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Effects of Climate Change on Forests of the Eastern United States

J.C. Randolph and Jae K. Lee
School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana 47405, U.S.A.

Abstract

A multi-phased approach was used to estimate potential impacts of climate change on forests of the eastern United States. Phase I was at community-level and Phase II examined selected species, both using three 2 x CO_2 climate scenarios. Geographic information systems (GIS) and statistical modeling techniques were used to manipulate and analyze climate and vegetation data, and model vegetation responses to climate change. The first two stages of the study indicated possible large-scale alteration of forest communities by future climate change. Although results varied among climate models, several trends were apparent. In northern states of the study area, ranges of several conifers declined significantly and ranges of oaks and hickories moved northward. In central states, ranges of sugar maple and tulip poplar became much smaller, with concomitant increases in ranges of southern oaks and loblolly pine. In southern states, American beech declined and ranges of southern oaks increased northward. This paper discusses results of the first two phases and current progress of the third phase.

Introduction

Future climate change resulting from increasing concentrations of greenhouse gases has been estimated by several general circulation models (GCMs). Although estimates vary somewhat (Table 1), predictions are for a 2.5° to 4.0° C increase in annual average global temperature and a 4 to 9 percent increase in annual average global precipitation as a result of a doubled concentration of carbon dioxide in the atmosphere (Hansen 1989, Schneider 1989, Smith and Tirpak 1989).

Future climate change will affect species composition of present ecosystems. Adjustment to new physical environments depends upon the environmental tolerance ranges of the species. Some species may migrate into new regions; a function of their dispersal ability as well as their ability to invade established communities. Dispersal abilities of plants are functions of reproductive mechanisms, seed type, germination and growth requirements, and the existence of dispersal barriers and corridors. Climate change will interact with such biotic and abiotic conditions to determine species' response to future climate change.

Zabinski and Davis (1989) combined Holocene estimates of species' dispersal distances with GCM climate change predictions for sugar maple (*Acer saccharum*), yellow birch (*Betula allegheniensis*), eastern hemlock (*Tsuga canadensis*), and American beech (*Fagus grandifolia*). Using a climate threshold model, they established climatic tolerances for these species and a potential climate space was projected using climate change estimates from GCMs. Results predicted that species ranges would shift hundreds of miles northward as climate warmed, with each species limited in its ability to colonize new climate space by the rate of dispersal, which could not keep pace with the predicted warming.

Other attempts to model vegetation response to climate change have used forest gap models. Various process models, most derived from JABOWA (Botkin 1993, Botkin *et al.* 1972) have been developed to analyze tree species responses under various growing conditions. Davis and Botkin (1985) combined paleoecological and forest gap model approaches. Botkin (1993), Botkin et al. (1989), Solomon (1986), Shugart (1990), and Urban and Shugart (1989) have incorporated GCM climate projections into gap models to examine future climate change on forest productivity and distribution.

Other studies (Burke *et al.* 1991, Overpeck et al. 1991, Rizzo and Wiken 1992) assessed sensitivity of ecosystems to climate change as represented by eco-climatic regions. Rizzo and Wiken (1992) used climate data to determine eco-climatic provinces in Canada. By applying 2 x CO_2 climate scenarios from GCMs, future locations for those eco-climatic provinces were predicted. This study agreed with the conclusions of

Table 1 Comparison of characteristics of three general circulation models (GCM). Climate changes resulting from a doubling of atmospheric CO_2 as projected by each model for three regions of the eastern United States are given.

Model characteristic or projection	CCC	OSU	GFDL
Grid latitude x longitude (°)	3.75 x 3.75	4.0 x 5.0	4.5 x 7.5
Grid area (km²)	123,314	175,380	295,954
Global temperature (°C)	+3.5	2.5	+4.0
Global precipitation (%)	+3.8	+7.8	+8.7
Northeast			
January temperature (°C)	+6.15	+4.81	+6.13
July temperature (°C)	+4.39	+2.84	+5.96
Annual precipitation (%)	-2.84	+11.30	+18.70
Southeast			
January temperature (°C)	+3.47	+4.87	+3.37
July temperature (°C)	+3.16	+3.32	+3.68
Annual precipitation (%)	-10.20	+3.70	+8.00
Midwest			
January temperature (°C)	+9.25	+5.30	+4.72
July temperature (°C)	+4.47	+3.30	+6.05
Annual precipitation (%)	-1.20	+3.87	+17.00

Emanuel *et al.* (1985) and Kauppi and Posch (1985) that high-latitude ecosystems may experience significant displacement during climate change.

The objective of this study was to assess potential sensitivity of forest ecosystems in the eastern United States to future climate change. A geographic information system (GIS) was used as the primary methodology for data manipulation, spatial analysis, and graphical representation, in combination with statistical analyses, the JABOWA II model, and other environmental modelling techniques. Our study is divided into three phases, each using different but related approaches.

Phase I is similar to the analysis of Rizzo and Wiken (1992) using historical climate and vegetation data to establish eco-climatic regions. This part of the study addresses the question of what changes in the potential distribution of plant communities might occur as a result of climate change. This analysis considers only climate and potential vegetation communities, and does not incorporate information about individual species, soils, topography, land-use, or barriers to dispersal.

Although results of the Phase I analysis indicate community-level responses, migration of entire communities to new locations is unlikely because of species-specific environmental tolerances, dispersal abilities, and competitive abilities. Thus, Phase II examined possible responses of individual tree species to climate change.

Phase III not only considers individual tree species and predicted climate change, but also incorporates information about soils, topography, land-use, dispersal, and growth. This paper presents results for phases one and two, and preliminary results for phase three.

Methods

The eastern half of the continental United States was used as the study region for the first two phases of this study (Figure 1). Because the Phase III analysis is very data intensive, the study region was reduced to the midwestern Great Lakes states of Wisconsin, Michigan, Illinois, Indiana, and Ohio.

Climate data were obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina for each climate division in the United States. Climate divisions, as defined by NOAA, typically are multi-county areas. Each climate division has averaged climate data measured at weather stations within the division. We used mean monthly temperature and precipitation data from 1951 through 1980 to describe current climate conditions. A climate division map was generated from latitude and longitude coordinates using ARC/INFO and current climate data were linked to each corresponding polygon.

Future climate data were generated from three general circulation models (GCM) obtained from the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Three GCMs were selected on the basis of: (1) performance in reproducing observed climate, (2) horizontal and vertical resolutions, (3) usage of CO_2 doubling scenarios, (4) representation of ocean/atmosphere processes, and (5) usage of transient results. Climate change scenarios from the Canadian Climate Center (CCC) model, Oregon State University (OSU) model, and Geophysical Fluid Dynamics Laboratory (GFDL) model were used (Table 1). Recent

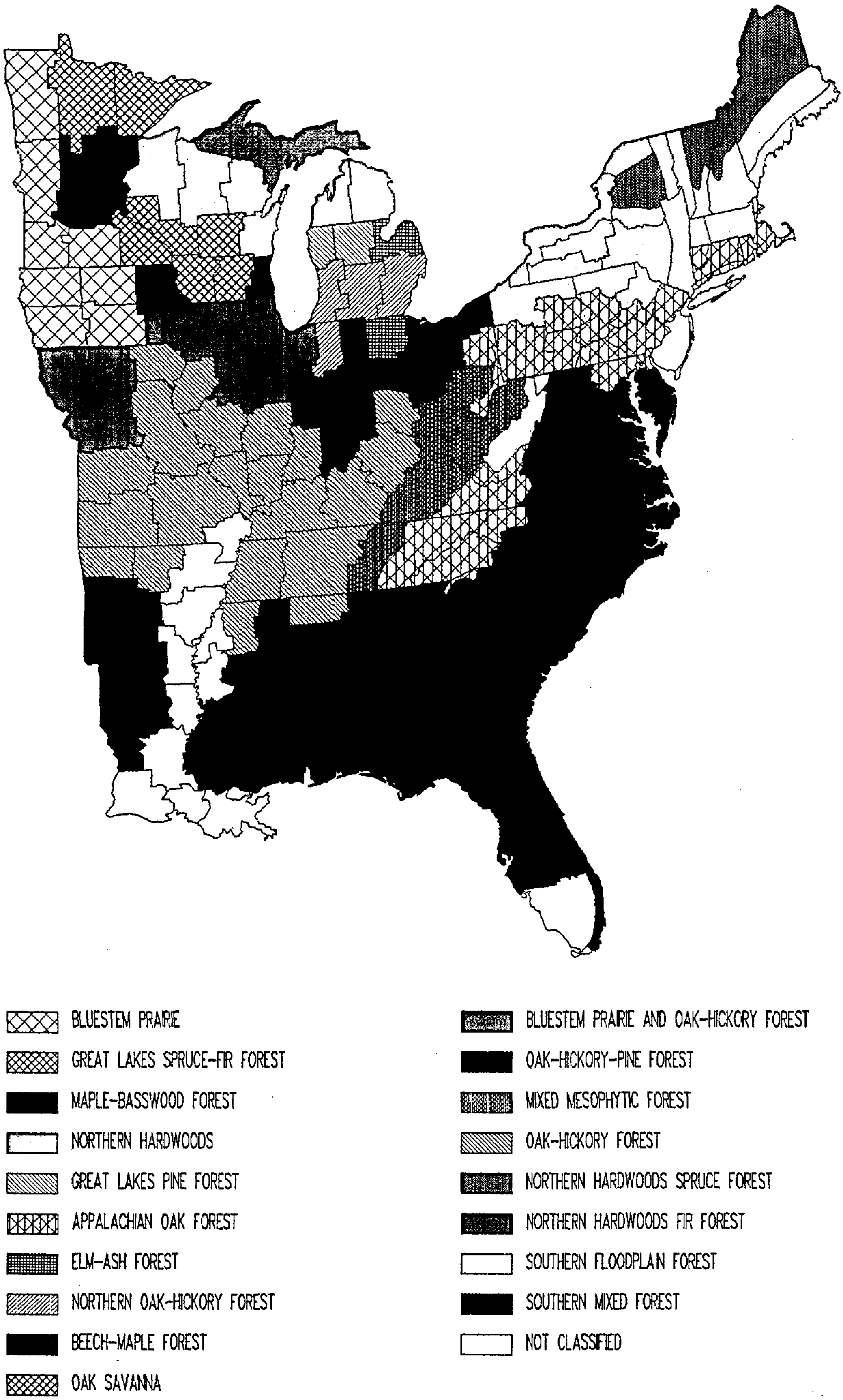

Figure 1 Vegetation community map used in Phase I. Each polygon represents a NOAA climate division with the dominant community shown.

improvements in the GFDL model added a local heat-flux procedure, enabling the model to reproduce sea-surface temperature and sea-ice extent. The model also increased its horizontal resolution from 4.44° latitude x 7.5° longitude to 2.22° latitude x 3.75° longitude. The CCC model also has relatively high horizontal resolution (3.75° x 3.75°). Boer *et al.* (1984) compared a five-year simulation from this model to observed climatic variables and found it successfully reproduced major features of tropospheric climate. Recent improvements in the OSU model include a significant change in vertical resolution and a complete update to the physical process components. Comparisons of climate scenarios for the eastern United States show that CCC and OSU projections are somewhat similar, whereas GFDL projects a drier climate (Table 1).

Current climatic conditions, defined by average monthly precipitation and temperature values between 1951 and 1980, were linked to climate divisions and an ARC/INFO grid map was created for current climate conditions. Then, an ARC/INFO grid map was created for each GCM and future climate data were linked to each grid cell, which was the same as the grid size used by each GCM. Future climate data assume a doubling of atmospheric CO_2 concentrations, and when combined with current climate data, predict future climatic conditions.

A plant community map for the Phase I analysis was created using the potential vegetation map by Küchler (1970). Each community boundary was manually digitized as a polygon coverage using ARC/INFO. The digitized polygon map initially represented 53 plant communities of the eastern United States. Community classifications followed Küchler (1970) and were consistent with other sources (Barrett 1980, Braun 1959, Omernik and Gallant 1988). A 53-community map was generalized into 18 communities by using the most commonly occurring community to represent each climate division.

For Phase I, a multivariate discriminant model was developed between current climate data (average monthly temperature and precipitation) and current community distributions. A linear combination of independent variables was developed and served to classify cases into groups (Norusis 1989). The multivariate discriminant model then was applied to current climate data to generate model-predicted current vegetation community maps. These model-predicted maps were compared to actual current community maps to evaluate model performance (Figure 2). Then, the model was applied to the three 2 x CO_2 climate scenarios to project new community distributions.

Because species will respond to climate change at different rates, Phase II examined potential impacts on forest ecosystems at the species level. Species range maps were taken from Little (1979). Range maps of the selected species were manually digitized as polygon coverages using ARC/INFO. Forty commonly occurring tree species were selected to represent the 18 forest communities used in Phase I. A logistic regression model was developed between binary-format species data and climate data of monthly average temperature and precipitation. The logistic model was used to estimate probability of each species occurrence in each polygon under future climate conditions. The logistic regression model generated probability values ranging from zero for minimum probability of occurrence to 1.0 for maximum probability; in general, a 0.5-probability rule was used for prediction (Norusis 1989). Polygons with probability ≥ 0.5 were classified as species present. To evaluate performance of the logistic model, species ranges were predicted using current climatic conditions. Then, the logistic model was applied to the three 2 x CO_2 climatic scenarios to project new species distributions under new climatic conditions.

An analysis of species sensitivity to climate change was performed based on results from Phase II. A sensitivity index was developed from the number of polygons for each species between the baseline map and the GCM-derived maps. This Sensitivity-to-Change Index was calculated for each species under each GCM. Two measures were used:

$$\text{Range Radio} = \frac{\text{Number of polygons in which species is predicted using GCM model}}{\text{Number of polygons in which species is predicted using baseline model}}$$

$$\text{Retention Ratio} = 1 - \frac{\text{Number of baseline polygons - number of retained polygons}}{\text{Number of baseline polygons}}$$

A species which experienced a greatly decreased range (as measured by number of polygons occupied) will have a value less than one for the Range Ration, whereas one with an expanded range will have a value greater than one. A species which retained its range will have a value close to one. A species which retained few polygons of its present range will have a small value for the Retention Ratio and a species which presisted in most of its current range (polygons) will have a value close to one. The natural log of the product of these indices increases the magnitude of differences. Thus, a species with a Sensitivity-to-Change Index of about one changes very little. Species with values greater than one and less than one will increase and decrease, respectively. The Sensitivity-

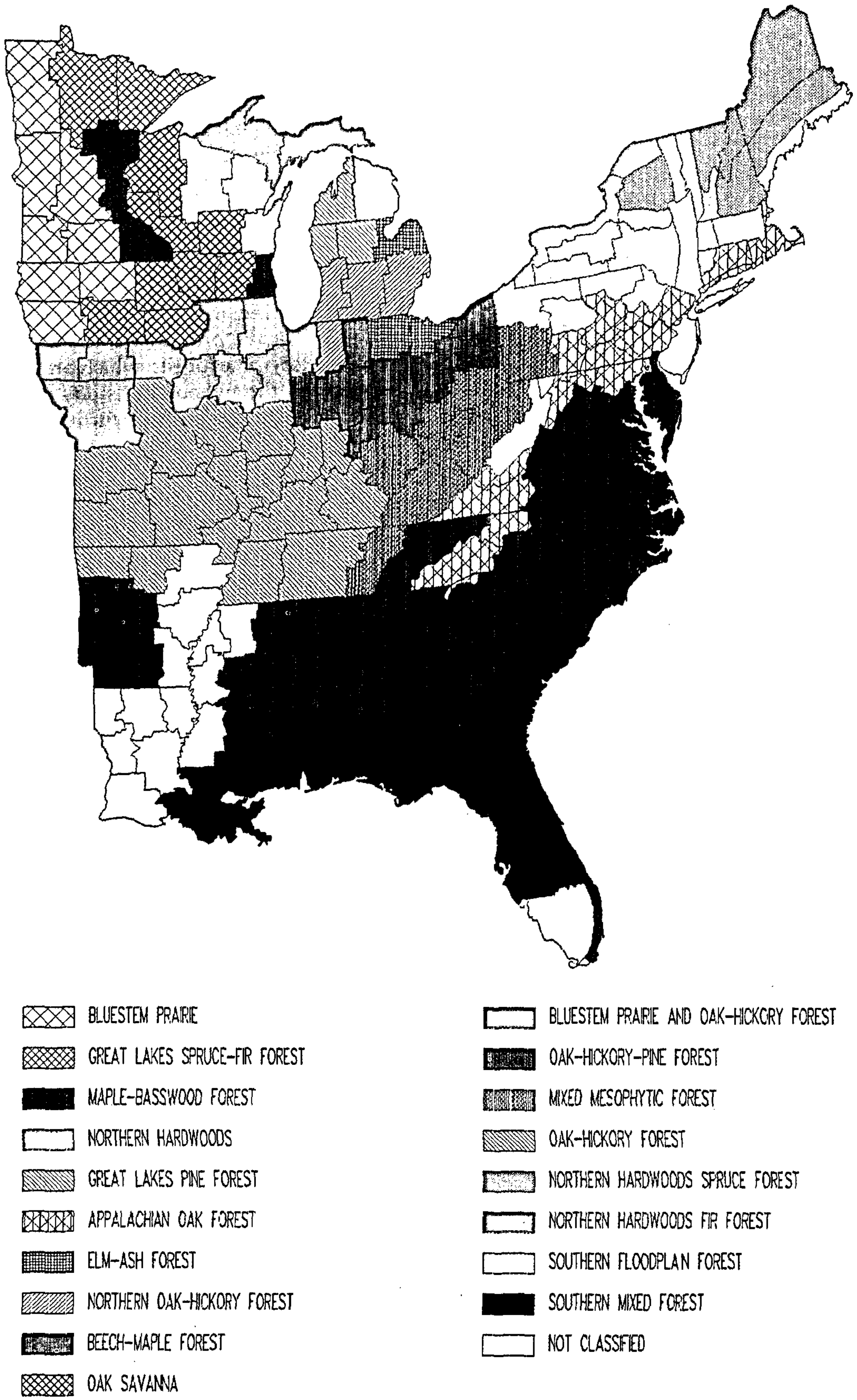

Figure 2 Present vegetation communities as predicted by the multivariate discriminant model.

to-Change Index applies only to distributions within the eastern United States. Some northern species migrate completely out of the study region into Canada under future climate scenarios.

Unlike previous approaches, Phase III used soils, topographic, land-use, physiological, and demographic data, as well as species range maps and climate data. New databases were constructed for Phase III modeling with higher resolution than used previously. The climate database was based on data from individual weather stations and a continuous climatic surface was created using a semi-variogram kriging procedure over the point coverages of weather stations. Digital soil maps and attribute data were obtained from the Soil Conservation Service's State Soil Geographic Database (STATSGO). Topographic data layers, including elevation, slope, and aspect, were generated from U.S. Geological Survey's Digital Elevation Model (DEM) data at 1:250,000 scale. U.S. Geological Survey's Land Use and Land Cover (LULC) data were used for land-use information, including dispersal barriers. Forest inventory information was taken from the Eastwide Database (EWDB) developed by the U.S. Forest Service. All modeling in Phase III used ARC/INFO GRID. Raster data structure was selected because it is more efficient in evaluating many processes over uniform cell sizes and scales (Lee *et al.* 1992).

Phase III used LULC and EWDB data to identify existing locations of forests through the study area and to associate forest inventory data with each location. STATSGO, DEM, and LULC data layers were used to assess habitat suitability and identify potential barriers to dispersal such as urban and agricultural land uses. A separate data layer for occurence of barriers to species dispersal was created using the STATSGO and LULC databases. Currently, the JABOWA II model (Botkin 1993) is being used to estimate future reproduction, growth, and mortality of dominant tree species in each location throughout the study area.

Results

For the model-predicted community distributions with current climates, 154 of 206 polygons (75%) were classified correctly by the model. Most misclassified polygons were located along the Mississippi River, indicating that these plant communities might be more closely associated with non-climatic factors, such as soils and hydrology. Classification errors also were observed in coastal communities such as mangroves and everglades in south Florida, pine barrens in New Jersey, and bluestem-sacahuista prairie in Louisiana. These coastal communities are influenced more by hydrologic conditions than climate; thus, they were excluded from Phase I modeling. After selected coastal communities were excluded, a new model-predicted community map was generated using the stepwise discriminant model. This model had 82% accuracy (Figure 2).

Future community maps were developed using each of the climate scenarios. Results from the CCC (Figure 3) and OSU (Figure 4) models were similar to each other, although results from the CCC reflect the drier conditions it projects. For the OSU model, southern mixed forest extended northward to the Great Lakes, while results from the CCC model show this community remaining in southern states. Results from the CCC model predicted considerable expansion of oak-hickory-pine forests, which presently occur in the southeast, throughout the study region. Although their distributions moved further northward, some coniferous communities persisted at northern latitudes using both models.

The community map developed from the GFDL model (Figure 5) showed patterns quite different from the other two models. Mixed mesophytic forest was projected throughout northern U.S. and oak-hickory forest was projected broadly in central U.S. GFDL-based patterns are more homogeneous than from the other two models. These different vegetation patterns appear to result from increased precipitation predicted by the GFDL model (Table 1). Results from the GFDL model project a striking loss of conifer-dominated communities throughout the eastern United States (Figure 5).

Using the Phase II approach, individual species responded in several different ways. Some species migrated far from their current range, others maintained some or all of their current range and gained some new areas, while others disappeared entirely. Species response varied according to GCM model, with the OSU model projecting smaller changes than the other two models.

Species were grouped into five categories of present distribution within the study area: (1) northern, (2) north-central, (3) south-central, (4) southern, and (5) wide range in eastern United States (Table 2). In general, northern conifers (*Abies balsamea, Picea glauca, Pinus resinosa, Pinus strobus, Tsuga canadensis*) experienced large decreases in their ranges within the United States. Although our analysis did not include Canada, significant expansion of their ranges in Canada seems likely. More xeric species such as oaks (*Quercus alba, Quercus falcata, Quercus lyrata, Quercus stellata*), hickories (*Carya glabra, Carya ovata*), and southern pines (*Pinus elliottii, Pinus palustris, Pinus taeda*) expanded their ranges within the study area. Ranges declined in more mesic species such as sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), black ash (*Fraxinus nigra*), and tulip poplar (*Liriodendron tulipifera*).

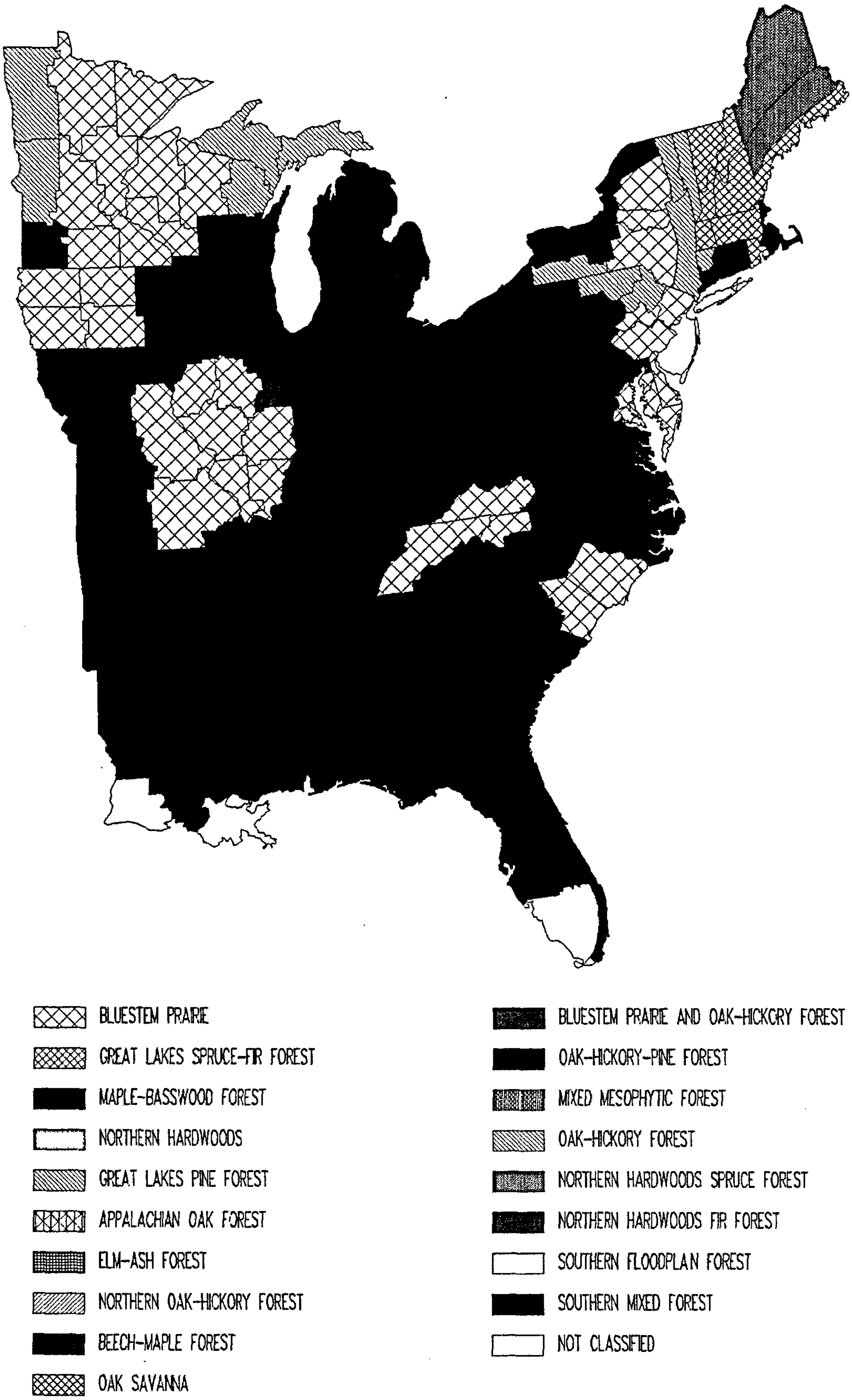

Figure 3 New community map under 2 x CO_2 climate scenario using CCC model.

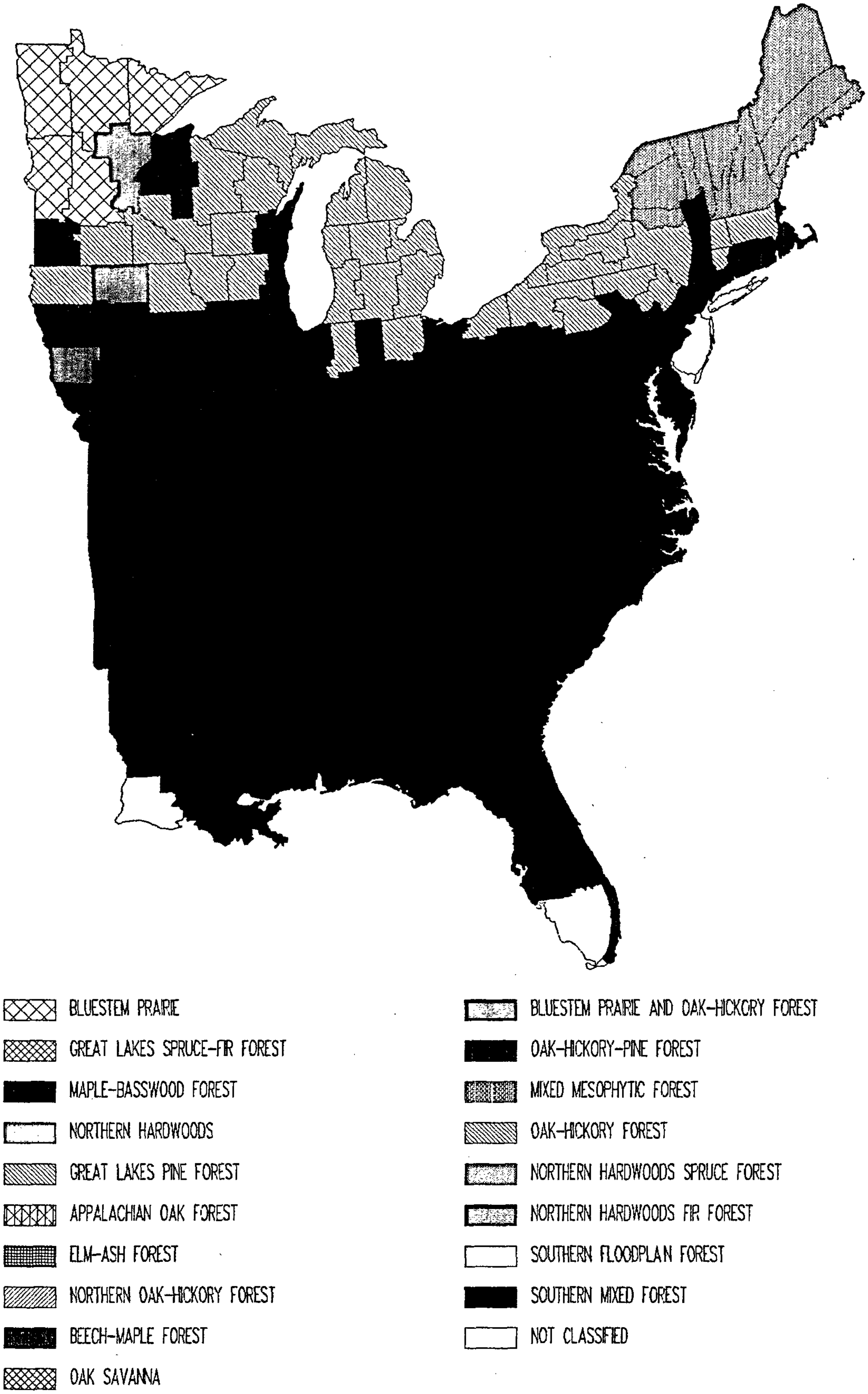

Figure 4 New community map under 2 x CO_2 climate scenario using OSU model.

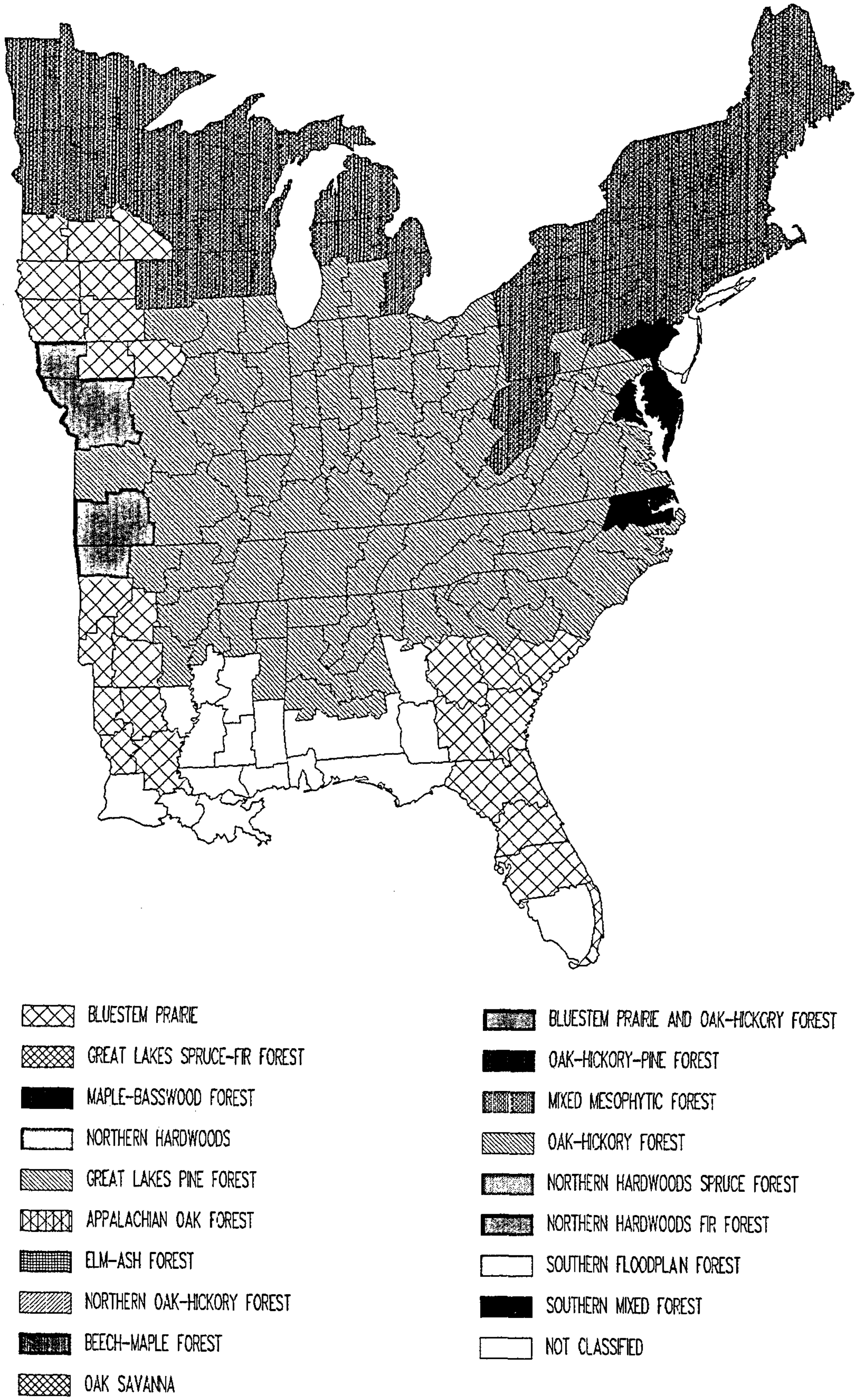

Figure 5 New community map under 2 x CO_2 climate scenario using GFDL model.

Table 2 Species response to climate change using three GCM scenarios. Negative values indicate loss of range; positive values, expansion. Cardinal directions (NSEW) indicate the primary direction in which the range expanded or contracted. Numeric values indicate the magnitude of change: 1 = 10 to 30%, 2 = 30 to 60%, 3 = 60 to 90%, and 4 = 100% of current range.

SPECIES	CCC	OSU	GFDL
Northern			
Abies balsamea (balsam fir)	-3S/-3W	-2S	-3S
Betula allegheniensis (yellow birch)	-2S/+2W	+3S/+2W	-3S/-3W
Fraxinus nigra (black ash)	-3S	-3S/-3W	-4
Pinus banksiana (jack pine)	-4	-4	-3E/-2S/+2W
Picea glauca (white spruce)	-4	-4	-4
Picea mariana (black spruce)	-3W/-2S	-3W/-2S	-3E/+2S/+2W
Pinus resinosa (red pine)	-3S	-3S	-3S
Tsuga canadensis (eastern hemlock)	-4	-3S	+3S/+3W
North-Central			
Acer saccharum (sugar maple)	-3S/-3W	-3W/-2S	-3E/-3W
Aesculus octrandra (yellow buckeye)	-3S/+2N	+4	+3N
Pinus strobus (eastern white pine)	-3S	-2S/-1W	-2S/-2W
Quercus coccinea (scarlet oak)	-3S/+1W	-3S/+2W	+3N/+3W
Quercus macrocarpa (bur oak)	+2S	-2E	+3S/+2E
Quercus prinus (chestnut oak)	-3S/-2E/+3W	-2S/+3W	+3N/+3W
Quercus rubra (northern red oak)	-2S/-2E	-1S	+3S
Tilia americana (American basswood)	+1S	-2S	-3S/-3E
South-Central			
Carya glabra (pignut hickory)	+2W	+2W/+1N	-1S/+3N/+2W
Liquidambar styaciflua (sweetgum)	+3N	+3N	+3N
Pinus echinata (shortleaf pine)	-1S/+3N	+3N	-2W/+2E
Quercus falcata (southern red oak)	+3N	+2N	-2E/+3N
Quercus lyrata (overcup oak)	+3N	+3N	+3N
Quercus marilandica (blackjack oak)	+4	-2N/-2E	+2N
Quercus shumardii (shumard oak)	+3N	+2N	-2S/+2N
Quercus stellata (post oak)	+4	+3N	-1S/+2N
Southern			
Magnolia grandiflora (southern magnolia)	-2W	-2W/+2N	+3N
Nyssa aquatica (water tupelo)	-2S/+3N	+3N	+3N
Pinus elliottii (slash pine)	-3S/+3N	+3N	-2S/+1N
Pinus palustris (longleaf pine)	+3N/-2S	+3N	+2
Pinus taeda (loblolly pine)	+3N	+3N	-3S/+3N
Quercus michauxii (swamp chestnut oak)	+3N	+3N	+3N
Quercus nigra (water oak)	+3N	+3N	-1W/+3N
Taxodium distichum (baldcypress)	-1W	+3N	+3N
Eastern US			
Carya cordiformis (bitternut hickory)	-3S/-2E	-2S/-2E	+4
Carya ovata (shagbark hickory)	-3S/+1N	-3S/+1N	+2N
Fagus grandifolia (American beech)	-3S/-3W	-3W/-2S	-3S
Liriodendron tuklipifera (tulip poplar)	-3S/+1W	-3S/+2W	-3N/-2S/+2W
Populus deltoides (eastern cottonwood)	+1N	-1S/+1N	+1N
Quercus alba (white oak)	+4	-1S/+1N	+1W
Quercus velutina (black oak)	-1W	+1N	+2N
Ulmus americana (American elm)	0	0	0

However, some mesic species such as baldcypress (*Taxodium distichum*), yellow buckeye (*Aesculus octandra*), sweetgum (*Liquidambar styraciflua*), and water tupelo (*Nyssa aquatica*) greatly expanded their ranges within the study area, especially using the OSU and GFDL scenarios. For several species, the models projected very different results. Eastern hemlock (*Tsuga canadensis*), red oak (*Quercus rubra*), and bitternut hickory (*Carya cordiformis*) lost most or all of their current range within the study area using the CCC model (driest), but greatly expanded their ranges using GFDL (wettest). For example, actual and baseline model distributions of eastern hemlock are shown in Figure 6. Using the CCC model, eastern hemlock was eliminated completely from the eastern United States, using OSU its range decreased (Figure 7), and using GFDL its range expanded (Figure 8).

The Sensitivity-to-Change Index was used to compare species responses among the three GCMs. Figure 9 shows Sensitivity-to-Change Indices for eight representative species. For a given climate scenario and species, an order-of-magnitude difference from one indicates a high potential to gain (>1.0) or lose (<1.0) range within the study area. The OSU model resulted in the least deviation from one in the Sensitivity-to-Change Indices for the species considered in Phase II. Conversely, the CCC resulted in the greatest deviations from one; typically values much < 1.0 indicating loss of range within the study area. Generally, northern species were most sensitive to change by migrating northward into Canada. Some southern and central species, such as pignut hickory

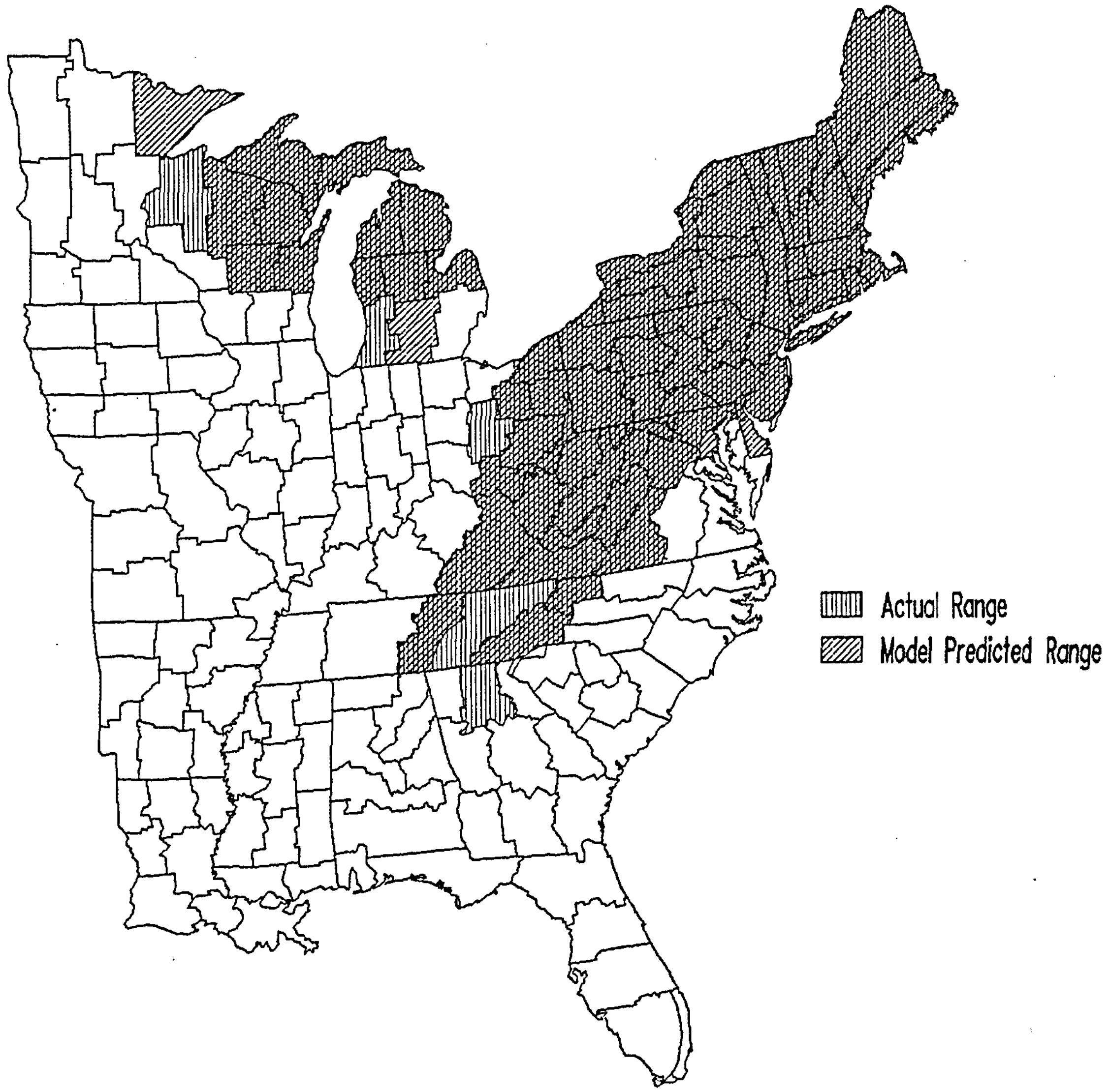

Figure 6 Present distribution of eastern hemlock and distribution predicted by the logistic regression model.

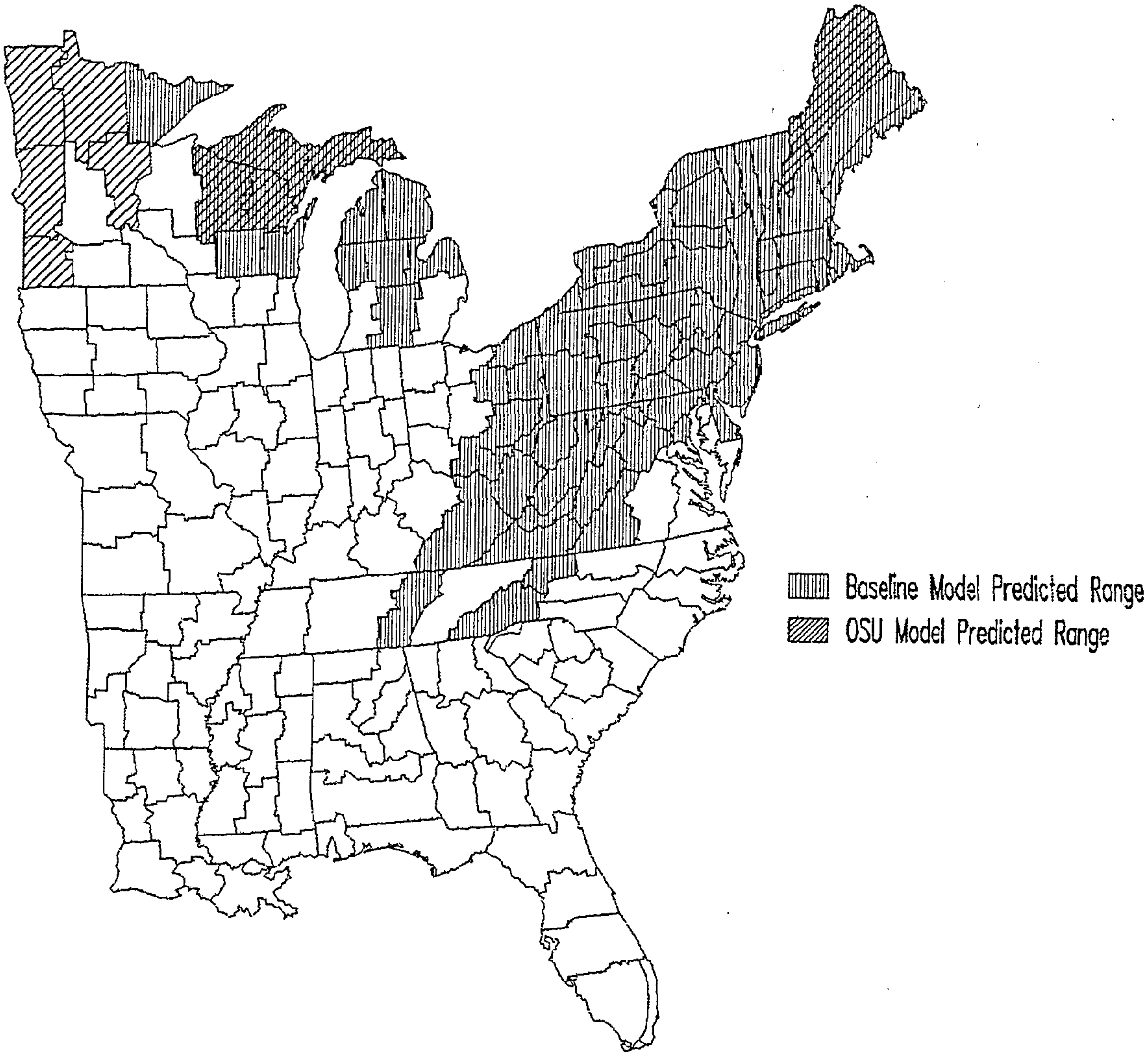

Figure 7 New range for eastern hemlock under 2 x CO_2 climate scenario using OSU model.

and white oak, had Sensitivity-to-Change Indices of approximately one, for all three models. Loblolly pine showed the greates sensitivity for range expansion, particularly for the CCC and OSU models.

Discussion

At the community level, projections of possible forest response to climate change varied among the three climate models used. Results from the CCC and OSU models (Figures 3,4) were somewhat similar and both differed greatly from GFDL results (Figure 5). Using CCC and OSU models, both southern mixed forests and southern oak-hickory-pine forests expanded ranges northward replacing northern hardwood, beech-maple, elm-ash, mixed mesophytic, Appalachian oaks, and northern an central oak-hickory forests. The CCC model predicts warmer and drier climates than does the OSU model (Table 1). Thus, southern oak-hickory-pine forest ranges expanded greatly using the CCC model, whereas more mesic southern mixed forests showed greatest range expansion using the OSU model. The drier conditions of the CCC model also resulted in considerable expansion of climate conditions suitable for bluestem prairie. While expansions of bluestem prairies seem possible in the northwestern part of the study area (Minnesota, Iowa, Illinois, Missouri), such communities are unlikely in the Appalachians, Carolinas, Middle Atlantic states, and central New York, as seen from CCC results (Figure 3), where other grassland communities would be more likely. Both models also indicated some expansion of Great Lakes

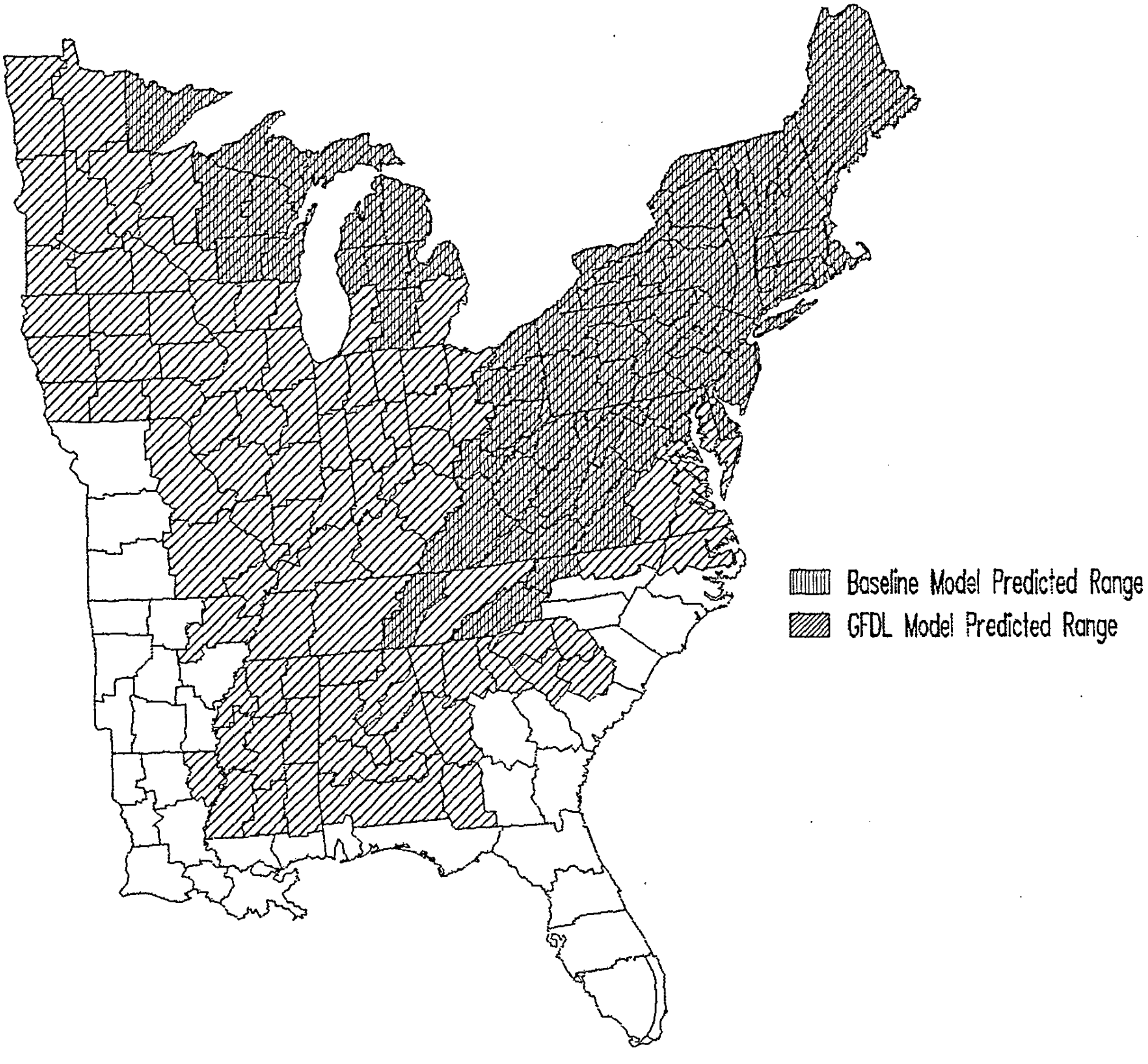

Figure 8 New range for eastern hemlock under 2 x CO_2 climate scenario using GFDL model.

pine forests, particularly using OSU model results.

GFDL model results were quite different. The GFDL model predicts temperature increases similar to those from the CCC model, but unlike the drier conditions from CCC, GFDL predicts greatly increased precipitation (Table 1). These warmer, more mesic conditions resulted in significant northern and eastern expansion of central oak-hickory forests (Figure 5) replacing southern oak-hickory-pine, Appalachian oak, beech-maple, elm-ash, and northern oak-hickory forests. Mixed mesophytic forests also expanded northward replacing northern hardwoods, pine, spruce, and fir forests. The most striking result from the GFDL model is the loss of all coniferous forests in the study area.

Both CCC and GFDL models predicted some community responses that seem improbable ecologically: (1) expansion of bluestem prairie using both climate scenarios and (2) extreme losses of coniferous forests using the GFDL model. By contrast, OSU model results had many fewer ecologically improbable community responses.

Phase II responses of individual species showed several patterns consistent with community responses, as well as some very different patterns. All three models predicted loss of range of northern species (Table 2), except for eastern hemlock using the GFDL model (Figure 8) in which its range greatly expanded. With this exception, both community and species responses of northern conifers showed significant loss of range, if not complete elimination.

Conversely, responses of southern pines, such as

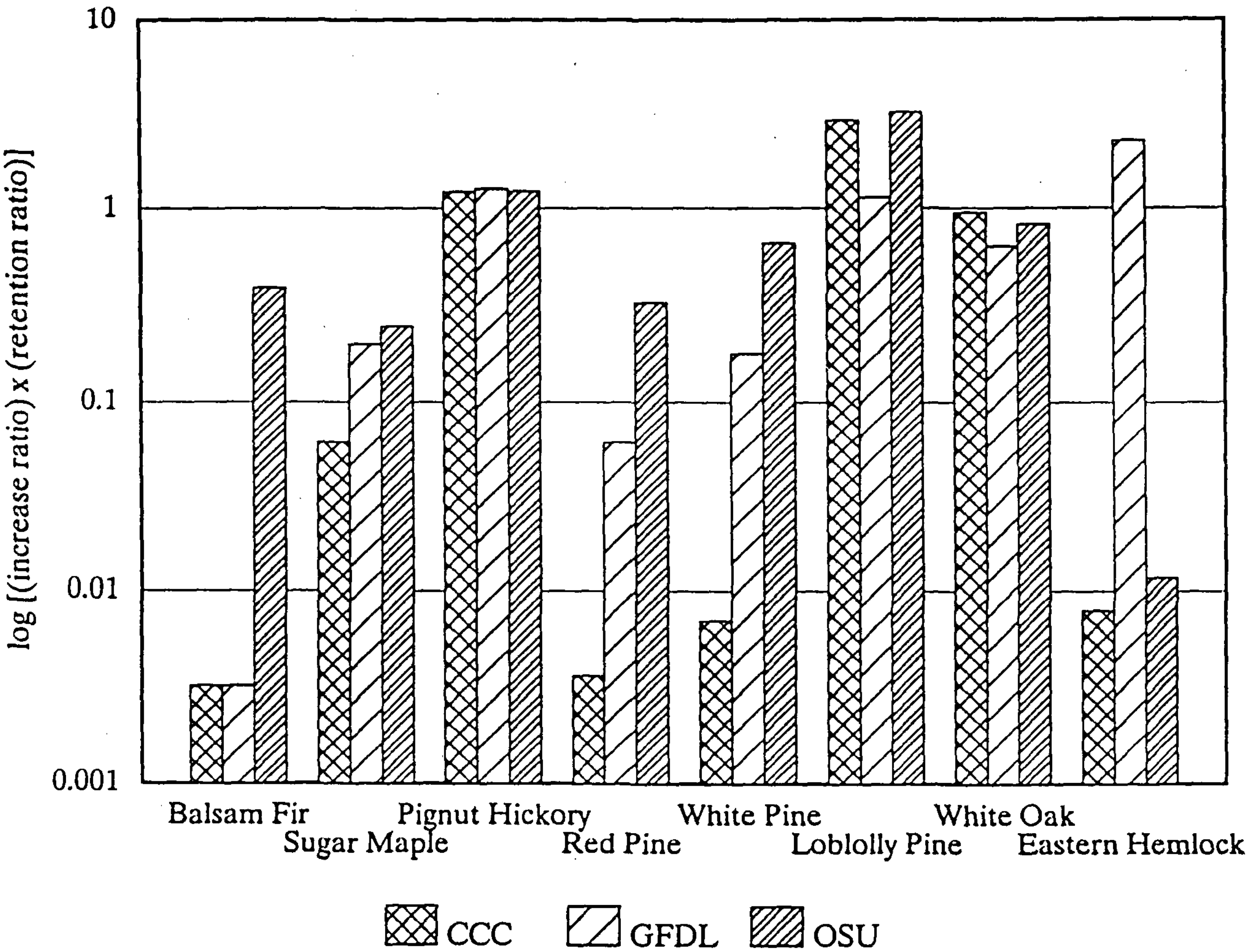

Figure 9 Sensitivity-to-Change Index for species response to climate change as predicted by three GCMs.

slash pine, longleaf pine, and loblolly pine, were northern migration with some reduction in southern range, or more commonly, retention of existing range and substantial northward expansion. Responses of southern pine species were consistent with community responses using CCC and OSU models, but very different from results using the GFDL model.

Using projections of distributions of individual species from the Phase II analysis, forest communities can be "reconstructed." Because OSU model results were more ecologically realistic for the community-level analysis, the OSU model was used for reconstructing new forest communities from individual species distributions. Although a 40-species overlay is too complex to present graphically, six locations in the eastern United States were selected to illustrate these "new" communities (Table 3). For northern Maine, white spruce disappeared and eastern white pine expanded into this area. In the northern lower peninsula of Michigan, eastern hemlock disappeared and white oak, chestnut oak, shagbark hickory and loblolly pine occurred in northern Michigan. In central Pennsylvania, no commonly occurring tree species disappeared, but loblolly pine expanded its range into this area. Southern Indiana lost sugar maple and tulip poplar, and had range expansions for several southern oak species, as well as loblolly pine. Western North Carolina lost sugar maple, tulip poplar, and eastern hemlock, and had increased ranges for pignut hickory, sweetgum, and loblolly pine. Finally, southern Georgio lost American beech and increased ranges for black oak and post oak.

Species long associated in natural communities may no longer occur together as differential dispersal abilities and life history traits affect the rates at which species migrate to their new ranges or their ability to adapt to changing conditions in a current location. New communities also will be a function of successful invasion in new geographic ranges. Species with wide environmental tolerances, high reproductive output, and superior competitive abilities should be favored in future climates.

Table 3: Comparison of commonly occurring tree species in six locations with possible future species distributions projected using *all* three climate models for community responses and the OSU model for species responses. Community classifications follow Kuchler (1970).

Location and Community	Current Common Species	Phase I Community	Phase II Species - OSU
Northern	balsam fir	CCC: northern	balsam fir
Maine	sugar maple	hardwoods-spruce	sugar maple
	yellow birch		yellow birch
northern hardwoods-spruce	American beech	OSU: northern	American beech
	white spruce	hardwoods-spruce	--
	black spruce		black spruce
	red pine	GFDL: mixed	red pine
	eastern hemlock	mesophytic forest	eastern hemlock
	--		eastern white pine
Northern Lower Peninsula	sugar maple	CCC: oak-hickory-pine	--
	yellow birch		yellow birch
	American beech		American beech
Michigan	jack pine	OSU: Great Lakes pine	--
	red pine		red pine
northern hardwoods	eastern white pine		eastern white pine
	eastern hemlock	GFDL: mixed mesophytic	--
	--	forest	white oak
	--		shagbark hickory
	--		loblolly pine
Central Pennsylvania	bitternut hickory	CCC: oad-hickory-pine	bitternut hickory
	shagbark hickory		shagbark hickory
	eastern white pine		eastern white pine
Appalachian oaks	white oak	OSU: oak-hickory-pine	white oak
	scarlet oak		scarlet oak
	chestnut oak		chestnut oak
	northern red oak	GFDL: mixed mesophytic	northern red oak
	--	forest	loblolly pine
Southern Indiana	sugar maple	CCC: oak-hickory-pine	--
	shagbark hickory		shagbark hickory
	American beech		American beech
oak-hickory	tulip poplar	OSU: southern mixed	--
	white oak	forest	white oak
	chestnut oak		chestnut oak
	northern red oak	GFDL: oak-hickory	northern red oak
	--		southern red oak
	--		bur oak
	--		post oak
	--		loblolly pine
Central North Carolina	sugar maple	CCC: oak-hickory-pine	--
	yellow buckeye		yellow buckeye
	American beech		American beech
	tulip poplar	OSU: oak-hickory-pine	--
oak-hickory-pine	white oak		white oak
	southern red oak		southern red oak
	eastern hemlock	GFDL: oak-hickory	--
	--		pignut hickory
	--		sweetgum
	--		loblolly pine
Southern Georgia	American beech	CCC: southern mixed	--
	sweetgum	forest	sweetgum
	southern magnolia		southern magnolia
southern mixed forest	slash pine	OSU: oak-hickory-pine	slash pine
	longleaf pine		longleaf pine
	loblolly pine		loblolly pine
	southern red oak	GFDL: bluestem prairie	southern red oak
	--		black oak
	--		post oak

Preliminary results from Phase III indicated species responses similar to Phase II results for the smaller study area; however, incorporation of soils, topography, and land-use data permit estimation of actual occurrence rather than potential ranges. Finally, incorporation of physiological and reproductive characteristics of individual species, using the JABOWA II model for assessing reproduction, growth, competitive ability, dispersal, and mortality provides more realistic species responses.

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