Pacific Northwest Research Station

Science Update

CHANGING WITH THE CLIMATE

Tom Iraci

IN SUMMARY

Carbon is a naturally occurring element, essential to life on this planet. We exhale it, while plants absorb it as part of the photosynthetic process. Human activities have altered the carbon balance, however, and as a result have triggered changes in climates around the world. By extracting and burning oil, coal, and natural gas, carbon that was locked in "long-term" storage underground has been released into the atmosphere. The associated greenhouse gases such as carbon dioxide, methane, and nitrous oxide trap heat that would otherwise radiate back into space. Changes to the global climate have significant repercussions and will affect nearly all the Earth's species in some way. A large source of uncertainty lies in the social changes that may or may not occur. As we grapple with what these changes mean for ecosystems, and how the output of critical services provided by these ecosystems will be affected, two broad-based strategies are at our disposal: adaptation and mitigation. Adaptation strategies aim to prepare the landscape and its habitants for the new climate, whereas mitigation strategies attempt to slow down the process of climate change. This issue of *Science Update* highlights research by scientists from the Pacific Northwest and Pacific Southwest Research Stations that addresses climate change in this context.

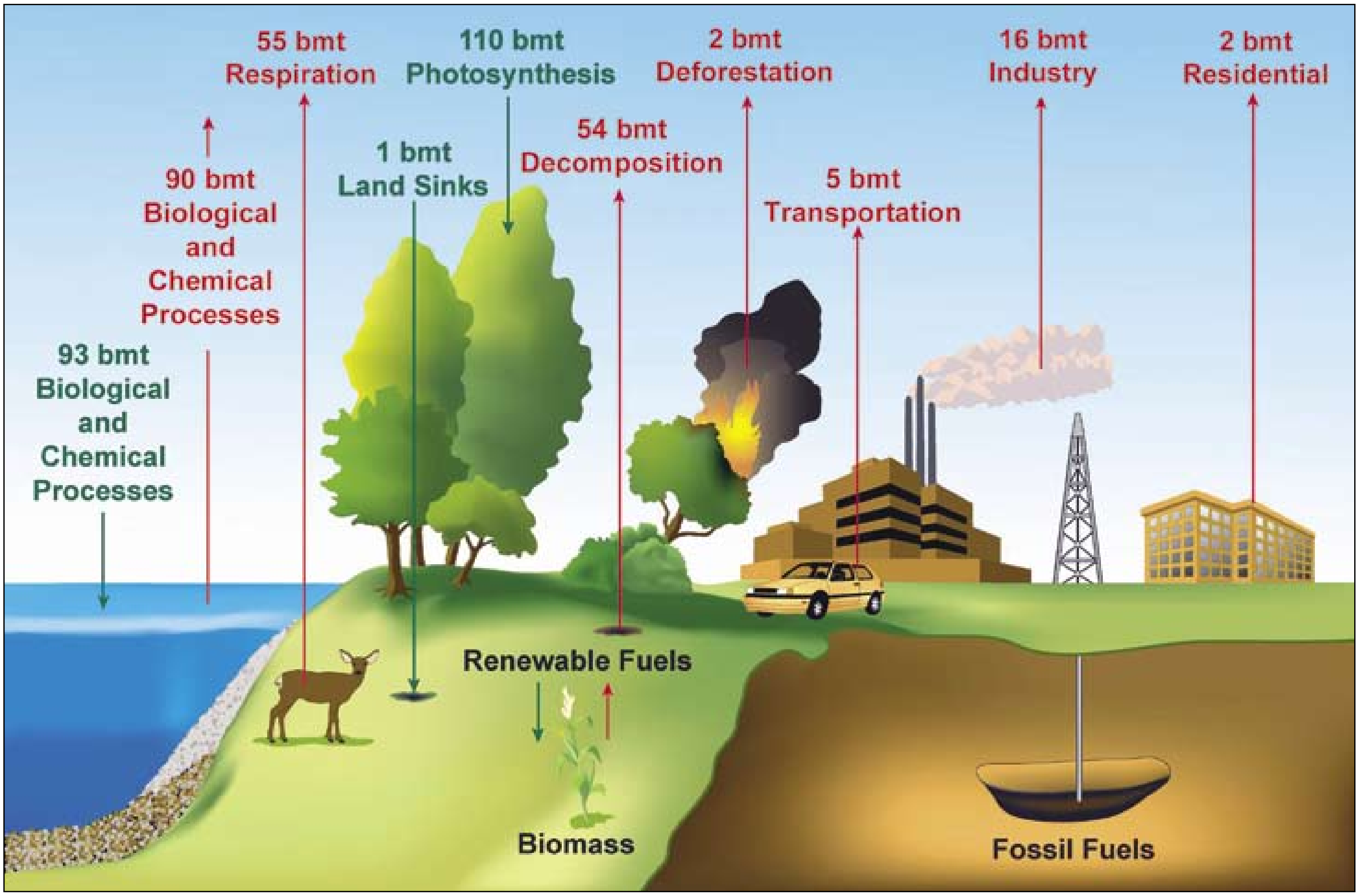
USDA United States Department of Agriculture

Forest Service

Pacific Northwest Research Station

http://www.fs.fed.us/pnw/

Issue 17
Summer 2008



U.S. Forest Service

Human activities have tilted the carbon balance so that more carbon is being released than is being stored. The figure above illustrates the major sources and sinks of atmospheric carbon dioxide. Numeric values are given in billion metric tons per year.

What lies ahead?

Evidence suggests that in the Northern Hemisphere, the last 50 years of the 20th century were warmer than any other period in the last 500 years, and likely warmer than any 50-year period over the last 1,300 years, according to the Intergovernmental Panel on Climate Change (IPCC).

By 2099, the best estimates of the IPCC project that the global temperature will increase from 3.2 to 7.2 °F. This increase is largely attributed to increases in greenhouse gases (GHG) such as carbon dioxide, methane, and nitrous oxide that have accumulated in the Earth's atmosphere. Climate models suggest that changes in temperature and the timing and amount of precipitation will differ by region. Some regions are projected to become warmer and wetter while others are projected to become warmer and drier.

These changes in temperature and precipitation will alter the growth patterns and distribution of species, both plant and animal. Species that are able to adapt and exploit the new conditions will thrive and likely outcompete those unable to adapt at the rate necessary for survival. The implications are weighty. In broad terms, these changes may increase the risk of extinction for up to 30 percent of the world's species (IPCC 2007). Some regions may experience severe droughts, while others may have increased forest and agricultural productivity. The risk of wildfire is projected to increase, further magnifying changes to wildlife habitat, affecting the ability of a forest to store and filter water, and degrading air quality as stored carbon is released into the atmosphere. In general, the goods and services ecosystems historically have provided, such as habitat, food, clean air, and water, may be fundamentally changed as ecosystems themselves are fundamentally changed.

Purpose of PNW Science Update

The purpose of the *PNW Science Update* is to contribute scientific knowledge for pressing decisions about natural resource and environmental issues.

PNW Science Update is published several times a year by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208
(503) 808-2592

Our mission is to generate and communicate scientific knowledge that helps people understand and make informed choices about people, natural resources, and the environment.

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Lack of Snow Leaves Alaska Yellow-Cedar Exposed to the Cold

In some parts of the world, effects of climate change are already visible. Alaska is one such place, and scientists are seizing the opportunity to document the effects. Paul Hennon and Dave D'Amore of the Pacific Northwest Research Station have been studying the retreat of the Alaska yellow-cedar. As Paul Hennon, a research forest pathologist explains, "We don't have to speculate on change that might happen. The demise of the yellow-cedar started a hundred years ago at the end of the Little Ice Age and continues today. We wanted to know what triggered this, and so looked back in time."

Yellow-cedar is the most economically valuable tree in southeast Alaska and also has significant cultural value to Native Alaskans. Research on the demise of the yellow-cedar didn't start off as climate change research, explains Hennon. "We were just trying to figure out why the trees are dying. It eventually became clear to us that it is related to lack of snow cover in February and March. Where snow cover occurs in February and March, cedars are healthy."

"Yellow-cedar has a unique vulnerability to freezing injury. It took us a long time to figure this out because of the paradox of a warming climate triggering a freezing problem," says Hennon.

Now Hennon and D'Amore are working on a conservation and management strategy. The current plan is to partition the landscape into areas that are suitable for cedar and likely will be suitable in the future and areas where it is no longer suitable. Under this strategy, yellow-cedar seedlings would be planted only in the suitable areas. Other tree species better suited to the new conditions would be favored in areas of yellow-cedar decline.

Paul Hennon

Researchers and land managers are developing an adaptation strategy for yellow-cedar that includes planting the species in areas where sufficient snow is projected to accumulate and protect the tree's roots from freezing injury.

Hennon and D'Amore are working with State and Private Forestry and The Nature Conservancy to map the distribution of healthy cedar in Alaska. "We are combining that information with models projecting snow zones under different warming scenarios to explore the range of the yellow-cedar under different climates," says Hennon. "We are working with the Tongass National Forest to plant yellow-cedar at higher elevations and to the northwest around the Gulf of Alaska," he says.

Changing one component of the landscape leads to other changes. D'Amore explains that yellow-cedars take up a lot of calcium. When they die, this calcium is left on the soil surface, changing the chemistry of the seedbed and influencing which species fill in behind the yellow-cedar. In the southern areas of Alaska, it appears that redcedar exploits the available calcium and overtops the competing hemlock. Redcedar is not present in the northern areas, and it appears that shrub blueberry and scrubby hemlock fill in. These changes to forest succession have implications for wildlife management that are still being explored.

The main issue, explains Ron Neilson, a bioclimatologist with the PNW Research Station, "is the rate at which things will change and how that would manifest in terms of species migration or potential extinction and ecosystem function, such as carbon balance, floods, droughts, insect infestation and diseases, and possible catastrophic fire. Some of these processes have significant lags, whereas others, such as drought-induced forest dieback, infestation, disease, and catastrophic fire can happen quite rapidly if an ecosystem is pushed beyond critical thresholds or key constraints."

Neilson has spent the last 25 years developing models to project what will grow where under different climate scenarios. "Virtually all ecosystems are at drought threshold," he explains. Changes in the amount of rain and snow an area receives may push past the threshold of survival for some species. Neilson and his colleagues have developed models such as the Mapped Atmosphere Plant Simulation System (MAPSS) to illustrate vegetative growth under different temperature and moisture conditions. MAPSS has provided a basis for other models such as the MC1 Dynamic Vegetation Model that couples biogeochemical cycling models and fire models. Results of a recent study using monthly data from 1901 to 2000 and nine 100-year future climate scenarios indicated that roughly one-third of the world's land surface could experience greater fire frequency.

Neilson explains that simulations from these models suggest that warmer temperatures in northern latitudes will enable trees to grow where they currently do not and thus sequester carbon from the atmosphere. If the temperature continues warming, however, boreal and temperate ecosystems will likely suffer from temperature-induced drought stress, leading to a heightened risk of fire.

"All of natural resource management has been developed assuming that the future will echo the past," says Neilson. This notion is now outmoded. Many biological responses to climate change are uncertain. "We will never have as clear a crystal ball as we thought we had before. We have to live with uncertainty and manage for change," says Neilson.

What are our management options?

Decisions and actions by people will be critical in facilitating adaptation to climate change and mitigation efforts. Connie Millar is a climate change scientist with the Pacific Southwest Station whose work has looked at the effects of climate change on forest structure and species composition. She defines adaptation as "approaches taken to adjust, prepare, and accommodate new conditions created by changing climates." Adaptation strategies can often complement mitigation strategies, which Millar defines as "actions taken to reduce and reverse the human influences on the climate system."

While working with managers on the Tahoe National Forest and other national forests in the PSW Region, Millar and her colleagues developed a succinct way to reframe land management strategies in the face of a changing climate. She calls it the "5 R's" approach: (1) increase **resistance** to change, (2) promote **resilience** to change, (3) enable ecosystems and resources to **respond** to change, (4) **realign** land conditions with current and anticipated environments, and (5) **reduce** greenhouse gases and use of nonrenewable energy. These five approaches range from conservative to proactive. Millar emphasizes that these approaches should be combined to best match the particular management context.

One fundamental shift in thinking that may serve as ballast in a sea of change is the idea of managing for future processes and ecosystem services rather than for desired future conditions. Millar explains, "People who deal with time, like geneticists or paleobiologists, tend to think in terms of processes rather than static conditions. We see the landscape as a river of change moving from the past toward the future. This is bigger than thinking about forest succession, which is like smaller circles of change—eddies within the river."

Millar continues, "This is also a good time to experiment with old techniques in new ways." For example, she proposes that in some cases assisted migration might be appropriate—that is, moving species from an area where they may not be suited in the near future to a site where conditions are projected to be more favorable. She also suggests increasing redundancy in the landscape to spread risk rather than concentrate it. For example, planting species in areas where conditions are projected to be favorable but also in additional sites.

Traditionally, Millar explains, reforestation and restoration efforts tried to match local genetic material to the planting or reintroduction site. There were discussions about what was local, and seed zones and rules were developed for how far to transfer material, all based on the notion of a stable climate background. "Now when we look at reforestation, we can think about interplanting with material from different seed zones and using assisted migration," she says. "Assisted migration is the exact opposite of keeping things local."

Brad St. Clair, a geneticist at the Pacific Northwest Research Station agrees: "Now it's time to rethink seed zones with climate change." St. Clair and his team have been studying genotypes of Douglas-fir, as well as those of grasses, shrubs, and forbs. "Basically we want to know, will these plants be adapted to a new climate?" St. Clair says.

Douglas-fir, for example, is generally considered a single species, but within that species there are variations suited to different microclimates. Populations of Douglas-fir growing at low elevations differ genetically from those growing at high elevations. Geneticists have explored these differences among populations of Douglas-fir and determined seed zones that are based on latitude and elevation. But as climates change, seed zones may essentially shift north and uphill. The growth and drought hardiness of populations will likely be a key factor in determining their success in adapting to changes in climate.

John Ahnstead

John Ahnstead

Thinning a dense stand of trees to reduce drought stress and fire risk is one strategy for adapting to a drier, warmer climate. The photos above were taken before and after a thinning treatment on the Blacks Experimental Forest in northern California.

The Shrinking Range of Lodgepole Pine in Alberta, Canada

As the climate changes, some species will thrive in the new conditions while others will struggle to adapt. But classifying an entire species as a winner or loser oversimplifies the matter. As Bob Monserud points out using lodgepole pine in Alberta, Canada, as an example, under various climate scenarios, some lodgepole stands are projected to thrive with warmer temperatures whereas others will suffer from the corresponding increase in dryness. Microclimates will play a determining role.

The rate at which the climate actually changes will play a large role in how or if a species adapts.

Monserud is a recently retired research forester with the Pacific Northwest Research Station. Over the last decade he and his Russian and Canadian colleagues have used an extensive permanent study plot network in Alberta to study the effects of climate on lodgepole pine in the province. Lodgepole pine is the dominant tree in Alberta and a commercially valuable timber species.

In his latest study, Monserud and his colleagues examined how a warming climate might influence the spatial distribution of lodgepole pine. "Northern Alberta is one big cold bog," says Monserud. "To imagine it drying out is inconceivable." But that is what climate models project.

Model simulations indicate that with warmer temperatures, and hence more growing days per year, dominant lodgepole pine will grow about 3 additional feet per decade over the next 90 years if sufficient moisture is present. But moisture is the limiting factor. Warmer temperatures for the region are projected while precipitation remains the same. Although some stands of lodgepole pines are projected to grow much faster than their current rate of about 1 foot per year, the overall range of the species will shrink. Based on these warmer, drier scenarios, lodgepole pine will be confined to the foothills of the Canadian Rockies where it will still receive enough precipitation to thrive.

The rate at which the climate actually changes will play a large role in how or if a species adapts. As Monserud explains, lodgepole pine is a slow-growing tree in Alberta, harvested on 100-year rotations. In 100 years, or one generation, tree physiology will not be able to change at the same rate as the climate is projected to. The climate will be changing faster than the species can either evolve or migrate to a more suitable habitat.

Factors other than those included in his model simulations likely will influence the lodgepole pine populations as well, explains Monserud. First, with warmer temperatures, the range of the bark beetle likely will expand, resulting in infestations in lodgepole pine stands that previously were protected by environmental buffers, such as long cold winters, and geographical buffers, such as the Canadian Rockies. Secondly, wildfires will likely get bigger, as drought and beetle-killed trees provide ample fuel.

The findings from this series of studies enables land managers to start planning ahead, anticipating change rather than reacting to it. Like Douglas-fir, lodgepole pine is a genetic specialist with different genotypes that have adapted to particular microclimates. This means that planting seedlings from populations that are adapted to a warmer climate may be one management option for maintaining some stands of lodgepole pine. "If we've just harvested an area, then the key is to replant with a population that can establish itself in the current conditions but that will be in its optimum environment in 30 to 40 years," says Monserud.

"Diversify to manage for uncertainty."

In a recent study, St. Clair and his colleague Glenn Howe found that current populations of coastal Douglas-fir were at risk of being maladapted to warmer climates. They suggest planting seedlings from warmer seed zones with local seedlings to increase genetic variation within the stand and, therefore, increase the stand's resiliency to climate change. "Silviculturalists on the national forests are asking us what they should do," says St. Clair. "We say, diversify to manage for uncertainty."

St. Clair explains that the Douglas-fir forests of the Pacific Northwest can store more carbon than any other terrestrial ecosystem. This means that as society tries to mitigate climate change by reducing carbon dioxide in the atmosphere, maintaining the health and productivity of Douglas-fir forests takes on added importance.

At work for eons, natural selection will continue. But as we consider our own well-being and place in the world, there is interest in managing proactively to facilitate resilient ecosystems.

Proactive management recognizes that climate may change faster than species can adapt on their own, but to anticipate change and plan accordingly requires science to stay apace of change so managers can use it to make informed decisions. One way to do this is to capitalize on existing research and add a climate component. Connie Millar sees an opportunity for this in genetic test sites established in the 1960s and 1970s. "We have common garden experimental sites that were established 30 to 40 years ago," she says. "These were basically plantations that were established to see what varieties of trees would grow the fastest and produce the best timber. But we can revisit them now and evaluate them from a climate perspective."

What are our options for mitigation?

Mitigation actions are those that we take to reduce GHG emissions or increase carbon storage capacity. Decisions about land use play a key role in mitigation—from where trees are planted, to zoning regulations and the resulting traffic patterns, to developing capacity for power generated by fuels other than oil, coal, or natural gas.

Not all mitigation actions are created equal in terms of their ability to reduce GHG emission, nor is the potential for action and impact the same for all landowners. Policies that favor one set of actions and ownership over another may have unintended consequences. Ralph Alig, an economist with the Pacific Northwest Research Station, has been exploring these connections. His work over the last 30 years has delved into the economic links between agriculture, forestry, and global change.

Both forest and agricultural land store carbon, although forests typically store more and for a longer period. Additionally forests don't need to be harvested and replanted each year with machinery that runs on fuel. Alig says, "Slowing down deforestation may be a critical step to mitigating climate change. Over the last 15 years we've lost an amount of U.S. forest land equivalent to the forest area in the state of Washington."

"Slowing down deforestation may be a critical step to mitigating climate change."

"Although forest areas have increased in some regions, we lose all sizes of trees through deforestation, while initially we gain only very small trees through afforestation. This means an acre lost is not necessarily the same as an acre gained," explains Alig. Afforestation (the planting of trees in an area where there weren't any, such as on former agricultural land) and subsequent tree growth is one method for increasing the globe's carbon storage capacity. But land use decisions are tied to economics.

Connie Harrington

Researchers note the emergence of buds as a part of a study examining the effects of warmer winter temperatures on budburst for different Douglas-fir populations.

Alig learned early on that markets can influence mitigation strategies and vice versa. “You can’t plant 10 million acres of trees to sequester carbon without having leakage,” he explains. In this sense, leakage refers to the economic ramifications rippling across related market sectors. “All those trees are going to drive down the cost of timber when they’re harvested, which will lead to some of that land being converted to higher value agricultural products.” It is a classic example of supply and demand: more timber means lower prices in markets, and therefore less benefit to landowners who keep their land forested, compared to prospective economic returns from other uses.

Ralph Alig

Land use and carbon emissions levels are tightly intertwined. Mitigation strategies to slow climate change can be crafted to preserve wildlife habitat and open space for recreation as well.

The mitigation potential is not the same across forest ownerships, explains Alig. Working with private forest-land owners is essential because most timber is harvested from private land. Alig points out that harvest on National Forest System land accounts for only 2 percent of the Nation’s timber harvest. The length of the harvest rotation can affect the amount of carbon that is sequestered, because older forests store more carbon than younger ones, and can affect the supply of wood products in the market. Valuing the ecosystem service of carbon sequestration in the marketplace is another aspect of mitigation and could create incentive for private forest owners to maintain or increase their forested acreage.

In the U.S. South, Alig says, there is a lot of private land suitable for either forestry or agriculture. Alig points out that when cropland is converted to forest land, it doesn’t have to be a monoculture. Multiple tree species and agro-forestry combinations of hybrid poplars or willows could be planted so that the converted land would provide multiple benefits. “If we do this in a clever way,” he says, “afforestation can help combat not just climate change but fragmentation and improve wildlife habitat and water quality.”

Agricultural subsidies also influence land use. For example, the current emphasis on biofuels has led to an increase in subsidized corn production for ethanol, leaving less land available for afforestation. Alig points out several unintended consequences that could stem from an emphasis on corn-based ethanol as an alternative to oil, including conversion of forest land to agriculture; greater use of pesticides, herbicides, and fertilizers that could negatively impact aquatic ecosystems; soil erosion; notably higher food prices; and forest fragmentation and reduced wildlife habitat.

At the request of the Environmental Protection Agency and Congress, Alig and his colleagues are exploring the economic impact on forestry and agricultural sectors if the production of biofuels is increased. They have developed a model called FASOM GHG to help evaluate the interplay of land use policy, alternative fuels, and the agricultural and forestry sectors. The model can help policymakers evaluate questions such as how would planting trees for the purpose of producing biofuels affect forestry and agriculture sectors in terms of income and prices? What are the environmental impacts? Where would it be most effective to locate such a project? Is it sustainable over the long term? And how do the costs and benefits for biofuel production change over time?

Government officials from other countries such as Australia, Norway, and Germany have asked Alig and his team to use FASOM GHG to help them assess opportunities and costs as they decide how to address climate change and, in some cases, implement the Kyoto Protocol.

Mitigation options also include using wood instead of non-wood products for building materials. Alig explains that life cycle analysis has shown that when wood products are used, the GHG emissions associated with housing construction are lower than if building materials such as steel, concrete, and bricks are used. Alig mentions that another mitigation strategy is to manage forest stands for sawtimber rather than pulpwood. Sawtimber comes from larger, older trees that sequester more carbon, and the final product, such as wood beams, tends to have a longer shelf life than paper products that tend to come from smaller pulpwood-size trees.

Urban land use policy also plays a role in carbon emissions and mitigation strategies. Jeff Kline, another economist with the Pacific Northwest Research Station, recently conducted a study in Oregon on the effects of land use laws on carbon emissions. "Lots of policies not directly associated with carbon do have an influence," he says. For example, ineffective urban planning can lead to more commuting by car and therefore more carbon emissions. On the other hand, land use planning that conserves forest land can actually offset increased carbon emissions. Kline explains that between 1990 and 2000, Oregon's land use planning program prevented shifts of agricultural and forest land to development that would have increased net GHG emissions an estimated 200 percent. "The fact that we had land-use planning created enough carbon storage to more than twice offset the amount of increase in carbon emitted from other sources," he says. Conserving forest land is a basic thing to do, he points out, and as shown from his study in Oregon, can have a lot of impact. Additionally he says, "We know how to conserve forest land, whereas other mitigation strategies like creating carbon markets are more complicated, and realistically, require federal caps to be effective."

What about using woody biomass to generate electricity?

Reducing use of fossil fuels is another mitigation strategy. Energy production is one of the largest sources of GHGs. Using woody debris to produce energy has the potential to address two issues: reducing demand for coal, oil, and natural gas and, if the wood comes from densely stocked, overgrown forests, reducing threat of wildfire, which also emits GHGs.

For many parts of western North America, climate models predict less snowfall in the winter and warmer, longer, drier summers. This scenario is expected to result in forests that are stressed by drought, increased outbreaks of wood-boring insects, and greater fire risk.

Mark Nechodom

One option for reducing fire risk and dependency on fossil fuel is to use wood fiber removed during forest fuel-reduction treatments to produce electricity.

Although fire is a part of the ecosystem and can play a key role in maintaining wildlife habitat and contributing to the health of aquatic ecosystems, the concern is that changing conditions may lead to fires that burn with greater severity than they did historically. It can take longer for a forest to recover from a stand-replacing fire than from one of less severity, and thus longer for it to begin sequestering an amount of carbon similar to that before the fire.

Rising oil costs brighten the prospects for bioenergy.

Thinning forests is one way to reduce fire risk. It is expensive, with few opportunities to offset the cost of treatment. Much of the product removed during fuel-reduction treatments has been generally thought to have little economic value. Consider the unmerchantable small trees as biomass, however, which can be used to generate electricity, or biogas, which can be converted to ethanol or other fuels. Can fuel-reduction treatments yield an economically feasible source of bioenergy, and what are the environmental impacts?

Mark Nechodom and his colleagues have been conducting the Biomass to Energy project for the state of California to quantify the costs and benefits of using woody biomass for energy production. Nechodom explains that, on average, electricity generated from fossil fuels costs 5.5 cents per kilowatt-hour, whereas biomass energy generally costs 6.5 to 8 cents per kilowatt-hour. But many of the benefits of using biomass energy, such as reducing fire risk, are not included in the equation. "Many of the benefits are currently unpriced," says Nechodom. This makes it difficult for biomass to compete with other forms of power generation on an open market. However, with cost of oil at more than $140 per barrel, compared to $33 in 2000 (adjusted for inflation), the time is ripe for assessing or re-assessing the prospects of biomass energy.

Nechodom and his colleagues have developed a life cycle assessment model to quantify the cost of biomass energy production. He explains that it integrates existing Forest Service models for fire planning and forest ecology with models of energy use, emissions, and costs. This means it includes the cost and carbon footprint of thinning, transporting the woody stock to the electrical power generation facility, and production as well as benefits such as reduced fire risk, wildlife habitat protection, and reduced use of fossil fuels. For the pilot project, a 2.7-million-acre area was selected in the northern Sierra Nevada range in California that included a variety of ownerships with different management objectives. "The model assumes that if the landscape is left untreated, an average of 66,400 acres would burn per decade," explains Nechodom.

How does a wildfire differ from a wood-burning power plant in terms of carbon emissions? Answering this question requires knowing how carbon moves through the ecosystem, and our knowledge here is not complete. Scientists are using data collected through the Forest Service's national Forest Inventory and Analysis program to estimate carbon stocks and flux. This is a relativity new question, however, and gaps exist in the data that was originally collected to address other questions.

"A ton of biomass burned in a wildfire releases the same amount of carbon dioxide as it would in a clean-burning biomass plant," says Nechodom. "The issue is the difference in greenhouse gasses emitted by wildfires of different severity. A severe wildfire produces more emissions than a less severe wildfire. A wildfire also releases other greenhouse gas components such as methane which has 21 times the global warming potential that carbon dioxide does," says Nechodom. Biomass energy emits greenhouse gases that have lower global warming potential than wildfire, he explains.

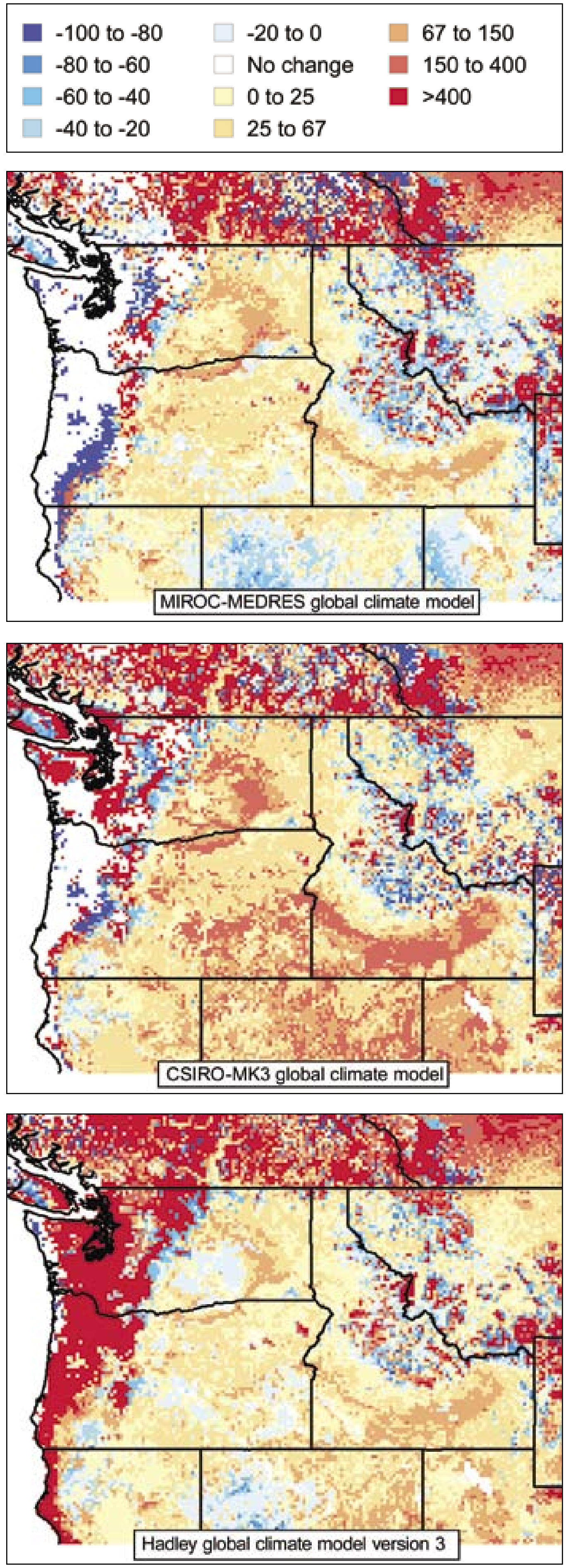
"The forests we're talking about thinning have a high fire hazard," says Nechodom. "The goal is to change the fire profile so when a fire does ignite, it will burn with lower severity and not consume as much of the forest. If by doing this, we can also generate bioenergy and reduce consumption of fossil fuel, that is an added benefit."Driven by incentives under the Public Utility Regulatory Policies Act, California invested in biomass generation plants 20 years ago. The state's 64 biomass plants had the capacity to produce over 1000 megawatts of energy, making it a world leader. In 1996, electric utilities in California were deregulated, and this changed the economy of bioenergy. Large utilities bought out or changed contracts because they were no longer obligated to buy renewable energy.

The energy market continues to change in California and the rest of the country. And the need for an economically feasible way to reduce wildfire risk throughout the West continues to grow. The tools developed from the Biomass to Energy project may help decisionmakers quantitatively assess the potential economic, energy, and environmental tradeoffs associated with forest management options.

Living with uncertainty

From the role of snow in buffering the root systems of Alaska yellow-cedar to the connections between drought, insects, and forest fire, the natural world is linked in ways we are just beginning to understand. Given the intricacies of the world's ecosystems, climate change stands to touch all levels of the plant and animal kingdoms. In many cases, however, we don't know exactly which pathways of change will be triggered and how those may trigger subsequent changes.

Coping with this uncertainty may require a shift in thinking. As Ron Neilson says, "The old worldview used to give us a warm feeling of certainty. As scientists, we will never be able to give a definitive answer about what will happen. But we



Ron Neilson

Global climate models provide a window to possible futures, and simulations are useful in visualizing the range of uncertainty. These scenarios from three climate models show the simulated percentage of change in annual average biomass consumed by fire, comparing the last half of the 21st century to the last half of the 20th century. In these scenarios, GHG emissions were assumed to increase with "business as usual." All three scenarios project drier conditions and more fire east of the Cascade Crest while response west of the Cascades is more uncertain.

Management goals that promote connected landscapes may better serve us in the long run.

will be able to provide a window on possible scenarios—what the possible risks are, how to manage change, how to build resilience in the landscape so change happens gradually rather than catastrophically."

Managing for change may also encounter some institutional challenges. The Endangered Species Act, for example does not take into account climate change that could alter the habitat of a species beyond human control at this point. Connie Millar suggests that the growing interest in ecosystem services may be one way to incorporate management practices that aim to facilitate future processes within ecosystems rather than creating desired conditions. "We're more used to a nuts and bolts, blueprint approach to land management," she acknowledges, "but more flexible management goals that promote connected landscapes may better serve us in the long run."

And a changing climate is only one aspect of a larger global change. As Ralph Alig explains, "Experts predict that the world's population will increase by 3 billion people by 2050. That includes at least 130 million more people in the U.S. in 50 years; that's a 40-percent increase. Even without climate change, the population increase and average increases in income to spend will change things. We need to consider how people, through choices, can adapt to climate change. In some areas, these changes will be beneficial in terms of increased forest and agricultural productivity. There will be winners and losers, and the equity question will increasingly be important."

Alig points out that a large source of uncertainty lies in the social changes that may or may not occur. "There are a lot of personal choices people can make about climate change," he says. How will people respond to mitigation measures? How will we adapt to changing climate? "We also don't know what technological advances will be made that can help us mitigate climate change. We don't know how adaptation and mitigation strategies in the future will interact. However, we do know that many decisions remain to be made by people, and those decisions will be critical regarding the future environment of this complex world." He continues, "If we broaden the discussion of climate change so that we're talking about global-scale change in a broad sense, then if we do implement adaptation and mitigation strategies, we can do it in a holistic way, addressing energy needs, adequate food supplies, places for people to live and recreate, biodiversity, forest fragmentation, and other issues at the same time."

Planning for Uncertainty

We encounter uncertainty every day and find ways to cope with it. Bringing a raincoat along based on the weather forecast or buying health insurance despite current good health are small examples. They are relevant, however, because even with an issue as large as climate change, small decisions can become part of an adaptive or mitigative strategy. The climate change guidebook for local, regional, and state governments (Snover et al. 2007) offers three strategies that acknowledge uncertainty but bypass paralysis:

- **No-regrets strategy:** actions that provide benefits now with or without climate change (certain fuel treatments in forests with short fire-return intervals, for example).
- **Low-regrets strategy:** actions that provide climate change benefits for little additional cost or risk, such as maintaining riparian areas and protecting headwater streams.
- **Win-win strategy:** actions that reduce climate impacts while providing other environmental, social, or economic benefits. Enhancing the resiliency of landscapes, for example, also may help conserve biodiversity.


Tom Iraci

Changing climate may bring greater variability in precipitation patterns and storm intensity.

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For Further Reading

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Resources on the Web

Biomass to Energy: http://www.fs.fed.us/psw/biomass2energy/

Climate Change Resource Center: http://www.fs.fed.us/ccrc/

Forestry and Agriculture Greenhouse Gas Modeling Forum: http://foragforum.rti.org/

Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Mapped Atmosphere-Plant-Soil System Study: http://www.fs.fed.us/pnw/mdr/mapss/index.shtml

Yellow-cedar decline and management: http://www.fs.fed.us/r10/spf/fhp/cedar/index.html

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PNW Science Update
U.S. Department
of Agriculture
Pacific Northwest
Research Station
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P.O. Box 3890
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