Ecosystem Services and Climate Change: Understanding the Differences and Identifying Opportunities for Forest Carbon

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Abstract—There are a number of misunderstandings about "ecosystem services" and "climate change" and these terms are often used incorrectly to describe different concepts. These concepts address different issues and objectives but have some important integrating themes relating to carbon and carbon sequestration. In this paper, we provide definitions and distinctions between ecosystem services and climate change. We describe some of the emerging markets for ecosystem services including carbon, water, wetland mitigation and species conservation banking and some of the national initiatives to address climate change with carbon markets. We also discuss some of the potential effects of climate change on forest ecosystems in the USA. Finally, we develop the concept of using an ecosystem services marketplace and the potential for mitigating climate change specifically focusing on the emerging markets for carbon. This integration of ecosystem services and climate change may provide some new opportunities for forest landowners and managers to enhance forest stewardship in addition to reducing greenhouse gas emissions through forest carbon sequestration.

Keywords: ecosystem services, climate change, carbon and forestry, carbon markets.

Introduction

Ecosystem Services and Climate Change

Ecosystem services are, in the broadest sense, the contributions or benefits that come from the natural environment. The Millenium Ecosystem Assessment (MEA 2005) provided a simple definition of *ecosystem services* as "the benefits people obtain from ecosystems." There is some disagreement among ecologists and economists on whether these benefits should include only the direct benefits for people or also include some of the supporting functions of ecosystems. The ecologist viewpoint (Daily 1997) focuses on the function and process of the ecosystem, and these services may include water purification, climate regulation, and biodiversity (figs. 1 and 2). The economist viewpoint generally focuses on ecosystem services that are components of nature, directly enjoyed, consumed, or used to yield human well-being (Boyd 2004; Boyd and Banzhaf 2006; Kroeger and Casey 2007). For our paper, we use the broad and previously defined typology for ecosystem services (MEA 2005) that highlights the wide-ranging importance and value of these services. The MEA divided up these services into four categories including provisioning, regulating, supporting, and cultural services (table 1). Provisioning services are a familiar part of the economy that provides goods such as food, freshwater, timber and fiber for direct human use. Regulating services maintain a world in which it is possible for people to live, and provide benefits

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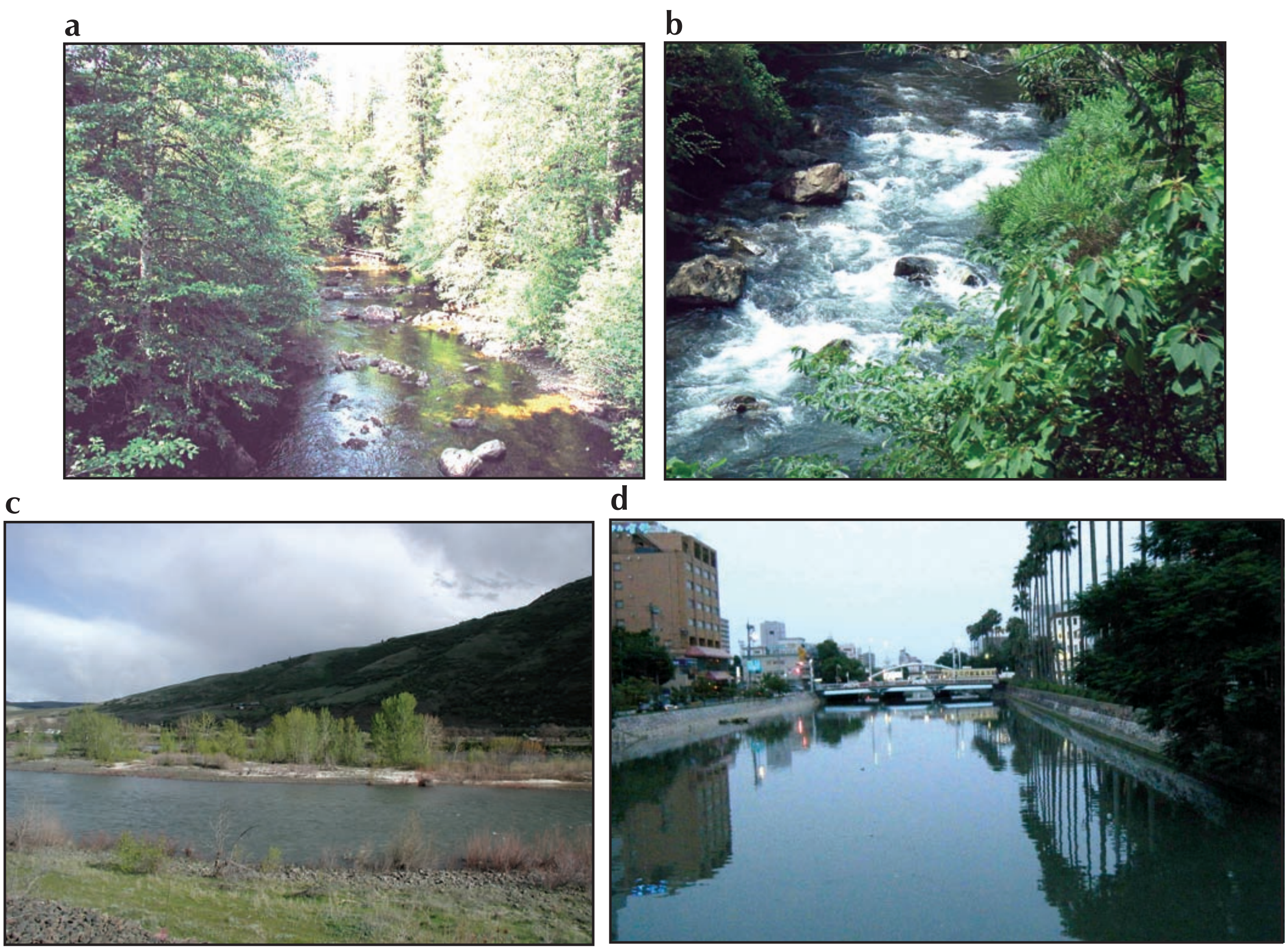

Figure 1—Examples of water as a global ecosystem service: a) Steelhead Creek, southeast Alaska, providing clear, cold water for high quality fish habitat and aquatic resources, b) headwater stream in Shikoku, Japan providing clear drinking water, c) Clearwater River in Idaho providing water for irrigation and flood control but with reduced habitat for migrating salmon, d) cement-walled river in Kochi, Japan, with highly degraded water quality and aquatic services.

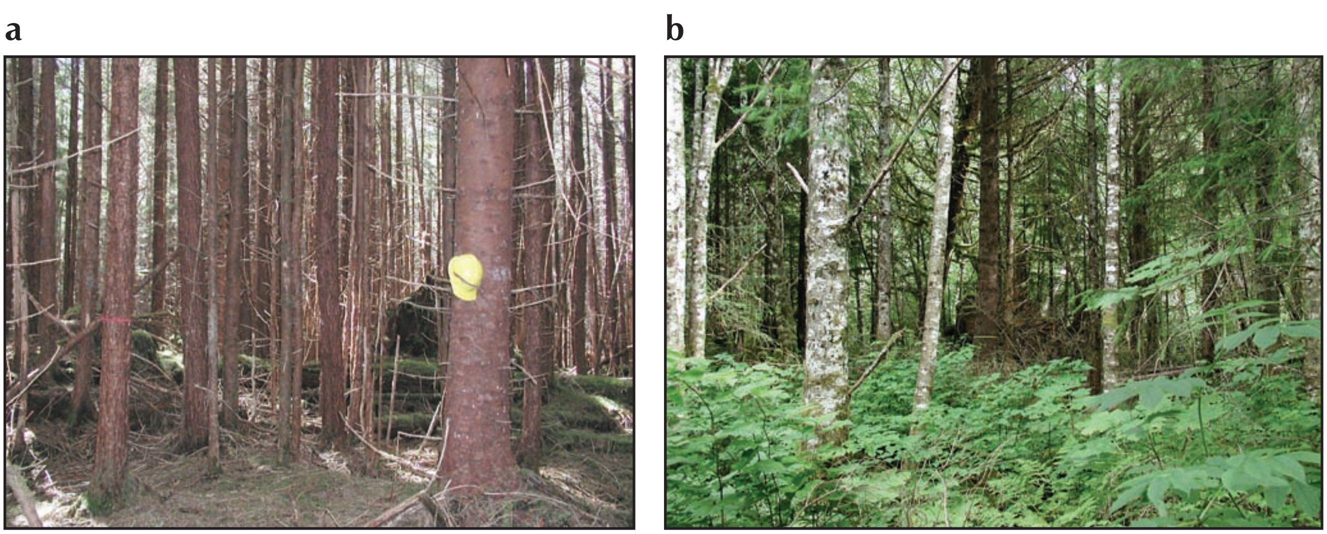

Figure 2—Examples of managed forest as an ecosystem service for biodiversity: a) pure 40-year-old conifer plantation in southeast Alaska with no plant understory and reduced wildlife habitat, b) mixed red alder-conifer 40-year-old forest in southeast Alaska with abundant plant understory and improved habitat for deer and small mammals.

Table 1—Categories of ecosystem services provided by nature. Modified from the Millenium Ecosystem Assessment (MEA 2005).

Ecosystem Services	
Supporting Services Nutrient cycling Soil formation Primary production	**Provisioning Services** Food (crops, livestock, wild foods, etc…) Fiber (timber, cotton/hemp/silk, wood fuel) Genetic resources Biochemicals, natural medicines, pharmaceuticals Fresh water
	Regulating Services Air quality regulation Climate regulation (global, regional, and local) Water regulation Erosion regulation Water purification and waste treatment Disease regulation Pest regulation Pollination Natural hazard regulation
	Cultural Services Aesthetic values Spiritual and religious values Recreation and ecotourism

such as flood and disease control, water purification, climate stabilization and crop pollination. Supporting services are the underlying processes that maintain the conditions for life on Earth and include nutrient cycling, soil formation and primary production from our ecosystems. Cultural services make the world a place where people want to live and include recreational, spiritual, aesthetic and cultural values.

Climate in a narrow sense is usually defined as the average weather over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate, in a wider sense, is the state of the climate system. Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or changes in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC 2007) defines *climate change* as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Integration of Ecosystem Services and Climate Change

Ecosystem service providers are increasingly recognized as having an important role to play in ecosystem protection. The emerging regulated market for carbon could also provide incentives for reducing greenhouse gas emissions and sequestering more carbon; both important considerations for mitigating climate change. The concept of providing incentives through market-based programs for ecosystem services, and the recent emergence of markets for carbon, water, wetlands and biodiversity has stimulated interest from a broad suite of new stakeholders. These markets provide incentives for landowners to provide clean air and water, wildlife habitat, and other goods and services from their forests and wetlands. These new financial incentives expand opportunities for forest landowners to gain revenue from their lands while providing public goods to society. Ecosystem services when considered as "natural capital" leads land managers to regard landscapes as natural assets that requires measuring different ecosystem services and ensuring the people who use these services know their value and the cost of losing them (Collins and Larry 2008; Kline 2006).

The importance of healthy, functioning ecosystems is widely recognized. Forests play a major role in the global carbon cycle through the ability of trees to withdraw or sequester carbon, and forests serve as a terrestrial carbon sink during most stages of forest development. Forests also have high conservation value for a number of threatened and endangered species, for mitigating pollution, for flood control and for other ecosystem services. Forests can play a major role in reducing greenhouse gas emissions through maintaining current carbon stores and by increasing the rate of carbon sequestration. Forest carbon is a particularly important ecosystem service to monitor and manage because there is interest in both maintaining current forest carbon stocks and also increasing carbon sequestration as a mitigation strategy for reducing atmospheric CO_2.

Deforestation accounts for approximately 20 percent of total greenhouse gas emissions (FAO 2005) and one of the major forestry concerns is reducing the loss of forestland from development. Maintaining these carbon stores is an important component of global carbon management. Forests can sequester large amounts of carbon in several ways including as carbon sinks in the standing forest, in wood products, and in avoided emissions when wood is used as a substitute for more fossil fuel-consuming products such as steel, concrete and brick. Other considerations include forest management practices that increase carbon sequestration such as extended rotations or increased growth rates through intensive forest management. Forest management will be required to help forests adapt and maintain high levels of carbon sequestration as climate changes.

The integration of ecosystem services markets and the role of forest carbon to reduce greenhouse gas emissions may be an effective framework for mitigating some of the effects of climate change. These markets can be helpful for both increasing carbon sequestration as part of a regulated carbon market and as financial incentives for landowners to prevent forestland from being developed. We explore some of these concepts in our paper and describe some of the markets for ecosystem services and the potential effects of climate change on forestry and some of the management practices relating to forests and carbon sequestration. The specific objectives of this paper include: 1) describe the policy and regulatory frameworks of emerging markets for ecosystem services in the USA, 2) describe the relationship between climate change, forest ecosystems and carbon, and some of the opportunities to mitigate climate change, and 3) develop a framework for integrating ecosystem services markets and climate change using forest carbon.

Markets for Ecosystem Services

Policy and regulations have an essential role for establishing markets for ecosystem services and market-based programs have developed in response to regulations for water, wetlands and endangered species. Examples of regulation driven markets include the Clean Water Act (33 U.S.C. 1344) that helped establish wetland mitigation banking and water quality trading (Brauman and others 2007; Gaddie and Regens 2000), and the Endangered Species Act (USFWS 1988) that led to the emergence of species conservation banking (Carroll and others 2007). However, these different ecosystem services are regulated and controlled by several different federal and state agencies with their own sets of policies and regulatory frameworks. For instance, at the national level, air and water quality is regulated by the Environmental Protection Agency (EPA), wetlands are regulated by the Army Corps of Engineers (USACE), and species conservation is controlled by the U.S. Fish and Wildlife Service (USFWS). Several markets for ecosystem services are emerging in the U.S. with potentially new revenue streams for forest landowners. These new markets offer potential financial incentives to landowners to maintain and manage forestlands rather than converting these forests to other uses. Overviews of U.S. carbon markets, water quality trading and wetland and species mitigation banking are outlined here.

Emerging Carbon Markets in the USA

The United States is not a signatory of the Kyoto Protocol (UNFCCC 2007) and the U.S. does not have a comprehensive national policy mandating limits in CO_2 emissions. Instead, the U.S. has voluntary, or state and region-based programs to reduce greenhouse gas emissions. Project-based transactions can generate offset credits by an approved activity that compensates for emissions by a business in a regulated sector. Examples of offset credits include forest carbon sequestration, methane recapture, and alternative energy use. Since about 20 percent of human-induced carbon dioxide emissions are due to land-use change and deforestation (FAO 2005), sustainable forest management can play an important role in climate change mitigation. Forestry offsets also provide a range of environmental benefits, such as wildlife habitat and water quality improvement.

Due to the absence of a comprehensive GHG regulatory emissions reduction standards (e.g. national cap-and-trade legislation), voluntary carbon markets have dominated in the USA and state and region-based programs are being developed to reduce greenhouse gas emissions. Regional and state programs include the Regional Greenhouse Gas Initiative (RGGI) in the Northeast USA (RGGI 2007), the Western Climate Initiative (WCI) in the Western USA (Capoor and Ambrosi 2008) and the Climate Action Registry in California (CCAR 2005). However, due to different regulatory frameworks being developed in each region and state, there is a need for developing national standards to help develop the registration and trading of carbon offset projects (Sampson 2004). Ruddell and others (2007) further contends that in the absence of such national standards, forestry offset projects will continue to be limited and inconsistent.

Although the voluntary U.S. carbon market is small compared with the global carbon market estimated at about $130 billion ($US) in 2009, the U.S. voluntary carbon market increased by 200 percent in 2007 with 13 percent of the carbon trading including carbon sequestration or forestry credits (Forestry Source 2007). By comparison, no forestry credits are accepted under the European Union Emission trading scheme and less than 1 percent of total transactions of 475 million tons made under the Kyoto protocol's Clean Development Mechanism involved forestry-based credits (UNFCCC 2007). With a regulated cap-and-trade mechanism that provides higher prices than current carbon values and the allowance of forest carbon offsets, the carbon market could provide a huge incentive for forestry. However, it is important that these forestry offsets provide high-quality carbon sequestration credits in order to assure early investors in the carbon market that these carbon offsets are credible and provide true reductions in GHG emissions.

To address GHG policy, the forestry community has a significant opportunity to shape what kinds of forest projects are included. Lawmakers in the U.S. have a variety of pending legislation with significant implications for carbon and forestry including the 2008 Farm Bill, 2009 American Clean Energy and Security (ACES) Waxman-Markey bill, and other federal and state legislation. Two key components for any forestry offset project include keeping forestland in forests, and increasing carbon sequestration through forest management. There are also a number of important policy issues to incorporate in forestry offsets including clear definitions for carbon baselines and additionality, permanence and leakage, possible inclusion of wood products for the long-term storage of carbon, and projects that promote additional carbon sequestration and discourage conversion of forests to other land uses (Cathcart 2000; Ruddell and others 2007).

Water Quality Trading

Ecosystem services for water include water supply, water damage mitigation, and water-related cultural services (Brauman and others 2007; fig. 1). Unlike global carbon markets, market-based schemes for improving water quality are generally limited to local or regional programs within a specific watershed. Forest landowners and farmers can be included as sellers of water quality credits in many programs. Other participants include water quality permitting authorities, third-party brokers, conservation organizations, watershed councils, and private industry groups. Local examples of water quality trading include the EPA watershed-based permit for the Tualatin River in Oregon that allows trading to achieve the permit requirement for temperature (Cochran 2007). Here, instead of installing refrigeration systems at two Tualatin River treatment plants (at a cost of $60 million), the wastewater utility paid upstream farmers to plant shade trees in the riparian areas (at a cost of $6 million).

Wetland and Species Mitigation Banking

Another market for ecosystem services is wetland mitigation and species conservation banking. These markets are based on regulations that require developers to obtain a permit to offset any loss of wetland or habitat before they are allowed to harm a wetland or an endangered species. Wetland mitigation banking has developed into a well-established, market-based system where buyers and sellers of credits conduct transactions through wetland banks. Wetland ecosystems provide a broad range of ecological services for people, and studies have shown the importance of services provided by wetlands including water quality and quantity, recreation, wildlife habitat, flood control and pollution interception (Azevedo and others 2000; Hoehn and others 2001). On-site wetland mitigation has been largely unsuccessful for restoring original wetland functions but larger offsite-wetland banks are now recognized for their broader functionality and production of multiple ecosystem services (Gaddie and Regens 2000; Willamette Partnership 2008).

Conservation banking, the creation and trading of credits that represent wildlife conservation values on private lands is more than a decade old, and the State of California has developed most of the conservation banking agreements in the U.S. (Fox and Nino-Murcia 2005). A conservation bank is a parcel of protected natural land that is authorized to sell a set number of credits, usually in the form of land area of habitat, to the customer that is required by law to mitigate their impact to the same species and habitat on nearby land. Private landowners reported that financial motives were behind most of their interest in conservation banking but bureaucracy was the biggest challenge with the average time for establishing banks more than 2 years and varied from 8 months to over 6 years (Fox and Nino-Murcia 2005). However, as Fox and Nino-Murcia (2005) contend, the fact that banks are profitable in most cases is an indication that conservation banking offers viable incentives to protect species on private land.

Climate Change and Forestry

Climate Change and Forest Ecosystems

Some effects of climate change on forest ecosystems and natural resources in North America are already detectable (IPCC 2007), and no historical analog exists for the combination of future climate conditions, disturbance regimes, and land-use patterns expected in the future. Climate provides an overarching control on the distribution of tree species (Woodward 1987). Climate-induced stress occurs in areas where species may be marginally suited, such as the edge of their geographic distribution. As a result, a warmer climate will lead to potential changes in species distribution and abundance at various spatial scales. Changes in composition may be slow even in a rapidly warming climate, because mature individuals are typically resistant to climatic variation. Therefore, disturbance will be a major agent of change and will promote change through forest regeneration at shorter time scales than the direct influence of climate (McKenzie and others 2004; fig. 3).

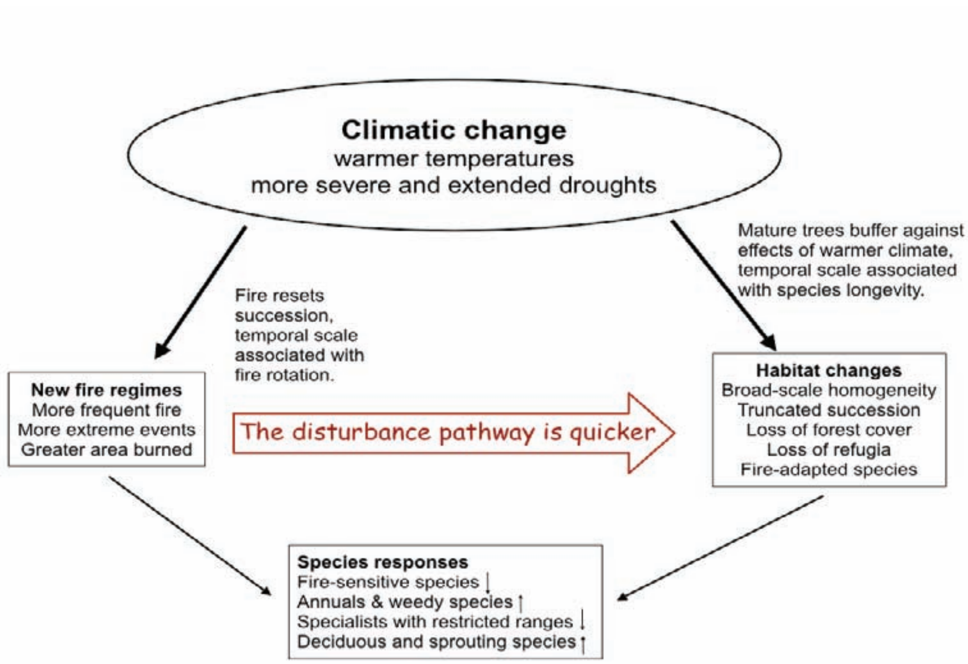

Figure 3—Conceptual model of the effects of climatic change and disturbance on forest ecosystems. Times are approximate. Adapted from McKenzie and others (2004).

Limiting factors act at the interface between organisms and their environment, and plant performance is affected when one or more resources (e.g., energy, water, nutrients) limits physiological function. Forests of western North America can be considered as energy limited, water limited, or some combination thereof (Littell and others 2008). Energy limitations are primarily light (e.g., productive forests where high leaf area reduces light exposure in the canopy) and temperature (e.g., subalpine and boreal forests). Some energy-limited forest systems appear to be responding positively to warming temperatures over the past 100 years (Peterson 1998).

Productivity in water-limited forests will decrease in a warmer climate, because negative water balances will reduce photosynthesis (Hicke and others 2002), although this may be partially offset if CO_2 fertilization increases water-use efficiency (Neilson and others 2005). For example, most montane Douglas-fir (*Pseudotsuga menziesii*) forests across the northwestern United States are water limited (Littell and others 2008), and the area and magnitude of this limitation will increase as the climate continues to warm. Limiting factors typically vary within species (Peterson and Peterson 2001), between seasons, and with respect to the balance between water and energy needs (Stephenson 1998).

The conceptual model of a "disease spiral" (*sensu* Manion 1991) in which tree death is caused by the accretion of multiple stresses can be scaled up to the concept of a "stress complex" for populations of tree species and for multiple populations at the ecosystem level (McKenzie and others 2009). Temperature increase is a predisposing factor causing stress in forest ecosystems of western North America by exacerbating negative water balance (Littell and others 2008; Stephenson 1998) and through increased frequency, severity, and extent of disturbances. Climate change and the combination of warmer temperatures, drought, and more severe disturbance regimes can create stressful conditions for forest ecosystems over large geographic areas.

The principal disturbance regimes of western North America, wildfire, and insect outbreaks, respond to short-term weather and annual-to-decadal cycles in climate. For example, synchronous fire years are associated with the El Niño Southern Oscillation cycle in the American Southwest and southern Rocky Mountains (Swetnam and Betancourt 1998; Veblen and others 2000) and to some extent in the Pacific Northwest (Hessl and others 2004). Short-term weather anomalies associated with atmospheric blocking ridges of high pressure promote extreme wildfire years in some areas of the West (Gedalof and others 2005). Insect defoliators are favored in years during which vegetation productivity is high (Weber and Schweingruber 1995), but overall forest vigor is low (Swetnam and Betancourt 1998).

Higher temperatures are expected to alter the frequency, severity, and extent of natural disturbances, and wildfire (McKenzie and others 2004; Westerling and others 2006) and mountain pine beetle outbreaks (Logan and Powell 2001) may become a more dominant feature of western landscapes. Where fire and insect disturbances interact, changes in forest ecosystem structure and function may be accelerated (Veblen and others 1994), resulting in altered combinations of species, productivity, and disturbance regimes (table 2).

Forest Management for Carbon Sequestration

Carbon sequestration in forests is one ecosystem service that will be sensitive to climate change, and forest management will be necessary to facilitate forest adaptation as the climate changes. Sustainable forest management can not only maintain carbon sequestration at current levels, but can also increase carbon sequestration to mitigate atmospheric CO_2 concentrations. Sustainable forest

Table 2—Examples of stress complexes in western North American forests that could be affected by a warmer climate.

Pinyon-juniper woodland (American Southwest)

Pinyon pine (*Pinus edulis* Engelm.) and various juniper species (*Juniperus* spp.) are among the most drought-tolerant trees in western North America and clearly occur in water-limited systems. Multi-year droughts have caused historical diebacks of pinyon pines over large geographic areas in the American Southwest, but the current dieback is unprecedented in terms of the scale of response to a period of low precipitation and high temperature (Breshears and others 2005). A warmer climate has been a predisposing factor, and wood-boring insects have contributed to weakening and ultimately killing trees.

Mixed conifer forest (Sierra Nevada, southern California)

Forests in central and southern California have a Mediterranean climate with long dry summers, and mild winters during which most of the annual precipitation occurs. Fire exclusion has increased fuel loadings (McKelvey and others 1996) and competitive stress as stand densities have increased (van Mantgem and others 2004). Elevated levels of ambient ozone have reduced net photosynthesis, growth, and interannual accumulation of biomass in ponderosa pine (*Pinus ponderosa* C. Lawson var. *ponderosa*) and Jeffrey pine (*P. jeffreyi* Balf.) in the Sierra Nevada and southern California mountains (Byternowicz and Grulke 1992; Miller 1992; Peterson and Arbaugh 1988; Peterson and others 1991). Bark beetle outbreaks in these regions have caused extensive mortality in recent years following protracted droughts.

Lodgepole pine forest (western North America)

Lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson) is the principal host of the mountain pine beetle (*Dendroctonus ponderosae*), and dense stands that are stressed from low soil moisture are particularly vulnerable to mortality during beetle outbreaks (Hicke and others 2006). Recent beetle outbreaks have caused extensive mortality across millions of hectares in western North America (Logan and Powell 2001), with large mature cohorts (age 70-80 yr) contributing to widespread vulnerability. Tree mortality caused by beetles produces rapid necromass (fuel) accumulation, and the potential for species conversion following stand-replacing fires, including a favorable environment in some locations for establishment of drought-tolerant species such as interior Douglas-fir and ponderosa pine.

Boreal forest (central and southern Alaska)

Alaska has experienced historically unprecedented areas burned by wildfire in the last decade (NIFC 2006). Concurrently, large outbreaks of the spruce bark beetle (*Dendroctonus rufipennis*) occurred in white spruce (*Picea glauca* [Moench] Voss) forests on and near the Kenai Peninsula in southern Alaska (Berg and others 2006). Fire and beetle outbreaks are likely associated with warmer temperatures in recent decades (Duffy and others 2005, Werner and others 2006). In interior Alaska, white spruce and black spruce (*Picea mariana* [Mill.] Britton, Sterns & Poggenb.) are more flammable than co-occurring deciduous species such as paper birch (*Betula papyrifera* Marsh.). Conifers are the target of bark beetles, so in southern Alaska they are disadvantaged compared to deciduous species. As a result, this system may transition to deciduous trees via more frequent and extensive disturbance associated with a warmer climate.

management practices aimed at mitigating atmospheric CO_2 are more likely to be successful if they are specific to different forest types and disturbance regimes within western North America. Furthermore, these mitigation strategies will be more effective if they are implemented with consideration of the expected effects of climate change on forest ecosystems given that some degree of climate change is inevitable despite current mitigation actions.

Afforestation and reforestation of previously forested lands are two forest management practices with the greatest potential to increase carbon sequestration. These management practices, if properly implemented, can remove additional carbon from the atmosphere and sequester it for decades to centuries. These projects will be more successful if they are implemented in combination with management practices that also facilitate forest adaptation to climate change. Adaptation strategies include selecting for planting species or varieties that are adapted to a warmer climate, planting a greater diversity of species, and planting at lower initial densities to reduce moisture stress in water-limited forests. These adaptation strategies will help maintain carbon storage by increasing forest productivity and resilience to warmer temperatures and more frequent disturbances.

Climate-driven increases in wildfire frequency, extent, and severity are expected to affect the potential of forest ecosystems to sequester carbon. In water-limited forests, climate change may also reduce regeneration success after severe wildfires due to greater climate-induced stress in seedlings. A vegetation type conversion (e.g. from forest to shrubland) or a reduction in forest density can reduce carbon sequestration more than the wildfire itself (Kashian and others 2006). Therefore, forest management practices that ensure adequate post-fire regeneration with appropriate species, genotypes, and densities are important for enhancing forest resilience to climate change and maintaining the carbon sequestration functionality of the forest ecosystem.

Thinning forests to reduce disturbance severity and extent (fuel treatments) is another forest management practice that can enhance resilience to disturbances, as well as maintain and enhance carbon sequestration. Individual wildfires are a large, one-time source of carbon emissions that can be significant in the short-term (Turner and others 2007; fig. 4). However, the carbon sequestration benefits of fuel treatments may be less than expected because of four common misconceptions regarding carbon and wildfires. First, wildfires, even those burning with high severity, typically consume less than 20 percent of total live and dead forest biomass (Campbell and others 2007). Although more than 80 percent of trees can be killed in high severity fires, the carbon is generally released slowly over decades as the biomass decomposes. Second, the difference between biomass consumption in high and low severity fires is small, about 10 percent (Campbell and others 2007). Third, as fire-killed material decomposes and releases carbon, carbon is returned to the system as post-fire regeneration and the productivity of these young regenerating forests is higher than that of the older forests they

a b

Figure 4—Examples of fire as an ecosystem service: a) severe fire intensity after B&B fire in central Oregon with loss of organic layers, exposed mineral soil and reduced forest productivity, b) moderate fire intensity after B& B fire with pre-fire thinning treatment to reduce fire severity resulting in relatively healthy forest ecosystem after fire.

replace. Fourth, at long temporal scales (the scale being relative to the ecosystem-specific fire return interval) the net release of carbon from any fire-disturbed ecosystem may be zero as long as the forest regenerates and reaches the pre-fire age and density (Kashian and others 2006).

The carbon benefits of fuel treatments in forest ecosystems depend on the fire regime characteristic of the ecosystem (fig. 4). Fuel treatments will not incur carbon storage benefits in high severity, low frequency fire regimes (fire return intervals on the order of centuries) (Mitchell and others 2009). Treatments may need to be repeated to maintain low fire hazard and the total carbon removed in successive treatments over centuries can exceed the carbon emitted in a single, high severity fire (Hurteau and North 2009). However, fuel treatments are unlikely to reduce fire severity in these forest types because fire severity is more a function of weather than fuel availability (Brown and others 2004).

Conversely, fuel treatments can enhance carbon storage in forests with low severity, high frequency fire regimes (fire return intervals on the order of years to decades) (Hurteau and North 2009; Mitchell and others 2009), especially forests that have experienced biomass accumulation due to fire suppression (Brown and others 2004). In these ecosystems, fuel treatments can effectively reduce subsequent wildfire severity and carbon emissions. Fuel treatments reduce forest productivity in the short term (1-3 years), but ecosystem productivity often returns to or exceeds pre-treatment levels within only a few years (Boerner and others 2008). Furthermore, reduced productivity in the tree component (in proportion to tree removal) is compensated by increased productivity in roots and understory vegetation, which respond positively in more open stands (Campbell and others 2009). However, the carbon benefits of fuel treatments are marginal even in low severity fire regimes. Fuel treatments remove substantial carbon from the site and a subsequent wildfire, even with effective fire severity reduction, will release additional carbon (Mitchell and others 2009). The total carbon removed in only a few treatments may exceed the carbon gains from fire severity reduction because of the small difference in biomass consumption between high and low severity wildfires (Hurteau and North 2009; Mitchell and others 2009). However, fuel treatments are a useful management tool for maintaining other ecosystem services, including air quality, water quantity, and wildlife habitat, and should be considered based on their benefits to multiple ecosystem services, not just carbon sequestration (fig. 2).

Certain forest management practices may increase the carbon sequestration potential of fuel treatments. Fuel treatments will have greater carbon storage benefits if a small area can be treated to reduce fire severity over a larger area through the strategic placement of treatments on the landscape (Finney 2001). Carbon sequestration can also be enhanced with specific uses of the biomass that is removed in treatments. The carbon may be stored for up to 100 years or longer if the material is used in long-lived forest products. Carbon benefits also increase if the biomass is used as an energy source that is substituted for energy that would otherwise be derived from fossil fuels (Mitchell and others 2009). Increasing the production of biofuels using biomass removed from thinning forests can increase the carbon benefits of fuel treatments (fig. 5).

Discussion

The Role of Ecosystem Services for Ecosystem Protection

Ecosystem services provide provisioning, supporting, and regulating services that are critical for the functioning of life on Earth and provide natural assets that are intrinsic components of our economy. However, recent evaluation of the state

Figure 5—Examples of biomass utilization and use of forest carbon: a) small-to-medium size diameter logs following forest thinning, b) grinding of branches and small diameter trees for wood chips and hogg fuel for biomass energy, c) bundling of biomass for hogg fuel for co-generation energy source.

of the world's ecosystems shows that about 60 percent of all ecosystems are rapidly degrading or are being used unsustainably (MEA 2005). Emerging markets for ecosystem services are increasingly recognized as having an important role to play in ecosystem protection. Market mechanisms can be used to provide incentives to private forest landowners to enhance provision of ecosystem services, often with the associated objective of providing a counterbalance to financial incentives to convert forests to other land uses (Kline 2006). These new financial incentives expand opportunities for forest landowners to gain revenue from their lands while providing public goods to society.

Collaborative efforts are being developed at local, regional, national and international levels to better conserve our natural resources (Boyd 2004; Daily 1997; Heal and others 2005; Oliver and Deal 2007). There are several organizations in the United States that are interested in developing an ecosystem marketplace that could buy and trade different ecosystem services (Bay Bank 2008; Katoomba 2007; Willamette Partnership 2008). This marketplace could help a single large landowner or a group of landowners sell wetland, endangered species, water quality and carbon credits from the same piece of land. For example, in Oregon, the Willamette Partnership recently received a NRCS Conservation Innovation Grant to develop a multi-credit market system to measure and account for multiple types of ecosystem service credits for use within the Willamette Ecosystem marketplace (Willamette Partnership 2008). This multi-credit marketplace would be able to take advantage of efforts to combine or bundle different ecosystem services. Other examples include the 2008 USDA Farm Bill, section 2709 (USDA 2008) that shifted an emphasis from commodity-oriented programs to more market-based payment programs, achieving movement toward this ecosystem services goal. Pending carbon cap and trade legislation such as the 2009 ACES Waxman-Markey bill could further reduce greenhouse gas emissions using market mechanisms and forestry and agricultural offset programs. Market-based incentives for ecosystem services has provided a new framework for a diverse coalition of conservationists, forest landowners and other stakeholders to work together to develop market based strategies for conserving ecosystem services. This has led to a shift from thinking about conservation as a burden or endangered species as a liability, to the concept of restoration and stewardship of ecosystem services as a profit making enterprise (Collins and Larry 2008; Heal and others 2005).

The Role of Forests, Forestry, and Wood Products for Sequestering Carbon

Forests and forestry have an important role for sequestering carbon and reducing greenhouse gas emissions. Forests can sequester large amounts of carbon in several ways including as carbon sinks in the standing forest, in wood products, and in avoided emissions when wood is used as a substitute for more fossil fuel-consuming products such as steel, concrete and brick. One of the obvious and most important roles for reducing CO_2 emissions is avoiding deforestation and keeping forestlands in forests. Globally, about 20 percent of human-induced carbon dioxide emissions are due to land-use change and deforestation (FAO 2005). This is important at the global scale and here in the United States where land conversion and development has led to more than 2,500 acres of forest loss each day, with more area being impacted by forest fragmentation (Alig 2007). Afforestation and reforestation of previously forested lands is an important and widely accepted forest management practice to increase carbon sequestration. Storage of carbon in wood products can also have a significant impact in storing carbon and avoiding use of more fossil fuel-intensive products. Preliminary calculations suggest a 20 percent to 50 percent decrease in fossil fuel use if forests and wood products are used to sequester carbon in place of more fossil fuel-consuming products such as steel, concrete and brick (Lippke and others 2004). An example of local biomass utilization is highlighted on the Deschutes National Forest in central Oregon. In fiscal year 2008, biomass utilization included 150,000 green tons of small diameter wood converted into mulch, pulp chips, animal bedding, lumber and poles with an additional 69,000 green tons converted into hogg fuel or firewood that was used for energy or heat as an offset to fossil fuel consumption (fig. 5). Wood can play an important role as a substitute for fossil fuels; however, it is important to note that wood used for energy is much less efficient than wood used for construction. Currently, approximately 50 percent of the world's wood harvest is used for fuel, primarily in areas of low economy such as Africa where approximately 90 percent of the wood harvest is used for fuel for cooking (Oliver and Deal 2007). Another key consideration is how carbon markets, forestry management, wood products and carbon credit programs are administered. Actual carbon market trading will involve a number of complex variables relating to establishment of existing carbon baselines and additionality, leakage and permanence, inclusion of wood products for the long-term storage of carbon, and programs that promote additional carbon storage through forest management practices that discourages forest land conversion (Cathcart 2000; Ruddell and others 2007).

Conclusion

Ecosystem services when considered as "natural capital" leads land managers to regard landscapes as natural assets. Furthermore, the integration of ecosystem services markets and the use of forests to sequester carbon may be an effective framework for mitigating some of the effects of climate change. Several markets for ecosystem services are emerging in the USA with potentially new revenue streams for forest landowners. These new markets offer potential financial incentives to landowners to maintain and manage forestlands rather than converting these forests to other uses. There is increasing interest in the use of market-based approaches to add value for these services and assist conservation of natural resources. This integration of ecosystem services and climate change may provide some new opportunities for forest landowners and managers to enhance forest stewardship in addition to reducing greenhouse gas emissions through forest carbon sequestration. There is a also a need for a more integrated approach that combines different ecosystem services and provides financial incentives for forest landowners to achieve broad conservation goals.

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