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COMMENTARY

Biodiversity in US Forests under Global Climate Change

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There is increasing evidence that humans are altering the climate of the Earth (Watson and others 1997; Kerr 2000). Among the challenges to scientists concerned with climate change are predicting the consequences of global climate change and evaluating strategies for mitigating the negative effects of these changes. To date, biodiversity has not been well integrated into global change studies.

Biodiversity refers to the "species, genetic and ecosystem diversity in an area" (Swingland 2000). We believe that biodiversity is highly relevant to both understanding global change and valuing its consequences. The diversity of organisms on the Earth provide a plethora of goods and services to humans, including foods, medicines, ecological services, and spiritual well-being (Pimental and others 1997). Biodiversity also influences how ecological systems respond to climate change. The responses of individual organisms to climate begins the cascade of ecological processes that are manifest as changes across landscapes, biomes, and the globe. The dynamics initiated by organisms often provide feedbacks to the atmosphere and oceans and further modify climate. Thus, the consideration of biodiversity is important for understanding ecological response to global change, predicting future responses, valuing these changes for humans, and designing strategies to mitigate negative effects.

The following four papers project the potential responses of species, communities, and biomes to the changes in climate predicted under an anthropogenic doubling of atmospheric carbon dioxide (CO_2) by general circulation models (GCM). They focus on the forest vegetation in the conterminous United States as reflected by changes in the distribution of biomes, community types, and tree species. Species richness of trees and terrestrial vertebrates is also analyzed. The studies were done within the context of the Forest Sector of the National Assessment of Climate Change and Variability (http://www.nacc.usgcrp.gov).

Predictions about climate change vary among the several GCM that have been developed. Climate scenarios from both the older equilibrium and newer transient GCM simulations (McNulty and Aber 2001) were used to drive the biodiversity analyses reported in these papers. We put greater confidence in biodiversity outcomes that were in agreement under several climate scenarios. Disagreement among biodiversity predictions was taken as an indication of uncertainty either in the predictions of the climate or biodiversity models. Thus, the authors report major findings where most of the models agree but also point out certain areas of disagreement.

The suite of papers uses three approaches to project climate change effects on forest diversity. The opening paper by Bachelet and others (2001) uses the biogeography models MAPSS and MC1 to project the potential distributions of plant biome types under climate change. These models determine leaf area based on climate, available soil water, and atmospheric CO_2. Biomes are determined by rules that consider climatic thresholds and leaf area of trees, shrubs, and grasses. Wildfire is simulated internally by these models. Potential distributions of individual tree species are simulated by Iverson and Prassad (2001) and Shafer and others (2001) using statistical models. Current relation-

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ships among tree distribution, climate, and soils are used to develop predictive statistical functions of tree distribution under future climate. Shafer and others (2001) focus on western tree and shrub species, whereas Iverson and Prassad (2001) focus on trees in the eastern United States. Iverson and Prassad (2001) also group the responses of individual species to predict changes in forest communities. Finally, Currie (2001) uses energy theory (Currie 1991) as a basis for projecting the potential species richness of trees, mammals, birds, reptiles and amphibians under changing climate. The methods of each of the papers are based on sets of simplifying assumptions. The authors carefully describe these assumptions so that the reader can make better judgments about the reliability of the results.

Collectively, the results suggest substantial change in the potential habitats of several species and communities. Forest area in the US is projected to decrease by an average 11% under global change (range, +23% to −45%), with the lost forest replaced by savanna and arid woodland biome types. Community types predicted to increase include oak/hickory and oak/pine in the East and ponderosa pine and arid hardwoods in the West. Several important community types, however, are projected to decrease greatly in area or disappear entirely from the conterminous US. These communities include alpine habitats, sagebrush, subalpine spruce/fir forests, and the aspen–birch and maple–beech–birch types. These predictions for community types reflect changes in potential habitat for individual tree and shrub species. Seven of the 80 eastern species modeled are predicted to be reduced in suitable habitat by at least 90%, including bigtooth aspen (*Populus grandidentata*), quaking aspen (*P. tremuloides*), sugar maple (*Acer saccharum*), northern white cedar (*Thuja occidentalis*), balsam fir (*Abies balsamea*), red pine (*Pinus resinosa*), and paper birch (*Betula papyrifera*). Regional importance is projected to increase by 100% or more for 12 species, including four oaks and one hickory. In the western US, the potential habitats for dominant rainforest conifers such as western hemlock (*Tsuga heterophylla*) are simulated to decrease west of the Cascade Mountains and expand into mountain ranges throughout the interior West. Potential habitat for several subalpine conifers, including Englemann spruce (*Picea engelmannii*), mountain hemlock (*Tsuga mertensiana*), and several species of true fir (*Abies*) are simulated to contract substantially in the western conterminous US. The potential habitat for big sagebrush (*Artemisia tridentata*) is simulated to shift largely from the US into Canada. It is replaced in the US by potential habitat for shrubs, such as creosote bush (*Larrea tridentata*), now found in the Southwest. The potential habitat for Ponderosa pine (*Pinus ponderosa*) is simulated to expand in the western US, including the area west of the Cascade and Sierra mountain ranges.

The potential habitats for most eastern species are projected to move to the north, several species by 100–530 km. While the ranges of many taxa in the West shift northward, topographic complexity results in some conifer species associated with mesic climates shifting south and east along the Rocky Mountains. The complex topography in the West results in many current tree populations being disjunct. Consequently, dispersal to new habitats under climate change will be more difficult in the West than in the East, where populations are more continuous and topography and microclimate are less variable.

Potential species richness is projected to increase for trees, reptiles, and amphibians, particularly in the coldest portions of the US. Potential bird and mammal species richness is projected to decrease in the southern US but increase to the north.

The extent to which biodiversity tracks such changes in potential habitats will depend on many factors not included in the analyses. Most important among these is organism dispersal. The pace of climate change is likely to exceed the natural dispersal rates of several species. Thus, these species are not likely to reach newly suitable habitats without human intervention. Rapidly dispersing weedy species may dominate these new habitats, leading to entirely new community types. Actual patterns of dispersal are likely to be influenced by factors that interact with climate, including disturbance regimes and human land use.

In summary, these analyses indicate that climate change is likely to exert a strong influence on biodiversity in the US. The relatively high level of uncertainty and simplifying assumptions of these analyses, however, are indication that much more research is needed before we fully understand the consequences of climate change for biodiversity and the implications of these changes for human society. Strategies for mitigating such changes or coping with them are currently underdeveloped (Hansen and others 2001). Ecologists have a great deal of work to do to help society understand and cope with the impact of climate change on biodiversity in the 21st century.

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