CHAPTER 16

Potential Changes in Tree Habitat for Illinois under Climate Change

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OBJECTIVES

One of the many applications of biological field data is their inclusion in predictive models. Such models are now being used to address questions facing society such as how will forest vegetation respond to a warming climate? What tree species are likely to be affected most? Models have been developed to help scientists predict how species might respond under a variety of future climatic scenarios. This chapter introduces some of the ways these predictions are being made and what the future may hold for Illinois trees.

INTRODUCTION

Global climate change increasingly is a factor influencing environmental and public policy. Understanding how these changes will affect vegetation is vital to making predictions about future conditions and in conservation planning.

An increasing number of cases are appearing in the scientific literature documenting changes in species patterns such as the timing of migration, flowering dates, timing of appearance in the spring, or disappearance in the autumn (1). Evidence is mounting that these changes will continue to accelerate through the twenty-first century. Though the habitats for trees change slowly relative to most animals and many herbaceous plants, the fossil record and multiple models show that they too are destined for changes in composition and abundance. Even though large lag times may occur due to long life spans for trees, catastrophic events such as ice storms or fires could hasten the changes to trees.

To address future impacts of climate change on trees, the potential changes in suitable habitat for 134 tree species in the eastern United States have been modeled (2, 3) including model outputs for Illinois. Detailed procedures for this analysis have been presented elsewhere (2, 4, 5) and are summarized here. These models represent *potential change* in suitable habitat by 2100, not what we expect the species range and abundance to be in that year. Other factors (e.g., changes to land cover, biotic and abiotic interactions not considered in the model) likely will have important influences on distribution and abundance of tree species.

METHODS

MODEL AND DATA PREPARATION include the following steps: 1) Calculate importance values (IV) for each tree species, based equally on number of trees and tree basal area (stem area at 4.5 ft. above ground) in more than 100,000 plots from the United States Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) sample sites. 2) Create 20- by 20-km grid of nearly 10,000 cells within the eastern United States (east of 100th meridian). 3) Summarize IV by 20- by 20-km cells. 4) Select species that met the criterion of being present in at least 50 cells (n=134). 5) Prepare 38 predictor variables that characterize individual species' habitat preferences based on current climate, elevation, and soil type. 6) Calculate weighted averages for each predictor variable by cell.

MODEL RUNS are tested with the following procedure: 1) Run Regression Tree Analysis (RTA), a sequence of statistical tests used to estimate importance values for tree species as influenced by the 38 predictor variables. 2) Determine stability of RTA models based on the variation among 30 individual runs of RTA for each species. 3) Create a robust predictive model of current and potential future importance values for each species using a statistical procedure called Random Forests (4). This procedure makes predictions of species' importance values based on the 38 input variables, including seven climate variables derived from past climate data (1960–1990). 4) Project the models onto scenarios of future climate to attain importance values for trees based on expected occurrences of suitable habitat. For this, the seven current climate variables were substituted with projected future climate estimates (2070–2100) according to three different climate models and two projected CO_2 emission levels (high and low). Differences between high and low emissions result from the energy and consumption choices humans make over the next few decades (high [hi] = humans stay on a similar track of increasing CO_2 emissions over the next 50 years, then emissions level off but end the century with roughly triple [970 ppm] the pre-industrial levels for CO_2; low [lo] = with increased conservation of energy we could end the century at about 550 ppm CO_2). The three climate models, known by their acronyms PCM, GFDL, and HadleyCM3, predict mild, moderate, and harsh future climates. To generalize information from these climate models, their outputs were averaged (Global Circulation Model average [GCM3]) under high and low emissions and reported as GCM3lo and GCM3hi, in addition to the projected mildest (PCMlo) and harshest (HADhi) scenarios.

OUTPUTS. Data generated from the model runs were used to map current and potential future suitable habitat. Maps of predicted current distribution were compared to recently collected FIA data to test the accuracy of the models. Also assessed was the relative importance of variables in predicting suitable habitat using outputs from the statistical procedures. Variable interactions, scale of influence, and relationship of predictor variables to RTA tree diagrams and maps were assessed. Finally, potential changes in suitable habitat under various climate scenarios were examined.

RESULTS AND DISCUSSION

Projected changes in climate across the eastern United States are anticipated to vary regionally and in magnitude based on the emission scenario and climate model. For example, under GCM3lo and GCM3hi emissions, the mean annual temperature is projected to increase by 3.0 and 5.7 C, respectively (Fig. 16.1).

OUTPUT AND SIGNIFICANCE OF THE CLIMATE CHANGE MODELS

It should be emphasized that these procedures merely model the potential suitable habitat changes and not the realized niche space. That is, there is no claim that the species will actually migrate to that space in the time frame of the future climate models. There are many other factors such as disturbance, competition, and land-use changes that are beyond the scope of this modeling framework. Researchers expect that disturbance agents more likely will hasten declines among species to a greater degree than they would accelerate the prominence of new species entering the region; however, if species already are present, they may increase in importance as competing tree species decrease. Trees generally live a long time and migrate slowly so that great lag times need to be considered to determine actual estimated ranges. This has been attempted for several species using a companion model (SHIFT). Scientists found that lag times and the fragmented nature of remaining forests greatly slow migration rates. For example, for five species tested, less than 15% of the newly created suitable habitat under climate change would have even a 2% chance of being colonized within 100 years (6, 7).

Illinois estimates of potential changes in tree species area-weighted importance values (AW IV) are tallied in Table 16.1 for both low emissions (PCMlo and GCM3lo) and high emissions (GCM3hi and HADhi) scenarios. The results from this modeling effort show that many species, including the most abundant ones, will have sizeable changes in suitable habitat in Illinois over the next century. In general, those species expected to increase or decrease under climate change will do so to a greater extent under higher emissions than lower emissions (Table 16.2). For visual examples, please see the Web site (3, http://www.nrs.fs.fed.us/atlas), which shows dozens of maps for each species. Although an exact timeline cannot be attributed to the potential changes outlined, suitable habitat importance will diminish over the next 100 years for many of the currently important species. These species, in descending order for the absolute loss of area-weighted importance values for the average high emission scenario, include Black Cherry (*Prunus serotina*), American Elm (*Ulmus americana*), White Oak (*Quercus alba*), Sugar Maple (*Acer saccharum*), Black Walnut (*Juglans nigra*), Northern Red Oak (*Q. rubra*), Shagbark Hickory (*Carya ovata*), White Ash (*Fraxinus americana*), and Black Oak (*Q. velutina*). Maps illustrating the potential change in geographic distribution of importance for White Oak, the state tree of Illinois, suggest that under either the high emission (e.g., GCM3hi) or low emission (GCM3lo) scenarios, suitable habitat could decline substantially in the state (Fig. 16.2). Several minor species also are greatly reduced including Paper Birch (*Betula papyrifera*), Eastern White Pine (*Pinus strobus*), Red Pine (*Pinus resinosa*; primarily in Illinois as a planted species), and Bigtooth Aspen (*Populus grandidentata*), suggesting a retreat of the northern forest types (8).

The extent of these changes depends largely on the emission scenario selected by humans over the next century. Changes would be much less dramatic, often less than half, if humans follow a low-emissions pathway. The species listed as potential losers currently provide most of the region's commercial and tourism value. Consequently, the potential economic impacts of such changes are likely to be substantial. Unfortunately, a recent report shows that current global trends of atmospheric carbon already are above that of the high emissions scenario (9). If that continues, for impacts shown here and elsewhere (e.g., 10), we are more likely to go even beyond the 'Hi' CO_2 emissions scenario.

Table 16.1. Potential species changes in importance value*area for habitat suitability for 112 species that currently reside in Illinois. Ratios below 1.0 are habitat loser species, while ratios >1.0 are habitat gainers.

Ratio of future habitat to present habitat (area-weighted importance value)

Scenario	< 0.5	0.5 - 0.9	0.9 - 1.1	1.1 - 2	> 2	decrease	increase
PCMlo	30	18	25	26	13	48	39
GCM3lo	29	17	19	35	12	46	47
GCM3hi	29	8	20	26	29	37	55
HADhi	25	7	13	41	26	32	67
Average	28.3	12.5	19.3	32.0	20.0	40.8	52.0

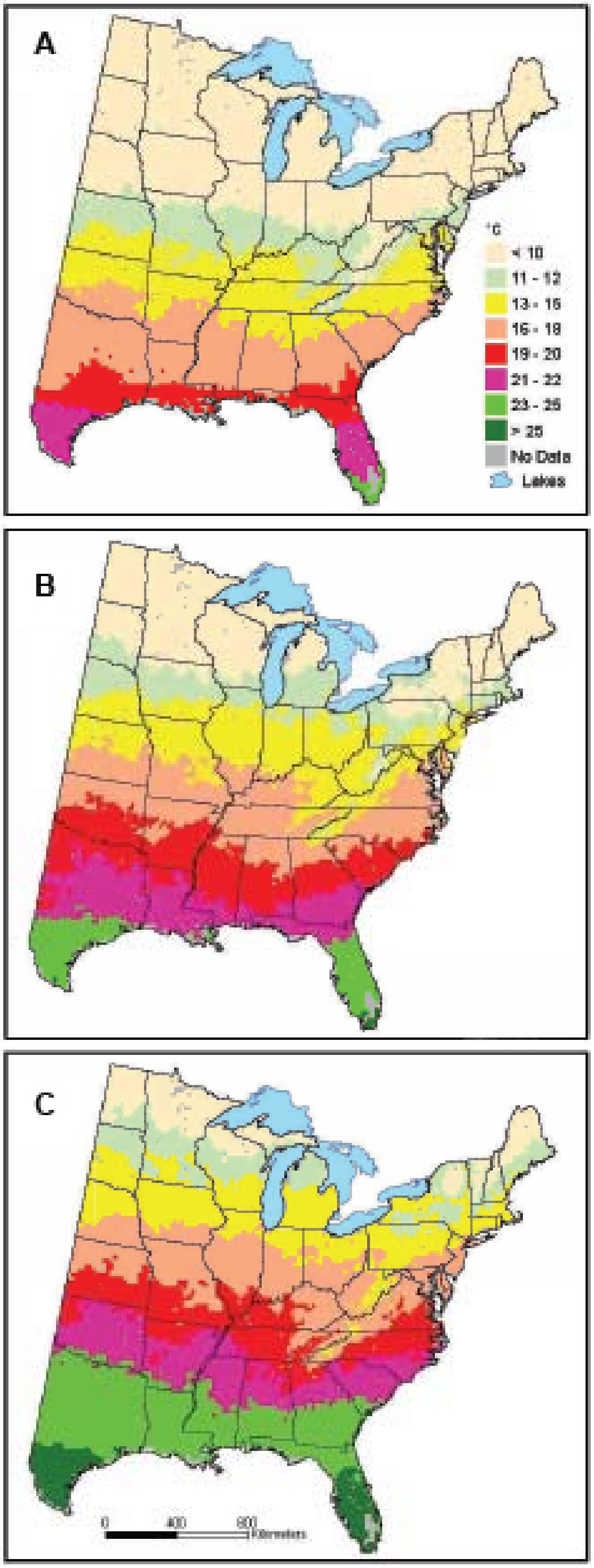

Figure 16.1. Mean annual temperatures (A) for current period (1960–1990), and potential future period (2070–2099) under (B) lower emissions average of three models, or (C) higher emissions (average of three models) scenarios.

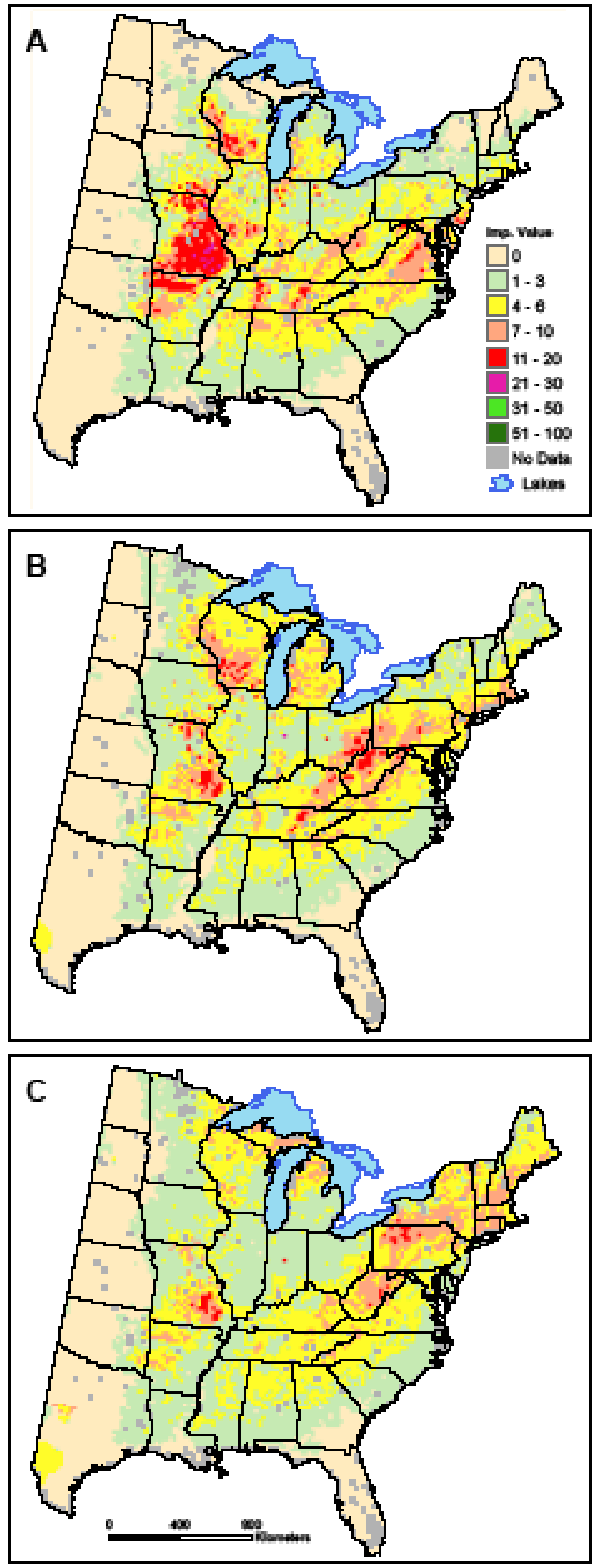

Figure 16.2. Potential suitable habitat for White Oak (*Quercus alba*) at (A) the current time, and potentially at year 2100 under (B) lower emissions or (C) higher emissions.

Table 16.2. Illinois tree species, sorted by decreasing modeled area-weighted importance values (AWIV), and percent potential changes according to four future climate scenarios. Species in red are species with projected major declines in suitable haibitat; species in blue are projected to have increasing suitable habitat. At bottom are five rare species that are in Illinois but not modeled as such; their actual (in parentheses) and estimated future AWIV are presented.

Common Name	Scientific Name	AWIV	PCMLO	GCM3LO	GCM3HI	HADHI
American Elm	*Ulmus americana*	3115	45.2	-9.8	-45.5	-59.9
White Oak	*Quercus alba*	2288	-14.2	-39.6	-57.7	-61.5
Black Cherry	*Prunus serotina*	1876	-38.8	-65.0	-77.6	-78.3
Silver Maple	*Acer saccharinum*	1858	49.1	35.0	45.1	19.1
Hackberry	*Celtis occidentalis*	1704	53.1	17.7	-18.3	-33.5
Black Oak	*Quercus velutina*	1452	1.6	-10.6	-33.3	-47.5
Shagbark Hickory	*Carya ovata*	1356	31.0	-20.2	-43.1	-55.0
Sugar Maple	*Acer saccharum*	1313	-20.0	-48.4	-71.7	- 85.7
Boxelder	*Acer negundo*	1290	18.8	47.3	87.4	65.3
Black Walnut	*Juglans nigra*	1267	63.5	-1.2	-50.4	-78.6
White Ash	*Fraxinus americana*	1182	-5.6	-25.8	-42.5	-53.0
Osage-orange	*Maclura pomifera*	1113	35.9	27.0	17.7	3.3
Green Ash	*Fraxinus pennsylvanica*	1039	65.6	54.5	64.6	72.8
Northern Red Oak	*Quercus rubra*	1015	11.8	-31.6	-61.2	-73.5
Honeylocust	*Gleditsia triacanthos*	967	87.5	54.2	31.7	18.8
Slippery Elm	*Ulmus rubra*	938	37.1	-4.3	-29.5	-47.3
Bur Oak	*Quercus macrocarpa*	790	27.7	19.1	50.9	38.1
Red Mulberry	*Morus rubra*	695	131.5	126.5	111.1	87.6
Shingle Oak	*Quercus imbricaria*	681	16.3	-2.2	-14.5	-20.0
Eastern Hophornbeam	*Ostrya virginiana*	679	16.2	-28.6	-46.7	-43.4
Red Maple	*Acer rubrum*	674	-8.8	-22.0	-16.6	-9.3
Sassafras	*Sassafras albidum*	667	2.2	-18.6	-32.4	-43.5
Eastern Cottonwood	*Populus deltoides*	664	46.4	34.3	20.2	9.5
Pignut Hickory	*Carya glabra*	598	-15.4	-28.6	-28.3	-17.7
Bitternut Hickory	*Carya cordiformis*	582	92.6	16.0	8.4	-5.5
Black Willow	*Salix nigra*	581	51.5	40.8	93.8	28.9
Sycamore	*Platanus occidentalis*	497	34.2	25.8	15.5	14.9
American Basswood	*Tilia americana*	475	-13.7	-21.3	-1.9	-31.4
Pin Oak	*Quercus palustris*	447	87.5	25.5	10.5	5.6
Mockernut Hickory	*Carya tomentosa*	431	29.0	24.6	29.0	39.9
Eastern Redcedar	*Juniperus virginiana*	422	110.2	120.1	166.4	169.2
Black Locust	*Robinia pseudoacacia*	395	29.6	119.2	7.3	-35.9
Flowering Dogwood	*Cornus florida*	317	42.3	17.7	30.9	38.8
Sweetgum	*Liquidambar styraciflua*	253	73.1	85.4	172.3	272.3
Eastern Redbud	*Cercis canadensis*	237	97.9	52.3	-6.3	-48.9
Common Persimmon	*Diospyros virginiana*	227	149.8	141.4	234.4	258.6
Eastern White Pine	*Pinus strobus*	173	-81.5	-92.5	-97.1	-98.3
River Birch	*Betula nigra*	139	109.4	77.0	260.4	174.1
Yellow-poplar	*Liriodendron tuliperfia*	134	114.9	-43.3	-8.2	2.2
Chinkapin Oak	*Quercus muehlenbergii*	131	228.2	175.6	102.3	42.0
Red Pine (cultivated)	*Pinus resinosa*	118	-61.9	-61.9	-58.5	-55.1
Winged Elm	*Ulmus alata*	116	737.9	1404.3	2500.0	2880.2
Swamp White Oak	*Quercus bicolor*	115	152.2	67.8	-27.8	-77.4
Black Ash	*Fraxinus nigra*	90	-73.3	-42.2	114.4	11.1
Quaking Aspen	*Populus tremuloides*	85	-91.8	-88.2	94.1	-64.7
American Beech	*Fagus grandifolia*	78	-53.8	-73.1	-75.6	-66.7
Shortleaf Pine	*Pinus echinata*	78	67.9	174.4	433.3	707.7
Blackgum	*Nyssa sylvatica*	74	62.2	33.8	127.0	232.4
Northern Pin Oak	*Quercus ellipsoidalis*	64	-29.7	-7.8	207.8	79.7
Blackjack Oak	*Quercus marilandica*	63	482.5	704.8	939.7	933.3
Jack Pine	*Pinus banksiana*	49	-24.5	32.7	326.5	151.0
Pawpaw	*Asimina triloba*	48	197.9	14.6	-14.6	-62.5
Sugarberry	*Celtis laevigata*	48	972.9	1775.0	2447.9	2454.2

Table 16.2 continued on next page

Common Name	Scientific Name	AWIV	PCMLO	GCM3LO	GCM3HI	HADHI
Southern Red Oak	*Quercus falcata* var. *falcata*	39	376.9	684.6	1297.4	1774.4
Shellbark Hickory	*Carya laciniosa*	37	264.9	140.5	108.1	54.1
Scarlet Oak	*Quercus coccinea*	35	-40.0	-77.1	-82.9	-77.1
American Hornbeam	*Carpinus caroliniana*	35	-8.6	-8.6	31.4	91.4
Ohio Buckeye	*Aesculus glabra*	34	8.8	-14.7	-67.6	-70.6
Bigtooth Aspen	*Populus grandidentata*	31	-96.8	-100.0	-100.0	-100.0
Black Hickory	*Carya texana*	31	819.4	1100.0	1509.7	1490.3
Wild Plum	*Prunus americana*	30	33.3	373.3	1080.0	793.3
Willow Oak	*Quercus phellos*	22	209.1	359.1	572.7	727.3
Loblolly Pine	*Pinus taeda*	22	463.6	909.1	3036.4	5627.3
Chestnut Oak	*Quercus prinus*	19	-63.2	-84.2	-78.9	-68.4
Post Oak	*Quercus stellata*	19	-63.2	-84.2	-78.9	-68.4
Cherrybark Oak	*Quercus falcata* var. *pagodaefolia*	19	147.4	326.3	563.2	752.6
Paper Birch	*Betula papyrifera*	15	-80.0	-80.0	-73.3	-93.3
Pecan	*Carya illinoensis*	13	2676.9	2569.2	3815.4	3892.3
Butternut	*Juglans cinerea*	11	-90.9	-100.0	-100.0	-100.0
Overcup Oak	*Quercus lyrata*	10	90.0	210.0	420.0	700.0
Northern Catalpa	*Catalpa speciosa*	8	-50.0	-12.5	25.0	12.5
Kentucky Coffeetree	*Gymnocladus dioicus*	8	875.0	1012.5	950.0	750.0
Chokecherry	*Prunus virginiana*	7	-42.9	-85.7	-85.7	-100.0
Virginia Pine	*Pinus virginiana*	7	-42.9	-71.4	-57.1	-57.1
Black Maple	*Acer nigrum*	5	-100.0	-100.0	-100.0	-100.0
Rock Elm	*Ulmus thomasii*	5	-20.0	-100.0	-80.0	-80.0
Northern White-cedar	*Thuja occidentalis*	4	-100.0	-100.0	-100.0	-100.0
Eastern Hemlock	*Tsuga canadensis*	4	-75.0	-75.0	-75.0	-75.0
White Spruce	*Picea glauca*	4	-75.0	-75.0	-75.0	-75.0
Balsam Poplar	*Populus balsamifera*	4	-25.0	- 50.0	-75.0	-75.0
Yellow Birch	*Betula alleghaniensis*	3	-100.0	-100.0	-100.0	-100.0
Water Hickory	*Carya aquatica*	3	-66.7	-66.7	-33.3	0.0
Sourwood	*Oxydendrum arboreum*	3	-66.7	-66.7	-66.7	0.0
Bald Cypress	*Taxodium distichum*	2	150.0	100.0	150.0	250.0
Water Tupelo	*Nyssa aquatica*	2	400.0	250.0	200.0	350.0
Tamarack	*Larix laricina*	1	-100.0	-100.0	-100.0	-100.0
Blue Ash	*Fraxinus quadrangulata*	1	-100.0	-100.0	-100.0	-100.0
Pin Cherry	*Prunus pensylvanica*	1	-100.0	-100.0	-100.0	-100.0
Yellow Buckeye	*Aesculus octandra*	1	-100.0	-100.0	-100.0	-100.0
Swamp Chestnut Oak	*Quercus michauxii*	1	100.0	100.0	100.0	200.0
Swamp Tupelo	*Nyssa biflora*	1	-100.0	-100.0	-100.0	-100.0
Cittamwood/Gum Bumelia	*Bumelia lanuginosa*	0(1)	0	0	0	0
American Chestnut	*Castanea dentata*	0(2)	0	0	0	0
Peachleaf Willow	*Salix amygdaloides*	0(4)	1	1	1	1
Cucumbertree	*Magnolia acuminata*	0(5)	2	2	2	2
Shumard Oak	*Quercus shumardii*	0(8)	8	75	87	54

Coupled with the reduced habitat for these primary species are the pests and diseases that are threatening several of the same species, such as Emerald Ash Borer on ash (11, 12), Dutch Elm Disease on elms (13), Spruce Budworm, Pine Bark Beetle, White Pine Blister Rust, Beech Bark Disease, and maple decline (cited in 14). As of 2005, Dutch Elm Disease was reported to cause moderate to heavy mortality in 45 Illinois counties (15). Thus, the compositional changes will be accelerated. Warming also tends to accelerate the rate of insect development and facilitate range expansions of pests and diseases such as those listed above. When climate change produces a mismatch between mature trees and the habitat upon which they live, there can be increased vulnerability to pests and pathogens (14). Invasive plants also are likely to spread under climate change as niches open, because the invaders are adapted to wider conditions and rapid colonization and growth could occur after disturbance or elevated CO_2 (16, 17). Of course, other human-derived disturbances associated with changes in land use and land cover have had, and will continue to have, profound impacts on the species composition (18).

Beyond the disturbances associated with insects and disease, a changing climate will increase the potential for other disturbances. Climatic effects such as increases in wind and ice damage, hurricane intensity, heavy precipitation events, drought in the later parts of the growing season, flooding during the growing season, and warmer winter and summer temperatures (19) can increase stress on species, leading to further changes. An analysis of 806 northern temperate trees and shrubs showed that few species can tolerate more than one of the following stresses: shade, drought, or waterlogging (20). Climate change will modify the proportions of these stresses (e.g., increases in both drought and waterlogging potential leading to changes in species composition). Additonally, though not so much a factor for Illinois, wildfire is liable to increase under climate change, at least in some portions of the country (21), and this could have a substantial effect on hastening species changes that are undergoing shifts in their habitat suitability.

Concurrently, some species will likely increase substantially in habitat importance in Illinois. These include several oaks: Southern Red (*Quercus falcata* var. *falcata*), Blackjack (*Q. marilandica*), and Bur (*Q. macrocarpa*); two hickories: Black (*Carya texana*) and Pecan (*C. illinoensis*); two pines: Loblolly (*Pinus taeda*; not currently native in Illinois) and Shortleaf (*Pinus echinata*); two maples: Silver (*Acer saccharinum*) and Box Elder (*A. negundo*); and Sugarberry (*Celtis laevigata*), Sweetgum (*Liquidambar syraciflua*), and Winged Elm (*Ulmus alata*). Shortleaf Pine, a southern species currently limited to far southern Illinois, is modeled to have a large net increases in habitat (Table 16.2), potentially resulting in a dramatic shift northward (Fig. 16.3). Increased habitat for oaks and hickories could indicate an increased commercial and wildlife resource, but oaks are currently undergoing a regeneration crisis in the absence of fire or other agents that can partially open the canopy (22, 23, 24). It is possible that some of the disturbances mentioned may open the canopy sufficiently to enhance the probability of oak regeneration. Additional research on this topic is

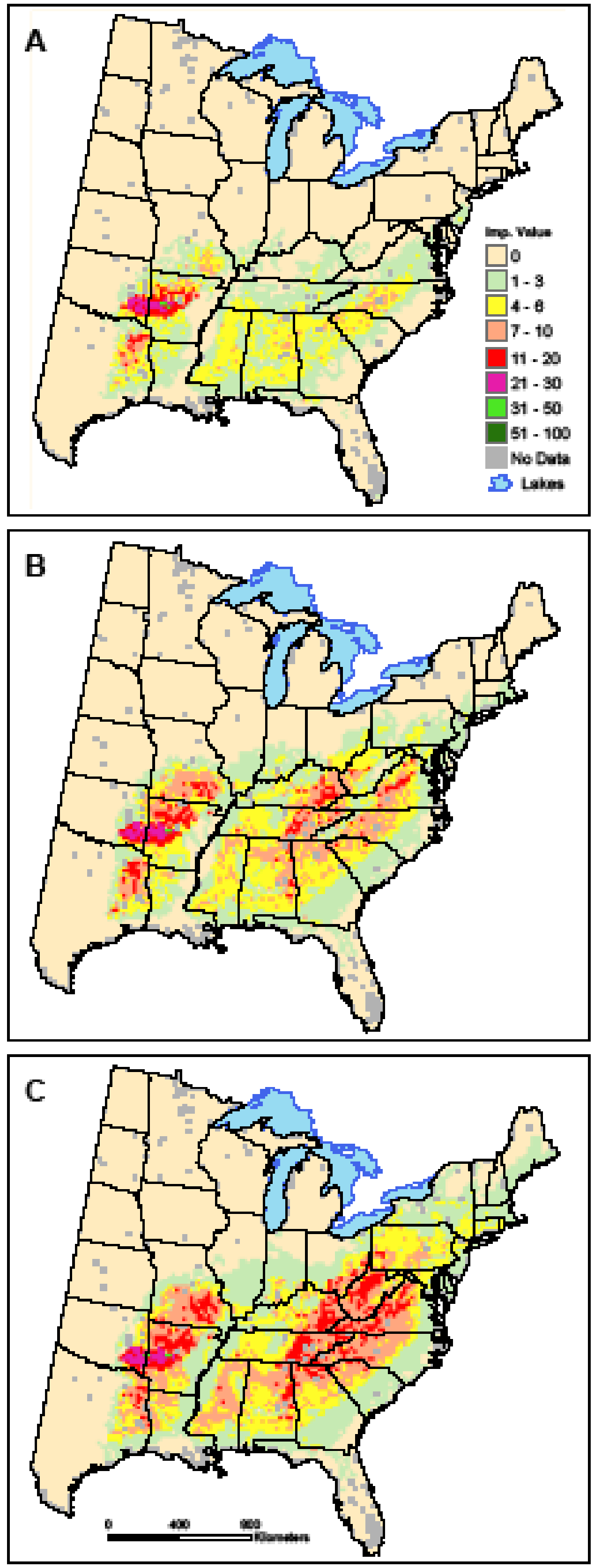

Figure 16.3. Potential suitable habitat for Shortleaf Pine (*Pinus echinata*) at the (A) current time, and potentially at year 2100 under (B) lower emissions or (C) higher emissions.

needed. Another series of species may enter Illinois from the south, including Water Oak (*Quercus nigra*), and Cedar Elm (*Ulmus crassifolia*), or greatly expand from the southern tip of Illinois such as Willow Oak (*Quercus phellos*) and Water Locust (*Gleditsia aquatica*).

The overall changes in potential suitable habitat reflected in these models reveal that, in general, there is a broad-scaled loss in habitat for many common upland species (but not complete loss—their habitats will remain but with lower suitability). There also would be a loss in habitat for species characterized as "northern" with the southern edge of their ranges moving north (and mostly out of Illinois). Finally, there would be a series of southern, and especially bottomland, species that have the northern edge of their habitat ranges moving northward to cover more area within Illinois.

These models show that species projected to have increasing suitable habitat outnumber those with decreasing habitat (Tables 16.1 and 16.2). Moreover, as the scenarios vary from PCMlo ("mild") scenario, to the average low and high emission scenarios, and to the HADhi ("harsh") scenario, the ratio of gainers to losers increases (Table 16.1). This trend can be partially explained by the nature of the biogeography associated with the ranges of tree species. In relation to the boundaries of Illinois, there is much territory and a great diversity of species towards the south but less territory and species diversity towards the north. Also, Canada is outside the range of FIA data, so exclusively Canadian species are not included in the models. However, the pressures (backed by paleo and ever increasing present-day data) are for the species to migrate northward; so it is logical that many southern species, especially ones driven largely by climate (particularly temperature), would gain suitable habitat within the boundaries of Illinois.

CONCLUSIONS

Climate change will provide a driving force over the next decades to alter the forest composition in Illinois. These changes can be expected to be gradual given lengthy life spans for most trees. Just because the climate is more suitable for a different species does not mean that already established trees will not survive well beyond the time their habitat is no longer suitable. Thus, it is not possible to put a time frame on the compositional changes discussed here. The larger, more noticeable, changes are likely to occur from direct human impacts like land-use change and land management, or from large disturbance events such as ice storms, severe droughts, and wildfires. However, large disturbance events also could accelerate forest compositional changes as discussed here.

ACKNOWLEDGMENTS

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