Title: Past, Present, and Possible Future Trends with Climate Change in Illinois Forests

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ABSTRACT

There have been dramatic changes to forest lands since the end of the last ice age, about 14,000 years before present, when boreal ecosystems were eventually replaced by deciduous forest and grassland. In Illinois at the time of Euro-American Settlement (circa 1820), forest lands, including fire-maintained woodlands and savannas, comprised about 42% of the land area. Habitat destruction, fire absence, livestock grazing, and infestations of non-native species have altered forests since the 1800s. Currently, forest land cover statewide is about 13.5%, mostly (83%) in private ownership and predominately (68%) classified as oak-hickory cover type. Further modifications can be expected due to climate change, predicted for Illinois over the next 100 years to include warmer winter temperatures, warmer and wetter springs, and hotter, drier summers.

Models predicting potential futures for 113 tree species as a response to climate change over the next 100 years were generated for ten primary Illinois ecoregions. Results indicate that there are likely to be increases in habitat suitability and capability for some species and decreased habitat suitability and capability for others with variability across ecoregions. Many species demonstrate differential responses to changing climate from north to south in the state. The dominant species in the oak-hickory cover type generally are projected to have fair to good capabilities, with some notable exceptions; however, *Acer saccharum*, a competitor in many oak-hickory stands, also is projected to have fair to good capability. Dominant species in mesic upland and bottomland forests include a rich variety of species about evenly split between those with fair-to-good capabilities and those expected to have poor capability. Potential 'New Habitat' and 'Migrate' species also are identified. New Habitat species are those that have potential habitat appearing in the state within 100 years; Migrate species have some potential for natural distribution to the state within 100 years and could be considered as candidates for assisted migration northward. Considerations for conservation and management of forest lands are discussed.

INTRODUCTION

The possible effects of climate change on vegetation are topics of current interest as they have implications for efforts to sustain biodiversity and conservation planning and design. Significant alterations over time are part of the vegetation history of Illinois. Here we focus on forest trends. To provide context for possible future forests, we provide a summary review of past forest trends in Illinois (adapted from Taft *et al.* 2009) with updated current status. We then present potential future trends for tree species across the state resulting from ongoing and anticipated future changes in climate over the next 100 years, which is expected to include increasing mean-annual temperature and precipitation as well as increased likelihood of summer droughts (Pryor *et al.* 2014; Wuebbles *et al.* 2021). Projected trends among tree species are the outcome of multivariate models developed for the eastern United States (Iverson *et al.* 2019a, 2019b), modified to apply specifically to the geographic context of Illinois ecoregions (Figure 1).

Past, Present, and Future Forests

Changes in vegetation composition and structure can be measured over a wide range of time scales, from seasonally to over thousands of years. Such changes inform many aspects of environmental condition. Illinois occurs within a temperate climate zone where a wide range of vegetation changes appear seasonally. When examining vegetation over longer time spans, from a few years to decades, composition and structure can vary greatly due to a variety of extrinsic factors, depending on their magnitude and duration (e.g., drought, flooding, grazing, fire, fire absence, invasive species), which in turn favor species adapted to, or more tolerant of, those conditions. When examining changes over even longer time spans, such as since the last glacial period about 14,000 years ago, far greater differences have occurred with sequential wholesale conversions of different vegetation types (King 1981). These more dramatic alterations largely correspond to changes in climate.

<u>Post-Pleistocene Trends</u> - The last glacial episode, known as Wisconsinan glaciation, covered the northeastern quarter of Illinois with a thick layer of ice from about 30,000 to 14,000 years ago (Killey 2007). Vegetational changes since that time throughout Illinois included, in places, a brief tundra phase followed by a period of domination by spruce and fir and then spruce and pine forests (Voss 1934; Boggess and Geiss 1968; King 1981). There is fossil pollen evidence of spruce woodland and tundra occurring in central Illinois (King 1981) and even in southern

Illinois (Voss 1934) during the late Pleistocene. These are vegetation types now limited to boreal zones hundreds of kilometers north of the state. This boreal phase lasted a few thousand years but by 9,000 years before present (B.P.), with the development of a warming cycle known as the xerothermic (Sears 1942), deciduous forest began to enter the region. By about 8,300 years B.P., forests were dominated by species of oak and hickory (Anderson 1991) and prairie species began to invade (King 1981) forming part of a Prairie Peninsula extending east of the Rocky Mountains to Ohio (Transeau 1935). Although there is regional variation, the period from about 8,000 years B.P. to 5,000 years B.P. included the emergence of savanna and open woodland habitats (Taft 1997; Anderson and Bowles 1998). Increased moisture in the southern portion of the prairie peninsula about 5,000 years B.P. resulted in an increase in forest in that region (King 1981). Since then and until the time of Euro-American settlement around 1820 to 1840, fire, including intentional burning by indigenous people, periodic droughts, and grazing animals helped maintain grassland, savanna, and open woodland habitats (Anderson 1970, 1983; Taft 1997).

<u>Forests at the time of Euro-American settlement (circa 1820)</u> - At the time of the first Euro-American settlements in Illinois, forest, woodland, and savanna covered about 6.2 million ha, or 42% of the land area (Szafoni *et al.* 2002). Large expanses of these wooded plant communities existed at the time of Euro-American settlement with the greatest concentrations in the western and southern regions (Figure 2). Characteristics of the landscape had great influence on forest distribution. Upland forests primarily were concentrated in areas of greater topographic relief such as the dissected terrain of riparian corridors where there was some, especially leeward, fire protection (Gleason 1913), while forested wetlands naturally occurred on poorly drained floodplains (Iverson 1988). About three-quarters of all forest cover in Illinois is associated with

slopes greater than 4% (Anderson 1991), while most of the timbered land with slopes less than 4% are associated with floodplains or undissected low fertility soils in the Illinoian till plain located in the southern half of the state.

Forests at this time differed from most current stands by their exposure to occasional fires. Woodland habitats, intermediate in structure and composition between forest and savanna, were common and strongly dominated by oak species. Of the 20 oak species native to Illinois, many were and remain common in the overstory of upland woodlands and forests statewide, such as *Quercus alba*, *Q. rubra*, *Q. velutina*, *Q. macrocarpa*, and *Q. muhlenbergii*, or regionally such as *Q. stellata*, *Q. marilandica*, and *Q. falcata*. Oaks greater than a few centimeters diameter are capable of enduring low intensity fires typical of woodlands, thereby favoring their past dominance and ecological significance. In contrast, species like *Acer saccharum* are favored in more closed and shaded forest stands and when young, tend to be fire sensitive. According to early surveyor records, *A. saccharum* was scarce in oak-hickory stands compared with modern forests (Ebinger 1986, 1997), supportive evidence that fire historically was a widespread and general phenomenon.

<u>Forest Trends Since Settlement</u> - Forest clearing, grazing by livestock, fire suppression, and infestations by non-native species have, to varying degrees, altered Illinois forests since the early 1800s. The extent of deforestation in Illinois can be deduced by the estimates of forest land cover in the 1800s and in periodic forest surveys beginning in 1924 (Telford 1926; Hahn 1987; Schmidt *et al.* 2000; Crocker *et al.* 2005; USDA 2019a). Following a period of intensive harvest, particularly from 1860 to 1900 (Iverson *et al.* 1989), forest area in Illinois reached its minimum extent in about 1920 with 1.22 million ha, 8.5% statewide coverage and just under a

quarter of the pre-Euro-American settlement total. During the next 100 years, area of forest land cover increased to about 1.96 million ha (Figure 3), 13.5% statewide coverage, a linear annual rate of increase of about 7,400 ha (0.61%). This trend can be partially attributed to a reduction in cattle grazing and conversion of marginal cropland and pastures to tree cover. In some cases, trees now grow where once was prairie. Statewide forest land cover in 2000 included about 353,966 ha that was non-forest land cover in the early 1800s (Szafoni *et al.* 2009).

As a result of habitat fragmentation and intentional suppression, fire frequency has declined dramatically and, as a result, there has been a shift in native species composition characterized by increasing tree density and abundance of shade-tolerant and generally fire-intolerant species in forest and woodland understories, a phenomenon widespread throughout forests in the eastern U.S. termed mesophication (Abrams 2005; Nowacki and Abrams 2008). Consequently, fire-dependent savannas and open woodland habitats, with their characteristic rich diversity of ground-layer species, have become quite scarce (Nuzzo 1986; Noss *et al.* 1995; Taft 1997).

<u>Current Status of Illinois Forests</u> - Current forest area is just under a third of the pre-Euro-American settlement (circa 1820) extent (Figure 3). However, based on the qualitative criteria developed for the Illinois Natural Areas Inventory (White 1978), only about 0.1% of the acreage at the time of settlement, and about 0.36% of remaining forests, persist in a condition relatively free of past habitat damage (IDNR 2008). Relevant to conservation efforts, most forest in Illinois occurs on private lands (83%) followed by federal (8%), local government (5%), and state (4%) land holdings (Figure 4). Of the current total forest and woodland area, most is classified as upland habitat and about 18% is bottomland forest and swamp (Suloway *et al.*

1992). Since 1985, forest stands classified as oak-hickory and elm-ash-soft maple-cottonwood, based on the canopy dominance of those species, have increased in area while stands classified as maple-beech-aspen have declined in area (Figure 5). Declining trends can be due to selective habitat destruction, reclassification, or both. Currently, most acreage is classified as oak-hickory (68%) followed by elm-ash-soft maple-cottonwood (23.9%) (Figure 6). However, in current forests, the proportion of oak-hickory forest types is much greater in the older age-class stands compared to younger age-class stands (Figure 7). As such, absence of fire and mesophication may be leading to the possibility of a general replacement of oaks in forest canopies by more shade-tolerant species (Nowacki and Abrams 2008). Simultaneously though, the changing climate will likely have a compounding influence on this outcome because droughty, hotter climates tend to favor the oak species (Iverson *et al.* 2019c).

<u>Future Climate-Related Effects on Illinois Tree Species</u> - Over the next 100 years, forests will be shaped by the responses of tree species to climate change as mediated by local conditions, with effects varying among species and even individuals of the same species. Models predicting potential futures for tree species throughout the eastern U.S. have been generated by the Landscape Change Research Group of the Northern Institute of Applied Climate Science, USDA Forest Service (Iverson *et al.* 2019a, b; Peters *et al.* 2019; Peters *et al.* 2020). To provide an assessment specific to Illinois, a new analysis was completed to summarize the potential tree species responses from these models for the primary ecoregions in the state (Figure 1). Our primary goals are to present the results of these models and how projected change will affect tree composition of Illinois forests and how conservation and management efforts can address these changes.

METHODS

We used two models to estimate potential tree species response to the changing climate. The first, DISTRIB-II, provides an estimate of the distributional range of the species currently, based on statistical relationships between their known locations (from inventories) and a series of 45 climatic, soil, and topographic variables. Then, seven climatic variables are changed according to climate estimates for 2100, and the models re-run to show potential suitable habitat in the future for each species. The DISTRIB-II model runs at either a 10x10 km or 20x20 km grid, depending on the density of inventory plots, as it requires a minimum of three plots to assign an average abundance for each species in the cell (Peters *et al.* 2019). The second model, SHIFT, is a mechanistic model which uses species abundance output from DISTRIB-II along with current land cover information and generalized historic (Holocene) rates of migration of 50 km per century (if fully forested, proportionately less as forest cover diminishes) to spatially represent possible changes in actual distribution within the next 100 years. We refer to earlier citations for details on the models (Iverson *et al.* 2019a, b, Peters *et al.* 2019). These two models, when combined, provide estimates of not only where tree habitat may change in the future (DISTRIB-II), but also how much of the newly suitable habitat may be colonized within the next 100 years (SHIFT).

A primary data set required for these models are the US Forest Service's Forest Inventory and Analysis (FIA) data, with over 100,000 plots across the eastern US (USDA 2019a), including 1,861 plots in Illinois (Gray *et al.* 2012, Crocker *et al.* 2015). These plots are laid down across the state in proportion to the forest cover so that a map of forest cover (e.g., see Crocker el al 2015; Figure 2) also represents the density of forest plots. Another key data set are the projections of climate according to various scenarios of climate change by 2100. In this study, we present results according to the average outcome of three Global Climate Models (GCMs) with the Representative Concentration Pathway (RCP) at a relatively high level of emissions (RCP 8.5), where the earth's atmosphere is trending so far (Wuebbles *et al.* 2021).

These models were evaluated for each of 10 major ecoregions (Figure 1) recognized for Illinois (Cleland *et al.* 2007); however, two small ecoregions in southernmost Illinois, Coastal Plains-Loess and White and Black River Alluvial Plains, were combined for this analysis. To capture enough area to ensure robust statistical analysis, ecoregions less than 8,000 km^2 (Table 1) were buffered with enough area to achieve this minimum sample area, sometimes expanding into bordering states and often overlapping other Illinois ecoregions until the 8,000 km^2 threshold was exceeded (Figure 8).

These data were used to calculate abundance for each species found in each ecoregion, currently and potentially into the future (~2100). Here we present two key variables for each species in each ecoregion. The first is *FIAsum*, which provides an indication of overall species importance within each ecoregion. For each species, a relative importance value is calculated, based equally on the average number of stems and basal area for all FIA plots within each 10x10 or 20x20 km cell; these importance values are then summed for all cells within each ecoregion. *FIAsum*, therefore, indicates the overall importance of a species in an ecoregion, reflecting not only the size and abundance of individual tree species but also total forest cover within the ecoregion. *Total FIAsum* (Appendix) is the sum of species importance across all ecoregions and is a measure of statewide importance based on FIA sample data. The second variable is capability (*Cap.*), a measure of species capacity, scaled 1-5 (very poor, poor, fair, good, very good), to cope or persist with the expected climatic changes based on its categories of current abundance, adaptability, and change class following projected climate change. As an example, for species currently abundant with high adaptability to the changing climate (Matthews *et al.* 2011), and with estimates of increased suitable habitat at 2100, the 'very good' capability was assigned, with decreasing capability as the three variables diminish. Mean capability (*MeanCap*) is a measure across all ecoregions based on ecoregions of occurrence (not including when a species is absent within an ecoregion [Appendix]). A curiosity of the FIA database is that species found native in the state, such as *Pinus strobus*, *P. resinosa*, and *Robinia pseudoacacia*, that are also planted and adventive outside of their native Illinois ranges, are considered native wherever recorded and we did not try to untangle the differences.

Also reported under the capability variable, *Cap*, is a designation of 'New Habitat' and 'Migrate' for certain species (Appendix 1). 'New Habitat' species are those that, according to the DISTRIB-II model, are not known to be present according to FIA plot data but have potential habitat appearing by 2100. Importantly, this designation does not consider whether the species will get there by 2100, only that suitable habitat may appear there. 'Migrate' species, on the other hand, are species not reported from FIA sample data or modeled to be in the zone, but have some potential, according to the SHIFT model, to naturally migrate there within 100 years. Thus, these 'Migrate' species could be considered as good candidates for assisted migration (Prasad *et al.* 2016; Iverson *et al.* 2019a). Of course, managers would need to use their local knowledge of matching species and habitats for final species selections. The SHIFT model incorporates landscape heterogeneity of forest cover into the expected range extensions and includes the capability estimates for each species.

Botanical nomenclature for the tree species in this study follows the USDA Forest Inventory and Analysis (USDA 2019a). Common names for tree species can be found in the Appendix.

RESULTS

Species Richness and Importance

A total of 113 tree species were evaluated in this study including 94 species currently detected by FIA plots and 19 modeled to have habitat available by 2100 under climate change (RCP 8.5) (Appendix). Of those detected recently within the 1,861 FIA plots, 83 native species, four adventive species (native to North America but not Illinois), and seven introduced non-native species were recorded. Seven of the native species had inadequate sample data for capability modelling. Currently, according to *Total FIAsum*, the overall top species in the buffered state are *Quercus alba*, *Acer saccharum*, *Ulmus americana*, *Liriodendron tulipifera*, and *Q. velutina* (Appendix). Total forest land cover and, thus, sample area differs among ecoregions (Table 2). Consequently, there is a correlation between species counts and the number of plots available for this analysis. The three ecoregions with the least richness also have the fewest plots because of the relatively small total area evaluated (222L and 222H, Table 1) or the highly urbanized landscape of northeastern Illinois (222K), which is >35% developed but still with a large amount of non-developed forest. Urban areas typically were not well sampled via the normal FIA protocols, thus relatively less dense sample plots are available for this ecoregion. Nevertheless, there is a general north-to-south increase in tree species number, following general latitudinal trends globally. For example, the number of species recorded by forest inventory plots ranged from 34 in the northwest corner of the state to 73 in the Shawnee Hills in the south. Of these, the total number of common species, with *FIAsum* > 10, ranged from 17 in the Southwestern Great Lakes Morainal to 59 species in the southernmost ecoregion. The species-rich White and Black River Alluvial Plains and Coastal Plains-Loess ecoregions in southernmost Illinois include unique habitats, such as forested swamps, interspersed among the upland forests more typical of the Shawnee Hills region. Importance of individual species also varies widely along a north-to-south latitudinal gradient. For example, *Liriodendron tulipifera* and *Sassafras albidum* are almost exclusively in the southern ecoregions while *Quercus macrocarpa* and *Populus tremuloides* are primarily in the north (*Q. macrocarpa* is found statewide but has greater *FIAsum* values in northern regions). We recognize there are also east-west gradients for eastern North America tree species, but the shape of Illinois allows for a more robust analysis of north-south gradients.

Summary tables of tree species' projected responses to climate change are available for various watersheds, urban areas, and 1x1 degree grid locations within Illinois or anywhere in the eastern U.S. (USDA Forest Service 2019b; Iverson *et al.* 2019a).

Capability

Across all ecoregions, there are roughly equivalent numbers of species with good or very good capability (mean across regions = 21.0) compared with species with poor or very poor capability (21.5), and another nearly 12 species with fair capability (Table 2). Because capability is based on current abundance, projected change in suitable habitat, and adaptability of the species, any of these traits can influence the capability of the species, and the capability varies widely among the nine ecoregions (Appendix). The southern ecoregions, once again, are expected to fare well, with 31-34 species with good or fair capability to cope or persist under climate change at the RCP8.5 level (Table 2). Based on an assessment of statewide capability (though we emphasize the spatial variability among ecoregions), the top-ranked species that would be expected to cope or persist well in the changing climate are *Liquidambar styraciflua*, *Quercus stellata*, and *Ulmus alata*, followed closely by *Quercus pagoda*, *Carya cordiformis*, *Celtis occidentalis*, *Juniperus virginiana*, and *Gleditsia triacanthos* (Table 3). Of the 20 species ranked with *MeanCap* 4.0 (good) or greater, seven are oaks (*Quercus* spp.). Median capability for all species currently in Illinois is 2.8. Some species currently ranked with the highest *Total FIAsum* within the state (>700) had ecoregion-specific capability rankings that were often poor to fair in some ecoregions, including *Liriodendron tulipifera*, *Quercus velutina*, *Carya glabra*, *Prunus serotina*, and *Juglans nigra* (Appendix). The capability of some species to persist in a changing climate varies by ecoregion. For example, *Q. alba*, the State tree, ranking with *MeanCap* just above fair (3.1), has wide variation among ecoregions from good and very good (in the southernmost two ecoregions and the far northwest) to poor (the northeastern quarter of Illinois) (Appendix), suggesting no correlation to a latitudinal response but rather a correlation to current abundance of the species. In contrast, *Ulmus americana* has better capability in southern Illinois compared to northern ecoregions (although, this assumes resistance to Dutch elm disease), while *Acer saccharum* has much greater capability ratings in northern regions.

Species currently present in the state with capability ranking poor to very poor (Table 4) include species that are uncommon to start with, meaning few individuals are likely to find refuge in suitable habitat with favorable climate conditions in the coming decades. However, some relatively common species (*Total FIAsum* > 100) also have low (poor to very poor) future capabilities, including *Carya glabra*, *Salix nigra*, *Tilia americana*, *Quercus imbricaria*, *Q. palustris*, and *Q. muhlenbergii*. Familiar species with the lowest *MeanCap* include *Populus tremuloides*, *P. grandidentata*, *Pinus strobus*, *Betula nigra*, *Asimina triloba*, and *Aesculus glabra* (Table 4).

New Habitat and Migrate Species

The DISTRIB-II model identifies a range of 11 to 21 'New Habitat' species, depending on ecoregion, with habitat under RCP8.5 appearing in Illinois by 2100 (Table 2). Of these, the 'Migrate' variable forms a subset of species that, according to the SHIFT model, provide a better indication of potential natural migration from zones farther south as well as provide a narrowed list of species to be considered as candidates for assisted migration. On average across all ecoregions, a little over half (7.8 out of 14.6) of the species with habitat potentially appearing are 'Migrate Species' (Table 2). Statewide, 19 are considered 'New Habitat' species, and of these, 10 are considered 'Migrate' species (Table 5), taxa that have the best chance of appearing naturally. Included among 'Migrate' species are *Carya aquatica* and *Planera aquatica*, two species that occur in swamps and wet forests in southernmost regions of Illinois but are rare and not captured in FIA samples. 'New Habitat' specie also could be considered for assisted migration, should managers wish to pro-actively establish species; however, the SHIFT model does not project natural migration into at least one of the Illinois ecoregions within 100 years as it does for the 'Migrate' species.

DISCUSSION

Tree Species and Forest Communities

Understanding past changes to vegetation communities provide a historical context for evaluating ongoing changes (Petit *et al.* 2008). In our review, we note vegetation types such as tundra and spruce forest formerly found within what would become the state boundaries that today are located in Canada. Mean increase in global temperatures during the next 100 years are estimated to range from 2-5^{o} C (O'Neill *et al.* 2016). Although the projected changes in Illinois forest composition during the next 100 years don't at first compare to the magnitude of the changes since the late Pleistocene, the influences of the ongoing changing climate do pose major challenges for conservation efforts to sustain *in situ* species assemblages. At currently projected levels of atmospheric emissions, the rate of climate change is expected to exceed the capacity for many species to adapt or migrate, particularly in a highly fragmented landscape (Handler *et al.* 2018). We expect species ranked with poor capability to gradually decline over the next 100 years, both by mortality of mature individuals and declining recruitment.

Increasing species richness from north to south for a wide variety of species groups is one of the most fundamental observed geographically based biotic trends (Fischer 1960; Schemske *et al.* 2009) and the pattern holds true for tree species along the nearly 650-km latitudinal gradient in Illinois (Taft *et al.* 2009; USDA 2019a). This pattern could magnify with the changing climate if northern species (e.g., *Populus tremuloides*, *Betula papyrifera*), occurring in Illinois near their southern range extent in the Midwest, decline disproportionately to southern species. Warming over the past century (Wuebbles *et al.* 2021) may have already contributed to declining populations for many northern species and many tree species demonstrate marked differences in projected future capabilities corresponding to the north-to-south latitudinal gradient.

To discuss changes in species composition that we can expect in the major forest and woodland types in Illinois, we use the IDNR (2010) natural community classification, a modification of White and Madany (1978), as a framework. There are major differences in capacity to cope with the expected new climate, at least regionally, among some of the more dominant and characteristic tree species in natural communities across the moisture gradient, from dry woodland to wet floodplain forest and swamp.

<u>Dry to Dry-Mesic Woodland and Related Communities</u> - Tree species response models to

climate change suggest that many dominant species in oak-hickory stands, the predominant cover type in Illinois, will have fair-to-good capabilities (e.g., *Quercus stellata*, *Q*. *marilandica*, *Q*. *falcata*, *Q*. *rubra*, *Carya texana*, *C*. *alba*, and *Ulmus alata*). Notable exceptions include *C*. *glabra* (including *C. ovalis* in FIA nomenclature) and *Q. muhlenbergii*, two species scoring with poor capabilities. *Carya ovata*, a characteristic co-dominant species of many upland stands, has only poor-to-fair capability. *Quercus alba* and *Q*. *velutina*, two of the more dominant species of upland wooded communities statewide, score with fair to just below fair capability, respectively. *Quercus macrocarpa*, a species found in a wide range of wooded community types, including savanna, has projected capability ranging from very poor in the far south to fair, only scoring good in northwestern Illinois. Trends among these latter three seminal species will depend on factors related to regeneration and recruitment dynamics. For example, some shade-tolerant and moisture-loving species (e.g., *Acer saccharum*), symptomatic of mesophication when established in understories of oak-dominated stands (Nowacki and Abrams 2008) and with the capacity to out-compete oaks particularly without burning, also are projected to have fair-to-good capabilities. Thus, outcomes for *Q*. *alba*, *Q*. *velutina*, and *Q*. *macrocarpa*, particularly, will hinge in part on how woodlands are managed. In addition to prescribed fire, silvicultural practices can be adapted that are designed to promote key species in the face of climate change (Nagel *et al.* 2017).

Quercus stellata, a characteristic species in upland woodland communities throughout the southern half of the state, is particularly dominant in barrens (Heikens and Robertson 1994) and southern flatwoods (Taft *et al.* 1995) and ranks among the three species with the highest capability to endure climate change. One of the others, *Ulmus alata*, a common associate of *Q*. *stellata*, can form thickets in dry and xeric woodlands and barrens in the southern quarter of

Illinois. Both species are projected to find new habitat, based on wide tolerances of climatic and edaphic conditions, in ecoregions north of current ranges and when abundant, both species can contribute to competition and shading of ground-layer species, resulting in species attrition (Taft 2009). Tree density of both *Q. stellata* and *U. alata* can be controlled with burning, but the practice of using prescribed fire needs to be maintained. Fire-return intervals greater than a few years can lead to further thicketization (Taft 2020).

Mesic Upland Forests - Characteristic species of mesic upland stands include a particularly wide range of projected responses to climate change. For example, *Acer saccharum*, *Quercus rubra*, and *Carya cordiformis* have fair to very good capabilities; *Fagus grandiflora* and *Carpinus caroliniana* have capabilities ranging from very poor (northern regions) to good (southern regions). In sharp contrast to *A. saccharum*, *Q. rubra*, and *C. cordiformis*, the characteristic species *Tilia americana*, *Aesculus glabra*, and *Asimina triloba* have very poor capabilities, among the lowest among species examined.

Sand Communities - Sand forest, woodland, and savanna are characterized statewide by dominance of *Quercus velutina* (Marcum *et al.* 2013). However, several other oaks with variable projected capacities to endure the expected climate changes, also can be found in wooded sand communities. These include, from across the dry-to-wet moisture gradient, *Quercus marilandica*, *Q. alba*, *Q. rubra*, *Q. ellipsoidalis*, and *Q. palustris*. *Quercus velutina* scored at the *MeanCap* median, between poor and fair capacity; the other upland species fare better with *Q. marilandica* ranked with good capacity. However, *Q. ellipsoidalis* and *Q. palustris*, characteristic of sand flatwoods in northeastern Illinois (Marcum *et al.* 2021), rank among the species with poorest capacity to endure expected climate changes within the state boundaries.

Floodplain Forests - The wide range of characteristic species of mesic to wet floodplain forest habitats include, due to expected highly fluctuating moisture regimes, about as many fair-to-very good capabilities as there are those scoring with very poor to poor capabilities. As such, we can expect notable shifts in species' suitable habitats, with trends towards more *Gleditsia triacanthos*, *Acer saccharinum*, *Liquidambar styraciflua*, *Celtis occidentalis*, *C. laevigata*, and *Ulmus americana*. On the other hand, less *Quercus palustris, Q. bicolor, Tilia americana*, *Asimina triloba*, *Carya laciniosa*, *Betula nigra*, and *Salix nigra* may be expected. *Liquidambar styraciflua* ranks as one of the species with the highest capability with a projection for new habitat in currently unoccupied northern ecoregions. *Fraxinus pennsylvanica* is projected to have fair capability but likely will continue to be impacted negatively by emerald ash borer.

Forested Swamp - Due to their relative scarcity, *Nyssa aquatica* and *Taxodium distichum* are projected to have very poor to poor capabilities. Some bottomland oaks associated with swamps, such as *Quercus michauxii*, *Q. lyrata*, and *Q. shumardii*, range in capability from poor, to fair, and good, respectively.

Response of Other Forest Species

Populations of understory and ground-layer plants in forests are greatly influenced by light and moisture availability and likely also will be affected by climate change. Although risk and likelihood of wildland fire in the western United States is increasing due to climate change, it is unclear whether we can expect more unplanned wildfires in Illinois in coming years. Of midwestern states, Illinois has the fewest wildfires and least annual average area burned by wildfires (Midwestern Regional Climate Center 2021), most likely due to the highly fragmented nature of the landscape and the overall low percentage of forest. Species adapted to abundant sunlight may benefit if fires increase in frequency and create a more open forest structure, but they would likely decline in the absence of fire and increased shading by the overstory. If sunlight is not limiting, warm-season plants that thrive during the summer may have advantage over cool-season species, since climate change is projected to increase average temperatures; these include the grasses of savanna and open woodland habitats, which also occur in prairies. However, warm-season grasses with the C_4 photosynthetic pathway, adapted to fix carbon at lower CO_2 levels than C_3 plants, may not be advantaged relative to C_3 plants under elevated CO_2 levels (Wang and Greenberg 2007); consequently, the outcome is complex and unclear.

Many rare plant species in Illinois are found in the northern ecoregions and occur in Illinois at the southernmost extent of their midwestern ranges (e.g., *Taxus canadensis*, *Betula alleghaniensis*, *Cornus canadensis*, various orchids, ferns and fern allies). These species typically have persisted in specialized habitats such as forest seeps, cooler north-facing forested slopes, peatlands, and canyon walls. Because many of these species are likely boreal relicts from a former time, they are likely to be at risk from a warmer climate and the likelihood of increasingly severe summer droughts (Wuebbles *et al.* 2021). Certain invasive, non-native species such as *Lonicera maackii*, *Celastrus orbiculatus*, and *Microstegium vimineum* could also become more problematic in remaining forests or future restorations because they are likely to benefit from longer growing seasons and milder winters.

Wildlife species are generally more mobile than plants and may be able to migrate in response to climate change. However, the ability of wildlife to migrate may be limited by the highly fragmented landscape in Illinois and a lack of adequate natural corridors to facilitate movement. There is also a risk of disrupted species interactions, particularly between pollinator and host-plant species.

Restoration and Preserve Design

On a per-area basis, forests have been reported to rank highest among all ecosystems in the Midwest for potential for carbon sequestration and help mitigate the effects of increasing CO_2 (Fargione *et al.* 2018). With forest cover currently only at 32% of the baseline at the time of Euro-American settlement, there are opportunities to plan reforestations to consolidate forest and woodland fragments. Reducing isolation of habitat fragments will allow for greater migration corridors for a wide range of plant and wildlife species. Forming large, consolidated conservation areas enhances conserving biodiversity by including greater levels of habitat heterogeneity within the established boundaries.

Assisted migration, or the introduction of a species outside its native range (McLachland *et al.* 2007), has been suggested for selected species of conservation concern (Barlow 2011) as a hedge against extinction resulting from climate change (Schwartz *et al.* 2012), but also to enhance survival of tree species not necessarily at risk of extinction (Pedlar *et al.* 2012; Iverson and McKenzie 2013; Williams and Dumroesse 2013; Handler *et al.* 2018). Experimental plantings under controlled conditions could be considered to test performance of tree species identified as candidates for migration (Table 5) to more northern locations (Iverson *et al.* 2019b). This effort is currently underway with multiple Adaptive Silviculture for Climate Change sites across the United States (Nagel *et al.* 2017; ASCC 2021) and other demonstrations assisted by the Northern Institute of Applied Climate Science (NIACS 2021). The topic is complex with many unknowns (Park and Talbot 2018) but unless CO_2 levels can be reduced well below RCP 8.5 projections, assisted migration may become increasingly necessary to allow species to keep pace with alterations and northward movement of optimal climatic conditions for many characteristic species of Illinois wooded habitats.

CONCLUSIONS

Efforts to maintain Illinois forests in the face of climate change are important because these ecosystems provide critical habitat to native flora and fauna, as well as numerous other benefits like clean air and water, and recreational opportunities. Conserving and restoring forests in the state also has the potential to contribute to both sequestering carbon emissions and building more resilience to climate change. Support for the formation of large forest conservation areas and corridors through both private and public consortia will be needed to maintain and enhance forest health and biodiversity in the state.

In this modeling study, we have attempted to provide insights into the potential modifications in forest communities in the coming decades under the changing climate. We first must emphasize that 'All models are wrong, some are useful' (Box and Draper 1987); our intention is to provide useful summaries of current tree species status and potential changes under climate change for nine Illinois ecoregions. As such, they are for adding to the toolbox managers may use in decisions related to regional forest management. For local managers, perhaps they can be of use to narrow the decision space in light of myriad options; but certainly, local knowledge of habitats and species requirements are necessary for any on-ground actions. We encourage testing and modification of these modeling results in hopes that with time, the best adaptation practices can be achieved for the forests of Illinois.

Effectively addressing the impacts of climate change on forests in Illinois will also require coordinated management, restoration, and protection plans informed by habitat monitoring. Many specific management practices can be included within these plans to foster habitat integrity and the maintenance of characteristic forest types in Illinois. Managers also need to be amenable to possible adjustments to management practices considering the cascading impacts from a changing climate. For example, the use of prescribed fire will be necessary to facilitate and promote the maintenance of oak-dominated habitats and the associated highly diverse ground-layer species. Yet, prescribed fire may be more difficult to achieve over large areas in the future because of increasing fragmentation of Illinois forests (Crocker *et al.* 2015) and the increasing variability of climate, possibly narrowing windows for implementation. Innovative harvesting techniques may also be needed to achieve goals of maintaining oak-hickory predominance in upland stands (e.g., Iverson *et al.* 2017). The silvicultural techniques continually need to be evaluated considering ongoing climate change (e.g., Iverson *et al.* 2019c) and increasing pressure from invasive species (Dukes *et al.* 2009). For example, *Ailanthus altissima* spread can be facilitated by certain silvicultural actions (Rebbeck *et al.* 2017) and we expect this to be true for other invasive non-native species such as *Morus alba*. Vigilant invasive species control is required to maintain ecosystem integrity in most forest stands. In certain cases, especially where habitat fragmentation is particularly pronounced, assisted migration may be needed to establish species whose suitable habitat is shifting into more northern areas.

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Figure captions

Figure 1. Illinois ecoregions used in this analysis.

Figure 2. Prairie and forest land cover in Illinois during the early 1800s. From Szafoni *et al.* (2002).

Figure 3. Trends for total forest area in Illinois from Government Land Office (GLO) surveys from about 1820 through current (2019) based on Forest Inventory and Analysis (FIA) data (USDA2019).

Figure 4. Percent of Illinois forest by ownership type. Minor ownership types (< 1%) include U.S. Fish & Wildlife, Department of Defense, and other federal. From unpublished 2019 Forest Inventory and Analysis data (USDA2019).

Figure 5. Trends in forest area in Illinois by type since 1962. From Taft *et al.* (2009) and unpublished 2019 Forest Inventory and Analysis data (USDA 2019).

Figure 6. Percent area of Illinois forest land by type. From unpublished 2019 Forest Inventory and Analysis data (USDA 2019).

Figure 7. Distribution of forest type in Illinois by age class. Unpublished 2019 Forest Inventory and Analysis data (USDA 2019). O = other, MB = maple-beech, EAC = elm, ash, cottonwood, OO = oak and other, OH = oak hickory.

Figure 8. Ecoregions used in this analysis (see Figure 1) as buffered for sufficient FIA plots for statistical treatment. Buffered ecoregions overlap each other and even extend beyond the Illinois boundary to achieve a minimum of 8000 km^2 area.

Table 1. The nine primary ecoregions from Illinois, used in this analysis. Area is the km2 of area used for analysis; a minimum of 8,000 km^2 was required such that several ecoregions were buffered until that minimum was reached. 231H and 234D were merged for this analysis.

CODE	PROVINCE	SECTION	AREA (acres)	SECTNAME
222H	Midwest Broadleaf Forest	Central Till Plains-Beech-Maple	8,700	IL_222H
222K	Midwest Broadleaf Forest	Southwestern Great Lakes Morainal	22,721	IL_222K
222L	Midwest Broadleaf Forest	North Central U.S. Driftless and Escarpment	8,300	IL_222L
223A	Central Interior Broadleaf Forest	Ozark Highlands	8,500	IL_223A
223D	Central Interior Broadleaf Forest	Interior Low Plateau-Shawnee Hills	10,900	IL_223D
223G	Central Interior Broadleaf Forest	Central Till Plains-Oak Hickory	43,800	IL_223G
231H	Southeastern Mixed Forest	Coastal Plains-Loess	8,700	IL_231H/234D
234D	Lower Mississippi Riverine Forest	White and Black River Alluvial Plains	8,700	IL_231H/234D
251C	Prairie Parkland (Temperate)	Central Dissected Till Plains	47,900	IL_251C
251D	Prairie Parkland (Temperate)	Central Till Plains and Grand Prairies	69,500	IL_251D

Table 2. Summary of species numbers and capability classes by Illinois ecoregion. Also shown is the land cover percentages and number of FIA plots by ecoregion. FIA = Forest Inventory and Analysis, Cap. = capability, NNIS = non-native invasive species, NLCD =

Ecoregion Name / Ecoregion Code	North Central U.S. Driftless and Escarpment 222L	South-western Great Lakes Morainal 222K	Central Till Plains and Grand Prairies 251D	Central Dissected Till Plains 251C	Central Till Plains-Beech-Maple 222H	Central Till Plains-Oak Hickory 223G	Ozark High-lands 223A	Interior Low Plateau-Shawnee Hills 223D	White and Black River Alluvial Plains/Coastal Plains-Loess 231H/234D	Total/ Average
Number of Species										
Total evaluated	53	66	79	80	62	89	82	87	95	77.0
Total present FIA plots	34	47	63	64	46	68	66	73	70	59.0
Total FIAsum	2124	620	553	2011	1319	2229	4381	5407	5069	2634.8
Species w/ FIAsum>10	24	17	20	32	28	39	50	51	59	35.6
Cap. 8.5 Very Good	4	0	0	3	0	1	7	15	14	4.9
Cap. 8.5 Good	11	13	10	16	14	23	22	19	17	16.1
Cap. 8.5 Fair	5	6	15	11	9	11	18	18	13	11.8
Cap. 8.5 Poor	5	10	19	12	10	15	9	4	12	10.7
Cap. 8.5 Very Poor	6	10	14	15	11	12	7	12	10	10.8
New Habitat	16	16	13	15	13	14	12	11	21	14.6
NNIS	2	5	2	2	1	3	2	3	3	2.6
FIA only	1	3	3	5	0	3	1	2	1	2.1
Migrate	12	11	6	10	8	5	5	3	10	7.8

Infill	21	15	32	34	14	40	38	46	17	28.6
Likely	3	2	2	0	2	2	0	1	1	1.4
unknown status	3	3	3	1	3	7	4	3	4	3.4
Land Cover 2016										
% NLCD Forest	30.0	10.6	6.1	23.2	23.3	22.5	35.7	61.0	35.6	27.6
%NLCD Agriculture	61.4	51.0	84.2	65.8	63.7	67.3	43.0	30.8	52.2	57.7
%NLCD Developed	5.5	35.0	8.5	6.8	10.9	7.7	13.5	5.1	5.9	11.0
FIA plot #/ecoregion	15	71	119	258	8	298	78	155	32	1025
FIA plot #/buffers	79	109	213	352	56	422	147	276	171	1861

Table 3. Tree species in Illinois scoring with good to very good capability to cope with ongoing and expected climate change under high (RCP 8.5) emissions. *Total FIAsum* is the sum of species importance across all ecoregions and is a measure of statewide importance based on FIA sample data, *MeanCap* = average capability among ecoregions where a species is present, * = non-native species.

Scientific_Name	**Common_Name**	***Total FIAsum***	*MeanCap*
Liquidambar styraciflua	sweetgum	590.6	4.5
Quercus stellata	post oak	493.5	4.5
Ulmus alata	winged elm	400.9	4.5
Quercus pagoda	cherrybark oak	150.7	4.4
Carya cordiformis	bitternut hickory	375.4	4.3
Celtis occidentalis	hackberry	758.6	4.3
Juniperus virginiana	eastern redcedar	562.3	4.3
Gleditsia triacanthos	honey locust	380.3	4.1
Acer saccharinum	silver maple	834.5	4.0
Carya texana	black hickory	97.7	4.0
Celtis laevigata	sugarberry	91.9	4.0
Diospyros virginiana	common persimmon	119.1	4.0
*Maclura pomifera**	Osage-orange*	158.4	4.0
Nyssa sylvatica	blackgum	179.8	4.0
*Pinus taeda**	loblolly pine*	77.8	4.0
Quercus falcata	southern red oak	113.1	4.0
Quercus marilandica	blackjack oak	27.2	4.0
Quercus phellos	willow oak	0.3	4.0
Quercus shumardii	Shumard oak	23.1	4.0
Quercus texana	Nuttall oak	0.5	4.0

Table 4. Tree species in Illinois scoring with poor or very poor capability to cope with ongoing and expected climate change under high (RCP 8.5) emissions. *Total FIAsum* is the sum of species importance across all ecoregions and is a measure of statewide importance based on FIA sample data, *MeanCap* = average capability among ecoregions where a species is present, * = non-native species.

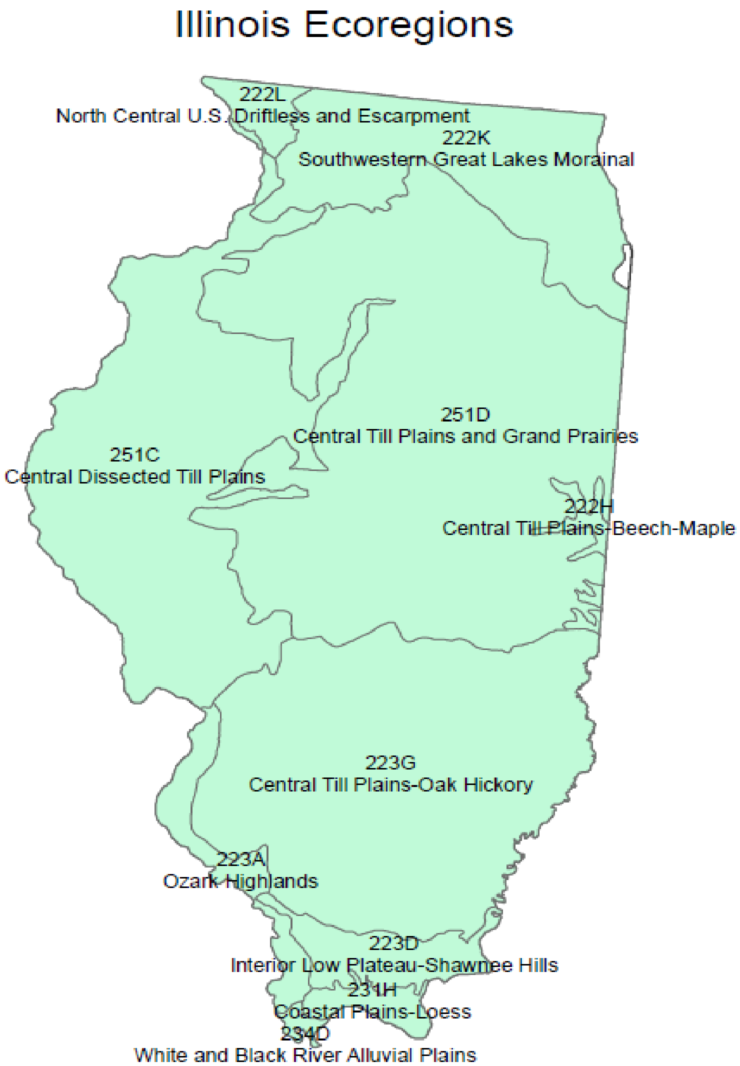
Scientific_Name	**Common_Name**	***Total FIAsum***	***MeanCap***
Acer nigrum	black maple	46.0	2.0
Pinus banksiana	jack pine	3.1	2.0
*Pinus virginiana**	Virginia pine*	17.6	2.0
Quercus ellipsoidalis	northern pin oak	11.0	2.0
Quercus imbricaria	shingle oak	351.4	2.0
Quercus michauxii	swamp chestnut oak	12.2	2.0
Taxodium distichum	bald cypress	63.7	2.0
Carya glabra	pignut hickory	982.9	1.9
Quercus muehlenbergii	chinkapin oak	112.2	1.9
Betula nigra	river birch	65.2	1.7
Salix nigra	black willow	537.8	1.7
Quercus bicolor	swamp white oak	43.1	1.6
Quercus coccinea	scarlet oak	53.4	1.5
Quercus palustris	pin oak	237.8	1.4
Amelanchier spp.	serviceberry	14.4	1.1
Tilia americana	American basswood	291.3	1.1
Aesculus glabra	Ohio buckeye	45.6	1.0
Asimina triloba	pawpaw	38.3	1.0
Betula papyrifera	paper birch	3.3	1.0
Fraxinus nigra	black ash	10.7	1.0
Fraxinus quadrangulata	blue ash	0.7	1.0
Magnolia acuminata	cucumbertree	12.4	1.0
Nyssa aquatica	water tupelo	26.2	1.0

*Picea glauca**	white spruce*	0.5	1.0
Pinus resinosa	red pine	17.9	1.0
Pinus strobus	eastern white pine	95.7	1.0
Populus balsamifera	balsam poplar	0.5	1.0
Populus grandidentata	bigtooth aspen	15.6	1.0
Populus tremuloides	quaking aspen	35.4	1.0

Table 5. New Habitat species, species with habitat conditions potentially entering the state during the next 100 years under RCP8.5, and Migrate species, species with potential to naturally migrate into the state in that time frame. Migrate species differentiated by: RCP8.5 - potential to migrate only under the higher emissions scenario; Either - potential to migrate under low or higher emission scenario; Native – species rare in Illinois and missed by FIA plots; Poss. native - species possibly in Illinois but missed by FIA plots.

Scientific_Name	**Common_Name**	**New Habitat**	**Migrate**
Acer barbatum	Florida maple	x	Either
Acer pensylvanicum	striped maple	x	
Carya aquatica	water hickory	x	Native
Ilex opaca	American holly	x	RCP8.5
Juniperus ashei	ashe juniper	x	
Magnolia grandiflora	southern magnolia	x	
Magnolia virginiana	sweetbay	x	RCP8.5
Nyssa biflora	swamp tupelo	x	Poss. native
Oxydendrum arboreum	sourwood	x	
Persea borbonia	redbay	x	
Pinus elliottii	slash pine	x	
Pinus palustris	longleaf pine	x	
Planera aquatica	water elm	x	Native
Prunus pensylvanica	pin cherry	x	
Quercus laurifolia	laurel oak	x	Either

Quercus nigra	water oak	x	Either
Quercus virginiana	live oak	x	
Sideroxylon lanuginosum	cittamwood/gum bumelia	x	Either
Ulmus crassifolia	cedar elm	x	RCP8.5


Illinois Ecoregions
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North Central U.S. Driftless and Escarpment
222K
Southwestern Great Lakes Morainal
251D
Central Till Plains and Grand Prairies
251C
Central Dissected Till Plains
222H
Central Till Plains-Beech-Maple
223G
Central Till Plains-Oak Hickory
223A
Ozark Highlands
223D
Interior Low Plateau-Shawnee Hills
231H
Coastal Plains-Loess
234D
White and Black River Alluvial Plains

Figure 1

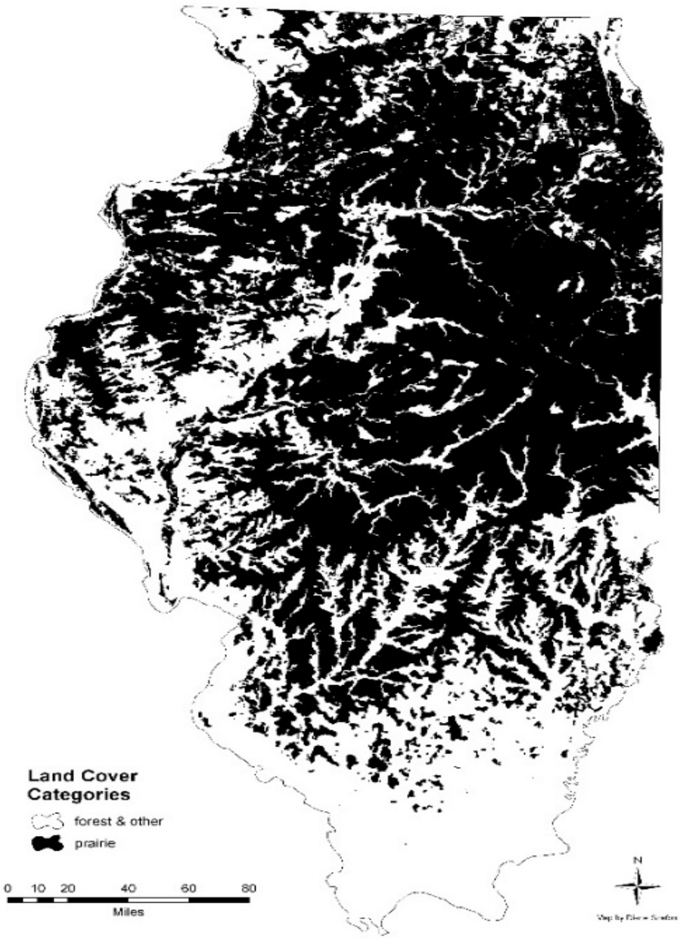

Land Cover
Categories
forest & other
prairie
0 10 20 40 60 80
Miles
N

Figure 2

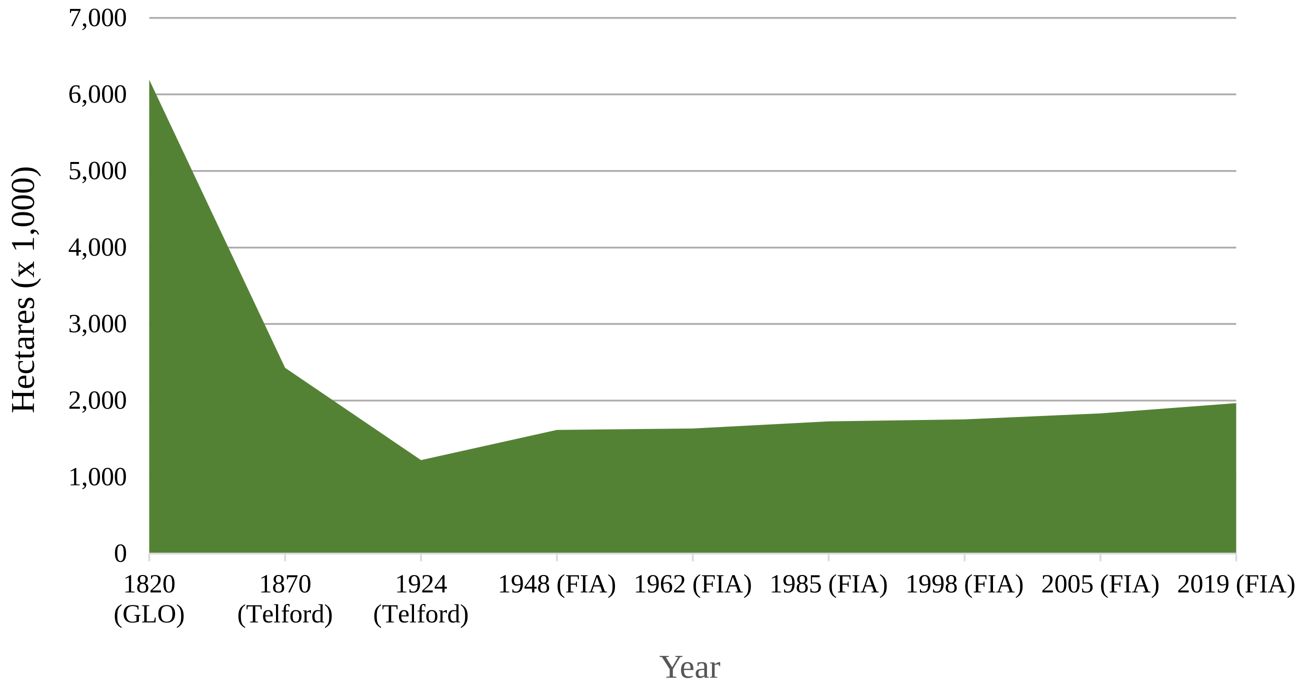

7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Hectares (x 1,000)
1820 (GLO)
1870 (Telford)
1924 (Telford)
1948 (FIA)
1962 (FIA)
1985 (FIA)
1998 (FIA)
2005 (FIA)
2019 (FIA)
Year

Figure 3

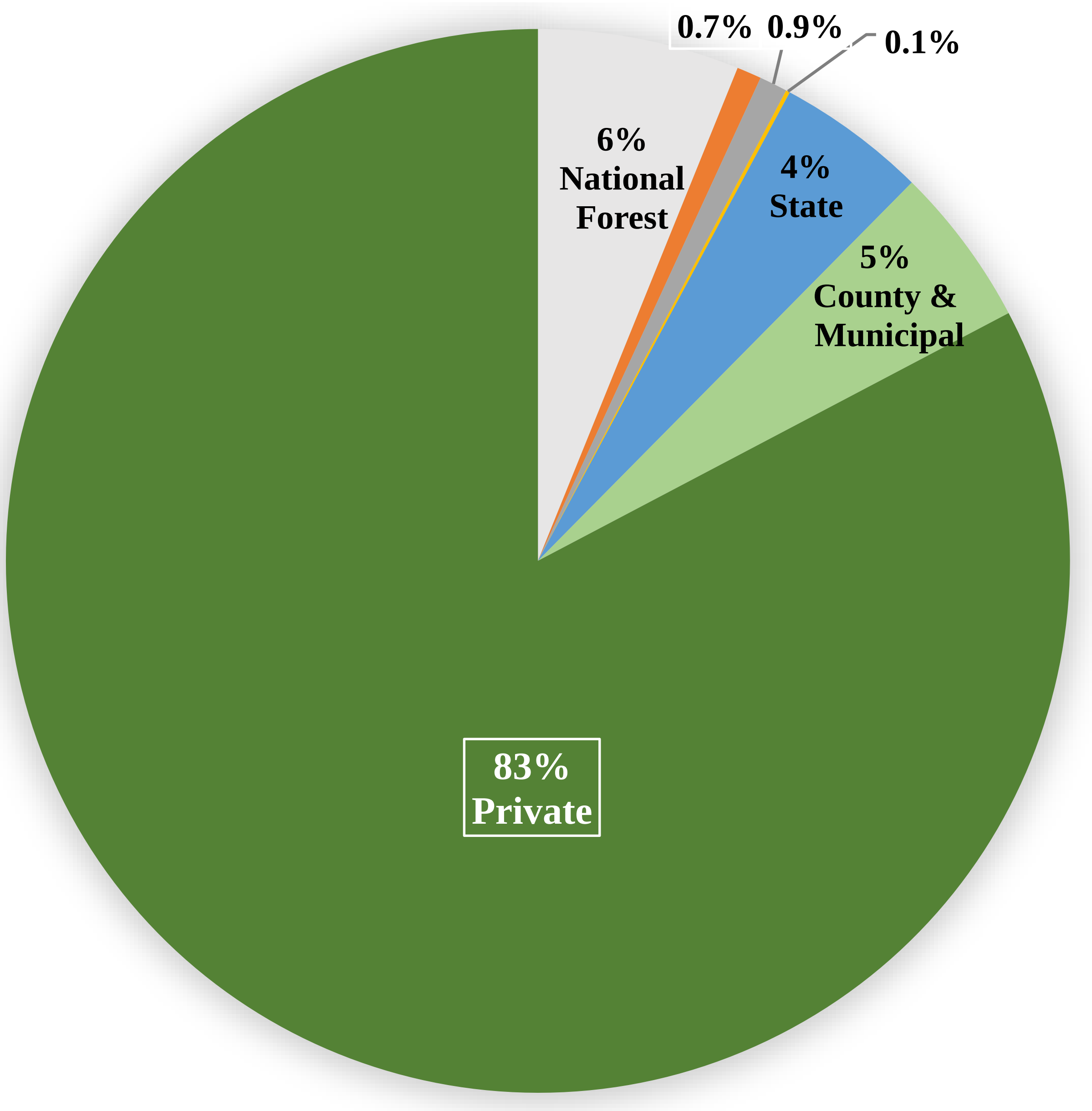
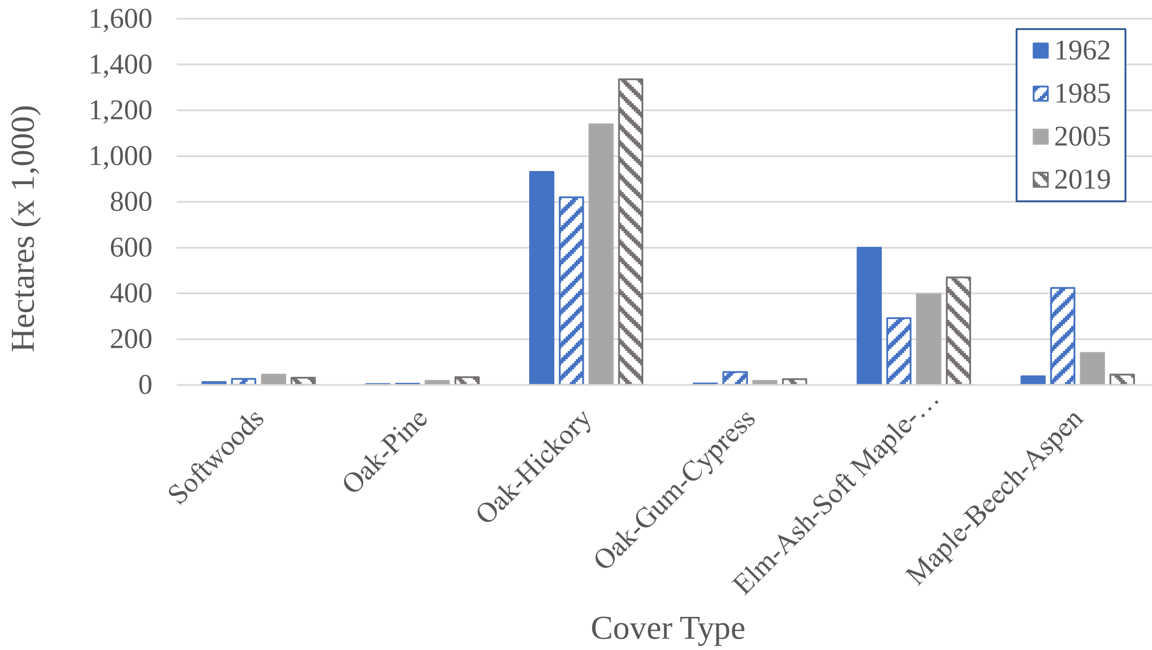

0.7%
0.9%
0.1%
6%
National
Forest
4%
State
5%
County &
Municipal
83%
Private

Figure 4



1,600
1,400
1,200
1,000
800
600
400
200
0
Hectares (x 1,000)
1962
1985
2005
2019
Softwoods
Oak-Pine
Oak-Hickory
Oak-Gum-Cypress
Elm-Ash-Soft Maple-…
Maple-Beech-Aspen
Cover Type

Figure 5

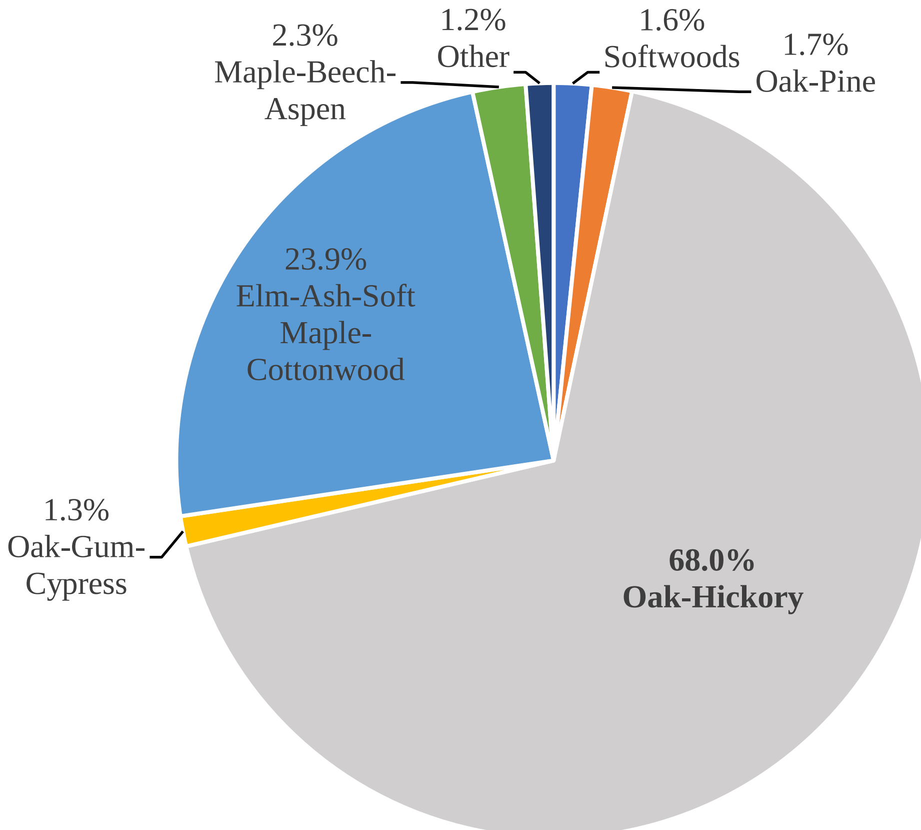

2.3%
Maple-Beech-
Aspen
1.2%
Other
1.6%
Softwoods
1.7%
Oak-Pine
23.9%
Elm-Ash-Soft
Maple-
Cottonwood
1.3%
Oak-Gum-
Cypress
68.0%
Oak-Hickory

Figure 6

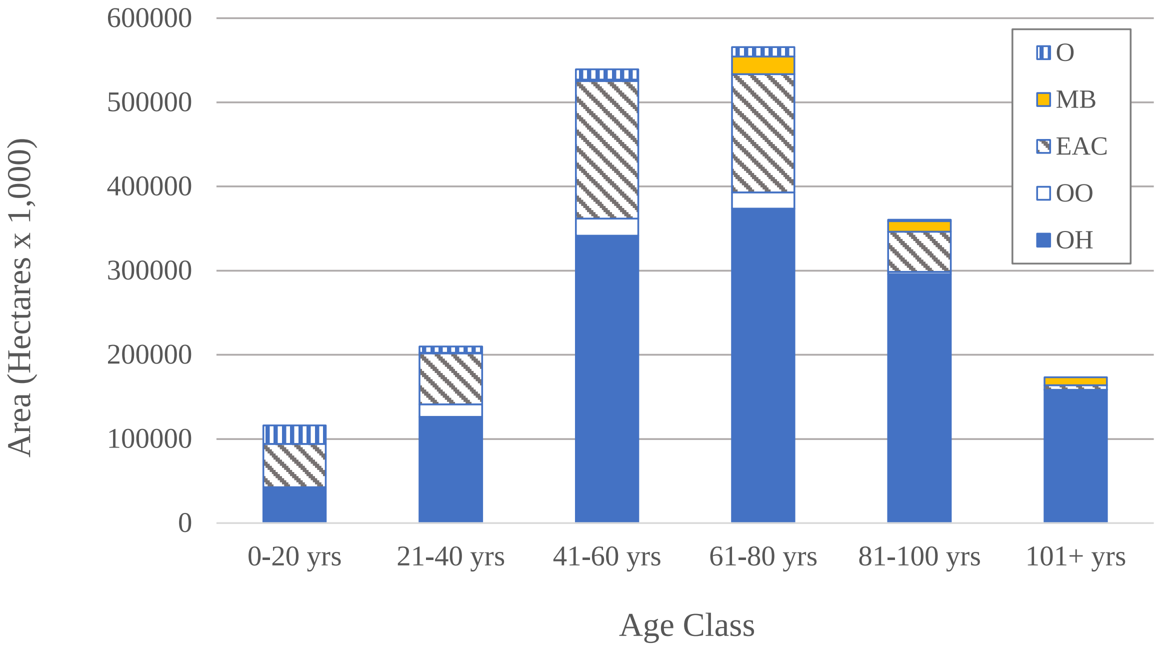

600000
500000
400000
300000
200000
100000
0
Area (Hectares x 1,000)
O
MB
EAC
OO
OH
0-20 yrs
21-40 yrs
41-60 yrs
61-80 yrs
81-100 yrs
101+ yrs
Age Class

Figure 7

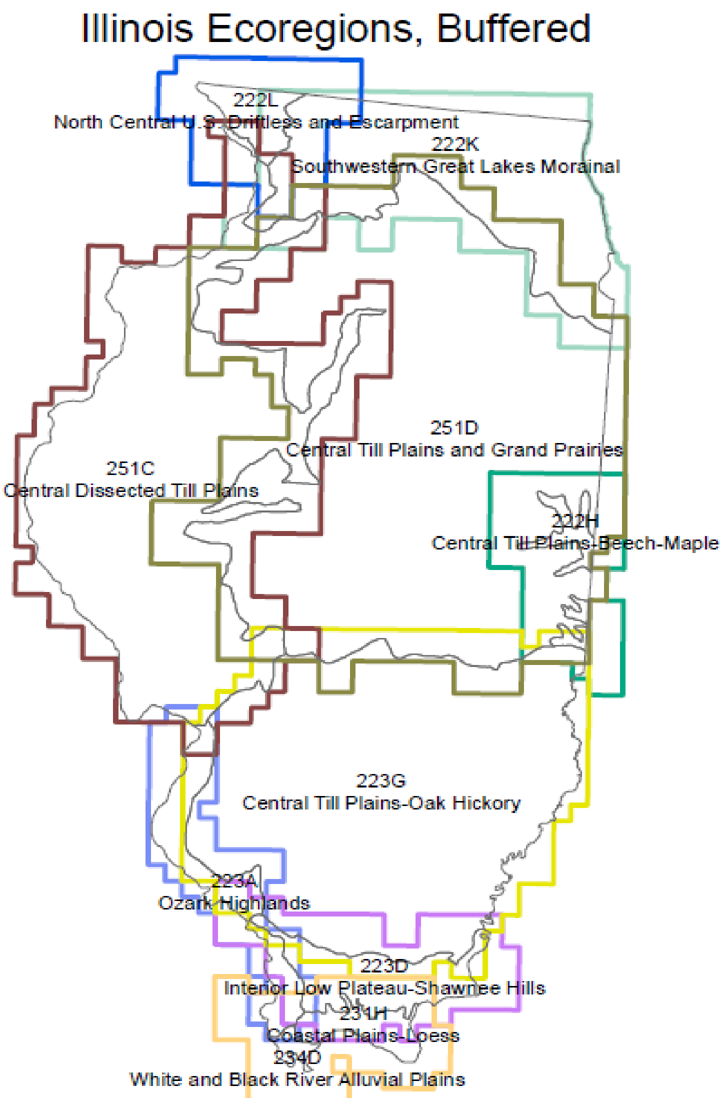

Illinois Ecoregions, Buffered
222L
North Central U.S. Driftless and Escarpment
222K
Southwestern Great Lakes Morainal
251D
Central Till Plains and Grand Prairies
251C
Central Dissected Till Plains
222H
Central Till Plains-Beech-Maple
223G
Central Till Plains-Oak Hickory
223A
Ozark Highlands
223D
Interior Low Plateau-Shawnee Hills
231H
Coastal Plains-Loess
234D
White and Black River Alluvial Plains

Figure 8

Appendix 1. Tree species from Forest Inventory and Analysis sample data (USDA 2019) shown in descending rank order of species importance (*Tle FIAsum*). Species importance values (*FIAsum*) based on abundance and areal coverage and capability (*Cap*) to cope or persist under climate change by 2100 according to higher emission models. Capability ratings are scored as VG = very good, G = good, F = fair, P = poor, VP = very poor; NH = New Habitat species with habitat by 2100; FIA = only current estimate made as insufficient data exist for modeling into the future; NNIS = non-native invasive species; Unk = unknown status. The NH species coded as: NH* = Migrate pecies with some likelihood of migration into the ecoregion within 100 years under either climate scenario, NH+ = species with potential to migrate under only the higher scenario, and NH# = species likely present but not detected in inventory plots. Ecoregion map# refer to Figures 1 and 8.

	Ecoregion	North Central U.S. Driftless and Escarpment		Southwestern Great Lakes Morainal		Central Till Plains and Grand Prairies		Central Dissected Till Plains		Central Till Plains-Beech-Maple		Central Till Plains-Oak Hickory		Ozark Highlands		Interior Low Plateau-Shawnee Hills		White and Black River Alluvial Plains/Coastal Plains-Loess			
	Ecoregion map#	**222L**		**222K**		**251D**		**251C**		**222H**		**223G**		**223A**		**223D**		**231H & 234D**			
Scientific_Name	**Common_Name**	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***FIAsum***	***Cap***	***Ttl FIAsum***	***MeanCap***
Quercus alba	white oak	93.6	VG	44.3	P	33.3	P	139.3	F	77.1	F	127.0	F	296.5	F	462.6	F	372.5	G	1636.2	3.1
Acer saccharum	sugar maple	44.8	G	7.1	F	25.5	F	75.9	VG	127.0	F	69.6	VG	229.5	G	399.7	F	252.1	F	1231.1	3.7
Ulmus americana	American elm	254.2	F	31.1	G	33.2	F	205.5	F	31.9	G	122.1	G	190.1	G	167.9	VG	124.1	VG	1160.2	3.9
Liriodendron tulipifera	yellow-poplar	0.0	NH+	0.0	NH	8.6	P	0.0	NH*	123.1	F	40.7	P	211.5	F	358.9	F	293.4	F	1036.1	2.7
Quercus velutina	black oak	47.6	G	19.6	F	18.5	P	114.0	P	32.2	P	70.8	F	215.2	F	265.6	F	217.3	F	1000.8	2.8
Carya glabra	pignut hickory	0.0	NH+	0.0	NH#	1.9	P	23.3	P	18.2	VP	82.6	P	195.1	P	366.9	P	295.0	P	982.9	1.9
Acer negundo	boxelder	175.8	F	87.5	F	12.3	F	27.7	G	17.6	G	90.7	F	203.9	G	119.6	VG	123.1	VG	858.3	3.8
Acer saccharinum	silver maple	23.7	G	9.4	G	29.6	G	131.4	G	45.7	G	98.4	G	120.0	VG	261.8	F	114.5	G	834.5	4.0
Fraxinus pennsylvanica	green ash	21.9	G	24.1	F	16.8	G	41.5	G	13.9	G	101.6	G	153.1	G	220.5	G	189.8	G	783.1	3.9
Prunus serotina	black cherry	153.0	P	87.3	VP	51.8	VP	85.9	P	116.4	VP	74.0	P	50.4	F	67.5	G	88.1	F	774.4	2.1
Celtis occidentalis	hackberry	94.5	VG	10.6	G	26.4	G	79.9	VG	6.7	G	159.8	F	157.0	VG	106.6	VG	117.2	G	758.6	4.3
Juglans nigra	black walnut	240.8	P	35.9	P	35.0	P	75.9	G	54.8	G	66.3	F	70.6	G	64.3	F	60.0	P	703.6	2.9
Quercus rubra	northern red oak	68.1	VG	12.8	G	14.6	P	79.7	F	95.8	F	35.6	P	143.6	F	113.3	G	53.7	VG	617.2	3.4
Liquidambar styraciflua	sweetgum	-	-	0.0	NH	0.1	G	0.0	NH*	0.6	G	16.9	G	114.0	VG	213.8	VG	245.2	VG	590.6	4.5
Sassafras albidum	sassafras	0.0	NH+	0.0	NH#	3.1	P	29.7	P	55.4	P	73.3	P	144.9	P	149.7	F	119.3	F	575.5	2.3
Fraxinus americana	white ash	32.0	F	9.3	F	11.5	P	59.7	F	40.0	P	63.5	F	95.7	F	146.5	F	114.3	F	572.5	2.8
Juniperus virginiana	eastern redcedar	174.0	G	0.8	G	4.0	G	28.4	G	9.0	G	18.9	G	122.6	VG	128.0	VG	76.6	VG	562.3	4.3
Carya ovata	shagbark hickory	72.9	F	20.9	VP	10.1	F	95.2	P	27.5	P	83.9	P	74.3	F	94.1	F	82.9	F	561.7	2.4
Salix nigra	black willow	0.0	NH#	1.2	P	11.1	VP	44.3	VP	0.0	NH#	37.6	VP	164.7	P	48.8	F	230.1	P	537.8	1.7
Quercus stellata	post oak	0.0	NH*	0.0	NH*	1.2	G	11.3	G	0.0	NH*	49.6	G	142.4	VG	162.9	VG	126.2	VG	493.5	4.5
Ulmus rubra	slippery elm	79.0	F	7.0	G	11.1	F	47.1	F	48.6	P	26.4	G	80.2	VG	72.5	VG	60.3	VG	432.1	3.8
Ulmus alata	winged elm	-	-	0.0	NH+	0.0	NH*	0.0	NH*	0.0	NH*	22.7	G	32.3	G	157.0	VG	188.9	VG	400.9	4.5
Gleditsia triacanthos	honeylocust	4.9	G	7.4	G	30.8	F	74.2	VG	53.4	G	71.9	G	36.0	G	52.3	VG	49.4	G	380.3	4.1
Platanus occidentalis	sycamore	0.0	NH*	0.4	G	4.5	P	31.4	P	34.0	F	45.5	F	107.8	G	63.7	VG	88.2	VG	375.5	3.5
Carya cordiformis	bitternut hickory	63.7	VG	4.3	G	9.9	G	52.5	G	29.7	F	40.4	G	54.5	VG	52.9	VG	67.6	VG	375.4	4.3
Pinus echinata	shortleaf pine	-	-	-	-	-	-	-	-	-	-	11.9	P	12.1	F	187.3	G	140.7	G	352.0	3.3
Quercus imbricaria	shingle oak	0.0	NH*	0.0	NH*	12.1	P	86.4	P	41.3	VP	91.2	P	63.4	P	33.9	F	23.2	P	351.4	2.0
Tilia americana	American basswood	190.5	P	19.9	VP	8.0	VP	48.4	VP	15.3	VP	2.7	VP	3.2	VP	0.6	VP	2.8	VP	291.3	1.1
Populus deltoides	eastern cottonwood	3.5	G	14.5	G	16.8	F	38.9	F	7.8	G	59.9	P	42.7	F	45.4	VP	60.7	P	290.1	2.9
Acer rubrum	red maple	0.0	NH*	3.1	P	1.8	F	0.1	G	11.2	F	66.1	G	33.3	G	74.1	VG	82.7	VG	272.2	3.8
Robinia pseudoacacia#	black locust#	4.2	G	14.4	P	8.3	P	31.5	F	1.7	G	28.4	P	108.6	F	22.9	G	49.1	F	269.0	3.0
Quercus palustris	pin oak	-	-	0.1	F	2.3	VP	10.1	VP	4.7	VP	43.4	VP	58.1	P	54.5	VP	64.6	VP	237.8	1.4
Carya alba	mockernut hickory	0.0	NH*	0.0	NH+	5.0	F	17.6	G	24.2	P	32.1	G	42.1	G	67.8	VG	43.8	G	232.6	3.7
Quercus macrocarpa	bur oak	124.8	G	43.6	P	21.4	F	10.0	F	13.8	F	12.5	P	1.0	VP	1.1	VP	-	-	228.2	2.4
Ostrya virginiana	eastern hophornbeam; irc	19.6	G	2.3	G	5.2	F	33.9	P	28.3	P	10.3	F	41.9	G	36.1	G	43.5	G	221.0	3.3
Morus rubra	red mulberry	27.0	P	1.5	G	8.9	F	34.8	F	8.8	P	17.8	VP	66.2	P	13.7	G	39.7	P	218.3	2.6
Nyssa sylvatica	blackgum	-	-	-	-	0.1	F	0.0	NH+	0.9	F	6.7	G	26.1	G	70.5	VG	75.6	VG	179.8	4.0
*Maclura pomifera^*	Osage-orange^	0.0	NH*	1.5	G	23.1	G	46.4	G	38.9	G	36.9	G	11.2	G	0.5	G	0.0	NH+	158.4	4.0
Quercus pagoda	cherrybark oak	-	-	-	-	0.0	NH+	1.0	G	0.0	NH	3.5	G	10.4	G	57.2	VG	78.5	VG	150.7	4.4
Fagus grandifolia	American beech	-	-	-	-	0.2	VP	0.0	NH*	4.1	VP	2.3	F	64.0	F	41.3	G	33.7	G	145.6	2.7
Diospyros virginiana	common persimmon	0.0	NH+	0.0	NH+	0.0	NH#	3.1	G	7.2	G	20.1	G	21.0	G	28.7	G	39.0	G	119.1	4.0
Quercus falcata	southern red oak	-	-	-	-	0.0	NH+	3.3	F	0.0	NH+	3.8	G	9.5	G	16.1	G	80.4	VG	113.1	4.0
Quercus muehlenbergii	chinkapin oak	0.0	NH#	0.0	NH*	2.6	P	5.2	P	18.3	VP	6.3	VP	25.5	F	24.7	F	29.8	VP	112.2	1.9
Cornus florida	flowering dogwood	0.0	NH#	0.0	Unk	0.2	VP	5.0	P	3.6	VP	6.2	P	27.6	F	39.5	F	27.5	F	109.6	2.1
Carya texana	black hickory	0.0	NH+	0.0	NH+	0.3	G	1.3	G	0.0	NH+	3.7	G	39.8	G	28.6	G	23.9	G	97.7	4.0
Pinus strobus#	eastern white pine#	10.4	VP	31.9	VP	6.7	VP	7.3	VP	-	-	0.8	VP	-	-	19.1	VP	19.7	VP	95.7	1.0
Celtis laevigata	sugarberry	0.0	NH	0.0	NH	0.0	G	7.6	G	0.0	NH+	1.3	G	52.5	G	5.2	G	25.3	G	91.9	4.0
Carya illinoinensis	pecan	-	-	0.0	NH*	0.1	F	2.5	F	0.0	NH#	5.0	F	39.5	F	19.7	F	21.1	F	87.9	3.0
Cercis canadensis	eastern redbud	0.0	NH*	0.0	NH*	0.6	F	10.6	P	0.7	G	17.1	P	27.5	F	14.7	G	12.3	F	83.4	3.0
*Pinus taeda^*	loblolly pine^	-	-	-	-	0.0	NH+	0.0	NH+	0.0	NH+	4.0	G	0.0	NH*	41.0	G	32.9	G	77.8	4.0
Betula nigra	river birch	-	-	-	-	0.5	VP	0.8	VP	1.8	VP	17.6	VP	0.6	F	19.6	F	24.3	P	65.2	1.7
Taxodium distichum	bald cypress	-	-	-	-	-	-	-	-	-	-	-	-	29.1	P	5.4	P	29.3	P	63.7	2.0
*Morus alba**	white mulberry*	25.7	NNIS	4.6	NNIS	4.4	NNIS	9.9	NNIS	-	-	3.6	NNIS	2.0	NNIS	2.1	NNIS	6.2	NNIS	58.6	
Carya laciniosa	shellbark hickory	-	-	-	-	0.3	P	0.8	VP	1.4	P	6.5	F	0.0	NH	8.3	F	38.1	P	55.4	2.2
Quercus coccinea	scarlet oak	-	-	-	-	-	-	-	-	-	-	0.5	P	18.3	P	17.9	VP	16.7	VP	53.4	1.5
Acer nigrum	black maple	27.8	P	7.0	P	1.7	P	7.0	P	-	-	0.0	P	-	-	1.1	P	1.4	P	46.0	2.0

Aesculus glabra	Ohio buckeye	-	-	-	-	1.8	VP	6.5	VP	7.7	VP	2.0	VP	27.4	VP	0.3	VP	0.0	Unk	45.6	1.0
Quercus bicolor	swamp white oak	1.7	G	1.8	P	1.0	P	9.3	VP	-	-	2.6	VP	9.1	VP	4.9	VP	12.7	VP	43.1	1.6
Fraxinus profunda	pumpkin ash	-	-	-	-	-	-	-	-	-	-	-	-	3.2	FIA	17.1	FIA	19.8	FIA	40.1	
Asimina triloba	pawpaw	0.0	Unk	-	-	0.4	VP	1.5	VP	2.6	VP	1.2	VP	8.3	VP	11.5	VP	12.7	VP	38.3	1.0
Populus tremuloides	quaking aspen	28.5	VP	6.8	VP	0.1	VP	-	-	-	-	-	-	-	-	-	-	0.0	Unk	35.4	1.0
Quercus prinus	chestnut oak	-	-	-	-	-	-	-	-	-	-	0.0	NH	10.4	F	8.1	F	10.2	F	28.7	3.0
Quercus marilandica	blackjack oak	-	-	0.0	NH*	0.0	NH+	0.2	G	0.0	NH+	2.5	G	10.9	G	9.9	G	3.7	G	27.2	4.0
Nyssa aquatica	water tupelo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.4	VP	17.8	VP	26.2	1.0
Carpinus caroliniana	American hornbeam	-	-	-	-	0.3	P	1.0	VP	3.3	P	0.0	G	4.1	G	2.4	G	14.8	G	25.8	3.0
Catalpa speciosa	northern catalpa	0.6	FIA	0.2	FIA	1.7	FIA	2.2	FIA	-	-	3.9	FIA	-	-	15.0	FIA	-	-	23.6	
Quercus shumardii	Shumard oak	-	-	0.0	NH+	0.0	NH#	0.5	G	-	-	2.3	G	4.2	G	1.2	G	15.0	G	23.1	4.0
Pinus resinosa#	red pine#	4.5	VP	10.3	VP	1.2	VP	1.7	VP	-	-	0.2	VP	-	-	-	-	-	-	17.9	1.0
*Pinus virginiana^*	Virginia pine^	-	-	-	-	-	-	-	-	-	-	0.0	NH*	-	-	0.0	NH#	17.6	P	17.6	2.0
Populus grandidentata	bigtooth aspen	-	-	-	-	2.0	VP	0.7	VP	12.9	VP	0.0	Unk	-	-	0.0	Unk	-	-	15.6	1.0
Amelanchier spp.	serviceberry	0.0	Unk	0.4	VP	0.0	P	0.3	VP	0.0	Unk	0.3	VP	5.6	VP	2.3	VP	5.5	VP	14.4	1.1
*Pinus sylvestris**	Scotch pine*	-	-	12.3	NNIS	-	-	-	-	-	-	0.6	NNIS	-	-	0.2	NNIS	-	-	13.1	
Quercus lyrata	overcup oak	-	-	-	-	0.0	NH	0.0	NH+	-	-	0.0	NH#	1.8	F	2.2	F	8.8	F	12.8	3.0
Magnolia acuminata	cucumbertree	-	-	0.0	Unk	-	-	-	-	-	-	0.0	Unk	6.1	VP	2.6	VP	3.7	VP	12.4	1.0
*Ulmus pumila**	Siberian elm*	0.3	NNIS	0.3	NNIS	4.5	NNIS	6.6	NNIS	0.6	NNIS	-	-	-	-	-	-	-	-	12.3	
Quercus michauxii	swamp chestnut oak	-	-	-	-	-	-	-	-	-	-	0.0	NH#	1.5	P	1.5	P	9.2	P	12.2	2.0
Quercus ellipsoidalis	northern pin oak	1.6	VP	8.6	P	0.8	P	-	-	-	-	-	-	-	-	-	-	-	-	11.0	2.0
*Ailanthus altissima**	ailanthus*	-	-	-	-	-	-	-	-	-	-	1.0	NNIS	6.1	NNIS	3.2	NNIS	0.6	NNIS	10.8	
Fraxinus nigra	black ash	6.0	VP	3.1	VP	0.0	Unk	1.6	VP	0.0	Unk	-	-	0.0	Unk	-	-	-	-	10.7	1.0
*Picea abies**	Norway spruce*	-	-	8.7	NNIS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.7	
Betula papyrifera	paper birch	3.3	VP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.3	1.0
Pinus banksiana	jack pine	-	-	1.0	P	2.1	P	-	-	-	-	-	-	-	-	-	-	-	-	3.1	2.0
Prunus americana	wild plum	-	-	-	-	1.2	FIA	0.7	FIA	-	-	-	-	-	-	-	-	-	-	1.8	
Gymnocladus dioicus	Kentucky coffeetree	-	-	-	-	0.2	FIA	0.9	FIA	-	-	0.1	FIA	-	-	-	-	-	-	1.2	
Fraxinus quadrangulata	blue ash	-	-	-	-	0.3	VP	0.4	VP	-	-	0.0	Unk	-	-	-	-	-	-	0.7	1.0
*Paulownia tomentosa**	paulownia*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	NNIS	0.6	
Populus balsamifera#	balsam poplar#	-	-	0.5	VP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	1.0
*Picea glauca^*	white spruce^	-	-	0.5	VP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	1.0
Quercus texana	nuttall oak	-	-	-	-	-	-	-	-	-	-	-	-	0.3	G	0.2	G	0.0	NH	0.5	4.0
Juglans cinerea	butternut	-	-	-	-	-	-	0.4	FIA	-	-	0.0	FIA	-	-	-	-	-	-	0.4	
Quercus phellos	willow oak	-	-	-	-	-	-	0.0	NH*	-	-	0.0	NH*	0.0	NH*	0.0	NH*	0.3	G	0.3	4.0
Prunus virginiana	chokecherry	-	-	0.2	FIA	-	-	0.0	FIA	-	-	-	-	-	-	-	-	-	-	0.3	
*Acer platanoides**	Norway maple*	-	-	0.1	NNIS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	
Salix amygdaloides	peachleaf willow	-	-	0.1	FIA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	
Acer barbatum	Florida maple	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH	0.0	NH	0.0	NH*		
*Acer pensylvanicum^*	striped maple^	-	-	-	-	-	-	0.0	NH	-	-	0.0	NH	0.0	NH	0.0	NH	0.0	NH		
Carya aquatica	water hickory	-	-	-	-	-	-	-	-	-	-	0.0	NH+	0.0	NH	-	-	0.0	NH#		
*Ilex opaca^*	American holly^	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH+		
*Juniperus ashei^*	ashe juniper^	-	-	-	-	-	-	0.0	NH	-	-	0.0	NH	0.0	NH	0.0	NH	0.0	NH		
*Magnolia grandiflora^*	southern magnolia^	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH		
*Magnolia virginiana^*	sweetbay^	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH+		
Nyssa biflora	swamp tupelo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH#		
*Oxydendrum arboreum^*	sourwood^	-	-	-	-	-	-	-	-	-	-	0.0	NH	0.0	NH	0.0	NH	0.0	NH		
*Persea borbonia^*	redbay^	-	-	-	-	-	-	-	-	-	-	0.0	Unk	-	-	-	-	0.0	NH		
*Pinus elliottii^*	slash pine^	-	-	-	-	0.0	NH	-	-	-	-	-	-	-	-	-	-	0.0	NH		
*Pinus palustris^*	longleaf pine^	-	-	-	-	0.0	NH	-	-	-	-	-	-	-	-	-	-	0.0	NH		
Planera aquatica	water elm	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH#		
*Prunus pensylvanica^*	pin cherry^	0.0	Unk	-	-	0.0	Unk	0.0	NH	0.0	Unk	0.0	NH	0.0	Unk	0.0	NH	0.0	NH		
*Quercus laurifolia^*	laurel oak^	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	NH*		
*Quercus nigra^*	water oak^	-	-	-	-	0.0	NH	0.0	NH+	0.0	NH	0.0	NH*	0.0	NH*	0.0	NH*	0.0	NH*		
*Quercus virginiana^*	live oak^	-	-	-	-	-	-	0.0	NH	-	-	0.0	NH	0.0	NH	0.0	NH	0.0	NH		
Sideroxylon lanuginosum ^	cittamwood^	-	-	-	-	0.0	NH+	0.0	NH+	0.0	NH+	0.0	NH+	0.0	NH+	0.0	NH+	0.0	NH*		
*Ulmus crassifolia^*	cedar elm^	-	-	-	-	0.0	NH	0.0	NH	0.0	NH	0.0	NH	0.0	NH+	0.0	NH	0.0	NH+		

* species not native to North America

^ species native to North America, absent or adventive in Illinois (currently)

\# = native species but most occurrences outside natural range