CHICAGO CLIMATE ACTION PLAN

CLIMATE CHANGE AND CHICAGO

PROJECTIONS AND POTENTIAL IMPACTS

CHAPTER FIVE – ECOSYSTEMS

11-07-2007

This research was commissioned by the Chicago Climate Task Force in the development of the Chicago Climate Action Plan. It does not represent official City of Chicago policy.

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CHAPTER
Five

ECOSYSTEMS

The greater Chicago area lies within a mid-continental forest-grassland transition zone characterized by rich soils and mosaics of forest, savanna (or woodland), grassland and wetland ecosystems[1]. Although these ecosystem types remain in the region, they have been highly modified during the past two centuries to support mechanized agriculture and to accommodate urban and suburban development. Many plant and animal species characteristic of the region's original ecosystems occur in these modified ecosystems, although often with population sizes differing from pre-development levels. Native or "indigenous" plants occur within forest preserves, parks, public and private natural areas, riverine habitats, roadside rights of way, utility corridors, and residential lots. They are valued for aesthetic reasons (e.g. large, pre-settlement bur, red and white oak trees) and for the ecological services they provide, including provision of wildlife habitat, modification of microclimate (shade and windbreaks), and regulation of water, sediment and nutrient releases to rivers and lakes. Many native birds, mammals, reptiles, amphibians, fishes and insects remain within the region, either occupying remnants of original ecosystems or inhabiting modified ecosystems. Some have been extirpated from the region (black bear for example) or become extinct (passenger pigeon), while others such as white-tailed deer and raccoons have increased. Some now common animals, like the house finch, are relatively recent arrivals. Important species to manage under climate change include insect pollinators such as honey bees and wasps, natural predators such as predatory beetles and insect parasitoids and endangered species such as the Indiana bat, the Karner blue butterfly, the Eastern massasauga rattlesnake, and the piping plover.

Changes in the region's ecosystems thus far result primarily from land use conversion (from prairies, woodlands, forests, and wetlands to farms, cities and suburbs) and species introductions (intentional and accidental). However, changes in temperature and precipitation resulting from increasing greenhouse gas emissions are altering plant growing conditions and are modifying animal habitats. For example, growing seasons in the Chicago region, similar to patterns across the Northern Hemisphere, have advanced by 1 to 1½ days per decade during the past 50 years[2]. As climate continues to change, ecosystems will be increasingly modified as plant and animal species move into and out of the region. The extent to which climate alters the composition and functioning of the region's ecosystems will vary according to the different emission scenarios described in this report (Chapter 2). In addition, ecosystems will be influenced by management decisions and land use choices, and by the interactions of these factors with climate change.

This chapter describes the likely impacts of warming temperatures and changing precipitation on plant species, wildlife, invasive species, pests, and agricultural ecosystems across the Chicago region. It will consider species currently present within the region as well as species that are expected to move into the region as climate zones shift northward through the coming century.

Climate impacts on natural vegetation

As regional temperature warms, plant hardiness zones (defined using average Annual Minimum Temperatures, or AMT), which determine what species can be planted and dates of planting, are projected to move northward. By 2040, the Chicago region will have shifted from its current USDA Plant Hardiness Zone designation of 5b, in which AMT ranges from –10 to –15 ºF, upwards to 6a, with AMT ranging from –5 to –10 ºF, depending if emissions are low or high (Figure 5.1). By 2070, plant hardiness is projected to remain at zone 6a under low emissions and to shift further to zone 6b (AMT = 0 to –5 ºF) under high emissions. By the end of the century, the projected hardiness zones could shift to 6b under low and to 7a (AMT = +5 to 0 ºF) under high emission scenarios. The projected shifts for mid- and late century are equivalent to present hardiness zones in southern Illinois under the low emission scenario. Under the high emission scenario, plant hardiness zones are projected to be equivalent to western Kentucky by mid-century and to northern Alabama by the end of the century.

Projected shifts in plant hardiness zones, as well as decreases in growing season moisture due to warmer, dryer summers, will have implications for the nearly 100 tree species and the larger numbers of shrubby and herbaceous species currently found in the region. The habitats of some dominant species will be likely to shift northward or otherwise decline in importance. Some less important species, and some species presently found further to the south, could assume greater importance. Projections by Iverson and colleagues[3,4] suggest that suitable habitats of important species such as northern red oak, black cherry, white oak, sugar maple and red maple will decline substantially, but will probably not disappear altogether. For example, projections of three climate models show dramatic declines in red oak habitat by 2100 under either low or high emission scenarios (Figure 5.2).

Figure 5.1. Projected changes in Chicago plant hardiness zones under higher (A1fi) and lower (B1) emission scenarios. The "present day" map is based on observed temperatures from 1978 to 1986[1]. Chicago's current climate zone is 5b, denoted by a green diamond. Near-term (2010-2039), the zone is projected to change to 6a (white square). By mid-century, under lower emissions it is likely to be 6a (light blue circle) or under higher emissions, 6b (light pink triangle). By end-of-century, the plant hardiness zone could be 6b (dark blue circle) under lower emissions or 7a (dark pink triangle) under higher.

Habitats of less common species, such as paper birch, black ash, quaking aspen, big-toothed aspen, butternut, balsam fir, black spruce, and eastern hemlock, will likely become rare or disappear altogether. Habitats for certain species which are now present, such as silver maple, bur oak, post oak, sweetgum, Kentucky coffee tree, black hickory, and wild plum will likely become more abundant as climate warms. Oak species that are now uncommon or absent from the region, such as southern red oak, Shumard oak, and blackjack oak, could extend their ranges northward into the Chicago region, especially if management plans were to assist in their migrations[5,6]. Such efforts by planners would have the effect of maintaining oak forests and savannas though the identity of oak species occupying these ecosystems might change. Recent analyses indicate that habitats could become suitable for southern species such as shortleaf pine (Figure 5.2), loblolly pine, water locust, water oak, willow oak, and cedar elm. However, it is not likely that this latter group of more southern species would migrate into the region during the next century without active management and planting[7]. We also do not yet know how severe cold snaps, such as witnessed in the spring of 2007 and will likely continue, though moderated, under every scenario, will affect final species outcomes.

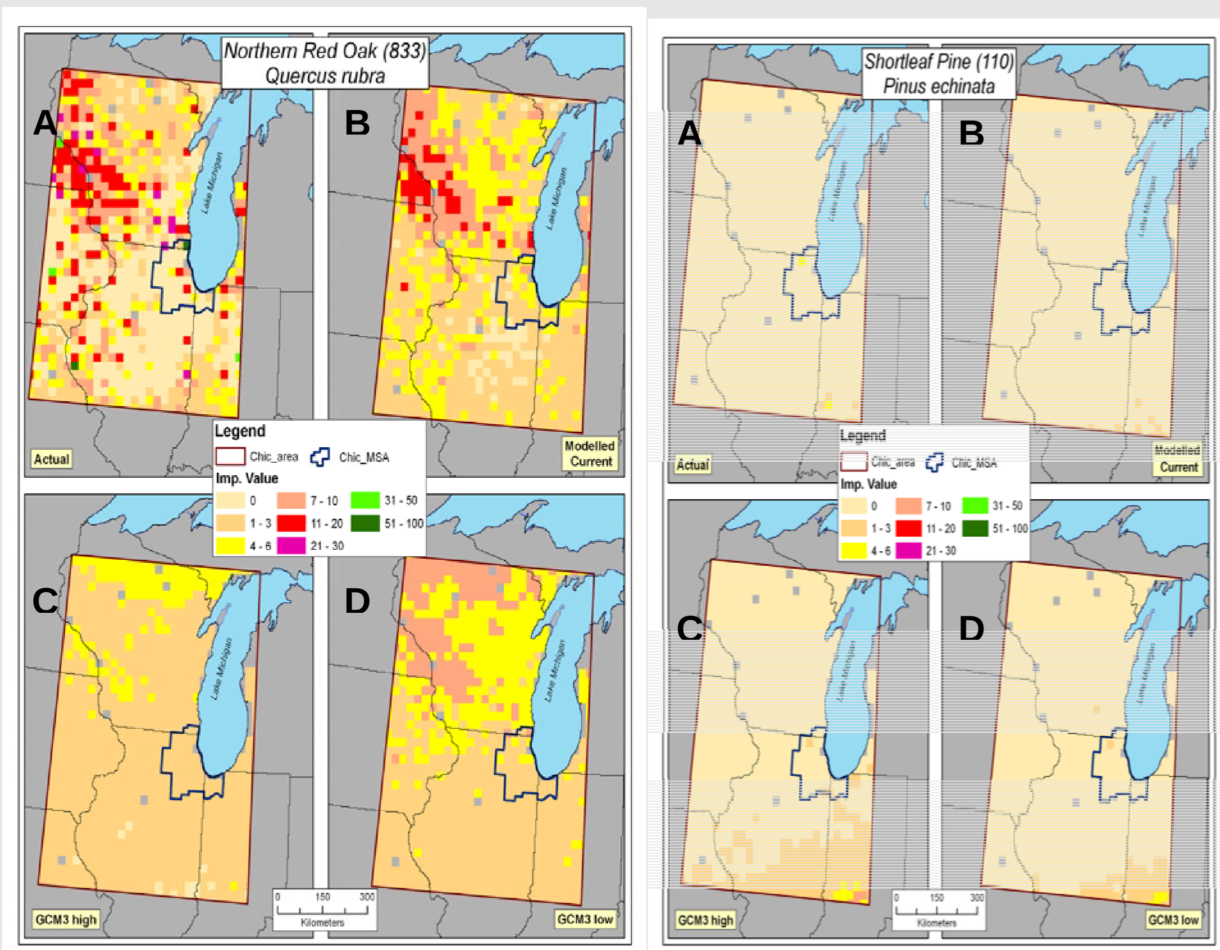

Figure 5.2. Maps of suitable habitat for northern red oak (*Quercus rubra*) and shortleaf pine (*Pinus echinata*) as measured (A), modeled under current conditions (B), and under high (C) and low emission (D) scenarios in 2100. Importance values indicate the relative importance of the species based on both how dense the trees are as well as how large they are, as determined by the U.S. Forest Service Forest Inventory and Analysis units. The higher the number, the more abundant and/or large the species is. A change in habitat importance values does not necessarily mean a change in actual location of the species by the century's end, as migrations rates are determined by other factors. (Source: Iverson et. al., *in press*)

The degree to which the habitats and abundances of tree species change through the century will differ in relation to emission levels through the century. Although the relative abundances of individual species will change due to climate change, consideration of general forest types is useful for management purposes. For example, projections for different emissions scenarios show that habitats for spruce-fir, aspen-birch, and white/red/jack pine forest types are largely eliminated by 2100 under any scenario (Figure 5.3). However, the maple-beech-birch forest habitat could remain stable under low emissions (not shown), but will largely be replaced by oak-hickory under high emissions. Overall, species declines and losses, and increases in abundances of more heat and drought-tolerant species, will likely be less pronounced under the lower of the two emissions scenarios presented in Chapter 2.

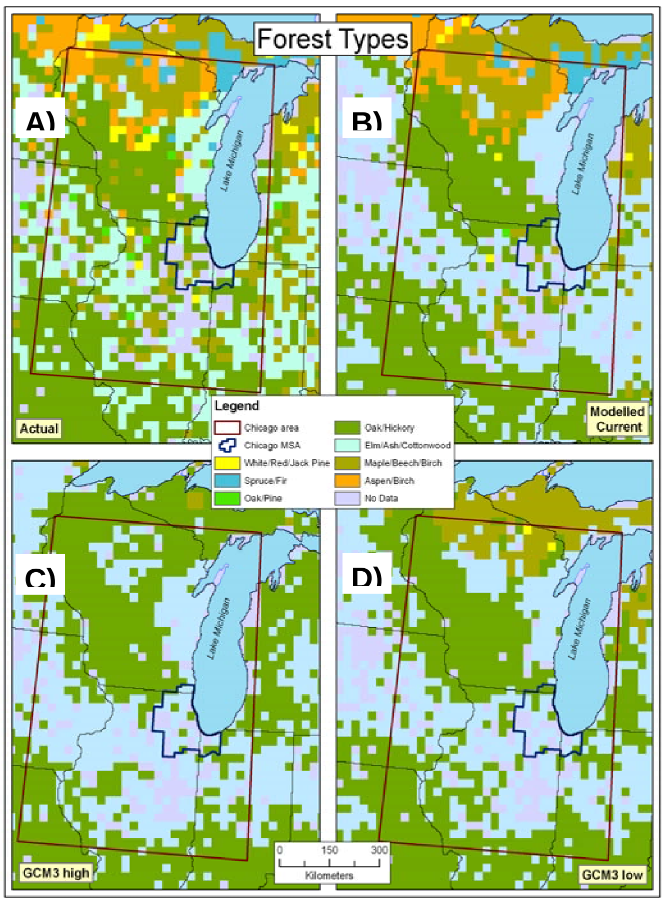

Figure 5.3. Forest-type maps for the Chicago region based on combining individual species maps of importance as measured (A), modeled under current conditions (B), and suitable habitat under higher (C) and lower emission (D) scenarios in 2100. (Source: Iverson et. al., *in press*)

The tree species present in ecosystems will also be altered by plant pests and diseases. Some, such as emerald ash borer[8,9], beech bark disease, maple decline, and oak wilt may combine with habitat loss to further decrease the populations of currently important species in the region's forests, woodlands, and residential areas. Susceptibilities of mature trees to pests and pathogens and the activities of pests themselves may increase with temperatures and growing season length[10].

Native grasslands (or prairies) and woodlands or savannas were major components of the pre-19th Century landscape. Conservation efforts in the region are often directed at maintaining remnants of these ecosystem types or at restoring them on degraded or abandoned lands. These ecosystems are composed of species favored under dry summers and periodic burning. As with forests, these ecosystem types can likely be maintained under active management, even though some characteristic plant species may decline while other less abundant species might increase and be augmented by more drought and heat adapted species from the south and west. Overall, grasslands and savannas are also valuable in maintaining habitat for indigenous and other valued plant and animal species.

Areas occupied by marshes, riverine wetlands and swamps have diminished greatly due to draining, channelizing of streams, and land use change. These ecosystem types may decline further due to more prolonged dry seasons and warmer summers, and to lowering of water tables. However, a high priority should be placed on maintaining and restoring these ecosystem types as they can serve to partially buffer the effects of increased storm intensities. In addition, these areas serve as biodiversity “hot spots” in the region, providing habitat for various fish, amphibians, reptiles, birds and mammals. Also, because several key riverine systems in the region, such as the Des Plaines, Fox, Rock and Chicago River, trend in a north-south direction, these systems can serve as migration corridors for various plant and animal species that may need to shift their geographic distributions northward under regional warming.

Climate impacts on animals

In addition to plants, changing climate is expected to affect the abundance and distribution of animals in the region, including birds, insects, and mammals. The responses of these species will depend on the climatic tolerances of the animals themselves and on the responses of key species with which they interact. Specialist species that depend heavily on a particular resource, a mutualistic relationship, or a particular habitat will be doubly affected both directly and indirectly by climate change. Consider a butterfly species that requires a particular host plant species: the butterfly is affected physiologically by climatic factors, but its presence also depends on the persistence of its host plant which itself may be affected by climatic change. Because of this indirect influence of food resources and habitats for many animal species, we can obtain a first-order approximation of animal response to climate change by considering changes in plant resources (as in section A). Where major shifts in vegetation type are predicted, we can expect corresponding changes in animal communities.

Climate change also will alter the timing of animal processes. A record of 55 different seasonal events (e.g., arrival dates of migratory birds) begun by Aldo Leopold in Sauk County, Wisconsin indicates that 19 of these events have occurred steadily earlier in the region over the last ~65 years[11]. Changes in the timing of plant processes also will affect animals if a shift involves a limiting factor in animal population growth or increases animal mortality. For example, changes in leaf chemistry brought on by elevated concentrations of CO_2 or by warmer temperature can change the timing of leaf flush, affecting the concentration of secondary chemicals that limit the growth of outbreaking insects such as gypsy moth[12,13,14,15]. Changes in the timing of bird migration relative to the timing of their food resources also have been shown to affect the reproductive success of some species of birds in Europe[16]. Changes in the abundance of animals due to changes in plants will require new or more intensive strategies of forest management in the case of outbreaking species (and invasive species, see below) and greater conservation effort in the case of declining species. Vulnerable or threatened species that occupy marginal habitats or use marginal plant resources may be particularly affected by changes in the timing and quality of their food plants.

Though animals will respond in complex ways to climate change, we still can make useful predictions about where they might occur under future climates. To do so, we make a simplifying assumption that climate alone is a key factor in where an animal species lives. This assumption is reasonable if an animal's resource base is widely available, is relatively insensitive to climate change, or responds to climate in a similar way to the animal itself (i.e., has similar climatic tolerances). The latter is a good approximation for suites of species that are adapted to similar conditions (e.g., dry soils dominated by drought-tolerant trees and grassland plants).

The future distribution of suitable habitat for 150 common Eastern bird species has been estimated for the entire Eastern U.S.[17,18] using Breeding Bird Survey observations for the period 1981-1990, historical weather data, and associated tree species importance to build models of their relationships. The models were used to map the species current distribution in terms of their incidence and presence. Incidence is an index of relative abundance and ranges from 0 to 1. As incidence increases towards 1 there is a greater chance of the species being found and thus more individuals within areas of suitable habitat. Then, employing three global circulation models (GCMs) and two emission scenarios, we extrapolated forward to generate the potential future distributions of suitable habitat for each bird species.

Using this larger database, we then tabulated those species that may change their distribution, and estimated the potential ''winners' and 'losers' in area-weighted incidence, a metric that incorporates the both incidence and area of a species distribution, within the Chicago region. This database of predictions was analyzed for the Chicago region and suggests that habitats for 48 (low emissions) to 50 (high) species would increase, while 73 (low) to 86 (high) species would lose habitat (Table 5.1). Of the losers, 46-51 species could lose more than half their total habitat, including the following species depicted on Table 5.2 (that lists the potential major losers and winners within the region): Hermit Thrush, Black-throated Green Warbler, Winter Wren, Canada Warbler, Magnolia Warbler, Evening Grosbeak, Dark-eyed Junco, Swainson's Thrush, Lincoln's Sparrow, and Common Loon. Also losing considerable suitable habitat could be American Goldfinch (Fig. 5.5). Of the gainers, 11-15 species could increase in area-weighted incidence by at least a factor of 5 (Table 5.1, 5.2): Loggerhead Shrike, Blue Grosbeak, Summer Tanager (Fig. 5.6), Great Egret, Chuck-Will's Widow, Red-shouldered Hawk, Scissor-tailed Flycatcher, Little Blue Heron, and Cattle Egret.

In total, we modeled that 46 (low emissions) to 51(high) bird species would lose at least half of their suitable habitat from the Chicago region, while 25 (low) to 34 (high) species would gain at least twice the suitable habitat, including many species of ecological, aesthetic, and economic importance..

	< 0.5	0.5 - 0.9	0.9-1.1	1.1 - 2.0	2.0 - 5.0	>5
Lower emissions	46	27	27	25	14	11
Higher emissions	51	35	16	14	19	15

Table 5.1. Summary of potential changes in suitable habitat for 150 species of birds in the Chicago region. Values shown are the ratios of future to current area-weighted incidence scores, such that a ratio below one indicates a loss of suitable habitat, while a ratio above one indicates a gain. Total gainers (>1.1) were 50 species under low emissions and 48 for high, while total losers (<0.9) were 73 species under low and 86 under high emissions.

Common Name	Current	Lower	Higher
American Robin	**957**	911.4	739.2
Common Yellowthroat	**943.9**	812.6	554.8
Barn Swallow	**940.9**	952.3	928.8
Brown-headed Cowbird	**939.8**	935.8	919.7
European Starling	**937.6**	909.4	793.3
Indigo Bunting	**936.5**	915.1	732.2
Mourning Dove	**930.6**	954.4	954.4
Song Sparrow	**929.5**	474.9	208.2
American Goldfinch	**928.5**	729.9	499.8
Killdeer	**912.8**	928.5	902.2
Hermit Thrush	99.2	***14.3***	***8.0***
Loggerhead Shrike	76.2	**470.4**	609.1
Black-throated Green Warbler	75.2	***11.7***	***7.1***
Winter Wren	72.7	***7.6***	***3.9***
Common Loon	61.6	***10.8***	***5.7***
Blue Grosbeak	53.3	**396.4**	**524.1**
Canada Warbler	44.6	***7.1***	***4.3***
Summer Tanager	39.5	**243.3**	**408.8**
Magnolia Warbler	30.6	***4.5***	***3.0***
Evening Grosbeak	27	***2.6***	***1.0***
Great Egret	24.6	147.0	**279.4**
dark eyed junco	16.3	***1.6***	***0.6***
Swainson's Thrush	8.3	***0.0***	***0.0***
Lincoln's Sparrow	7.5	***0.3***	***0.0***
Chuck-Will's Widow	3.1	**131.9**	**296.5**
Red-shouldered Hawk	2.8	**35.0**	**102.8**
Scissor-tailed Flycatcher	1	**159.7**	**308.0**
Little Blue Heron	0.1	**204.4**	**438.4**
Cattle Egret	0.1	**152.7**	**401.7**
Yellow-crowned Night-Heron	0.1	**7.4**	**47.4**
Fish Crow	0.1	**2.2**	**7.6**

Table 5.2. Area-weighted incidence of selected bird species for the Chicago region. Values are an indication of abundance and range for their current distribution, and suitable habitat for end-of-century under lower and higher emissions within the mapped area depicted in Figures 5.4 and 5.5. "Current" indicates incidence according to modeled Breeding Bird Survey data, "Lower" indicates potential importance in future under low emissions (using average of three climate models), and "Higher" indicates potential future incidence under high emissions. Bold letters indicate the species rank in the top ten for all 150 species. Italics bold indicate the species ranks in the bottom ten among all species. The table thus shows the major current species, the major gainers, and the major losers under climate change.

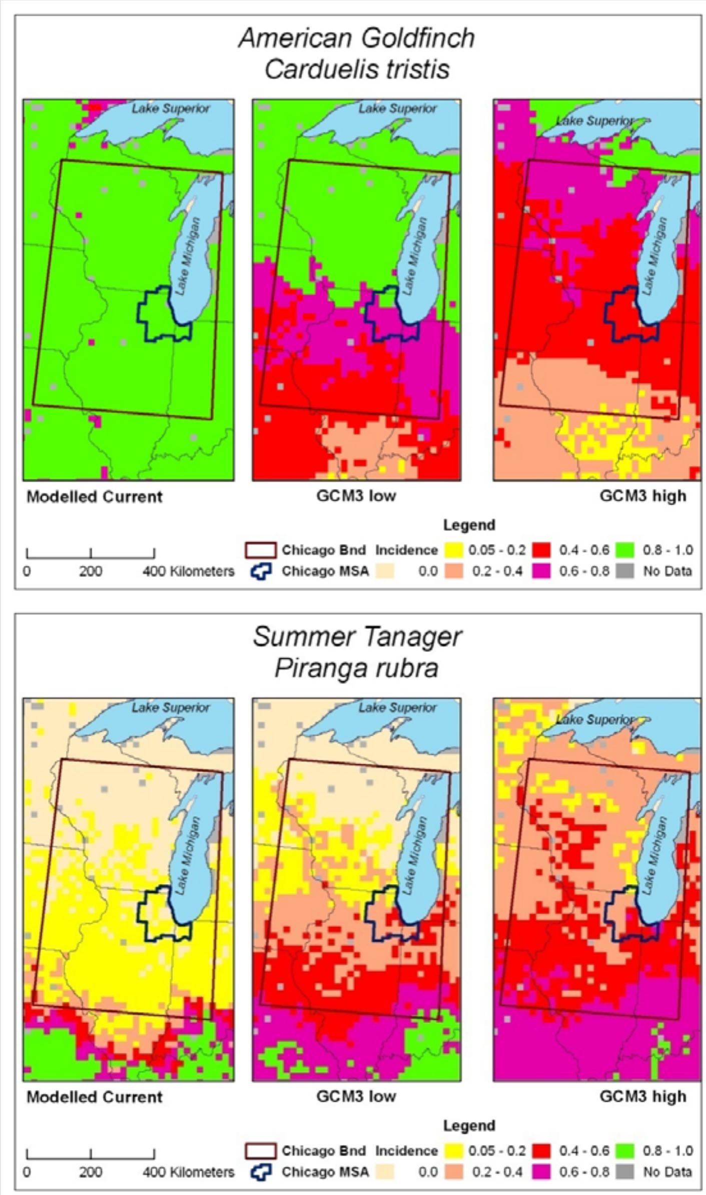

Figure 5.4. Projected distribution and incidence under climate change for one species that will likely undergo a large decrease from the Chicago region, the American goldfinch, and one that will likely undergo a large increase, the Summer Tanager. Bird incidence is an index of relative abundance that ranges from 0 to 1. As incidence increases towards 1 there is a greater chance of the species being found. The left-most map illustrates the historical distribution of the species based on data from the annual Breeding Bird Survey. The right-most maps are projections based on the average of three climate models (GCM3avg) under lower emissions (center map) and higher emissions (right map). These models were based on climate, elevation, and potential future tree abundance, as described in the tree section of this report (Source: Matthews et al. 2007).

Projected changes in the geographic ranges of butterflies can be used to illustrate the potential impacts of climate change on insects. Butterflies are useful indicators of other insect species because they often depend on one or just a few specific plant species for food, and like most insects, their cold-blooded nature makes them sensitive to changes in temperature[19,20]. Because the geographic ranges of butterflies are better known than many other insect species, they also offer greater predictive power of future geographic occupancy. Using the online database of Butterflies of North America[21], we made simple projections about future changes in the butterfly community of the Chicago region (broadly defined as for birds above). A more sophisticated analysis of range changes, analogous to that discussed for birds above, has been performed for Canadian butterfly species[22].

We used the rules that a species will go locally extinct if its historical, southern range boundary occurs in proximity to the Chicago area and that it will appear in the Chicago area under climate change if it is currently occupying areas include climates that are projected to emerge in Chicago (e.g., southern Illinois Tennessee, Kentucky, northern Alabama). The Chicago area currently contains 115 species of butterflies, of which we expect 20 species to leave the region and 19 species might appear in the region using the rules above (Figure 5.5). In addition, some species that currently reach their northern range boundary near Chicago might become more abundant, including the Hoary Edge, Southern Cloudywing, Horace's Duskywing, Fiery Skipper, Zabulon Skipper, Pipevine Swallowtail, Zebra Swallowtail, Spicebush Swallowtail, Cloudless Sulphur, Sleepy Orange, Juniper Hairstreak, Red-banded Hairstreak, White Hairstreak, and Goatweed Leafwing. The appearance of new species into a region is difficult to predict for butterflies because butterfly colonization in a region is predicated on the existence of a suitable host plant. To encourage the establishment of southerly butterfly species, therefore, we also may need to assist in the migration and establishment of novel host plants[23].

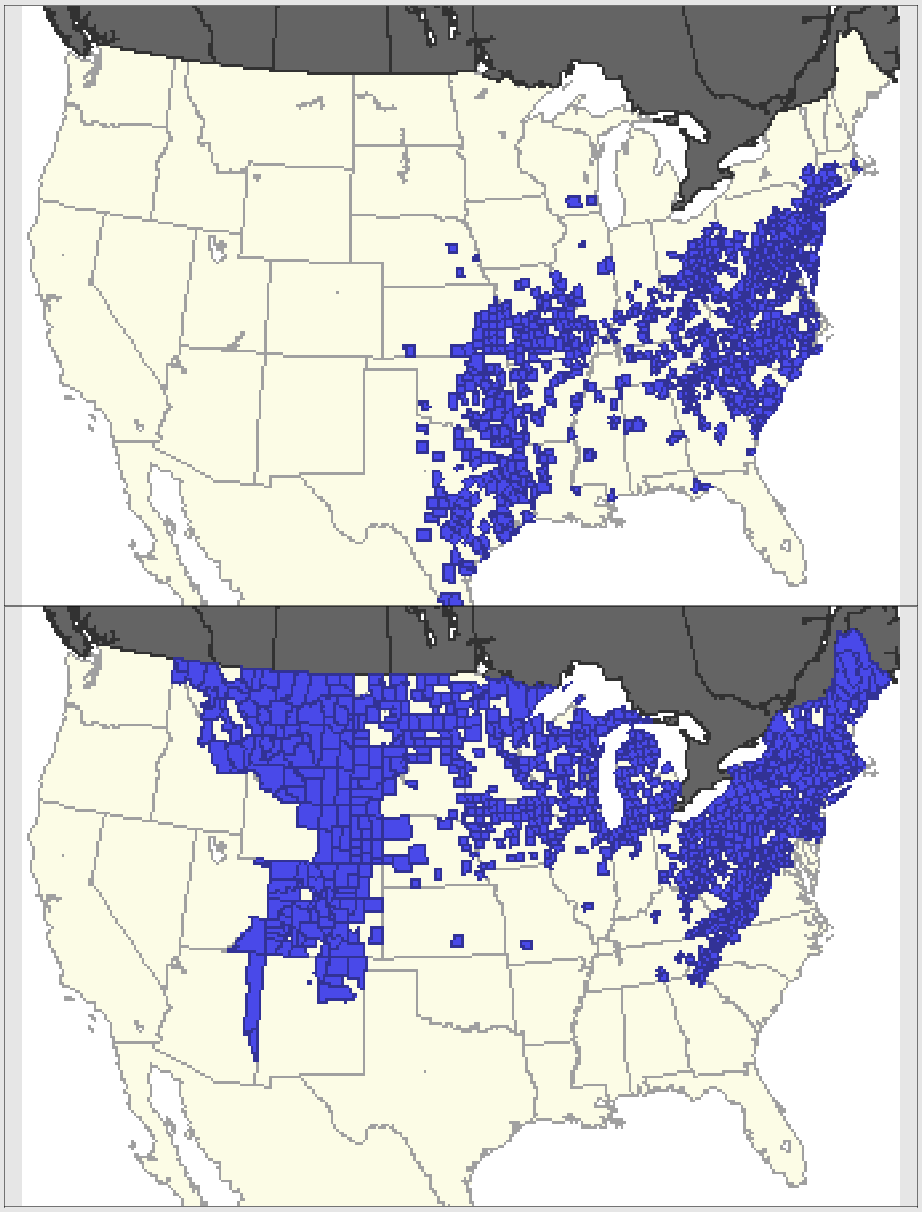

Figure 5.5. Historical geographic distribution of two example butterfly species where blue symbols indicate counties where individuals have been observed. Species with a southerly distribution such as the Falcate orangetip (A) may expand into the Chicago region with climatic warming, while northerly species such as the Aphrodite frittilary (B) may disappear from the area.

For insects in general, warmer temperatures should accelerate development causing earlier emergence and a greater number of generations per year, all other factors such as resource quality being equal. In the case of pest species, a greater number of generations per year can mean greater total damage[24]. A number of more southerly pest species also may extend their ranges northward into the Chicago region if climate change reduces overwintering mortality by raising minimum winter temperatures[25]. Projections for the southern pine beetle, for example, show the species reaching northern Indiana and occasionally even Minnesota if winter temperatures increase[26,27]. Plants that are stressed by climatic factors (e.g., drought) or climate-related disturbance (e.g., fire) also may become more susceptible to pest or pathogen attack[28,29].

The response of mammals to climate change is very likely to vary strongly by species. Large species that move over large distances might be able to track climate change as long as habitats are available and human residential and development do not block their way. Studies by Myers and colleagues[30] indicate that deer mice, white-footed mice, opossums, southern flying squirrels and other small mammals also have extended their ranges steadily northward throughout the Midwest. However, analysis by Saunders et al.[31] of mammalian species collected in northwest Indiana suggests that the Great Lakes could impede northward migration of some mammalian species. In their simulations of a high emission scenario, some species “dead end” at the top of the lower peninsula of Michigan. This suggests that migration routes through Chicago, up the west side of Lake Michigan, may be important for species to keep pace with changing climatic conditions. As the urban and suburban landscape of Chicago is a formidable barrier to movement for many mammals, again, assisted migration may be needed.

The dynamics of local, native species are also very likely to change. The most basic expectation is that species toward the northern range boundary will increase and species toward the southern edge of their range will decrease, but many factors will complicate this theoretical response. For example, populations locally adapted to climates in the Chicago region from local selective pressure and isolation from other populations may experience stress that could increase their susceptibility to disease[32], decrease their competitive ability relative to other native species or invasive species[33,34,35], or reduce their reproductive output[36] in response to altered climatic conditions.

In the absence of dispersal barriers such as urban development, and given considerable time for organismal migration through the landscape, native species that currently occur in the Chicago area could be replaced with more southerly species and associated changes in species richness. Ecosystems would look and function considerably differently, but many taxa could persist by relocating geographically. Under modern climate change, however, geographic transition is unlikely to be easy because of fragmented landscapes, habitat loss, and the rapid rate of change, and some biodiversity loss is highly likely[37]. In addition, the disassembly of communities during climate change may open niches that can be preferentially filled by invasive species from distant locations that disperse easily, grow rapidly, and cause ecological or economic damage[38]. For this reason, the future is unlikely to be a simple replacement of one community type for another but involve more complicated dynamics.

Invasive species, weeds and climate change

Many invasive plants are known to respond to increased atmospheric concentrations of CO_2, suggesting that they will become more aggressive and more costly to control with increasing greenhouse gas emissions[39]. These include species already occupying the Chicago area such as spotted knapweed and Canada thistle[40] and species that occur to the south that could spread into the region such as kudzu (discussed below). Changes in leaf defenses also can be associated with growth changes due to the fertilization effect of elevated CO_2. Recent data presented at a Chicago meeting, for example, suggest that elevated CO_2 could affect the attack rate of the invasive Japanese beetle on soybean, a key agricultural crop in the lower Great Lakes region[41].

In addition to making some invasive species better suited to Chicago's environment, climatic change could influence the geographic spread of non-native species. By definition, invasive species are those that have expanded their ranges from areas of historical occupancy and that cause economic or ecologic damage in their new range. Some invasives are spreading under current climatic conditions due to human-mediated dispersal, and climate change could exacerbate invasives' rates of dispersal[42]. A species for which there is great concern about range change is the gypsy moth, a generalist defoliator that can cause tree death and increases the incidence of stress-related tree disease. Gypsy moth was introduced to Massachusetts in the mid-1800s, and the species has steadily spread westward, now covering Michigan, eastern Wisconsin, and northern Indiana. The Chicago region, on the current front of this spreading species' range, plays an important role in slowing the westward migration and damage of this species. However, climate change could exacerbate the spread of this species and hinder efforts to keep the gypsy moth at bay. Like other overwintering insects, increases in winter temperature could accelerate the spread of gypsy moth by enabling larger population sizes and an extended season of activity and breeding. Plants stressed directly by climate change or indirectly through some climate-mediated change in forest communities could face higher probability of attack by the gypsy moths that attempt to colonize Chicago each year.

Changing concentrations of CO_2 also may affect the likelihood of tree mortality when attacked by gypsy moth, but studies suggest that the direct effects of increased temperature on the development time of gypsy moth has a greater effect on moth dynamics than do indirect effects of CO_2 on leaf quality[43]. Invasive pests like the gypsy moth already demand management attention; managers should intensify those efforts in anticipation of increased threat due to climate change.

Another important invasive that could emerge in the Chicago area is kudzu, an invasive weed that causes extensive ecological and economic damage in the southeastern US. Kudzu has spread from central Kentucky into southern Indiana and Illinois in the last 30 years. Recent studies suggest that this spread is due to rising minimum winter temperatures, so much so that temperatures have not dipped below the plant's lethal temperatures since 1996 (see agriculture section, below). If this rate of winter warming were to continue, kudzu is predicted to pass through the Chicago region and reach central Wisconsin and Michigan (45 degrees north latitude) by 2020[44] (Figures 5.6 and 5.7). Unlike many native species with range shifts that may be impeded by urban and suburban development, kudzu thrives in urban landscapes. Some recent data suggest that cities may protect themselves against such invasion by promoting native greenspace and minimizing disturbance of intact ecosystems[45].

Climate change and agriculture

Agriculture in Illinois, as in much of the Great Plains, is characterized by a soybean/corn rotation. At the state level, soybean and corn contribute approximately 3 and 4 billion dollars, respectively, to the 9 billion dollar agricultural economy. Additional economic input from agricultural machinery, manufacturing and value added food products also provide additional billions of dollars to the Illinois economy. Overall, the state ranks third nationally in total prime farmland acreage, and agriculture contributes significantly to the state and national economy.

Soybean production is sensitive to temperatures greater than 35ºC (95ºF) during flowering[46]. Corn, in turn, being a tropical grass, is less temperature sensitive. For soybean, for every 1ºC rise in temperature there was estimated, on average, a 17% decline in yield[47]. This would suggest a decline of 30-55% for the low and high emissions projections by 2100, respectively, for soybean grown in northern Illinois.

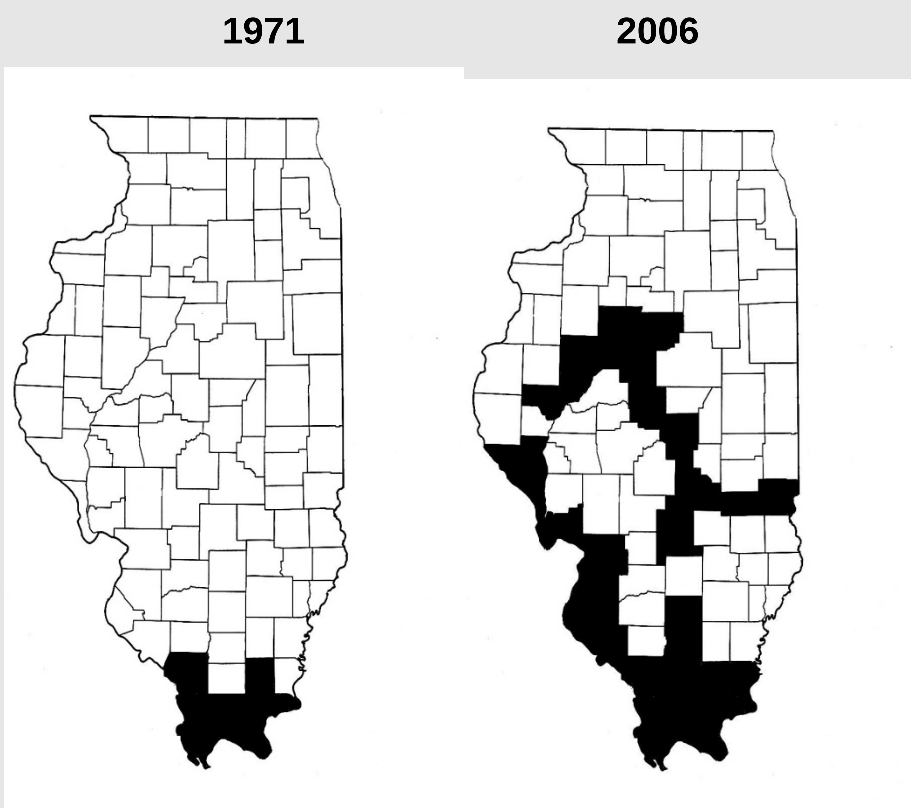

Figure 5.6. Change in distribution of kudzu populations for Illinois, by county, from 1971 and 2006. 1971 estimates are from maps drawn by Clyde Reed, a USDA researcher, from 1970. Current estimates of kudzu distribution for Illinois were evaluated using three separate sources: a) National Resource Conservation Service NRCS), database of invasive U.S. Species (plants.usda.gov/java/profile?symbol=PUMO) b) the National Agricultural Pest Information Service (NAPIS) in cooperative agreement between the Animal Plant Health Information Service (APHIS) and Purdue University as part of their Cooperative Agricultural Pest Survey (CAPS) program (ceris.purdue.edu/napis/pests/weeds/imap/kudzu.html), and c) the Department of Natural Resources (DNR) for Illinois, including the publication of "The Green Plague Moves North" by the Illinois DNR.

Increasing spring precipitation also could delay planting and could impose damage on early germination and emergence of corn and soybeans. Different scenarios suggest differences in precipitation patterns. For the higher emissions scenario, decreases in summer precipitation are possible, with subsequent declines in crop production. Alternatively, if intensity of precipitation events increases during summer and fall, this would impose flooding and storm damage with detrimental effects on field activities, most notably harvesting with subsequent loss of revenue.

Crop plants are likely to respond to increases in atmospheric concentration of CO_2 as they are typically fertilized and their growth is less dependent on nutrient limitation than is growth in more natural, non-fertilized ecosystems. The recent and projected changes in CO_2 could therefore benefit agriculture because rising CO_2 could either directly stimulate photosynthesis, or allow greater water conservation. However, initial research suggests that any positive effect of increased CO_2 on plant yields may not always compensate for the negative effects of increased heat stress[48,49]. In addition, there are a number of reports[50] indicating differential stimulation of weeds relative to crops in response to rising carbon dioxide, with subsequent reductions in crop yields.

Because climate determines the suitable geographic range of pests as well as agricultural crops, changes in temperature and precipitation are likely to influence the types of weeds, pests and diseases the region's farmers will face in the future. Of particular concern to Illinois is that warmer temperatures may allow the northward spread of invasive weeds and insects that are associated with major plant damage in more southern states. For example, if soybean yields are compared in a north-south line from the Great Lakes States to the Gulf States, soybean losses due to the projected increase in weeds range from 22% in the north to 35% in the south for corn, and 22% in the north to 64% in the south for soybean[51]. Nor can it be assumed that greater weed-induced crop losses could be compensated for by increased chemical control[52]. In addition, warmer temperatures may allow the spread of highly aggressive weeds such as kudzu (above and Figures 5.6 and 5.7), whose presence is not only disruptive to agriculture, but also acts as a host to soybean rust.

In addition to weeds, milder winters and warmer temperatures are also likely to affect the range and viability of insect pests. Although these pests may be introduced into a region by contamination (e.g. the emerald ash borer in northern IL), their ability to over-winter and persist in a given area will be dependent on climate (see climate impacts on natural vegetation section above). Overall, warmer temperatures and changing precipitation are likely to result in a number of new challenges for Illinois agriculture.

As the Chicago metropolitan region expands, greater pressure will be brought to bear on agricultural land and competition between urban and rural needs is likely to intensify. It is unclear at present how additional economic demand for corn-based ethanol or food products in general will affect land use changes for Illinois. These indirect effects of climate change, changes motivated by a desire to reduce greenhouse gas emissions, could have significant consequences for land conservation just as the effects of conservation-motivated changes can have consequences for climate.

Although the challenges posed by climate change for farming are substantial, there are a number of potential adaptation strategies available for Illinois farmers. For example, adjusting planting and harvesting dates, planting of more heat-tolerant varieties or switching to warmer season crops (e.g. melons) are among the first-line options. However, long-term adaptation may involve larger capital investment in irrigation, crop storage or livestock facilities, and information-intensive decision-making which may impose a greater financial burden on smaller family farms. Climate change could also provide opportunities for farmers to develop win-win strategies, such as farming to increase carbon sequestration, or development of more marginal land for bio-fuels as a means to increase income[53]. Overall, an increased focus on agricultural research is justified as a means to identify management strategies and mitigation options for Illinois farmers in order to identify adaptation strategies. Such research could be used to screen heat-tolerant or CO_2 sensitive genetic lines of soybean (i.e. lines that could more effectively convert atmospheric CO_2 increases into seed yield); identify ongoing and future pest problems, and the appropriate management approaches, as well as determine potential economic opportunities that could simultaneously benefit farmers and the environment.

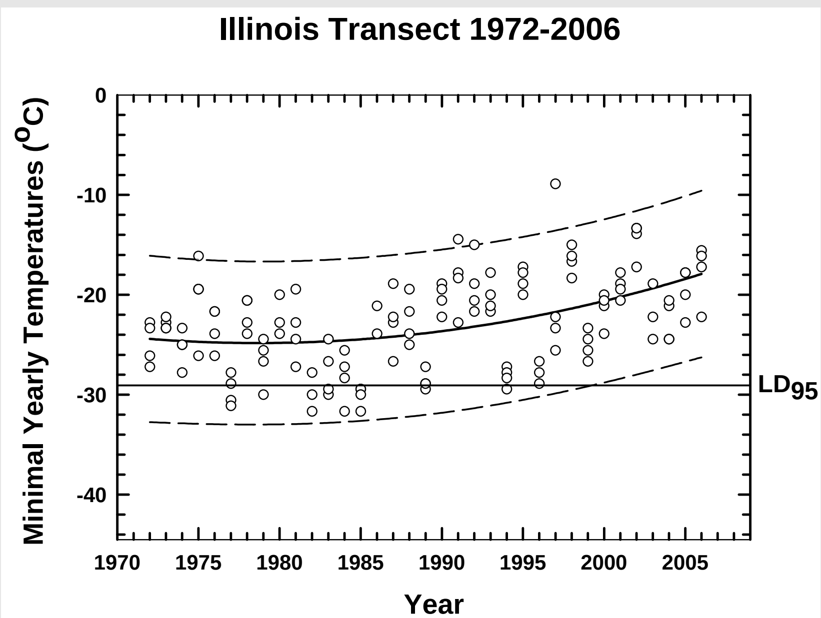

Figure 5.7. Minimal yearly temperatures for selected counties for each region and state over the period 1972-2006. Counties selected had reported the appearance of kudzu since the 1971 census. Line is best-fit secondary function. Dashed lines are the 95% predictive interval. Solid straight line is the LD_{95} for minimal winter temperature tolerance in kudzu stems and is shown for comparison to changes in minimum temperature. Temperatures below the -28.6°C lethal threshold have not been observed in any location since 1996.

[1] Olson, D. M., E. Dinerstein, E. D. Wikramanayake, and others. 2001. Terrestrial ecoregions of the world: A new map of life on Earth. Bioscience 51:933-938.

[2] Schwartz, M. D., R. Ahas, and A. Aasa. 2006. Onset of spring starting earlier across the Northern Hemisphere. Global Change Biology 12: 343-351.

[3] Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. *in press*. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management.

[4] Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/tree, Northern Research Station, USDA Forest Service, Delaware, Ohio.

[5] McLachlan, J. S., J. J. Hellmann, and M. W. Schwartz. 2007. A framework for debate of assisted migration in an era of climate change. Conservation Biology 21: 297-302.

[6] Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. In review. Five potential consequences of climate change for invasive species given changes in the invasion pathway. Conservation Biology.

[7] Iverson L. R., M. W. Schwartz, and A. M. Prasad. 2004a. How fast and far might tree species migrate under climate change in the eastern United States? Global Ecology and Biogeography 13:209-219.

Iverson L. R., M. W. Schwartz, and A. M. Prasa . 2004b. Potential colonization of new available tree species habitat under climate change an analysis for five eastern US species. Landscape Ecology 19:787-799.

[8] Poland, T.M., and D.G. McCullough. 2006. Emerald ash borer: Invasion of the urban forest and threat to North America's ash resource. J. of Forestry, 104, 3, 118-124.

[9] Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. *in press*. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management.

[10] Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simerloff, F.J. Swanson, B.J. Stocks, and B.M. Wooton. 2001. Climate change and forest disturbances. BioScience. 51, 9, 723-734.

[11] Bradley, N. L., A. C. Leopold, J. Ross, and W. Huffaker. 1999. Phenological changes reflect climate change in Wisconsin. Proceeding of National Academy of Sciences 96: 9701-9704.

[12] Lindroth, R. L, and K. K. Kinney. 1998. Consequences of enriched atmospheric CO2 and defoliation for foliar chemistry and gypsy mothe performance. Journal of Chemical Ecology 23: 1677-1695

[13] Kinney, A. J. 1998. in Genetic Modification in the Food Industry (Roller, S. and Harlander, S., eds), pp. 193–213, Chapman & Hall, London.

[14] Ayres, M. P., and M. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262: 263-286.

[15] Watt, A. D., and A. M. McFarlane. 2002. Will climate change have a different impact on different trophic levels? Phenological development of winter moth Operophtera brumata and its host plants. Ecological Entomology 27: 254-56.

[16] Both, C., S. Bouwhuis, C. M. Lessells, and M. E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. Nature 441: 81-83.

[17] Matthews, S. N., R. J. O'Connor, L. R. Iverson, and A. M. Prasad. 2004. Atlas of climate change effects in 150 bird species of the eastern United States. USDA, Forest Service, Northeastern Research Station, General Technical Report NE-318.

[18] Matthews, S. N., L. R. Iverson, A. M. Prasad, and M. P. Matthews. 2007. A Climate

Change Atlas for Bird Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/bird , Northern Research Station, USDA Forest Service, Delaware, Ohio.

[19] Hellmann, J. J. 2002. Butterflies as model systems for understanding and predicting the biological effects of climatic change. Pages 93-126 In: *Wildlife Responses to Climate Change.* Edited by Schneider, S. H., and T. L. Root. Island Press, Washington, D.C.

[20] White, P., and J. T. Kerr. 2006. Contrasting spatial and temporal global change impacts on butterfly species richness during the 20th century. Ecography 29: 908-918.

[21] Opler, P. A., H. Pavulaan, R. E. Stanford, M. Pogue, 2006. Butterflies and Moths of North America. Bozeman, MT: Mountain Prairie Information Node. http://www.butterfliesandmoths.org/ (Version July, 2007)

[22] Peterson, A. T., E. Martinez-Meyer, C. Gonzalez-Salazar, and P. W. Hall. 2004. Modeling climate change effects on distributions of Canadian butterfly species. Canadian Journal or Zoology 82: 851-858.

[23] McLachlan, J. S., J. J. Hellmann, and M. W. Schwartz. 2007. A framework for debate of assisted migration in an era of climate change. Conservation Biology 21: 297-302.

[24] Logan, J. A., J. Regniere, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1: 130-137.

[25] Ayres, M. P., and M. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262: 263-286.

[26] Ungerer, M.J., M.P. Ayers, and M.J. Lombardero. 1999. Climate and the northern distribution limits of Dendroctonus frontalis Zimmermann (Coeoptera: Scolytidae). J. Biogeogr. 26: 1133-45.

[27] Ayres, M. P., and M. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262: 263-286.

[28] Ayres, M. P., and M. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262: 263-286.

[29] Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simerloff, F.J. Swanson, B.J. Stocks, and B.M. Wooton. 2001. Climate change and forest disturbances. BioScience. 51, 9, 723-734.

[30] Myers, P., B. Lundrigan, and B. Vande Kopple. 2005. Climate change and the distribution of Peromyscus in Michigan -- is global warming already having an impact? In: *Mammalian Diversification: From Chromosomes to Phylogeography (A Celebration of the Career of James L. Patton).* Edited by Lacey, E.A. and Myers, P. Univ. California Press.

[31] Saunders, M., K. E. Francl, K. Hayhoe, and E. P. Maurer. In press. Quantifying the impacts of land-use and climate change on past and future mammal migration in the southern Great Lakes region. **Journal?**

[32] Garrett, K. A., Dendy, S. P, Frank, E. E., Rouse, M. N., and Travers, S. E. 2006. Climate change impacts on plant disease: genomes to ecosystes. Annual Review of Pytopathology 44: 489-509.

[33] Dukes, J. S., and Mooney, H. A. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution 14: 135-139.

[34] Ward, N. L., and Masters, G. J. 2007. Linking climate change and species invasion: an illustration using insect herbivores. Global Change Biology 13: 1605-1615.

[35] Hellmann, J. J., Byers, J. E., Bierwagen, B. G., and Dukes, J. S. In review. Five potential consequences of climatic change for invasive species.

[36] Thomas, D. W., Blondel, J. Perret, P.. Lambrechts, M. M., and Speakman, J. R. 2001. Energetic and fitness costs of mismatching resource supply and demand in seasonally breeding birds. Science 291: 2598-2600.

[37] Thomas, D. W., Blondel, J. Perret, P.. Lambrechts, M. M., and Speakman, J. R. 2001. Energetic and fitness costs of mismatching resource supply and demand in seasonally breeding birds. Science 291: 2598-2600.

[38] Hellmann, J. J., Byers, J. E., Bierwagen, B. G., and Dukes, J. S. In review. Five potential consequences of climatic change for invasive species.

[39] Dukes, J. S, and H. A. Mooney. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution 14 (4): 135-139.

[40] Ziska L. H., S. S. Faulkner, and J. Lydon. 2004. Changes in biomass and root:shoot ratio of fieldgrown Canada thistle (*Cirsium arvense*), a noxious, invasive weed, with elevated CO2: implications for control with glyphosate. Weed Science 52:584-588.

[41] Casteel, C., J. Zavala, M. Berenbaum, and E. DeLucia. 2007. Modulation of soybean, Glycine max defenses to herbivory by Japanese beetle (*Popillia japonica*) under ambient and elevated atmospheric CO_2. Joint Congress of Botany and Plant Biology, Chicago, IL.

[42] Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. In review. Five potential consequences of climate change for invasive species given changes in the invasion pathway. Conservation Biology.

[43] Williams, R. S., D. E. Lincoln, and R. J. Norby. 2003. Development of gypsy moth larvae feeding on red maple saplings at elevated CO2 and temperature. Oecologia 137: 114-122.

[44] Ziska, L. H., H. C. Coiner, K. George, and R. F. Sage. In press. Increasing minimum winter temperature since 1990 explains northward range expansion of kudzu (Pueraria montanta (Lour.) var. lobata), an invasive species in North America. Proceedings of the National Academy of Sciences.

[45] Mandryk, A. M., and R. W. Wein. 2006. Exotic vascular plant invasiveness and forest invisibility in urban boreal forest types. Biological Invasions 8: 1651-1662.

[46] Salem, M.A., V.G. Kakani, S. Koti,, and K.R. Reddy 2007. Pollen-based screening of soybean genotypes for high temperatures. Crop Science 47:219-231.

[47] Lobell, D. B., and G. P. Asner 2003. Climate and management contributions to recent trends in U.S. agricultural yields. Science 299:1032.

[48] Jifon, J, and D. W. Wolfe 2005. High temperature-induced sink limitation alters growth and photosynthetic acclimation response to elevated CO_2 in beans. Journal of the American Society of Horticultural Science. 130:515-520.

[49] Matsui, T., O.S. Namuco, L.H Ziska**,** and T. Horie 1997. Effects of high temperature and CO_2 concentration on spikelet sterility in Indica rice. Field Crops Research 51:213-221.

[50] Ziska, L. H., and E. G. Goins 2006. Elevated atmospheric carbon dioxide and weed populations in glyphosate treated soybean. Crop Sci. 46:1354-1359.

[51] Bunce, J. A. and L. H. Ziska 2000. Crop/Weed Interactions. In: *Climate Change and Global Crop Productivity*, Edited by K.R., Reddy and H.F. Hodges. CAB International Press. pp 333-348.

[52] Archambault, D. J. 2007. Efficacy of herbicide under elevated temperature and CO2. In: *Agroecosystems in a Changing Climate*, Edited by Newton, P.C.D., R.A. Carran, G.R. Edwards, P.A. Niklaus, CRC Press, Boca Raton, FL, pp 333-337.

[53] Tilman, D. J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomes. Science 314: 1598-1600.