDO, were cool; and the 1975-1998 period, another warm one, saw positive PDO values.

Summary

While the world is currently warming, warmer periods have occurred in the past. Looking at climate at time periods longer than a few decades gives a different perspective. The current warming may be largely the result of natural cyclical changes. The United States and Oregon have experienced warming in the past 100 years, but the 1930s were as warm as current years. Since the thermometer was invented only 300 years ago, "proxy" methods are used to estimate earlier conditions, and they may not be accurate. Modeling the earth's climate is not an exact science and General Circulation Models can vary and be arbitrary, but changes in greenhouse gases are based on these models. There is clearly human influence on climate, but in my opinion, natural variations have dominated the climate system and continue to do so, and doubtless, there remain strong influences on climate that we as yet do not understand.

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CHAPTER FIVE

HIGHLIGHTS:

Forest Management Strategies for Carbon Storage

Introduction

- Forests play a major role in the global carbon cycle. Stored carbon in live biomass, dead plant material and soils represents the balance between absorbing CO_2 from the atmosphere and releasing through respiration, decomposition, and burning.
- A solid body of knowledge demonstrates how patterns of forest harvest, regeneration and growth control the carbon balance on forest lands.

Assessment of the Role of Forests

- Major recent scientific advances help with understanding the role of forests.
- A consensus is evolving about global carbon patterns from deforestation and regrowth.
- Technological advances employ satellite observations and more sophisticated research.
- Overlooked carbon fluxes and other impacts on climate are being analyzed.

Forest Management and Carbon Storage: A conceptual overview

- Disturbances such as timber harvest and fire have a profound effect.
- Options to increase on-site carbon stores include longer rotations.
- Net effects depend on initial conditions, for example, agricultural land or old growth.
- In the Pacific Northwest, carbon patterns are complex and shift rapidly.

Carbon Storage and Other Management Objectives: Synergies, Trade-offs and Additional Considerations

- Objectives such as recreation, improved fisheries and biodiversity are compatible with increasing carbon stores on-site.
- Gains from accelerated tree growth may be offset by declines in density and decay.
- Fire and disease prevention can result in maintaining carbon stores.

Protecting Carbon Gains against the Impacts of Future Climate Change

- Species can be selected for potential growth and resilience in warmer climates.
- Stand and landscape architecture can be designed to increase stability.
- Plans for coping with large-scale disturbance events can ensure optimal results.

Forest Management and Carbon Storage: Pacific Northwest Forests

- Potential for additional carbon storage in Pacific Northwest forests is among the highest in the world; altering management practices offers considerable potential.
- Protecting remaining old growth, creating more protected areas and using longer rotations may be more effective than in other forest regions.
- Forest management can contribute significantly to addressing the global problem of ongoing rise of carbon dioxide in the atmosphere.

CHAPTER FIVE
Forest Management Strategies for Carbon Storage

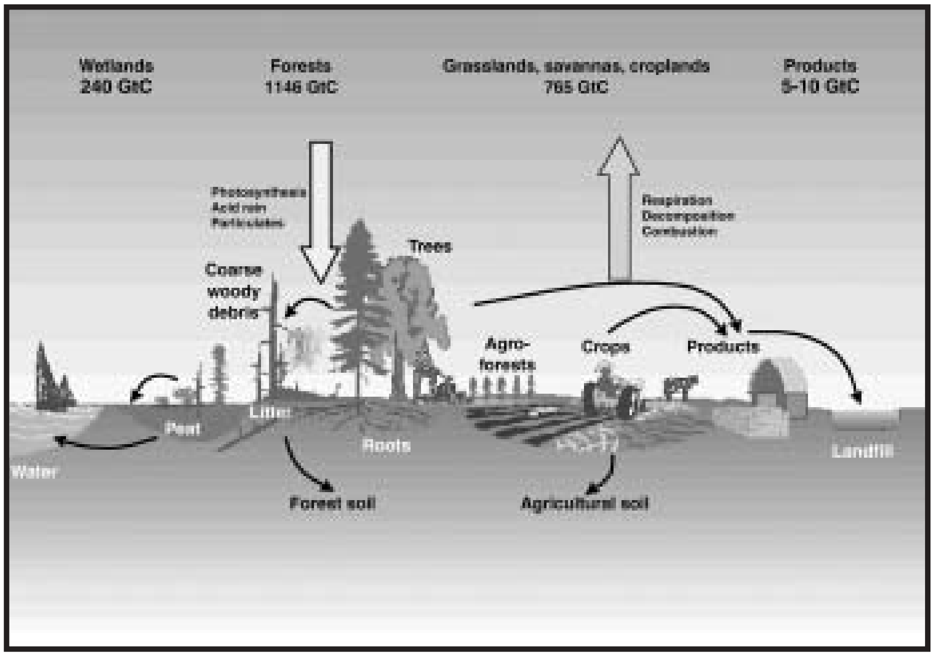
Olga N. Krankina and Mark E. Harmon

Introduction

Forests play a major role in the global carbon cycle by storing carbon in live plant biomass (approximately 50% of dry plant biomass is carbon), in dead plant material, and in soils. Forests contain three-fourths of all plant biomass on earth, and nearly half of all soil carbon. The amount stored represents the balance between (1) absorbing CO_2 from the atmosphere in the process of photosynthesis and (2) releasing carbon into the atmosphere through live plant respiration, decomposition of dead organic matter, and burning of biomass (*Figure 1*). Forests that are managed for timber production also generate a flow of carbon into the forest products pool, which includes manufactured products at all stages of use and disposal, and manufacturing waste. In the products pool carbon is stored and gradually released through decomposition and combustion; furthermore, the use of forest products may contribute to the reduction of carbon emissions in other sectors if forest products substitute more energy-intensive materials such as concrete and metals (*see Chapter 7 for details*).

While large-scale assessments and future projections of the role of forests in carbon exchange with the atmosphere (Chapter 2) are contradictory and uncertain, there is a solid basic understanding of how this role can be modified by forest management. This understanding is supported by the body of knowledge of the effects of management practices on forest ecosystems, including the patterns of forest harvest, regeneration, and growth. These processes are among the principal driving forces controlling the carbon balance on forest lands and causing predictable changes over time in response to management practices and natural disturbance events (*Figure 2*). The goal of this chapter is to show how this rich local knowledge and experience can be applied to evaluate forest management practices in terms of carbon storage in the forest (hereafter referred to as on-site storage) and how the objective of increasing carbon storage on-site can be integrated with other diverse objectives of forest management.

Figure 1



Carbon stocks and flows in terrestrial ecosystems. Carbon is withdrawn from the atmosphere through photosynthesis (vertical down arrow), and returned by oxidation processes that include plant respiration, decomposition, and combustion (vertical up arrow). Carbon is also transferred within ecosystems and to other locations (horizontal arrows). Both natural processes and human activities affect carbon flows (Kauppi *et al.,* 2001). http://www.grida.no/climate/ipcc_tar/wg3/fig4-2.htm).

Assessments of the Role of Forests

The contribution of forests to greenhouse gas emissions and removals from the atmosphere remains the subject of active research, which has produced a very extensive body of literature. Detailed summaries of peer-reviewed literature are compiled regularly by the Intergovernmental Panel on Climate Change[1] with the new Fourth Assessment Report expected in 2007. Major recent scientific advances in our understanding of the role of forest and forest management in global climate change are related to:

(1) **An evolving consensus on broad global patterns of carbon sources and sinks on land.** Deforestation in the tropics and forest regrowth in the temperate and parts of the boreal zone are major factors responsible for carbon emissions and removals, respectively. While the rates of forest expansion and regrowth in the temperate and boreal zones appear relatively well constrained by available data and are consistent across published results, the rates of tropical deforestation remain uncertain and hotly debated (Fearnside and Laurance 2004, Mayaux *et al.*, 2005).

(2) **Technological advances that have improved observational data.** Over the last three decades, earth observation satellites have increased in number and sophistication and tremendous progress has been made in methods for extraction of thematic information, such as global forest cover, leaf area index, surface albedo (surface reflectance), etc. (Janetos and Justice 2000; Belward *et al.*, 2003). Studies based on remote sensing of forest cover report lower rates of tropical deforestation than the UN-ECE/FAO (2000) and imply lower emissions of carbon than previously reported (Achard *et al.*, 2002, DeFries 2002).

Remote sensing methods are expected to play an increasing role in future assessments, especially as a tool for mapping land cover and its change over time, however, converting these maps into estimates of carbon sources and sinks remains a challenge and will continue to depend on in-situ measurements and modeling. The experimental use of LIDAR (LIght Detection And Ranging instrument) shows promise for improved mapping of several important forest attributes including height and biomass.

The exchange of carbon dioxide between a forest stand and the atmosphere can be calculated from continuous measurements of CO_2 concentration at different heights within forest canopy and above it using flux towers. The measurements of CO_2 exchange using flux towers provide a wealth of information on environmental controls on carbon exchange of terrestrial vegetation (including forests) over relatively small spatial scales (Law *et al.*, 2002). Converting these measurements into large area estimates can be problematic because flux towers generally miss the major carbon emission events (e.g., following fires, clearcut harvest, blowdown, and insect outbreaks) that tend to be short-lived and stochastic, or random, in forest ecosystems (Körner 2003). Because of the high cost of flux towers, their number cannot increase significantly and several studies that used flux tower measurements in regional analyses have had to rely heavily on other types of measurements such as forest and land inventories (Law *et al.*, 2004, Janssens *et al.*, 2003).

(3) **Consideration and in some cases quantification of previously overlooked fluxes of carbon**, such as carbon export through river systems, volcanic activity and other geological processes, outgassing, transfers of material in and out of the forest products pool, and uptake in freshwater ecosystems.

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[1] *(IPCC; http://www.ipcc.ch/pub/online.htm)*

Together these relatively small flows were shown to be quite significant for the overall carbon budget of the U.S. (Pacala *et al.*, 2001).

(4) **Improved understanding of limitations and uncertainties of current estimates** and the need for an integrated approach to evaluating the impact of terrestrial ecosystems on climate. To formulate the policy for climate change mitigation in the forest sector it is important to consider the impact of forest management on carbon stores in the context of other effects on climate, including the role of the albedo, the fluxes of sensible and latent heat, evaporation, and other factors, however, methods for such an integrated assessment are yet to be developed (Marland *et al.*, 2003).

The opportunities to store additional carbon in terrestrial ecosystems are strongly influenced by historical land-use changes and the associated losses of carbon. Because forests tend to contain more carbon per unit area than agricultural land, historic process of forest clearing for agriculture over thousands of years contributed to carbon accumulation in the atmosphere. Clearing of the European Mediterranean region began approximately 5000 years ago; in Central Europe and in China deforestation occurred in early Medieval times; and in North America clearing occurred mainly in the 19th century (Foster *et al.*, 1998, Mather 1990). Globally, between 1850 and 1998 an estimated 136± 55 Pg (a petagram is 1.1 billion U.S. tons) of carbon were released into the atmosphere in the process of changing land use, 87% from deforestation, the rest from cultivation of grasslands (IPCC 2001). This represents about one fourth of all carbon released into the atmosphere by human activities; the burning of fossil fuels represents three-fourths. Since the mid-20th century the net decline of forest area in the temperate zone has stopped, and currently in many temperate regions the forest area is increasing.

The 2005 Forest Resource Assessment (FAO-FRA 2005) estimated that the world's forests store 283 Pg of carbon in live biomass (including dead plant material and soils would increase this number). Carbon in forest biomass decreased in Africa, Asia, and South America in the period 1990–2005, but increased in virtually all other regions. For the world as a whole, carbon stocks in forest biomass decreased by 1.1 Pg of carbon annually, owing to continued deforestation and forest degradation, which are partly offset by forest expansion and an increase in growing stock per hectare in some regions (Key Findings of FAO–FRA 2005). The net loss of carbon by forests estimated by land-based measurements is at odds with the results of atmospheric inversion models which estimate net carbon sink on land (e.g., 1.34 PgC/yr, Gurney *et al.*, 2002).

Future changes in the role of forests are difficult to project, especially at the global scale. The IPCC reports of 1995 and 2001 estimated the global potential for additional cumulative carbon storage on land at 60-87 PgC over 50 years, most of it in forests. The recent EPA (2005) report assessed the current growth of carbon stores on land in the U.S. at 0.225 PgC/yr (offsetting 12% of U.S. fossil fuel emissions) with forests responsible for 90% of the estimated carbon sink. Incentives for additional carbon sequestration on land at $55/ton of carbon are projected to generate additional carbon sink in the U.S. of 0.18 PgC/yr on average by 2025 (EPA 2005).

Forest Management and Carbon Storage: A Conceptual Overview

In terrestrial ecosystems, including forests, the carbon cycle exhibits natural cyclic behavior on a range of time scales. Most ecosystems, for example, have a diurnal and seasonal cycle (e.g., a source of carbon to the atmosphere in the winter and a sink in the summer). The seasonal cycle shows up as fluctuations at the global scale, as illustrated by the annual oscillations in

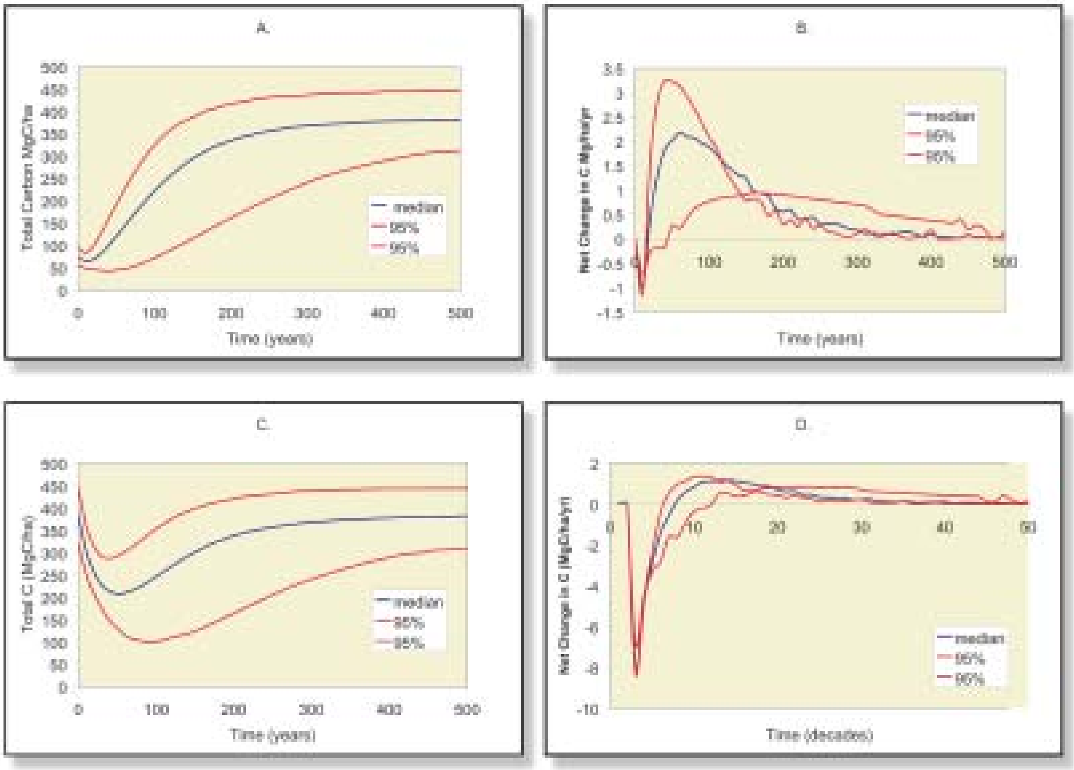


Figure 2

Changes in on-site forest carbon stores following disturbance. (Live and dead wood only; median value and 95% confidence interval). Following harvest, the negative change in carbon stores on-site is small because much of the wood is moved off-site. Figures based on field data and regression equations reported by Janisch and Harmon (2002). C Mg/ha are megatons of carbon per hectare.

A. Carbon stores following timber harvest
B. The net change in carbon stores following harvest
C. Carbon stores following forest fire
D. The net change in carbon stores following forest fire Janisch, J. E. and M. E. Harmon., Tree Physiology, 2002.

the global atmospheric CO_2 concentration. Large-scale fluctuations occur at other temporal scales as well, ranging from decades to centuries and longer. Of relevance for forest management decisions are the changes that occur on an annual to centennial time scale, including the harvest cycle of managed forests (*Figure 2*). In addition, forest management decisions influence the quantity and quality of material that is transferred into the forest products pool (*Figure 3*). The strategies for greater overall carbon sequestration (on-site plus off-site) may differ from those that maximize carbon stores on-site only.

The intent of forest management for carbon storage is to reduce atmospheric CO2 relative to that which would occur otherwise. A consequence of the conservation of mass is that the net

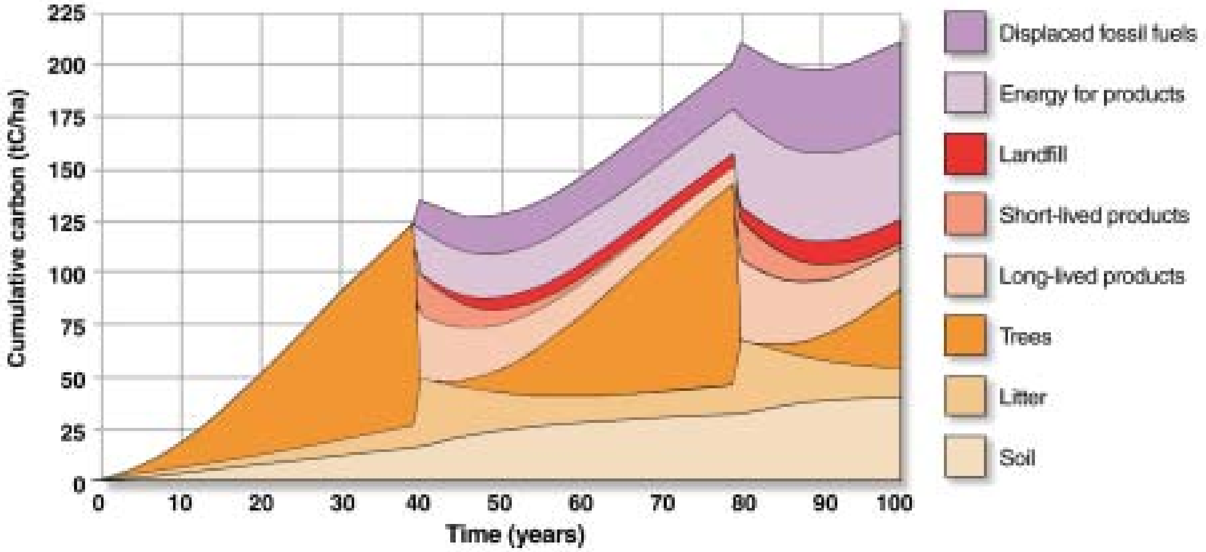
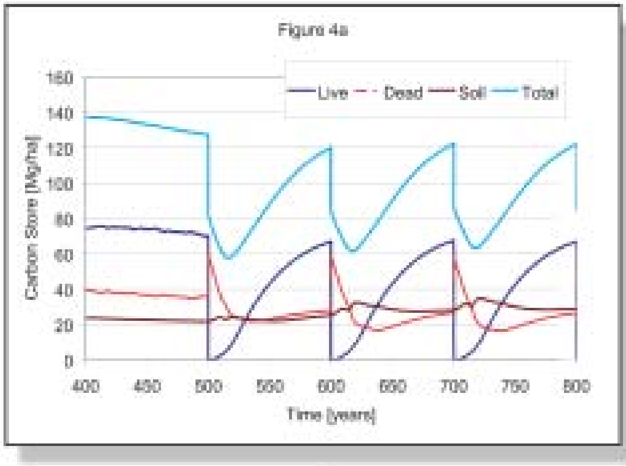
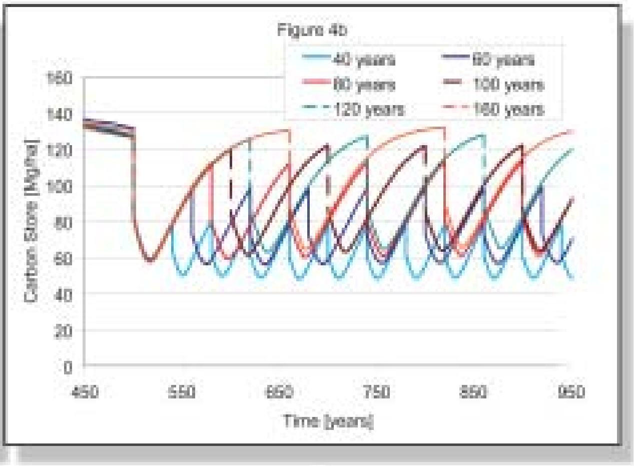


Figure 3

Carbon dynamics for a management scenario involving harvest and afforestation (new planting) on 40-year rotation. Included are carbon pools on land, in wood products, and in avoided fossil fuel emissions assuming that wood products substitute more energy-intensive materials (energy for products) and wood waste substitutes fossil fuels in the production of energy (adapted from Marland and Schlamadinger 1999). Note that the initial carbon store in soil is not shown and the increase in this pool reflects the anticipated increase over the initial soil stores. The validity of assumed substitutions depends on product supply-and-demand patterns in energy and materials sectors. Printed with permission from Elsevier.





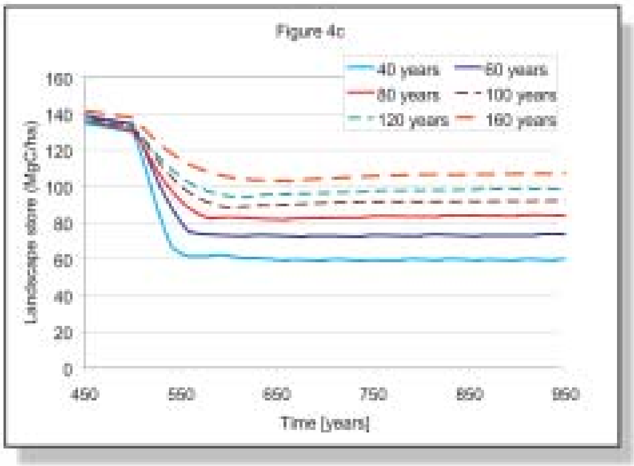


Figure 4

Dynamics of carbon stores in a forest ecosystem as predicted by a simulation model (STANDCARB).

A. Carbon stores in various pools following conversion of an old-growth forest to a harvest system with a 100-year rotation. Upon harvest, a large fraction of live biomass is converted to dead material, which eventually forms soil. The store of carbon in live biomass increases once the stand regenerates.
B. Total carbon stores (live, dead, and soil) with conversion of old-growth forest to various harvest intervals (40-160 years).
C. Landscape average carbon stores with conversion of old-growth forest to various harvest intervals (40-160 years).

balance of all of the carbon flows (measured in units such as tons of carbon/year (tC/yr) or tons of carbon/hectare/year (tC/ha/yr) into and out of a forest stand, landscape, or region during a period of time must equal the change in the stock during that period. Conversely, a change in stock of carbon during a given period must exactly equal the total of carbon flows into and out of the system during that period. In the forest management context it is often easier to estimate the net change in carbon stock than individual flows of carbon (e.g., photosynthesis and respiration). A gain in on-site carbon stores indicates carbon is being removed from the atmosphere, whereas a loss in on-site stores indicates carbon is being added to the atmosphere and in case of harvest – transferred off-site. To assess the overall carbon balance of the forest sector, the changes in off-site stores and fossil fuel offsets need to be considered as well (*Chapter 7*).

The Role of Forest Disturbance

Disturbance events such as fire, windthrow, insect outbreak, or timber harvest have a profound impact on the carbon balance of forest ecosystems. These impacts may be considered at the level of individual stands, landscapes comprised of multiple stands, or regions comprised of multiple landscapes. At the stand level, disturbances cause several things to occur. First, they redistribute the existing carbon stock by transferring carbon from living material, above- and below-ground, to the dead organic matter pools. As the carbon uptake by living trees is interrupted and the emissions from decomposition increase, a disturbed forest stand shifts from sink to source of carbon relative to the atmosphere. It remains in the source phase until carbon uptake by the new generation of trees exceeds emissions from decomposing dead organic material (*Figure 2*).

Second, disturbance events often transfer some of the carbon out of the ecosystem — in the case of harvest, into the forest product pool, in the case of fire, into the atmosphere as combustion products. Third, the disturbance restarts the successional cycle for new stand development, lasting from many decades to centuries, and creating a long-term "echo" of disturbance events. Thus, disturbances, both human-induced and natural, are major driving forces that determine the transition of forest stands, landscapes, and regions from a carbon sink to a source and back. In regions with active forest disturbance regimes, such as the Pacific Northwest, patterns of carbon sources and sinks are complex and shift relatively rapidly over time reflecting the evolving history of disturbance (Cohen *et al.*, 1996).

A significant confusion in literature about the impact of forest management practices on carbon stores is related to the fact that for an individual stand the impact depends on the selected time frame. After disturbance, carbon stores in forests inevitably decline and then increase, so it is impossible to reach the peak rate of uptake without first experiencing the loss of carbon on-site. A landscape-scale analysis can be more meaningful as it compares the averages of carbon stores over a landscape where a selected management option is repeated indefinitely (*Figure 4*, Harmon 2002). The average carbon store in a landscape where the management regime is constant also equals that of a typical stand over time when the disturbance interval is regular (Harmon 2002).

At the landscape level, one needs to consider the characteristics of the disturbance regime (i.e., the frequency, size, and severity of many disturbances). Increasing the average interval between disturbances increases the landscape store of carbon (Smithwick *et al.*, in press). This is because the longer interval allows for a greater accumulation of carbon in forest stands. The landscape store of carbon is also influenced by disturbance intensity or the amount of carbon removed by the disturbance: the more severe the disturbances, the lower the carbon store in the landscape. If carbon store declines with age in very old forests, then it is also possible for landscapes to store more carbon with disturbance than without. However, the optimum age for maximum storage (200-500 years) is much older than the typical harvest rotation (30-100 years) in the Pacific Northwest. Finally, random intervals of disturbance lead to greater stores than regular intervals of disturbance. This is due to several factors, one being that regardless of the regularity of the disturbance interval the minimum carbon stores is very similar. Another is the fact that random disturbance intervals have occasional periods when stands accumulate carbon for a longer period than the regular intervals (Smithwick *et al.*, in press).

Options to Increase Carbon Storage on Forest Land

The options available to mitigate carbon accumulation in the atmosphere by measures within the forest sector can be grouped into three general categories: (1) Increasing or maintaining the forest area by avoiding deforestation. (2) Increasing carbon density (ton of carbon per hectare), either at the forest-stand level, using silvicultural techniques that accelerate forest regeneration and growth, or slow decomposition (*Figure. 2*), or at the landscape level, using longer rotations, conservation, and protection against fire and insects (*Figure 4*). (3) Increasing product substitution using forest-derived materials to replace materials with high fossil fuel requirements, and increasing the use of biomass-derived energy to substitute fossil fuels (*Figure 3*; see also Chapter 7).

Once these options are implemented, their impact on carbon stores lasts for many decades and changes over time. For example, conservation measures such as protecting forest from logging or clearing offer immediate benefits via prevented emissions, while effects of silvicultural practices like afforestation (new planting) often follow an S-shaped growth curve: accrual rates are highest after an initial lag phase and then decline towards zero as carbon stocks approach a maximum (*Figure 2*).

Substitution benefits (i.e., emissions prevented by using wood instead of metal, cement, or other energy-intensive materials) often occur after an initial period of net emission, but these benefits may continue almost indefinitely into the future (*Figure 3*). Clearly, there are important interactions among the options. For example, the use of longer harvest rotations not only increases average landscape-level carbon stores (*Figure 4*) but also may generate high-value forest products that remain in use longer, thus increasing the carbon pool in forest products. However, there are also important trade-offs between increasing carbon stores on-site by conservation measures versus off-site carbon stores in forest products and reduced emissions related to product substitution.

Forest management options for increasing carbon storage on-site are elaborated below; options for maintaining and increasing forest area are presented in Chapter 6 and the effects of product substitution are described in Chapter 7.

The Role of Initial Conditions

The net effect of different forest management practices on carbon storage depends on initial conditions (Harmon and Marks 2002). For example, on degraded agricultural land, establishing forest plantations with a short harvest rotation will increase carbon stores on-site and result in net uptake of carbon from the atmosphere. In addition, carbon accumulates in forest products that are produced from harvest. Furthermore, there may be potential emission reductions from fossil fuels when wood products substitute more energy-intensive materials, or when wood waste is used to generate energy (*Figure 3*).

When the initial condition of land is a productive old-growth forest, the conversion to forest plantations with a short harvest rotation can have the opposite effect lasting for many decades even with all the actual and potential emission reductions accounted for (compare figures 2 and 3). Over the course of 100 years, the cumulative effect of afforestation followed by timber harvest on a 40-year rotation in a productive Douglas-fir forest is estimated at slightly more than 200 tons of carbon per hectare (tC/ha) (Figure 3). In contrast, the carbon stores in an old-growth forest of this type would exceed 350 tC/ha on average (Figure 2). The difference of 150 tC/ha exceeds even the most generous assumption about the off-site effects from the initial old-growth forest harvest and thus in this example, 100 years of rotation forestry system do not appear long enough to offset the losses of carbon from harvesting the old-growth forest.

The Role of Woody Debris

The amount of debris left on-site after a forest disturbance is an important and often overlooked factor that influences the net effect of management practices (Janisch and Harmon 2002). Following timber harvest, carbon emissions from decomposing slash usually exceed carbon accumulation in young trees (in spite of their vigorous growth) for about a decade. In contrast, a stand disturbed by fire may release carbon into the atmosphere for over 50 years because higher stores of coarse woody debris increase the loss associated with decomposition (*Figure 2*). At first glance, harvested forest would appear to lose less carbon than forest burned by fire, however, much of the losses from harvested forest occurs off-site in the forest products manufacturing process (Harmon *et al.*, 1996). As much as 50% of the harvested material is released to the atmosphere within a few years, while coarse woody debris decomposing on-site tends to lose carbon at a much slower rate. For example, common exponential decomposition rates of softwood species range between 0.01 and 0.03 per year (Harmon *et al.*, 2001) suggesting that it takes between 25 and 70 years for this material to lose one half of its carbon to the atmosphere. For species with higher decomposition rates, such as poplars, the differences between carbon losses in manufacturing and on-site will be smaller.

Carbon Storage and Other Management Objectives: Synergies, Trade-offs, and Additional Considerations

Over the last two decades Pacific Northwest forest managers showed remarkable adaptability as they shifted from singular dominant focus on timber production to balancing a large set of management objectives including recreational use of forests, protecting habitat for endangered species, biodiversity, fire management, watershed management, forest health, etc. All these objectives are generally compatible with the goal of increasing carbon stores on-site in that they require maintenance of forest cover and prevention of large-scale catastrophic disturbance events that would release large quantities of carbon into the atmosphere. However, there are also significant trade-offs and additional factors to consider when carbon storage becomes a management objective.

The goal of increasing carbon storage on forest lands is fully synergistic with the goal of conservation of old-growth forests and endangered species that depend on these ecosystems. Other management objectives that restrict timber harvest (for example, buffers along streams to improve fisheries or along highways to enhance the visual appeal for tourists) also lead to greater carbon stores on-site.

Measures to accelerate the growth of trees may provide for faster uptake of carbon from the atmosphere. However, the effect on carbon storage may be smaller than the increase in growing stock volume if the wood density declines, or if the decay resistance of a faster-growing tree is lower, or if the product mix from fast-growing trees shifts towards shorter-lived wood products. Moreover, if the rotation interval is shortened as growth rate increases (a primary goal of increasing growth rates), then there will be little net carbon gain on-site. Some of the new genetic engineering research aims to increase decay-resistance of fast-growing poplars by increasing the proportion of lignin in wood (Rosenberg *et al.*, 1998); this may enhance carbon storage in decomposing woody material on-site as well as in wood products.

In addition to creating carbon stores and emission offsets in the forest products sector, increasing timber production may be compatible with the goal of carbon storage on-site as well, depending on specific conditions. For example, maintaining the current harvest rotation and forest productivity will eventually lead to steady-state carbon stores in a forest landscape (with no net change over time). Salvage of trees killed by fire would reduce carbon stores on land unless the salvage replaces a similar level of harvest of live trees elsewhere. Increasing productive forest area by reducing the lag time of regeneration or enhancing growth rates increases carbon storage in a landscape, but these gains need to be balanced against the losses from burning slash (often required for improved regeneration) or the possibility of increased decomposition caused by fertilization.

The recent effort to design landscapes for fire or disease prevention can also help in maintaining carbon stores. Consideration of carbon losses in catastrophic fires may influence the analysis of trade-offs between maintaining large unroaded areas vs. those accessible to ground-based fire-fighting equipment and evaluation of fuel reduction programs. Fuel reduction measures such as prescribed burns reduce carbon stores as well (at least temporarily), but they can reduce the burning intensity in future fires and thus maintain higher carbon stores in forest landscapes in the long run.

Protecting Carbon Gains against the Impacts of Future Climate Change

The risk of future losses of carbon from forest ecosystems due to impacts of climate change and other factors is often used as an argument against carbon sequestration on land in general and in forests in particular. However, most of the technological measures that reduce CO_2 emissions by improving efficiency in industry and energy production imply that the conserved fossil fuels will be used eventually and thus the emissions are strictly speaking only delayed, not permanently prevented. The possibility of future losses of carbon sequestered on land also implies delayed emissions creating a similar temporal pattern of the mitigation effect. Moreover, decreases of carbon stores in one stand may be offset by gains in another stand creating a certain permanent mitigation effect at the landscape or regional level.

Higher carbon stores on land might mean the risk of higher future carbon emissions as the changing climate is expected to cause a higher rate of forest disturbance. Depending on the rate and magnitude of change, the new climatic condition may exceed the ability of certain tree species to adapt and lead to large-scale dieback of the most vulnerable ones. Invasion of new pests and pathogens is an additional risk factor which might be exacerbated in an altered climate. While it is difficult to anticipate the specifics of future impacts, several general measures can increase the stability of forests in changing environment and reduce the risks of economic losses as well as losses of carbon.

Choice of species. In selecting species for planting at a given site it is important to consider their potential growth and resilience in a warmer climate, with possibly more frequent droughts and weather extremes. Drought resistance is probably the most important trait, as few trees die of excess temperature alone. Long-term resistance to fire, pests, and pathogens is also important as all may become more active. In addition to local pest and pathogen species, those likely to migrate from the south need to be considered as well.

Stand and landscape architecture can be designed to increase resistance and resilience of forests. For example, avoiding extensive coverage by a single species and maintaining mixed species within stands and landscapes or creating fire breaks with reduced fuel loads tend to increase the stability of forests. Thinning treatments can improve stand stability as well.

Plans for coping with large-scale disturbance events are needed to ensure optimal timing for salvage, regeneration, and other important decisions with long-lasting consequences (Lindenmayer *et al.*, 2004).

Forest Management and Carbon Storage: Pacific Northwest Forests

The potential for carbon storage in the forests of the Pacific Northwest is among the highest in the world because the major dominant tree species (Douglas-fir) is very long-lived and maintains high growth rates for a very long time compared to other regions (Smithwick *et al.*, 2002). Hence, protecting the remaining old-growth, creating additional protected areas, and using longer rotations may be more effective for increasing carbon storage on land than in other forest regions. Timber harvest in this region over the last 100 years has decreased carbon stores in forests (Harmon *et al.*, 1990). For example, between 1953 and 1993 carbon stores in live forest biomass declined by 206 million tons or by 13% (Melson 2004, in review). The extent of this decrease has been a function of ownership with declines higher on private industrial (24%) than federally owned lands (7%). Thus, areas with more frequent harvests are storing less carbon on-site than those with less frequent disturbances. Total carbon stores on forest land across all ownerships also appeared to decrease in western Oregon during the 1972-2002 period, although the rate of decline is predictably slowing as the transition from natural disturbance regime to a more intensively managed one comes to an end (Cohen et al. 1996, Wallin *et al.*, in review).

There is considerable potential to increase on-site carbon stores in the region by altering management. Because the time to field-test various management systems is prohibitively long, simulation models are used to assess how various forest management alternatives will perform. STANDCARB is a simulation model that accounts for the regeneration, growth, death, decomposition, and disturbance of forest stands (Harmon and Marks, 2003). The types of carbon accounted for in this model include live (broken into various parts such as leaves, branches, stems, and roots), dead (all the types of live parts that have died), and stable (soil) pools. Disturbances include windthrow, insects, fire, and timber harvest (including salvage of dead wood). Simulation experiments with the STANDCARB model, using parameters for Douglas-fir and western hemlock typical of the Oregon Cascades, indicated that forests protected from fire stored the greatest amount (93% of the maximum) of carbon at the landscape level and agricultural fields stored the least (15% of the maximum) (Harmon and Marks 2003). Conversion of old-growth forests to any other management or disturbance regime resulted in a net loss of carbon on-site, whereas conversion of agricultural systems to forest systems had the opposite effect.

Based on the model's results, the three factors most crucial in developing an optimum on-site carbon storage system are, in order of increasing importance; (1) amount of detritus removed by slash burning, (2) amount of live mass harvested, and (3) rotation length (*Figure 5*). Carbon stores increased as rotation length increased, but decreased as the fraction of trees harvested and detritus removed increased. The effects of continuous-cover forestry depend on many factors, including the intensity and frequency of thinnings, and the growth response of the remaining tree stand. As the use of partial harvest expands and the long-term effects are studied, the impact on carbon stores will become clearer. The simulations with STANDCARB indicated that partial harvest and minimal fire use may provide as many forest products as the traditional clearcut and broadcast burn system while maintaining higher carbon stores on-site.

In conclusion, forest management cannot fully solve the problem of carbon accumulation in the atmosphere (and no other individual sector can). However, measures in forestry and other types of land management can contribute significantly to the solution. Over the course of 50 years, reduced deforestation, reforestation, afforestation and other measures could provide a cumulative sequestration of 25 billion metric tons of carbon globally. This is similar to the effect of doubling the current global nuclear power generation capacity or doubling the fuel economy of cars (Pacala and Socolow 2004). Increased carbon storage on land, in combination with a host of emission reduction measures, can help reduce and even end the ongoing rise of carbon concentration in the atmosphere.

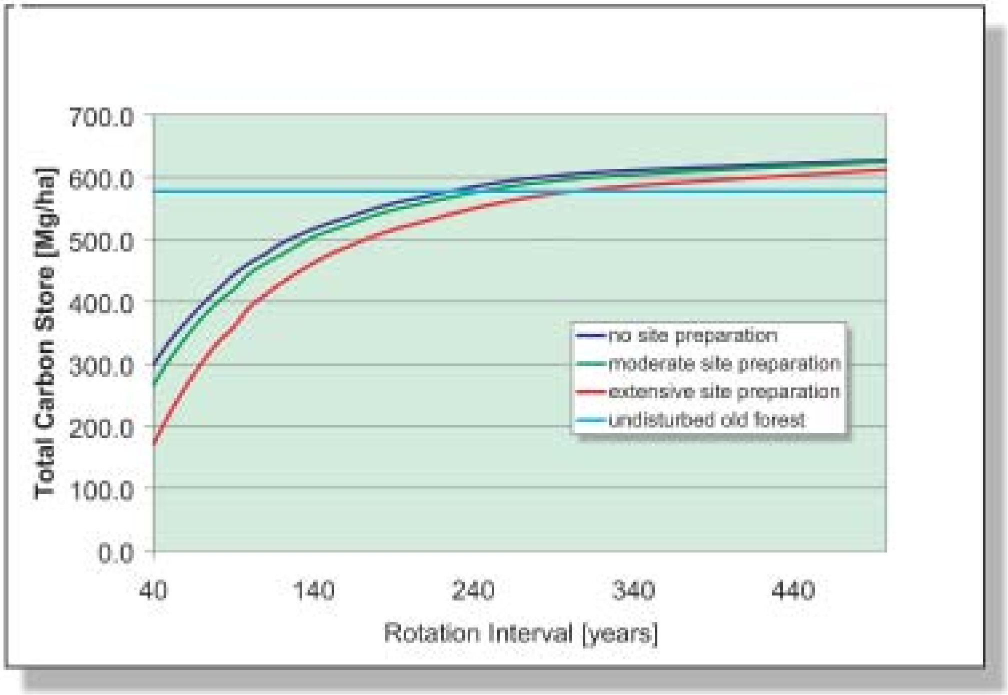


Figure 5

Effect of degree of site preparation and interval between harvests on landscape average total carbon stores as predicted by a simulation model (STANDCARB). In the case of extensive site preparation, it was assumed that most of the surface dead organic matter was removed, and for the moderate site preparation case approximately 25% that amount was removed. The undisturbed old forest represents the long-term average of a very old (500+ years) forest.

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CHAPTER SIX

HIGHLIGHTS:

KEEPING LAND IN FOREST

Forestland Development

- Forestlands are the largest source of land for development.
- One million acres were lost annually in the U.S. from 1992-1997.

Socioeconomic Factors

- Growing population and income increase demand for forestland development.
- Timber revenue alone may not offer enough owner incentive to keep land in forests.
- Affluent people may be more willing to protect remaining forestland.
- Projections for Oregon/Washington combined show 2.8 million additional acres of forestland could be lost by 2050.

Oregon's Land Use Law

- Panacea to some, bane to others, 1973 Land Conservation and Development Act doesn't permanently protect forests from development, but restricts rate, location and density.
- Estimates suggest that less than 1% of forestland was saved from 1974-1994, but urban growth boundaries included forestland likely to be developed.
- Projections suggest that approximately 4% of forestland could be developed as a result of Measure 37, but significant uncertainty exists about the measure.

Development Effects on Forests and Forestry

- With parcelization, owners of smaller tracts are less likely to manage for timber.
- Proximity to residential development may change forest management activities.
- The most productive forestlands tend to be steep and inaccessible, which may counter development pressures.

Policy Strategies for Maintaining Forestlands

- Land use regulations and zoning are low-cost but perhaps less effective in the long run.
- A variety of preferential tax programs help support forestland owners.
- Private land preservation and land trusts offer public and private protection.
- Ecosystem services compensation can offer financial incentives to maintain forestland.
- Cost share, Direct Payment and Carbon Markets can encourage owners to conduct particular forestry activities.

The Future

- Socioeconomic factors exert a strong pressure favoring development.
- Policies and implementation tend to evolve over time.
- The future depends on willingness to evaluate policies and outcomes to achieve desired balance of forestland protection and development.

CHAPTER SIX

KEEPING LAND IN FOREST

Jeffrey D. Kline

Forestland Development

Forestlands have been the largest source of land for development in the U.S. in recent years. The most significant trend affecting forests is their conversion to residential, commercial, industrial, and infrastructure uses. While forestry, agriculture, grazing, and developed uses all compete for a fixed amount of land, forests have been most affected. One million acres of forests have been lost to development annually from 1992 to 1997 (Natural Resources Conservation Service 2001). Another 26 million acres could be lost by 2030, with two million of those acres located in the Pacific Northwest (Alig and Plantinga 2004). This trend will affect our ability to sequester carbon in growing forests.

Forestland development can affect carbon sequestration in several ways. The most direct and visible effect is the loss of forest cover—trees and other vegetation—when buildings, roads, and other infrastructure are built. Forests act as carbon sinks, transforming CO_2 into trees and vegetation, roots, woody debris, litter, and forest soils (Murray *et al.,* 2000). Removing these through development releases sequestered carbon into the atmosphere and reduces future sequestration on affected lands.

The net effects of development on stored carbon depend on the intensity of development—how much vegetation is removed and how much it is replaced by lawn and landscaping that offset released carbon. These net effects can differ depending on whether they are considered locally or globally. Reducing forestland development in one location—Oregon, for example—can help sequester carbon locally, but if that causes greater development elsewhere, then the net global benefits could be less.

With remaining forestlands, effects can be less direct and less visible, depending on how the forests are managed. The standing stock of forest biomass is influenced through activities such as fertilization, pest management, fuel and fire management, harvest, and planting (Murray *et al.,* 2000). Parcelization—the breaking up of large forest parcels into smaller parcels for development—is believed to make forest management activities more costly. Development also can lead to changes in the objectives of remaining forestland owners. People who purchase small forestland parcels primarily as home sites often are less inclined to invest in forestry activities. Less intensive management could cause slower tree growth, resulting in lower forest biomass and less carbon sequestered over time. As with development, reduced local harvesting might sequester additional carbon, but if it results in greater harvesting elsewhere, then net global value could be less.

Many of the social and economic forces that cause forestland development are beyond the control of planners, managers, and policymakers. But policies can be used to influence the location and rate at which development occurs. Policies can be regulatory—telling landowners where, when, and how they are allowed to develop. They also can be incentive-based, providing financial or other compensation to landowners who manage their lands in socially desired ways. What types of policies are appropriate in particular situations depend on the socioeconomic factors influencing development and society's willingness to adopt particular measures. Because both of these can change over time, policymakers periodically may need to reevaluate their policy approaches.

Forestland development has been a persistent issue for planners and policymakers in Oregon where forests comprise 49% of the land area (Campbell *et al.,* 2004) and the population grew by 69% from 1970 to 2003 (Population Research Center 2005). Although southern states increasingly provide a larger share of U.S. timber harvests—55% in 1996 compared to 44% in 1986—the Pacific Northwest, including Oregon and Washington, remains a major timber-producing region, over the past decade averaging 50 million cubic meters per year (Haynes 2003). Pacific Northwest forests, however, increasingly will be shared among more people. Oregon's population, concentrated largely in the Willamette Valley, is expected to grow by 53% by 2040 (Office of Economic Analysis 2004). Oregon's approach to protecting forestland has been predominantly through its land use planning program, zoning, property tax code, and more recently the Forest Resource Trust. Whether these policies will be sufficient to address population and development trends in the future remains to be seen.

Support for forest carbon sequestration goals in Oregon depends in part on understanding the factors that influence forestland development, what trends and projections imply about future forestland loss, and what policies may be appropriate, effective, and socially acceptable. This chapter draws upon a large body of research conducted in Oregon and elsewhere to describe forestland development causes and trends, what they imply about future forestland development in Oregon, what the potential effects might be for carbon sequestration, and what might be done about it.

Socioeconomic Factors

Forestland development results mostly from increasing human populations and incomes, economic growth, and people's life-style choices. Growing populations, wealth and economic expansion combine to increase demands for land in residential, commercial, industrial, and infrastructure uses. Demands also increase with lifestyle choices when, for example, people seek bigger homes on larger lots, or build second homes in scenic forest settings. When demands for developed land uses increase, so do land prices and the financial incentives for forestland owners to sell.

Timber-producing landowners typically view forestland as a source for timber and non-timber forest products demanded in local and global markets. (Aronow *et al.,* 2004). Forestland market values are based on the land's capacity to earn revenue from forest commodities, as well as its speculative value for development. Forestland owners also may receive other non-commodity benefits from their land, such as personal recreation and aesthetic enjoyment, which also can be reflected in forestland market values.

Sometimes development may offer forestland owners greater potential revenue than they can earn from maintaining land in forest, offering a financial incentive to sell. It can be quite high. Development typically is at the top of an economic hierarchy of land uses (Alig and Plantinga 2004), such that forestry revenues alone often do not justify owners keeping land in forest when development is an option. When these market forces are in play, some forestland development is inevitable.

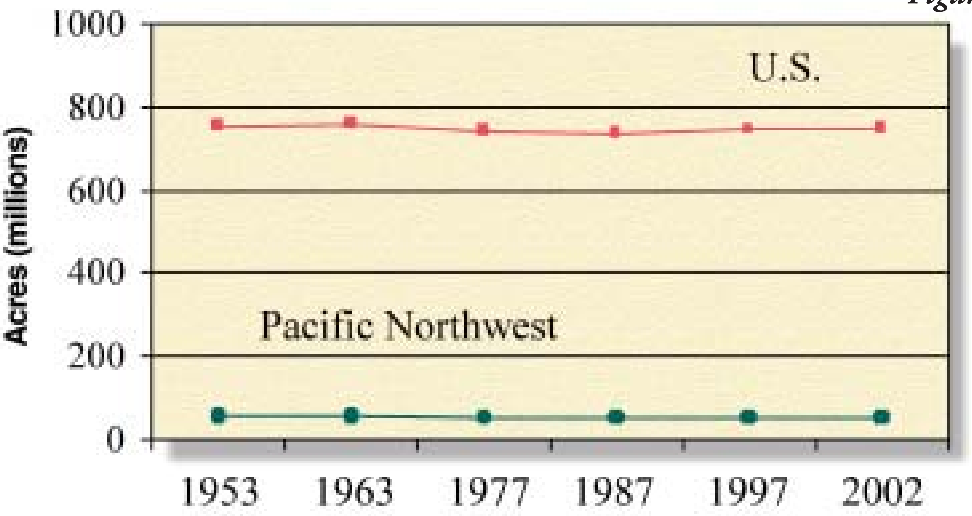
Other socioeconomic changes also have an influence. Energy prices, for example, can affect both demand for particular forest commodities, including fuel wood, as well as demand for developed land through their effect on commuting costs. Rising energy prices enable some forestland owners to earn additional income producing and selling firewood, which can favorably compete with development opportunities. If rising gasoline prices increase commuting costs, fewer people may be willing to live in rural locations far from their jobs. Regional and global markets for forest and other commodities affect the relative profitability of forestry, influencing how well forestry can compete with development.

Socioeconomic changes also influence people's desire to protect forestland and other open space. In many places of the U.S., urbanites are migrating to rural areas seeking an improved quality of life; they often have different attitudes about forests than long-term rural residents (Egan and Luloff 2000). Often these attitudes focus more on environmental amenities than on management for timber production, and can lead to increasing political support for protecting forestland and other open space. As places become more populated and affluent, and forestland and other open space lands increasingly are lost to development, people tend to become more willing and able to afford protecting remaining lands (Kline 2006). Studies in Oregon suggest that as the state has become more populated and its residents more urban, educated, wealthy, and politically liberal, and less affiliated with the timber industry, Oregonians have developed stronger environmental orientations toward forests (Schindler et al. 1993, Steel *et al.,* 1994, Kline and Armstrong 2001).

Regionally for Oregon and Washington combined, forestland declined by 1.5 million acres from 1977 to 2002, almost 3% (*Figure 1*). Although this trend is consistent with other regions in the U.S. that are losing forestland, nationally forestland area actually increased by 5.3 million acres (Smith *et al.,* 2004). Much of this increase resulted from pasture and agricultural land reverting back to forest, as well as tree planting under state and federal incentive programs (Smith *et al.,* 2001). Of forestlands that are lost, some are cleared for agriculture, but most are converted to developed uses (Natural Resources Conservation Service 2001). Historically, most forestland sold for development was owned by nonindustrial private forest owners. These owners control the most U.S. forestland—363 million acres (48%). In Oregon and Washington combined they own 11 million acres (21%). The gradual loss and fragmentation of forestland over time bring more and more people living in greater proximity to remaining forestlands. Currently, 12% of U.S. forestland is located in major metropolitan counties, and an additional 16% is in small or intermediate metropolitan counties (Smith *et al.,* 2001).

Development in Oregon, as elsewhere, is an inevitable outcome of socioeconomic trends. In addition to the 69% increase in Oregon's population since 1970, median household income rose by 26% after adjusting for inflation—about the same increase as for the U.S. (U.S. Bureau of the Census 2005). Higher incomes enable people to buy larger lots, bigger houses, and afford second homes for vacation, rental, and retirement. Also, people are more often seeking out locations rich in environmental amenities. Central Oregon, for example, is characteristic of the "new West" where natural resource industries increasingly find themselves sharing the landscape with growing numbers of tourists, outdoor

Figure 1



Forestland area in the Pacific Northwest and U.S., 1952 to 1997 (Smith *et al.*, 2004)

recreationists, and new residents attracted to the area's many environmental amenities (Judson *et al.,* 1999). Central Oregon is recognized nationally as a desirable travel destination (e.g., Laskin 2004, Preusch 2004). Many U.S. residents view Oregon's natural endowments—mountains, rivers, coast, and easy access to national forests—as strong enticements to relocate.

Oregon still retains a significant amount of forestland and much of it is public-owned and conceivably off limits to development. Of more than 30 million acres of forestland in the state, over 19 million (63%) are public-owned by federal, state, county, or municipal entities. The remaining 11 million acres (37%) are split between forest industry with about 6 million acres and non-industrial private owners with about 5 million acres (Campbell *et al.,* 2004). Non-federal-owned forestland has declined by about 2% in western Oregon since the early 1970s (Lettman 2002) and about 1% in eastern Oregon (Lettman 2004) mostly as a result of low-density residential development. More significant development has occurred on agricultural lands, particularly in western Oregon where they are located closer to existing cities and transportation corridors and agricultural land has declined by 7%. Most recent development in eastern Oregon has been on rangelands (Lettman 2004). Much of Oregon's forestlands is comparatively more buffered from the effects of population growth and development by their relative geographic isolation, steep slopes, and poor accessibility.

Land use projections for Oregon and Washington combined suggest that forestland area will continue to decline in the region, with a projected 2.8 million acres (over 5%) lost by 2050 (Alig *et al.,* 2004). Although greater losses are expected on nonindustrial private forestlands than on forest industry-owned lands, the increasing transfer of lands from forest industry owners to timber investment management organizations creates uncertainty. Some forestry professionals and policymakers feel that investment management organizations may manage lands on shorter time horizons than forest industry, and may give greater consideration to development.

More detailed development projections for western Oregon suggest relatively low to moderate growth in development, largely at the expense of agricultural lands (Kline 2005b). Major private-owned land uses in 2004 were estimated to include 6.9 million acres of relatively undeveloped forestland with building densities of 16 or fewer buildings per square mile. Also included in the estimate were 216,630 acres of additional forestland developed at relatively low densities of 17 to 64 buildings per square mile (*Table 1*). Projections suggest that by 2024, undeveloped and low-density developed private forestland together will decline only slightly, by about 19,000 acres. Greater development is forecast for agricultural lands, especially at low densities, with such development projected to increase by almost 6% (*Table 1*). While projections can provide some indication of what future land use changes may be in Oregon they remain uncertain based on the unpredictable future of land use planning in the state and other factors.

Oregon's Land Use Law

A panacea to some, a bane to others, Oregon's land use planning program permeates most Oregonians' views about development and their ability to control it. The program can be traced to concerns over rapid population growth in western Oregon during the 1950s and 1960s and the associated loss of forest and farmlands to development. Although existing legislation already authorized local governments to manage urban growth, residential development outside of incorporated cities was often unplanned and unregulated (Gustafson *et al.,* 1982). In response, Oregon's legislature enacted the Land Conservation and Development Act in 1973. Often referred to in Oregon as "the land use law," it required all cities and counties to prepare comprehensive land use plans consistent with several statewide goals, and established the

Table 1.

Estimated distribution of 2004 private forest and agricultural lands in western Oregon among building density classes, and projected distribution in 2024 with and without land use zoning in effect

Dominant land use	Total	Number of buildings per square mile 0 to 16 (undeveloped)	17 to 64 (low-density)	>64 (developed)
Estimated for 2004:			Acres	
Forest	7,197,000	6,909,839	216,630	70,531
Agriculture	1,924,000	1,172,486	578,931	172,583
Mixed	774,000	597,141	140,404	36,455
Total	9,895,000	8,679,466	935,965	279,569
Projected 2024 (with zoning):			Acres	
Forest	7,197,000	6,906,241	200,796	89,963
Agriculture	1,924,000	1,168,060	546,224	209,716
Mixed	774,000	594,742	128,252	51,006
Total	9,895,000	8,669,043	875,272	350,685

Source: Kline (2005b).

Land Conservation and Development Commission to oversee the program (Knaap and Nelson 1992, Abbott *et al.,* 1994). It has been cited as a pioneer in U.S. land use policy for its statewide scope (Gustafson *et al.,* 1982), has won national acclaim by the American Planning Association (Department of Land Conservation and Development 1997), and has served as a model for statewide planning in other states (Abbott *et al.,* 1994).

Among 19 program goals are the orderly and efficient transition of rural lands to urban uses, the protection of forests and agricultural lands, and the protection and conservation of natural resources, scenic and historic areas, and open spaces which "promote a healthy environment and natural landscape" (Department of Land Conservation and Development 2004). To advance these goals, cities and counties must focus new development inside urban growth boundaries, and restrict development outside of those boundaries by zoning land for exclusive farm or forest use, or as "exception areas" (Pease 1994). Exception areas are unincorporated rural areas where low density residential, commercial, and industrial uses prevail, and where development is allowed pending approval by local authorities (Einsweiler and Howe 1994). Within urban growth boundaries, cities are required to maintain a 20-year supply of developable land.

The land use law does not prevent forest and farmland development, but rather restricts the rate, location, and density at which it can occur. Some development within forest and farm use zones can be approved by local authorities but must be reported to the Land Conservation and Development Commission (Land Conservation and Development Commission 1996a, 1996b). Criteria defining such development vary across counties, but generally include minimum parcel sizes and limits on the number of new dwelling permits issued. Construction of personal residences by commercial farmers and forestland owners is allowed with some restrictions. By 1986, land use plans had been acknowledged by the Land Conservation and Development Commission for all 36 counties and 241 cities in the state (Knaap 1994).

For many forest and farmland protection advocates, Oregon's land use planning program is perceived as infallible—the primary factor that makes Oregon such a uniquely attractive place to live. In reality, however, realizing measurable effects from land use planning programs alone is a rather slow process involving incremental changes in land use patterns over long periods of time. Whether forest and farm zones, and urban growth boundaries adopted with Oregon's land use planning program have been successful at conserving significant areas of forest and farmland somewhat depends on how you define success.

Resulting Protection

Research conducted by the USDA Forest Service estimated forest and farmland development with and without land use planning in western Oregon using a statistical model and detailed data describing the numbers and locations of buildings of all types (Kline 2005a). Estimates suggest that from 1974 to 1994, Oregon's land use planning saved less than 1% of forestland from low-density development (17 to 64 buildings per square mile), and about 0.5% percent from higher-density development (64+ building per square mile). For agricultural land, estimates suggest that from 1974 to 1994, Oregon's land use planning had saved nearly 11% of agricultural land from low-density development, and 3.5% from higher-density development. For mixed forest/agricultural land, estimates suggest that just over 2% were saved from low-density development, and just over 3% from higher-density development (Kline 2005a). Whether the magnitudes of these estimates—and they are only estimates—indicate that Oregon's land use planning program has been successful at protecting forest and farmlands from development is open to interpretation. The estimates also must be considered in light of several caveats.

First, Oregon's land use law was not intended to stop development, but rather to facilitate the orderly and efficient development of rural lands while protecting forest and farmlands (Knapp and Nelson 1992, Abbott *et al.,* 1994). The law allows forest and farmland development within urban growth boundaries, and allows owners to construct personal residences and other buildings within forest and farm zones subject to restrictions. Also, because urban growth boundaries were drawn around already existing cities, they tended to include those forest and farmlands most likely to be developed. These factors tend to reduce the magnitude of forest and farmland protection we might expect from such a program.

Measure 37 and the Future

Oregon's land use planning is not without detractors. Since its inception, the program has created tension between its advocates, who see land use planning as necessary to the long-term conservation of forest and farmlands, and its detractors, who argue that land use regulations unduly burden private landowners (Oppenheimer 2004b, 2004c). A recent result of that tension is Measure 37—a ballot measure approved by Oregon voters in November 2004. Measure 37 requires the state to compensate landowners for property value losses resulting from land use regulations adopted after landowners purchased their properties, or to waive regulations. Compensating affected landowners is viewed by many planners and policymakers in the state as virtually impossible because of the potential expense involved (Oppenheimer 2004a). Although this creates some uncertainty regarding the continued enforcement of land use regulations on affected lands, enforcement will likely remain unchanged for most landowners whose land does not qualify for Measure 37 claims.

Table 2.

Projected distribution of 2004 private forest and agricultural lands in western Oregon among building density classes in 2024 with and without land use zoning in effect

Dominant land use	Total	Number of buildings per square mile 0 to 16 (undeveloped)	17 to 64 (low-density)	>64 (developed)
With land use zoning, 2024:			Acres	
Forest	7,197,000	6,906,241	200,796	89,963
Agriculture	1,924,000	1,168,060	546,224	209,716
Mixed	774,000	594,742	128,252	51,006
Total	9,895,000	8,669,043	875,272	350,685
Without land use zoning, 2024:			Acres	
Forest	7,197,000	6,591,732	468,525	136,743
Agriculture	1,924,000	497,354	934,102	492,544
Mixed	774,000	483,363	201,704	88,933
Total	9,895,000	7,572,449	1,604,331	718,220

Source: Kline (2005b). Assumes Oregon's land use planning program remains intact.

If land use zones were no longer enforced, projections suggest that 267,729 acres (3.7%) of additional forestland could be developed by 2024 at low densities (17 to 64 buildings per square mile), and 46,780 acres (0.7%) could be developed at higher densities (64+ buildings per square mile) (*Table 2*). Projections also suggest that 387,878 acres (20.2%) of additional agricultural land could be developed at low densities, and 282,828 acres (14.7%) could be developed at higher densities. For mixed-forest and agricultural land, projections suggest that 73,452 acres (9.5%) could be developed at low densities, and 37,927 acres (4.9%) could be developed at higher densities (*Table 2*). Although neither scenario in its extreme—zoning remaining unchanged by Measure 37 or zoning made completely unenforceable—is likely, the projections suggest a set of bounds describing a range of future development.

At the time of this writing, significant uncertainty exists about the future outcome of Measure 37, for example, the degree to which property loss claims will be upheld, who will be eligible to file such claims, and whether the rights to develop land granted to select landowners by Measure 37 can be passed on to buyers when land is sold. Related measures are proposed for future ballots, some of which, if passed, would strengthen Measure 37 objectives, while others would mitigate or counter them. Perhaps most certain is that some change is afoot in the way Oregonians will approach forestland protection in the future. Oregonians generally see significant benefit in the forests and other open space lands of their state. Statewide surveys typically indicate that Oregonians place a high value on clean air and water, and the protection of wilderness and wildlife (e.g., Davis and Hibbits, Inc. 1999). In one survey, Oregonians cited natural beauty and recreation opportunities as the attributes they most value about living in the state (Oregon Business Council 1993). How these attitudes and beliefs will combine with the apparent desire among many residents for a new approach to land use planning remains to be seen.

Development Effects on Forests and Forestry

Research suggests that forestland development can influence forest structure and other conditions in many ways, in addition to the direct loss of tree cover and vegetation when land is developed. Changes in forest structure and other conditions result from changes in the ways in which remaining forestland owners manage their forestlands in response to development-related factors. These include parcelization, shifting management objectives, potential conflicts between timber-producing and nontimber-producing neighbors, and forestry as development draws near.

Parcelization

Parcelization—the breaking up of large forest parcels into smaller parcels—is thought to reduce the economic feasibility of forestry activities, leading to less intensive management of remaining forestlands (Mehmood and Zhang 2001). Research suggests that managing several small parcels can cost more than managing fewer larger parcels (e.g., Row 1978, Thompson and Jones 1981, Cleaves and Bennett 1995). For this reason, forestland owners on smaller tracts are thought to be less likely to manage their land for commercial timber production. They may reduce their management activities or stop them altogether, conceivably leading to lower forest biomass and slower growth.

Changing Objectives of Owners

Residential forestland development is thought to lead to changes in the management objectives of remaining forestland owners. Research suggests that urbanites increasingly are moving into rural areas seeking to improve their quality of life. These new residents tend to value forestland for its aesthetic and recreational appeal rather than for timber production (Egan and Luloff 2000). Nonindustrial private forest owners, in particular, have long been noted for their tendency to base forest management decisions on nontimber values in addition to or in place of timber production (e.g., Binkley 1981). An estimated 40% of nonindustrial private forestland owners in western Oregon and western Washington possess primarily recreation or passive ownership objectives rather than timber production objectives (Kline *et al.,* 2000a, 2000b). These owners tend to own smaller parcels and are less likely to harvest timber. If residential development on forestland increases the proportion of nonindustrial and other forest owners motivated more by nontimber values than by timber production, management of remaining forestland could change over time. Owners may reduce their investments in thinning and planting, become more selective in their harvesting, or stop harvesting altogether.

Forest/Urban Conflicts

Some policymakers believe that the proximity of residential development to productive forestlands causes conflict between those owners who continue forestry and new, more urban-minded residents. Such conflicts are thought to reduce forestry profitability by increasing vandalism of gates or logging equipment, trespass, and liability issues associated with equipment and forestry activities. Few studies, however, have documented such conflicts or linked them to lower forest productivity. Research in Oregon finds little evidence that population density increased the likelihood of forest/urban conflicts, but did find that estimated costs associated with forest/urban conflicts are higher for smaller forest parcels than for large (Schmisseur *et al.,* 1991).

Owners' Expectations about Future Development

It is thought that the expectations of forestland owners can change when development draws near, as owners ponder whether they might end up selling land for development themselves. Such expectations might deter forestry investment because they may see a limited productive future for their land. Remaining forestland owners may reduce or forego more expensive management activities and investment opportunities as they anticipate continued population growth and eventual development (Wear *et al.,* 1999). Some forestry professionals warn that many of the problems development may create for forestry—higher land prices, higher taxes, and greater regulation—extend far in advance of actual development, making it more tempting to sell (DeCoster 2000).

The extent to which any of these factors might contribute to forestland development in specific areas can not be known with certainty. However, growing evidence suggests that forestland owners do tend to manage their lands differently with increasing development. Research in the U.S. south indicates that owners are less likely to manage for commercial timber production (Wear *et al.,* 1999) and are less likely to harvest timber (Barlow *et al.,* 1998, Munn *et al.,* 2002) as population density and urban proximity increase. Such trends over time could lead to changes in forest density, age class, species composition, successional stage, and other characteristics. In Oregon, increasing building densities have been linked to some reductions in forest stocking, pre-commercial thinning, and post-harvest planting, but not to harvest likelihood (Kline *et al.,* 2004b). One wonders, however, about the likelihood of harvest on those forestlands receiving less intensive management—will those forestland owners have any interest in harvesting in the future?

Management Effects on Carbon

The many different types of management activities that forestland owners pursue can vary in their effects on stored carbon. Planting trees where there were none, replanting following harvest, and interplanting understocked forests generally increase stored carbon, as would fertilization that increases growth. Newly-planted or regenerating forests take up carbon for 20 to 50 years or more depending on species and site conditions (Watson *et al.,* 2000). However, other activities intended to improve timber quality, such as thinning and pruning, are less certain in their net carbon effects (Murray *et al.,* 2000: 9). Measuring the carbon sequestration effects of different activities conducted in specific locations is feasible (e.g., Hoover *et al.,* 2000) but current scientific literature describing these effects is limited (Watson *et al.,* 2000).

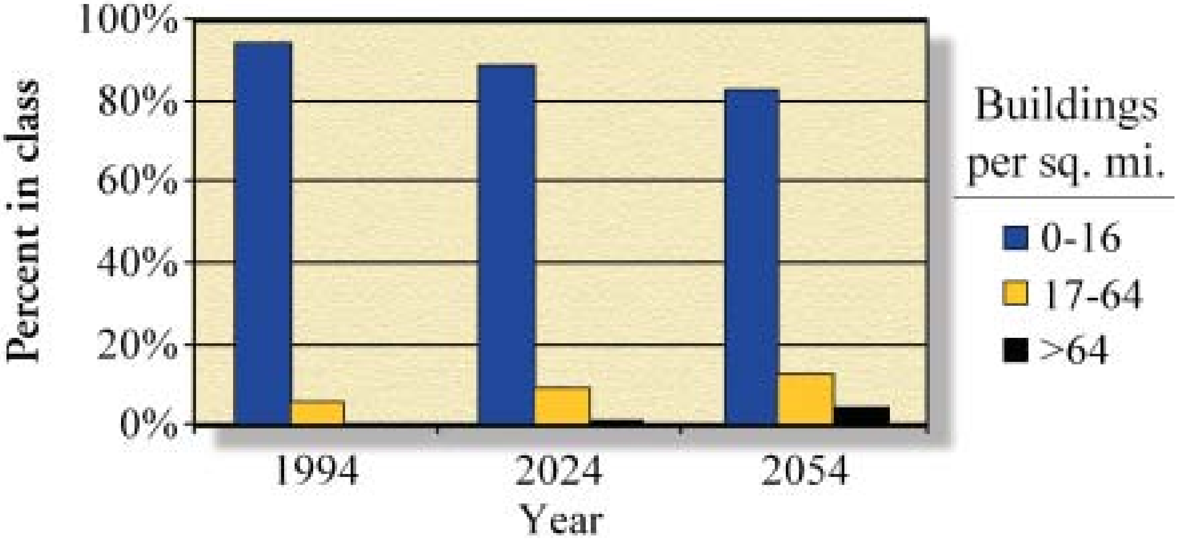
The net carbon sequestration effects of harvesting also are uncertain and depend on the use of harvested timber, which can continue to store carbon for decades or centuries in solid wood products, for months or years in paper products, or nearly permanently in landfills. It also can be burned as fuel, releasing carbon but also offsetting the use of fossil fuels (Murray et al. 2000: 11). Carbon storage effects are even more ambiguous when one considers them in global contexts. For example, although reduced harvesting in Oregon forests might increase stored carbon in Oregon, the net effect on global carbon stocks depends on the degree to which reductions in harvested timber in Oregon are replaced by increased harvesting elsewhere. Timber markets, after all, will respond to reductions in timber supplied from Oregon with production from other sources to fulfill global timber demands.

Development Effects in the Pacific Northwest

To what degree forestland development will affect private forest management in Oregon is not known for certain. In 1993 private-owned forestland in Oregon was held by an estimated 166,200 companies and individuals (Birch 1997) and that number has grown over time, suggesting that some parcelization probably is occurring. However, development projections for western Oregon, coupled with models of forestland owner behavior, suggest that future development may not necessarily result in dramatic reductions in forest management. The most productive forestlands tend to be geographically isolated, steep, and poorly accessible, relative to many less productive lands located closer to existing population centers and transportation corridors where future development is more likely (Kline and Alig 2005). Greater uncertainty exists for eastern Oregon because there has been less research on the effects of development there. So far, forestland development in eastern Oregon has been relatively slow, but recent growth in places such as central Oregon bears watching (Lettman, 2004; Kline *et al.,* in press).

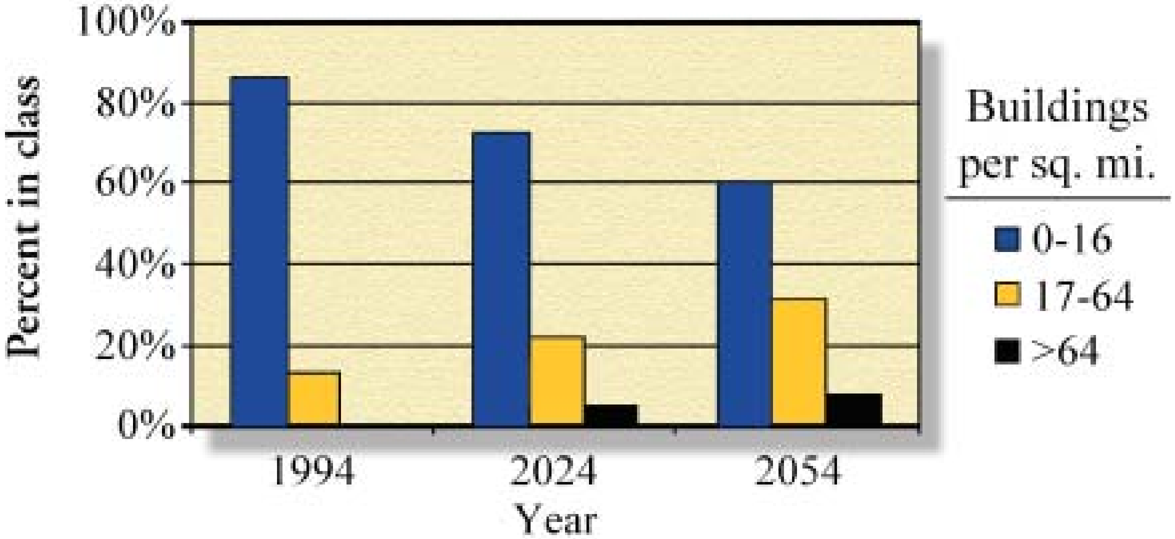
In western Oregon, about 94% of private forestlands are classified as timberland—capable of annually growing at least 20 cubic feet per acre of industrial wood. The remaining 6% are classified as other forest, including oak savanna (Azuma *et al.,* 2002). In 1994 nearly all timberland (94%) comprised relatively low building densities of 16 buildings per square mile or less (*Figure 2*). Projections suggest that a significant proportion (83%) will remain the same through 2054 (Kline and Alig 2005). A relatively lower proportion (86%) of other forestland fell into the low building density class in 1994, and projections suggest that proportion will decrease to 60% by 2054 (*Figure 3*). Although other forestlands represent a smaller proportion of all private land, they likely will bear a greater share of future development owing to their greater prevalence along the edges of the Willamette Valley, where most development in western Oregon is expected. Timberlands tend to be located more distant from the Valley on steeper slopes and in less accessible areas of the Coast and Cascade Ranges, which somewhat limits their economic potential for more intensive developed uses. A notable exception might be forestlands possessing significant amenity values, such as those along the Oregon coast, which could present attractive development opportunities. For more inland timberland, however, the combination of greater earning potential from timber production and limited accessibility to Willamette Valley cities may counter development pressures.

Figure 2



Private timberland by projected building density class, western Oregon, 1994 to 2054 (Kline and Alig, 2005).

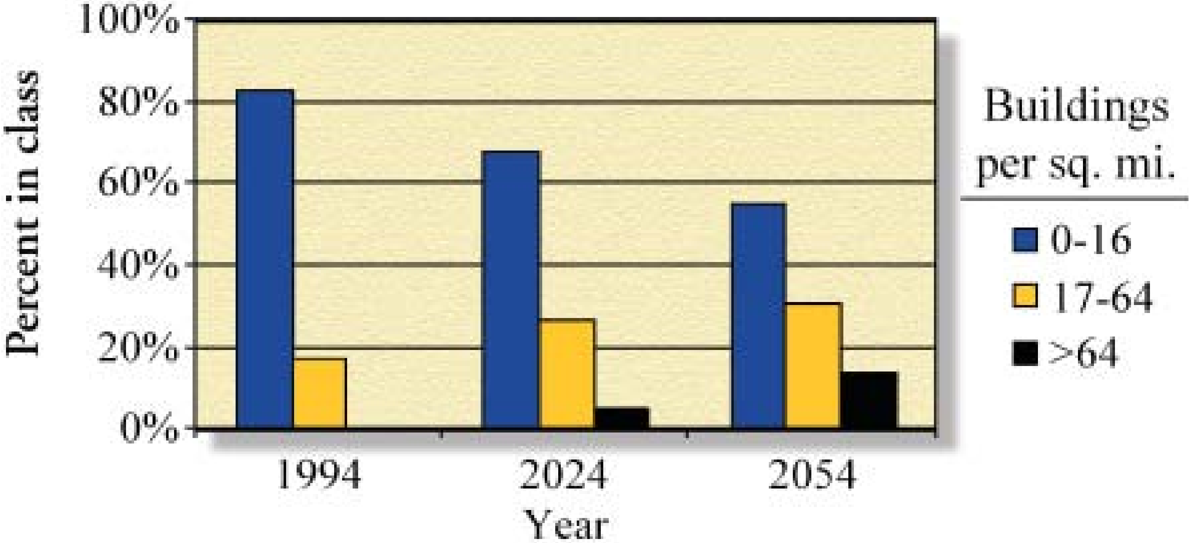
Figure 3



Private other forestland by projected building density class, western Oregon, 1994 to 2054 (Kline and Alig, 2005).

Future forestland development also is more likely to affect nonindustrial private-owned forestlands more than industrial-owned lands. Nonindustrial lands are owned by farmers, Native American groups, and other private owners (Azuma *et al.,* 2002). In 1994, only 17% of these forestlands had a density of more than 16 buildings per square mile or less. Projections suggest that by 2054, that will increase to 45%. (*Figure 4*). Industrial forestlands are owned by companies growing timber for industrial uses including companies with and without wood processing facilities. In 1994 almost all industrial forestlands (98%) had low densities of 16 buildings per square mile or less. Projections indicate that by 2054, the density will remain almost the same (97%)

Figure 4



Nonindustrial forestland by projected building density class, western Oregon, 1994 to 2054 (Kline and Alig, 2005).

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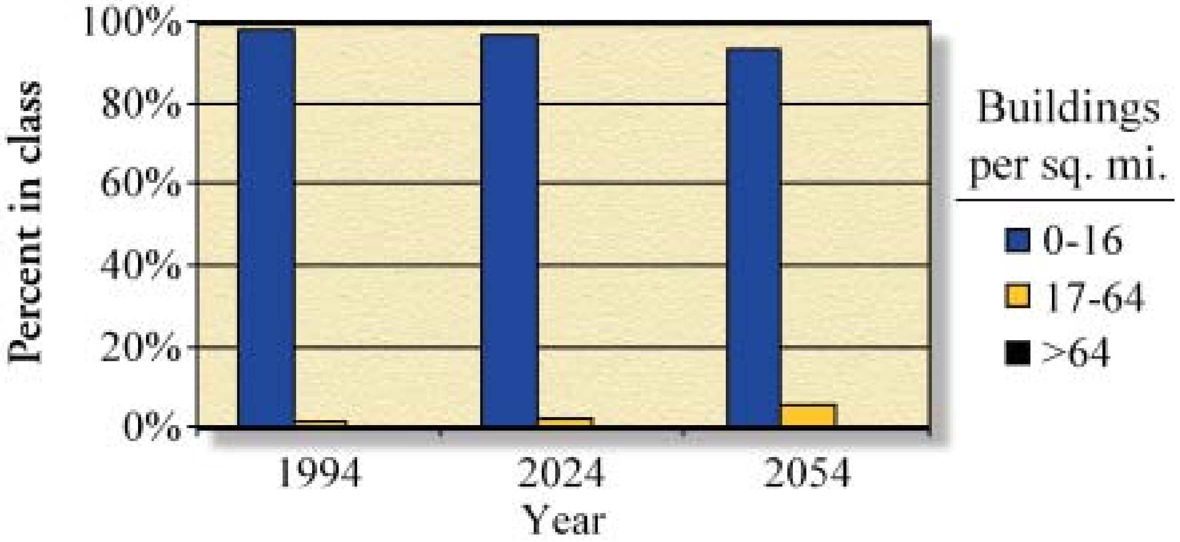
Figure 5



Industrial forestland by projected building density class, western Oregon, 1994 to 2054 (Kline and Alig, 2005).

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(*Figure 5*). A current trend in forestland ownership is the transfer of land from traditional industry owners to timber investment management organizations. This has given rise to questions about whether or not these organizations will manage forestlands on shorter rotations and include possible sale of land for development among their various management options. These possibilities could eventually bring the fate of those lands currently owned by industrial owners closer to that of nonindustrial owners.

The net effects that development-related changes in forest management will have on carbon sequestration locally and globally are uncertain. Less intensive management—lower tree planting rates, for example—could lead to lower forest biomass and slower growing forests, conceivably reducing sequestration. However, if greater numbers of private forestland owners are motivated by environmental concerns, they may be more willing to pursue carbon sequestration to benefit the environment and society, with relatively little incentive beyond education and technical assistance. Forestland development in Oregon is most likely to affect those lands located near existing population centers and transportation corridors. A significant portion of private forestland, along with extensive public-owned forestlands, are likely to remain unaffected, at least for the foreseeable future. Only time can tell, however.

Policy Strategies for Maintaining Forestlands

Addressing forestland development through public policy is a persistent challenge. How do we encourage private forestland owners to continue to provide valued forest benefits when development presents other opportunities? Here I outline some of the most common approaches used to protect forestland. More detailed discussion can be found in other sources (e.g., Bengston *et al.,* 2004). Two issues have the strongest influence on the success of any policy aimed at protecting land from development: (1) How well it addresses the socioeconomic factors that motivate landowners to develop land; and (2) How well it balances the interests of private landowners with the land conservation interests of society as those factors change over time. Protecting forestland from development mostly entails utilizing regulations or financial incentives to counter the socioeconomic incentives landowners have to develop—rising land values, increasing costs of forestland ownership, decreasing profitability of forestry, for example. Regulations and incentives can also influence management, such as cost-sharing particular activities. Education and outreach can appeal to forestland owners' own conservation objectives. Different approaches can be successful in different circumstances and these can change over time.

Land Use Regulations and Zoning

Land use regulations such as zoning are among the most commonly adopted measures to control land use and development. They are implemented at state, county, and municipal levels throughout the U.S. Regulatory approaches, such as city and regional planning, most typically focus on controlling the pace and density of development. They had been less commonly used in the U.S. at broad scales to protect forest and farmlands until implementation of comprehensive state and regional land use planning efforts such as Oregon's in 1973 and New Jersey's Pinelands Protection Act of 1979, which covered 19% of that state. One advantage of regulatory approaches—Oregon's land use planning program, for example—is that they generally can be implemented and administered at relatively low cost to governments when compared to other land conservation methods. They may, however, be less effective over the long term because of persistent tension between society's desire to both conserve land and uphold certain private property rights. For this reason, policies that encourage the voluntary participation of landowners in maintaining valued forest benefits or compensate them for land use restrictions can be important complements to regulation.

Preferential Taxation Programs

All states, for example, have preferential programs that reduce property taxes on private-owned forest and farmlands as long as they are enrolled. Most impose penalties when owners withdraw the land. These programs attempt to lower the costs of maintaining land in forests and farming by reducing the property taxes that owners must pay. In Oregon, forestland owners can receive preferential assessment if they meet a two-acre minimum parcel size as well as stocking and species standards. Oregon's Department of Revenue conducts annual market studies of forestland sales to maintain accurate estimates of the real market value of forestland in the state.

One disadvantage of preferential taxation programs, which typically have a minimum acreage or some other criteria, is that they shift property tax burdens from forest and farmland owners to those owners whose land does not qualify. For this reason, property tax relief tends to benefit larger (and conceivably wealthier) landowners. Arguably, non-qualifying landowners, like all members of the public, benefit from the forest and farmland conservation effects of preferential taxation programs. But policymakers and the greater public must remember that those benefits come at a cost to someone.

Another disadvantage of preferential taxation programs is that they do not offer permanent protection. At some point, as development expands and land values increase, no measure of property tax relief is going to keep some landowners from selling their land; the financial payoff is simply too high. For many, the value of their forest and farmlands represents a significant proportion of their wealth. Tapping that wealth to finance retirement, children's education, or other needs often involves selling land. If would-be purchasers view development as the highest and best use, sold land is likely to be developed.

Purchase of Development Rights, Easements, Transferable Development Rights

Other policies—purchasing development rights and easements, for example—address the desires of some landowners to cash in on a portion of their forest and farmland wealth without having to resort to development (Wiebe *et al.,* 1996). Purchasing development rights or conservation easements generally involve paying a landowner to permanently give up their right to develop a parcel of land or agree to some maximum amount of future development that would be allowed. Development restrictions become part of the deed and apply to all future owners. Although purchasing development rights typically is advocated for preserving farmland, it is equally viable for protecting forestland. Another policy is purchasing land "in fee simple"—the outright purchase of land by a government that either then retains purchased land under public ownership or resells it with deed restrictions on future development. One drawback of any of these programs is that you never know whether participating landowners would have actually developed their land had they not been able to sell development rights, easements, or land. It is not always possible to identify those lands on which development is imminent.

Numerous state, county, and municipal entities purchase development rights, easements, and land in fee simple for conservation purposes. An example of such an effort in Oregon is Portland's $135.6 million open spaces bond measure approved by voters in 1995. By 2006 the program had acquired more than 8,146 acres of land for regional natural areas, trails and greenways (Metro 2006). Another bond measure is planned for November 2006. The federal government began providing funds to existing farmland protection programs with the modestly-funded federal Farmland Protection Program included in the 1996 Farm Bill. The USDA Forest Service's Forest Legacy Program provides funds to protect forestland. In Oregon, 2005 legislation allows cities and counties to create nonprofit Community Forest Authorities able to finance forestland purchases by issuing bonds that can be repaid with timber revenue earned from purchased land (Postrel 2005).

Compensating landowners for development restrictions through purchasing development rights, easements, and land in fee simple generally is more acceptable to landowners than regulatory approaches, and can offer more permanent protection than preferential taxation programs. They do, however, tend to come at greater expense because the costs of compensation generally rise as forest and farmlands come under greater threat of development. The significant expense of such programs tends not to be palatable to taxpayers until the potential loss of valued lands becomes imminent and the public sufficiently committed to its protection. Research suggests that public willingness to adopt public-financed forest and farmland protection programs is more prevalent in faster-growing and more densely populated places where open space lands are being lost, causing the public to demand their protection (Kline and Wichelns 1994, Solecki *et al.,* 2004, Kline 2006). Whether socioeconomic trends in Oregon will eventually lead to greater use of such programs in light of Measure 37 remains to be seen.

Less common, though frequently advocated, are transferable development rights programs, which are designed to encourage a shift in growth away from protected lands to areas where protection concerns are not a factor. Landowners are empowered to sell their development rights to purchasers who may then use those rights to build in designated growth areas at higher-than-allowable densities. In this way, land use planning is combined with development rights trading. Although appealing as a means to finance permanent forest and farmland protection, the program's success depends on the right balance of building density and financial incentives. This can be a tricky undertaking in the political environment of land use planning. Interest has persisted, however, and attempts at using these programs appear to be growing. Perhaps the most notable of such efforts near Oregon is the Transfer of Development Rights Program in King County, Washington.

Private Land Preservation and Land Trusts

Also of interest are private non-profit organizations, such as the Nature Conservancy and Trust for Public Land, as well as numerous land trusts that focus on preserving land in particular municipalities, watersheds, or regions. Private land preservation usually involves purchasing conservation easements or land in fee simple. Donations of easements and land to qualified conservation organizations are eligible as charitable contribution deductions for federal income tax purposes, providing incentives to gift all or a portion of protected lands. The Internal Revenue Service defines "conservation purposes" as preserving land for outdoor recreation, protection of natural habitat and ecosystems, or preserving open space for scenic enjoyment or historic preservation, or any other objective consistent with federal, state, or local conservation policy (Land Trust Alliance 1990). Easements also may specify additional directives, such as limits on certain forestry practices or guarantees of public access for certain types of recreation (Land Trust Alliance 2001).

Data for Oregon indicate 16 land trusts operating in 2003 with 5,200 acres owned, 174,337 acres under easement, and 20,606 acres protected by other means, for a total of 200,143 acres of protected land (Land Trust Alliance 2004). This is in addition to ongoing activity by national organizations such as the Nature Conservancy and Trust for Public Land. Zumwalt Prairie in northeast Oregon, for example, is the Nature Conservancy's largest acquisition in Oregon at 27,000 acres and also is North America's largest remaining grassland of its type (The Nature Conservancy 2006). A recent acquisition of the Trust for Public Land is a conservation easement on the 11,400-acre Drew's Valley Ranch in south central Oregon, subsequently transferred to the Oregon Rangeland Trust for long-term management (Trust for Public Land 2006b). A growing trend in nonprofit land conservation is cooperation between nonprofits and public entities. In 2005 in Oregon, for example, the Trust for Public Land acquired the first 17 acres of a planned 119-acre park along the Willamette River and subsequently transferred ownership to the City of Keizer (Trust for Public Land 2006a).

Forest Legacy Program

Partnering also can involve the federal government. The Forest Legacy Program (created in 1978, re-amended in 1996) is a voluntary private land conservation program among the USDA Forest Service, states, land trusts, and private landowners, where cost-sharing is leveraged by federal financial assistance (Forest Legacy Program 2002). From 1992 through 2001, Forest Legacy Program funds contributed to purchasing conservation easements on 125,163 acres of forestland in 16 states, totaling $68 million or about $546 per acre nationally. The program has also protected an additional 26,295 acres of forestland through in fee simple purchase or combinations of in fee simple and conservation easement purchase, at a cost of $36 million. Oregon's legislature authorized the state to begin participating in the Forest Legacy Program in 2005 on lands located within urban growth boundaries. Initial projects are planned for the 2007 federal fiscal year (Oregon Department of Forestry 2006b).

Ecosystem Services Compensation

Compensating forestland owners for ecological services produced on their lands — through increased forest commodity prices and direct economic incentives — is another approach gaining interest among some policymakers (e.g., Collins 2005). Owners would be induced to retain forestland by the creation of markets for the ecosystem services their lands produce for public benefit—prevention of soil erosion, water filtration, mitigation of droughts and flooding, and maintenance of wildlife habitat and healthy waterways, for example. Whether such compensation actually could reduce forestland development in the U.S. is uncertain. Methods for measuring ecosystem services would have to be developed, and success would depend on how much consumers or taxpayers would be willing to pay in higher prices for forest commodities and higher taxes to fund economic incentives. Some forestry professionals (e.g., Binkley 2001) suggest that technological innovation, tree planting, and the global transition from extensive forestry to plantations will greatly increase productivity in the near future. Much less forestland may be needed to supply world forest commodity demand. Whether consumers would be willing to pay higher prices for U.S. forest commodities in a global market potentially characterized by over-production is uncertain. Ever-increasing prices for developed lands do not improve the prospects. There also is the question of whether taxpayers would support compensating forestland owners for what some may view simply as good forest stewardship.

Programs to Increase Sequestered Carbon — Cost Shares, Direct Payments, Carbon Markets

Other related policies would induce remaining forestland owners to manage forests specifically for net increases in sequestered carbon. Tree planting, as well as fertilization, generally will provide net increases in stored carbon over time, but as previously noted, the net effects of other actions—harvesting, thinning, and pruning, for example—are more ambiguous. Activities that reduce the likelihood of extensive or catastrophic wildfires reduce the chances that stored carbon would be released by wildfires. Also as previously noted, the net affects of different forestry activities can vary depending on whether they are considered in a local versus global context.

Cost-shares, and comparable forms of assistance, can encourage willing forestland owners to conduct particular forestry activities. Federal programs such as the Forestry Incentives Program, the Conservation Reserve Program, and the Forest Land Enhancement Program have offered cost-share assistance to landowners willing to plant trees or thin stands to improve conditions. Many states also have their own programs. Oregon's Department of Forestry offers cost-share assistance to landowners interested in developing Forest Stewardship Plans and advises landowners about the various state and federal forestry incentive programs available to them. Oregon's Forest Resource Trust's Stand Establishment Program offers cost-sharing and technical assistance to landowners willing to establish trees on marginal agricultural and rangelands or improve stand conditions on abandoned or poorly stocked forestlands.

Some private nonprofit organizations also offer direct financial incentives to landowners willing to pursue conservation activities. The Nature Conservancy, for example, offers annual payments to forestland owners in Virginia to curtail logging, with the resulting "forest bank" managed using an ecosystem-based approach that includes limited timber harvest (Dedrick *et al.,* 2000). Such financial incentives, along with landowner education and technical assistance, could be crafted to focus on carbon sequestration objectives. Research conducted in Oregon and Washington suggests that conservation objectives may be consistent with the interests of many nonindustrial private forestland owners in both states (Kline *et al.,* 2000a, 2000b). Whether the potential gains in sequestered carbon would be worth the expense of administering financial incentives, education, and technical assistance is uncertain.

Carbon markets are another approach. Such markets (also called carbon trading) enable forestland owners to sell "carbon credits" to industries or other entities whose activities produce carbon emissions in excess of allowable limits. The opportunity to sell carbon credits provides forestland owners an economic incentive to conduct activities that result in net increases in sequestered carbon. Carbon and similar markets are growing and they are widely advocated as a leading policy tool for meeting Kyoto Protocol treaty obligations to reduce greenhouse gases (e.g., Henri 2000). Oregon's Forest Resource Trust operates similar to a carbon market by cost-sharing carbon sequestration activities on private lands using funds provided by a utility company in exchange for future carbon emission offsets (Cathcart 2000). The recent Oregon House Bill 2200 authorizes Oregon's State Forester to establish a more formal carbon market on behalf of nonfederal forestland owners in the state, which also will be administered by Oregon's Forest Resource Trust (Oregon Department of Forestry 2006a).

The Limits of Policies

There can be limits to what can be achieved in increased carbon sequestration through public and private forestland protection. Land use policies and programs usually emerge from political processes that involve concession and compromise, and while they may make sense in theory, what emerges may not always provide ideal solutions. Land-use regulations generally restrict land to broad use classes, often without regard to forest conditions. Regulations also are limited by what courts will allow under takings provisions of the U.S. Constitution. Preferential taxation programs generally do not differentiate between lands of significant social value—carbon sequestration potential, for example—and lands of little value. Neither regulations nor preferential taxation programs offer permanent protection. Purchasing development rights, easements and land in fee simple can yield more lasting protection, but tend to be expensive and limited to willing sellers. Protecting particular forestlands permanently may be unnecessary if those lands have little development potential or landowners are unlikely to develop. Policymakers must continually weigh the effectiveness, costs, and equity considerations of different policies when devising and revising conservation strategies.

The Future

Development in the U.S. accelerated in the 1990s and projections suggest substantial new development through 2025 (Alig *et al.,* 2004). Many states have considered smart growth policies and other approaches to address what some policymakers see as undesirable urban sprawl at the expense of valued forest and farmlands. Despite these efforts, a larger population spread across a fixed land base will result in higher population densities on many forest landscapes. How these trends will affect Oregon remains to be seen. Given comparatively slow rates of forestland development in Oregon's recent past, it is tempting to suggest that future changes may also be relatively slow. But there might be unforeseen factors that have the potential to draw more significant development in the future—even greater in-migration of people attracted to Oregon's wealth of environmental amenities, for example. There are also likely changes afoot with land use planning as Oregonians grapple to define an outcome for Measure 37.

Forestland development is influenced not just by rates and patterns of population growth, but by geography, economics, inherent site productivity, environmental amenities, and landowners, among other factors. Much of Oregon's forestlands so far have been buffered from the effects of development by their relative geographic isolation, steep slopes, and poor accessibility. What effects forestland development might have in Oregon and the attention they warrant from policymakers will depend on what lands will be affected in the future. Economic and ecological characteristics vary across the landscape, resulting in a range of implications that depend on the locations and densities at which development will occur. The effects of development on timber production so far appear to be relatively small because the most productive forestlands and ownerships happen to be those least affected by development. While public policies can influence some of the factors causing forestland development, the socioeconomic forces that accompany population growth—increased demand for housing, commercial and industrial sites, and public infrastructure—persist and exert strong pressures in land markets favoring development.

Successful implementation of any policy approach to protecting forestland and enhancing carbon sequestration will depend on a variety of circumstances that can change over time. Since 1973, Oregon's approach to forestland protection has relied mostly on land use planning, by designating particular lands as forest where development is greatly restricted. Oregon's program was implemented at a time when the production of timber and other forest products generated greater economic activity relative to other sectors than today, and rising agricultural export demands provided strong incentives to farmers to keep farming. Years since have brought new industries, more people, and new attitudes among Oregonians toward forests. A timely question to consider is whether Oregon's continued reliance on land use planning to protect forest and farmland remains consistent with these changes.

If Measure 37 did nothing else it may have forced an opportunity for Oregonians to consider the ways in which they now value their landscapes and how to best secure them for future generations. Until recently Oregonians seem to have viewed land use planning as somewhat of a permanent fix to forest and farmland development—the envy of planners and policymakers in other states. What they might find, however, is that land use planning may be just one step in a longer process of addressing land use change—a process that inevitably may involve an evolution of policy over time that is not unique to Oregon. Land use planning likely will still play a prominent role in Oregon's future, but other approaches to forest and farmland protection may need to be considered. The future will depend on the willingness of Oregonians to investigate and evaluate potential outcomes of different policies, and consider new policies in their quest for a desired balance of forestland protection and development.

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CHAPTER SEVEN

HIGHLIGHTS:

USING WOOD PRODUCTS TO REDUCE GLOBAL WARMING

Introduction

- Wood products can reduce significantly-increasing greenhouse gases through:
- Storing carbon in forest, building products, and landfills.
- Substituting wood for fossil fuel-intensive products like steel and concrete.
- Using wood as fuel instead of fossil fuels.

Measure of Wood Products' Performance

- Global warming potential can be measured in terms of the CO_2 equivalent amount of carbon dioxide, methane and nitrous oxide emissions released into the atmosphere.
- Carbon and global warming potential reduction can be calculated for sequestration and product and fuel substitution.

Environmental Performance of Wood Products

- Performance data for most products was documented by CORRIM.
- Building materials were studied in houses for a warm and cold climate.

The Dynamic Effects of Various Management Scenarios

- **Carbon storage in forests.** In one study, taking "no action" rather than harvesting stored more carbon.
- **Carbon storage considering forests, wood products, and concrete substitution.** Collectively a 45-year harvest cycle, wood products and substitution for non-wood products stored more carbon than the "no action" managed forest scenario.
- **Carbon storage in houses.** Wood-framed houses store more carbon than steel-framed or concrete-framed houses.
- **Carbon storage in U.S. housing stock.** Annual home construction using wood products prevent millions of metric tons of CO_2 from being in the atmosphere.

Wood Fuel Use Reduces Global Warming

- When wood is substituted for fossil fuels, less of harmful CO_2 is released.
- In the Pacific Northwest, wood generates about 43% of the total energy in the production of wood products from seedling to product.

Ways to Foster Increased Use of Wood Products and Wood Fuel

- New practices, policies, research, incentives and education are needed.
- Carbon markets are developing to trade the wood industry's greenhouse gas assets.

Summary

- Wood should be a material of choice for building green.
- Policies and practices are needed to promote the use of wood to reduce global warming.

CHAPTER SEVEN

USING WOOD PRODUCTS TO REDUCE GLOBAL WARMING

James B. Wilson

Introduction

Global warming can be attributed to two factors, those that occur naturally and those that may be human-induced. The exact contribution of each has not been determined, but it is evident that global warming has increased due to record greenhouse gases with the advent of the Industrial Revolution. If the predictions of global warming effects come true, the way many of us live will be impacted.

Greenhouse gases released to and trapped in the atmosphere cause global warming (IPCC 2001). The greatest contributors are three gases that are both naturally-occurring and human-induced: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These three are released into the atmosphere at various stages of any product's or material's life cycle. For a wood product's life cycle, the stages proceed from the planting or natural regeneration of trees, through harvesting, product manufacturing, home construction, home use and maintenance, and end-life, where wood products are landfilled, burned or recycled. Water vapor is also considered a greenhouse gas, but is not usually included in impact assessments because its contribution is not fully understood.

This chapter examines wood products as a building material for home construction, and how this appears to reduce greenhouse gases in the atmosphere, and in turn, reduce global warming. The ways that the use of wood can reduce greenhouse gases include storing carbon in forest and wood products, by substituting wood products for fossil fuel-intensive products such as steel and concrete, and by using wood as fuel instead of fossil fuels. If the dire predictions of global warming effects are true, bold action in the form of practice, policy, research and education is needed to economically address the reduction of greenhouse gases. Increased use of wood products represents a partial solution to this major concern.

Dramatic Increase of Greenhouse Gases

Measured levels of carbon dioxide, nitrous oxide, and methane in ice cores reveal that greenhouse gases are at the highest level of concentration in the past 650,000 years (Brook 2005). The last 200 years, with the onset of the Industrial Revolution, have brought a dramatic increase, and can be attributed to human activity through the combustion of fuels and related practices.

Throughout the past 650,000 years, the three significant gases have all cycled periodically, but have dramatically increased in the past 200 years. Carbon dioxide, previously cycling from about 180 ppm (parts per million) to 300 ppm, has increased to about 375 ppm. Nitrous oxide periodically cycled from 200 and 280 ppb (parts per billion), but now has increased to 320 ppb, while methane, which previously cycled from 400 to 700 ppb, has increased the most — to about 1750 ppb. The alarming trend of increasing concentrations of greenhouse gases needs to be slowed or stopped if global warming is to be abated (Flannery 2006).

Formula for Wood Products' Performance

Emissions of these three gases provide a useful, quantitative way to measure and compare the environmental performance of wood products and other materials, and their relationship to global warming. Carbon dioxide is used as a reference standard to determine the global warming potential of a gas. The heat-absorbing ability of nitrous oxide and methane are compared to the CO_2 equivalent. The Intergovernmental Panel on Climate Change (IPCC 2001) uses a 100-year horizon to estimate the atmospheric reactivity or stability of each of these gases; they can be used to establish a Global Warming Potential Index (GWPI) based on a CO_2 equivalent which is defined as:

$$\textbf{GWPI (kg } \mathbf{CO_2}\textbf{) = } \mathbf{CO_2} \textbf{ kg + (} \mathbf{CH_4} \textbf{ kg x 23) + (} \mathbf{N_2O} \textbf{ kg x 296)}$$

This formula can be applied to the life cycle of wood products and comparison materials, to calculate whether or not, and by how much, a given material, process or system reduces, controls or eliminates the release of carbon dioxide into the atmosphere, thus reducing the magnitude of global warming potential.

To reduce the concentration of CO_2 within the atmosphere, three approaches can be taken in consideration of the life cycle of wood products. The first, carbon sequestration, removes CO_2 from the atmosphere by storing, or sequestering, carbon in the trees, roots and soil of a forest, and by sequestering carbon in wood products — in housing stock, recycled into other products, and wood products in landfills.

The second is to use the formula for an energy accounting — evaluating the reduction of CO_2 equivalent in the atmosphere as a result of the wise selection of a product or process. For example, the life cycle of one product or material that emits less CO_2 into the atmosphere can be substituted for another.

The third is the use of biomass (wood, bark and agricultural residue) as a fuel. Fossil-origin fuels such as oil, gasoline, coal, natural gas and propane contribute CO_2 to the atmosphere, and are non-renewable and non-sustainable. The U.S. Environmental Protection Agency (EPA) considers CO_2 emissions from the combustion of biomass "impact-neutral" on global warming because of the ability of forests to recycle the CO_2 back into carbon in wood, and release oxygen to the atmosphere (EPA 2003).

Wood products sequester carbon, but that resulting decrease in carbon dioxide in the atmosphere can be offset by the use of fossil fuels in the process. For the life cycle of wood products used as building materials, coal, natural gas and oil are used to generate the electricity that powers saws. Diesel fuels trucks transport lumber. Wood and bark are burned in boilers to generate steam to dry wood. If buildings are deconstructed, fuel is used to run the equipment for the operation.

All of these factors, and many more, have to be calculated to determine the total impact of using wood products, or any products, on global warming.

Environmental Performance of Wood Products

The Consortium for Research on Renewable Industrial Materials (CORRIM) was formed in 1996 by 15 research institutions to document the environmental performance of all wood products (Bowyer *et al.,* 2004, Lippke et al. 2004b, Perez-Garcia *et al.,* 2005a). Their study covered that life cycle, from the forest resource through manufacturing, product use, and eventual product disposal or recycle.

Life cycle inventories — all the inputs and outputs to produce, use and dispose or recycle a product— were tracked through each stage. The multitude of factors included fuel use (by type and amount), electricity use (and the fuels to produce it), materials use, and CO_2, CH_4 and N_2O emissions, as well as many other types of emissions, to the air, water, and land.

The first phase of this research effort covered resource use and manufacturing of structural wood building materials in the U.S. Pacific Northwest and Southeast. Forest resource data for a variety of management scenarios were developed using inventory data, combined with growth and yield model simulations, and the Landscape Management System (Oliver 1992) to simulate inventory conditions through time (Johnson *et al.,* 2005). Data for harvesting, transportation of resources to mills, and product manufacturing inputs and outputs were collected by survey and analyzed (Johnson *et al.,* 2005, Kline 2005, Milota *et al.,* 2005, Puettmann and Wilson 2005a,b, Wilson and Dancer 2005a,b,Wilson and Sakimoto 2005).

Two U.S. building sites were selected to study the environmental impact of a house designed of various materials—a cold climate (Minneapolis) house designed to code for both wood- and steel-framed comparison, and a warm climate (Atlanta) house designed to code for both wood- and concrete-framed comparison (Perez-Garcia *et al.,* 2005a).

Life-cycle assessments were made of the various material selections for the two houses. Input data for the study was provided by the Athena Sustainable Materials Institute (ATHENA 2004) for non-wood materials and Winistorfer *et al.,* (2005) on use and maintenance for the two house designs. CORRIM (Bowyer *et al.,* 2004) provided life-cycle inventory data for forest resources, softwood lumber, softwood plywood, oriented strandboard, composite I-joist, laminated veneer lumber, and glue-laminated (glulam) beams. The analyses included life-cycle assessments comparing the use of various construction materials (wood, steel, and concrete) in terms of such factors as global warming potential, air emissions that include the greenhouse gases of CO_2, CH_4 and N_2O, and fuel use, among other impact factors (Perez-Garcia *et al.,* 2005a). Also included was a tracking of carbon through the product life cycle from the forest through construction (Perez-Garcia *et al.,* 2005b).

A Novel Approach in Modeling Carbon Storage

When carbon is sequestered in forest and wood product pools, it is not being recycled or returned to the atmosphere as CO_2. Perez-Garcia *et al.,* (2005b) modeled carbon storage in the CORRIM project looking at the carbon storage for forest and wood product pools. They took a novel approach of looking at the carbon saved as a result of differences in the CO_2 equivalent emissions when substituting the use of wood products for non-wood materials in the construction of a house.

To determine the amount of carbon stored in the forest and wood product pools, carbon conversion factors from wood mass to carbon mass (Birdsey 1992, 1996) were used. As an approximation, dry wood can be considered to be 50% carbon by mass. The model includes all mass related to storage in trees—the canopy, the stem (tree trunk and bark), roots, litter and snags, and also considers their rate of decay. Tracking carbon from the forest pool to the product pool, they again used Birdsey (1992, 1996) for mass conversion factors.

Perez-Garcia *et al.,* (2005b) took the conservative approach of converting the harvested wood into only lumber, which has a conversion efficiency of wood-into-lumber of 50% and is considered a long-term use product with an assumed service life of 80 years, the assumed service life of a house. The remaining 50% of wood in the conversion went into pulp chips, sawdust, shavings, and bark, and were all considered short-term products or wood fuel used for production of energy. Short-term products were assumed to decay over 10 years.

The Dynamic Effects of Various Management Scenarios

Perez-Garcia *et al.,* (2005b), in their example of carbon storage, examined three components: storage in the forest, storage in wood products, and the carbon difference from the use of fuels when substituting wood for some of another material such as concrete in construction of a house. The primary goal of their study was to show the dynamic affects of various management scenarios on carbon storage.

Carbon Storage in Forests

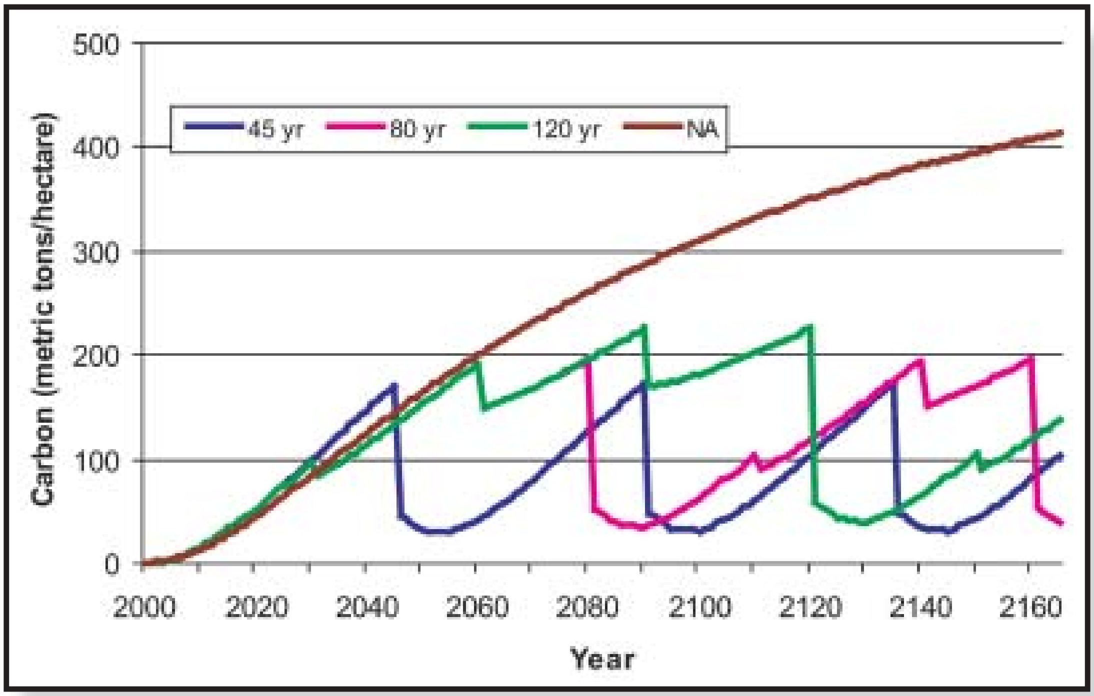

Figure 1

Carbon storage in forest pool for 45-, 80-, 120-year harvest cycles and no action (NA) taken which includes no harvesting, fires, or biological damage and should be considered a potential maximum storage (adapted from Perez-Garcia *et al.*, 2005b).

Figure 1 shows the first component of the carbon storage, the carbon stored in the forest as a result of alternative management scenarios: (a) “no-action” taken to negatively influence tree growth, whether natural or human-induced, and (b) harvesting cycles of 45, 80, and 120 years with periodic thinning. As would be predicted, the no-action scenario stores the greatest amount of carbon   Of significance, the greatest rate of carbon storage occurs in the first 50 years of growth and then the rate lessens over time; although the graph shows carbon storage increasing over time, from empirical data there is little if any increase beyond 120 years (Lippke *et al.*, 2004a). Carbon storage in these forest management scenarios does not include the carbon stores of the harvested wood used in buildings and to displace fossil intensive products which are huge sources of emissions.

Carbon storage in Forests vs. Wood Products vs. Concrete Substitution

To analyze the three components, a house design was compared using either wood or concrete framing. Both have similar construction features, such as a concrete foundation, a wood roof truss and sheathing system. One has concrete-framed exterior walls, constructed of concrete block, wood framing, gypsum, and insulation. In the second, wood was substituted for concrete, creating wood-framed exterior walls of wood studs, gypsum, and OSB sheathing. *Figure 2* depicts the comparison of carbon storage for a 45-year harvesting cycle for all three components —the forest, wood products and substituting wood for some concrete. (Perez-Garcia *et al.*, 2005b.) This figure illustrates the dramatic contribution to carbon storage as a result of substituting wood for concrete in the construction process.

Figure 3 illustrates that taking “no action” to manage a forest sequesters less carbon than when considering the management scenario of a 45-year harvest cycle, producing wood products, and substituting wood for concrete in a house construction’s exterior walls

Carbon Storage in Houses

Individual houses

A significant amount of wood products go into wood-framed house construction. For example, the CORRIM cold climate house has two stories and a full basement, for a total of 192 m^2

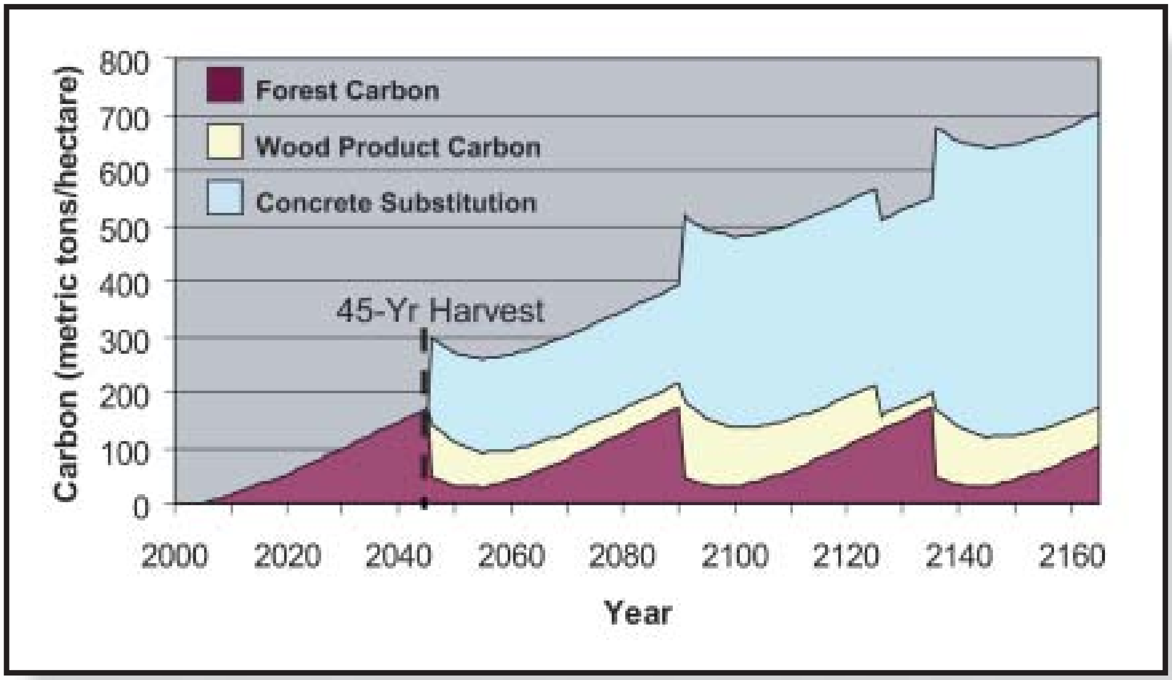

Figure 2

Carbon in the forest and product pools with concrete substitution for the 45- year harvest cycle scenario (adapted from Perez-Garcia *et al.*, 2005b).

of floor space. Its construction used 12,993 kg of wood in the form of lumber, plywood, oriented strandboard (including site construction waste), and the wood fuel to process these products. The warm climate house has a one-story concrete slab-on-grade design of 200 m^2 of floor space, and its construction took 9,811 kg of wood (Meil *et al.*, 2004).

To calculate the actual mass of wood in the two houses, the on-site waste loss and process wood fuel were subtracted from the total wood use mass. Thus, the cold climate house contains 10,411 kg of wood, while the warm climate house contains 7,078 kg. All wood products were considered to be lumber (Perez-Garcia *et al.*, 2005b).

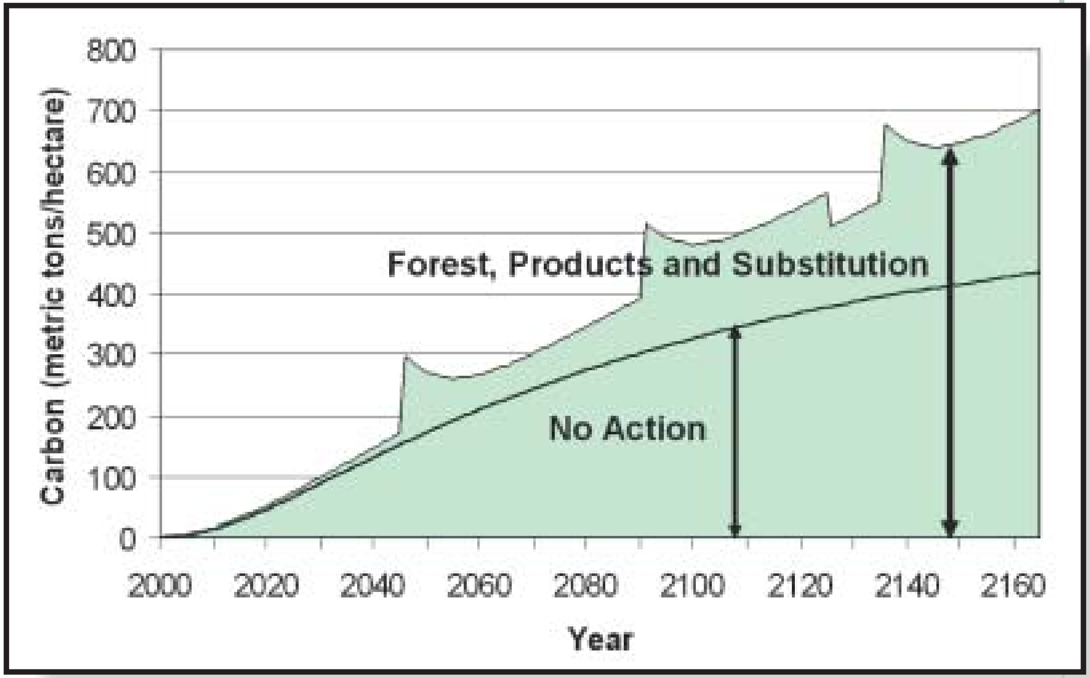

Figure 3

Total carbon over time for forest, products and concrete substitution compared to the no-action taken management scenario.

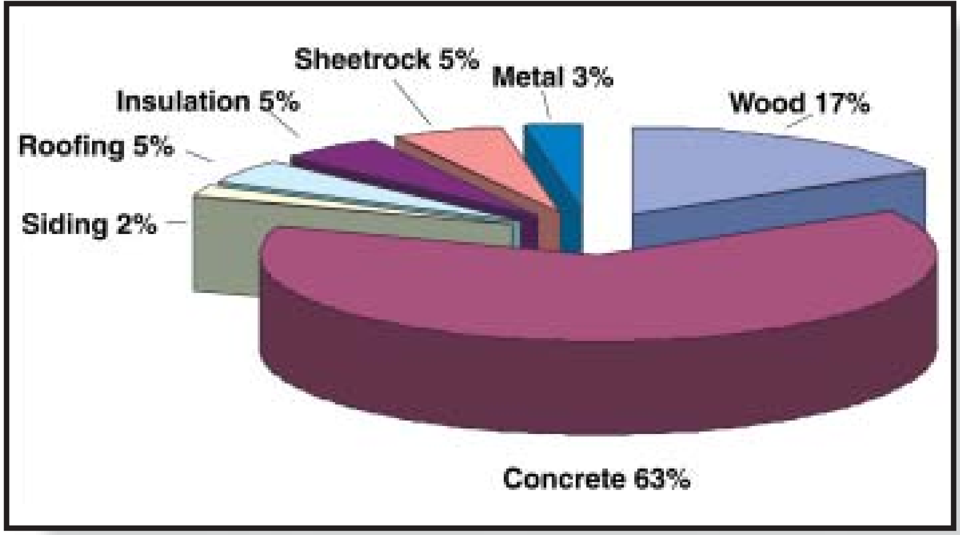

Figure 4

Cold climate wood-framed house building components by their mass.

Figure 4 shows the cold climate wood-framed house in terms of the mass of its building components. Wood represents only 17% of the total mass; concrete dominates at 63%. For the steel-framed house, the wood component drops to 8.6% and the steel component raises to 12.6%; all other components remain about the same. All house designs use a variety of common materials for their construction— wood, concrete, and steel, as well as several other materials. As with the cold climate house, it's typical that mass-wise, wood is not the largest component in a house. Normally concrete is the largest. The advantage of wood is that it can store carbon, carbon that does not occur as CO_2 in the atmosphere for at least the 80-year service life of the house, and it continues to store carbon at the end of its service life in landfills when disposed of or in products when recycled. Literature indicates that wood building products such as lumber, plywood and oriented strandboard (which excludes paper products) placed in modern landfills stay indefinitely with little or no decay, thus continuing to store carbon (Skog and Nicholson 1998).

The Global Warming Potential Index can be used to compare the environmental performance of various building materials and house designs. *Table 1* gives the GWPI for the CORRIM houses – a cold-climate design, framed in either wood or steel, and a warm-climate design, framed in either wood or concrete. CO_2 as a result of the combustion of biomass fuels is considered impact-neutral for global warming potential and is not included in the GWPI calculation. The GWPI for the steel-framed design is 26% greater than the wood-framed design, and the concrete-framed design is 31% greater than the wood-framed design.

Housing stock

Carbon in housing stock can be assessed in two ways, the carbon flow into the stock on an annual basis, also referred to as carbon flux, and the total carbon pool or store for all housing stock in the

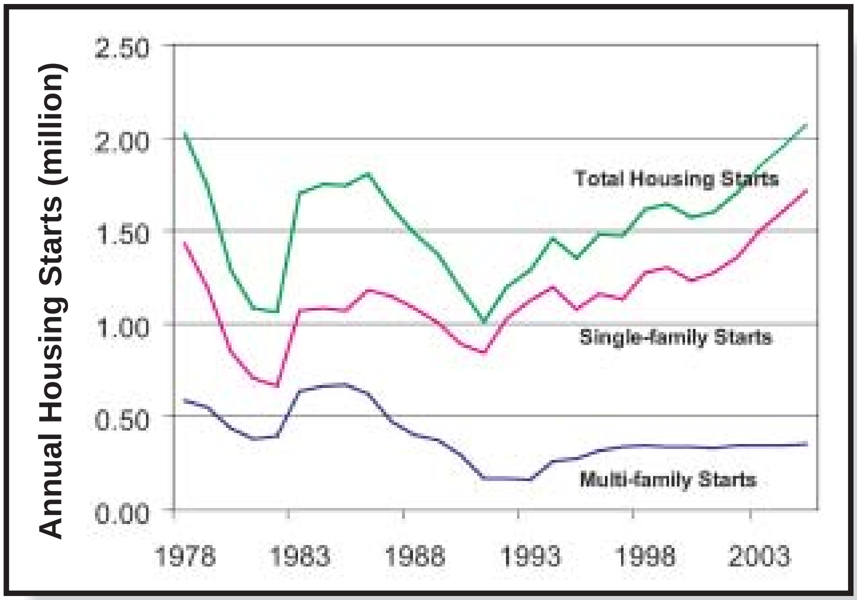

Figure 5

U.S. housing starts for 1978-2005; source NAHB (2006) based on U.S. Census Bureau data.

Table 1

Release of greenhouse gases (GHG) and the Global Warming Potential Index (GWPI) for materials, transportation, product manufacturing and construction of both CORRIM house designs

	Cold-climate house by framing type				GWPI contribution wood design
	Steel	Wood	Steel-Wood		
GHG	**kg**	**kg**	**kg**	%	%
CO_2 fossil	45,477	35,743	9,734		96.56
CO_2 biomass	526	1,547	-1,021		"
N_2O	0.227	0.211	0.016		0.17
CH_4	54.5	52.7	1.8		3.27
GWPI	46,797	37,017	9,780	26.4	

	Warm-climate house by framing type				GWPI contribution wood design
	Concrete	Wood	Concrete-Wood		
GHG	**kg**	**kg**	**kg**	%	%
CO_2 fossil	27,150	20,570	6,580		96.29
CO_2 biomass	1,291	1,388	-97		"
N_2O	0.188	0.172	0.016		0.24
CH_4	33.63	32.22	1.41		3.47
GWPI	27,979	21,362	6,617	31.0	

Meil *et al.*, 2004.

U.S. Not considered in this paper, but also of importance, are remodeling applications and other uses of wood, especially those applications where the high leverage use of wood occurs when displacing steel or concrete.

For the first method, annual starts, *Figure 5* illustrates new housing stock from 1978-2005, ranging from a minimum of 1.0 to a maximum of 2.0 million based on 2006 U.S. Census Bureau data (NAHB 2006). Using an average carbon storage mass per house of 4,380 kg for the wood structure (lumber framing, plywood sheathing, oriented strandboard), *Figure 6* shows that the carbon flow for total housing starts annually ranges from about 4.5 to 9 million metric tons. The annual average over the time period is a little less than 7 million metric tons, which translates into approximately 25 million metric tons of CO_2 removed from the atmosphere annually. The actual amount of

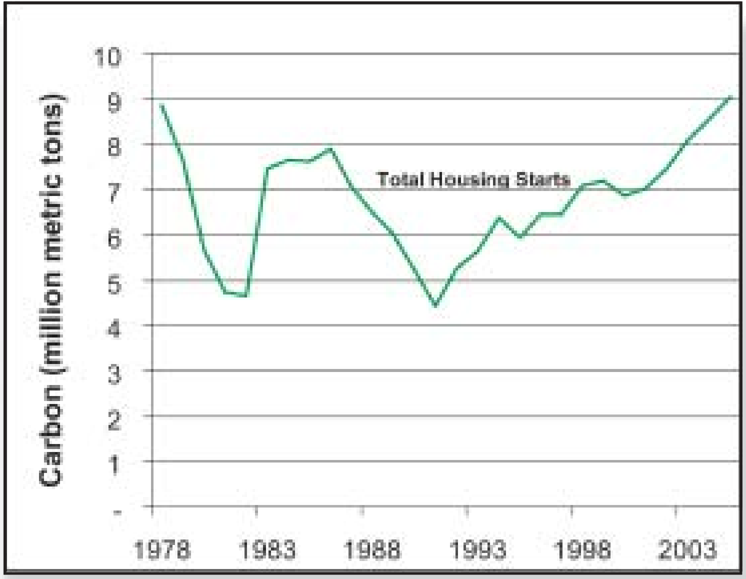

Figure 6

Annual carbon storage in U.S. housing starts 1978-2005.

Table 2

Fuel use in the production of plywood for the Pacific Northwest (PNW) and Southeast (SE) U.S.

Fuel	PNW on-site energy		SE on-site energy	
	MJ/m³	%	MJ/m³	%
Biomass fuel (wood)	1,400	87.3	1,990	85.6
Natural gas	150	9.4	277	11.9
Liquid petroleum gas	20	1.3	35	1.5
Diesel	34	2.1	23	1.0

Wilson and Sakimoto, 2005.

Note: *Energy values were determined for the fuels using their higher heating values (HHV) in units of MJ/kg as follows: liquid petroleum gas 54.0, natural gas 54.4, diesel 44.0, and wood oven-dry 20.9.*

carbon stored in a house is much larger considering the mass of other standard wood products including doors, molding and millwork, cabinets, flooring and furniture. Offsetting some of these carbon stores are those associated with houses removed annually for any reason.

Calculations for the second method, total carbon store for all housing stock, also referred to as the cumulative stock, are based on the 2003 U.S. housing inventory estimate of 120.6 million houses (HUD 2006). The service life of a house is assumed to be 80 years, with half the houses removed prior to 80 years and the other half still in service. However, this is a conservative estimate. There are about 10 million houses still in service that were built prior to 1920, thus the actual service life is likely greater. Half of all housing stock is removed as a result of zoning changes, road widening and other factors not related to the materials' functional performance over time. Total carbon stored in the U.S. housing stock, based on 4,380 kg of carbon per house and 120.6 million houses in 2003, is 528 million metric tons. This amount is equivalent to removing 1,939 million metric tons of CO_2 from the atmosphere. The flux of carbon would be the annual change in total carbon store. The more wood products used in houses, especially where they substitute for fossil-fuel intensive products like steel, concrete and plastics, the greater the carbon store, and the lesser the impact on global warming. Wood should be a material of choice for those wanting to build green.

Wood Fuel Use Reduces Global Warming

The type of fuel used in the life cycle of a product can influence its impact on global warming. The use of wood for fuel and its release of CO_2 emissions due to combustion is seen by the U.S. Environmental Protection Agency (EPA) to be impact-neutral when it comes to global warming because the growing of trees absorbs CO_2 from the atmosphere, storing carbon in wood substance and releasing oxygen to the atmosphere (EPA 2003). Simply put, the growing of trees offsets the combustion of wood fuels—essentially a closed loop. Therefore, when wood fuel is substituted for fossil fuels, the contribution to global warming is decreased.

Wood fuel generates a significant percentage of the energy used in the production of wood building products such as lumber, plywood and oriented strandboard. *Table 2*, from the CORRIM study on the life-cycle inventory of plywood production (Wilson and Sakimoto

Table 3

Fuel use in the life cycle of a wood building product from the generation of the forest through product manufacturing; includes all fuels and feedstock to produce and deliver electricity, resin, wood and product

	Pacific Northwest Production				Southeast Production				
Fuel Source	**Glulam %**	**Lumber %**	**LVL %**	**Plywood %**	**Glulam %**	**Lumber %**	**LVL %**	**Plywood %**	**OSB %**
Coal	3.9	2.5	4.2	3.6	13.7	10.2	13.9	12.0	11.4
Crude oil	9.9	9.7	15.1	13.4	14.7	9.7	13.2	13.4	16.9
Natural gas	36.5	39.1	33.3	24.7	32.2	8.0	35.0	27.2	34.2
Uranium	0.6	0.2	0.3	0.3	1.3	1.0	1.0	0.9	1.0
Biomass (wood)	42.1	43.0	37.2	49.5	37.5	70.8	35.8	45.5	35.5
Hydropower	7.0	5.4	9.8	8.5	0.3	0.1	0.7	0.8	0.9
Other	0.0	0.1	7.0	0.1	0.2	0.2	0.3	0.3	0.2
Total energy (MJ/m^3)	**5,367**	**3,705**	**4,684**	**3,638**	**6,244**	**3,492**	**6,156**	**5,649**	**11,145**

Puettmann and Wilson, 2005a.

2005), documents that wood fuel comprises about 86% of the total on-site manufacturing facility fuels, which also include natural gas, liquid petroleum gas (LPG) and diesel. Wood fuel and natural gas are used to heat veneer dryers, hot presses, and logs prior to peeling. The LPG is used to operate fork lift trucks in the facility and the diesel is used to operate log haulers in the facility's yard. Similar percentages of wood fuel use are seen for the production of oriented strandboard (Kline 2005) and Southeast lumber (Milota *et al.,* 2005). For Pacific Northwest lumber, wood fuel use is only about 65% of total fuel use on-site (Milota *et al.,* 2005). The wood used for fuel makes use of low-valued bark and wood residuals and does not compete with higher-valued and higher-leveraged product substitutes. Economics of the high cost of fossil fuel and readily-available, low-valued wood fuels has driven its current high use. Sufficient low-valued wood residuals remain to provide additional fuel for heat and to generate electricity.

Wood fuel, or biomass energy, also represents a significant portion of the total cradle-to-gate energy needs for the production of wood products. Total energy is determined from the planting or natural regeneration of tree seedlings (referred to as the cradle), to managing the forests, harvesting, transporting logs to the production facility, and product manufacturing (referred to as the gate). The energy also includes the feedstock and fuel needed to produce and deliver the resins for the production of glulam, laminated veneer lumber, plywood, and oriented strandboard, and includes all the fuels to generate electricity and fuels, and to deliver them to the production facility.

Table 3 gives a breakdown of the cradle-to-gate fuel uses for each of the wood products produced in the Pacific Northwest and the Southeast (Puettmann and Wilson 2005a). Biomass fuel represents a significant portion of the energy needs, ranging from a low of 36% for oriented strandboard (OSB) to a high of 71% for Southeast lumber. The totals at the bottom of *Table 3* show the total energy needed to produce a unit volume of product.

Table 4

Carbon dioxide (CO_2) emissions in the cradle-to-gate life cycle of a wood building product from the generation of the forest through product manufacturing

	Pacific Northwest Production				Southeast Production				
Emission	Glulam kg/m^3	Lumber kg/m^3	LVL kg/m^3	Plywood kg/m^3	Glulam kg/m^3	Lumber kg/m^3	LVL kg/m^3	Plywood kg/m^3	OSB kg/m^3
CO_2 (biomass)	230	160	141	146	231	248	196	229	378
CO_2 (fossil)	126	92	87	56	199	62	170	128	294

Puettmann and Wilson, 2005a.

Emissions of CO_2 by fuel source, whether for fossil or biomass sources, can also be tracked through the cradle-to-gate life cycle of a product. *Table 4* gives the CO_2 emissions for the production of various wood products (Puettmann and Wilson 2005a). CO_2 emissions from fossil fuels range from 56 to 294 kg/m^3 of product. The CO_2 biomass emissions are given as a separate category since biomass fuel combustion is considered impact-neutral for global warming. Fossil fuel CO_2 emissions represent an opportunity to reduce global warming by substituting the use of wood fuel for fossil fuel at the plant site for process energy and for the generation or co-generation of electricity.

Ways to Foster Increased Use of Wood Products and Wood Fuel

Since the use of wood products and related practices can reduce greenhouse gases, which in turn reduces global warming, it would be wise to implement ways that foster their use in a manner that would be both economical and good for the environment. A strategic position should be taken that develops a pathway for new practices, policies, research, and education in order to identify preferred forest management practices, wood products, and opportunities for further product development and improved building design. There are many opportunities for increased efficiencies, and for wood products and biofuel to replace fossil-fuel intensive products and fossil fuels.

Individuals, companies, universities, government agencies, and legislators could all participate in promoting the wise use of wood. For example: identifying and implementing forest management practices that best meet a diverse set of objectives that include carbon storage, and adopting green building practices that highlight the superior environmental performance characteristics of wood building products. Other actions could include standards and guidelines for buildings that encourage the substitution of wood products for fossil-fuel-intensive products like concrete, steel and some plastics, and promoting the increased use of wood fuels.

Implementing ways to increase the favorable environmental performance of wood by modifying practices and increasing its use can be both good for the environment and cost-effective. In addition to the already competitive position of wood products, other incentives can be developed such as tax incentives for reducing emissions, improving energy efficiencies, and supporting renewable energy technologies. Another approach is to foster the trading of carbon credits that consider the benefits of using long-lived wood products as a storehouse for solar energy. The wood products industry is recognized as having greenhouse gas assets and can generally be considered as a seller of tradable CO_2 allowances. For example, the newly-started Chicago Climate Exchange trades credits at about $4.00 per metric ton of CO_2 (CCX 2006).

This trade price would be expected to increase with marketplace maturity, considering that the more established European Climate Exchange currently trades credits at about $21.00 per metric ton of CO_2 (ECX 2006). New non-wood products or processes that emit large quantities of CO_2 from the combustion of fossil fuels could buy credits from the wood products industry which could be used to help finance process or product improvements.

Considerable data on the favorable environmental performance of wood as a building material already exist through CORRIM (Bowyer *et al.,* 2004) and the U.S. LCI Database (NREL 2006) to use as a basis for promoting its use to reduce greenhouse gas emissions. To support a strategic policy shift we should embark upon an outreach education program that promotes wood's use to the consuming public, industry, government agencies, builders, architects, engineers and legislators.

Summary

The use of wood products can reduce the amount of CO_2, a major greenhouse gas, in the atmosphere, which in turn may reduce global warming. Wood can accomplish this in several ways: storing carbon in forest and wood products, as substitution for fossil-fuel intensive products like concrete and steel in housing construction, and as biomass that replaces fossil fuels to generate process heat and electricity.

When trees absorb CO_2 from the atmosphere, carbon is stored in wood at about 50% of its mass. Trees release oxygen back to the atmosphere. The carbon remains in wood in a forest or product until it is either combusted, or chemically or biologically decomposed, returning CO_2 to the atmosphere. A significant amount of carbon is stored in the forest and in wood products for a long period of time. Carbon is stored in wood products in houses, which remain in service, on average, for at least 80 years; at the end of its service life it is stored in modern landfills for even greater duration.

Total carbon stored in wood products, or saved when wood is substituted for a material such as concrete in house framing, can be greater than the total carbon sequestered in a forest where no action is taken in terms of harvesting, fire or biological damage.

The production of wood building materials—glulam, lumber, plywood, laminated veneer lumber, and oriented strandboard —uses significant quantities of wood fuel to generate process heat, and sometimes electricity. Using wood fuel instead of fossil fuel also helps to reduce global warming, since its CO_2 emissions are considered to be impact -neutral for global warming, whereas the combustion of fossil fuels is not.

Wood presents opportunities for reducing global warming by growing more trees, managing the forest, producing wood products that are used in long-term applications, using more wood to build houses rather than fossil-intensive substitutes like steel and concrete, and substituting the use of wood fuel for fossil fuels. This can be good for the environment and still be economical when considering the high price of fossil fuels, tax incentives and carbon credits. Policies and practices are needed to further promote the use of wood for this purpose.

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CHAPTER EIGHT

HIGHLIGHTS:

EMERGING MARKETS FOR CARBON STORED BY NORTHWEST FORESTS

Introduction

- The capacity to store carbon can be turned into a marketable product.
- Such a market for forests poses some unique challenges and unique benefits.

Do Forests Matter?

- Deforestation since 1850 has been a major source of CO_2 buildup in the atmosphere.
- The U.S. has the potential to mitigate 384 million metric tons of CO_2 annually.

Market-based Approaches to Reducing Greenhouse Gas Emissions

- Regulatory approaches include cap-and-trade systems and emission trading schemes.
- Voluntary approaches include carbon offsets.

Current and Developing Mechanisms and Markets for Emission Reduction

- Kyoto Protocol treaty signators are establishing programs; largest is the European Union trading scheme, with a 2005 market value of $8.2 billion.
- Non-Kyoto signators U.S. and Australia, states and others are setting emission targets.
- A voluntary carbon market is emerging; in 2005, 10-20 mmt of carbon were transacted.

Understanding Carbon Offsets

- Carbon offset projects must cancel out emissions and be recorded in a registry.
- Land management-based forest offsets can include afforestation, reforestation, avoiding deforestation, and changing forest management practices.
- Substitution-based offsets substitute wood for other products or energy creation.
- Challenges include permanence, ownership and legal title, insurance and vintaging.

Co-Benefits and Ecosystem Services

- Offset projects can generate additional environmental and social co-benefits, such as job generation, habitat enhancement, water quality improvements and recreation.
- Ecosystem services can be “bundled” to further capitalize on financial opportunities.

Summary: Options for Oregon Forests

- Collaboration between the forest industry and environmental groups.
- Establishing a cap-and-trade system.
- Pursuing a regional carbon market trading system.
- Investing in infrastructure to support an active carbon market.
- Investing in the intellectual capital needed for market development.
- Developing trading patterns.

CHAPTER EIGHT

EMERGING MARKETS FOR CARBON STORED BY NORTHWEST FORESTS

Bettina von Hagen and Michael S. Burnett

Forests, particularly the long-lived, carbon-rich forests in the Pacific Northwest, have a significant role to play in mitigating greenhouse gas emissions. In this chapter we explore how this carbon storage value can be turned into a marketable product, and examine the state of development of emission trading markets and the role that forest carbon plays in them. Relative to other emission reduction strategies – such as energy efficiency, renewable energy, or shifting to lower carbon energy sources – carbon sequestration in forests poses some unique challenges, but also offers some unique benefits.

After exploring these, we describe how the Climate Trust –an Oregon-based non-profit and the largest institutional buyer of carbon offsets in the United States – chooses among projects, and how it selected and funded one of the first forest carbon purchases involving reforestation under a regulatory system. We conclude with some thoughts about the role forest carbon offsets might play in forest management in the region, and the steps needed to develop robust markets.

Do Forests Matter?

How significant is forest carbon to the global challenge of greenhouse gas accumulation? Human-induced degradation of forests has been a major source in the buildup of greenhouse gases in the atmosphere. Over the last 150 years (from 1850 to 1998), an estimated 500 billion metric tons (over one quadrillion pounds) of carbon dioxide have been released into the environment from deforestation (IPCC 2001). This source of atmospheric carbon dioxide increase is second only to the combustion of fossil fuel, which contributed almost 1,000 billion metric tons of carbon dioxide during the same period (Schlamadinger and Marland 2000). Globally, the current standing stock of carbon in forest vegetation (including savannas), exclusive of soil carbon, represents the equivalent of 1,560 billion metric tons of carbon dioxide (IPCC 2000). This remaining carbon stock is over sixty times larger than current annual global fossil fuel-related emissions, which totaled 24.4 billion tons,(EIA 2005). A relatively small change in this stock – on the order of 1.6% – would be equivalent to annual global carbon dioxide emissions from fossil fuels. Relatively small proportional reductions in this stock have the potential to contribute to carbon dioxide buildup, as has occurred in the past. Conversely, relatively small proportional increases in this stock have the potential to contribute to mitigation of fossil-based emissions.

Since deforestation has been such a major source of carbon dioxide buildup, it is possible to utilize forests to help remove some of the accumulated carbon dioxide from the atmosphere, if we manage lands to increase forest biomass. This potential for the terrestrial biosphere to serve as a carbon sink is sizable. Nationwide for the United States (U.S.), afforestation and forest management have the potential to mitigate a total of 384 million metric tons of carbon dioxide per year (USEPA 2005), which is 6.5% of the nation's total carbon dioxide emissions of 5,842 million metric tons.

Scientific evidence of (WRI 2006) and concern about (National Academies of Science 2005) climate change continues to grow. For a society increasingly concerned about climate change, it is prudent to move forward on mitigation on all fronts. One key challenge is enacting policies that will result in increased forest biomass.

Greater use of natural sinks for carbon dioxide is one of a number of currently available strategies – along with energy efficiency, renewable energy, nuclear energy, coal to gas conversion, and geological sequestration, among others – that can be combined to significantly flatten the growth in emissions over the next 50 years (Pacala and Socolow 2004). Clearly, it is important to establish a set of effective mitigation policies, and forestry has an important role to play. This is particularly true in the forests of the Pacific Northwest, where long-lived trees and fast growth rates combine to produce some of the most carbon-rich ecosystems in the world (Smithwick *et al.,* 2002).

Market-based Approaches to Reducing Greenhouse Gas Emissions

Policies can be in two basic forms: regulations and incentives. A regulatory approach is one where requirements to reduce carbon dioxide emissions are put into place. For forestry, an example would be a requirement to conduct selective harvest, leaving a minimum amount of standing biomass in each logging operation. An incentive approach is one where a monetary reward is provided to encourage a desired outcome, for example, establishing a payment system to support the build up of biomass. There are a number of regulatory and incentive approaches for encouraging forest carbon sequestration. In this chapter we focus on how an incentive-based market approach – carbon offsets – can, and is, being used to stimulate behavioral changes that cause sequestration to occur. As we gain more experience with these market mechanisms and the pace and consequences of global warming, we will have to decide on the best—or the best mix—of policies and instruments to reduce emissions. From the perspective of forest sequestration, a regulatory policy approach – for example, a fossil fuels emission cap – may lead to an incentive policy approach – the market for emissions reductions.

The approach currently favored in international, national, regional, and state climate policy involves market-based environmental regulation. Governments are beginning to implement greenhouse gas emissions caps as a means of reducing future climate change. These caps typically apply to power plants, and some apply to industry and large commercial operations as well. These “cap-and-trade” systems are a modern form of environmental regulation which are being implemented in lieu of “command and control” technology regulation. Such market-based mechanisms for regulating greenhouse gases provide flexibility for business while ensuring that the goal of reducing emissions is met. Under this approach, once a cap on fossil fuel-based emissions is established, entities subject to the cap can trade emissions reductions. An entity that achieves reductions below its cap can sell this surplus to an entity whose emissions exceed its cap. This type of emissions trading scheme is viewed with concern and skepticism by some in the environmental community, who consider this approach to be unproven and believe that polluters should be obliged to reduce emissions at their own facilities rather than by purchasing reductions achieved by others.

Market-based greenhouse gas regulatory systems are a relatively new phenomenon, but they typically allow four mechanisms for compliance: (1) internal emissions reductions, (2) purchase of allowances in an auction, (3) trading of allowances, and (4) purchase of project-based emissions reductions, also know as “carbon offsets” or “carbon credits” – the focus of this chapter. In some trading schemes, a portion of the allowances – the government-granted right to emit – are auctioned off to the highest bidder. In this case, a company can outbid others subject to the cap if it can’t reduce its facility emissions sufficient to meet the cap. Alternatively, a company can buy allowances from a company whose allowances exceed its emissions. Finally, most trading schemes allow for the purchase of offsets from projects in sectors that are not subject to the cap, although the amount, type, and location of offsets is restricted under many trading schemes. Offsets are viewed as a cost-effective tool to be used to meet greenhouse gas reduction targets; when they are not the lowest cost of the four options, then they are not likely to be used for compliance.

It is important to note that not all emissions are likely to be subject to a cap. For example, personal and business automobile use is unlikely to be capped directly. Likely policies to influence emissions from auto use include requiring more efficient vehicles, adding a carbon tax to increase the purchase price of gasoline or increasing the attractiveness of mass transit. Emissions related to land use change, such as farming and forestry activities, are more challenging to cap. Since emissions accounting on a national level includes these sectors, other types of regulations might be put into place that require certain carbon-storage enhancing land management practices.

To summarize, a capped entity can meet its cap by making reductions at its own facilities, by buying allowances in an auction, and by purchasing reductions from capped entities with surplus reductions. In addition, a capped entity can purchase reductions, i.e, carbon offsets, from a greenhouse gas reduction project. These projects reduce emissions by either preventing the release of greenhouse gases, or by sequestering carbon in vegetation or soil. While this latter strategy – carbon sequestration in forests – is the focus of this chapter, forest carbon projects compete in a global marketplace with a wide array of reduction projects, so it is important to understand the universe of carbon offset strategies, and their relative strengths.

Greenhouse gas reduction projects include three basic strategies: (1) energy efficiency and conservation (improving energy efficiency in buildings, transportation, factories and power plants), (2) shifting to lower-carbon energy sources (from coal to natural gas, for example, or developing renewable energy sources such as solar, wind, tidal, hydropower, or biofuels), and (3) preventing the creation, release or combustion of industrial greenhouse gases such as hydroflourocarbons and of methane (produced primarily by landfills and livestock). While these industrial and agricultural greenhouse gases – namely methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons – have much smaller concentrations in the atmosphere than carbon dioxide, they are important because their global warming potential is very high – 20 to 10,000 times higher than the effect of releasing the same mass of carbon dioxide. As a consequence, many of the early offset projects have focused on reducing emissions of industrial gases (Capoor and Ambrosi 2006).

Sequestration projects include geological sequestration (for example, capturing power plant emissions and storing them underground in geological formations), agricultural sequestration (capturing carbon dioxide in agricultural soils), and forest sequestration, which includes forest conservation (avoiding deforestation), planting trees, and managing existing forests to enhance carbon storage (for example, by extending rotations). Ocean sequestration, and sequestering carbon in marine environments such as kelp forests, is another potential strategy (Parker, 2004) which has tremendous potential but has not yet been translated into a commercial carbon offset purchase.

For a variety of reasons, forest sequestration projects have captured only 1-2% of the $10 billion global carbon market, while reducing industrial greenhouse gas emissions – especially hydrofluorocarbons – has captured over 60% of the global carbon market (Capoor and Ambrosi 2006). While forest carbon projects pose some unique challenges – such as whether the carbon storage is permanent, as discussed below – the primary reason for the small representation of forest projects is that the rules established by the Kyoto Protocol (described below) do not favor forest projects. This is largely because of the initial resistance by the environmental community to forest sequestration projects, preferring to focus the attention of emitters on directly reducing emissions, rather than offsetting them. However, increased recognition of the scale of carbon dioxide emissions from forest conversion and forest fires is leading to increased acceptance of forest carbon projects. Oregon's rules, established in 1997 for new power plants, allow forest projects, and over 20% of the carbon offset projects generated by the Oregon Carbon Dioxide Standard (and implemented primarily through the Climate Trust) involve forestry. This illustrates the importance of market trading rules in project selection, and the capacity of Oregon to influence state, regional, and national markets through creating a robust and rigorous market for forest carbon.

Current and Developing Mechanisms and Markets for Emission Reductions

The most significant system to address global climate change is that established by the Kyoto Protocol – the international agreement made under the United Nations Framework Convention on Climate Change. The treaty was first negotiated in Kyoto, Japan in December, 1997, and came into force in February, 2005, following ratification by Russia. The U.S. and Australia are both signatories of the Framework Convention, but have not ratified the Kyoto Protocol to date. Because of this, news coverage of carbon markets in the U.S. is limited and many of us imagine there is not much happening. In the meantime, the value of the global aggregated carbon markets was over US $10 billion in 2005, the first year the Kyoto Protocol was in effect (Capoor and Ambrosi 2006), larger than the entire $7.1 billion domestic wheat crop (Timmons 2006). In countries that have not ratified Kyoto – most notably the U.S. and Australia – regulatory systems to control emissions are emerging at local, state, and regional levels. In addition, a voluntary market for carbon is also emerging, along with its own rules, intermediaries, and pricing structures. Each of these three segments – Kyoto markets, other regulatory systems, and the voluntary market – is described below.

The Kyoto Protocol and its Market Mechanisms

Countries that ratify the Kyoto Protocol commit to reduce (or limit the increase) of carbon dioxide and other greenhouse gases. The Protocol establishes emissions trading as a method of meeting country targets. A number of international, regional, and country programs have emerged to facilitate the meeting of targets under Kyoto. The largest of these to date (from a value perspective) is the multinational European Union Trading Scheme, in which all 25 member countries of the European Union participate. In 2005 – the market's first year of operation – 362 million metric tons of carbon dioxide were traded, with a market value of $8.2 billion. The price of carbon dioxide increased steadily to about $36 per metric ton in April, 2006, leading to enthusiastic predictions of robust market growth to $80 to $250 billion by 2010. After an active first quarter with $6.6 billion traded, the market crashed in May, 2006, to $13 per metric ton of carbon dioxide (and rebounded somewhat shortly after) on reports that many industries were easily meeting their targets and didn't need to reduce emissions further, largely because their initial allocation of allowances had been set too high. While some argue that the market crash was an indication of structural flaws in the trading system, others argue that "price corrections" are an inevitable component of emerging markets (Capoor and Ambrosi 2006).

In terms of volume of metric tons, the largest market segment in 2005 was the Clean Development Mechanism (CDM), a program developed under the Kyoto Protocol which allows companies or countries in the industrialized world to purchase credits generated by offset projects in the developing world to meet their emission reduction targets (Point Carbon

2006). In 2005, CDM projects generated a forward stream of reductions totaling 346 million metric tons of carbon dioxide, with a value of $2.5 billion. Over 70% of these projects come from hydrofluorocarbon projects in China. Joint Implementation is the sister mechanism to CDM and allows industrialized countries to meet their emission reduction targets through an investment in another industrialized country, which also has emission reduction targets but where costs might be lower and investments can be made more efficiently. The Joint Implementation market totaled 18 million metric tons of carbon dioxide in 2005 with a value of $82 million (Capoor and Ambrosi 2006).

The European Union Trading Scheme, the Clean Development Mechanism, and Joint Implementation all operate under rules designed to meet targets established under the Kyoto Protocol. Most significantly for the forest carbon sector, the role of sequestration offsets under these rules is limited. The Kyoto Protocol does recognize the role forests can play in removing and storing carbon dioxide from the atmosphere and storing it in trees, and establishes two mechanisms for creating forest carbon sequestration credits: Article 3.3 addresses afforestation (planting trees on lands that were not previously forested), while Article 3.4 deals with reforestation (replanting trees on deforested lands) and appropriate management of natural forests. However, avoided deforestation and forest management are currently not eligible under Kyoto in the first commitment period (2008-2012). Due to stringent application standards and complicated rules, uncertainty over the role of forest sinks after the initial commitment period of 2008-2012, and resistance by environmental groups and others to the use of forest sequestration projects in trading schemes, forest carbon projects have been very limited under the Kyoto-compliant systems (Sedjo 2006).

Markets for Emission Reductions in the U.S. and Other Non-Kyoto Countries

While the U.S. has not ratified the Kyoto Protocol, regions, states, tribes, and local governments have all been active in setting emission reduction targets and implementing programs to reach these targets. Oregon was an early innovator and the first state to establish a regulatory framework. In 1997, the state required new power plants to offset part of their carbon dioxide emissions. The Climate Trust was created at that time to purchase quality offsets on behalf of these newly regulated emitters. Washington added a similar regulation in 2004. In addition, Oregon's governor-appointed Carbon Allocation Task Force is investigating the design of a load-based cap-and-trade system. A load-based system places the cap on the utility delivering the electricity rather than on the electric generator. It is likely to include offsets as an alternative compliance mechanism. In California, Governor Schwarzenegger issued an Executive Order to establish greenhouse gas emissions goals and create a Climate Action Team to determine the best means to meet such goals. California has also established a voluntary system of reporting emissions, the California Climate Action Registry, and there are several proposed pieces of legislation, including Assembly member Pavley's California Climate Change Act of 2006. In addition to initiatives under consideration in Oregon and California, several other states are at various stages of establishing climate policy.

The Climate Trust is the largest institutional buyer of carbon offset projects in the U.S. Sidebar 1 describes the Climate Trust's criteria to determine eligibility for funding and selection for carbon offset projects. Sidebar 2 describes the Climate Trust's process for originating offset projects.

Sidebar 1

The Climate Trust's Criteria to Determine Eligibility for Funding and Selection for Carbon Offset Projects

The Climate Trust, an Oregon-based non-profit, is the largest institutional buyer of carbon offsets in the United States. It plays an important role in the implementation of Oregon's Carbon Dioxide Standard. Its focus is acquiring high quality offsets. In 2005, the Climate Trust released a request for proposals for a minimum of US$ 4.3 million in carbon dioxide offsets,[1] a similar request to those from 2000 and 2001.[2] All proposals contained the following criteria that the Climate Trust uses (1) when determining which proposed offset projects are eligible for funding, and (2) when selecting among proposed offset projects. These criteria are presented as an example of the criteria applied by a buyer of offsets. Other buyers of offsets use different, but generally similar, criteria.

Number and Size of Projects. The Climate Trust sought projects requesting $1 million or greater in carbon funding and anticipated entering into carbon purchase agreements with 2-5 projects.

Type of Greenhouse Gas. As required by Oregon statute, The Climate Trust only considered offsets that directly avoid, displace, or sequester emissions of carbon dioxide when using Oregon funds. Although the Climate Trust did not consider emissions reductions of other greenhouse gases for purposes of quantifying emissions reductions, it did consider these when evaluating co-benefits.

Additionality Requirement. The Climate Trust only funded projects where mitigation measures would not occur in the absence of offset project funding. In order to meet the additionality criterion, evidence must be provided that the carbon funding is essential for the implementation of the project. The Climate Trust assesses additionality on a project-by-project basis.

Regulatory Surplus. The Climate Trust considered only projects where the carbon dioxide emissions benefit is over and above what is required by law. An emission reduction is surplus if it is not otherwise required of a source by current regulations or other obligations.

Quantifiability of Offsets. The Climate Trust considered only projects that directly avoid, displace, or sequester the emissions of carbon dioxide, and where the amount of carbon dioxide offsets can be quantified, taking into consideration any proposed measurement, monitoring, and evaluation of mitigation measure performance.

Timing of Project Implementation. The Climate Trust considered only projects where mitigation measures will be implemented in the future, subsequent to contract execution. The Climate Trust did not consider projects where mitigation measures have been implemented prior to contract execution. Projects selected for funding must be implemented within three years from the date of execution of the carbon purchase agreement.

Length of Project Contract. The Climate Trust typically does not enter contracts with terms longer than 15 years irrespective of the lifetime of the measures implemented under the contract. Thus, if the underlying measure has an expected life of more than fifteen years, the Climate Trust will contract for a maximum of fifteen years of carbon dioxide offsets. One exception to this is biological sequestration projects which typically require a longer project life.

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[1] *The Climate Trust, 2005*

[2] *The Climate Trust, 2000; The Climate Trust, 2001*

Permanence. The Climate Trust prefers projects that permanently avoid or displace emissions of carbon dioxide, such as energy-related projects, over projects that temporarily sequester carbon. The Climate Trust has invested in projects that avoid emissions or in permanent sequestration projects, i.e., those that plan to grow a forest harvest-free to old growth.

Types of projects. The Climate Trust considered any and all project activities that reduce carbon dioxide based emissions. Please be advised of the treatment of the following sectors:

Nuclear Power. As Oregon law does not permit the siting of nuclear power facilities, the Climate Trust does not fund nuclear power-based offset projects.

Biological Carbon Sequestration (includes afforestation, reforestation, forestry conservation, etc.). As a large portion of the Climate Trust's offset portfolio is currently invested in biological sequestration projects, it did not anticipate spending more than 25% of the funds from this 2005 RFP in biological sequestration projects.

Eligible Project Proposers. The Climate Trust accepted proposals from any non-profit and for-profit corporations, government agencies, national laboratories, and combinations of these parties.

Project Price Range. The Climate Trust used cost effectiveness as the primary selection factor for offsets, while achieving a balance between the desire to acquire the least expensive reasonably assured offsets available with the desire to acquire a diverse portfolio of projects. The Climate Trust anticipated that \$5/metric ton CO_2 would be a competitive proposal.

Geographic Limitations and Preferences. The Climate Trust has no geographic constraint on the projects that can be funded. Note for international project applicants: Non U.S.-based projects must have a U.S. partner or affiliate organization that can be used for negotiations of the carbon purchase agreement. The Climate Trust encouraged applicants with projects based in Oregon to submit proposals.

Co-Benefits. The Climate Trust prefers projects with environmental, health, and socioeconomic co-benefits, and will request information on co-benefits from proposers. Special consideration was given to projects with excellent co-benefits.

Monitoring and Verification. The Climate Trust requires that carbon dioxide benefits be quantified by a monitoring and verification process. National and international experts are engaged to help prepare and implement monitoring and verification protocols for its offset projects, and independent third parties are required to certify the emissions benefit. It is important that realistic baselines be used as a starting point for quantifying offsets. (See Chapter 9 regarding baselines and leakage.)

Leakage. The Climate Trust requires that the potential for leakage, or the extent to which events occurring outside of the project boundary tend to reduce a project's carbon dioxide emissions benefit, be addressed. Proposals were required to describe how carbon dioxide benefit leakage is addressed by the project, both in terms of project activities to minimize leakage and in terms of adjustments to the project's carbon dioxide benefit calculations to reflect leakage.

Sidebar 2

The Climate Trust's Process for Originating Offset Projects

The Climate Trust uses a systematic, sequential process for acquiring offsets. The following flowchart is taken from the Climate Trust's five year report.[3] From a proposer's point of view, there are three phases to the Climate Trust's project selection process. It typically takes around 18 months from the time of the announcement of an RFP until the final carbon dioxide purchase agreements are completed.

Phase I: Submission of Project Information Document. This is a "short form" proposal comprised of ten pages of text, a budget spreadsheet, and an emissions benefit spreadsheet.

Phase II: Detailed Project Information Document. Selected proposals are invited to submit a more detailed project information document, including responses to project-specific questions from the Climate Trust.

Phase III: Contract negotiations. Winners of Phase II are invited to negotiate a carbon dioxide offset purchase agreement. The amount of the funding and its terms are set forth in the final purchase agreement.

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[3] *The Climate Trust, 2004*

At the regional level, the fastest-moving initiative is the northeastern states' Regional Greenhouse Gas Initiative, known as RGGI. As of May, 2006, it included Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, Vermont, and Maryland. The draft rules, which are expected to be finalized in the summer of 2006, address electric generating units capable of producing 25 megawatts or more power, and commit participating states to cap their emissions at 1990 levels by 2009 and then decrease them by 10% by 2018. RGGI has proposed allowing an entity to use offsets to meet approximately 50% of the required emissions reductions (or 3.3% of total emissions). If prices rise beyond the expected level of $10 per metric ton of carbon dioxide, then additional percentages of emissions may be covered by offsets. In addition, as prices rise, a greater proportion of the offsets may take place outside of the region covered by the participating states (Biello 2006).

Although ratification of the Kyoto Protocol by the U.S. is unlikely in the near future, emission reduction discussions continue both at the national level and at the international level outside of the Kyoto framework. At the national level, the Climate Change White Paper recently issued by Senators Domenici and Bingaman includes a discussion about an offset pilot program, the McCain-Lieberman Climate Stewardship Act allows entities to use offsets for up to 15% of their required reductions, and Senator Feinstein's Strong Economy and Climate Protection Act includes unlimited offsets from the uncapped agricultural sector. At the international level, the Asia-Pacific Partnership on Clean Development and Climate, which includes Australia, India, Japan, the People's Republic of China, South Korea, and the U.S. outlines a non-binding plan to cooperate on development and transfer of technology that enables reduction of greenhouse gas emissions. Member countries account for around 50% of the world's greenhouse gas emissions, energy consumption, Gross Domestic Product, and population.

Despite these developments, it is important to note that in the U.S. we are still in the initial stages of what has been termed the "carbon market." In fact, it is not a true market yet in the classic definition. There are few buyers, few sellers, rare transactions, and limited information about the transactions. Carbon trading in the U.S. is best viewed as a proto-market, one in which there is not yet a true financial market commodity available to buy and sell. A broader national market for emissions reductions will no doubt come in time, but it is not here today. It is possible that it will develop first on the basis of the state and regional regulatory initiatives described above, with a federal trading scheme coming later. What we do have today are a series of individual transactions involving allowances from voluntary exchanges and from project-based offsets, some of which involve forestry.

Australia, as the other notable country that has failed to ratify the Kyoto Protocol, is also developing emission reduction schemes at the state level. New South Wales, the state in southeastern Australia which houses Sydney, high mountains and coast, and is the state with the most economic activity, has been the leading innovator. The New South Wales greenhouse gas abatement scheme is based on a penalty of AU$10.50 (US $8) for excess greenhouse gas emissions over the energy pool target. The target equates to a 5% per capita reduction in emissions from the electricity sector over a five year period which began in 2003 (Brand and Kappalli n.d.). In 2005, some 6.1 million certificates were exchanged, a 20% increase over 2004, with an estimated value of US $57.2 million. Activity increased sharply in the first quarter of 2006 with 5.5 million certificates valued at US $86.6 million. Forestry projects are allowed, reflecting perhaps the strong leadership role of State Forests of New South Wales, the government-owned forest agency, which has been active since the mid 1990s in developing forest carbon opportunities and structure. In April, 2005 a deal was closed to provide approximately 3.2 million tons of carbon dioxide offsets from 30,000 hectares of eucalyptus plantings (Capoor and Ambrosi 2006).

The Voluntary Carbon Market

In addition to Kyoto-compliant market mechanisms and state regulatory systems in countries that have not ratified the Kyoto Protocol, there is an emergent voluntary carbon market that – while there are no official numbers— is estimated to have transacted anywhere from 10 to 20 million metric tons of carbon dioxide in 2005. This is approximately the amount traded in the European Union Emissions Trading Scheme in a single week in April, 2006 (Bayon *et al.,* in press), illustrating the power of regulation to stimulate market activity relative to voluntary action. This is a significant point to bear in mind, given the current federal administration's preference for voluntary programs to reduce carbon emissions.

Estimates suggest the voluntary carbon market may grow five-fold to 100 million metric tons by 2007. Bayon et al. identify four categories of voluntary carbon purchases: (1) entities seeking to offset the emissions generated by their facilities or business activities, (2) entities seeking to produce carbon-neutral products such as transportation services or events, (3) government and philanthropic buyers of carbon, and (4) individual consumers seeking to offset their daily activities. Motivations for purchases include learning about carbon markets and preparing for regulation (often termed "pre-compliance,") public relations, and the desire to do the right thing. Most trading activity takes place either directly, between a project originator and a buyer, or through dozens of intermediaries – both for-profit and non-profit – that have emerged to service the voluntary market. Taiyab (2005) estimates about 30-40 intermediaries worldwide, most based in Europe, the US, and Australia. Prices vary considerably from $1 to $35 or more per metric ton of carbon dioxide, depending on the quality and location of the project, the co-benefits it provides, and the price sensitivity of the buyer.

One of the most comprehensive mechanisms for the voluntary market is the Chicago Climate Exchange (CCX), an emission registry, reduction, and trading system for all six greenhouse gases - carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons. Members make voluntary but legally binding commitments to reduce greenhouse gas emissions. The baseline period is 1998-2001. By the end of 2006 (Phase I), members are targeted to reduce direct emissions 4%, and a 6% reduction is required by 2010. The market was down in 2005 relative to the prior year, with only 1.5 million tons of carbon dioxide traded at a weighted average of $1.95 per metric ton for a total value of $2.8 million. As of the first quarter of 2006, the market has become much more active with 1.25 million tons of carbon dioxide exchanged, and prices have moved up to $3.50 per ton. CCX members range from large industrial concerns such as DuPont, to utilities such as American Electric

Power, to cities such as Chicago, IL, to farmers in Iowa and Nebraska, as well as a variety of non-profit organizations. Eligible emission offset projects include agricultural soil carbon sequestration, reforestation, landfill and agricultural methane combustion, and switching to lower-emitting sources such as biomass-based fuels (Chicago Climate Exchange web site).

The Exchange is expanding to the northeast to develop financial instruments relevant to RGGI (described above) through the formation of the New York Climate Exchange and the Northeast Climate Exchange (Capoor and Ambrosi 2006).

Understanding Carbon Offsets

What are "carbon offsets projects" and why are they an important part of a comprehensive climate policy? A carbon offset project is one implemented specifically to reduce the level of greenhouse gases in the atmosphere. A wide variety of technological approaches can be employed, including energy efficiency in buildings, factories, power plants, and transportation; renewable energy, such as wind, hydro, biomass, and solar energy; cogeneration of electricity from waste industrial heat; shifting to lower carbon energy sources, e.g., from coal to natural gas and biofuels; capturing carbon dioxide in forests and forest products and in agricultural soils; and capturing power plant emissions and storing them underground in geological formations.

However, achieving the important benefits that offsets offer to society is predicated on their being equally effective in reducing atmospheric greenhouse gas levels as on-site reductions by emitters. Thus, an offset project has three elements: (1) it cancels out emissions, (2) reductions are recorded in a greenhouse gas registry (or the atmosphere), (3) the end effect is as though the cancelled emissions had not occurred. An offset makes a basic promise: that the end result in the atmosphere is as if the emissions that are being offset never occurred in the first place.

Project-based greenhouse gas offsets hold much potential to help address climate change at the lowest overall cost. Since greenhouse gases have global rather than local effects, it makes sense to direct our mitigation funding towards the lowest cost sources. If we do this, we will have more money to spend on everything else, such as food, shelter, health care, security, and recreation. By directing funding from emitters to those who are most able to deliver mitigation cost-effectively, offsets are critical to maximizing the non-climate goods and services that we all really want.

Offsets also offer a number of other benefits, both environmental and economic. They can reduce air pollution; improve habitat, watersheds, and water quality; reduce soil erosion; and preserve biodiversity and endangered species. They can create jobs, stimulate demand for clean energy products, save money on energy, and enhance energy security by reducing oil imports. Finally, they can drive funding and new technology into uncapped sectors, helping to rectify inequities between emitters and those taking the brunt of climate change. Given that offset projects can occur across a wide variety of sectors and can potentially be located anywhere in the world, offsets can provide carbon-reducing strategies at the lowest cost.

Project-based emissions reductions, when properly implemented, are a high-quality environmental commodity. In order to ensure that real reductions are achieved, in the jargon of the offset world, it is necessary to prove project's emissions reductions have "additionality," that is, they result in emission reductions *in addition to* those that would occur in the business-as-usual scenario. If the project underlying the offsets would have occurred anyway, then atmospheric greenhouse gas levels will not really be reduced, and the emissions go unmitigated. In emissions trading schemes, additionality is addressed through the application of stringent project review processes, procedures, standards, and criteria. Proving additionality is an important challenge for offset projects.

Types of Forestry-Related Offsets

Forests and changes in forest management have the potential to serve as project-based offsets in a number of ways. The two most basic project types are those involving land management and product substitution.

Land Management-Based Offsets

Potential land management-based offsets act to increase the buildup of carbon in the forest. Offset types include avoided deforestation, afforestation, reforestation, and forest management. In all cases additionality needs to be demonstrated.

Forest Conservation simply means not clearing a forest, and can also be called avoided deforestation or forest preservation. When a forest is cleared, a pulse of carbon dioxide is emitted to the atmosphere, adding to greenhouse gas emissions.

Afforestation is planting trees on land that has not previously been forested. The trees grow, and over time contain more carbon than the prior unforested ecosystem.

Reforestation is planting of trees on land that has been logged. If the reforestation is required by logging regulations, this replanting is not "additional" and cannot serve as an offset. There are several sub-types of reforestation. One involves riparian zones, and has proven to be popular due to its watershed quality benefit. Another sub-type involves plantations to be commercially harvested at a later date, while a third is plantations of very short-rotation trees, such as hybrid poplars.

Forest management involves changing harvest approaches so that biomass is increased, such as extending rotations or increasing the number of trees that are retained at harvest. Reducing fire risk is also important and receiving increased attention, as forest fires are a significant source of carbon emissions. In addition, practices such as forest thinning to reduce fire risk can stimulate growth in the remaining trees and increase carbon storage.

Product Substitution-Based Offsets

Forests can potentially serve as offsets through substitution of forest products for higher-carbon materials and energy. There are a large number of potential technologies and processes for using biomaterials and bioenergy (Ragauskas *et al.,* 2006).

Material substitution typically involves the use of wood as a structural component in lieu of concrete and steel.

Energy substitution involves the use of bioenergy to replace fossil fuels. The energy captured in forests can be converted by various technologies to electricity, gaseous fuels, and liquid fuels.

Challenges to Carbon Markets in Forest Sequestration

Forest offsets present some unique challenges compared to other types of carbon offset projects and also produce a wide array of co-benefits. Three aspects of forestry-based offsets require more analysis, and are addressed below: permanence, ownership, and co-benefits.

Permanence

Sequestration differs from energy-related offsets in one key regard: permanence. Permanence addresses whether the emissions reductions last forever (avoided emissions) or whether they might be returned to the atmosphere, typically inadvertently. Permanence, the most challenging offset quality criteria, is also called reversibility, as the emissions benefit could be reversed. Two examples can help to illustrate this distinction. Suppose a wind farm is constructed and operates for ten years, at which time it is destroyed by a tornado. While the wind farm would no longer generate any emissions reductions in the future, all of the emissions reductions is caused in its first ten years will still reside as a benefit in the atmosphere. Contrast this to a reforestation project that grows for forty years, at which time it is consumed by a catastrophic forest fire and releases much of the carbon dioxide that it had previously absorbed. In this instance, none of the emissions benefit created by the project before the catastrophe will still reside in the atmosphere. The carbon dioxide would have been sequestered, and then "reversed" into the atmosphere.

Concerns about permanence manifest themselves in two forms: end-of-contract effects and unplanned disturbances. The contractual commitment for forest sequestration offsets can either have a specific end date or they can continue into perpetuity. A conservation easement is an example of an "into perpetuity" obligation. Several approaches have been suggested for addressing the uncertainty regarding permanence (USEPA 2005). One is a temporary crediting approach, where regulatory credit for sequestration-related reductions expire after a fixed time period. Other approaches include "renting" or "leasing" the carbon dioxide locked up by forest sequestration.

Unplanned disturbances include fire, insects, disease, and illegal harvest. All can affect a sequestration project while a contract is in effect. Approaches for addressing this type of permanence concern include discounting the anticipated reductions from a project up front (USEPA 2005), use of a reserve pool of comprised of a certain percentage of the offsets generated by a project, and use of insurance for offset performance. The Chicago Climate Exchange addresses the issue of net losses in carbon stocks (for example, from a forest fire) by requiring that a quantity of offsets equal to 20% of all forest offsets in the forest portfolio be held in a Chicago Climate Exchange carbon reserve pool throughout the life of the program (Chicago Climate Exchange). The Climate Trust has addressed forest offset risks by investing in projects which do not allow harvest of trees, by requiring the establishment of reserve pools, and by requiring that the project developer replace tons that they fail to deliver.

In addition to self-insuring, as the Chicago Climate Exchange does, there is a potential role for an insurance company or other entity to quantify the risk of non-delivery of the required carbon tons and offer insurance to the carbon buyer (or seller, depending on who retains the ultimate liability) for non-performance. The issue of vintaging – matching the timing of emission reductions or sequestration to annual required targets — is also very significant to forest carbon offsets in an illiquid market where not all vintages are available for purchase. Forward markets are developing in which future vintages will be appropriately discounted based on prevailing interest rates, future price expectations, and an assessment of the creditworthiness of the seller. All of this – along with issues of permanence and temporary crediting - may well result in lower prices for forest offset projects relative to other project types.

Ownership and Legal Title

Not all emissions reductions can qualify to be carbon offsets. There are a number of carbon offset quality criteria that serve as distinguishing factors when determining which types of emissions reduction approaches are eligible to become offsets, or make them more or less attractive to the offset buyer. One key criterion is ownership of the offsets.

When one sells an offset, one is paid for the legal rights to a ton of sequestered carbon dioxide. This sale is conducted under the terms of an emissions reduction purchase agreement. Each such contract includes extensive legal definitions regarding the offsets. In order to enter into such a contract, one must have the legal right to sell the emission reduction. The Climate Trust's contracts require that the offset developer transfer any and all rights to carbon dioxide reductions resulting from their project in exchange for funding. The offset developer (and other implementation partners) is excluded from selling the same tons to another entity, using the tons for other purposes, or selling the carbon dioxide in other environmental products. In addition, each contract also includes a requirement for written disclaimers from all project partners and participants, disclosure of sale to regulatory authorities and other parties, and definitions on what "bragging rights" are acceptable. Offset developers may be required to indemnify the purchaser against competing claims of offset ownership. In programmatic offsets in which participants enroll in a program operated by the offset developer, offset contracts require participation agreements to create a clear ownership trail to tons of CO_2. This participation agreement provides a "chain of custody" for the offsets. The documents that are necessary to transfer the rights to an offset, in addition to the contract itself, include a Bill of Sale, an Annual Offset Certificate, and third party verification of the quantity of offsets delivered.

Land-management based offsets – avoided deforestation, afforestation, reforestation, and forest management – involve the landowners consent, either as a signer of the offset contract or as a signer of a participation agreement. As such, the legal title to the offsets is generally not subject to questions regarding ownership, at least not for private landowners in the U.S. However, ownership of forest carbon rights should not be taken for granted. For example, to the deep consternation of private forestland owners, New Zealand nationalized carbon offsets from forestry, gaining a carbon asset for the national account worth approximately $2 billion and negating the need to regulate the politically powerful agricultural sector which was responsible for about half of the country's greenhouse gas emissions (Brand and Kuppalli n.d.). In Canada, where much of the forestland is owned by the Crown and licensed to forest companies for harvesting, ownership of the carbon asset associated with changes in forest management has been a source of fierce debate between provincial governments and private forest companies.

In the United States, ownership issues that do arise are not related to legal title to sell the offsets, but rather to the landowner's willingness to enter into a legally binding commitment to manage the forest to generate offsets and the potentially long-term nature of this commitment. Chapter 9 provides an overview of the experience of Oregon's Forest Resource Trust in attracting landowner participation in a long-term offset program.

Substitution-based offsets – material substitution and energy substitution – have a different type of ownership issue. Here the issue is one of a clear title to the offsets. In the case of the use of wood as a substitute for higher carbon materials, the owner of the reduction may not be the entity that chose to use wood in lieu of metal. Rather, the emission reduction would occur at the smelter, where less metal would be produced, and therefore, less fossil energy consumed and less carbon dioxide emitted. This type of emission reduction is called an indirect emission reduction. The offset occurs at a point in a product's life cycle that is not under direct control – and therefore, potentially, ownership – of the entity that engaged in the substitution. Due to this indirect nature of the emissions reduction created, material substitution is a difficult form of emissions reduction to use as the basis for an offset. The treatment of materials substitution-based reductions will depend on the rules of any trading systems that are established. Ownership of these reductions could accrue to the entity choosing to implement the low-carbon substitution, or it could accrue to the smelter, as is the case in this example.

For energy substitution, the offsets may be direct if the owner of a facility that previously burned fossil fuel converts to wood as a fuel source. The offset is tied to the amount of fossil fuel combustion that is foregone. However, wood burning offsets may be indirect as well, as in the case when a new biofueled electricity project is constructed. The emissions reductions come from reduced fossil fuel electricity generation on the power grid, but they do not have the same

Table 1

An offset market perspective: relative attractiveness of forest sequestration and other project types

Type of Carbon Offset Project	Advantages	Challenges
Energy Efficiency	Once equipment is installed, project generates permanent reductions. Measurement of energy efficiency is well developed. Any leakage is likely to be captured in program impact evaluation procedures.	Ownership may be claimed by implementer, but for indirect emission reductions involving electricity, load-serving entity may claim or be deemed to have rights.
Renewable Energy	Avoided emissions are permanent, with little potential for leakage. Measuring electricity production is routine for renewable energy projects, as it is a salable commodity.	Wind developer or generator avoiding emissions may both claim ownership. In addition, renewable energy credit market and offset market have yet to be reconciled.
Transportation	Avoided emissions are permanent.	Ownership may be difficult to establish for certain projects, e.g., where commuters do not sign a participation agreement. Baseline and reduction in vehicle miles traveled are difficult to directly measure.
Agricultural Soil Sequestration	Landowner is likely to be entitled to ownership, and may cede them to an aggregator for marketing purposes. Leakage rating is fair.	If land use practice changes or other events (drought, flood, etc) occur, carbon pulse could result. Soil carbon dynamics are complex, and the subject of considerable scientific study. Quantification is likely to remain site specific, unless a standardized approach with considerable discounting is used. A difficulty is getting landowners to commit to a long-term or permanent change in land management practices.
Geological Sequestration	It is anticipated that sequestration will exceed that for forestry, but still the subject of considerable research and uncertainty. Leakage is rated good because of well-defined project boundary.	Measuring amount of CO_2 injected is feasible. Measuring any potential leakage from the reservoir would likely be difficult.
Forestry: Forest Conservation	Landowner owns emissions benefit, and either sells it directly or via a participation agreement. Although it carries risks common to any forest-based offset (fire, disease, etc.), land is usually permanently committed to forested-state through a conservation easement.	May shift logging to different area, with little or no net emissions benefit. Benefit is measured against emissions associated with historic and predicted rate of deforestation. Actuals may be different that the assumed baseline. The difficulty is getting landowners to commit to a long-term or permanent change in forest management practices. There is also a risk of illegal logging

Table 1 continued next page

ownership status as the prior example. In some trading schemes, this type of energy substitution would create an emissions benefit for the bioenergy facility owner, while in other schemes, it would not. It is important for those considering building bioenergy facilities to gain an understanding of the structure of the trading schemes into which they hope to sell offsets, and how these schemes treat direct and indirect emissions reductions.

The emerging market for offsets is global, and it involves a much wider range of technologies and approaches than forest sequestration. It is important for those interested in forestry-based offsets to understand how these offsets compare

Table 1 Continued

Type of Carbon Offset Project	Advantages	Challenges
Forestry: Afforestation/ Reforestation	Landowner owns emissions benefit, and either sells it directly or via a participation agreement. Although it carries risks common to any forest-based offset (fire, disease, etc.), land is usually permanently committed to forested-state through a conservation easement. Leakage rating is good – Such projects are unlikely to result in displacing logging elsewhere. Complex site-specific monitoring and protocol needed, but measurement is practical and reasonably accurate.	There is a risk of illegal logging.
Forestry: Forest Management	Landowner acceptability is likely higher than with forest conservation since some revenues from logging are anticipated.	Defining baseline of anticipated predicated forest management practices is difficult. In addition, periodic active logging makes site verification more difficult. Benefit is measured against emissions associated with historic and predicted rate of deforestation. Actuals may be different that the assumed baseline. Landowner must be committed to management practice. Carries same risks of permanence as other forest-based projects (may be lower due to active management practices).

to those based upon other technological approaches. *Table 1* contrasts forestry-based offsets with other offset types such as transportation, renewable energy and geological sequestration. Forest-based offsets face some important challenges in comparison with other offset types, especially as regards to permanence, leakage, ownership, and measurability. While these are significant challenges, they are by no means insurmountable, and approaches that allow forestry-based offsets to participate in trading schemes have been or should be able to be developed. In addition, it is important to note that the types of forestry-based offsets are quite different relative to the criteria presented in the table.

The Co-Benefits of Forestry Offsets

Forest offset projects often generate attractive environmental and social co-benefits, including job generation, habitat retention/enhancement, water quality improvements, recreational opportunities, and enhancement of scenic vistas, not to mention potential co-production of timber and non-timber forest products. (*Table 2*) Many of these public benefits can be quantified and monetized, resulting in a “layer cake” of ecosystem service market sales. It is no accident that many carbon transactions in the voluntary market involve forestry and agricultural offset projects that generate considerable public benefit beyond the sequestration of greenhouse gases.

For example, the New South Wales State Forests agency in Australia has been exploring ways to attract private funding for reforestation in areas of low rainfall, using the “layer cake” strategy. In parts of Australia, removal of the original forest cover has caused greater volume of rainwater to penetrate deep into the soil and raise the water table, bringing naturally-occurring salt to the surface and increasing the salt content in surface water, to the detriment of biodiversity and agricultural production. By bundling potential revenue from timber production, carbon sequestration, and salinity reduction, State Forests is experimenting with a financially viable model to finance large-scale restoration of dryland forest regions. For example, in a pilot project in the Macquarie cachement, the agency has

Table 2
Examples of forest based project co-benefits

Project or Program Name	Funding Organization	Project Type	Co-Benefits
Deschutes River Basin Riparian Restoration, Oregon	The Climate Trust	Afforestation – Restores riparian forest cover along denuded areas of the Deschutes River watershed.	Improved water quality and stream flows, improved fish and wildlife habitat and increased aesthetic qualities.
Forest Climate Program	Future Forests (through The Pacific Forest Trust)	Forest Conservation – secured conservation easements on 5,000 acres of privately owned forestland in California to achieve forest management above requirements of the California Forest Practices Act.	Future Forests projects house numerous threatened and endangered fish and wildlife species — including Coho salmon, spotted owls, peregrine falcons and marbled murrelets — and contain stands of old-growth redwoods and Douglas - fir. In addition, the easements protect important watersheds and municipal water supplies.
Noel Kempff Climate Action Project	Fundación Amigos de la Naturaleza (FAN), the Bolivian government, The Nature Conservancy, American Electric Power, BP and PacifiCorp.	Forest Conservation – Prevents forest logging by termination of logging rights and prevents deforestation by a variety of activities to local communities on 1.6 million acres of government-owned land and incorporate that land into the Noel Kempff Mercado park.	Conserves biodiversity and provides for continued habitat for giant river otters, capybaras, pink river dolphins and black and spectacled caiman. Provides social and economic benefits to five communities in and around the park including improved schools and medical care. Provides sustainable resource opportunities such as small-scale heart-of-palm harvesting and sustainable sales of wood from certified forests.
Oregon's Forest Resource Trust Stand Establishment Program	Klamath Cogeneration Project	Afforestation – Conversion of underproducing agriculture, range and brush land back into healthy, productive forests.	Increased timber supply, increased forest cover for wildlife, improved water quality, aesthetics.
Rio Bravo Conservation and Management Area, Belize	The Nature Conservancy	Forest Conservation – Prevents deforestation and provides for sustainable management on 260,000 acres of mixed lowland, moist sub-tropical broadleaf forest.	Conserves biodiversity and provides for continued habitat for endangered black howler monkey and jaguar, numerous migratory birds, mahogany and other important tree species.

established 100 hectares of newly planted forest, funded in part by a fee from a downstream agricultural user (the Macquarie River Food and Fibre Company) for the transpiration services provided by the trees, which will eventually reduce salinity of the surface water and increase agricultural yields. State Forests retains the timber and carbon rights of the planted trees, and pays the landowner an annuity for the lease of the land.[4] This strategy is illustrated in *Figure 1*.

Closer to home, Ecotrust, a Portland-based conservation organization, recently launched a private equity forestland investment fund that will take advantage of expanding and emerging markets for the array of goods and services produced by forests.

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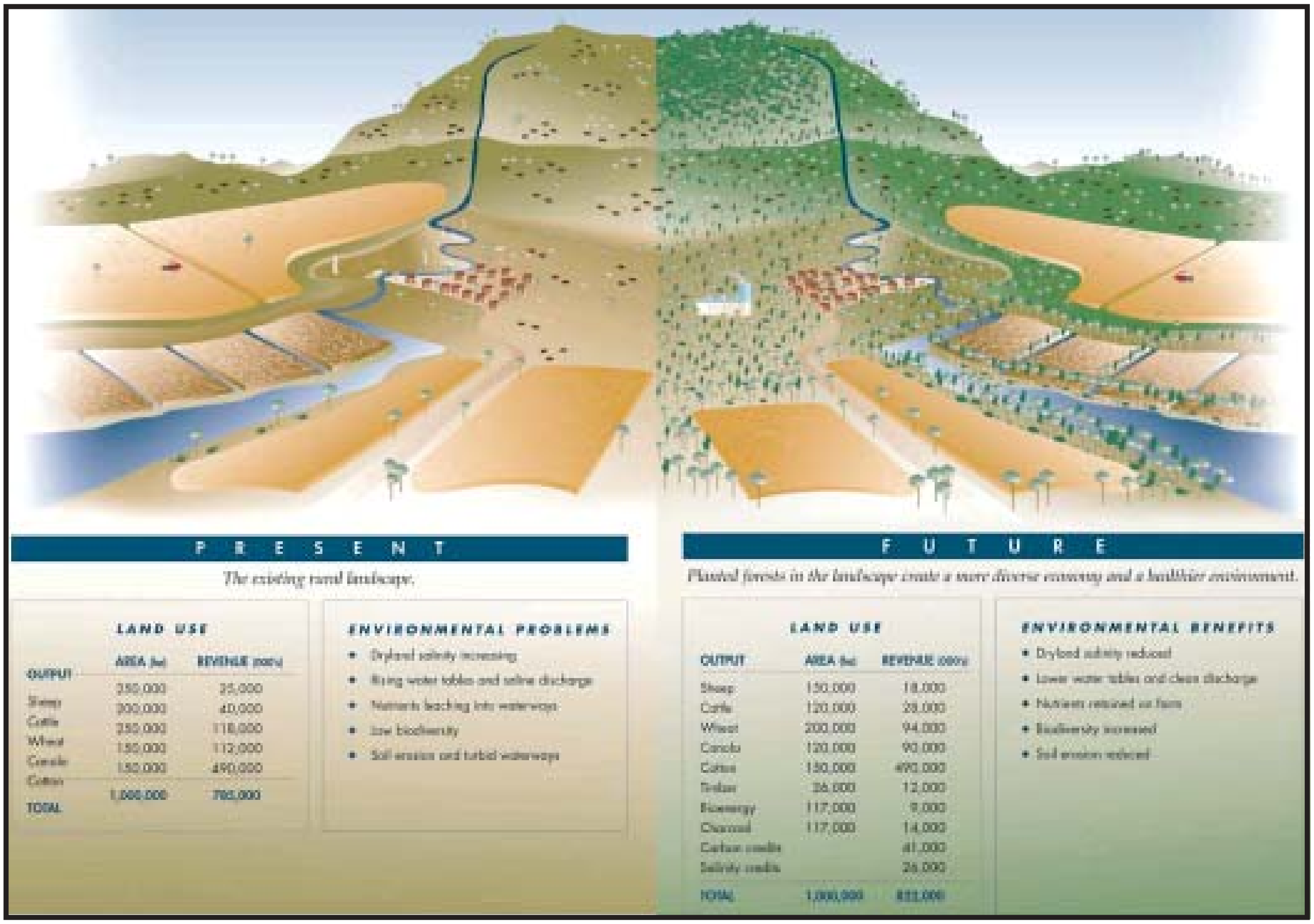
[4] *http://www.unep-wcmc.org/forest/restoration/docs/NSW_Australia.pdf*



PRESENT

The existing rural landscape.

LAND USE

OUTPUT	AREA (ha)	REVENUE (000's)
Sheep	250,000	25,000
Cattle	300,000	40,000
Wheat	250,000	118,000
Canola	150,000	112,000
Cotton	150,000	490,000
TOTAL	1,000,000	785,000

ENVIRONMENTAL PROBLEMS

- Dryland salinity increasing
- Rising water tables and saline discharge
- Nutrients leaching into waterways
- Low biodiversity
- Soil erosion and turbid waterways

FUTURE

Planted forests in the landscape create a more diverse economy and a healthier environment.

LAND USE

OUTPUT	AREA (ha)	REVENUE (000's)
Sheep	150,000	18,000
Cattle	120,000	28,000
Wheat	200,000	94,000
Canola	120,000	90,000
Cotton	150,000	490,000
Timber	26,000	12,000
Bioenergy	117,000	9,000
Charcoal	117,000	14,000
Carbon credits		41,000
Salinity credits		26,000
TOTAL	1,000,000	822,000

ENVIRONMENTAL BENEFITS

- Dryland salinity reduced
- Lower water tables and clean discharge
- Nutrients retained on farm
- Biodiversity increased
- Soil erosion reduced

Figure 1

An example of stacking ecosystem services and commodity production in a salinity-prone watershed in Australia. The land management strategy which includes restoration and sale of enhanced ecosystem services outperforms the existing management scheme which is based solely on commodity production. Carbon credit sales play a prominent role in making this restoration strategy financially viable.
Source: http://www.unep-wcmc.org/forest/restoration/docs/NSW_Australia.pdf

While the New South Wales example draws on ecosystem service markets to fund reforestation, Ecotrust Forests LLC is looking to emerging markets to help fund a forest management approach that results in greater value from a triple bottom line perspective – higher quality and more abundant wood products, healthier and more diverse forests, and higher employment and opportunities for local communities. This ecosystem-based forest management approach relies on longer rotations, thinnings, and enrichment plantings to increase structural and functional diversity, and results in higher carbon storage, better habitat, and enhanced recreational and scenic values, as well as producing higher value logs. The benefits of extending rotations for biodiversity, carbon storage, or wood quality are well recognized (Carey *et al.,* 1999, Haynes 2005).

However, the financial challenge is that delaying harvests delays cash flow, and results in a lower net present value at prevailing discount rates, even if the cumulative cash flow of long rotation forestry is ultimately higher.

Binkley *et al.,* (2006) compared the financial performance of an industrial regime focused exclusively on timber production with an ecosystem-based forest management regime that focused explicitly on co-producing an array of forest products and services. As in other studies, the extension of rotation from 40 to 60 years (which included one to two commercial thins at age 30 and 45) reduced the internal rate of return (IRR) from timber sales – in this case from 6% to 5.5%. However, as can be seen in *Figure 2*, the ecosystem-based forest manage-

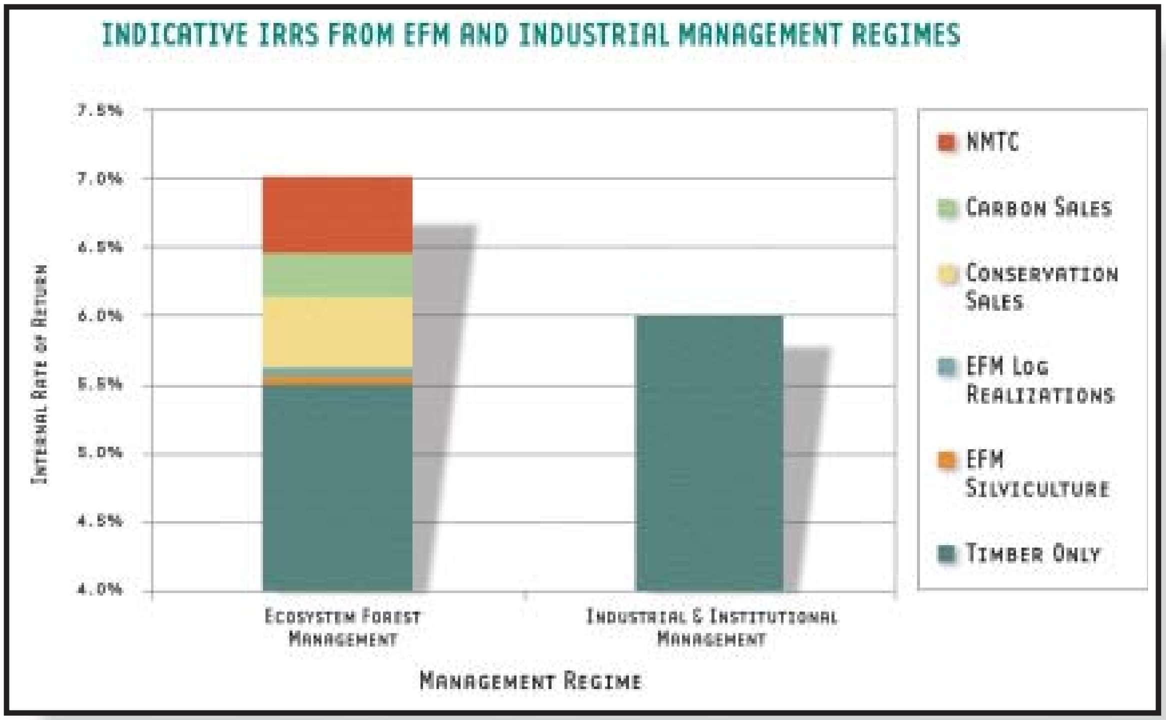


Figure 2

Source: Binkley et al, 2006. Reprinted by permission of Ecotrust

ment approach opened up other revenue sources, including a small premium from higher valued logs, the sale of conservation easements (51 basis points), the sale of carbon sequestration credits (32 basis points), and the sale of New Market Tax Credits (55 basis points), bringing the total IRR to a projected 7%, one percentage point higher than the 6% yielded by the industrial forestry approach.

The analysis includes a fairly conservative assessment of carbon potential, selling additional carbon as it is generated — rather than up front as is currently customary for voluntary forest carbon transactions. In this study, carbon is valued at $5 per metric ton of carbon dioxide, and only a portion of the carbon stored was considered. At this price, carbon alone is not enough to shift the forest management approach from industrial to ecosystem-based. However, if impacts on biodiversity are considered (captured here as conservation easement sales) and local job generation (New Market Tax Credits, a federal program to spur investment in financially distressed communities, which includes much of the rural West), and if these values can be adequately monetized and sold, a rational forestland owner would shift to the longer-rotation approach.

The concept of aggregating various sources of commodity and ecosystem service revenues – often referred to as “bundling,” “stacking,” or more derisively, “double-dipping” — has its detractors. Federal and state agencies responsible for administering the Endangered Species Act or Clean Water Act, for example, are concerned that allowing landowners to bundle sales of ecosystem services – in essence, allowing the same unit of land to serve as mitigation for the loss of more than one ecosystem function – might result in a net loss of habitat at the landscape level, unless an extremely sophisticated accounting system is conceived and implemented to ensure no net loss. The concern is based on the way impacts on endangered species, wetlands, and habitat are mitigated, which raises the potential that a developer might impact one acre of wetland and a separate acre of, for example, habitat for the threatened California red-legged frog, and compensate for both impacts by buying credits from a single acre at a conservation bank selling credits for both wetland and endangered species habitat under a multi-credit system. Conservation banks for mitigating impacts to endangered species, as well as other emerging ecosystem service markets, are described in *Sidebar 3*.

Sidebar 3

Reforesting an Ecuadorian Rainforest Biodiversity Hotspot: a sequestration project funded by the Climate Trust

Less than two percent of Ecuador's coastal rainforest remains. The forests in northwestern Ecuador have suffered deforestation from population growth and a doubling of farm land. Tall grasses that invade disturbed areas prevent native trees from being re-established.

The Climate Trust contracted to purchase offsets from Conservation International and Jatun Sacha Foundation from the reforestation of more than 680 acres of highly degraded pasture in northwest Ecuador. The project is located in one of the most biologically diverse areas on Earth and in one of Conservation International's top five conservation targets worldwide. Over three years, 15 native hardwood species will be replanted on the site. This project, located in the 7,140-acre Bilsa Biological Reserve, will restore and protect the land and allow it to grow back to old-growth forest. Over the 99-year life of the project, it will capture at least 65,000 metric tons of carbon dioxide. Since this project contained no financial returns or harvesting, the Climate Trust's offset funding was crucial to proceed with reforestation and protection of the site.

The Climate Trust has employed Winrock International to develop and help implement the monitoring and verification plan for this project, which will include measurement of carbon fluctuations on the ground and verification of current carbon estimates. Scientifically valid measurement of trees will be undertaken periodically throughout the project life to measure carbon accumulation. Monitoring and verification will also measure any leakage that may occur. However, leakage it not expected to occur in this project given that it is not "avoided deforestation," forcing harvesting to shift elsewhere.

In addition to sequestering carbon, this projects has many valuable environmental co-benefits. This remnant forest has a unique composition of flora and fauna, internationally renowned for both its diversity and rarity. Rare animals found at the reserve include the jaguar, several small cat species, the long wattled umbrella bird, the giant anteater and abundant populations of the threatened mantled howler monkey. The Reserve's bird species diversity (about 330 species) is among the highest of any coastal site in Ecuador. A number of bird species in the Reserve are threatened, and some of the migratory birds that breed in Bilsa spend part of their lives in Oregon forests. The ongoing botanical inventory at Bilsa has uncovered 30 plant species new to science. The Jatun Sacha Foundation conducts field research and education with researches, students, interns, and tour groups.

While the concern may be legitimate for mitigating impacts to habitat and species, there are a number of ecosystem service sales that can be appropriately grouped to create financially viable models for ecosystem-based management while creating increasing and unique incentives for habitat restoration with each sale. In the Ecotrust Forests LLC example described above, the sale of a conservation easement relinquishes development rights on the land; a carbon offset sale then provides compensation for increasing rotations to sequester additional carbon. The New Market Tax Credit, which compensates the investor for directing their investment to a distressed community with high unemployment and high poverty, is not an ecosystem service market per se, but its goal – increasing employment – is well served by ecosystem-based forest management which also produces higher carbon stores and enhanced habitat.

The issue of aggregating ecosystem service credits within a single unit of land is far more than academic. It is of vital importance to rural landscapes. In places with high development pressure and high land values, developers are motivated to pay sufficiently high prices for mitigation credits to adequately fund viable conservation banks. In rural settings with lower development activity, the price of credits is correspondingly lower, and may not be sufficient to sustain a wetland or conservation bank under a system where only one ecosystem service can be sold per unit of land. Markets for multiple ecosystem services are also required when conservation objectives are competing with intensive land uses such as agriculture and plantation forestry. For example, Temple Inland, a Texas-based company with over two million acres of forestland under management, has been exploring a conservation management strategy where commercial forestry activities can be complemented with mitigation banking, carbon storage, flood control and water filtration services. Given the small and disjointed nature of these early ecosystem service markets, the company still finds it difficult to put deals together on a regular basis, and is pursuing a "stacking" of ecosystem service revenue streams from carbon sequestration, recreational leases, wetland and stream mitigation banking, and selective timber harvesting to overcome uneven demand and uncertain pricing (Hawn 2005). Without the ability to stack ecosystem service market sales, Temple Inland – and other forestry companies - may find it difficult to expand the conservation and social benefits that their forests can provide.

In addition to enhancing the awareness of ecosystem service revenue markets by developers and others whose activities may impact habitat or water quality, market growth has also been limited by uneven capacity and interest at the array of federal and state agencies which must approve and monitor ecosystem service trades. One of the emerging approaches to creating a market for biodiversity is through the establishment of a conservation banking system, in which developers compensate for their impacts on habitat for endangered species by buying "credits" in a conservation bank which purchases and develops habitat for the species that is being impacted by the development project. While California, for example, has developed over 50 conservation banks, Oregon and Washington are just beginning to establish their first banks. Bank development in the Pacific Northwest, for both species conservation and wetlands, has been very slow, due in large part to the limited staff resources and slow response of the necessary agencies. To address this issue – and to establish a coherent set of performance standards around mitigation banks – the U.S. Army Corps of Engineers (responsible for administering Section 404 of the Clean Water Act which mandates no net loss of wetlands) and the U.S. Environmental Protection Agency (EPA) recently released a new draft regulation, the Compensatory Mitigation for Loss of Aquatic Resources, which is expected to significantly expand the use of mitigation banking. Among other provisions, the regulation imposes performance standards on both agencies and on mitigation bank owners.

While carbon markets have developed largely in isolation from other ecosystem service markets – such as wetland and conservation mitigation banking, water quality trading, flood control credits, and other emerging markets – we would do well to pay close attention to the developing rules, structures, market areas, and market leaders across all of these market types. We need to think holistically about how to structure these developing ecosystem service credit markets, both individually and in aggregate, to accomplish a host of public benefit objectives, from restoring degraded landscapes, to providing new economic development strategies for economically distressed areas, to providing incentives for approaches to forestry and agriculture which align private incentives with public values. An example of this approach is described above for Ecotrust Forests LLC, which draws on a number of emerging ecosystem service markets and economic development incentive programs to profitably buy and manage forests for carbon storage, habitat creation, job generation, and the provision of wood products. A number of non-profit and for-profit entities are emerging to capitalize on these new opportunities and the growing availability of capital and interest from socially-responsible investors (Social Investment Forum 2006)

What does this Mean for Oregon Forests?

Relative to other ecosystem service markets – such as water quality trading and conservation banking - carbon is probably the most significant near-term ecosystem service market opportunity, and has the unique advantage of being a global market. Pacific Northwest forests can store more carbon than most other forest ecosystems (Smithwick et al 2002), giving Oregon and the region a unique competitive advantage in this developing market. The region's forests also have other distinct advantages: almost all of the native tree species are commercially valuable, the forests provide scenic vistas and recreational opportunities to a growing population, forested watersheds are the source of drinking water for much of Oregon, and forests provide habitat to a wide array of commercially valuable species, including Pacific salmon. All of this suggests a viable strategy for Oregon's forestland owners, where the production of timber, carbon storage, high-quality water and habitat yield a diverse array of revenue streams which make forestry financially attractive, and retain forestlands on the landscape for generations to come.

In addition to abundant forestlands, which lend themselves well to carbon storage, Oregon also has strong institutional capacity for ecosystem market development, with leading carbon organizations such as the Climate Trust and Trexler Climate & Energy Services headquartered here. The state is recognized for its long history in leadership and innovation on environmental legislation and market creation. In a national and global system of emissions trading, Oregon can emerge as a strong player, and Oregon's forestland owners can gain a competitive advantage. Abundant carbon sinks throughout the state include not only forests but agricultural lands and marine environments, relatively clean power sources and industries, strong institutional capacity, an entrepreneurial business sector, and a progressive citizenry.

The markets are moving quickly, however, and if Oregon is to gain an advantage as a national market develops it will have to gain a seat at the table and help formulate the rules in a way that favors our natural resources and creates long-term benefits for the region's residents.

In this spirit, we suggest the following options for consideration:

- **Collaboration between the forest industry and environmental groups.**

  The forest industry and environmental groups should move beyond past history and work together to develop mechanisms to structure and sell forest carbon offsets, as well as other forest-based ecosystem services. Without an effective system in place to compensate landowners for forest stewardship, conversion of forestland will continue to increase in the region, to the detriment of all. Continued debate and lack of trust among these important constituencies will significantly limit market development, and may cause forest carbon to be excluded from an emission trading system.

- **Establish a state cap-and-trade system.**

  Oregon should continue to move aggressively on establishing a cap-and-trade system, and ensure that forest carbon offsets and other sequestration strategies are included appropriately.

- **Pursue a regional carbon market trading system.**

  Efficient and cost-effective emission reductions require deep and robust markets. While multi-state trading systems take time and commitment to develop, Oregon is not large enough to create a vigorous market on its own. The state should continue to pursue a regional trading system with sufficient volume and value to attract and support the necessary financial, technical, and informational resources.

- **Invest in infrastructure to support an active, efficient and equitable carbon market.**

  In anticipation of market development, Oregon should invest now in the legislative and institutional structures needed to support an active carbon market. This includes separation and clarification of carbon ownership rights (as distinct from the property rights of the land and timber where the carbon is stored), development of mechanisms to address permanence (for example, insurance products, temporary crediting, and pooling,) and enforcement mechanisms.

  Participating in ecosystem service markets also carries high transaction costs. The need to measure and verify that emission reductions have indeed occurred and that carbon is being sequestered as agreed is expensive and time-consuming. At this point, only very sophisticated entities and relatively large transactions can participate in these markets. Oregon needs to stimulate and nurture the formation of efficient intermediaries that can “bundle” individual transactions – for example, reforestation efforts by small forestland owners – to allow broad participation in carbon and other emerging ecosystem service markets.

- **Invest in the intellectual capital needed for market development.**

  Oregon needs to make a substantial investment in the intellectual capital necessary to support market development. This includes developing the underlying rules for all kinds of emission reductions and offsets, including forest carbon. For example, how should forest carbon be measured? Should carbon stored in wood products be considered? How about strategies that minimize the risk of catastrophic forest fires?

  In addition to developing rigorous and transparent protocols that will allow Oregon carbon offsets to be widely marketable around the globe, the state needs to recruit or develop a wide array of technical assistance entities to provide structuring, monitoring, and verification services. Much of the needed framework and accounting protocols could be provided through reviewing, adapting, and possibly adopting the thorough and well-regarded California Climate Action Registry, the voluntary registration system recently adopted in California, as well as a review of other existing and developing trading systems.

- **Develop trading platforms**

  Oregon – or the regional market of which Oregon is part – needs to entice or develop the necessary trading platforms, including market exchanges, that will create market liquidity and transparency, and encourage confidence and participation in the carbon market and market growth.

Summary

With its reliance on snowpack for summer water flows and the importance of climate-sensitive sectors such as forestry and agriculture, Oregon is particularly vulnerable to the effects of climate change. By building on its strong tradition in innovation and forward thinking, Oregon can begin to address the threat of climate change in ways that create financial opportunities, enhance the health and integrity of its landscapes, build social capital, and create a long-term competitive advantage.

The unique qualities of Oregon's forests, which are capable of producing high quality wood products while storing large amounts of carbon and producing a host of other benefits – such as habitat and scenic vistas – give Oregon a unique advantage in not only meeting a portion of its own greenhouse gas reduction targets efficiently, but in selling quality offsets to others. This competitive advantage will only materialize, however, if we act quickly and decisively in developing an effective, rigorous, and robust trading system that includes forest carbon, and meets the standards and pricing requirements of global carbon markets.

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CHAPTER NINE

HIGHLIGHTS:

CARBON ACCOUNTING — DETERMINING CARBON OFFSETS FROM FOREST PROJECTS

Introduction

- Projects offer landowners income while helping reduce greenhouse gases.
- The science of carbon accounting is still in early stages; concepts are pioneering.

Principles of Carbon Accounting

- For additionality, offsets must be developed from actions that would not have otherwise occurred.
- A baseline is established to estimate carbon offset.
- Lost carbon benefits due to countervailing activities are known as leakage.
- Permanence addresses the time period to ensure benefits aren't reversed.
- Forecasts made for investment analysis include consideration of factors of reliability, timing and risk.

Measurement Standards

- Four U.S. CO_2 reduction initiatives (private and government sector programs) facilitate reporting, purchase or trade of carbon offsets.
- 2002 reporting guidelines include grading system for the quality of the measurement standard.

What to Measure

- U.S. Department of Energy's technical guidelines provide overview of measurement protocols and calculation methods for various forest types.
- Measurements can include: live trees and understory vegetation; standing dead and down logs; soils, litter and debris; and forest products.

Roles and Responsibilities in Forest-Based Carbon Projects

- An investor (usually a utility or power company) has an interest in offsetting a portion of CO_2 emissions arising from business activities.
- The forest landowner may be directly responsible or host a project.
- A professional forester or natural resource specialist brings necessary expertise in estimating, and can coordinate measurement and reporting.
- A third-party coordinating organization assists with longevity and overall reliability.

Summary

- Over the past 15 years, carbon accounting has evolved, but principles and standards are still in early stages of development.
- Standards will progress to improve market confidence that reported carbon offsets represent actual reductions in atmospheric carbon dioxide.

CHAPTER NINE

CARBON ACCOUNTING — DETERMINING CARBON OFFSETS FROM FOREST PROJECTS

Jim Cathcart and Matt Delaney

Introduction

Forest-based carbon projects offer the potential to provide landowners with income from their forestry activities while simultaneously helping to reduce greenhouse gases, specifically carbon dioxide (CO_2), in the atmosphere. The challenge that forest landowners face is knowing what will be required of them for measuring and reporting the amount of CO_2 emission reduction benefit that can be sold or credited. This is a difficult task, since CO_2 is a natural component of the atmosphere, and forests are a natural part of the global carbon cycle. Determining the amount of carbon offset from forest activities can appear at first to be nothing more than trying to sell "thin air." What needs to be recognized is that selling carbon offsets is no different from selling any other commodity accruing to the forest as a result of management action – and that is, if you can't measure it, you can't sell it.

The purpose of this chapter is to introduce the principles and standards for carbon accounting – a short-hand term for estimating, measuring, reporting and monitoring CO_2 emission reduction benefits (henceforth, carbon offsets). These generally arise from specific projects or management activity such as planting trees, conserving older forests, improving forest health, improving timber yields for wood products or simply taking actions to maintain a productive, forestland base.

A carbon offset is a transferable certificate, note or other form of documentation (e.g., a registry) that warrants a measured amount of carbon dioxide emission reduction benefit from an eligible activity, practice or policy. Carbon accounting is discussed in two contexts. One is the estimate or forecast of the amount of carbon offsets anticipated from a proposed forest-based carbon project – for example, when a project is reviewed for investment analysis purposes. Another is the measurement and reporting of the actual quantity of carbon offsets that a project has produced.

Verification, as defined here, is not part of carbon accounting, and is considered separate and distinct. Carbon accounting is the responsibility of the seller of the carbon offset. Verification is the responsibility of either an independent party, or a representative of the purchaser who validates what the seller is claiming as the quantity to be sold.

The following United States (U.S.) CO_2 reduction initiatives (i.e., specific private or government sector programs that facilitate the reporting, purchase or trade of carbon offsets) illustrate how the principles and standards for carbon accounting are being applied[1]:

The California Climate Action Registry. Established by California statute, a non-profit registry that helps companies and organizations in the state to establish greenhouse gas emission baselines against which future emission reduction requirements may be applied.

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[1] The four major CO reduction initiatives being implemented in the U.S. For more information see:
The California Climate Action Registry — http://www.climateregistry.org/
The Chicago Climate Exchange — http://www.chicagoclimatex.com/
The Climate Trust — http://www.climatetrust.org/
Voluntary Reporting of Greenhouse Gas Emissions – http://www.eia.doe.gov/oiaf/1605/frntvrgg.html

The Chicago Climate Exchange. A self-regulatory registry, reduction and trading system for all six greenhouse gases, with legally binding agreements to reduce greenhouse gas emissions.

The Climate Trust. A non-profit organization providing carbon offsets to power plants, regulators, businesses and individuals.

Voluntary Reporting of Greenhouse Gas Emissions. Also known as 1605(b) reporting. Administered by the U.S. Department of Energy, Energy Information Agency to facilitate the voluntary collection and reporting of annual reductions of greenhouse gas emissions and carbon sequestration achieved through any measures, forest management practices and tree planting.

In Oregon, an example of how the carbon accounting principle and standards are applied is the state's Forest Resource Trust Stand Establishment Program. This financial and technical assistance program is administered by the Oregon Department of Forestry for non-industrial private landowners who wish to convert marginal agriculture, pasture or brush land back into healthy productive forests (i.e., afforestation). In 1999, the Stand Establishment Program received $1.5 million of an expected $3.0 million investment in afforestation from the Klamath Cogeneration Project in south Central Oregon for the purpose of offsetting a portion of the cogeneration plant's CO_2 emissions (Cathcart 2000).

As the science of carbon accounting is still in the early stages of development, the concepts presented here are pioneering and may not be applicable to the various carbon trading policy arenas that are developing both internationally and inter-regionally within the U.S. This chapter provides information for the forest landowner or practicing forester who has an interest in conducting a forest-based carbon project. As such, the scope is limited to project-level accounting from the perspective of how principles and standards for the carbon accounting of such projects could be implemented in Oregon.

Principles of Carbon Accounting

There are five key principles of carbon accounting — Additionality, Baseline, Leakage, Permanence, and Measurement — which are defined and explained below. These are quality assurances that have become almost universal for any carbon project to address. In some cases, they have direct implication on how, what and for how long the carbon offsets are measured and reported. In other cases, the principles primarily address factors to be considered in forecasting the expected amount of carbon offsets from a proposed project, as well as other factors regarding project design quality.

The following issues and objectives of each principle provide a perspective of what Oregon landowners might face in the accounting of carbon offsets.

Additionality

Under current U.S. CO_2 emission reduction initiatives, purchasers must have the assurance that the offsets they are buying are additional – that is, the offsets arise from an activity that would not have otherwise occurred "but for" the carbon investment in the activity. Current U.S. CO_2 emission reduction initiatives do not treat regulatory obligations of the landowner as additional. For example, in Oregon reforestation following timber harvest is required by the Oregon Forest Practices Act[2]. In this case, if a stand of timber was harvested and the land has to be replanted, this would not qualify as being additional because of the legal obligation to reforest. In contrast, afforestation projects may be considered additional because forest establishment on marginal agriculture, pastureland or brush land is voluntary. This is the case for the acceptance of Oregon's Forest Resource Trust Stand Establishment Program as a

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[2] *Oregon Revised Statute (ORS) 527.745; Oregon Administrative Rule (OAR) 629.610.*

CO_2 emission reduction project by the Oregon Energy Facility Siting Council (Cathcart, 2000). However, not all voluntary actions or activity may be considered additional. Trexler et al. (2006) review specific additionality tests with respect to legal requirements, institutions, technology, investment, barriers to implementation, common practices, and timing.

One concern for additionality results from U.S. CO_2 emission reduction initiatives not being part of a comprehensive "cap and trade" system. Under such a system, everyone's actions are measured against the cap – the total allowable CO_2 emissions. The total allowed CO_2 are then allocated to the emitters. This cap allocation creates the scarcity (only so much CO_2 can be emitted) that gives carbon offsets value. Those emitters that cannot stay underneath their allocation of CO_2 emissions will become purchasers of carbon offsets and those emitters that emit underneath their allocation can sell the unused allocation as carbon offsets. Under a cap and trade system, it makes no difference whether projects or actions are additional or business as usual. However, if a particular business sector is not held accountable to the cap, then projects in that sector used for carbon offsets would still be subject to additionality.

The practical outcome of additionality is that successful forest-based carbon projects are grant-based and contractual – the purchaser provides some or all of the capital to conduct the project in exchange for the rights to the carbon offsets. The additionality of the project is proven in part because the project cannot be started or implemented until the grant or contract is awarded. Examples include afforestation projects funded with Oregon's Forest Resource Trust Stand Establishment Program or projects funded by The Climate Trust through a specific Request for Proposal process.

Baseline

With respect to carbon accounting, additionality is addressed by establishing a "without project" baseline (also known as a "business as usual" scenario) and estimating the CO_2 emissions that would occur in the project area absent the project, and then comparing an estimate of the amount of CO_2 emissions that occur with the project. Any reduction in CO_2 emissions, either from sequestration and/or emission avoidance, provides the initial estimate that can be credited to the project. For an afforestation project, this would involve comparing the carbon content of newly-planted trees versus the carbon content under the current land use system, such as agriculture, pasture or brush (*Figure 1*). For forest management projects (for example, extending rotations, alternative silvicultural practices), the baseline is set at how the land would normally be managed based on a legal, profit-maximizing motive for management. This is no different than a baseline used for valuing the forest land at fair market value based on the most economic efficient (and legal) management strategy or opportunity for development – a first step in valuing deed or management restrictions placed on forestland through conservation easements.

Many of the assumptions used to estimate the project's baseline may need to be measured as part of reporting the carbon offsets for the implemented project. This is especially true for forest management projects and forest conservation projects such as avoiding a forest's conversion to development (Table 2). While project investors prefer the certainty of a known baseline, baselines can increase or decrease over time depending on the measured outcomes for driving assumptions. In the context of reporting actual CO_2 emission reduction benefits, measuring the project baseline over time can be as important as measuring the CO_2 emission reduction benefits from the implemented project. Actually, the benefits cannot be calculated without a good measure of the baseline and as such, baseline measurements are subject to the same principles and standards as the accounting for project benefits.

Leakage

Leakage is when an investment is made in a carbon project and some of the carbon benefits that accrue to the project are lost by countervailing activities or actions that occur elsewhere as a result of implementing the project. Similar to additionality, leakage becomes a concern for carbon offset buyers because current markets in the U.S. are developing voluntarily, and without a formal cap and trade allocation system.

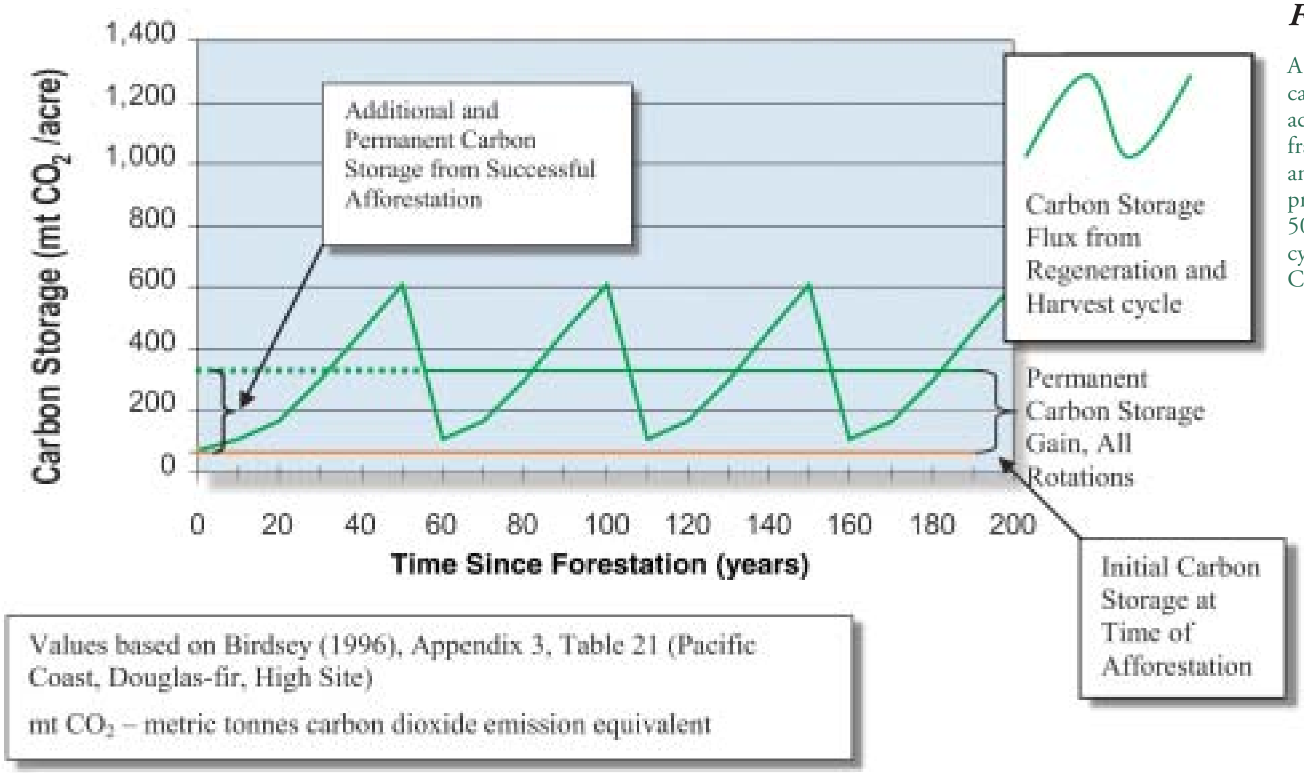
Leakage can include the physical CO_2 emissions from countervailing activities directly linked to the project, or calculated as indirect effects from market responses to the project's implementation. For example, a carbon investor purchases a conservation easement on mature forestland to retire the non-forest development rights to the property, and as part of the purchase, receives rights to the accruing carbon offsets from the avoided emissions from not developing the forest land. Physical leakage occurs when the landowner selling the easement makes up for the loss of development by developing another parcel of land elsewhere.

Another type of leakage is called market leakage or economic leakage (Murry *et al.,* 2004). In competitive markets where development or timber supply is in equilibrium with demand, there will be a marginal price effect. For example, a project that extends a forest's harvest rotation age is withdrawing available timber from the market and as a result restricts some of the available supply. A market in equilibrium will make a price adjustment - in this case, a price increase due to the increased scarcity in supply. The result is that some other supplier of timber will be induced to harvest their timber elsewhere. This effect is economic leakage. It can be estimated by comparing the relative elasticities (or steepness) of the supply and demand functions – which also must be known and quantified. Murry *et al., (*2004) empirically estimated ranges for economic leakage for the U.S. from less than 10 percent to over 90 percent of the initial CO_2 emission reduction estimate, depending on the type of forest project activity and region.

Permanence

One unique feature of forest-based carbon projects is the possible reversal of carbon benefits. This can occur either from natural disturbance, such as fires and weather events, or from a lack of reliable guarantees that the CO_2 emissions avoided or removed will not be permanently removed from the atmosphere (Brown *et al.,* 2000). Permanence addresses the intent that the CO_2 emission reduction project removes fossil fuel-sourced CO_2 emissions from the atmosphere on the same geologic time scale it was initially stored as fossil fuels. In practicality, permanence is defined as carbon storage that is temporal, but long enough, such that the removal of CO_2 from the atmosphere can influence the rate at which climate change is occurring. In this context, permanence represents the time period over which the fate of the carbon offsets from the project are accounted for to ensure the CO_2 emission reduction benefits are not reversed and returned to the atmosphere prematurely. For forest-based carbon projects, this tracking can last from several decades up to 100 years or longer.

A related principle is duration. Duration is the time period during which the carbon offsets are measured and reported. Using afforestation as an example, the project activity itself might last five years (the period from initial site preparation for tree planting to the time the tree seedlings are well established and free-to-grow), but the fate of the newly-created forest might have to be monitored for one or more rotations to ensure that the carbon benefits are permanent. While none of the U.S. CO_2 emission reduction initiatives currently accepts the stock-flow accounting approach for afforestation presented in Cathcart (2000), the approach does illustrate the differences between duration and permanence. The approach in



Values based on Birdsey (1996), Appendix 3, Table 21 (Pacific Coast, Douglas-fir, High Site)

mt CO_2 – metric tonnes carbon dioxide emission equivalent

Figure 1

A stock-flow carbon accounting framework for an afforestation project on a 50 year rotation cycle (from Cathcart 2000).

Cathcart (2000) allows for measurement of the physical change in carbon stocks as the forest grows over a duration over 30 years - the point where the amount of stock change equals the permanent carbon offsets available to the site. This is based on the change in average stock flow, calculated with and without the forest established (*Figure 1*). Stock change measurements can cease after age 30, but the project site is still monitored over a longer time period to ensure that the change in forestland use is considered permanent.

Measurement

The quantification of the CO_2 benefit is measured through direct means, indirect means such as look-up tables, modeling or some combination thereof. Forecasts are used to estimate the anticipated CO_2 benefits for investment analysis purposes. The quality assurances underlying measurement as a carbon accounting principle are reliability, timing and risk. These quality assurances address measurement in the context of estimating the amount of carbon offsets anticipated from a proposed forest-based carbon project for investment analysis purposes. The standards for measurement to use when reporting actual carbon offset accomplishments is discussed under measurement standards.

Reliability

Reliability addresses the legal and organizational infrastructure necessary to ensure that the carbon project is properly implemented, that the carbon accounting be conducted over the project's duration, and that the fate of activity giving rise to the carbon offsets is tracked over a long-enough time to sufficiently be considered permanent. As indicated above, most forest-based carbon projects have carbon benefits that span multiple years and decades. Monitoring requirements for permanence may last as long as 100 years. This calls for long-term legal and contractual arrangements, project management and accounting by organizations (or subsequent organizations) that are expected to last over time.

For example, the $1.5 million carbon mitigation investment in the Forest Resource Trust Stand Establishment Program was considered reliable because the Oregon Department of Forestry – a state governmental agency – administered the program. It was felt that through its network of field foresters and centralized administrative staff, the department had (a) infrastructure to conduct the necessary outreach, (b) technical assistance to sign up eligible landowners for the afforestation projects, and (c) centralized staff to perform the requisite measurement, monitoring and reporting functions. The contractual relationships between the department and participating landowners provided the legal mechanism for continued access to the site for measurement purposes and for transferring the carbon offsets. However, in the experience of the Stand Establishment Program, many of the reliability factors such as staffing and the amount of participation by landowners have not been realized (TRC Global Management Solutions 2005), calling into question the project's performance[3].

Timing

Many forestry projects, such as afforestation, are long-term in nature and take many years before the carbon offsets can be measured and reported. Timing issues will challenge afforestation projects in the future if the U.S. CO_2 emission reduction initiatives adopt specific emission reporting periods. If this occurs, the type of forest-based carbon projects that purchasers will be interested in will be determined in large part by the timing of the associated carbon offsets – such that the time the carbon offset is realized occurs in the period the purchaser wishes to report the offset. For example, for the Forest Resource Trust Stand Establishment Program's receipt of $1.5 million in carbon offset funding from the Klamath Cogeneration Project, the amount of carbon offsets to arise from this funding was estimated to accrue over a 100 year period.

In contrast, the expected life (and the period of CO_2 emissions) of the Klamath Cogeneration Project is 30 years. The lesson being learned is that while the plant has now operated and emitted CO_2 for five years (16 percent of its operating life), planted stands under the Stand Establishment Program are just achieving free-to-grow status with no CO_2 yet sequestered to offset the plant's emissions (TRC Global Management Solutions 2005). In all likelihood, the planted forests under the Stand Establishment Program will not achieve enough carbon sequestration to overcome the initial or baseline carbon on the site until around age 15, with the majority of the net CO_2 sequestration occurring between age 15 and 30 years (Cathcart, 2000) – toward the end of the cogeneration plant's operating life. In addition, about one-third of the awarded forecasted carbon offsets accrue after 65 years in the second rotation – 35 or more years past the expected life of the cogeneration plant (Oregon Office of Energy 1996). As such, investments in afforestation projects, or the purchase of carbon offsets from them, will likely involve purchasers interested in making investments in offsets to be used in future reporting periods.

Risk

Risk addresses whether the forecasted carbon offsets are realized and maintained throughout the crediting period. Forests can be at risk of loss from human and natural disturbances such as fire, insect and disease outbreaks and other disturbance events such as wind, ice or landslides. This puts individual landowners at a disadvantage in selling carbon offsets from smaller projects – perhaps only involving tens or hundreds of acres – because the entire project could be lost.

Another type of risk is whether the assumptions used in an initial forecast of CO_2 emission reduction benefits, which set expectations for the performance of the project, are realized by the project. Using the Klamath Cogeneration Project's $1.5 million CO_2 emission reduction investment as an example, one driving assump-

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[3] *Letter dated April 28, 2005 from Sam Sadler, Oregon Department of Energy to Joe Misek, Oregon Department of Forestry.*

tion underlying the initial forecast of 1.51 million metric tonnes of CO_2 emission reduction benefits was the estimated afforestation cost (site preparation to free-to-grow) of $480 per acre so that the $1.5 million could afforest 3,125 acres (Cathcart 2000). Other driving assumptions were that all lands afforested would be of high site quality and that enough landowners would participate in the Stand Establishment Program so that the entire $1.5 million would be allocated to specific afforestation projects within five years.

However, after five years of project implementation, these driving assumptions have not been met. Most notable is the actual cost of afforestation, which is approaching two to three times the amount used in the forecast (TRC Global Management Solutions 2005). As a result, the revised forecast of the carbon benefits is 428,000 metric tonnes CO_2 from 880 acres afforested (Cathcart 2003).

One way to account and manage for this risk is for individual landowners to pool their carbon projects together through a cooperative, or by working with a third party that aggregates individual projects. In 2001, the State Forester (head of Oregon's Department of Forestry) was given statutory authority through Oregon's forestry carbon offset law[4] to serve as an aggregator of forest-based carbon projects on non-federal lands for this purpose. The advantage with a large, aggregate pool of carbon offsets is that a certain percent (for example, 20 percent) of the available offsets can be held in reserve as a form of self-insurance and used as replacement offsets for projects lost to catastrophe. Also, the offsets can be used to make up for performance shortfalls arising from the inability to achieve the key assumptions used in the original carbon offset forecast.

One approach to address this type of risk is to conduct multiple forecasts using different outcomes for the driving assumptions, such that a range of performance outcomes is projected. Weights or probabilities could be assigned to the different outcomes to estimate the expected CO_2 emission reduction benefit as well as their variability. This variability, in relationship to the expected outcome, can be used as a measure of risk; the more variable the range of outcomes around the expected outcome, the more risky the project.

Table 1 summarizes how key principles have been addressed by existing U.S. CO_2 reduction initiatives. *Table 2* compares and contrasts the relative ease of addressing these accounting principles for different categories of forest-based carbon projects.

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[4] *House Bill 2200 creating new provisions; and amending Oregon Revised Statutes (ORS) Chapters 526 and 530. Passed in 2001 by the 71st Oregon Legislative Assembly; regular session.*

Table 1

COMPARISON OF U.S. CARBON DIOXIDE (CO_2) EMISSION REDUCTION INITIATIVES WITH RESPECT TO SELECTED CARBON ACCOUNTING PRINCIPLES AND MEASUREMENT

CO_2 Emission Reduction Initiative[1]	Baseline	Additionality	Leakage	Permanence	Measurement
California Climate Action Registry (CCAR)	Projection of the forest management practices (or absence thereof) that would have occurred within a project's boundaries in the absence of the project, including applicable land use laws and forest practice regulations.	Forest activities that exceed those activities occurring under the baseline characterization.	*Activity leakage:* The displacement of activities from within the project's physical boundaries to locations outside of the project's boundaries as a direct result of the project activity. Market leakage: The creation of CO_2 emissions outside project's boundaries through market substitution.	Commitment to forest activities secured through the mandatory use of a permanent conservation easement.	Annual increase or decrease in the project's reported total carbon stocks (i.e., stock changeaccounting).
The Climate Trust	Projected CO_2 emissions in the absence of the project include applicable land use laws and forest practice regulations.	CO_2 emission reductions over and above what would have occurred without the project.	The extent to which events occurring outside the project boundary tend to reduce a project's CO_2 emissions benefit.	A project's ability to weather exposure to variables and events that put at risk their ability to maintain the reduction in carbon dioxide output.	Stock change accounting. The quantity of offsets generated by a project is the difference between the "with-project" emissions baseline, and the "without-project" emissions baseline."
Chicago Climate Exchange	Same as CCAR.	Same as CCAR.	Same as CCAR.	Same as CCAR.	Stock change accounting. Look up tables for small projects, direct measurements of carbon stocks for large projects.
U.S. DOE 1605b program	Not addressed.	Not defined.	Not defined	Not defined	Stock change approach using look up tables and/or direct measurements in the field.

(1) California Climate Action Registry (CCAR) - http://www.climateregistry.org/docs/PROTOCOLS/Forestry/Forest_Project_Protocol_10.21.04.pdf
Climate Trust - http://www.climatetrU.S.t.org/pdfs/RFPs/Offset%20Glossary.pdf
The Chicago Climate Exchange - http://www.chicagoclimatex.com (Note: The Chicago Climate Exchange adopted the CCAR accounting protocols for forestry projects).
U.S. Department of Energy (DOE) 1605b Reporting - http://www.pi.energy.gov/pdf/library/TechnicalGuidelines_March2006.pdf

Table 2

EVALUATION OF SPECIFIC CLASSES OF FOREST-BASED PROJECTS AND THE DIFFICULTY (EASY, MEDIUM AND HARD) OF ADDRESSING THE QUALITY ASSURANCES IN PROJECT DEVELOPMENT AND CARBON ACCOUNTING

Type of Forest-Based Carbon Project	Additionality	Leakage	Permanence and Duration	Timing	Reliability	Measurability
Afforestation	Easy – Afforestation of underproducing lands is voluntary, has a distinct baseline condition (agriculture or pasture) and has readily observed changed behavior (conversion to forest).	Easy – Marginal agricultural, pasture and brush land is not being fully realized. Forest land use may be the best options of these lands. Unlikely that afforestation efforts will trigger conversion of forests to agriculture lands elsewhere. Project needs only be tracked within the project boundary (the area afforested).	Medium – Usually set at 100 years. What is necessary is continued commitment to the forest land use from afforestation. Practically, if the forests are managed through at least two rotations or for 100 years, the carbon benefits can be considered permanent.	Hard – Afforestation projects have a delay in the timing of the realized carbon benefits. Early project activity may be an emitting activity – so these projects could contribute to emissions in the short term. Forests will come on line after 20 to 30 years – toward the end of the life of most energy plants. Afforestation projects represent an investment in future carbon benefits.	Hard – Afforested stands will need to be tracked over a long-period of time – more than one generation. Contractual relationships need to pass on from landowner to landowner. Reliable third parties needed to manage and track the portfolio of individual afforestation parcels.	Direct measurement or use of yield tables validated by periodic measurements. The amount and timing of timber harvest needs to be tracked. Knowledge regarding the fate and utilization of harvested wood products desirable.

Table 2 (continued on next page)

Table 2 (continued)

Type of Forest-Based Carbon Project	Additionality	Leakage	Permanence and Duration	Timing	Reliability	Measurability
Extend Forest Rotations and Alternative Silvicultural Practices such as Variable Retention, Structure-Based Management.	Hard – Rotation or silvicultural management decision and carbon benefit intent needs to be documented in a forest management plan to establish change in behavior. Baseline analysis must look at how ownership and parcel would be managed without the rotation or silvicultural management choice in effect. Baseline can shift over time.	Hard – Difficult to apply the practice only at the stand scale. Practice or project needs to be applied at the landowner or timber parcel scale. Economic leakage likely. Price effect at the competitive market equilibrium may induce another landowner to shorten their rotation.	Medium – The carbon benefit is temporary unless landowner commits to the rotation or silvicultural decision as a matter of policy.	Medium – Extending rotations and changes in silvicultural management conducive to the notion of renting the carbon benefits over the extended rotation period. Avoided emissions benefit is immediate.	Hard – Rotation or silvicultural management decision may need to be secured through conservation easement or a binding forest management plan applicable to the entire ownership or timber parcel.	Medium – Direct measure of change in carbon storage from one stand age to the extended rotation age. Measuring effect of economic leakage problematic – best measured through regional timber supply modeling and applied through use of look-up tables. Measurements should account for changes in the wood products flow for the two rotations considered.
Conserving Forestland from Development (Forest Conservation)	Hard – Depends on whether there is a clear higher and best use market value if forest land area developed. Without project baseline is the amount of emission and the loss of sequestration potential resulting from loss of forestland. Baseline could shift over time.	Hard – Will development just occur somewhere else? Economic leakage likely. Price effect at the competitive market equilibrium may induce another landowner to develop forest land elsewhere.	Hard – Development rights sold or donated and retired permanently through a conservation easement.	Easy – Avoided emissions are immediate.	Medium – Existing legal and contractual arrangements exist such as conservation easements.	Medium – Need to estimate amount of residual vegetative cover and emissions associated with development (i.e., baseline measurement). See extended rotation and alternative silvicultural practice for difficulty in measuring the sequestration benefits for the continued forestland use

Table 2 (continued)

Type of Forest-Based Carbon Project	Additionality	Leakage	Permanence and Duration	Timing	Reliability	Measurability
Treatments to Improve Forest Resiliency to Wildfire, Insects and Diseases	Hard – The carbon credit capital must be necessary to make the project happen even when available financial assistance or end use markets are available. Baseline difficult to establish because fire occurrence, extent and severity is probabilistic. The effect of individual stand treatments on landscape resiliency to severe wildfire or pest outbreaks needs to be established.	Easy – Doubtful that forest fuels or forest health treatments in one area will induce fuel build up in another area.	Medium – Carbon benefits will need recurring treatment to avoid recurrence of stand conditions less resilient to fire, insect and disease outbreaks of high severity.	Medium – Avoided emissions are immediate. Residual stand carbon sequestration conducive to the notion of renting the carbon benefits over the timeframe selected for the project.	Medium – Need a commitment to perform recurring treatments and to track the condition of treated acres over the timeframe selected for the project. An individual project may not be sufficient to realize the carbon benefit; rather a grouping of projects strategically placed on the landscape may be necessary to influence fire extent and severity on the landscape.	Hard – While the amount of forest residue and timber removed can be measured and the sequestration benefit of the residual stand measure or modeled, the amount of carbon offset will ultimately rely on stochastic modeling of fire occurrence with and without the aggregate amount of sufficient treatments applied in the right spatial pattern on the landscape.

Measurement Standards

Standards for measuring carbon offsets from forest-based projects vary from the use of indirect measures — such as look-up tables — to direct measures that follow a systematic measurement protocol and are designed to achieve a desired level of certainty. The existing U.S. CO_2 emission reduction initiatives all use a stock change accounting approach (*Table 1*). With this system, physical carbon stocks are measured, estimated or assigned values based on look-up tables, and the incremental gain or loss of carbon stocks is reported periodically as an emission reduction credit or debit.

Reporting of greenhouse gas emissions began in the early 1990s when companies saw the need to gain recognition for efforts designed to manage or offset greenhouse gas emissions. In 1992, the U.S. Congress passed Section 1605(b) of the Energy Policy Act (Public Law 102-486) for the purpose of facilitating the voluntary reporting of greenhouse gases – the so-called 1605(b) reporting requirements administered by the Energy Information Administration of the U.S. Department of Energy. Reporting standards were in the form of look-up tables developed for specific project sectors including forestry (U.S. Department of Energy n.d.).

In February 2002, the Bush Administration released its strategy to reduce U.S. greenhouse gas intensity – the ratio of greenhouse gas emissions to economic output – by 18 percent by 2012. Included in the President's strategy was direction to the U.S. Department of Agriculture to come up with recommendations to reduce greenhouse gases and increase carbon storage on agriculture and forest lands through the targeted application of existing incentives to landowners such as Environmental Quality Incentives Program (EQIP), the Conservation Reserve Program (CRP) and the Forest Land Enhancement Program (FLEP)[5]. In 2002, the Energy Information Administration announced that the 1605(b) reporting guidelines would be updated to reflect new policy direction from the current U.S. Administration, including the development of new technical reporting guidelines for forest-based activities (U.S. Department of Energy 2006a).

One of the major changes coming out of the new 1605(b) reporting guidelines was the development of a grading system for the *quality* of the measurement standard used in the reporting. Using specific criteria, the system grades the reported CO_2 emissions from A to D, indicating the highest to lowest quality of measurement. To receive an A rating, the reported carbon offsets must be based on site specific values measured continuously over multiple time periods (U.S. Department of Energy 2006b). Reported carbon offsets will receive a C or D rating if the values reported are not based in part on some form of direct measurement. The exception is when look-up or default values are used from published, peer-reviewed and widely accepted literature, in which case a B rating is given (U.S. Department of Energy 2006b).

Simultaneous to the 1605(b) reporting standards was the development of the California Climate Action Registry protocols (California Climate Action Registry 2005a, 2005b, and 2006). Non-profit and voluntary, the registry was established by California statute as an official record of greenhouse gas emissions. Its purpose is to help companies and organizations with operations in the state to establish greenhouse gas emissions baselines and for reporting emission reductions from actions or projects implemented above and beyond the baseline activity. Many different types of carbon reduction projects are accepted, including forest-based activities.

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[5] *News release, June 6, 2003. Veneman announces new incentives for greenhouse gas reduction and carbon storage. Bonner Springs, Kansas: U.S. Department of Agriculture, Office of Communications. Release No. 0194.03.*

The California forestry protocols cover entity and project reporting, certification of forest-based carbon projects, voluntary reforestation, conservation based forest management, and conservation. They also stress the importance of addressing issues of additionality, leakage and permanence, as well as requiring direct measurements of some forest carbon pools (*Table 1*). Projects that do not use direct measurements are not eligible for certification by the Registry.

Another reduction initiative, the Chicago Climate Exchange, has adopted the California Climate Action Registry forestry protocols (Bayon 2005).

What to Measure

Measurement standards for carbon accounting are moving in the direction of conducting periodic measurements to support a project's carbon benefit claims. The U.S. Department of Energy's final technical guidelines has an appendix for the forestry sector. It provides a thorough overview of measurement protocols for forest carbon sequestration and methods for calculating the carbon stocks for various forest types of the U.S. In addition, guidelines are included for using models to project forest growth and yield, or forest ecosystem processes, in carbon calculations (U.S. Department of Energy 2006a).

The types of carbon stocks that could be measured and monitored in the reporting of carbon offsets from a forestry-based project are: the live trees (both above and below ground), understory vegetation, soil organic material, standing dead trees and downed logs, and forest products.

Which forest carbon stocks to measure is determined by the size of the carbon pool to be measured, and what pools are affected by the project's activities. Also taken into consideration are the costs of conducting the measurement, and any restrictions placed by the carbon purchaser or registry. For example, with afforestation projects, the largest carbon pool that will be affected by the activity will be the planted trees. In contrast, while understory vegetation could be measured, this is more a transitory pool that is not much affected by the project and may contribute little, if any, to permanent carbon storage. It is also important not to overlook those carbon pools that may be negatively affected by the project, such as the loss of existing carbon stocks and soil organic material disturbance from site preparation in the case of afforestation.

Units of measurement are usually expressed in terms of a CO_2 equivalent. It is important to verify that the units of measure are either CO_2 or carbon, because the units differ substantially. For example, 100 metric tonnes of carbon storage expressed in *carbon* is equivalent to 367 metric tonnes of *carbon dioxide*. Sidebar 1 reviews some common units of measure used in carbon accounting.

Live Trees and Understory Vegetation

Measurement of trees typically involves establishing a temporary or permanent inventory using fixed or variable plots. Forest inventories provide estimates of total and merchantable timber volume, either gross or net of volume defects. Volume is then calculated and converted to carbon using indirect conversion factors. An example is the ratio of merchantable volume to total biomass volume — either through the use of biomass regression (e.g., Smith *et al.,* 2002) or through estimated conversion factors defining the ratio of above-ground volume to total above- and below-ground volume (e.g., Birdsey 1996). Other conversion factors needed to convert volume to carbon by weight are specific gravities (to convert volume to weight) and percent carbon by weight factors (Birdsey 1996, U.S. Department of Energy 2006a).

An acceptable rule of thumb for converting biomass to carbon is to use 50 percent carbon-to-biomass dry weight as the factor. This value is within the range of biomass to carbon factors reported in Birdsey 1996. For example, 100 tons of dry weight biomass equals approximately 50 tons of stored carbon, or the equivalent of 183.5 tons of CO_2 emission reduction benefits.

A variety of biomass regression equations are available to estimate carbon content in above-ground vegetation; some have been developed for specific species in specific regions (e.g., Means 1994, Smith *et al.,* 2002).

For afforestation, an important project milestone to measure is the level of free-to-grow stocking at the end of project implementation. Free-to-grow means the new planted seedlings have been successfully maintained from competing vegetation and animal damage or browse, usually within 3 to 6 years. As a result, the afforestation project becomes a stand of well-distributed trees with a high probability of becoming a healthy, vigorous. and dominant forest over the foreseeable future. There are several, well established methods for conducting stocking surveys of recently planted stands (Cleary *et al.,* 1978). The Forest Resource Trust Stand Establishment Program uses the stocking quadrant method for determining stocking at free-to-grow.

Standing Dead and Down Logs

Standing and downed dead logs can be measured for carbon projects, particularly if they involve mature forests, for example, a forest conservation carbon project, or manipulated carbon pools in forest fuel reduction and forest health restoration projects. Standing dead wood is measured in a similar fashion as live trees; Pearson *et al.,* (2005) provide methods for estimating volume. Density of the wood is also an important measurement, because material that is sound, or in intermediate or advanced stages of decay, has different amounts of stored carbon for a given volume (e.g., see Pearson *et al.,* 2005). Downed logs can be measured using the line intersect method; a description of the methodology can be found in Harmon and Sexton (1996).

Sidebar 1

Conversion Factors for Units used to Report Carbon Offsets

2,000 pounds carbon stored = 1 short ton of carbon stored

1 short ton of carbon stored = 0.9072 metric tonnes of carbon stored

1,000 pounds carbon stored = 0.454 metric tonnes of carbon stored

1 metric tonne of carbon stored = 3.67 metric tonnes of carbon dioxide (CO2) equivalent

1 metric tonne of carbon stored = 1.102 short tons of carbon stored

1 metric tonne of carbon stored = 4.044 short tons of CO2 emission equivalent

1000 grams = 1 kilogram

1000 kilograms = 1 metric tonne

10,000 square meters = 1 hectare

1 hectare = 2.4711 acre

Soils, Litter and Debris

As trees grow, they can add carbon to soils via roots and litter fall, and over time through a build-up of soil organic material. But the amount of soil carbon that increases after trees are growing is not always significantly greater than the initial baseline carbon stock. For example, if a project area was heavily degraded via intensive agriculture it is likely that soil carbon would increase over the project lifetime

(Kimble *et al.,* 2003). However, if the land was in pasture (and the soil profile intact) the increase in carbon content would not likely increase significantly as the planted trees grow.

A cost-benefit analysis should be done to determine if soil carbon estimation is financially beneficial. When soil carbon accumulation becomes an included measurement pool, then the soil baseline stock will need to be calculated. Details on soil measurements can be found in Pearson *et al.*(2005).

Forest Products

The fate of carbon stored in live trees once the trees have been harvested is accounted for in the forest products pool, which addresses the permanence principle. While there are carbon emissions from timber harvest (e.g., soil disturbance and slash decomposition), accounting for the forest products pool ensures that the total biomass removed from the forest is not treated as an emission.

The amount of continued carbon storage that can still be credited depends on a number of factors, including how much of the timber harvest goes into utilization as solid wood products, such as lumber or plywood, and how much becomes pulp or paper. The decomposition rate of the wood products is also important, and is based on longevity of use and the type of disposal (e.g., landfills, burning) (Row and Phelps 1996). This type of accounting was used in the forecast of CO_2 emission reduction benefits for afforestation projects funded by Oregon's Forest Resource Trust Stand Establishment Program (Oregon Office of Energy 1996).

Perez-Garcia *et al.,* (2004) provide a carbon accounting framework that includes both the cumulative storage of carbon in the forest products pools, as well as the benefit of substituting wood products for more greenhouse gas-intensive products — such as steel in home construction. Factors and methods for calculating the amount of continued carbon storage in forest product pools can be found in the technical appendix for the U.S. Department of Energy's greenhouse gas voluntary reporting guidelines (U.S. Department of Energy 2006a).

Roles and Responsibilities in Forest-Based Carbon Projects

Forest-based carbon projects typically involve four parties: the carbon investor or purchaser of the carbon offsets; the forest landowner or producer of the carbon offsets; a professional forester or natural resource specialist with expertise in project implementation and carbon benefit measurement; and an organization (private, federal, or state) for coordinating and/or validating the reported carbon offsets.

Investor. An investor is typically a private company such as a utility or power company or other entity with an interest in offsetting a portion of the CO_2 emissions arising from their business activities. This desire can either be to achieve regulatory requirements (e.g., the Climate Trust) or to achieve voluntary commitments (e.g., Chicago Climate Exchange, California Climate Action Registry, U.S. Department of Energy 1605(b) Reporting).

Forest Landowner. Landowners can either be directly responsible for the implementation of the carbon project or activity, or can host the project on their lands through a lease or some other contractual relationship. It is important for landowners to understand their legal responsibilities, including accountability for failure to implement the project, or for any failure of the project to perform to expectations. Currently, most carbon project agreements are long-term and can take the form of long-term contracts or easements or other legal arrangements that are binding to subsequent landowners. Since competitive markets for carbon offsets in the U.S. have yet to develop, it is currently difficult for landowners to assess the merits of the amount being paid for the carbon offsets.

Professional Forester or Natural Resource Specialist. Professional expertise is necessary for successful planning and implementation of a forest-based carbon project. The same or additional expertise is necessary for making preliminary estimates of carbon stocks and the flow of carbon offsets over the project's lifetime or period of accounting. Resource professionals can also conduct or coordinate the measurement of carbon pools used to calculate and report the actual carbon offset accomplishments arising from the project.

Coordinating Organization. Third-party organizations can assist the landowner or investor with stability and longevity to ensure the project's reliability. Since forest-based carbon projects involve contracts and accounting periods that span decades (e.g., 50 -100 years), coordinating organizations are especially important. Through their involvement, the investor can be assured that the monitoring, measurement and reporting requirements will be fulfilled over time. Coordinating organizations can also aggregate carbon projects to meet the quantity of carbon offsets sought by investors or purchasers, as well as to provide consistency in the carbon accounting of individual project CO_2 emission reductions.

Summary

Carbon accounting includes estimating, measuring, reporting and monitoring of CO_2 emission reduction benefits (carbon offsets) arising from specific projects or activities. Over the past 15 years, measurement standards for reporting carbon offsets from forest-based projects have evolved from the use of indirect measurement factors and look-up tables to some form of reliance on the direct measurement of forest carbon pools, such as the volume in a forest. Important carbon pools to be measured in forest-based carbon projects are the live tree biomass (above and below ground), standing dead trees and down wood, soil organic material and forest products.

Currently in the U.S., there are four CO_2 emission reduction initiatives that recognize forest-based carbon projects: the U.S. Department of Energy's Voluntary Reporting of Greenhouse Gas Emissions (i.e., 1605(b) reporting), the Climate Trust, the California Climate Action Registry and the Chicago Climate Exchange.

The principles and standards for carbon accounting are in the early stages of development. They are being applied when estimating project expectations, as well as measuring and reporting accomplishments. Specific measurement and accounting protocols, such as the U.S. Department of Energy's 1605(b) technical guidelines for forestry and the forest carbon protocols developed by the California Climate Action Registry (and also accepted by the Chicago Climate Exchange), will continue to be tested as markets for carbon offsets develop.

Debate on the role of forests in mitigating sources of CO_2 emissions will continue. Carbon markets will dictate the quality assurance needs of purchasers as well as what needs to be measured to determine a carbon offset, and to what standard and over what period of time. Carbon accounting principles and measurement standards will evolve to address these quality

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CHAPTER TEN

HIGHLIGHTS:

GOVERNOR'S GLOBAL WARMING INITIATIVE

West Coast Governors' Global Warming Initiative

- Impacts from global warming are likely to be extensive and destructive.
- Governors from Oregon, California and Washington created an initiative.
- New technologies can protect environment and grow region's economy.
- Recommendation for forests: market-based carbon allowance program.

Oregon Governor's Advisory Group on Global Warming

- Goal: to achieve measurable and meaningful reductions in greenhouse gases.
- Sixty recommendations — would stop growth of greenhouse gases and begin to reduce them by 2010.
- Recommendation for forests:
    - Increase carbon "captured" in forests.
    - Reduce wildfire risk through market for small trees that fuel flames.
    - Consider greenhouse gases in forest land use decisions.
    - Increase forestation on marginal agriculture and pasturelands.

Renewable Energy Action Plan

- Plan directs the achievement of greenhouse gas reduction goals.
- Working group of 33 members appointed to implement, track and promote the plan.
- Directives for forests: Focus on biomass as an renewable energy source.
    - Generate electric power.
    - Convert into gas to produce liquid fuels in biorefineries.
    - Create small biomass heating/electrical systems.
- Directives for Department of Forestry:
    - Study and seek funds for biomass energy generation.
    - Support aggressive fire suppression on public and private forestlands.
    - Work with federal agencies to promote forest biomass energy.

Next Stage: Climate Change Integration Group

- Citizen-led group appointed to track implementation of the strategy, work as clearinghouse for shared information, make additional recommendations.

CHAPTER TEN
GOVERNOR'S GLOBAL WARMING INITIATIVE

Gail L. Achterman

"Global warming is underway and the impacts of its changes on Oregon citizens, businesses and environmental values are likely to be extensive and destructive. Coastal and river flooding, snowpack declines, lower summer river flows, impacts to farm and forest productivity, energy cost increases, public health effects, and increased pressure on many fish and wildlife species are some of the effects anticipated by scientists at Oregon and Washington universities."

-Executive Summary, *Oregon Strategy for Greenhouse Gas Reduction,* Governor's Advisory Group on Global Warming

Introduction

In 1997, Oregon became one of the first states to regulate carbon dioxide emissions from energy facilities. Oregon's leadership continues in cooperation with other West Coast states and through several broad citizen-led initiatives. This chapter describes Oregon's strategy for reducing greenhouse gas emissions with a focus on those that affect Oregon's forests.

West Coast Governors' Global Warming Initiative

A regional commitment to reduce greenhouse gas emissions

After he took office, Governor Ted Kulongoski directed his staff and the Oregon Department of Energy to participate in negotiations and prepare recommendations for a tri-state initiative on climate change and clean energy. On September 22, 2003, the governors of Oregon, California and Washington created the West Coast Governors' Global Warming Initiative. With this effort, they committed their states to act individually and regionally to reduce greenhouse gas emissions because of global warming's serious adverse consequences on the economy, health, and environment of the whole West Coast. This effort is widely considered one of the leading state initiatives on climate change in the United States.

In late 2004, the three states agreed on a detailed list of recommendations.[1] The one most relevant to forests is the development of a market-based carbon allowance program. Through this service, new power plants and other sources emitting greenhouse gases could purchase CO_2 offset dollars to fund forest-biomass renewable energy projects and carbon sequestration, along with other projects that reduce emissions. Such a program could foster new investment in forests and reforestation. The governors restated their belief that, given the promise of new technologies, reducing greenhouse gases will simultaneously protect the environment and grow the economy across the region.

Governor's Advisory Group on Global Warming

Developing directives for Oregon to achieve measurable and meaningful reductions in greenhouse gas emissions

In late 2003, to complement the work of the Initiative, Governor Kulongoski appointed a broad-based group of citizens and public

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[1] *West Coast Governors' Global Warming Initiative, http://www.ef.org/westcoastclimate/*

officials to draft a Global Warming Strategy for Oregon. The Advisory Group was co-chaired by Mark Dodson (President and Chief Executive Officer of NW Natural) and Dr. Jane Lubchenco (Wayne and Gladys Valley Professor of Marine Biology at Oregon State University). The 23 voting members included utility executives, farmers, local government officials, scientists, representatives from businesses, environmental and religious organizations, and others.

The Advisory Group's work was supported by State agency staff, and informed by the *Scientific Consensus Statement on the Impacts of Climate Change on the Pacific Northwest,*[2] which resulted from a conference, "The Impacts of Climate Change" held at Oregon State University on June 15, 2004. This Statement underscored that global warming caused by greenhouse gas emissions from human activities poses a serious threat to human civilization and natural ecosystems.

The Advisory Group attempted to determine Oregon's share of the global responsibility to reduce greenhouse gas emissions. Worldwide, the average of CO_2 emissions per capita is about four metric tons. Oregonians emit almost 17 metric tons of CO_2 per capita.

Several principles were adopted, including a focus on cost-effective solutions, the creation of long-term investment strategies for efficiency and energy savings, and a commitment to innovation. Particular emphasis was placed on achieving real, measurable and meaningful reductions in greenhouse gas emissions, goals firmly grounded in science and commensurate with the state's share of the larger global problem.

One strategy consistent with these principles is an increase of biological sequestration in farms and forests. The Advisory Group recommended taking action to increase the amount of carbon that can be captured and fixed in new or restored forest growth. Land management choices could restore much of the natural sequestration capacity that has been lost to development. Reforestation and conservation reserves in lands of marginal economic value could be stepped up dramatically, encouraged and sustained with government policies and public investment dollars.

A draft report was released for public review and comment, three public meetings were held, and over 250 comments were received.[3] The Advisory Group unanimously adopted its report, *Oregon Strategy for Greenhouse Gas Reductions* on December 17, 2004.[4]

The report made 60 recommendations, noting "We can arrest and reverse Oregon's contributions to these global warming trends. In doing so, we will set ourselves on a path to reduce emissions over time and stabilize the local climate conditions we bequeath to our children."

Table 1 shows the reductions possible from the various recommended actions.

"If we continue 'business as usual,' by 2025 Oregon's greenhouse gas emissions would be 61% higher than 1990 levels." The report's goals aim to stop the growth of Oregon's greenhouse gas emissions and begin to reduce them by 2010. Based on 1990 levels, a 10% reduced in greenhouse gases would be achieved by 2020, and a 75% reduction, or a "climate stabilization" level, by 2050.

Besides reducing greenhouse gas emissions, other significant strategies include energy efficiency targets, increasing the amount of electricity supplied by renewable energy, reducing carbon emissions — particularly for utilities and transportation — and adopting stricter auto tailpipe standards.

Biological sequestration is an important strategy, and of the six measures proposed, three directly relate to forests. Cumulatively, the three actions would decrease CO_2 emissions by 4.3 metric million tons by 2025.

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[2] *Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest, http://inr.oregonstate.edu/download/climate_change_consensus_statement_final.pdf*

[3] *Draft report and comments, http://www.oregon.gov/ENERGY/GBLWRM/Draft_Intro.shtml.*

[4] *Report, Oregon Strategy for Greenhouse Gas Reductions, http://www.oregon.gov/ENERGY/GBLWRM/Strategy.shtml*

TABLE 1. Biological Sequestration (BIOSEQ)

Refer to Part One, Figure 8 in Section 4 for the cumulative effect of all actions.

	CATEGORY 1: SIGNIFICANT ACTIONS FOR IMMEDIATE STATE ACTION	MMT CO_2E 2025	C/E?
BIOSEQ-1	Reduce wildfire risk by creating a market for woody biomass from forests.	3.2	Y
BIOSEQ-2	Consider greenhouse gas effects in farm and forest land use decisions.	0.6	Y
BIOSEQ-3	Increase forestation of under-producing lands	0.5	Y?

In the table above, column three shows estimated CO2 sequestration in million metric tons (MMT) in 2025. Column four asks if the action is cost-effective (C/E) - yes (Y) or no (N) to the consumer over the action's lifetime. (This does not address whether it is cost-effective to Oregon and Oregonians broadly, considering the projected effects of global warming and the costs of adapting to those effects.) A question mark means that the estimates of cost-effectiveness are uncertain and more analysis is needed. Because actions interact, CO2 savings cannot be added. Refer to Figure 8 in Part Two, Section 1 (Introduction to Recommended Actions) for the cumulative effect of actions.

BIOSEQ-1. Reduce wildfire risk by creating a market for woody biomass from forests. Some forests are at risk of catastrophic fire because small-diameter trees act as fuel for the flames. When forests burn, large amounts of stored carbon in trees are released into the atmosphere as CO_2. If these small trees (also known as woody biomass) can be removed, the risk of large CO_2 emissions from extreme fires is reduced. An added benefit is that that this biomass, when used to general electric power, produces less greenhouse gas emissions than fossil fuel. Currently, only a limited amount of forest thinning is done because of the lack of a market for biomass fuel. Since existing biomass-generating plants are not located near forests, the "emissions" cost of trucking the fuel outweighs the value of power generated. A recommendation is to locate small (two- to four-megawatt) biomass-fueled generating plants near forests to reap all the advantages.

BIOSEQ 2: Consider greenhouse gas effects in farm and forest land use decisions. Oregon's statewide land use planning program reduces CO_2 emissions by keeping forest land in forest production. It is estimated that Oregon's program prevented 51 million metric tons of CO_2 (1.7 MMT annually) from 1974 through 2004 by avoiding conversion of farm and forest lands to development.

BIOSEQ-3: Increase forestation of underproducing lands. Oregon already has programs that encourage reforestation of underproducing lands by providing a 50 percent tax credit. If more marginal lands — agriculture, pasture and unproductive brush lands capable of growing forests — were restored to healthy forests, carbon dioxide emissions could be reduced by 0.5 million metric tons of CO_2 per year.

Other strategies that involve forests relate to the technology and construction of biomass-fueled electric generation. Directives advise the Oregon University System to target research and develop demonstration programs for greenhouse gas reduction technologies such as renewable energy production using forestry biomass. Development of incentives for renewable energy hold great promise for forest land management. Twenty-five megawatts of biomass-fueled electric generation are underway in plants already built or under construction.

The report notes, "Oregon has significant competitive advantages. We have a broad array of technical expertise in energy-efficiency research, forestry and renewable energy. The state's entrepreneurs, supported by Oregon's academic and technological capabilities, can prosper by positioning themselves at the leading edge of change."

Renewable Energy Action Plan

A process to achieve the greenhouse gas reduction goals

On April 13, 2005, the governor formally accepted the Working Group's report and announced new greenhouse gas emission reductions goals based on their recommendations. He stated that this work will "put Oregon on the map as a national leader in the efforts to combat global warming and reduce greenhouse gas emissions."

To achieve those goals, the governor asked the Department of Energy and several state agencies to develop a comprehensive state Renewable Energy Action Plan (REAP).

The Plan contains numerous renewable energy policy goals and a long list of actions for promoting the development of renewable energy. Relative to forests, it centers on biomass as an energy source. Not only can biomass be used to generate electric power with lower greenhouse gas emissions, it can be used to fuel integrated biorefineries. Such refineries can gasify (rather than burn) biomass to produce liquid fuels and high-value chemicals, as well as electricity, in the same facility. The state Department of Forestry is encouraged to join with the state Department of Energy to seek federal funds for the development of this industry.

As further support for forest-generated biomass energy, the Plan suggests aiding the formation of partnerships between private companies and consumer-owned utilities to develop energy systems for local communities. Small, energy-efficient biomass heating and electrical systems could be created for heating and providing power to institutions, state offices, schools and other buildings, especially in rural Oregon. The Plan suggests identifying how to secure long-term biomass supplies, determining whether financial support or incentives are necessary to transport the supplies, and generating a program of greater public awareness of all the benefits of biomass energy production.

In February, 2006, the governor created a Renewable Energy Working Group to implement the Plan. Currently, this 33-member group includes representatives of electric utilities, municipalities, agriculture, forest biomass, environmental groups and industry, along with legislators and a representative from the governor's office. The Working Group will guide implementation of the Renewable Energy Action Plan, acting as advocates and advisors in the private and public sectors to encourage the growth of renewable energy and accompanying economic development. They also will track renewable energy development in Oregon and submit regular status reports on the implementation of the Plan to the governor's office for public dissemination.

In addition, the governor created a separate Forest Biomass Working Group to develop policy proposals on how best to achieve the Plan's renewable energy goals, and more generally, how to expand the market for forest biomass in Oregon. Staffed by the Department of Forestry, the group is comprised of representatives from the forest product sector, energy developers and advocates, environmental advocates, and academia.

The governor has asked both the Renewable Energy Working Group and the Forest Biomass Working Group to complete their work and present information or proposed legislation in time for consideration by the 2007 legislature session.

A number of directives of the Renewable Energy Action Plan are aimed at the Oregon Department of Forestry — mainly to study, support, promote, and seek federal funds for biomass energy generation. For example, the department is urged to investigate the benefits of reduced and avoided carbon dioxide emissions from forest fuel reduction projects in conjunction with biomass energy generation. Foresters are asked to promote active fuels and vegetation management, along with aggressive fire suppression on public and private forestlands, as key tools to produce biomass for energy generation and to manage forest health. They will work with federal agencies to promote forest biomass energy opportunities through administration of the National Fire Plan, the Healthy Forests Restoration Act and the Tribal Forest Protection Act. Along with the state Department of Energy, foresters will monitor available federal funds for biomass projects and provide assistance with the application process.

Next Steps: Climate Change Integration Group

Continuing to carry out the Strategy

The governor highlighted the importance of the forest biomass sector to his energy policy in his speech to the Oregon Business Council in January 9, 2006, and again in his response to questions at his State of the State Address on February 24, 2006.

The governor is currently in the process of appointing a new citizen-led Climate Change Integration Group. This group will track implementation, receive reports from state agencies, provide a clearinghouse for shared information, and continue to make additional recommendations to achieve the Strategy's goals. Fortunately, through all of the efforts at the legislative, administrative, local government, academic and citizen levels, Oregonians are grappling with what they can do to reduce greenhouse gas emissions and address the impacts of climate change. There is growing recognition of the fundamental need for real, meaningful emission reductions and a realization that Oregon can capture economic opportunities by doing so.

The author served on the Governor's Advisory Group on Global Warming and was a member of the drafting committee that prepared the Final Report. The author would like to acknowledge that this chapter is based, in large part, on materials provided to the Advisory Group, the Final Report, and Oregon's Renewable Energy Action Plan.

OREGON FOREST
RESOURCES INSTITUTE

Oregon Forest Resources Institute
317 SW Sixth Avenue, Suite 400
Portland, Oregon 97204
(971) 673-2944
1-800-719-9195

www.oregonforests.org