ECOLOGY

Resurgent Forests Can Be Greenhouse Gas Sponges

When people talk about combating global warming, they usually mean cutting back on the burning of fossil fuels or on slash-and-burn agricultural practices in the tropics. But ecologists and other researchers are realizing that there's another way to control the carbon dioxide build up that may be warming the planet: plant trees.

The strategy grows out of recent evidence suggesting that forests store much more carbon than had been thought. Previous estimates indicated that they take up about as much carbon dioxide while photosynthesizing as they give off when respiring—resulting in little net carbon flow into or out of forests. But new results, some from reanalyses of old data and others from field studies, indicate that "forests, and the carbon they sequester, have been undervalued," says Harvard University environmental economist Theodore Panayotou.

Earlier studies had neglected to include the huge amounts of carbon stored in peat and other organic matter in soils—now estimated to account for about two-thirds of the total sequestered, primarily in high-latitude forests. In addition, contrary to popular belief, many forests are expanding, which also helps draw carbon dioxide out of the atmosphere and lock it away in organic matter.

R. BIRDSEY/USDA

Greenhouse harvest. Managed forests like this loblolly pine plantation in the southern United States can sequester carbon dioxide.

This new picture of forest dynamics may help solve a long-standing puzzle. When researchers estimate annual carbon dioxide releases and compare those figures to actual carbon dioxide concentrations in the atmosphere and known sinks, such as the oceans, they typically come up short by about 1 billion to 2 billion metric tons. In other words, roughly 20% of the total released each year is apparently missing. But the forest studies suggest where at least part of this carbon dioxide could be going. "Terrestrial systems, including forests and their soils and agriculture, can account for some of the missing carbon," says ecologist Steven Hamburg of Brown University.

On the practical side, the findings have led to the idea that better forest management techniques, including, for example, stemming tropical deforestation and replanting logged areas, could lead to even greater removal of carbon dioxide from the atmosphere. Indeed, some electrical utilities have already begun to put such strategies into practice as a way of compensating for their emissions. "In the last year or two, we've gone from modeling to real experiments," says ecologist Robert Dixon, who directs the U.S. Country Studies Program, a federal interagency activity that inventories greenhouse gas emissions and identifies ways to reduce their impact.

No one believes that such practices alone can stem escalating carbon dioxide emissions. But a special working group within the Intergovernmental Panel on Climate Change, which is putting together ideas to manage global climate change, suggests that improved use of forests worldwide could sock away enough carbon in soils, trees, and other vegetation between 1995 and 2050 to offset 12% to 15% of fossil fuel emissions during that period. "Generally speaking, there is agreement that forestry is one piece of a set of mitigation strategies that should be pursued," says analyst Mark Trexler, president of a climate-change mitigation consulting firm in Portland, Oregon.

Data suggesting the strategy's potential began building about 5 years ago. In a study reported then, forest researcher Pekka Kauppi and his colleagues at the Finnish Forest Research Institute in Helsinki assessed the growth in European forests from 1970 onward (*Science*, 3 April 1992, p. 70). They started with data in the various national forest inventories—information that had long been neglected, Kauppi says, because it was published in the "gray literature," the agency reports of different governments. But, he adds, "the quality of these data is often very high."

Analysis of those data showed that each year during the 1970s and 1980s, European forests accumulated 70 million to 105 million tons of carbon, with an additional 15 million tons tied up annually in wood that was harvested and used in construction. Based on these figures, Kauppi and his colleagues calculated that the carbon picked up by European forests could account for 8% to 10% of the missing carbon dioxide worldwide.

Some of that carbon accumulation was due to growth of existing forest vegetation, but reversion of agricultural lands to forests played a bigger role—a finding since bolstered by more recent studies, such as one completed just last year by forest scientist Richard Birdsey of the U.S. Department of Agriculture Forest Service Laboratory in Radnor, Pennsylvania, and his colleagues.

They found that over the last 100 years, between 9 million and 11 million hectares of agricultural lands in the eastern and southern parts of the United States have reverted to forests. Indeed, Birdsey calculates that the increase in biomass and organic matter on U.S. forest lands over the last 40 years has stored enough carbon to offset 25% of U.S. greenhouse gas emissions for that period. In addition, Birdsey's projections show there is enough land available for further forestry to increase carbon sequestration by perhaps up to 40%, at least until 2040.

Taking a more global view, Dixon, forest ecologist Sandra Brown of the University of Illinois in Urbana, and others completed the first inventory of the carbon stored in all forests about 3 years ago. They calculate that worldwide, temperate forests, because they are young and still growing, sequester about 0.7 billion metric tons of carbon annually. That figure is more than offset by the 1.6 billion metric tons released each year by deforestation in the tropics. But it suggests that good management could turn forests into major carbon "sinks."

Much of the carbon stored by these temperate forests is not in trees, shrubs, or other aboveground vegetation. Dixon and Brown's survey showed that only about one-third is in vegetation; the other two-thirds is in soils, much of it in peat, especially at high latitudes. These results help explain why previous estimates of the carbon sequestered by forests were low: They did not take into account the large amount of carbon in peat.

But the capacity of these high- or mid-latitude forests to store carbon may pale compared to that of tropical rain forests, according to an analysis now being carried out in Panama, Malaysia, and nine other tropical locales by a team from Harvard University and the Smithsonian's Center for Tropical Forest Science. These researchers, including Harvard's Panayotou and the Smithsonian's Elizabeth Losos, are monitoring the growth of every tree in a series of 50-hectare plots and recording their responses to catastrophes, both natural and those caused by human activities, such as logging. These and other studies show that tropical forests can sequester as much as 200 metric tons of carbon per hectare, says forest economist Marco Boscolo of Harvard. This is about one and one-half to two and one-half times the storage capacity of forests of mid- and high latitudes.

The problem will be in realizing the vast sequestration potential of the tropics, given the ongoing deforestation there. Still, there are signs that deforestation can be curbed, if governments make the necessary commitment. "Although reducing deforestation in the tropics may appear to be difficult, it is happening in countries such as Brazil, India, and Thailand," says Brown. Strong forest legislation, a large reforestation program, and community awareness are responsible for the turnaround, she says.

In some cases, electrical utilities are helping out, partly because it may help them win the permits they need to expand production. Because carbon dioxide can travel around the world, U.S. utilities can be recognized for reforestation done abroad. For example, a group of utilities including Wisconsin Electric Power and the PacifiCorp is spending $3.5 million to protect about 2500 hectares of forest in Belize. And in Sabah, Malaysia, that state's largest logger, the Innoprise Corp., is cooperating with the Forest Absorbing Carbon Dioxide Emissions Foundation, a group started by the Dutch Electricity Generating Board, to rehabilitate 25,000 hectares of degraded, logged forests with a mix of long-lived local trees, known as dipterocarps, and forest fruit trees. The goal is to increase the carbon sequestered in those areas by at least 200 metric tons of carbon per hectare.

Similar projects are under way at home. For example, the Klamath Cogeneration Project, which beat out two competitors to build a new, gas-fired power plant in Klamath Falls, Oregon, plans to reforest 1000 hectares of Oregon grassland, pasture, and scrub—at a cost of $1.5 million—to offset some of the plant's carbon dioxide emissions.

Even as these efforts are getting started, researchers are beginning to test novel ideas about how forests can be managed to soak up even more carbon. A computer-modeling effort by Gregg Marland and his colleagues in the Environmental Sciences Division of the Oak Ridge National Laboratory in Tennessee indicates, for example, that actively managed, fast-growing forests that are harvested and replanted can tie up even more carbon than mature, protected forests that are left alone. That's because harvesting wood for use in long-lived products, such as home construction, takes the carbon out of circulation, in effect creating a new carbon sink. Moreover, wood fuels can substitute for fossil fuels, such as coal and oil, that throw more carbon dioxide into the atmosphere.


ELIZABETH LOSOS

Carbon storehouse. Reduced-impact logging, as in this forest in Sabah, Malaysia, may help reduce atmospheric carbon dioxide.

The Marland team's results are buttressed by the results of a study in which J. Piers Maclaren, Steve Wakelin, and Lisa Morenga of the New Zealand Forest Research Institute Ltd. analyzed that nation's plantations of *Pinus radiata*. They found that a radiata pine plantation that is replanted each time it is harvested puts away 112 metric tons of carbon per hectare by the time the trees mature. "This," says Maclaren, "can be seen as a one-time, permanent movement of carbon from the air to the land surface."

Maclaren calculates that from 2008 to 2026, New Zealand could more than offset its carbon emissions from fossil fuel combustion by intensive forest planting, at a rate of about 100,000 hectares per year. However, carbon sequestration would decrease rapidly after 2045, when plantable land was used up.

Indeed, forestry can go only so far in offsetting global warming, because land for new forests will eventually run short. Kauppi suggests that well-managed forests may serve as a carbon sink only through the end of the 21st century, while Brown sees forests filling a role as major carbon sinks for at least several centuries. Whatever the limits, she says, "it's an opportunity that must be pursued."

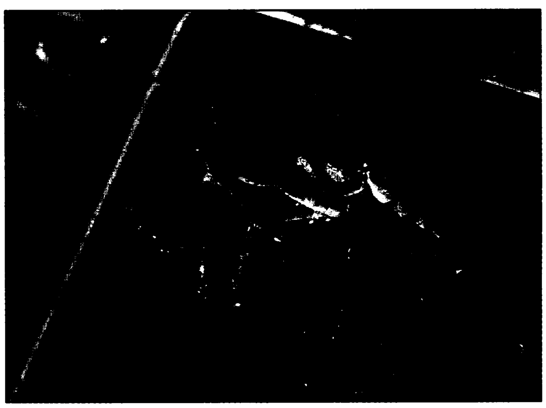
–Anne Simon Moffat

ECOLOGY

Hybrids Consummate Species Invasion

BOULDER, COLORADO—When biologists think of the comings and goings of species, they often think of war—of new species invading and pushing out the old. In midwestern lakes, however, love seems to be the driving force. In lake after lake, an invading crayfish species is pushing local crayfish to extinction. But biologists at the University of Notre Dame in Indiana are finding that the local crayfish are having their own effect on the invader, as the two species produce a new population of vigorous hybrids.

The finding is a surprise, researchers say, because ecologists often expect animal hybrids to be sterile, unable to play more than a bit part in species invasions. But at the annual evolution and natural history meetings here,* William Perry, a graduate student in the labs of ecologist David Lodge and biologist Jeff Feder, described molecular studies showing that hybrids of Kentucky native *Orconectes rusticus*, or the rusty crayfish, and a native crayfish, *O. propinquus* (the blue crayfish), are indeed fertile. Other work by Perry, Lodge, and Feder suggests that these hybrids are outcompeting both natives and invad-


W. PERRY

Sleeping with the enemy. Female rusty crayfish (on bottom) courts local male.

* Joint meetings of the Society for the Study of Evolution, the American Society of Naturalists, and the Society of Systematic Biologists, Boulder, Colorado, 14–18 June.