Assessment of the Karner Blue Butterfly’s Response and Managed Relocation under Climate Change

A Thesis
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

Yudi Li

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

Dr. Jessica J. Hellmann, Advisor

June 2020

Acknowledgements

First and foremost, I pay my deep sense of gratitude to my faculty advisor Jessica Hellmann. In the past three years, Jessica kept inspiring me on how to think, speak, and write as a real scientist. I became more qualified and ready for my Ph.D. study in the near future. This thesis would not have been possible without Jessica's dedicated and patient instructions.

I would like to express my gratitude to the members of my graduate committee for their advice on this thesis, and more broadly for my ability training. David Wilson taught me on proficiently applying R coding for statistics and modeling. Joe Knight guided me on remote sensing and geospatial analysis. Jim Perry inspired me a lot on logical and critical thinking.

I would also like to extend my gratitude to Ralph Grundel of USGS and Leroy Walston of Argonne National Laboratory. Ralph provided me with professional opinions on the biology and ecology of Karner blue butterfly, and helped me build networks with other Karner blue scientists. Lee directed my internship research on solar pollinator habitats with unforgettable field work experiences.

A special note of thanks to all the contributors of Karner blue population count data: Randy Knuston (National Park Services – NPS), Ann Swengel and Scott Swengel (individual researchers), Chelsea Gunther and Tim Wilder (Wisconsin DNR), Steven Campbell and Neil Gifford (Albany Pine Bush Preserve), as well as Christopher Hoving (Michigan DNR). Their data are the foundation of this thesis.

Last but not least, thanks to my family and friends, who have always encouraged me to never stop pursuing my career goals. Because of their support, I have had the chance to study abroad and was committed the science of natural resources as a key to salvage our homeland for the well-beings of humans and wildlife.

Abstract

The Karner blue butterfly (*Lycaeides melissa samuelis*), an endangered species in decline from habitat loss, may be further threatened by climate change. Evaluating how climate shapes the dynamics and the distribution of Karner blue is helpful for developing adaptation plans. The demographic models generally used for insect populations are either density-dependent or are applied to population presence-absence data. The bulk of this thesis is concerned with the creation of scale-based, mixed density-dependent and density-independent ("endo-exogenous") models for this butterfly based on the long-term count data shared by other Kaner blue researchers. The endo-exogenous models showed that both density dependence and environmental factors were important drivers of Karner blue population trends and that populations in different regions and the species' bi-voltine generations have differing responses to climate (chapter 1). These models were then used to examine extinction risk and distribution shift under several scenarios of climatic change (elevated temperature and increased precipitation variance) by 2050. The predictions displayed relatively poor efficiency of local management on the populations of Central Wisconsin and Indian Dunes National Park under climate change, and they were projected to have high occupancy in the northern Midwest, especially Minnesota. These results suggested that some populations would benefit from managed relocation and that it would be possible to reintroduce the Karner blue back to Minnesota. To further identify target sites for relocation, the distributions of 179 utility-scale solar energy (USSE) were overlapped with model projections. There were 35 solar facilities located on sandy soil, and some of these were within the range of high occupancy of Karner blue populations, suggesting that if planted with native vegetation, including wild blue lupine (sole host plant of the Kaner blue), and converted into solar-pollinator habitats, USSE might have the potential to be developed as a refugia of this butterfly (chapter 2).

Table of Contents

Chapter 1: Mixed Endo-Exogenous models for the endangered Karner blue butterfly across its range

Chapter 2: Sensitivity analysis and forecasting of extinction risk and distribution shift for Karner blue butterfly using mixed endo-exogenous models

List of Tables

Chapter 1

Appendices

List of Figures

Chapter 1

Chapter 2

Appendices

List of Abbreviations

Climate Predictors

AT	Maximum Temperature
IT	Minimum Temperature
MT	Mean Temperature
PT	Total Precipitation

Density-Dependent Predictors

CF	Current-Year First-Generation Density
GR	Growth Rate
PF	Previous-Year First-Generation Density
PS	Previous-Year Second-Generation Density

Generations

G1	First Generation
G2	Second Generation

Microclimate Predictors

EV	Elevation
SL	Slope
TP	Trasp
CC	Canopy Cover

Response Variables

C	Between-Generation Change
D	Density

States

IN	Indiana
NY	New York
WI	Wisconsin

Time Periods

OW	Overwinter
SP	Spring
JN	June
JL	July
AG	August

Spatial Scales

E	Ecoregion
W	Whole Species

Introduction

In the coming century, climate change may further endanger the Karner blue butterfly (*Lycaeides melissa samuelis*). Yet, lack of knowledge about the factors that affect the Karner blue, as well as uncertainties inherent in future climate change, make projections difficult (Pearson, 2006). In this study, statistical models were built for a nuanced understanding of the butterfly's responses to climate, and variations in those responses in different locations. This information was then used for projecting forward with the goal of aiding conservation decision-making and suggesting adaptation actions (Hannah et al., 2002).

In chapter 1, a series of endo-exogenous models, combining density dependence with density-independence (environmental factors), were set up according to the historic trends of Karner blue across its range for each of the species' two generations. To identify possible predictor variables, the species distinct life stages were assessed for sensitivity to various climatic conditions. The resulting models showed *how* density dependence and density independence affected the dynamics of Karner blue populations.

In chapter 2, the endo-exogenous models were applied to simulate future demographic trends of Karner blue by midcentury and to calculate population-specific extinction risks, under different assumed climate scenarios and habitat areas. The predictions were helpful to indicate *which* populations would be vulnerable to changing climate and might require conservation intervention. Regional projections of occupancy in the upper Midwest suggested *when* and *where* conditions would likely support Karner blue populations and thus become the target locations for managed relocation.

Moreover, renewable energy infrastructure, especially utility-scale solar energy (USSE) is changing the land use / land cover of U.S. (Hernandez et al., 2015). To facilitate the sustainability and land-use efficiency, restoring native prairie among solar PV arrays is becoming a mainstream technique for landscape management (Macknick et al., 2013). Such habitat restoration can promote local pollinator diversity (Kennedy et al., 2014) by offering nesting and foraging habitats and may benefit rare or at risk species such as the Karner blue. Therefore, in chapter 2, the locations of currently established USSE were also examined by overlapping with the distributions of sandy soil and the occupancy projections of Karner blue in Minnesota, to explore the possibility of utilizing these solar facilities as refugia for managed relocation if they could be converted into solar-pollinator habitats with the addition of wild blue lupine (*Lupinus perennis*), the sole host plant of the Karner blue, and other native nectar species.

Chapter 1

Mixed endo-exogenous models for the endangered Karner blue butterfly across its range

Introduction

The Karner blue butterfly (*Lycaeides melissa samuelis*) was listed as federally endangered in 1992 (Baker, 1994; U.S. Fish and Wildlife Service, 2011). The butterfly was once common across the upper 12 states of the Midwest and Eastern U.S. from Minnesota to Maine (Dirig, 1994), a classic meta-population with local populations (Givnish et al., 1988; Schweitzer, 1994). Today, native populations are isolated in New York, Michigan, and Wisconsin, reintroduced in Ohio, New Hampshire, Minnesota, and extirpated elsewhere (Haack, 1993; Chan & Packer, 2006; Hess & Hess, 2015). There are two major causes of the decline of the Karner blue. First, the species has an inherently limited dispersal range (less than 1 km) and habitat fragmentation restricts their range expansion (Swengel, 1993; Chan & Packer, 2006). Second, the Karner blue has complex habitat requirements (Lane & Andow, 2003), including the quality and quantity of resources needed by adults (i.e., adequate nectar sources) and larvae (i.e., host plant availability), as well as restricted thermal regimes (Packer, 1990; Grundel et al., 1998b; Lane & Andow, 2003; Dennis et al., 2006). Karner blue butterflies require high-quality oak savanna habitat on sandy or loamy sandy soils, the only landscape that supports wild blue lupine (*Lupinus perennis*). Oak savanna has been in decline for decades (Shuey, 1997; Opler & Malilul, 1998). Due to fire suppression, agricultural expansion, and urbanization (Grossmann & Mladenoff, 2007; Schetter & Root, 2011), less than 0.02% of historic savannas persist in the U.S. (Nuzzo, 1986; Pickens & Root, 2008; Fahey, Lindsay

& Jim, 2015). In recent years, these same areas have experienced changing climate, including prolonged drought in summer and milder springs and winters (Hess & Hess, 2015).

The effects of climate change on biodiversity and on entire ecosystems have been well-documented (Sparks & Carey, 1995; Walther et al. 2002; Parmesan 2006; Cramer et al. 2014), including changes in physiology, phenology, and species distributions (Parmesan et al., 1999; Parmesan & Yohe, 2003; Root et al., 2003; Møller et al., 2008). Butterflies can be useful indicators of how species respond to climate change (Warren et al. 2001; Wilson et al. 2005; Poyry et al. 2009; Diamond et al. 2011) because they are ectotherms and are widespread across heterogeneous landscapes (Bickford el al., 2011; Ohlberger, 2013). They also have complex life cycles with varying vulnerability through their life spans (Radchuk et al., 2013; Buckley et al., 2015). As a bivoltine species, the Karner blue overwinters as an egg until mid-April; matures from larvae to pupae around late-May; and experiences peak flight in June. A second generation occurs in July with peak flight and egg-laying in August (Grundel et al. 2000). The second generation is typically three to four times more abundant than the first generation (Grundel et al., 2000; U.S. Fish and Wildlife Service 2003; Chan and Packer, 2006). In this study, we investigated the effects of climate and microclimate factors, together with density dependence, on the historic population dynamics of Karner blue at multiple geographical scales (Hugall et al., 2002; Graham et al., 2006; Ruegg et al., 2006). As environmental factors may vary through the growing season, it was necessary to examine the two generations separately to gain an understanding on their interactions with Karner blue life cycles (Kingsolver et al., 2011; Walsh, 2016). In exploring climatic predictors using statistical models, we drew upon a growing literature that suggests ways that butterflies are sensitive to changing climatic conditions.

Thermal regime controls the survival of many ectothermic organisms (Overgaard & Sørensen, 2008; Sunday et al., 2011; Araújo et al., 2013). Climate change scenarios for the Midwest predicted exposure to higher temperatures, especially overwinter (Clusella-Trullas et al., 2011; Hoffmann et al., 2013). This could undermine the fitness of multivoltine species (Le & Haffner, 2008) if it causes earlier maturation and smaller body sizes (Terblanche et al., 2011; Horne et al., 2015). Specialist butterflies may be particularly susceptible to temperature changes (McKechnie & Wolf, 2010; Sentis, Hemptinne & Brodeur, 2013) experiencing declines in reproduction and increases in mortality (Jiguet et al., 2011). For instance, Long et al. (2017) found that severely low temperatures might be tolerated by overwintering eggs but detrimental to adults; whereas severely high temperatures had the opposite effect on eggs and adults. Consequently, understanding upper and lower thermal conditions (specifically, maximum and minimum temperatures experienced) (Zimmermann, 2009; Kellermann, 2012) is necessary for understanding climate impacts on butterflies. However, under warmer conditions, extra generations may appear, as has been reported anecdotally for the Karner blue (Fischer et al., 2004; Hopwood et al., 2016; English et al., 2016). Besides, thermal tolerance is usually specific to each life stage (Potter et al., 2011; Hettinger et al., 2012; Pincebourde & Casas, 2015; Klockmann et al., 2017), but heat stress can be conveyed from one stage to the next through ‘carry-over effects’ (Hernández Moresino, Gonçalves, & Helbling, 2014). Conditions experienced by one generation also affect subsequent generations through ‘transgenerational effects’ (Fox, 1997; Marshall, 2008; Donelson, 2016). Both carry-over and transgenerational effects should be taken into consideration when modeling responses to temperature (Bowler et al., 2008; Kingsolver et al., 2011) to incorporate the impact of organismal ontogeny (Pahkala, 2001; Radchuk, 2013; Fischer & Philips, 2014; Levy et al, 2015).

Precipitation patterns also are changing with the climate, and rainfall can be as important as temperature in affecting demography (Tingley, 2012; Gehne et al., 2016). For pollinators in particular, interactions with rainfall are intricate and scale-based. For example, rainfall can interfere with the process of pollen transportation and can dilute nectar (Eisikowitch & Woodell, 1975), leading to lower pollinator visitation rates and poorer host plant reproduction (Cnaani et al. 2006). For some butterfly species, it has been shown that total monthly precipitation is a better predictor of population abundance than either temperature or relative humidity (Shahabuddin & Ponte, 2005; Wallisdevries, Baxter & van Vliet, 2011). The explanation is that seasonal butterflies have uneven temporal distribution and patchy spatial patterns, exacerbating their vulnerability to more intense variations of rainfall (Pimm et al. 1988; Shahabuddin & Ponte, 2005). Compared to generalist butterflies, specialist butterflies can have higher sensitivity to drought or other conditions that affect the availability of host plants at the beginning or at the end of growing season (Hellmann 2002).

Terrain plays a key role in determining microclimates, which have distinct temperature and water availability (Weiss & Murphy, 1990). According to Lenoir et al. (2013), Villellas et al. (2013) and Pironon et al. (2016), geographic gradients across topographic conditions (i.e., slope, aspect, elevation) are usually decoupled from broad climatic gradients. Both wind speed/direction and solar radiation are affected by landscape texture (Geiger et al. 2003) and in turn, influence the local thermal and precipitation environment (Collins et al. 2013). For instance, south-facing slopes are generally warmer than north-facing slopes in the northern hemisphere (Geiger et al., 2009), and higher elevations are associated with cooler and drier conditions than lower altitudes (Fridley, 2009). According to Clausen et al. (2001), adult Karner blue butterflies prefer south-facing slopes that are warm and rich with wild lupine and nectar sources; however, butterfly reproductive success has been shown to be higher on cooler slopes because lupine has better quality and senesces later under those conditions. These attributes are especially helpful for the growth of the second generation when the area experiences extensive drought. This suggests that butterfly survival models should incorporate fine-scaled topo-climatic variables (De Frenne et al., 2013; Franklin et al., 2013; Potter et al., 2013). Moreover, distribution and survivorship of both the Karner blue and wild lupine are dependent on heterogeneous habitat patches with gradients in tree canopy cover (Knutson et al. 1999; Brown et al., 2011). Larvae tends to eat high-quality lupine that cluster under moderate shade, since heavily shaded areas can restrict lupine growth by the shortage of solar radiation, and canopy gaps without shade may trigger water stress (Grundel et al. 1998a; Lawrence, 1994).

Rather than using species distribution models (SDM) with population presence-absence as dependent variables and a 30-year normal climate dataset as predictors (Araújo et al., 2014; Elith &Graham, 2009; Franklin et al., 2013), incorporating environmental factors into autoregressive time-series can better portray how populations varied among years (Guiney, Andow, & Wilder, 2010). In addition, focusing on how long-term climate trends affect multiple stages of the lifecycle appears to be a meaningful approach for generating possible predictors of population dynamics (Hellmann et al., 2008). Consistent with those arguments, this study assumed the existence of carry-over and transgenerational effects in a series of mixed endo-exogenous models that captured the two generations of adult Karner blue. We used these models to test three major hypotheses. First, we asked if density-independent factors were as important as density-dependent effects in predicting population trend. Second, we asked how various sets of density-independent factors acted differently in the two generations of Karner blue within a year. Third, we asked how the best-fit models of Karner blue varied among locations and spatial scales.

Methods

Density-Dependent Data

We used time-series count data of adult Karner blue from five locations across the species' range, shared by the researchers who collected the data over decades (Figure 1). Populations were sampled during the flight period from late May to late June for the first generation, and from mid-July to mid-August for the second generation. For these five locations (Table 1), populations were assessed annually over time frames of 8 – 27 years on 48 sites in 3 states, and were counted along transects, a common method for population field surveys (Brown & Boyce, 1998).

We calculated population density index in each generation as the number of individuals per kilometer of transect, assuming a uniform detection function (i.e., identical individual detection probability with distance from the transect line) (following Buckland et al., 2001). At each site, surveys were repeated on average every 7 days, a time frame such that densities from individual surveys could be summed with little concern of double counting, given observed mean adult lifespans of about 3.5 days (Knuston, Kwilosz & Grundel, 1999). Although habitat management, like mowing and burning, periodically occurred onsite, we assumed that conditions in each site were constant over time and trend fluctuations were independent of management efforts. We also calculated between-generation density change as the difference between the current and the previous generation, with negative values indicating a decrease in density. We modeled both population density and between-generation change as separate response variables. These two variables have different biological meanings and distinct model interpretations.

Density-dependent effects were assessed by including flight-period population density of the preceding year. In similar models, Roy et al. (2001) found that including generations from more than the previous year did not increase explanatory power. Thus, in our study, population size of the first and the second generations of the previous year were incorporated as predictor variables in the first generation; predictors for the second generation were the first generation of the current year and the second generation of the previous year.

Density-Independent Data

Monthly climate data (Table 2) were downloaded from PRISM (Parameter-elevation Relationships on Independent Slopes Model)(PRISM Climate Group, 2004) as raster maps at a resolution of 30 arc-seconds (1/40th of a decimal degree). Each pixel was 800 m x 800 m (Watling et al., 2015). Temperature and precipitation in PRISM are gridded interpolations of climate data and digital elevation models (DEM) (Daly et al., 2008; O'Donnell & Ignizio, 2012). For each Karner blue popualtion, we used monthly climatic data that corresponded to the location and time period over which surveys were conducted. We examined twelve climate variables for the first generation: monthly minimum, maximum, and mean temperature, and total precipitation, each calculated over periods approximating three life stages: egg (Dec – Mar as overwinter), larvae and pupae (April – May as spring), and peak adulthood (June). Another set of twelve climate variables was applied to the second generation corresponding to egg (June), larvae and pupae (July), and peak adulthood (August).

Topographic variables, including slope and aspect, were also included as density-independent predictors. They were derived from 30 m DEMs obtained from US Topo (USGS, 2019) in ArcGIS (ESRI, 2019). The circular aspect layer was further converted to topographic solar radiation index (*trasp*) using the following linear transformation:

$$trasp = \{1 - \cos[(\pi/180)(\text{aspect-}30)]\}/2$$

Output of the equation is a continuous variable between 0 and 1 where north-oriented slope are assigned 0, and south-oriented slope are assigned 1 (Roberts & Cooper, 1989). Canopy coverage was extracted from 2011 National Land Cover Database (NLCD) USFS Tree Canopy Cover of CONUS from Multi-Resolution Land Characteristics (MRLC) Consortium at 30 m resolution (Wickham et al., 2017). We assumed that both topography and tree canopy cover had been constant over the past two decades. Finally, the geographic location of each site (latitude and longitude), was included as predictor variables to explore the effect of position within the distribution ranges of Karner blue.

Modeling Process

Both density dependence and density independence are essential for insect population dynamics (Stacey & Taper, 1992; Foley, 1994; Schultz & Chang 1998). We combined our density data with environmental explanatory variables to create mixed endo-exogenous models with a total of 21 variables per generation. The statistical models were built at two spatial scales: i) Level III ecoregion (Omernik & Griffith, 2014), and ii) integration of all populations in a single analysis.

At ecoregional scale, we found that each of the five Karner blue population groups was located in a distinct ecoregion (Figure 2). Besides, all the populations within the same ecoregions were surveyed with consistent sampling strategies through time by the same research teams (Table 1), allowing us to model across sites. We also modelled our entire population as one unit, rather than any specific population, for three reasons: first, density estimates for each population were too small to create robust models; second, variations among transect measurements at an individual site could be very high, particularly when local population density was low; third, there was no measured variance of topography or canopy on individual sites. The population sample sizes and the number of years in our data set varied among regions (Table 1). Thus, we used weighting adjustment, a common correction technique to reduce estimation bias (Herrando et al., 2019), with bootstrapping and oversampling the underrepresented classes (IN Dunes National Park, in specific, which had smallest sample size) in a training set (following Rota & Laitila, 2015).

Several diagnostics were carried out to check model assumptions. First, we plotted the density of multiple, adjacent Karner blue sites versus time. One of the characteristics of a meta-population is asynchronous fluctuations among the component populations (Levins, 1970). Second, we tested multi-collinearity among predictor variables with “rfUtilities” R package, which is more efficient than using VIF when many predictors are involved in models (Evans & Murphy, 2017). Third, we examined homogeneity, normality, and outliers of population density and between-generation density change, since any non-conformity may need transformation or alternative algorithms.

The R package “caret” (Kuhn, 2018) was then applied to evaluate all the mixed endo-exogenous models with five-fold cross-validation, repeated 100 times. The caret package can determine the best tuning parameter subsets (Kuhn, 2008) and includes more than two hundred model types. In this study, we applied six approaches to check model performance: two were regression-based algorithms – generalized linear model (GLM) and multivariate additive regression spline (MARS), and four were machine-learning algorithms – random forest (RF), gradient boost machines (GBM), support vector machines (SVM), and neural network analysis (ANN). We preprocessed low-variance predictors using principal component analysis (PCA) in all models, and standardized variables in regression-based algorithms with centering and scaling. We also calibrated the models with cross-validation, which is a data partitioning approach that divides the data into ‘training’ and ‘testing’ subsets (Watling et al., 2015). Since we did not have categorical variables, models were evaluated with mean absolute error (MAE), root-mean-square error (RMSE), and R-squared (R^2). Both MAE and RMSE are scale-dependent (Hyndman & Koehler, 2006), so it’s appropriate to use them within a single spatial scale, but not across scales.

We selected the genetic algorithm (GA) function in the "caret" package for feature selection, a wrapper method searching for the variable combinations with the best model performance and inspired by evolutionary global search (Saeys et al., 2007). Because of the high-dimensionality of the predictor space, GA typically results in less time to run models (John et al., 2014), in which an entire population of feasible solutions (or good fitness) is generated, and then repeatedly subjected to "cross-over" and "random mutation" until the combinatorial optimization with lowest Akaike Information Criterion (AIC) is discovered (Mitchell, 1998). A major problem for wrapper methods, however, is potentially overfitting the models. Therefore, partial least square (PLS) was applied as an additional method of feature selection using the jack-knife approach of the "mdatools" R package (Kucheryavskiy, 2018). This is a linear latent approach that is suitable when the matrix of predictors has more variables than observations (Kennedy & Neville 1986), identifying the estimated coefficient, standard error, and p-value of each predictor.

Finally, we juxtaposed the selection outputs from GA and PLS with variable importance rankings. Based on the rankings, we could identify the top explanatory variables (1 ~ 3 density-dependent predictors and 1 ~ 6 density-independent predictors), especially those with regression coefficients greater than 0.1 (Dormann et al., 2013). We also converted variable importance into ranking scores (ranging from 0 to 200) with weighting adjustment to make direct comparisons on the importance of each predictor between density models and between-generation change models, and between ecoregion and whole-species scales. This would let us gain a nuanced understanding on the roles played by multivariate realized climate and microclimate.

Results

Diagnostics and Modeling Algorithms

We did not find asynchronous fluctuation through time among populations in an ecoregion (Figure A1), which confirmed our assumption that there were no meta-population structures. We also did not find multi-collinearity among variables in any of the models applied. The distributions of population density, but not between-population change, were slightly right-skewed, so log transformation was applied to the density model when running the two regression-based algorithms (GLM and MARS). RF was always among the top three methods with lowest MAE and RSME, and highest R^2 (Table A1) for further feature selection process with GA.

PLS Regressions

For the first generation (Table 3), the following five variables emerged as significant across spatial scales and among ecoregions using either density or between-generation change models: population density of the second generation in the previous year (positive in density models and negative in between-generation change models, but not significant in Northwestern WI), population density of the first generation in the previous year (again, positive in density models and negative in between-generation change models, but not significant in Northwestern WI and Fort McCoy), overwinter mean temperature (negative, but not significant in Central WI and Northwestern WI), overwinter minimum temperature (positive at whole-species scale and in Central WI, and negative in Fort McCoy and Albany Pine Bush), and spring total precipitation (all were negative, but not significant in Northwestern WI, IN Dunes National Park, and Albany Pine Bush). The mean and maximum temperatures and total precipitation in June, plus spring mean and minimum temperatures, were not significant in any ecoregion, except a strong positive association between spring mean temperature and population density at whole-species scale. Other climate variables were only statistically significant in certain ecoregions. For example, spring maximum temperature was consistently positive, but only significant in Central WI and Albany Pine Bush. For density models solely, canopy cover had negative coefficients in Northwestern WI and the IN Dunes National Park; elevation, slope, and *trasp* were also negatively associated with population density in Northwestern WI.

For the second generation, the following five variables emerged as significant across spatial scales and among ecoregions using either density or between-generation change models: population density of the previous-year second generation (positive), August mean temperature (positive, but not significant in IN Dunes National Park and at whole-species scale), August maximum temperature (positive in Northwestern WI, Fort McCoy, and Albany Pine Bush, and negative in Central WI and at whole-species scale, but not significant in IN Dunes National Park), June minimum temperature (positive, but not significant in Central WI and IN Dunes National Park), and July total precipitation (positive, but not significant in Albany Pine Bush). Only June total precipitation was not significant in any model. For the rest of climate variables that were only statistically significant in certain ecoregions, the mean, and maximum temperatures in June and the mean and minimum temperatures in July were consistently positive; whereas July maximum temperature and August total precipitation were mixed. Canopy cover was positively associated with population density in Northwestern WI, but negative in IN Dunes National Park, and the three topographical predictors were consistently negative.

Variable Importance

Three variables best described the variance in first-generation Karner blues (Table 4): previous-year second-generation density, spring total precipitation, and previous-year first-generation density; those three were followed by growth parameter, and overwinter mean and minimum temperatures. June temperatures and precipitation had low or zero importance. Comparing density models with between-generation change models: spring temperatures had much higher ranking scores in the density models than the between-generation change models. On contrary, climate variables generally had much higher ranking scores than topographical variables in the between-generation change models. Comparing whole-species with ecoregion scales: there were nine variables (four June climate predictors, four topography predictors, and spring minimum temperature) had zero importance scores in the whole-species models, but only June mean and maximum temperatures were zero in the ecoregion models.

For the second generation, previous-year second-generation density, current-year first-generation density, and July total precipitation were the top three ranked variables, followed by August maximum temperature and June minimum temperature. Comparing density models with between-generation change models: four August climate variables had much higher ranking scores in the density models than the between-generation change models; whereas July climate variables were the reverse. Comparing whole-species with ecoregion scales: June minimum temperature and slope were much more important at whole-species scale than at ecoregional scale; however, June maximum temperature, August minimum temperature, and the other three topography variables (except slope) had zero importance scores at whole-species scale.

Model Equations

Density-dependent variables, previous-year second-generation density in particular, were retained in all the models (Table 5) with largest estimated coefficients. In the first generation, overwinter minimum temperature and spring total precipitation were generally shared across models, overwinter total precipitation was specific to density models, and June minimum temperature was specific to change models. Spring minimum and June mean and maximum temperatures were not present in any models. In the second generation, June minimum and August maximum temperatures and July total precipitation were generally shared across models, and August mean temperature was specific to density models. June total precipitation was not present in any models. All the other climate predictors not mentioned were locally-specific. Both first-generation models of Northwestern WI were not well dependent upon any climatic factor. Tree canopy cover and topography were especially important in Northwestern WI and IN Dunes National Park, and slope was particularly important in the second-generation whole-species model.

The R^2 ranged from 0.22 to 0.85, with the values relatively smaller at whole species scale than ecoregion scales, and greater in the Northwestern WI, IN Dunes National Park, and Albany Pine Bush, perhaps since the populations in these three regions were spatially closer together and had smaller sample sizes. Not all the variables kept in the equations were statistically significant (p-value < 0.1). Standard Error of climatic variables was generally small, ranging from 0.01 to 3.0, and was smaller than Estimated Coefficient, indicating the relatively high certainties of Karner blue's responses to climate.

Discussion

The mixed endo-exogenous models established differed among ecoregions, across generations, and between the two dependent variables (i.e., density and between-generation density change). This implicated the roles for both density-dependent and density-independent environmental factors in the dynamics of the Karner blue and the patterns in sensitivity of this endangered species across its range (Ward et al., 2014). In the next chapter, we turned to the literature about the Karner blue and similar butterflies to suggest the processes that could underlie those sensitivities.

Our primary finding was that density dependence was a stronger driver of Karner blue population trends than density independence (consistent with Nowicki et al., 2009; Bancila et al., 2016). This indicated that climate fluctuations could be overwhelmed by density dependent effects in the absence of consistent environmental changes or extreme climate events (Opdam & Wasscher, 2004; Oliver et al., 2015). The positive density dependence in the density models, in the form of steadily decreasing population trends, was possibly related to population bottlenecks and Allee effects (Swengel et al., 2011). The negative density dependence in the between-generation change models resulted in a seasonal fluctuation pattern: the second generation was generally more abundant than the first generation of the same year (Swengel & Swengel, 2018). This could be caused by timing of wild lupine growth (Freckleton et al., 2006): the larvae of first generation survives several months overwinter and feeds on newly sprouted wild lupine leaves as the insects emerge from dormancy, whereas the larvae of the second generation is hatched a week after eggs are laid on mature wild lupine leaves with better nutrient quality.

The detrimental effects of higher overwinter temperatures and total precipitation on the first-generation flight-period density in most ecoregions and in the whole-species model were consistent with previous research on the Karner blue (Dennis & Sparks, 2007; Defra, 2009; Jenkins et al. 2009; Long et al., 2017). Three major mechanisms have been shown to be important to overwinter survival of butterflies. First, heat stress in the egg stage has been shown to denature proteins and membrane structure (Chown & Terblanche, 2006), leading to dehydration (Potter, Davidowitz, & Woods, 2009) and reduced hatchling success (Klockmann, Kleinschmidt & Fischer, 2017). Second, warm, moist conditions might cue earlier hatching and subsequent mortality from limited food sources (Wiklund, Lindfors & Forsberg, 1996; McLaughlin et al., 2002; Patterson et al., 2019). Third, incidence of overwinter diseases, such as fungal infections, could increase under elevated temperature and precipitation (Harvell, 2002). These negative effects on the egg stage could be carried over to subsequent life stages, resulting in higher mortality during flight periods (Weinig & Delph, 2001; Zhang et al., 2005; Potter, Davidowitz, & Arthur, 2011). Overwinter minimum temperature in Central WI exhibited positive association with first-generation population density for unknown reasons, a finding similar to that of Swengel & Swengel (2018) on the Karner blue.

We also found that elevated spring temperatures benefited first-generation peak flight density in all ecoregions and in whole-species models, suggesting that spring temperature might be important to the final larval instar stage, accelerating metamorphosis (Shingleton, 2011). Higher temperatures (mean, minimum, and maximum) during the pupal stage had been demonstrated to cause earlier maturation in other butterfly species (Dennis, 1993; Roy et al. 2001; Horne, Hirst & Atkinson, 2015;

Fenberg et al., 2016), though multivoltine species, like the Karner blue usually develop smaller adult sizes under higher spring temperature (Sheridan & Bickford, 2011). The strong adverse effects of higher spring total precipitation on first-generation population density in most ecoregions and in whole-species models indicated that the shortage of rainfall may not be harmful to larval and pupal developments, and wild lupine is relatively drought-tolerant when water stress is not a problem in spring, supporting the negative association between seasonal butterfly abundance and spring monthly rainfall observed in previous research (Checa et al., 2016). It also supported the microclimatic cooling hypothesis that better plant growth under plentiful rainfall would cause a shading effect, with the larvae suffering from cooler microclimate and lupine senescing more quickly underneath shaded leaves (Wallis De Vries & Van Swaay, 2006).

June temperatures and precipitation were rarely significant except for the minimum temperature for the populations in Central WI. This result contradicted previous research on the positive associations between temperature and population abundance unless exposed to severely high temperatures (Calvert, Zuchowski & Brower, 1983; Warren et al., 2001; Wallis De Vries, Baxter & van Vliet, 2011), and the negative association of precipitation during adult phase because of the nectar dilution effect (Long et al., 2017). This indicated that the stress experienced early in the lifecycle might not be compensated for during flight period. The negative effect of June minimum temperature for the populations in Central WI might be caused by the increasing energy expenditures for flight activity under high temperatures (Ghosh, Testa & Shingleton, 2013).

In the second generation, the positive association between temperature and population dynamics was apparent. According to Long et al. (2017), a warm summer tends to be conducive to butterflies. Higher June mean and minimum temperature might promote better host plant quality (wild lupine in this case) that enhances the feeding of larvae and provides a longer growing season with increased number of sunny days (Higgins et al. 2014), resulting in larger adult sizes (Horne, Hirst & Atkinson, 2015). Higher July temperatures could also lead to earlier adult emergence, with a greater probability that a third generation would be produced (Roy et al., 2001). Lower August temperatures (maximum temperature, in particular) may result in localized extinction (Lawson et al. 2012 & 2013), whereas a warmer August may extend flight periods and facilitate nectar plant growth as food sources for the Karner blue (Brown, Kenny & Corry, 2011). In addition, higher August temperature has been shown to correlate with higher egg-laying rate, so the benefit of warming could be extended to the next generation (Thomas et al. 2001; Davies et al. 2006).

Adverse effects of July maximum temperature and August mean and maximum temperatures on second-generation population density in Central WI perhaps resulted from water stress in hot summer on wild lupine and other nectar sources, heightening vulnerability of Karner blue (Knutson et al. 1999; Roy et al., 2001). With similar mechanism, the uniformly positive influence of total precipitation, especially in July, indicated that rainfall can help alleviate drought influences (O'Brien et al. 2004; Guiney, Andow, & Wilder, 2010) and may also reduce parasites and other natural enemies (Pollard, 1991; Dooley et al., 2013). Extinction of populations at IN Dunes National Park has been attributed to drought in recent decades that led to desiccation of host and nectar plants, impairing reproduction of Karner blue (Wallis De Vries, Baxter & van Vliet, 2011).

Overall, weather-related, density-independent processes (e.g., senescence timing of host plants) were also proved as important to population dynamics for this temperate butterfly (Hellman et al. 2002). Actually, it's a combination of temperature and precipitation, with density dependence, that best predicted Karner blue population trends (Sinclair et al., 2016), and minimum and maximum temperatures appeared as crucial as mean temperature (Zimmermann, 2009; Kellermann, 2012). Temperature generally had a positive effect on Karner blue abundance except during the winter (Frazier et al., 2006): perhaps elevated temperature enabled individuals to gradually reach their physiologic optimum (Savage et al., 2004), overriding harmful effects of warmer winter (Kingsolver, 2009). Although temperature is often considered to be the primary climatic driver of targeted species, our study showed that precipitation, especially during spring and July, was also a key driver (McDermott Long et al., 2016). Since previous studies were either purely density-dependent or based on presence-absence data, rather than population count data, these results added new insights into how Karner blue might respond to a variety of climate factors.

As for microclimate, we found tree canopy cover was negatively associated with population density of both generations in IN Dunes National Park and first generation in Northwestern WI, and positively associated with population density of second generation in Northwestern WI. This may suggest that the photosynthetic activity of lupine could be increased by receiving more solar insolation (Holl, 1995) during Karner blue's first generation if tree canopy gaps are larger to compensate for relatively low temperatures in these two regions (Lane & Andow, 2003). During second generation, extensive tree canopy cover might offer both thermal refugia for populations (Grundel et al., 1998; Grundel & Pavlovic, 2007) and suitable moisture conditions for lupine and other nectar species to prevent them from senescing too early (Plowright, 1981 & 1987; Cresswell & Galen, 1991) in Northwestern WI where has warmer summer; whereas the Northern Lakes and Forests ecoregion, where the populations of IN Dunes National Park were located, often experiences mild winters, cool summers, and high humidity (Omernik et al., 1988) because of its adjacency to Lake Michigan, resulting in the benefits of low tree canopy cover. In the other three ecoregions, open areas may also contain a high percentage of grass and herb covers which compete with wild lupine (Leach, 1993); whereas under extensive shadings, plant growth would be limited by lack of sufficient solar radiation (Nicolson & Thronburg, 2007). Thus, neither full gap nor full shade was able to support high abundance of Karner blues (Turner et al., 1987; Currie, 1991; Hawkins et al., 2003); rather, an intermediate canopy cover with moderate shading might be ideal (Grundel et al., 1998) – this nonlinear pattern might explain why it didn't vary significantly in either positive or negative direction.

Similarly, topographic predictors were not significant in Central WI, Fort McCoy, or Albany Pine Bush, probably because the ecoregional climate effects overwhelmed the microclimate effects formed above different topographic landscape features, and the low wind microclimatic habitat preferred by butterfly species could be more readily found in a more complex landscape (Brown et al., 2011). In IN Dunes National Park and Northwestern WI, however, the negative regression coefficients of elevation confirmed the "elevational microclimate effect" that the scarcity of soil moisture might be more severe at higher altitude (Fridley, 2009; Rajczak et al., 2013). Both negative slope and *trasp* coincided with the findings of Clausen et al. (2001) and

Geiger et al. (2009): north- and east-facing gentle slopes were related to higher survivorship of wild lupine which tend to senesce later, leading to greater reproductive success of the butterflies, since they were much cooler than south- and west-facing steep slopes in the northern hemisphere.

Karner blue is a specialist species, though unlike generalist species whose position within the species' range is an important factor determining sensitivity to climate change and population distributions (Garcia et al., 2000; Warren et al. 2001; Hellmann et al. 2008), there is usually a larger safety margin of temperature of the thermal tolerance at the northern edge than at the southern edge (Sunday et al. 2014). This asymmetrical fitness to thermal gradient (Araujo et al., 2013) could well explain why no climatic variables were significant overwinter in Northwestern WI: these populations were at the northern edge of Karner blue's range, where annual temperatures were lowest among the five ecoregions with shortest growing season, so they are more limited by the phenology of wild lupine than climate (Bjørnstad & Grenfell, 2001; Deutsch et al., 2008).

Using the predictors to model both generations separately was helpful to identify timing of long-term effects of temperature and precipitation on lifecycles with relatively high certainties (Roy et al., 2001): consistent with previous research, the first-generation adult stage typically showed less sensitivity to climate variables compared to the second-generation adult stage (Long et al., 2017). In addition, the ecoregion-specific differences in significant variables could be caused by local adaptation (Ayres & Scriber, 1994; Myers-Smith et al., 2015), because each ecoregion had a unique combination of climate, topography, soil, hydrology, and plant communities (Wood et al., 2016). Conversely, at the whole-population scale, because of the considerable spatial heterogeneity, some strong correlations at ecoregion scale may have been dampened, as demonstrated by smaller R^2 at whole-population scale than ecoregion scale. Therefore, models at ecoregion level might be preferable to whole-species integration for conservation purposes and for directing management plans.

Detectability may have influenced our results. The Karner blue is a rare, seasonal species, which means that observations of zero individuals along a transect might occur even though they were actually present (Swengel & Swengel, 2017). Our calculations of population density assumed all individuals along a transect were detected, and that they were randomly and evenly distributed within the habitat. However, one might expect that Karner blue individuals were clustered close to wild lupine, and that transects were placed perpendicular to density gradients (Buckland, 2004). Further, we determined that our Karner blues did not function as a meta-population because there were synchronous fluctuations within ecoregions. However, Karner blue meta-populations have been reported from recolonizations on disturbed sites (Guiney, Andow, & Wilder, 2009; Schultz et al., 2017). Moreover, essential assumptions in our study included “carry-over” and “transgenerational” effects, which were the basis for our inferences about climate effects from other life stages or previous generations. Tree canopy cover and topography were low-variance predictors compared to climate predictors because they varied across space but not with time. However, reprocessing using PCA in this study appeared to have dealt well with this issue and highlighted the influence of tree canopy cover and topography on population trends (Markus Ringnér, 2008).

In order to have a comprehensive understanding of the mechanisms through which Karner blue responds to climate change, we suggest that future studies involve additional variables including microclimate, sexual dimorphism, lupine dynamics, soil textures, ants, and management efforts including herbicide application and burning (Diamond & Kingsolver, 2010; Stillwell et al., 2010; Forster, Hirst & Atkinson, 2012; Ghosh, Testa & Shingleton, 2013). Those variables would augment PRISM climatic data and allow future researchers to better understand the role of biotic interactions. The abundance of adults does not necessarily reflect total population abundance (Kishimoto-Yamada & Itioka, 2015), so data for immature stages can be very helpful. Bioclimatic variables, reflecting seasonal trends and extreme conditions (Nix, 1986), could be good indicators if target species have large geographic ranges (Araújo & Guisan, 2006). However, such variables were not appropriate in our study because the correspondence would be blurred: for instance, one of the bioclimatic variables was precipitation of warmest quarter, but "warmest quarter" could vary among years and locations. Pollard and Yates (1993) found that monthly climate predictors, like monthly mean temperature and monthly total precipitation, had twice the effects on butterfly abundance as did extreme climate predictors, because monthly climate, rather than bioclimatic data possesses more direct and proximal influences on the physiologic responses (Austin, 2002 & 2007) of the Karner blue. Moreover, extremes are defined as the number of days exceeding certain thresholds during certain time periods, a level of details too fine-scale for our study with so many populations and long history of monitoring records. Hopefully, the factors mentioned above plus interactions among variables could be incorporated in future researches on the Karner blue.

Illustrations

Table 1. Summaries of long-term Karner blue population count data during flight periods shared from other Karner blue researchers, including sampling methods, sampled populations, dates & durations, and contributors

Location	County	Group	Sampling Method	Sampled Population	Date & Duration	Data Source
Wisconsin	Jackson	Central WI	Unlimited Width Linear Transect	8	1990 - 2018	Ann & Scott Swengel (Independent Researchers)
	Wood			5	1990 - 2018	
	Portage			1	2000 - 2018	
	Burnett	NW WI		8	2005 - 2013	
	Monroe	Fort McCoy	Fixed Width Linear Transect	12	1997 - 2018	Tim Wilder (Department of Defense)
Indiana	Porter	IN Dunes National Park	Walkthrough Count	6	1994 - 2011	Randy Knuston (National Park Services)
New York	Alany	Albany Pine Bush	Unlimited Width Linear Transect	8	1995 - 2018	Steven Campbell (APB Commission)

Table 2. Summaries of three categories of density-independent data applied in this study, including specific variables, years, resolutions, extents, and sources.

	Monthly Climate	Topography	Canopy Cover
Variable	12 (each G)	4	1
Year	1990 ~ 2019	2018	2011
Resolution	30 arc-seconds	1 arc-second	1 arc-second
Extent	U.S. CONUS	Midwest	U.S. CONUS
Source	PRISM	U.S. TOPO	MRCS NLCD

Table 3.a-b. Regression coefficients of significant variables ($p < 0.1$), predicted by partial least squares (PLS), at whole-species and (five) ecoregion scales for first and the second generations. The values ranged from -10 to +10, and were categorized into six different colors (red: 1~10; orange: 0.1~1; yellow: 0.01~1; green: -0.01~-0.1; blue: -0.1~-1; purple: -1~-10). Non-significant variables were all highlighted in gray, and the five shared significant variables for each generation were bolded, respectively.

(3.a). First Generation

	Whole Species Integration		Central Wisconsin		Northwestern Wisconsin		Fort McCoy Wisconsin		Indiana Dunes National Park		Albany Pine Bush New York	
	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change
GR							🟦	🟪			🟧	
PS	🟧	🟪	🟧	🟪		🟪	🟧	🟪	🟧	🟪	🟧	🟪
PF	🟧		🟧	🟪					🟧	🟪		🟪
MT_OW	🟩	🟪						🟦		🟦	🟩	🟦
MT_SP	🟨	🟥										
MT_JN												
AT_OW			🟦	🟪					🟩		🟩	
AT_SP	🟨		🟨								🟧	🟥
AT_JN												
IT_OW	🟨	🟥	🟨	🟥			🟦	🟪			🟦	🟪
IT_SP												
IT_JN				🟪								
PT_OW							🟦		🟦		🟦	🟪
PT_SP	🟦	🟪	🟦	🟪			🟦	🟪				
PT_JN												
Canopy					🟩				🟩			
Elevation					🟩							
Slope					🟩							
Trasp					🟩							
Location												

(3.b.) Second Generation

	Whole Species Integration		Central Wisconsin		Northwestern Wisconsin		Fort McCoy Wisconsin		Indiana Dunes National Park		Albany Pine Bush New York	
	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change
GR	⬜	⬜	🟧	⬜	⬜	⬜	🟨	⬜	⬜	⬜	⬜	⬜
PS	🟧	⬜	🟧	⬜	⬜	⬜	🟧	⬜	🟧	⬜	🟧	🟧
CF	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟧	🟧	⬜	🟧	⬜
MT_JN	⬜	⬜	⬜	🟨	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
MT_JL	⬜	⬜	⬜	⬜	⬜	⬜	🟨	⬜	⬜	⬜	⬜	🟨
MT_AG	⬜	⬜	🟨	⬜	🟨	🟨		⬜	⬜	⬜	🟨	⬜
AT_JN	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟨	⬜	⬜	⬜
AT_JL	🟩	🟩	🟩	🟩	⬜	⬜	🟨	⬜	⬜	⬜	⬜	⬜
AT_AG	🟩	🟩	🟩	🟩	🟨	🟨	🟨	⬜	⬜	⬜	⬜	🟨
IT_JN	🟨	🟨	⬜	⬜	🟨	⬜	⬜	🟧	⬜	⬜	⬜	🟨
IT_JL	🟨	⬜	🟨	🟨	⬜	⬜	🟨	⬜	⬜	⬜	⬜	⬜
IT_AG	⬜	⬜	⬜	⬜	⬜	🟨	⬜	⬜	⬜	⬜	🟨	🟨
PT_JN	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
PT_JL	🟨	🟨	🟨	🟨	🟨	🟨	⬜	🟧	🟨	⬜	⬜	⬜
PT_AG	⬜	⬜	⬜	⬜	⬜	🟨	🟩	⬜	⬜	⬜	⬜	⬜
Canopy	⬜	⬜	⬜	⬜	🟨	🟨	⬜	⬜	⬜	🟩	⬜	⬜
Elevation	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	🟩	🟦	⬜
Slope	🟩	🟦	🟩	🟦	⬜	⬜	⬜	🟦	⬜	🟩	⬜	⬜
Trasp	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜
Location	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

🟥	🟧	🟨	⬜	🟩	🟦	🟪
10 – 1	1 – 0.1	0.1 – 0.01	0.01 – 0 – -0.01	-0.01 – -0.1	-0.1 – -1	-1 – -10

Table 4.1-b. Variable importance ranking scores, ranging from 0 to 200, calculated from the outputs of genetic algorithms (GA). They were grouped by density model VS between-population change model and ecoregion scale VS whole-species scale, for the first and second generations, respectively.

(4.a). Density Models VS Change Models

	First Generation				Second Generation			
	Density Models		Change Models		Density Models		Change Models	
150-200	PS		PS		CF	PS	PS	
100-150	PT_SP	PF	PT_SP	PF	PT_JL		PT_JL	
50-100	IT_OW	GR	IT_OW	MT_OW	IT_JN	AT_AG	AT_AG	IT_JN
	MT_OW	AT_SP	GR	PT_OW	MT_AG	PT_AG	CF	AT_JL
	MT_SP	AT_OW			AT_JL		Slope	MT_JL
0-50	PT_OW	PT_JN	AT_OW	IT_JN	Slope	IT_JL	GR	IT_JL
	Elevation	Canopy	PT_JN	AT_SP	GR	MT_JL	MT_AG	Canopy
	Slope	Trasp	MT_SP	Canopy	Canopy	MT_JN	PT_AG	Elevation
			Elevation	IT_SP	Elevation	AT_JN	IT_AG	MT_JN
					Trasp	IT_AG	Trasp	
0	MT_JN	IT_SP	MT_JN	AT_JN	PT_JN		AT_JN	PT_JN
	IT_JN	AT_JN	Slope	Trasp				

(4.b). Ecoregion Scale VS Whole-Species Scale

	First Generation				Second Generation			
	Ecoregion Scale		Whole-Species Scale		Ecoregion Scale		Whole-Species Scale	
150-200	PS		PS		PS		PS	
100-150	PT_SP		PT_SP	PF	CF	PT_JL	CF	PT_JL
			MT_OW				IT_JN	
50-100	PF	IT_OW	IT_OW	MT_SP	AT_AG	MT_AG	AT_AG	Slope
	PT_OW	GR	AT_OW		AT_JL		AT_JL	
	MT_OW	AT_SP						
	PT_JN							
0-50	AT_OW	IT_JN	GR	PT_OW	IT_JL	MT_JL	GR	PT_AG
	Canopy	Elevation	AT_SP		IT_JN	Slope	MT_AG	MT_JN
	MT_SP	Slope			PT_AG	Canopy	IT_JL	PT_JN
	IT_SP	Trasp			GR	Elevation	MT_JL	
					MT_JN	Trasp		
					IT_AG	AT_JN		
0	MT_JN	AT_JN	MT_JN	AT_JN			AT_JN	IT_AG
			IT_SP	IT_JN			Canopy	Elevation
			PT_JN	Canopy			Trasp	
			Elevation	Slope				
			Trasp					

Table 5.a-d. Best-fit density and between-generation change model equations at whole-species and (five) ecoregion scales for the first and the second generation, separately, based on GA and PLS feature selections. The Estimated Coefficient (EC), Standard Error (SE), and p-value of the predictors in the equations were included. The R-squared value of each model equation were included next to the spatial levels.

(5.a). Density Models for First Generation

	Whole Species (0.409)			Central WI (0.418)			Northwestern WI (0.606)			Fort McCoy (0.424)			IN Dunes National Park (0.753)			Albany Pine Bush (0.615)		
	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value
GR				0.08	0.08	0.198				-0.25	0.09	0.057				0.25	0.07	0.026
PS	0.38	0.08	0.007	0.25	0.10	0.050	0.08	0.06	0.230	0.77	0.10	0.001	0.58	0.08	0.002	0.48	0.10	0.007
PF	0.23	0.06	0.014	0.17	0.05	0.029							0.32	0.04	0.001			
MT_OW																-0.10	0.03	0.036
MT_SP	0.05	0.02	0.040							0.04	0.05	0.125						
MT_JN																		
AT_OW																-0.02	0.03	0.026
AT_SP	0.05	0.01	0.010	0.09	0.03	0.056												
AT_JN																		
IT_OW	0.03	0.01	0.072	0.14	0.03	0.024				-0.11	0.06	0.022				-0.14	0.01	0.001
IT_SP																		
IT_JN																		
PT_OW										-0.22	0.04	0.004	-0.14	0.06	0.088	-0.19	0.04	0.008
PT_SP	-0.21	0.03	0.003	-0.35	0.03	0.000				-0.18	0.08	0.085						
PT_JN																		
Canopy							-0.03	0.01	0.060				-0.02	0.01	0.074			
Elevation							-0.08	0.02	0.014				-0.04	0.06	0.380			
Slope							-0.04	0.01	0.011				-0.03	0.03	0.254			
Trasp							-0.04	0.01	0.018				-0.01	0.07	0.263			
Location																		

(5.b). Density Models for Second Generation

	Whole Species (0.468)			Central WI (0.447)			Northwestern WI (0.523)			Fort McCoy (0.478)			IN Dunes National Park (0.785)			Albany Pine Bush (0.733)		
	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value
GR				0.13	0.04	0.031				0.08	0.01	0.004				0.09	0.06	0.162
CF	0.36	0.08	0.013	0.38	0.10	0.052				0.16	0.04	0.010	0.48	0.11	0.012	0.68	0.15	0.011
PS	0.24	0.08	0.045	0.18	0.07	0.062	0.06	0.02	0.019	0.18	0.05	0.016	0.35	0.07	0.009	0.17	0.10	0.039
MT_JN																0.07	0.04	0.198
MT_JL										0.08	0.01	0.003						
MT_AG				0.03	0.01	0.053	0.03	0.02	0.074							0.05	0.02	0.035
AT_JN													0.05	0.03	0.089			
AT_JL	-0.04	0.02	0.063							0.07	0.02	0.037						
AT_AG	-0.06	0.03	0.098	-0.06	0.02	0.032	0.03	0.01	0.025	0.10	0.02	0.007						
IT_JN	0.06	0.02	0.019	0.03	0.02	0.249	0.02	0.01	0.016									
IT_JL							0.05	0.02	0.094	0.09	0.01	0.001						
IT_AG																0.06	0.03	0.068
PT_JN																		
PT_JL	0.06	0.02	0.019	0.08	0.06	0.025	0.04	0.03	0.024				0.08	0.05	0.062			
PT_AG																		
Canopy							0.06	0.02	0.049				0.02	0.03	0.304			
Elevation													-0.02	0.05	0.306			
Slope	-0.07	0.02	0.011										-0.07	0.06	0.293			
Trasp													-0.06	0.03	0.154			
Location																		

(5.c). Change Models for First Generation

	Whole Species (0.453)			Central WI (0.448)			Northwestern WI (0.849)			Fort McCoy (0.301)			IN Dunes National Park (0.732)			Albany Pine Bush (0.591)		
	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value
GR										-2.47	0.99	0.062						
PS	-7.92	3.00	0.028	-8.84	3.59	0.037	-7.94	3.51	0.013	-1.80	1.23	0.022	-8.15	3.86	0.097	-4.62	2.18	0.094
PF				6.33	2.18	0.046							-8.84	1.46	0.004	-6.84	1.20	0.005
MT_OW	-6.91	2.22	0.038							-0.74	0.29	0.070	-0.95	0.16	0.004	-0.86	0.28	0.038
MT_SP	2.57	0.80	0.033															
MT_JN																		
AT_OW				-9.80	2.52	0.017				-0.29	0.27	0.337						
AT_SP																2.19	0.41	0.006
AT_JN																		
IT_OW	6.27	2.09	0.042	7.94	1.62	0.008				-1.06	0.39	0.053				-1.87	0.70	0.060
IT_SP																		
IT_JN	-3.16	1.39	0.192	-5.63	1.31	0.014				1.08	0.44	0.073						
PT_OW																-2.71	0.20	0.000
PT_SP	-5.26	0.53	0.001	-9.55	0.41	0.000				-1.61	0.49	0.029	-2.77	1.70	0.183			
PT_JN				3.37	1.26	0.054												
Canopy							-0.51	0.62	0.383				-0.28	0.22	0.252			
Elevation							-1.12	0.64	0.148				0.87	0.72	0.301			
Slope							-0.52	0.38	0.138				1.12	0.70	0.189			
Trasp							-0.18	1.06	0.308				1.47	0.70	0.105			
Location																		

(5.d). Change Models for Second Generation

	Whole Species (0.225)			Central WI (0.296)			Northwestern WI (0.391)			Fort McCoy (0.368)			IN Dunes National Park (0.319)			Albany Pine Bush (0.296)		
	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value	EC	SE	p-value
GR																		
CF	-0.36	0.22	0.172	-0.47	0.11	0.140				-0.92	0.54	0.207				0.14	0.12	0.281
PS	0.21	0.06	0.021	0.15	0.04	0.021	0.07	0.03	0.091	0.40	0.15	0.087	0.08	0.07	0.282	0.13	0.07	0.012
MT_JN				0.05	0.02	0.037												
MT_JL										0.05	0.03	0.145						
MT_AG							0.04	0.02	0.058							0.08	0.03	0.045
AT_JN																		
AT_JL	-0.04	0.04	0.035	-0.09	0.04	0.096												
AT_AG	-0.07	0.04	0.016	-0.09	0.04	0.077	0.04	0.02	0.063	0.14	0.08	0.133				0.08	0.03	0.045
IT_JN	0.08	0.02	0.011							0.46	0.36	0.096				0.08	0.03	0.081
IT_JL				0.06	0.03	0.067												
IT_AG							0.05	0.02	0.081							0.08	0.03	0.055
PT_JN																		
PT_JL	0.09	0.04	0.076	0.09	0.02	0.022	0.05	0.03	0.085	0.20	0.08	0.056	0.02	0.02	0.264			
PT_AG							0.04	0.03	0.041									
Canopy							0.08	0.02	0.022				0.08	0.01	0.004			
Elevation													-0.03	0.02	0.086			
Slope	-0.10	0.03	0.023	-0.11	0.03	0.011				-0.29	0.05	0.005	-0.09	0.02	0.008	0.06	0.04	0.155
Trasp													-0.07	0.02	0.010			
Location																		

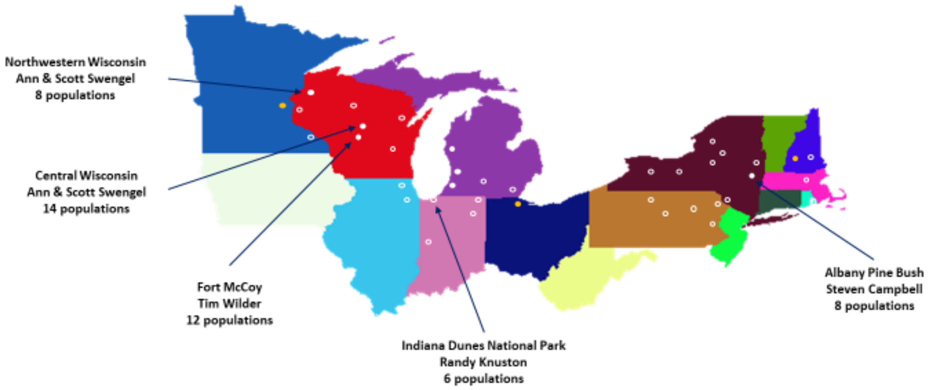


Figure 1. Locations of Karner blue butterfly's habitats in Central Wisconsin, Northwestern Wisconsin, Fort McCoy (Wisconsin), Indiana Dunes National Park, and Albany Pine Bush (New York). White filled circles represent extant Karner populations, open circles represent historical Karner populations that are now extinct, and yellow filled circles represent sites with Karner reintroduction management ongoing.

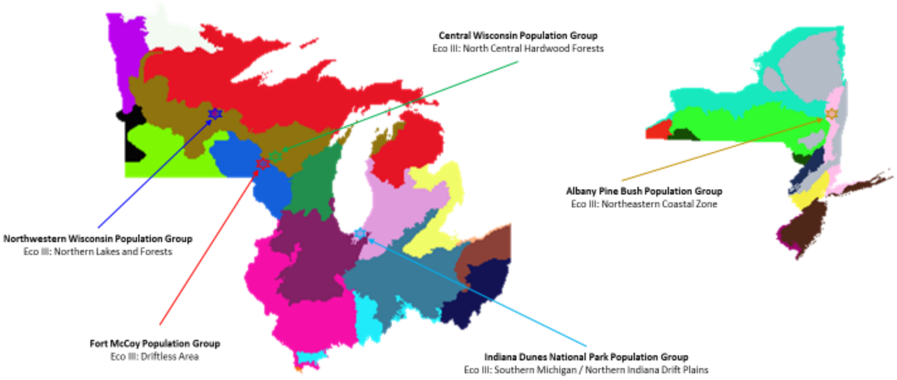


Figure 2. EPA ecoregions level III. Karner blue populations were grouped into five regions (Central Wisconsin, Northwestern Wisconsin, Fort McCoy, Indiana Dunes National Park, and Indiana Dunes National Park) for analysis. The five groups belongs to five distinct ecoregions (North Central Harwood Forests, Northern Lakes and Forests, Driftless Area, Southern Michigan/Northern Indiana Drift Plain, and Northeastern Coastal Zone, respectively).

Chapter 2

Sensitivity analysis and forecasting of extinction risk and distribution shift for Karner blue butterfly using mixed endo-exogenous models

Introduction

Climate change has already significantly impacted global ecosystems (Ryan & Vose, 2012), causing northward shifts in latitude, upward shifts in elevation, and other changes in species' geographic ranges. These changes are consistent with the historic response to climatic changes in the paleo-ecological record (Thomas & Lennon, 1999; Davis & Shaw 2001; Parmesan 2006; Seimon et al,. 2007; Lenoir et al. 2008). According to Loarie et al. (2009), global mean temperature and annual precipitation are projected to change at an average velocity of 0.42 and 0.22 km per year, respectively. The ability of species to keep pace with these changes is dependent on availability of suitable habitat and the species' dispersal ability (Pearson, 2006; Sutherland et al., 2000). Species that cannot shift quickly risk losing habitat and experiencing range contractions (Foden et al. 2007; Bertrand et al. 2011; Devictor et al. 2012) (Parmesan et al. 1999; Foden et al. 2013; Warren et al. 2013). As temperatures are going to steadily rise and precipitation will become more variable, the risk of these ecological declines is expected to continue or increase in the future (Melillo et al. 2014; IPCC, 2007b). To forestall these changes, species' conservation requires that we understand how species respond to climate change and identify management actions to enhance species' persistence (Hannah et al., 2002).

Climate and climate change are highly heterogeneous across space and time (IPCC, 2013). Species do not experience a static climate, even within their historic range (Karlsson, Jonsson & Jansson, 2005; Ibáñez et al. 2013). Species also occupy a range of micro-climates that are not readily captured by many low-resolution climate projections (Roots, 1989). Uncertainties regarding the particulars of climate change (Peterson et al. 2003), complexities in climate models (CM) (Knutti & Sedl´a.cek, 2013), and inaccuracies of climatic downscaling (Weeks et al., 2011) all make species' range prediction difficult (Lawler et al., 2010). Therefore, the best methods for statistical estimation of species' tolerances and projection of future range rely on biologically relevant climate variables, a range of initial conditions, and multiple climate forcing scenarios (Moss et al., 2010; Snover et al., 2013; Porfirio et al., 2014). An ensemble approach and scenario-based analysis help managers consider alternative possible futures and develop management strategies and expectations that are robust to those alternatives (Peterson et al. 2003; Lawler, 2009).

Climate envelope models (CEM) that link species' presence-absence and climate variables (Watling et al., 2015) are commonly used to infer a species' climatic tolerances (Thomas et al., 2004). However, CEMs do not describe functional relationships between climate and organismal performance (Guisan & Zimmermann, 2000; Kearney & Porter, 2004). In addition, outputs of CEMs can be biased because of inaccurate geo-references (Wieczorek et al., 2004), leading to underestimation of geographic range sizes (Hijmans et al., 2000; Kadmon et al., 2004; Thuiller et al., 2004). Finally, CEMs do not allow extrapolation into novel combinations of temperature and precipitation because those conditions are not reflected in the species' current distribution

(Fielding & Bell, 1997; Pearson et al., 2006). In chapter 1, we developed mixed endo-exogenous models as an alternative to CEMs; those models involved density dependence and life-cycle development to improve demographic forecasting accuracy by accounting for time series, spatial scales, and species biology (i.e., carry-over and transgenerational effects)(Elith et al., 2006). Besides, the applications of random forest (RF) could well avoid the overfitting issue in CEMs for better generality (Randin et al., 2006).

There are many strategies for helping conserve at-risk species under climate change. Hoegh-Guldberg et al. (2008), for example, proposed that fortifying habitat resilience and enhancing connectivity might be sufficient if extinction risk is low and moderate. When populations are threatened with high extinction risk and potential habitat is far away (Walther et al., 2002), however, managed relocation (assisted migration) might be a viable option (Richardson et al., 2009). There is also a special case in which a historical site of a species could become suitable again, so that restoration and reintroduction should be considered (Lawler, 2009). Importantly, none of these options is risk-free (Lumsden & Drever, 2002; Stanley Price & Soorae, 2003). Reliable predictions, that identify climatically-suitable locations, both temporally and spatially, and enable cost-benefit analysis, would help evaluate these alternatives (Honnay et al., 2002).

In this study, we used a suite of mixed endo-exogenous population dynamic models to generate future projections of abundance and occupancy of a flagship endangered species: the Karner blue butterfly (*Lycaeides melissa samuelis*). A small butterfly like the Karner blue, with limited natural dispersal, cannot reach areas far from current habitats; managed relocation (assisted migration) would be necessary to place individuals in targeted locations (Richardson et al. 2009). In the previous chapter, we found that demography of the two per-annum generations of the Karner blue was predicted by combinations of temperature and precipitation variables that varied by ecoregion, with the microclimate shaped by topography and tree canopy cover. These relationships suggested that Karner blue populations would respond differently to climate change. In this chapter, we sought to identify populations needing managed relocation, and the target locations for relocation. Moreover, land use change, such as expansion of utility-scale solar energy (USSE) facilities across the species' current and future distribution, could facilitate the creation of new habitat, and thus serve as sites for introduction (Hertmann et al. 2016). To explore these options, we quantified population-specific extinction risk under a variety of *climate scenarios*, *habitat areas*, and *predictive windows*, and examined land areas that could become suitable for the Karner blue butterfly in the upper Midwest and Minnesota in particular. These procedures can be applied to other taxa, particularly other specialist species that can be modeled using population count data and occupy similar climates in the Great Lakes region.

Methods

Modeling Approach

To assess the extinction risk and potential geographic distributions of multiple Karner blue populations under climate change, we generated projections of population abundance and climate envelopes using mixed endo-exogenous models of population density and between-generation density change at both ecoregion and whole-species scale for both generations (chapter 1). The models were built with random forest (RF), an ensemble-based, machine learning technique that combines predictions from multiple regression trees (Cutler et al., 2007). This technique is robust to outliers, bias, high dimensionality, and non-linear and unbalanced data.

Training Data

The density-dependent data to train the models were taken from long-term survey (count) data of 48 Karner populations among five population groups in Central Wisconsin (14 populations, ecoregion: North Central Hardwood Forests), Northwestern Wisconsin (8 populations, ecoregion: Northern Lakes and Forests), Fort McCoy (12 populations, ecoregion: Driftless Area), Indiana Dunes National Parks (6 populations, ecoregion: Southern Michigan / Northern Indiana Drift Plains), and Albany Pine Bush (8 populations, ecoregion: Northeastern Coastal Zone) (chapter 1). Predictor variables were assembled from monthly climate (mean, minimum, and maximum temperatures, and total precipitation), topography (elevation, slope, and aspect), and canopy cover, derived from PRISM (800 m resolution), US Topo (30 m resolution), and MRLC NLCD (30 m resolution) (chapter 1). In total, we generated models for populations in five ecoregions and for the species as a whole (see equations and ecoregion definitions in chapter 1).

Predicting Data

After developing an algorithm that described the dynamics of Karner blue populations in different ecoregions and for the species as a whole, we then used future climate predictions as inputs for climatic variables to predict future abundance. Specifically, we selected CMIP5 GFDL-CM3 (Geophysical Fluid Dynamics Laboratory, Coupled Physical Model Third Version) monthly climate data, with 1/24 arc degree resolution (~ 4 x 4 km; Taylor et al. 2012). The GFDL model has played a central role in each assessment of the Intergovernmental Panel on Climate Change, and CM3 has been shown to demonstrate good climate fidelity while incorporating a variety of explicit carbon dynamics (Dunne et al., 2013). These climate projections applied Bias Corrected Spatial Disaggregation (BCSD) with linear interpolation as a downscaling technique (Gudmundsson, et al., 2012). In our predictions, we focused on the time period immediately preceding mid-century (2011 ~ 2049). This time horizon is pertinent for adaptation decision-making because substantial changes are projected within this timeframe and longer time periods (i.e., to 2100) involve much greater uncertainty.

To create climate scenarios for the Karner blue, we averaged the four monthly representative concentration pathways (RCPs), from 2.6 (low-forcing scenario) to 8.5 (high-forcing scenario) (Rogelj et al. 2016) of the GFDL model (IPCC 2014). Because RCPs do not diverge until mid-century, an average of them is suggestive of climatic change over the next couple of decades (i.e., applying more than one scenario is not necessary in the time frame of this analysis) (WallisDeVries, Baxter & van Vliet, 2011). In this baseline scenario, mean winter temperature would increase by approximately 1.5 °C and mean summer temperature by 2 °C in 2050, relative to the averages of 1861 – 1890 in the Midwest. Precipitation in this scenario would increase by 3 – 4% relative to the historic baseline (Donner et al. 2011). To explore the effect of climate differences (a kind of sensitivity analysis), we varied the average GFDL projection: increasing mean, minimum, and maximum temperature by 0.5, 1.0, and 1.5 °C in all months to capture the warming effect, and increasing the variations of total monthly precipitation by 1%, 2%, and 3% to capture the influence of stronger rainfall and drought events (Parmesan, Root

& Willig, 2000; Bauerfeind & Fischer, 2014). We kept using the same sets of tree canopy cover and topography data, assuming they would change little by midcentury.

Extinction Risk Simulations

To forecast population-specific extinction risk (48 populations, Table A2 & Figure A2), we divided the time series into four *prediction windows*: start year (either 2012-14 or 2018-19) – 2019, 2020 – 2029, 2030 – 2039, and 2040 – 2049. We also considered two habitat sizes in modeling: 1 hectare (ha) and 10 hectare (ha). Multiplying area by population density, we explored differences in initial and potential population abundance under different climatic scenarios (following Semmens et al., 2016). We ran 1000 simulations using the default settings of "randomForest" in R (Breiman et al. 2018) for each population under 32 combinations: two *modeling strategies* (density and between-generation change in density; see chapter 1), two *spatial scales* (ecoregion and whole-species levels; see chapter 1), four *climate scenarios* (above), and two *habitat areas* (above). Outputs of each simulation were generation-by-generation population abundance from the start year to 2049. Mean values across these 1000 simulations were plotted as temporal trends and smoothed with an exponential smoothing technique (a factor of 0.9) so that patterns stand out against random variations and noises.

We defined a threshold of functional extinction as one individual, since population cannot breed with only one left. Therefore, if population abundance in a generation fell below one, we counted that generation an extinction event (Howden et al., 2007). Next, we calculated the probability of extinction in each of the 32 combinations as the fraction of extinction occasions across the 1000 simulations, then averaged that fraction within each of the four prediction windows (above). Then, we summarized population-specific risks at the ecoregion level, as each population was run separately using local climate predictions. If a population went extinct in the simulation, we did not end the run, but rather allowed it to return if conditions became suitable. This kind of “resurrection” explored the possibility of recolonization (natural or facilitated by people) after local extinction. We divided extinction risk into seven categories based on percentage of the 1000 simulations: no risk – 0%, low risk (0 – 19%), moderate-low risk (20 – 39%), moderate risk (40 – 59%), moderate-high risk (60 – 79%), high risk (80 – 99%), extinction – 100%. Those years with a high probability of population extinction demonstrated unfavorable conditions.

Occupancy Projections

To identify sites that may become suitable for the Karner blue in the future, we simulated introduction of five first-generation and five second-generation adult individuals onto 1 ha buffer area at the center of each 4 km x 4 km pixel across the upper Midwest at year 2020 (from 41.1 N, 97.1 W to 48.4 N, 82.4 W). We assumed that managers would not pursue individual population conservation for the Karner blue but instead would consider assisted migration within an ecoregion either for efficiency or to create introduced populations with regional genetic diversity (Sabo et al., 2004). Projections for these introduced populations, implemented in R with the “raster” and “randomForest” packages (Hijmans et al., 2019), were repeated 100 times from 2020 to 2049 for each of 16 combinations: two *modeling strategies* (above), two *spatial scales* (above), four *climate scenarios* (above), and one *habitat area* (1 ha). We defined pixels projected with at least 50 Karner blue individuals as high occupancy, and calculated mean areas of high occupancy in each of the 16 combinations across 100 projections, averaged within each *prediction window* (2020 – 2029, 2030 – 2039, and 2040 – 2049).

Finally, we recognized that there were forces operating in the Midwest, particularly in Minnesota that could facilitate creation of new prairie habitat for mixed-cover butterfly species like the Karner blue. These habitats, planted with native vegetation, are associated with utility-scale solar energy (USSE, > 1 MW electricity generation per year) production. To further refine sites of potential future occupancy in Minnesota, we explored suitability of these solar parks by overlaying possible occupancy and a distribution map of sandy soil (SURRGO; Figure 1) in ArcGIS 10.6.1 (ESRI, 2019), these being preferred soil conditions for the host plant of the Karner blue, wild lupine (*Lupis perennis*). Using 2018 U.S. Energy Information Administration data (EIA, 2019), we identified 179 utility-scale, solar energy facilities in Minnesota that were located on sandy soils (Figure 2). Four of these sites already have been planted with native vegetation, including wild lupine: Anoka Solar, Atwater Solar, Chisago Solar, and Eastwood Solar, and planning is ongoing for more to be converted to solar-pollinator habitats. If all 179 sites were transformed, it would provide 440 hectares of solar-based, prairie habitat in Minnesota. We summarized the average number of USSE in Minnesota that might become suitable for Karner blue assisted migration across four *climate scenarios* (above), three *focal years* (2029, 2039, and 2049), and two *spatial scales* (above).

Results

Future Climate Patterns

Climate data used in our projection models showed an increase of overwinter and August mean temperatures, and July minimum temperatures from 2020 to 2049 especially in the northern Midwest. July mean and maximum temperatures, and August minimum temperatures changed relatively little. Spring temperatures decreased remarkably from 2030 to 2049. June temperatures were mixed, shifting northward from 2020 to 2039, and southward from 2039 to 2049. Precipitation varied annually from 2020 to 2049 (Figure A3).

Population Extinction Risk and Abundance Trends

At the ecoregion level (Figure 3), simulations with 10 ha habitat area predicted averages of 15%, 17%, 38%, 29%, and 40% fewer extinction events compared with 1 ha habitat area for the populations in Central WI, Northwestern WI, Fort McCoy, IN Dunes National Park, and Albany Pine Bush, respectively ($p < 0.001$). At 10 ha, the between-generation change models predicted 12%, 9%, 29% more extinction occasions compared with the density models in Central Wisconsin, Fort McCoy, and Indiana Dunes National Park, and 19% fewer occurrences for Northwestern Wisconsin ($p < 0.001$). At 1 ha, there were 17% more extinction events for Fort McCoy and 18% fewer in Indiana Dunes National Park ($p < 0.001$). Over time, there were 24% and 8% more extinction occasions before 2020 than the remaining 30 years (2020 ~ 2049) for Central WI and IN Dunes National Park using between-generation change models ($p < 0.05$). Differences over prediction windows were not significant using density models ($p > 0.1$). Across four climate scenarios, between-generation change models at the ecoregion scale predicted 21% more extinction occasions at the +1.5-3% scenario than baseline and +0.5-1% scenarios at 1 ha in Central WI ($p = 0.02$). In Northwestern WI, between-generation change models at the ecoregion scale predicted 24% fewer extinction events at the +1.5-3% scenario than baseline and +0.5-1% scenarios at 10 ha habitat area ($p < 0.05$). IN Dunes National Park, in contrast, had 29% and 20% more extinction events at +1.5-3% and +1.0-2% scenarios than baseline scenario at 1 ha and 10 ha, respectively, predicted by between-generation change models at whole species scale ($p < 0.05$).

Patterns of temporal trends and extinction risk for each population in five ecoregions are briefly summarized below (for more details, see Table A3 and Figure A4).

Central Wisconsin

Buena population was predicted to go extinct even when habitat area was 10 ha; whereas Lichtner and Bauer Cut populations would have high extinction risk only when habitat areas were 1 ha. CTHX, XS, and SBRW populations were predicted, especially by the between-generation change model, to have moderate-high risks before 2020, but low risks thereafter. WoodCFX, CTHX, Dike 17, and NBRE populations generally had moderate-low risks over prediction windows. The extinction risks at Bauer Cut, StanM, WildSp, and WCM populations increased with increased temperature and increased precipitation variance. In contrast, Buena, Dike 17, and Lichtner populations had the opposite pattern. According to temporal trends, when habitat areas were 10 ha, populations of WoodCFX, CTHX, XEW, XS, Sand 5, Dike 17, StanM, WildSP, and SBRW were predicted to have more than 50 Karner blue individuals before midcentury, and populations of Buena, Bauer Cut, Lichtner, NBRE, and WCM would persist with low abundance. With 1 ha habitat, all 14 populations would either stay at low abundance (less than 10 individuals) or go extinct.

Northwestern Wisconsin

Populations of PuBeet, CrNefR, CrCreedE, CrPhant, and CrKJM were predicted to go extinct when habitat area was 1 ha, and even at 10 ha, they had moderate-high extinction risk, except BuPeet (moderate risk). CrCorner had a moderate-high extinction risk when habitat area was 1 ha, and a moderate-low extinction risk when habitat area was 10 ha. Populations of Crover and St had moderate-low extinction risk at both 1 ha and 10 ha. Risk of extinction at CrCorner, CrReedE, and CrPhant decreased with increased temperature and increasing precipitation variance. Because of low initial abundance, all populations had high risk of extinction in the first year of simulation (2014). According to temporal trends, only Crover and St populations could recover to more than 50 individuals before midcentury; all others would stay at very low abundance (about 1 individual) even when habitat area was 10 ha.

Fort McCoy, Wisconsin

When habitat area was 1 ha, density models predicted: extinction of populations of A1, B7, B16, and B18; high or moderate-high extinction risk of the populations of C11 and D6; moderate-low or low risk at D4, B8, E131, and E132; and no extinction risk at B13. Between-population change models predicted extinction at B16; high or moderate-high extinction risk at B18, C11, and E13; moderate or moderate-low risk at A1, A5, B8, and D6; and low extinction risk at B13 and D4. When the habitat area was 10 ha, density models predicted low or zero extinction risks of all populations; between-population change models also predicted low or zero extinction risk generally, except moderate or moderate-low risks for A5, C11, and E132 populations. Risk of extinction at A1, A5, and E131 would increase with increased temperature and precipitation variance; the opposite trend occurred on the populations of C11, B7, B8, B16, and E132. Populations of B7 and C11 would have high risk of extinction in the first year of simulation (2013). According to temporal trends, even with 10 ha habitat, only B13 would have high abundance using both models; populations of B8 and E132 were predicted to have more than 50 individuals before midcentury using the between-population change models, but many fewer individuals with density models; all the other populations were predicted to have less than 50 individuals.

Indiana Dunes National Park

Long Lake population would go extinct when habitat area was 1 ha and have a moderate to high extinction risk when habitat area was 10 ha. Inland Marsh and Miller Woods population had moderate to low extinction risk using between-generation change models, and zero extinction risks using density models. At Marquette Trail and West Beach, populations generally had moderate-high extinction risk when habitat area was 1 ha, and moderate-low risk when the habitat area was 10 ha. Populations at Tollestone Dunes were predicted to have moderate-low extinction risk at both 1 ha and 10 ha. Extinction risk at Marquette Trail increased with increased temperature and increased precipitation variance; whereas Miller Woods and Long Lake had the opposite pattern. All six populations were predicted to go extinct in the first year of simulation (2012) by between-generation change models. According to temporal trends, only Inland Marsh would have more than 50 individuals before midcentury; all other populations had abundances far below 50, even when habitat area was 10 ha.

Albany Pine Bush, New York

The populations of Karner Barrens West and King Road Barrens West had consistently zero risk of extinction, regardless of habitat area. When habitat area was 10 ha, Baron House, Pine Bush Northwest, Pine Bush Southeast, and Pine Bush Southwest populations had low extinction risk. When habitat area was 1 ha, extinction risk for Baron House and Pine Bush Southwest populations increased to moderate-low, but the Pine Bush Southeast population was predicted to go extinct. The Pine Bush Northwest population had a low risk of extinction before 2020, but a moderate risk especially after 2030. Populations of Karner Barrens East and King Road Barrens East had a high risk of extinction at 1 ha and dropped to moderate-low risk at 10 ha. Extinction risk at Pine Bush Northwest increased with increasing temperature and increased precipitation variance; whereas Karner Barrens West population had the opposite pattern. The population of King Road Barrens East were predicted to have high risk of extinction in the first year of simulations (2019). According to temporal trends, Karner Barrens West, King Road Barrens West, and Pine Bush Southwest populations would be able to recover to more than 50 individuals before midcentury if habitat area was 10 ha.

Occupancy Projections

Summaries of projected highly occupant areas for each of the five ecoregions are shown in Figure 4 (for more details about the map projection, see Figure A5).

Central Wisconsin

The northwestern portion of the upper Midwest (Minnesota) was projected to have higher occupancy for the Karner blue populations in Central WI than other regions (210,687 km^2 on average, and 15,362 km^2 on sandy or loamy sandy soil in Minnesota). According to the between-generation change models at whole-species scale, projected areas would increase across prediction windows and along with increased temperature and precipitation variance. At the ecoregion scale, projected areas were about 2.5 times smaller than at whole-species scale, and there were no significant changes through time. The +1.5-3% climate scenario led to bigger areas than the other three scenarios in both Minnesota and the other states of upper Midwest. Density models at both ecoregion and whole-species scales exhibited remarkable northward and eastward shifting of high occupancy in Minnesota and other states of the upper Midwest. This pattern resulted in a decrease of area, with a shift in the northern boundary of high-occupant range beyond the Midwest into Ontario, Canada.

Northwestern Wisconsin

Between-generation change models predicted high occupancy across the upper Midwest (208,788 km^2 on average, and 7,272 km^2 on sandy or loamy sandy soil in Minnesota), and current habitats of northwestern Wisconsin populations remained within the suitable range. There were no differences in areas across prediction windows in either Minnesota or other states of the upper Midwest. As temperature and precipitation variance increased, the range of high occupancy would gradually shift northward and covered larger areas in Minnesota. The projected areas were 10 times smaller at ecoregion than at whole-species scale. Density models projected zero because no regions in the upper Midwest were predicted to have more than 50 individuals during the first Karner blue generation.

Fort McCoy, Wisconsin

Projections for populations in Fort McCoy were similar to those in Northwestern WI: according to between-generation change models, highly occupied regions would be present across the whole upper Midwest (438,998 km^2 on average, and 14,726 km^2 on sandy or loamy sandy soil in Minnesota), and current habitats of Fort McCoy populations would be within the suitable range. The differences in the areas across prediction windows were not apparent in either Minnesota or other states of upper Midwest. As temperature and precipitation variance increased, the range of high occupancy would gradually shift northward and covered more area in Minnesota. As above, density models projected zero in the upper Midwest because of the mismatch of projected occupancies between two generations. The only difference from Northwestern WI populations was that the areas projected by between-generation change model at ecoregion scale was similar to whole-species scale.

Indiana Dunes National Park

Similar to Central WI populations, high-occupant regions of Indiana Dunes National Park populations were projected to occur in northern Minnesota and Wisconsin according to the between-generation change model (174,416 km^2 on average, and 10,441 km^2 on sandy or loamy sandy soil in Minnesota). The areas would increase across prediction windows. In addition, similar to Fort McCoy populations, the areas projected by between-generation change models at whole-species and ecoregion scales were not significantly different; whereas similar to Northwestern WI populations, density models projected zero in upper Midwest. However, unlike all the other ecoregions, projected areas would decrease under the scenarios of increased temperature and precipitation variance. Those changes resulted from remarkable northward shifts of high-occupant range in Minnesota and Wisconsin, where the northern boundary of the range would gradually shift into Ontario, Canada.

Albany Pine Bush, New York

No areas in the upper Midwest were projected with high occupancy for the populations of Albany Pine Bush for both generations under all modeled conditions.

Solar pollinator Habitat

At time of our analysis, there were 35 utility-scale solar energy (USSE) facilities located on the sandy soils (fine sand, loamy sand, and loamy fine sand) in southeastern Minnesota (Figure 5): Chisago county had 12, Sherburne county had 9, Sterns county had 6, Scott and Wright counties had 2, Anoka, Dakota, Hennepin, and Isanti counties had 1. These 35 USSE facilities would potentially offer 88 hectares of wild lupine habitat for Karner blue.

For populations of Central WI, between-generation change models at whole-species scale predicted that about half of the 35 USSE facilities would be suitable, except those in Chisago County (Table A4). This suitability tended to increase from 2020 to 2049, as more sites overlapped with suitable climate as conditions expanded eastward from Northwestern Minnesota. At the ecoregion scale, the projected highly occupant areas did not overlap with any USSE. For populations of Northwestern WI, 34 USSE facilities were located within projected suitable habitats. At the ecoregion scale, however, because projected suitable habitats were not in Minnesota, no USSE were identified. For populations of Fort McCoy, 33 USSE facilities (except Johnson I and II Community Solar in Chisago County) were consistently located within the Karner blue's high occupancy regardless of *predictive windows*, *climate scenarios*, or *spatial scales*. For populations of IN Dunes National Park, viable USSE facilities tended to decrease along with increased temperature and precipitation variance because the southern boundary of projected high occupancy would quickly shift north bypassing most solar facilities in southeastern Minnesota.

Discussion

We found a much lower risk of extinction for the populations on larger habitat areas and with greater initial population densities. The decreases of extinction risk were particularly evident for the populations of Fort McCoy (WI) and Albany Pine Bush (NY) – close to 40% by increasing habitat areas 10 times from 1 ha to 10 ha. This suggested local conservation effort might be best directed to these sites where enlarging habitats could further reduce Karner blue's extinction risks (Akçakaya et al., 2014). In contrast, populations in Northwestern Wisconsin and Indiana Dunes National Park had much lower initial population densities than the others. In the models with habitats even as large as 10 ha, full population recovery would be unlikely. In fact, no Karner blues had been detected in Indiana Dunes National Park after 2012, confirming the predictions of our between-generation change models. This also indicated that between-generation change models might have better predictive power than more conservative density models. For small or now-extinct populations, it might be necessary to consider alternative options as habitat expansion may not be sufficient. Our models did reveal some exceptions to the risks of small population size, however. For example, the Dike 17 population in Central Wisconsin was predicted to have consistently low risk of extinction even though its initial population density was very low, because historically this population had high density and lambda, causing the models to predict population success (Voorhies et al., 2019).

We also found differences in extinction risk across prediction windows and among climate scenarios. For example, in Central Wisconsin and Albany Pine Bush, the risks of extinction were much higher before 2020 than the rest of the 30-year periods. This result implicated some populations might recover if they could be managed well and would successfully pass through a bottleneck of low population size or unfavorable climate. Our predictions on 20 out of 48 populations aligned with previous butterfly research that suggested a lower risk of extinction under elevated temperature (Thomas et al., 2004; Foden et al., 2013). This was particularly true for ectothermic species at the northwestern limit of the range (Dennis 1993; Thomas et al. 1999; Roy et al. 2001) and appeared to be the case for Karner blue populations in Northwestern Wisconsin. The future climatic trends, according to GFDL-CM3, will be heterogenous, and the effects of climate variables, unlike habitat size that the larger the areas the lower the risk of extinction, varied annually among different ecoregions (Dalgleish et al., 2011; Adler et al., 2012; Diez et al., 2014). Besides, the populations, even in the same ecoregion and thus involving the same predictive model, did not show consistent responses to climate change, because in addition to different initial densities, populations tended to experience localized future climate. Previous researches on the interaction between precipitation and butterfly species indicated that precipitation variance could exacerbate population declines and override the positive effects of warmer temperature in spring and summer (Trenberth et al., 2003; WallisDeVries, Baxter & van Vliet, 2011; Cahill et al., 2013).

Our model projections showed which regions could have high occupancy and how climate can reshape the species' distribution through time (Chardon et al., 2015). Because of our rigorous selection of predictor variables in chapter 1, we found divergent spatial predictions between ecoregion and whole-species scales, even when model performances were similar (Austin, 2002; Araújo and Guisan, 2006). There were robust conclusions among climate scenarios, however. For example, because the current habitats of the populations in Fort McCoy and Northwestern Wisconsin would be still located within the ranges of projected high occupancies by 2050 under all climate scenarios, conservation would be advanced by local management and habitat expansions to improve persistence and resilience to climate change. In contrast, populations in Central Wisconsin and Indiana Dunes National Park were projected to find their suitable conditions primarily in northwestern Minnesota and northern Wisconsin, and those in Indiana Dunes Nation Park tended to shift further northwardly along with increased temperature and precipitation variance. The substantial declines and the extinctions of the populations in Central Wisconsin and Indiana Dunes National Park, respectively, might be caused by the fact that their favorable climate had already presented far from their current habitats. For these distances, managed relocation (assisted migration) would be needed (Walther et al., 2002). Populations in Albany Pine Bush had no projected area with high occupancy in the upper Midwest under climate change. Perhaps they had locally adapted to the northeastern U.S., including humid climate and equally distributed precipitation year-round, such that suitable conditions may not emerge in the Midwest within the next several decades, coinciding with the findings of Hällfors et al. (2016) using species distribution model (SDM).

Based on our between-generation change models, most solar facilities on the sandy soils in Minnesota could serve as refugia for populations in Fort McCoy (WI) and Northwestern Wisconsin under all the climate scenarios. Nonetheless, for populations in Central Wisconsin and Indian Dunes National Park, northern and western Minnesota, with an expanse of sandy and loamy sandy soils, were projected with high occupancy in the future, but no solar facilities have been constructed there. We do not suggest that these solar facilities should be viable options in the long-term as our study extended only to the middle of the century (Hannah et al., 2002; Keppel et al., 2012), but some appeared suitable for Karner blue relocation on shorter time-scales and under certain climate scenarios (Ashcroft, 2010; Mackey et al., 2012; Olson et al., 2012). At a minimum, they might be useful as the starting point in buffering regional fluctuations and demographic bottlenecks in the species, and in reintroducing the Karner blue butterfly back to Minnesota (Maron et al., 2015). Moreover, we also recommend a metapopulation approach in which Karner blue could be translocated to multiple, proximal solar facilities. Chisago and Sherburne Counties would be good choice for such an approach based on the fact that the eleven and nine solar facilities currently in place, respectively, were on sandy soil and spatially closed to each other. The establishment of solar-pollinator habitat networks could facilitate the resilience of Karner blue populations to climate change (Heller & Zavaleta, 2009).

We leave it to another study on how to restore Karner habitat in these solar locations, but we knew that sites with excessively xeric conditions didn’t drain well enough for the growth of wild lupine (Kleintjes et al., 2003). In addition, Karner blue butterflies use a variety of nectar plants when nectar availability is high (Grundel & Pavlovic, 2000; Savanick, 2005), manifesting the value in having a high diversity of native plant species. Chan & Packer (2006) found that wild lupine density need to be a least 1.5 stem per meter square, and nectar source density at least 47.5 stem per meter square. We also noted that butterflies are sensitive to topographically induced microclimate complexity, and particularly preferred low wind speed (Luoto et al., 2001; Heikkinen et al., 2005), but most of these solar facilities were previously farmlands with grading and leveling, reducing the local capacity to form diverse niche communities (Brown et al., 2011). Further, although the configurations of solar panels ideally provided a mix of gaps and shades, and Karner blue preferred semi-canopy cover (25% - 75%) on sandy soils (Leach ,1993; Lane, 1997; Grundel et al, 1998), it seemed that they preferred no canopy cover on loamy sand (Lawrence, 1994). Thus, managed relocation should be preceded by systematic evaluations of microclimate, hydrology, soil, and solar panel configurations, in support of future decisions (Kleijn et al., 2006; Turlure et al., 2014).

Overall, determining species’ responses to novel climate shifts is inherently uncertain and scale dependent. Nonetheless, our mixed endo-exogenous models demonstrated the Karner blue sensitivity to climate, suggesting that climate variables could be as important drivers as habitat loss on population extinction (Hoffmann et al. 2010). Moreover, even though the viability of managed relocation (assisted migration) was still debatable with concerns on some critical ecological and ethical issues raised, since the local ecosystem functions could be altered, forming new communities (Hunter, 2007; Seddon et al., 2009; Hewitt et al., 2011), we believed the impending detrimental effects of climate change on the Karner blue might overshadow the recolonized Karner blue's impact on the new habitats (Kostyack et al., 2011). Even within climate envelopes projected to be suitable, the persistence of some Karner blue populations may still be tenuous, but this doesn't support taking no actions. Instead, relocated Karner blue populations could be further moved to favorable areas in favorable times to complete their life cycles (Aitken et al., 2008; Willis et al., 2008). Establishing refugia in the upper Midwest and Minnesota for the managed relocation (assisted migration) of Kaner Blue appeared to be an effective and worthwhile adaptation strategy for at least some populations threatened by high extinction risks (Gavin et al., 2014; Morelli et al., 2016).

There were several important caveats limiting inferences in our study. First, our models were built on the historic interaction between Karner populations and climate conditions, and these interactions could evolve and change over time that were not captured in the historic data. For this reason, the further our analysis projects out from 2020, the higher the uncertainties (McCarl, Norton, & Wu, 2014; Turlure et al., 2014). Second, stochasticity was a major factor in population extinction, such that sometimes a population with small size and negative growth rate might be able to sustain itself for quite a long period of time (Dennis, 1994). When evaluating extinction risk, the reliability of parameters, such as density dependence and environmental factors, was important (Boyce, 1992; Morris et al., 1999), but data quality usually made it difficult to capture dynamics driven primarily by stochasticity (Dennis & Taper, 1994). Third, our models didn't account for climate extremes or other threats (Parmesan et al., 2000; Cardillo et al., 2005). The frequency of extreme weather could be very important to the Karner Blue survivorship as suggested by the extremely hot and dry year of 2012 that corresponded to the loss of populations at the Indiana Dunes (Anderson et al., 2003; Diffenbaugh et al., 2005 & 2007; Jones et al., 2014). Our predicted extinction risks and projected occupancies would be overly optimistic if we missed significant contributing predictors; in contrast, simply relying on biological variables can lead to overestimation of extinction and range reduction (Porfirio et al., 2014; Beaumont et al., 2005). Further, of course, our models made a number of assumptions that restrict generality, e.g., that extinction occurred with one individual, that populations could recover from zero, that translocated populations involved 5 individuals for both generations in 2020, and that a pixel was defined as high occupancy if it could support at least 50 individuals. However, the probabilities of extinction and geographic extent of predicted occupancy would scale with changes in these parameters, offering flexibility in our modeling approach.

Future studies are also needed to explore cases that suggest possible adaptation strategies for the Karner blue, including managed relocation (assisted migration) (Schwartz et al., 2012; Klenk, 2015; Klenk & Larson, 2015). Because there were uncertainties in our population forecasts (Ricciardi & Simberloff, 2009), the application of ensemble approaches of multiple modeling algorithms (Porfirio et al., 2014) and future climate data other than GFDL would be wise before conducting any translocation activity (Kujala et al., 2013; Runting et al., 2013; Maxwell et al., 2015). Moreover, we recommend for explicit consideration of the balance among these variables, for example, asking if benefits of warmer summers will be outweighed by detrimental warmer winter effects. We assumed that (re)colonization would be conducted in 2020, but additional studies could examine precisely when action should be taken (Stanton et al., 2014). There is also a need to further understand solar-pollinator habitats, especially the micro-climate effects of the panel arrays: for example, temperatures under canopy cover usually are less extreme than in the open atmosphere. However, in our case, measured temperatures below the “panel cover” were more rather than less extreme, an observation needing further investigation. Multi-state conservation complemented by long term monitoring could be an excellent test of our model predictions and is critical for understanding Karner blue relocation efforts and the stability of local ecosystems in new habitats under impending climate change (Voorhies et al., 2019). Lastly, the conservation of other lupine-feeding butterflies could be hosted within the same program of solar-pollinator habitats, as the Karner blue is an umbrella species (Swengel, 1993), and our research can form a basis for future studies.

Illustrations

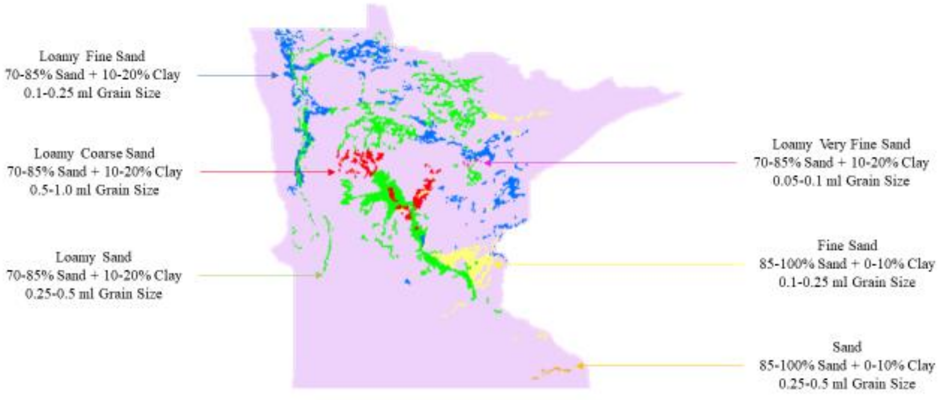


Figure 1. Distributions of six types of sandy and loamy sandy soil in Minnesota.

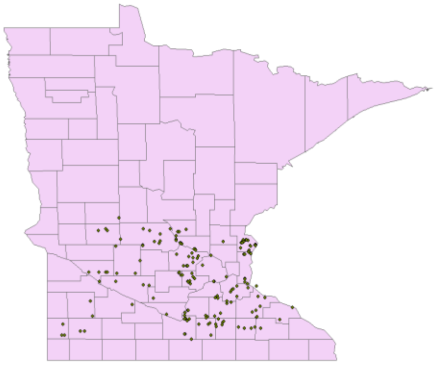


Figure 2. Distributions of 179 utility-scale solar energy (USSE) facilities in Minnesota.

Predictive Windows

Climate Scenarios

Central Wisconsin

Northwestern Wisconsin

Fort McCoy Wisconsin

Indiana Dunes National Park

Albany Pine Bush New York

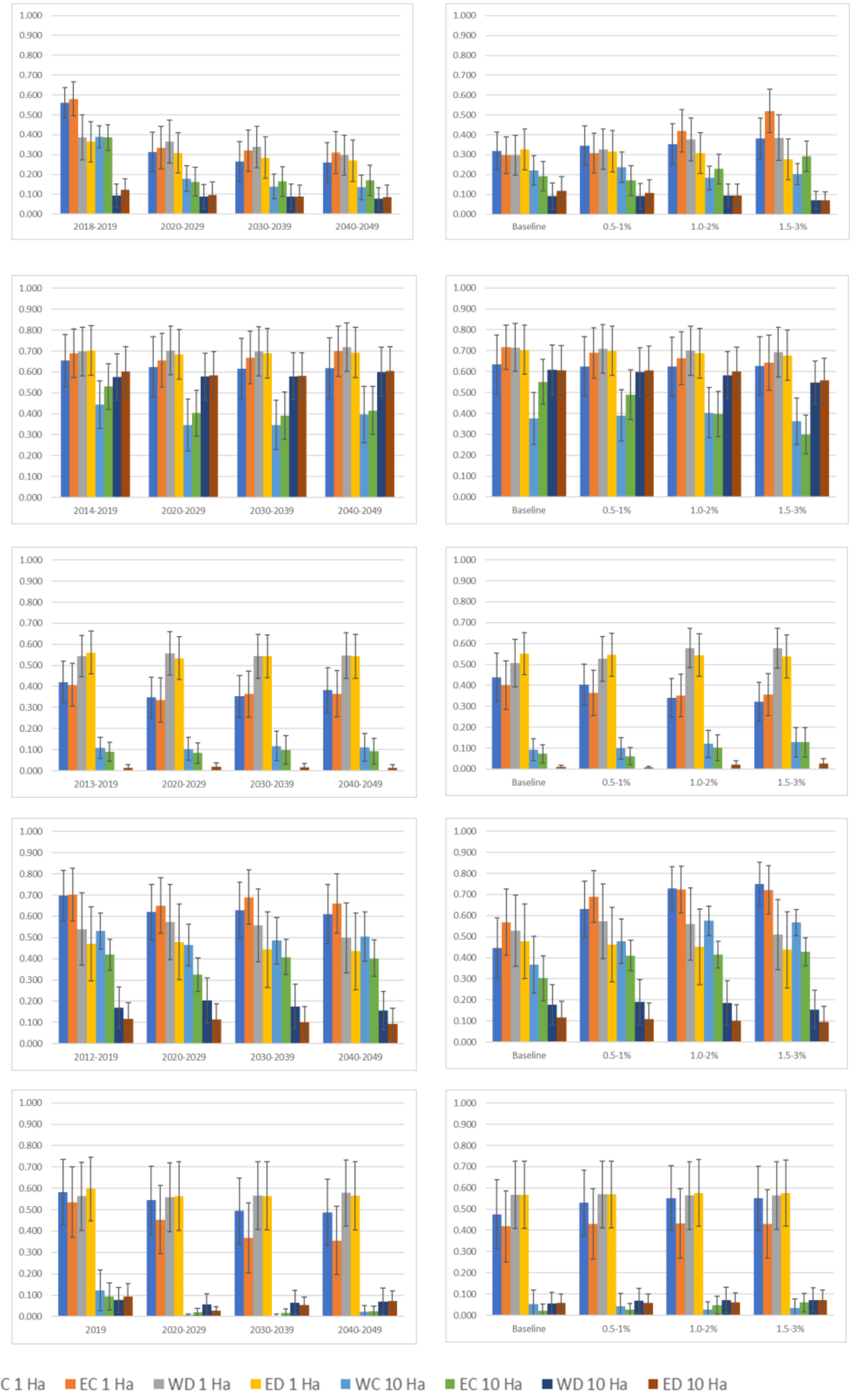


Figure 3: Mean extinction risk, ranging from 0 to 1, on 1 ha and 10 ha habitat areas predicted by density models and between-generation change models at both whole-species and ecoregion scales through four *predictive windows* (before 2020, 2020-2029, 2030-2039, 2040-2049) and four *climate scenarios* (baseline, +0.5-1%, +1.0-2%, +1.5-3%) for populations in each of five ecoregions, respectively.

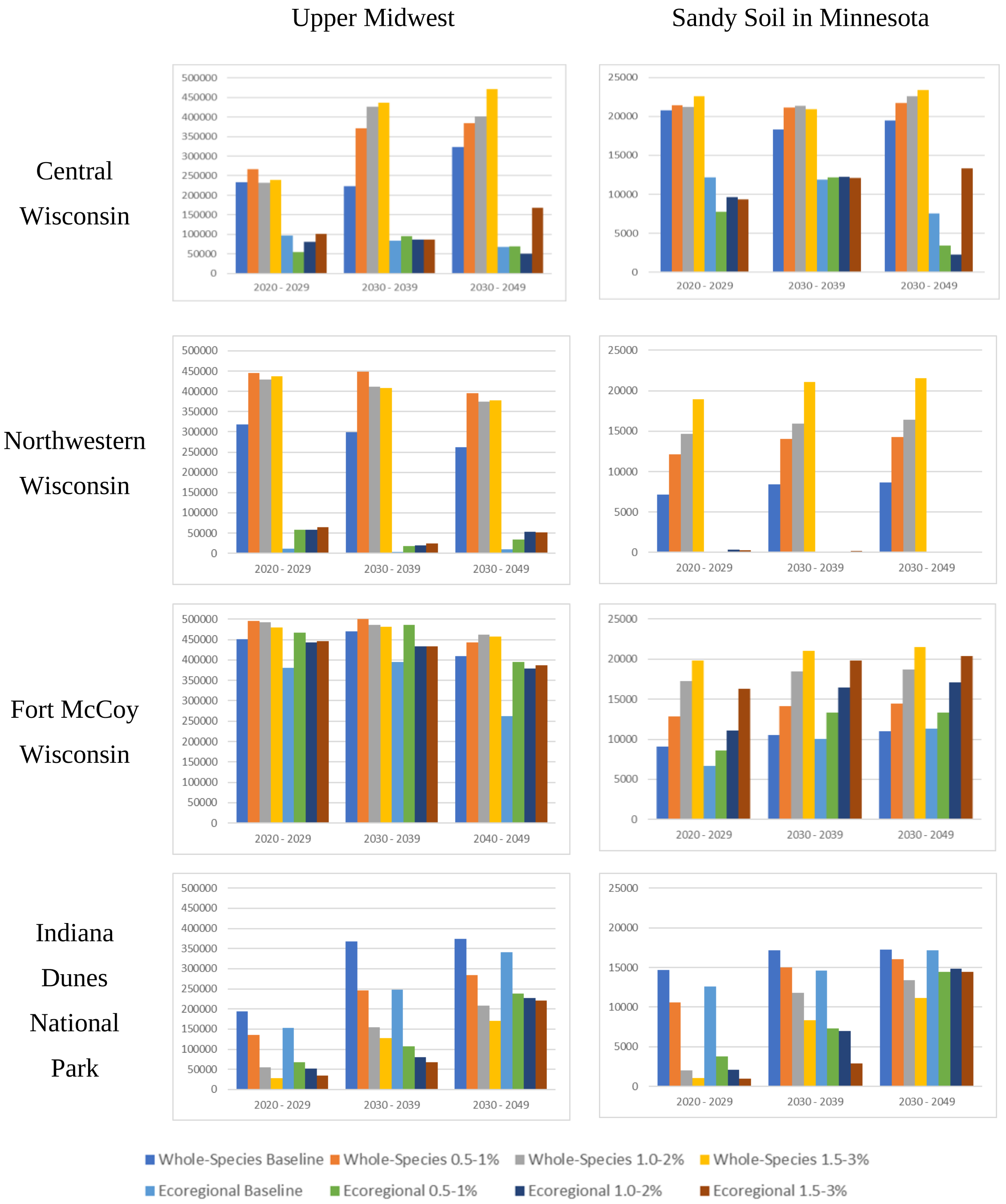


Figure 4. Areas (km^2) of high occupancy in upper Midwest and on the sandy soil in Minnesota with more than 50 Karner blue individuals under two *spatial scales* and four *climate scenarios* within three *prediction windows* (2020-2029, 2030-2039, 2040-2049) for populations of Central Wisconsin, Northwestern Wisconsin, Fort McCoy and Indiana Dunes National Park predicted by between-generation change models.

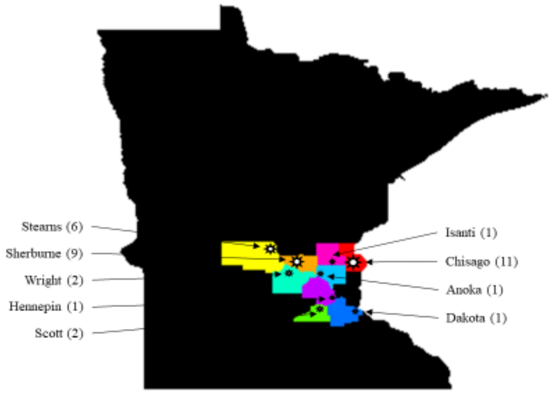


Figure 5. Nine counties with utility-scale solar facilities on sandy soils of Minnesota (colored). Approximate locations of solar facilities in each county shown as sun-stars, and the number of facilities indicated in parenthesis.

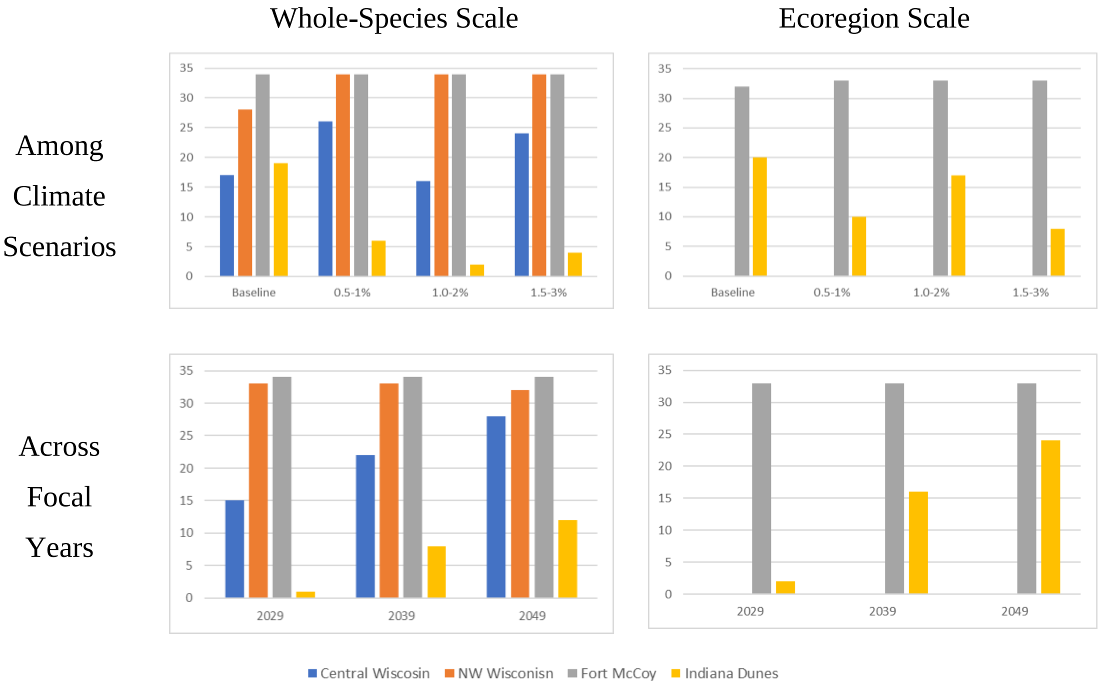


Figure 6. Average number of USSE on sandy soil in Minnesota across four climate scenarios, three focal years (2029, 2039, and 2049), and two spatial scales overlapping with projected suitable habitat of populations in Central Wisconsin, Northwestern Wisconsin, Fort McCoy and Indiana Dunes National Park.

Bibliography

Adler, P., Dalgleish, H., & Ellner, S. (2012). Forecasting plant community impacts of climate variability and change: When do competitive interactions matter? *Journal of Ecology*, 100(2), 478-487.

Araújo, M., Cabeza, M., Thuiller, W., Hannah, L., & Williams, P. (2004). Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. *Global Change Biology*, 10(9), 1618-1626.

Anderson, A. R., Collinge, J. E., Hoffmann A. A., Kellett, M., & McKechnie, S. W. (2003). Thermal tolerance trade-offs associated with the right arm of chromosome 3 and marked by the hsr-omega gene in Drosophila melanogaster. *Heredity*, 90(2), 195-202.

Akçakaya, H.R., Butchart, S.H.M., Watson, J.E.M., & Pearson, R.G. (2014). Preventing species extinctions resulting from climate change. *Nature Climate Change*, 4(12), 1048-1049.

Araújo, Ferri-Yáñez, Bozinovic, Marquet, Valladares, & Chown. (2013). Heat freezes niche evolution. *Ecology Letters*, 16(9), 1206-1219.

Araujo, M.B. & Guisan, A. (2006). Five (or so) challenges for species distribution modelling. *Journal of Biogeography*, 33, 1677-1688.

Aitken, S.N., Yeaman, S., Holliday, J.A., Wang, T.L. & Curtis-McLane, S. (2008). Adaptation, migration or extirpation: climate change outcomes for tree populations. *Evolutionary Applications*, 1, 95-111.

Ashcroft, M.B. (2010). Identifying refugia from climate change. *Journal of Biogeography*, 37, 1407-1413.

Austin M.P. (2002). Spatial prediction of species distribution: an interface between ecological theory and statistical modeling. *Ecological Modelling*, 157, 101-118.

Austin M.P. (2007). Species distribution models and ecological theory: a critical assessment and some possible new approaches. *Ecological Modelling*, 200, 1-19.

Ayres, M.P. & Scriber, J.M. (1994). Local adaptation to regional climates in Papilio canadensis (Lepidoptera: Papilionidae). *Ecological Monographs*, 64, 465-482.

Baker, R.J. (1994). The Karner blue butterfly: 1993 and beyond. *Karner blue butterfly: a symbol of vanishing landscape* (eds. Andow, D. A., Baker, R. J., & Lane, C. P.). University of Minnesota, St. Paul, 163-169.

Bancila, R.I., Ozgul, A., Hartel, T., Sos, T., & Schmidt, B.R. (2016). Direct negative density-dependence in a pond-breeding frog population. *Ecography*, 39, 449-455.

Bauerfeind, S.S. & Fischer, K. (2014). Simulating climate change: temperature extremes but not means diminish performance in a widespread butterfly. *Population Ecology*, 56, 239-250.

Beaumont, L., Hughes, L., & Poulsen, M. (2005). Predicting species distributions: Use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distributions. *Ecological Modelling*, 186(2), 251-270.

Bertrand, R., Lenoir, J., Piedallu, C.,… Gégout, J. (2011). Changes in plant community composition lag behind climate warming in lowland forests. *Nature*, 479(7374), 517-520.

Breiman, L., Cutler, A., Liaw, A., & Wiener, M. (2018). randomForest: Breiman and Cutler's Random Forests for Classification and Regression. R package version 4.6-14.

Brown, R.D., Kenny, N., & Corry, R.C. (2011). Testing the Microclimatic Habitat Design Framework in Abandoned Sand and Gravel Extraction Sites Using the Karner Blue Butterfly. *Ecological Restoration*, 29, 1-2.

Bowler, K., & Terblanche, J. (2008). Insect thermal tolerance: What is the role of ontogeny, ageing and senescence? *Biological Reviews*, 83(3), 339-355.

Boyce, M., Haridas, Lee, & The Nceas Stochastic Demography Working Group. (2006). Demography in an increasingly variable world. *Trends in Ecology & Evolution*, 21(3), 141-148.

Boyce, M.S. (1992). Population viability analysis. *Annual Review of Ecology and Systematics*, 23, 481-506.

Buckland, & Buckland, S.T. (2001). *Introduction to distance sampling : Estimating abundance of biological populations*. Oxford, New York: Oxford University Press.

Buckley, L., Nufio, C., Kirk, E., & Kingsolver, J. (2015). Elevational differences in developmental plasticity determine phenological responses of grasshoppers to recent climate warming. Proceedings. *Biological Sciences*, 282(1809), 20150441.

Bickford, D.P., Sheridan, J.A. & Howard, S.D. (2011). Climate change responses: forgetting frogs, ferns and flies? *Trends in Ecology & Evolution*, 26, 553-554.

Brown, R., Kenny, N., & Corry, R. (2011). Testing the Microclimatic Habitat Design Framework in Abandoned Sand and Gravel Extraction Sites Using the Karner Blue Butterfly. *Ecological Restoration*, 29(1-2), 52-63.

Cahill, A., Aiello-Lammens, M., Fisher-Reid, M., Hua, X., Karanewsky, C., Ryu, H., . . . Wiens, J. (2013). How does climate change cause extinction? *Proceedings. Biological Sciences*, 280(1750), 20121890.

Calvert, W., Zuchowski, W. & Brower, L. (1983). The effect of rain, snow and freezing temperatures on overwintering monarch butterflies in Mexico. *Biotropica*, 15, 42-47.

Cardillo, M., Mace, G., Jones, K., Bielby, J., Bininda-Emonds, O., Sechrest, W., . . . Purvis, A. (2005). Multiple causes of high extinction risk in large mammal species. *Science*, 309(5738), 1239-1241.

Chan, P., & Packer, L. (2006). Assessment of Potential Karner Blue Butterfly (Lycaeides melissa samuelis) (Family: Lycanidae) Reintroduction Sites in Ontario, Canada. *Restoration Ecology*, 14(4), 645-652.

Chardon, N.I., Cornwell, W.K., Flint, L.E., Flint, A.L., & Ackerly, D.D. (2015). Topographic, latitudinal and climatic distribution of Pinus coulteri: Geographic range limits are not at the edge of the climate envelope. *Ecography*, 38(6), 590-601.

Checa, M.F., Levy, E., Rodriguez, J., & Willmott, K. (2016). Rainfall as a significant contributing factor to butterfly seasonality along a climate gradient in the neotropics. *bioRxiv preprint*.

Chown, S., & Terblanche, J. (2006). Physiological Diversity in Insects: Ecological and Evolutionary Contexts. Advances in Insect Physiology, 33, 50-152.

Clausen, H., Holbeck, H., & Reddersen, J. (2001). Factors influencing abundance of butterflies and burnet moths in the uncultivated habitats of an organic farm in Denmark. *Biological Conservation*, 98(2), 167-178.

Clusella-Trullas, S., Blackburn, T., & Chown, S. (2011). Climatic Predictors of Temperature Performance Curve Parameters in Ectotherms Imply Complex Responses to Climate Change. *The American Naturalist*, 177(6), 738-751.

Cnaani, J., Thomson, J., & Papaj, D. (2006). Flower Choice and Learning in Foraging Bumblebees: Effects of Variation in Nectar Volume and Concentration. *Ethology*, 112(3), 278-285.

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.L., Fichefet, T…Wehner, M. (2013). Long-term Climate Change: Projections, Commitments and Irreversibility. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Cramer, W., Yohe, G.W., Auffhammer, M., Huggel, C., Molau, U., Dias, M.A.F.S., & Leemans, R. (2014). Detection and attribution of observed impacts.

Cresswell, J., & Galen, C. (1991). Frequency-Dependent Selection and Adaptive Surfaces for Floral Character Combinations: The Pollination of Polemonium viscosum. *The American Naturalist*, 138(6), 1342-1353.

Currie, D. J. (1991). Energy and large-scale patterns of animal species and plant species richness. *American Naturalist*, 137, 27-49.

Cutler, D. R., Edwards, T.C., Beard, K.H., Cutler, A., Hess, K.T., Gibson, J., & Lawler, J.J. (2007). Random forests for classification in Ecology. *Ecology*, 88(11), 2783-2792.

Davies, Z. G., Wilson, R. J., Coles, S. & Thomas, C. D. (2006). Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. *Journal of Animal Ecology*, 75, 247-256.

Davis, M., & Shaw, R. (2001). Range shifts and adaptive responses to quaternary climate change. *Science*, 292(5517), 673-679.

Defra. (2009). Adapting to climate change UK climate projections. *UK Climate Projections*, 52.

Dalgleish, H., Koons, D., Hooten, M., Moffet, C., & Adler, P. (2011). Climate influences the demography of three dominant sagebrush steppe plants. *Ecology*, 92(1), 75-85.

Daly, C., Halbleib, M., Smith, J., Gibson, W., Doggett, M., Taylor, G., . . . Pasteris, P. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*, 28(15), 2031-2064.

Dennis, R. (1993). *Butterflies and climate change*. Manchester ; New York : New York: Manchester University Press ; Distributed exclusively in the USA and Canada by St. Martin's Press.

Dennis, B., & Taper, M. (1994). Density Dependence in Time Series Observations of Natural Populations: Estimation and Testing. *Ecological Monographs*, 64(2), 205-224.

Dennis, R., Shreeve, T., & Van Dyck, H. (2006). Habitats and resources: the need for a resource-based definition to conserve butterflies. *Biodiversity and Conservation*, 15, 1943-1966.

Dennis, R., Sparks, T., & Dennis, R.L.H. (2007). Climate signals are reflected in an 89 year series of British Lepidoptera records. *European Journal of Entomology*, 104(4), 763-767.

Deutsch, C.A., Tewksbury, J.J., Huey, R.B., Sheldon, K.S., Ghalambor, C.K., Haak, D.C., & Martin, P.R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences of the United States*, 105(18), 6668-6672.

Devictor, V., Van Swaay, C., Brereton, T., Brotons, L., Chamberlain, D., Heliölä, J. . . Jiguet, F. (2012). Differences in the climatic debts of birds and butterflies at a continental scale. *Nature Climate Change*, 2(2), 121-124.

Frenne, Graae, Rodríguez-Sánchez, Kolb, Chabrerie, Decocq, . . . Verheyen. (2013). Latitudinal gradients as natural laboratories to infer species' responses to temperature. *Journal of Ecology*, 101(3), 784-795.

Di Marco, M., Butchart, S., Visconti, P., Buchanan, G., Ficetola, G., & Rondinini, C. (2016). Synergies and trade-offs in achieving global biodiversity targets. *Conservation Biology*, 30(1), 189-195.

Diamond, S. E. & Kingsolver, J. G. (2010). Environmental dependence of thermal reaction norms: host plant quality can reverse the temperature-size rule. *American Naturalist*, 175, 1-10.

Diamond, S., Frame, A., Martin, R., & Buckley, L. (2011). Species' traits predict phenological responses to climate change in butterflies. *Ecology*, 92(5), 1005-1012.

Diez, J., Ibáñez, I., Silander, J., Primack, R., Higuchi, H., Kobori, H., . . . James, T. (2014). Beyond seasonal climate: Statistical estimation of phenological responses to weather. *Ecological Applications*, 24(7), 1793-1802.

Dirig, R. (1994). Historical notes on wild lupine and the Karner blue butterfly at the Albany Pine Bush, New York. In Andow, D. A., Baker, R. J., Lane, C. P. (Ed.), *Karner blue butterfly: a symbol of vanishing landscape* (pp. 23-36). University of Minnesota, St. Paul.

Diffenbaugh, N., Pal, J., Giorgi, F., & Gao, X. (2007). Heat stress intensification in the Mediterranean climate change hotspot. *Geophysical Research Letters*, 34(11).

Diffenbaugh, N., Pal, J., Trapp, R., & Giorgi, F. (2005). Fine-scale processes regulate the response of extreme events to global climate change. *Proceedings of the National Academy of Sciences of the United States*, 102(44), 15774-15778.

Donelson, J., Wong, M., Booth, D., & Munday, P. (2016). Transgenerational plasticity of reproduction depends on rate of warming across generations. *Evolutionary Applications*, 9(9), 1072-1081.

Donner, L.J., Wyman, B.L., Hemler, R.S., Horowitz, L.W., Ming, Y., Zhao, M., . . . Zeng, F. (2011). The Dynamical Core, Physical Parameterizations, and Basic Simulation Characteristics of the Atmospheric Component AM3 of the GFDL Global Coupled Model CM3. *Journal of Climate*, 24(13), 3484-3519.

Dooley, C., Bonsall, M., Brereton, T. & Oliver, T. (2013). Spatial variation in the magnitude and functional form of density-dependent processes on the large skipper butterfly Ochlodes sylvanus. *Ecological Entomology*, 38, 608-616.

Dormann, Elith, Bacher, Buchmann, Carl, Carré, . . . Lautenbach. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, 36(1), 27-46.

Dunne, John, John, Jasmin, Shevliakova, Elena, Stouffer, Ronald, Krasting, John, Malyshev, Sergey, . . . Zadeh, Niki. (2013). GFDL's ESM2 Global Coupled Climate-Carbon Earth System Models. Part II: Carbon System Formulation and Baseline Simulation Characteristics. *Journal of Climate*, 26(7), 2247-2267.

Ehrlén, J., & Morris, W. (2015). Predicting changes in the distribution and abundance of species under environmental change. *Ecology Letters*, 18(3), 303-314.

[EIA] Energy Information Administration. (2019). Form EIA-860 Detailed Data for 2018. Available at https://www.eia.gov/electricity/data/eia860/. Accessed 25 October 2019.

Eisikowitch, D., & Woodell, S. (1975). Some aspects of pollination ecology of Armeria Maritima (Mill.) Willd. in Britain. *New Phytologist*, 74(2), 307-322.

Elith, H. Graham, P. Anderson, D., Ferrier, G . . . Zimmermann, E. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29(2), 129-151.

Elith, J., & Graham, H.C. (2009). Do they? How do they? Why do they differ? On finding reasons for differing performances of species distribution models. *Ecography*, 32, 66-77.

English, S., Cowen, H., Garnett, E., & Hargrove, J. (2016). Maternal effects on offspring size in a natural population of the viviparous tsetse fly. *Ecological Entomology*, 41(5), 618-626.

ESRI. (2019). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Evans, J.S. (2018). rfUtilities: Random Forests Model Selection and Performance Evaluation. R package version 2.1-4.

Fahey, R. T., Darling, L., & Anderson, J. (2015). *Oak Ecosystems Recovery Plan: Sustaining Oaks in the Chicago Wilderness Region*. Chicago: Chicago Wilderness.

Fenberg, P., Self, A., Stewart, J., Wilson, R., & Brooks, S. (2016). Exploring the universal ecological responses to climate change in a univoltine butterfly. *Journal of Animal Ecology*, 85(3), 739-748.

Fielding, A., & Bell, J. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation*, 24(1), 38-49.

Fischer, K., Bot, A. N. M., Zwaan, B. J., & Brakefield, P. M. (2004). Genetic and environmental sources of egg size variation in the butterfly Bicyclus anynana. *Heredity*, 92(3), 163-169.

Fischer, J., & Phillips, N. (2014). Carry-over effects of multiple stressors on benthic embryos are mediated by larval exposure to elevated UVB and temperature. *Global Change Biology*, 20(7), 2108-2116.

Foden, W., Midgley, G., Hughes, G., Bond, W., Thuiller, W., Hoffman, M., . . . Hannah, L. (2007). A changing climate is eroding the geographical range of the Namib Desert tree Aloe through population declines and dispersal lags. *Diversity and Distributions*, 13(5), 645-653.

Foden, W., Butchart, S, Stuart, S., Vie, J-C., Akcakaya, H., Resit, A…Mace, G. (2013). Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. *PLoS ONE*, 8(6), E65427.

Foley, P. (1994). Predicting Extinction Times from Environmental Stochasticity and Carrying Capacity. *Conservation Biology*, 8(1), 124-137.

Forster, J., Hirst, A.G. & Atkinson, D. (2012). Warming-induced reductions in body size are greater in aquatic than terrestrial species. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 19310-19314.

Fox, W., Weisberg, S., & Fox, J. (2011). In Jogn. F (Ed.), *An R companion to applied regression*. (2nd ed.). Thousand Oaks, Calif.: SAGE Publications.

Franklin, J., Davis, F., Ikegami, M., Syphard, A., Flint, L., Flint, A., & Hannah, L. (2013). Modeling plant species distributions under future climates: How fine scale do climate projections need to be? *Global Change Biology*, 19(2), 473-483.

Frazier, M., Huey, R., & Berrigan, D. (2006). Thermodynamics constrains the evolution of insect population growth rates: ‘‘Warmer is better’’. *The American Naturalist*, 168, 512–520.

Freckleton, R.P., Watkinson, A.R., Green, R.E., & Sutherland, W.J. (2006). Census error and the detection of density dependence. *Journal of Animal Ecology*, 75, 837–851.

Fridley, J.D. (2009). Downscaling climate over complex terrain: high finescale (<1000 m) spatial variation of near-ground temperatures in a montane forested landscape (Great Smoky Mountains). *Journal of Applied Meteorology and Climatology*, 48, 1033–1049.

Gavin, D., Fitzpatrick, M., Gugger, P., Heath, K., Rodríguez-Sánchez, F., Dobrowski, S., . . . Williams, J. (2014). Climate refugia: Joint inference from fossil records, species distribution models and phylogeography. *New Phytologist*, 204(1), 37-54.

Gehne, M., Hamill, T., Kiladis, G., & Trenberth, K. (2016). Comparison of Global Precipitation Estimates across a Range of Temporal and Spatial Scales. *Journal of Climate*, 29(21), 7773-7795.

Geiger, R. (1959). *The climate near the ground*. Cambridge: Harvard University Press.

Givnish, T.J., Menges, E.S., & Schweitzer, D.F. (1988). *Minimum area requirements for long-term conservation of the Albany Pine Bush and Karner blue butterfly: An assessment*. Albany, NY: Report to the City of Albany from Malcolm Pirnie, Inc.

Ghosh, S., Testa, N., & Shingleton, A. (2013). Temperature-size rule is mediated by thermal plasticity of critical size in Drosophila melanogaster. *Proceedings. Biological Sciences*, 280(1760), 20130174.

Graham, C.H., Moritz, C., & Williams, S.E. (2006). Habitat history improves prediction of biodiversity in rainforest fauna.(Author abstract). *Proceedings of the National Academy of Sciences of the United States*, 103(3), 632-636.

Grossmann, E., & Mladenoff, B. (2007). Open woodland and savanna decline in a mixed-disturbance landscape (1938 to 1998) in the Northwest Wisconsin (USA) Sand Plain. *Landscape Ecology*, 22, 43-55.

Grundel, R., Pavlovic, N., & Sulzman, C. (1998). The effect of canopy cover and seasonal change on host plant quality for the endangered Karner blue butterfly (Lycaeides Melissa samuelis). *Oecologia*, 114, 243-250.

Grundel, R., Pavlovic, N., & Sulzman, C. (2000). Nectar Plant Selection by the Karner Blue Butterfly (Lycaeides melissa samuelis) at the Indiana Dunes National Lakeshore.(Statistical Data Included). *The American Midland Naturalist*, 144(1), 1-10.

Grundel, R., & Pavlovic, N. (2007). Resource availability, matrix quality, microclimate, and spatial pattern as predictors of patch use by the Karner blue butterfly. *Biological Conservation*, 135(1), 135-144.

Grundel, R., Pavlovic, N., & Sulzman, C.L. (1998). Habitat use by the endangered Karner blue butterfly in oak woodlands: the influence of canopy cover. Biological Conservation, 85, 47-53.

Gudmundsson, L., Bremnes, J., Haugen, J., & Engen-Skaugen, T. (2012). Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations - a comparison of methods. *Hydrology and Earth System Sciences*, 16(9), 3383-3390.

Guiney, M., Andow, D., & Wilder, T. (2010). Metapopulation structure and dynamics of an endangered butterfly. *Basic and Applied Ecology*, 11, 354-362.

Guisan A, & Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling*, 135, 147–186.

Haack, R.A. (1993). "The endangered Karner blue butterfly (Lepidoptera: Lycaenidae): biology, management considerations, and data gaps". In Gillespie, A.R.; Parker, G.R.; Pope, P.E. (Ed.). Proceedings, 9th central hardwood forest conference, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station (pp 83-100).

Hällfors, M., Liao, J., Dzurisin, J., Grundel, R., Hyvärinen, M., Towle, K., . . . Hellmann, J. (2016). Addressing potential local adaptation in species distribution models: Implications for conservation under climate change. *Ecological Applications*, 26(4), 1154-1169.

Hannah, L., Midgley, G., & Millar, D. (2002). Climate change-integrated conservation strategies. *Global Ecology and Biogeography*, 11(6), 485-495.

Hannah, L. (2008). Protected Areas and Climate Change. *Annals of the New York Academy of Sciences*, 1134(1), 201-212.

Harvell, C.D. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science*, 296, 2158–2162.

Hawkins, B.A. & Porter, E.E. (2003). Does herbivore diversity depend on plant diversity? The case of California butterflies. *American Naturalist,* 161, 40–49.

Hawkins, B.A., Field, R., Cornell, H.V., Currie, D.J., Guegan, J.F., Kaufman, D.M., Kerr, J.T., Mittelbach, G.G., Oberdorff, T., O'Brien, E.M., Porter, E. & Turner, J.R.G. (2003). Energy, water, and broad-scale geographic patterns of species richness. *Ecology,* 84, 3105-3117.

Hawkins, B.A. & Porter, E.E. (2003). Water–energy balance and the geographic pattern of species richness of western Palearctic butterflies. *Ecological Entomology*, 28, 678-686.

Heikkinen, R., Luoto, M., Kuussaari, M., & Poeyry, J. (2005). New insights into butterfly-environment relationships using partitioning methods. *Proceedings of the Royal Society of London, Series B: Biological Sciences*, 272(1577), 2203-2210.

Heller, N. & Zavaleta, E. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation*, 142, 14–32.

Hellmann, J. (2002). The effect of an environmental change on mobile butterfly larvae and the nutritional quality of their hosts. *Journal of Animal Ecology*, 71, 925-936.

Hellmann, J., Pelini, J., Prior, S., & Dzurisin, L. (2008). The response of two butterfly species to climatic variation at the edge of their range and the implications for poleward range shifts. *Oecologia*, 157(4), 583-592.

Hernández, M., Gonçalves, R., & Helbling, E. (2014). Direct and indirect acquisition of photoprotective compounds in crab larvae of coastal Patagonia (Argentina). *Journal of Plankton Research*, 36(3), 877-882.

Hernandez, R.R., Hoffacker, M.K., Murphy-Mariscal, M.L., Wu, G.C., & Allen, M.F. (2015). Solar energy development impacts on land cover change and protected areas. *Proc. Natl. Acad. Sci. U.S.A.*, 112 (44), pp 13579 – 13584.

Herrando, S., Titeux, N., Brotons, L., Anton, M., Ubach, A., Villero, D., . . . Stefanescu, C. (2019). Contrasting impacts of precipitation on Mediterranean birds and butterflies. *Scientific Reports*, 9(1), 5680.

Hettinger, A., Sanford, E., Hill, T., Russell, A., Sato, K., Hoey, J., . . . Gaylord, B. (2012). Persistent carry-over effects of planktonic exposure to ocean acidification in the Olympia oyster. *Ecology*, 93(12), 2758-2768.

Hewitt, N., Klenk, Smith, Bazely, Yan, Wood, . . . Henriques. (2011). Taking stock of the assisted migration debate. *Biological Conservation*, 144(11), 2560-2572.

Hijmans, R., Garrett, K., & Huama´n, Z. (2000) Assessing the geographic representative of genebank collections: the case of Bolivian wild potatoes. *Conservation Biology*, 14, 1755–1765.

Hijmans, R., van Etten, J., Summer, M., Cheng, J., Bevan, A…Karney, C. (2019). raster: Geographic Data Analysis and Modeling. R package version 2.8-19.

Hess, R. & Hess, A. (2015). A Development of Management Techniques. *American Entomologist*, 61(2).

Hoegh-Guldberg, O., Hughes, L., Mclntyre, S., Lindenmayer, D., Parmesan, C., Possingham, H., & Thomas, C. (2008). Assisted Colonization and Rapid Climate Change. Science, 321(5887), 345-346.

Hopwood, P., Moore, A., Tregenza, T., & Royle, N. (2016). Niche variation and the maintenance of variation in body size in a burying beetle. *Ecological Entomology*, 41(1), 96-104.

Horne, C., Hirst, A. & Atkinson, D. (2015). Temperature-size responses match latitudinal-size clines in arthropods, revealing critical differences between aquatic and terrestrial species. *Ecology Letters*, 18, 327-335.

Hoffmann, A., Chown, S., & Clusella-Trullas, S. (2013). Upper thermal limits in terrestrial ectotherms: How constrained are they? *Functional Ecology*, 27(4), 934-949.

Holl, K. (1995). Nectar Resources and Their Influence on Butterfly Communities on Reclaimed Coal Surface Mines. *Restoration Ecology*, 3(2), 76-85.

Howden, S.M., J.F. Soussana, F.N. Tubiello, N. Chhetri, M. Dunlop, and H. Meinke. (2011). Adapting agriculture to climate change. *Economía Agraria Y Recursos Naturales*, (2), 109-122.

Hugall, A., Moritz, C., Moussalli, A., & Stanisic, J. (2002). Reconciling paleodistribution models and comparative phylogeography in the Wet Tropics rainforest land snail Gnarosophia bellendenkerensis (Brazier 1875). *Proceedings of the National Academy of Sciences of the United States of America*, 99(9), 6112-6117.

Hunter, M. (2007). Climate Change and Moving Species: Furthering the Debate on Assisted Colonization. *Conservation Biology*, 21(5), 1356.

Ibáñez, I., Gornish, E., Buckley, L., Debinski, D., Hellmann, J., Helmuth, B., . . . Uriarte, M. (2013). Moving forward in global-change ecology: Capitalizing on natural variability. *Ecology and Evolution*, 3(1), 170-181.

Jenkins, G., Murphy, J., Sexton, D., Lowe, J., Jones, P. & Kilsby, C. (2009). UK Climate Projections: Briefing Report. Met Office Hadley Centre, Exeter, UK.

Jiguet, F., Brotons, L. & Devictor, V. (2011). Community responses to extreme climatic conditions. *Current Zoology*, 57, 406-413.

John, G. , Kohavi, R., & Pfleger, K. (2014). *Irrelevant Features and the Subset Selection Problem*.

Jones, M., Blenkinsop, S., Fowler, H. & Kilsby, C. (2014). Objective classification of extreme rainfall regions for the UK and updated estimates of trends in regional extreme rainfall. *International Journal of Climatology*, 34, 751-765.

Kadmon, R., Farber, O., Danin, A. (2004). Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. *Ecological Applications*, 14, 401–413.

Karlsson, J., Jonsson, A. & Jansson, M. (2005). Productivity of high-latitude lakes: climate effect inferred from altitude gradient. *Global Change Biology*, 11, 710-715.

Kearney, M., Porter, W. (2004). Mapping the fundamental niche: physiology, climate, and the distribution of a nocturnal lizard. *Ecology*, 85, 3119–3131.

Kellermann, V., Overgaard, J., Hoffmann, A., Fløjgaard, C., Svenning, J., & Loeschcke, V. (2012). Upper thermal limits of Drosophila are linked to species distributions and strongly constrained phylogenetically. *Proceedings of the National Academy of Sciences of the United States of America*, 109(40), 16228-16233.

Kennedy, C., Lonsdorf, E., Neel, M., Williams, N., Ricketts, T…Mandelik, Y. (2013). A global quantitative synthesis of local and landscape effects on wild pollinators in agroecosystems. *Ecol. Lett.*, 16 (5), 584-599.

Kennedy, J. & Neville, A. (1986). Basic Statistical Methods for Engineers and Scientists. (1970). *Students Quarterly Journal*, 40(159), 108.

Keppel, G., Van Niel, K., Wardell-Johnson, G., Yates, C., Byrne, M., Mucina, L., Schut, A., Hopper, S. & Franklin, S. (2012). Refugia: identifying and understanding safe havens for biodiversity under climate change. *Global Ecology and Biogeography*, 21, 393-404.

Kingsolver, J. (2009). The well-temperatured biologist. The American Naturalist, 174, 755-768.

Kingsolver, J., & Huey, R. (2008). Size, temperature, and fitness: Three rules. Evolutionary Ecology Research, 10(2), 251-268.

Kingsolver, J., Woods, H., Buckley, L., Potter, K., MacLean, H. & Higgins, J. (2011). Complex life cycles and the responses of insects to climate change. *Integrative and Comparative Biology*, 51, 719-732.

Kishimoto-Yamada, K. & Itioka, T. (2015) How much have we learned about seasonality in tropical insect abundance since Wolda (1988)? *Entomological Science*, 18, 407–419.

Kleijn, D., Baquero, R.A., Clough, Y., Díaz, M., Esteban, De, J., Fernández, F., . . . West, T.M. (2006). Mixed biodiversity benefits of agri-environment schemes in five European countries. *Ecology Letters*, 9, 243-254.

Kleintjes, P., Sporrong, J., Raebel, C., & Thon, S. (2003). Habitat Type Conservation and Restoration for the Karner Blue Butterfly: A Case Study from Wisconsin. *Ecological Restoration*, 21(2), 107-115.

Klenk, N. (2015). The development of assisted migration policy in Canada: An analysis of the politics of composing future forests. *Land Use Policy*, 44, 101-109.

Klenk, N., & Larson, B. (2015). The assisted migration of western larch in British Columbia: A signal of institutional change in forestry in Canada? *Global Environmental Change*, 31, 20-27.

Klockmann, M., Kleinschmidt, F., & Fischer, K. (2017). Carried over: Heat stress in the egg stage reduces subsequent performance in a butterfly. *PLoS ONE*, 12(7), E0180968.

Knutson, R., Kwilosz, J., & Grundel, R. (1999). Movement Patterns and Population Characteristics of the Karner Blue Butterfly (Lycaeides melissa samuelis) at Indiana Dunes National Lakeshore. *Natural Areas Journal*, 19(2), 109-120.

Knutti, R. & Sedláček, J. (2012). Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Climate Change*, 3(4), 369-373.

Kostyack, J., Lawler, J., Goble, D., Olden, J., & Scott, J. (2011). Beyond Reserves and Corridors: Policy Solutions to Facilitate the Movement of Plants and Animals in a Changing Climate. *BioScience*, 61(9), 713-719.

Kucheryavskiy, S. (2018). mdatools: Multivariate Data Analysis for Chemometrics. R package version 0.9.1.

Kuhn, M. (2018). caret: Classification and Regression Training. R package version 6.0-81.

Kujala, H., Moilanen, A., Araujo, M., & Cabeza, M. (2013). Conservation Planning with Uncertain Climate Change Projections. *PLoS ONE*, 8(2), E53315.

Lane, C. (1997). *Forest management guidelines: developing management plans compatible with Karner blue butterfly persistence*. Wisconsin Department of Natural Resources. Madison, Wisconsin. United States Fish and Wildlife Service. Fort Snelling, Minnesota.

Lane, C., & Andow, D. (2003). Oak savanna subhabitat variation and the population biology of Lycaeides melissa samuelis (Lepidoptera: Lycaenidae). *Annals of the Entomological Society of America*, 96, 799-809.

Lawler, J. (2009). Climate Change Adaptation Strategies for Resource Management and Conservation Planning. *Annals of the New York Academy of Sciences*, 1162(1), 79-98.

Lawler, J., Tear, T., Pyke, C., Shaw, M., Gonzalez, P., Kareiva, P., . . . Pearsall, S. (2010). Resource management in a changing and uncertain climate. *Frontiers in Ecology and the Environment*, 8(1), 35-43.

Lawrence, W. (1994). Karner blue butterfly populations in the Allegan state game area, Michigan. In Andow, D., Baker, R., & Lane, C. (Ed.), *Karner blue butterfly: a symbol of vanishing landscape* (pp 53-62). University of Minnesota, St. Paul.

Lawson, C., Bennie, J., Thomas, C., Hodgson, J. & Wilson, R. (2012). Local and landscape management of an expanding range margin under climate change. *Journal of Applied Ecology*, 49, 552–561.

Lawson, C., Bennie, C., Thomas, J., Hodgson, T., Bernhard, P., & Budd, A. (2013). *The Status and Conservation of the Silver-Spotted Skipper Hesperia Comma in South-East England 2000-2009*. University of Exeter, Exeter, UK.

Lawson, C., Vindenes, Y., Bailey, L., & Pol, M. (2015). Environmental variation and population responses to global change. *Ecology Letters*, 18(7), 724-736.

Leach M. (1993). Status and distribution of the Karner blue butterfly at Fort McCoy, Wisconsin: final report on a two-year study. Unpublished Report Prepared for the Natural Resources Management Division, Fort McCoy Military Research Reservation, U.S. Army. The Nature Conservancy, Wisconsin Chapter.

Le Moullac, G., & Haffner, P. (2000). Environmental factors affecting immune responses in Crustacea. *Aquaculture*, 191(1-3), 121-131.

Levins, R. (1970). Extinction. *Lectures on Mathematics in the Life Sciences*, 2, 75-107.

Levy, O., Buckley, L., Keitt, T., Smith, C., Boateng, K., Kumar, D., & Angilletta, M. (2015). Resolving the life cycle alters expected impacts of climate change. *Proceedings. Biological Sciences*, 282(1813), 20150837.

Lenoir, J., Gegout, J., Marquet, P., de Ruffray, P., & Brisse, H. (2008). A significant upward shift in plant species optimum elevation during the 20th century. *Science*, 320, 1768-1771.

Lenoir, J., Graae, B., Aarrestad, P., Alsos, I., Armbruster, W., Austrheim, G., Bergendorff, C., Birks, H., Brathen, K., Brunet, J. (2013). *Local temperatures inferred from plant communities suggest strong spatial buffering of climate warming across northern Europe*.

Loarie, S., Duffy, P., Hamilton, H., Asner, G., Field, C. & Ackerly, D. (2009). The velocity of climate change. *Nature*, 462, 1052-1055.

Long, O., Warren, R., Price, J., Brereton, T., Botham, M., & Franco, A. (2017). Sensitivity of UK butterflies to local climatic extremes: which life stages are most at risk? *Journal of Animal Ecology*, 86, 108-116.

Lumsden, H., & Drever, M. (2002). Overview of the Trumpeter Swan reintroduction program in Ontario, 1982–2000. *Waterbirds*, 25, 301-312.

Luoto, M., Kuussaari, M., Rita, H., Salminen, J., & Bonsdorff, T. (2001). Determinants of distribution and abundance in the clouded apollo butterfly: A landscape ecological approach. *Ecography*, 24(5), 601-617.

Mackay, A. (2008). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Journal of Environmental Quality*, 37(6), 2407.

Mackey, B., Berry, S., Hugh, S., Ferrier, S., Harwood, T. & Williams, K. (2012) Ecosystem greenspots: identifying potential drought, fire, and climate-change micro-refuges. *Ecological Applications*, 22, 1852-1864.

Macknick, J., Beatty, B., & Hill, G. (2013). *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. National Renewable Energy Laboratory: Golden, CO.

Markus, R. (2008). What is principal component analysis? *Nature Biotechnology*, 26(3), 3-4.

Maron, M., McAlpine, C., Watson, J., Maxwell, S., & Barnard, P. (2015). Climate-induced resource bottlenecks exacerbate species vulnerability: A review. *Diversity and Distributions*, 21(7), 731-743.

Marshall, D. (2008). Transgenerational plasticity in the sea: context-dependent maternal effects across the life history. *Ecology*, 89(2), 418-427.

Maxwell, S., Rhodes, J., Runge, M., Possingham, H., Ng, C., & McDonald-Madden, E. (2015). How much is new information worth? Evaluating the financial benefit of resolving management uncertainty. *Journal of Applied Ecology*, 52(1), 12-20.

McCarl, B., Norton, R., & Wu, X. (2014). Assessing Climate Change Effects of of IDB Projects: Concepts and Procedures. American Development Bank Washington, December 2014 © BID

McDermott Long, O., Warren, R., Price, J., Brereton, T.M., Botham, M.S., & Franco, A.M.A. (2016). Sensitivity of UK butterflies to local climatic extremes: Which life stages are most at risk? *Journal of Animal Ecology*, 108-116.

McKechnie, A., & Wolf, B. (2010). Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. *Biology Letters*, 6(2), 253-256.

McLaughlin, J., Hellmann, J., Boggs, C. & Ehrlich, P. (2002). Climate change hastens population extinctions. Proceedings of the National Academy of Sciences of the United States of America, 99, 6070-6074.

Mitchell, M., & NetLibrary, Inc. (1996). *An introduction to genetic algorithms: Complex adaptive systems*. Cambridge, Mass.: MIT Press.

Melillo, J., & U.S. Global Change Research Program. (2014). *Climate Change Impacts in the United States: The Third National Climate Assessment*.

Møller, A., Rubolini, D. & Lehikoinen, E. (2008). Populations of migratory bird species that did not show a phenological response to climate change are declining. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 16195–16200.

Morelli, T., Daly, C., Dobrowski, S., Dulen, D., Ebersole, J., Jackson, S., . . . Beissinger, S. (2016). Managing Climate Change Refugia for Climate Adaptation. *PLoS ONE,* 11(8), E0159909.

Morris, W., Doak, D., Groom, M., Kareiva, P., Feiberg, J., Gerber, L., Murphy, P., & Thomson, D. (1999). *A practical handbook for population viability analysis*. The Nature Conservancy, Arlington, Virginia,

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., Van Vuuren, D.P.. . . Wilbanks, T.P. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282), 747-74756.

Multi-Resolution Land Characteristics Consortium (U.S.). National land cover dataset (NLCD). [Research Triangle Park, NC]: [Multi-Resolution Land Characteristics Consortium].

Myers-Smith, I., Elmendorf, S., Beck, P., Wilmking, M., Hallinger, M., Blok, D., . . . Vellend, M. (2015). Climate sensitivity of shrub growth across the tundra biome. *Nature Climate Change*, 5, 887–891.

Nicolson, S., Thornburg, R., Nepi, M., & Pacini, E. (2007). *Nectaries and Nectar*.

Nix, H. (1986). A biogeographic analysis of Australian elapid snakes. In *Longmore R., Atlas of elapid snakes of Australia*. Australia flora and fauna series 7. Bureau of Flora and Fauna, Canberra.

Nowicki, P., Bonelli, S., Barbero, F., & Balletto, E. (2009). Relative importance of density-dependent regulation and environmental stochasticity for butterfly population dynamics. *Oecologia*, 161, 227-239.

Nuzzo, V. (1986). Extent and status of midwest oak savanna: presettlement and 1985. *Nat Areas Journal*, 6, 6-36.

O'Brien, D., Boggs, C., Fogerl, M. (2004) Making eggs from nectar: the role of life history and dietary carbon turnover in butterfly reproductive resource allocation. *Oikos*, 105, 279-291.

O'Donnell, M., & Ignizio, D. (2012). *A Bioclimatic Predictors for Supporting Ecological Applications in the Conterminous United States*. U.S. Department of the Interior, U.S. Geological Survey.

Omernik, J., & Griffith, G. (2014). Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. *Environmental Management*, 54(6), 1249-1266.

Ohlberger, J. (2013) Climate warming and ectotherm body size – from individual physiology to community ecology. *Functional Ecology,* 27, 991-1001.

Oliver, T., Marshall, H., Morecroft, M., Brereton, T., Prudhomme, C., & Huntingford, C. (2015). Interacting effects of climate change and habitat fragmentation on drought-sensitive butterflies. *Nature Climate Change*, 5, 941–945.

Olson, D., DellaSala, D., Noss, R., Strittholt, J., Kass, J., Koopman, M. & Allnutt, T. (2012). Climate change Refugia for biodiversity in the Klamath Siskiyou ecoregion. *Natural Areas Journal*, 32, 65–74.

Opdam, P., & Wascher, D. (2004). Climate change meets habitat fragmentation: Linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation*, 117(3), 285-297.

Opler, P., & Malilul, V. (1998). *A field guide to eastern butterflies*. Houghton Mifflin Co., Boston.

Overgaard, J., & Sørensen, J. (2008). Rapid thermal adaptation during field temperature variations in Drosophila melanogaster. *Cryobiology*, 56(2), 159-162.

Pacifici, M., Foden, W., Visconti, P., Watson, J., Butchart, S., Kovacs, K…Rondinini, C. (2015). Assessing species vulnerability to climate change. *Nature Climate Change*, 5(3), 215-224.

Packer, L. (1990). The status of two butterflies, Karner blue (Lycaeides Melissa samuelis) and Frosted Elfin (Incisalia irus), restricted to oak savannah in Ontario. In Allen, G., Eagles, P., & Price, S. (Ed.), *Conserving Carolinian Canada* (pp 253-271). Waterloo, ON: University of Waterloo Press.

Pahkala, M., Laurila, A., & Merilä, J. (2001). Carry-over effects of ultraviolet-B radiation on larval fitness in Rana temporaria. Proceedings. *Biological Sciences,* 268(1477), 1699-1706.

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, 37, 637.

Parmesan, C., Root, T., & Willig, M. (2000). Impacts of Extreme Weather and Climate on Terrestrial Biota. *Bulletin of the American Meteorological Society*, 81(3), 443-450.

Parmesan, C., Ryrholm, N., Stefanescu, C…Warren, M. (1999). Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature,* 399(6736), 579-583.

Parmesan, C., Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421, 37-42.

Pearson, R. (2006). Climate change and the migration capacity of species. *Trends in Ecology & Evolution*, 21(3), 111-113.

Peterson, G., Cumming, G., & Carpenter, S. (2003). Scenario Planning: A Tool for Conservation in an Uncertain World. *Conservation Biology*, 17(2), 358-366.

Patterson, T., Grundel, R., Dzurisin, J., Knutson, R., & Hellmann, J. (2020). Evidence of an extreme weather-induced phenological mismatch and a local extirpation of the endangered Karner blue butterfly. *Conservation Science and Practice*, 2(1).

Pickens, B., & Root, K. (2008). Factors Affecting Host-plant Quality and Nectar Use for the Karner Blue Butterfly: Implications for Oak Savanna Restoration. *Natural Areas Journal*, 28(3), 210-217.

Pincebourde, S., & Casas, J. (2015). Warming tolerance across insect ontogeny: Influence of joint shifts in microclimates and thermal limits. *Ecology*, 96(4), 986-997.

Pironon, S., Papuga, G., Villellas, J., Angert, A., García, M., & Thompson, J. (2017). Geographic variation in genetic and demographic performance: New insights from an old biogeographical paradigm. *Biological Reviews*, 92(4), 1877-1909.

Price, M., & Soorae, P. (2003). Reintroductions: Whence and whither? *International Zoo Yearbook*, 38(1), 61-75.

Plowright, R. (1981). Nectar production in the boreal forest lily Clintonia borealis. *Canadian Journal of Botany*, 59(2), 156-160.

Plowright, R. (1987). Corolla depth and nectar concentration: An experimental study. *Canadian Journal of Botany*, 65(5), 1011-1013.

Pollard, E. (1991) Synchrony of population fluctuations: the dominant influence of widespread factors on local butterfly populations. *Oikos*, 60, 7-10.

Pollard, E., & Yates, T. (1993) Monitoring butterflies for ecology and conservation. Chapman and Hall, London conservation planning and management under climate change. *PLoS ONE*, 9, e113749.

Potter, K., Woods, H., & Pincebourde, S. (2013). Microclimatic challenges in global change biology. *Global Change Biology*, 19, 2932–2939.

Potter, K., Davidowitz, G., & Woods, H. (2011). Cross-stage consequences of egg temperature in the insect Manduca sexta. *Functional Ecology*, 25(3), 548-556.

Potter, K., Davidowitz, G., & Woods, H. (2009). Insect eggs protected from high temperatures by limited homeothermy of plant leaves. *Journal of Experimental Biology*, 212(21), 3448-34454.

Poyry, J., Luoto, M., Heikkinen, R., Kuussaari, M. & Saarinen, K. (2009). Species traits explain recent range shifts of Finnish butterflies. *Global Change Biology*, 15, 732-743.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Radchuk, V., Turlure, C. & Schtickzelle, N. (2013). Each life stage matters: the importance of assessing the response to climate change over the complete life cycle in butterflies. *Journal of Animal Ecology*, 82, 275-285.

Rajczak, J., Pall, P., & Schär, C. (2013). Projections of extreme precipitation events in regional climate simulations for Europe and the Alpine Region. *Journal of Geophysical Research: Atmospheres*, 118(9), 3610-3626.

Randin, C., Dirnböck, T., Dullinger, S., Zimmermann, N., Zappa, M., & Guisan, A. (2006). Are niche-based species distribution models transferable in space? *Journal of Biogeography*, 33(10), 1689-1703.

Ricciardi, A., & Simberloff, D. (2009). Assisted colonization is not a viable conservation strategy. *Trends in Ecology & Evolution*, 24(5), 248-253.

Richardson, D., Hellmann, J., Mclachlan, J., Sax, D., Schwartz, M., Gonzalez, P., . . . Vellend, M. (2009). Multidimensional evaluation of managed relocation. *Proceedings of the National Academy of Sciences of the United States of America*, 106(24), 9721-9724.

Roberts. D., & Cooper, S. (1989). Concepts and techniques of vegetation mapping. In *Land Classifications Based on Vegetation: Applications for Resource Management* (pp. 90-96). USDA Forest Service GTR INT-257, Ogden, UT.

Rota, B. & Laitila, T. (2015). Comparisons Of Some Weighting Methods For Nonresponse Adjustment. *Lithuaninan Journal of Statistics*, 54(1), 69-83.

Ruegg, K., Hijmans, R., Moritz, C. (2006) Climate change and the origin of migratory pathways in the Swainson’s Thrush, Catharus ustulatus. *Journal of Biogeography*, 33, 1172–1182.

Ryan, M., & Vose, J. (2012). Effects of climatic variability and change. In: Vose, J., Peterson, D., Patel, W. (Ed.), *Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector* (pp. 7-95). Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Roots, E. (1989). Climate change: high-latitude regions. *Climatic Change*, 15, 223-253.

Root, T., Price, J., Hall, K., Schneider, S., Rosenzweig, C. & Pounds, J. (2003). Fingerprints of global warming on wild animals and plants. *Nature*, 421, 57-60.

Roy, D. B., Rothery, P., Moss, D., Pollard, E. & Thomas, J. (2001). Butterfly numbers and weather: predicting historical trends in abundance and the future effects of climate change. *Journal of Animal Ecology*, 70, 201-217.

Sabo, J., Holmes, E., & Kareiva, P. (2004). Efficiency of simple viability models in ecological risk assessment: does density dependence matter? *Ecology*, 85(2), 328-341.

Saeys, Y., Inza, I., & Laranaga, P. (2007). A review of feature selection techniques in bioinformatics. *Bioinformatics*, 23, 19, 2507-2517.

Sagarin, R., Gaines, S., & Gaylord, B. (2006). Moving beyond assumptions to understand abundance distributions across the ranges of species. *Trends in Ecology and Evolution*, 21, 524–530.

Savage, V., Gillooly, J., Brown, J., West, G., & Charnov, E. (2004). Effects of body size and temperature on population growth. *The American Naturalist*, 163, 429-441.

Schetter, T., & Root, K. (2011). Assessing an Imperiled Oak Savanna Landscape in Northwestern Ohio using Landsat Data. *Natural Areas Journal*, 31(2), 118-130.

Seddon, P., Armstrong, D., Soorae, P., Launay, F., Walker, S., Ruiz-Miranda, C., . . . Kleiman, D. (2009). The Risks of Assisted Colonization. *Conservation Biology*, 23(4), 788-789.

Sentis, A., Hemptinne, J., & Brodeur, J. (2013). Parsing handling time into its components: Implications for responses to a temperature gradient. *Ecology*, 94(8), 1675-1680.

Seimon, T., Seimon, A., Daszak, P., Halloy, S., Schloegel, L., Aguilar, C., . . . Simmons, J. (2007). Upward range extension of Andean anurans and chytridiomycosis to extreme elevations in response to tropical deglaciation. *Global Change Biology*, 13(1), 288-299.

Sheridan, J. & Bickford, D. (2011). Shrinking body size as an ecological response to climate change. *Nature Climate Change*, 1, 401-406.

Shafer, C. (1999). National park and reserve planning to protect biological diversity: some basic elements. *Landscape Urban Planning*, 44, 123-153

Shahabuddin, G. & Ponte, C. (2005). Frugivorous butterfly species in tropical forest fragments: correlates of vulnerability to extinction. *Biodiversity and Conservation*, 14, 1137-1152.

Shingleton, A. (2011). Evolution and the regulation of growth and body size. In, Flatt, T., & Heyland, A. (Ed.), *Mechanisms of Life History Evolution* (pp. 43-55). Oxford University Press, Oxford, USA.

Schultz, C., & Chang, G. (1998). Challenges in insect conservation: Managing fluctuating populations in disturbed environments. In P. Fiedler, & P. Kareiva (Ed.), *Conservation biology for the coming decade* (pp. 228-254). New York: Chapman and Hall.

Schwartz, M., Hellmann, J., McLachlan, J. (2012). Managed Relocation: Integrating the Scientific, Regulatory, and Ethical Challenges. *BioScience*, 62(8), 732-743.

Schweitzer, D. (1994). Prioritizing Karner blue butterfly habitats for protection activities. In Andow, D., Baker, R., & Lane, C. (Ed.), *Karner blue butterfly: A symbol of a vanishing landscape*, (pp. 173-184). St. Paul: Minnesota Agricultural Experiment Station.

Shuey, J. (1997). Dancing with fire: ecosystem dynamics, management, and the Karner blue (Lycaeides melissa samuelis Nabokov)(Lycaenidae). *J Lepid Soc*, 51, 263-269.

Sinclair, B., Marshall, K., Sewell, M., Levesque, D., Willett, C., Slotsbo, S., . . . Huey, R. (2016). Can we predict ectotherm responses to climate change using thermal performance curves and body temperatures? *Ecology Letters*, 1372–1385.

Snover, A., Mantua, N., Littell, J., Alexander, M., Mcclure, M., & Nye, J. (2013). Choosing and Using Climate-Change Scenarios for Ecological-Impact Assessments and Conservation Decisions. *Conservation Biology*, 27(6), 1147-1157.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov.

Sparks, T., Carey, P., & Sparks, T. (1995). The responses of species to climate over two centuries: An analysis of the Marsham phenological record, 1736-1947. *Journal of Ecology*, 83(2), 321-329.

Stacey, P., & Taper, M. (1992). Environmental Variation and the Persistence of Small Populations. *Ecological Applications*, 2(1), 18-29.

Stanton, J., Shoemaker, K., Pearson, R., & Akçakaya, H. (2015). Warning times for species extinctions due to climate change. *Global Change Biology*, 21(3), 1066-1077.

Stillwell, R., Blanckenhorn, W., Teder, T., Davidowitz, G. & Fox, C. (2010). Sex differences in phenotypic plasticity affect variation in sexual size dimorphism in insects: from physiology to evolution. *Annual Review of Entomology*, 55, 227-245.

Stocker,Thomas, Qin, Plattner, Tignor, Allen, Boschung, Judith, . . . Bex, Vincent. (2013). IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

Sunday, J., Bates, A., Kearney, M., Colwell, R., Dulvy, N., Longino, J., & Huey, R. (2014). Thermal-safety margins and the necessity of thermoregulatory behavior across latitude and elevation. *Proceedings of the National Academy of Sciences USA*, 111, 5610-5615.

Sutherland, G., Harestad, A., Price, K., Lertzman, K. (2000). Scaling of natal dispersal distances in terrestrial birds and mammals. *Conservation Ecology*, 4, 16-52.

Swengel, A., & Swengel, S. (1993). Observations of Karner Blues and the Barrens Butterfly Community in Wisconsin 1987 – 1993. Website: https://www.researchgate.net/publication/321037815.

Swengel, S., Schlicht, D., Olsen, F., & Swengel, A. (2011). Declines of prairie butterflies in the midwestern USA. *Journal of Insect Conservation*, 15(1), 327-339

Swengel, A, & Swengel, S. (2018). Patterns of Long-Term Population Trends of Three Lupine-Feeding Butterflies in Wisconsin. *Diversity*, 10(2), Diversity, Jun 2018, Vol.10(2).

Taylor, K., Stouffer, R., & Meehl, G. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, 93(4), 485-498.

Terblanche, J., Hoffmann, A., Mitchell, K., Rako, L., Le Roux, P., & Chown, S. (2011). Ecologically relevant measures of tolerance to potentially lethal temperatures. *The Journal of Experimental Biology*, 214(22), 3713-3725.

Thomas, C., Bodsworth, E., Wilson, R., Simmons, A., Davies, Z., & Musche, M. (2001). Ecological and evolutionary processes at expanding range margins. *Nature*, 411, 577-581.

Thomas, C., Cameron, A., Green, R., Bakkenes, M, Beaumont, L., Collingham, Y…Williams, S. (2004). Extinction risk from climate change. *Nature*, 427(6970), 145-148.

Thomas, C., & Lennon, J. (1999). Birds extend their ranges northwards. *Nature*, 213.

Thomas, J., Rose, R., Clarke, R., Thomas, C., & Webb, N. (1999). Intraspecific variation in habitat availability among ectothermic animals near their climatic limits and their centres of range. *Functional Ecology*, 13(S1), 55-64.

Thuiller, W. (2003). BIOMOD – optimizing predictions of species distributions and projecting potential future shifts under global change. *Global Change Biology*, 9(10), 1353-1362.

Thuiller, W. (2004). Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology*, 10, 2020–2027.

Tingley, M., Koo, M., Moritz, C., Rush, A., & Beissinger, S. (2012). The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. *Global Change Biology*, 18(11), 3279-3290.

Trenberth, K., Dai, A., Rasmussen, R., & Parsons, D. (2003). The changing character of precipitation. *Bulletin of the American Meteorological Society*, 84, 1205-1217.

Turlure, C., Van Dyck, H., Goffart, P., Schtickzelle, N. (2014). Resource based habitat use in Lycaena helle: significance of a function, ecological niche-oriented approach. In Habel, C., Meyer, M., & Schmitt, T (Ed.), Jewels in the mist: a synopsis on the endangered violet copper butterfly Lycaena helle (pp. 67-85). Pensoft Publishers, Moscow.

Turner, J., Gatehouse, C. & Corey, C. (1987). Does solar energy control organic diversity? Butterflies, moths and the British climate. *Oikos*, 48, 195-205.

U.S. Fish and Wildlife Service. (2003). *Final Recovery Plan for the Karner Blue Butterfly (Lycaeides melissa samuelis)*. US Fish and Wildlife Service, Fort Snelling, Minnesota.

U.S. Fish and Wildlife Service. (2003). *Karner blue butterfly (Lycaeides melissa samuelis) recovery plan*. Minnesota: Fort Snelling., 221.

U.S. Fish and Wildlife Service. (2011). *Update to KBB recovery plan; Inclusion of Michigan Oak Openings potential recovery unit*. Greenbay, WI.

Villellas, J., Morris, W., & García, M. (2013). Variation in stochastic demography between and within central and peripheral regions in a widespread short-lived herb. *Ecology*, 94(6), 1378-1388.

Voorhies, K., Szymanski, J., Nail, K., & Fidino, M. (2019). A Method to Project Future Impacts From Threats and Conservation on the Probability of Extinction for North American Migratory Monarch (Danaus plexxipus) Populations. *Frontiers in Ecology and Evolution*, 7.

WallisDevries, M., & Van Swaay, C. (2006). Global warming and excess nitrogen may induce butterfly decline by microclimatic cooling. *Global Change Biology*, 12(9), 1620-1626.

WallisDeVries, M., Baxter, F., & Vliet, W. (2011). Beyond climate envelopes: Effects of weather on regional population trends in butterflies. *Oecologia*, 167(2), 559-571.

Walsh, K. & Ryan, B. (2000). Tropical cyclone intensity increase near Australia as a result of climate change. *Journal of Climatology*, 13, 3029-3036.

Ward, E., Holmes, E., Thorson, J., & Collen, B. (2014). Complexity is costly: A meta-analysis of parametric and non-parametric methods for short-term population forecasting. *Oikos*, 123(6), 652-661.

Watling, J., Brandt, L., Bucklin, D., Fujisaki, I., Mazzotti, F., Romañach, S., and Speroterra, C. (2015). Performance metrics and variance partitioning reveal sources of uncertainty in species distribution models. *Ecological Modelling*, 309-310, 48.

Walther, G., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T…Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, 416(6879), 389-395.

Warren, R. (2011). The role of interactions in a world implementing adaptation and mitigation solutions to climate change. Philosophical Transactions. *Series A, Mathematical, Physical, and Engineering Sciences*, 369, 217 – 241.

Warren, M., Hill, J., Thomas, J., Asher, J., Fox, R., Huntley, B. . . Thomas, C. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, 414(6859), 65-69.

Warren, R., Vanderwal, J., Price, J., Welbergen, J., Atkinson, I., Ramirez-Villegas, J. . . Lowe, J. (2013). Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change*, 3(7), 678-682.

Weeks, D., Malone, P., & Welling, L. (2011). Climate change scenario planning: a tool for managing parks into uncertain futures. *Park Science*, 28, 26-33.

Wieczorek, J., Guo, Q., Hijmans, R. (2004). The point-radius method for georeferencing point localities and calculating associated uncertainty. *International Journal of Geographic Information Science*, 18, 745-767.

Weinig, C., & Delph, L. (2001). Phenotypic plasticity early in life constrains developmental responses later. *Evolution*, 55(5), 930-936.

Weiss, S., Murphy, D., & Berger, J. (1990). Thermal microenvironments and the restoration of rare butterfly habitat. *Illumina Biological Content - Unstructured*, 50-60.

Wiklund, C., Lindfors, V. & Forsberg, J. (1996). Early male emergence and reproductive phenology of the adult overwintering butterfly Gonepteryxrhamni in Sweden. *Oikos*, 75, 227-240.

Willis, C., Ruhfel, B., Primack, R., Miller-Rushing, A., & Davis, C. (2008). Phylogenetic patterns of species loss in Thoreau’s woods are driven by climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 17029-17033

Wilson, R., Guti_errez, D., Guti_errez, J., Mart_ınez, D., Agudo, R. & Monserrat, V. (2005). Changes to the elevational limits and extent of speciesranges associated with climate change. *Ecology Letters*, 8, 1138-1146.

Woods, A., & National Health Environmental Effects Research Laboratory. (2006). Level III and IV Ecoregions of Illinois.

Zhang, W., Chang, X., Hoffmann, A., Zhang, S., & Ma, C. (2015). Impact of hot events at different developmental stages of a moth: The closer to adult stage, the less reproductive output. *Scientific Reports*, 5(1), 10436.

Zimmermann, N., Yoccoz, N., Edwards, T., Meier, E., Thuiller, W., Guisan, A., . . . Pearman, P. (2009). Climatic extremes improve predictions of spatial patterns of tree species. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 19723-19728.

Appendices

Table A1.a-b. Performance comparisons among six modeling algorithms (GLM, MARS, GBM, RF, ANN, SVM) of density and between-generation change models at whole-species and ecoregion scales for the first and the second generation, respectively, measured by MAE, RSME, and R-squared. Top 3 algorithms were bolded in whole-species integration and five ecoregions.

(A1.a). First Generation

		Density Model						Change Model					
		GLM	MARS	GBM	RF	ANN	SVM	GLM	MARS	GBM	RF	ANN	SVM
Whole Species	MAE	10.91	10.39	**9.82**	**9.22**	13.05	**8.55**	10.99	**10.17**	10.68	**9.83**	15.34	**9.97**
	RSME	21.52	21.53	**20.62**	**19.78**	28.10	**19.96**	**21.47**	**22.59**	24.29	**23.56**	31.96	24.98
	R^2	0.35	0.31	**0.35**	**0.44**	NA	**0.46**	**0.51**	**0.47**	0.42	**0.45**	NA	0.38
Central Wisconsin	MAE	15.79	13.46	**12.78**	**11.90**	17.58	**11.27**	15.49	**13.67**	14.64	**13.31**	20.18	**14.13**
	RSME	27.93	27.05	**24.17**	**23.55**	34.62	**23.85**	**26.87**	**26.41**	30.99	**30.25**	39.12	31.63
	R^2	**0.30**	0.36	0.43	**0.47**	NA	**0.46**	**0.51**	**0.50**	0.40	**0.43**	NA	0.37
Northwestern Wisconsin	MAE	4.33	**3.64**	3.97	3.65	**3.42**	**3.59**	**4.18**	**3.36**	14.28	**8.17**	17.46	14.27
	RSME	**7.41**	**6.86**	7.46	**7.34**	8.74	8.12	**6.93**	**6.57**	28.41	**20.61**	38.99	30.67
	R^2	**0.53**	**0.55**	0.44	**0.44**	0.16	0.26	**0.95**	**0.94**	0.63	**0.78**	NA	0.53
Fort McCoy Wisconsin	MAE	7.64	6.88	**6.53**	**6.58**	9.32	**6.20**	10.20	**6.37**	**6.08**	**6.15**	7.98	6.40
	RSME	26.33	**12.05**	**11.60**	12.17	16.70	**12.17**	39.61	11.67	**10.08**	**10.69**	12.67	**10.58**
	R^2	**0.48**	0.41	**0.43**	**0.47**	NA	0.36	0.23	0.24	**0.34**	**0.26**	NA	**0.28**
IN Dunes National Park	MAE	24.90	**19.00**	25.90	**18.60**	40.10	**23.10**	26.10	**16.60**	23.40	**17.30**	53.90	**22.90**
	RSME	53.20	**2.40**	46.60	**32.00**	71.00	**45.00**	57.40	**30.10**	**39.70**	**31.10**	91.70	39.90
	R^2	**0.68**	**0.74**	0.59	**0.75**	NA	0.62	0.77	**0.87**	0.80	**0.89**	NA	**0.81**
Albany Pine Bush NY	MAE	5.50	5.47	5.39	**5.16**	8.50	**5.06**	5.55	**5.26**	**5.47**	**5.39**	7.66	5.86
	RSME	**7.75**	7.95	**7.66**	**7.87**	13.32	8.42	**7.62**	**7.40**	9.99	**8.15**	12.21	8.86
	R^2	**0.70**	**0.65**	0.58	**0.59**	NA	0.53	**0.63**	**0.64**	0.41	**0.62**	0.20	0.55

(A1.b). Second Generation

		Density						Change					
		GLM	MARS	GBM	RF	ANN	SVM	GLM	MARS	GBM	RF	ANN	SVM
Whole Species	MAE	15.49	13.61	**13.54**	**12.98**	21.58	**12.30**	15.27	13.88	**13.56**	**12.54**	13.70	**12.30**
	RSME	29.80	27.67	**26.78**	**25.87**	40.35	**26.63**	29.38	**28.64**	28.84	**27.66**	31.08	**27.55**
	R^2	0.33	0.41	**0.44**	**0.49**	NA	**0.46**	0.11	**0.19**	0.14	**0.21**	0.06	**0.23**
Central Wisconsin	MAE	19.50	**16.15**	16.39	**16.36**	26.66	**15.74**	20.25	17.37	18.01	**17.25**	**17.17**	**16.57**
	RSME	35.41	**29.81**	30.22	**29.42**	45.38	**29.97**	37.17	**31.38**	36.04	**34.90**	37.32	**34.38**
	R^2	0.22	**0.41**	0.41	**0.43**	NA	**0.41**	0.11	**0.26**	0.08	**0.16**	0.12	**0.17**
Northwestern Wisconsin	MAE	26.29	22.99	18.76	**17.55**	**18.23**	**17.68**	26.85	20.05	17.55	**16.49**	**16.24**	**16.65**
	RSME	41.82	47.24	**34.08**	**33.16**	40.30	**35.68**	43.35	39.66	**32.83**	**32.18**	36.46	**34.78**
	R^2	**0.36**	0.30	**0.41**	**0.41**	NA	0.20	0.23	**0.24**	**0.29**	**0.31**	NA	0.09
Fort McCoy Wisconsin	MAE	8.16	7.57	**6.95**	**6.82**	13.49	**6.68**	7.92	7.60	**7.37**	**7.05**	8.90	**7.42**
	RSME	11.74	10.87	**9.80**	**9.99**	19.05	**10.59**	**11.42**	**11.60**	12.58	**12.03**	15.29	12.93
	R^2	0.41	0.48	**0.50**	**0.50**	NA	**0.49**	**0.38**	**0.40**	0.36	**0.41**	0.12	0.30
IN Dunes National Park	MAE	**44.30**	**40.40**	46.00	**42.60**	87.30	47.10	47.20	39.40	**38.30**	**37.60**	47.90	**38.00**
	RSME	**69.90**	**68.80**	82.20	**73.10**	153.50	83.70	72.40	68.70	**62.30**	**63.10**	86.80	**63.00**
	R^2	**0.77**	**0.80**	0.70	**0.76**	NA	0.71	0.39	**0.46**	**0.46**	**0.46**	NA	0.44
Albany Pine Bush NY	MAE	7.54	**6.38**	7.81	**6.13**	13.53	**6.87**	7.79	5.78	**5.73**	**5.42**	6.23	**5.49**
	RSME	11.10	**8.41**	11.87	**9.43**	20.57	**10.86**	11.15	8.00	**7.80**	**7.68**	9.12	**7.55**
	R^2	0.61	**0.72**	0.52	**0.71**	NA	**0.65**	**0.18**	0.16	0.17	**0.20**	NA	**0.23**

Table A2. The states, counties, latitudes, and longitudes of all the 48 populations in the five ecoregions.

Central Wisconsin

Site	County	Latitude	Longitude	Site	County	Latitude	Longitude	Site	County	Latitude	Longitude
Dike 17	WI Jackson	44°18'36"	90°33'50"	StanM	WI Jackson	44°13'55"	90°39'21"	WildSp	WI Jackson	44°16'40"	90°40'40"
Lichtner	WI Jackson	44°22'55"	90°41'22"	NBRE	WI Jackson	44°18'43"	90°44'24"	SBRW	WI Jackson	44°17'31"	90°44'34"
Bauer Cut	WI Jackson	44°17'49"	90°45'7"	WCM	WI Jackson	44°16'22"	90°45'50"	WoodCFX	WI Wood	44°19'39"	90°4'49"
CTHX	WI Wood	44°20'24"	90°7'48"	XS	WI Wood	44°19'1"	90°7'40"	XEW	WI Wood	44°18'18"	90°7'44"
Sand 5	WI Wood	44°19'1"	90°11'9"	Buena	WI Portage	44°21'36"	89°32'60"				

Fort McCoy, Wisconsin

Site	County	Latitude	Longitude	Site	County	Latitude	Longitude	Site	County	Latitude	Longitude
A1	WI Moroe	43°56'5"	90°45'6"	A5	WI Moroe	43°55'47"	90°38'26"	B7	WI Moroe	43°57'22"	90°38'26"
B8	WI Moroe	43°56'45"	90°36'43"	B13	WI Moroe	43°58'7"	90°42'1"	B16	WI Moroe	43°57'33"	90°38'51"
B18	WI Moroe	43°58'37"	90°40'41"	C11	WI Moroe	44°5'50"	90°38'59"	D4	WI Moroe	44°7'11"	90°41'16"
D6	WI Moroe	44°7'26"	90°38'51"	E131	WI Moroe	44°6'50"	90°41'56"	E132	WI Moroe	44°6'48"	90°42'26"

Northwestern Wisconsin

Site	County	Latitude	Longitude	Site	County	Latitude	Longitude	Site	County	Latitude	Longitude
BuPeet	WI Burnett	45°54'18"	92°32'34"	CrCorner	WI Burnett	45°54'18"	92°32'60"	CrReedE	WI Burnett	45°43'7"	92°35'13"
CrNRefR	WI Burnett	45°53'13"	92°35'60"	CrKJM	WI Burnett	45°52'37"	92°33'9"	Crover	WI Burnett	45°52'40"	92°37'55"
CrPhant	WI Burnett	45°50'15"	92°40'12"	St	WI Burnett	45°44'6"	92°44'24"				

Indiana Dunes National Park

Site	County	Latitude	Longitude	Site	County	Latitude	Longitude	Site	County	Latitude	Longitude
Miller	IN Porter	41°36'29"	87°16'43"	Tollestone	IN Porter	41°36'23"	87°15'19"	Marquette	IN Porter	41°36'55"	87°13'9"
Long Lake	IN Porter	41°36'52"	87°12'59"	Inland	IN Porter	41°36'55"	87°12'36"	West Beach	IN Porter	41°37'5"	87°12'51"

Albany Pine Bush, New York

Site	County	Latitude	Longitude	Site	County	Latitude	Longitude	Site	County	Latitude	Longitude
PBNW	NW Albany	42°44'39"	73°54'8"	BH	NW Albany	42°44'14"	73°53'10"	KRBE	NW Albany	42°43'19"	73°52'0"
KBE	NW Albany	42°44'56"	73°51'39"	KBW	NW Albany	42°43'0"	73°52'55"	PBSW	NW Albany	42°42'27"	73°53'49"
PBSE	NW Albany	42°41'52"	73°51'55"	KRBE	NW Albany	42°43'34"	73°52'39"				

Table A3.a-e. The mean extinction risks, ranging from 0 to 1, of all the 48 Karner blue populations in the five ecoregions during four *predictive windows* (before 2020, 2020-2029, 2030-2039, 2049-2049) on two *habitat areas* (1 ha and 10 ha) across four *climate scenarios* (baseline, +0.5-1%, +1.0-2%, +1.5-3%) using both between-generation change model and density model at both *spatial scales* (whole species and ecoregion), respectively. The initial population densities of the two generations in the preceding year were included in the columns.

(A3.a). Central Wisconsin

Buena		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 0.7; PF: 1.1)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.991	1.000	1.000	0.999	0.917	0.948	1.000	0.999	0.992
	+0.5-1%	1.000	1.000	0.998	0.991	1.000	1.000	1.000	1.000	1.000	0.922	0.970	0.866	0.925	0.946	0.886	0.849
	+1.0-2%	0.985	0.514	0.133	0.008	1.000	0.995	1.000	1.000	0.778	0.865	0.867	0.838	0.623	0.941	0.639	0.759
	+1.5-3%	0.265	0.000	0.000	0.000	1.000	0.720	0.870	0.983	0.515	0.613	0.691	0.731	0.385	0.536	0.405	0.654
WoodCFX		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 6.7; PF: 4.4)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.250	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.193	0.477	0.480	0.432	0.215	0.492	0.495	0.456
	+0.5-1%	0.265	0.001	0.023	0.007	0.250	0.000	0.025	0.000	0.175	0.445	0.461	0.375	0.123	0.491	0.450	0.410
	+1.0-2%	0.498	0.054	0.229	0.087	0.400	0.007	0.171	0.022	0.108	0.320	0.342	0.304	0.000	0.376	0.302	0.355
	+1.5-3%	0.500	0.418	0.487	0.479	0.463	0.082	0.307	0.409	0.013	0.085	0.231	0.109	0.000	0.263	0.065	0.061
10 Ha	Baseline	0.250	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.250	0.000	0.003	0.002	0.250	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.495	0.040	0.142	0.030	0.295	0.003	0.155	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.500	0.339	0.458	0.460	0.403	0.062	0.304	0.371	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

CTHX		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 14; PF: 17.5)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.313	0.016	0.000	0.000	0.288	0.000	0.009	0.000	0.000	0.009	0.000	0.000	0.313	0.016	0.000	0.000
	+0.5-1%	0.390	0.020	0.000	0.000	0.485	0.000	0.038	0.007	0.000	0.000	0.008	0.005	0.390	0.020	0.000	0.000
	+1.0-2%	0.373	0.066	0.000	0.000	0.398	0.000	0.024	0.016	0.000	0.024	0.025	0.004	0.373	0.066	0.000	0.000
	+1.5-3%	0.250	0.019	0.001	0.000	0.473	0.035	0.008	0.040	0.000	0.009	0.000	0.000	0.250	0.019	0.001	0.000
10 Ha	Baseline	0.250	0.000	0.000	0.000	0.250	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000
	+0.5-1%	0.260	0.000	0.000	0.000	0.270	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.260	0.000	0.000	0.000
	+1.0-2%	0.278	0.003	0.000	0.000	0.255	0.000	0.006	0.004	0.000	0.000	0.000	0.000	0.278	0.003	0.000	0.000
	+1.5-3%	0.250	0.020	0.000	0.000	0.345	0.013	0.005	0.018	0.000	0.000	0.000	0.000	0.250	0.020	0.000	0.000
XEW		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 15.4; PF: 19.2)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.490	0.076	0.000	0.000	0.340	0.000	0.018	0.000	0.003	0.000	0.000	0.000	0.003	0.069	0.029	0.000
	+0.5-1%	0.500	0.126	0.000	0.000	0.328	0.039	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.007	0.008
	+1.0-2%	0.495	0.181	0.000	0.000	0.648	0.206	0.169	0.106	0.000	0.000	0.000	0.000	0.000	0.017	0.001	0.000
	+1.5-3%	0.383	0.076	0.003	0.000	0.630	0.513	0.417	0.536	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.250	0.000	0.000	0.000	0.250	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.288	0.000	0.001	0.000	0.253	0.025	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.285	0.000	0.000	0.000	0.468	0.109	0.085	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.250	0.013	0.000	0.000	0.500	0.369	0.298	0.401	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
XS		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 1.4; PF: 0)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.475	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.500	0.001	0.000	0.000	0.518	0.008	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.500	0.003	0.000	0.000	0.750	0.139	0.000	0.000	0.000	0.037	0.005	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.505	0.087	0.000	0.000	1.000	0.136	0.018	0.012	0.000	0.001	0.005	0.005	0.000	0.000	0.000	0.000

10 Ha	Baseline	0.383	0.000	0.000	0.000	0.470	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.500	0.000	0.000	0.000	0.495	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.500	0.000	0.000	0.000	0.638	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.468	0.087	0.000	0.000	0.745	0.066	0.011	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sand 5		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 3.8; PF: 1.3)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.808	0.223	0.071	0.080	0.428	0.133	0.161	0.564	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.488	0.097	0.000	0.000	0.035	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.118	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.280	0.005	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.578	0.178	0.070	0.095	0.398	0.140	0.190	0.580	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.425	0.381	0.001	0.000	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.003	0.006	0.005	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.023	0.022	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dike 17		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 0; PF: 0.6)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.335	0.077	0.101	0.305	0.048	0.045	0.042	0.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.195	0.019	0.000	0.032	0.080	0.000	0.004	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.105	0.014	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.205	0.050	0.076	0.267	0.005	0.031	0.026	0.168	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.140	0.004	0.001	0.030	0.003	0.000	0.002	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.028	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

StanM		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 3.3; PF: 3.3)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.255	0.001	0.000	0.000	0.250	0.000	0.000	0.000	0.668	0.050	0.083	0.047	0.590	0.007	0.010	0.008
	+0.5-1%	0.455	0.000	0.000	0.000	0.640	0.002	0.009	0.000	0.895	0.336	0.175	0.130	0.263	0.006	0.007	0.005
	+1.0-2%	0.383	0.000	0.000	0.000	0.920	0.613	0.053	0.039	1.000	0.818	0.505	0.217	0.250	0.002	0.003	0.002
	+1.5-3%	0.498	0.006	0.000	0.000	1.000	0.967	0.990	0.963	1.000	0.940	0.809	0.523	0.250	0.000	0.000	0.001
10 Ha	Baseline	0.500	0.423	0.147	0.025	0.250	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.278	0.000	0.000	0.000
	+0.5-1%	0.500	0.498	0.495	0.494	0.418	0.001	0.006	0.000	0.233	0.003	0.000	0.000	0.250	0.000	0.000	0.000
	+1.0-2%	0.493	0.485	0.485	0.485	0.430	0.400	0.044	0.030	0.238	0.023	0.010	0.000	0.250	0.000	0.000	0.000
	+1.5-3%	0.500	0.500	0.500	0.500	0.510	0.515	0.651	0.540	0.003	0.004	0.000	0.000	0.235	0.000	0.000	0.000
WildSP		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 2.5; PF: 1.3)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.490	0.021	0.000	0.000	0.253	0.000	0.000	0.000	0.740	0.197	0.008	0.000	0.988	0.184	0.000	0.000
	+0.5-1%	0.645	0.158	0.056	0.000	0.750	0.030	0.030	0.000	0.993	0.674	0.401	0.001	0.753	0.178	0.001	0.000
	+1.0-2%	0.830	0.217	0.142	0.067	1.000	0.871	0.792	0.706	0.995	0.835	0.690	0.612	0.750	0.117	0.000	0.000
	+1.5-3%	1.000	0.648	0.100	0.154	1.000	0.999	1.000	0.971	1.000	0.840	0.477	0.388	0.290	0.001	0.000	0.000
10 Ha	Baseline	0.500	0.060	0.000	0.000	0.250	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.243	0.000	0.000	0.000
	+0.5-1%	0.330	0.218	0.052	0.008	0.323	0.001	0.018	0.000	0.023	0.004	0.000	0.000	0.233	0.002	0.000	0.000
	+1.0-2%	0.465	0.031	0.019	0.000	0.478	0.592	0.404	0.475	0.175	0.051	0.032	0.001	0.250	0.000	0.000	0.000
	+1.5-3%	0.593	0.245	0.063	0.092	0.745	0.649	0.801	0.497	0.070	0.040	0.006	0.004	0.218	0.000	0.000	0.000
Litchtner		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 1.4; PF: 2)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	0.906	0.910	0.891	1.000	0.883	0.834	0.963	1.000	0.992	0.992	1.000	1.000	1.000	1.000	1.000

10 Ha	Baseline	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.248	0.392	0.319	0.191	0.498	0.500	0.494	0.381
	+0.5-1%	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.028	0.354	0.229	0.254	0.258	0.500	0.487	0.419
	+1.0-2%	0.500	0.500	0.500	0.500	0.500	0.444	0.395	0.469	0.248	0.332	0.212	0.181	0.155	0.500	0.491	0.421
	+1.5-3%	0.500	0.492	0.424	0.431	0.500	0.157	0.054	0.294	0.053	0.088	0.108	0.149	0.068	0.454	0.423	0.325
SBRW		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 5.6; PF: 4.1)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.500	0.000	0.013	0.000	0.288	0.000	0.047	0.001	0.000	0.107	0.042	0.000	0.240	0.282	0.234	0.000
	+0.5-1%	0.500	0.000	0.000	0.000	0.260	0.001	0.010	0.055	0.000	0.055	0.046	0.001	0.213	0.267	0.247	0.057
	+1.0-2%	0.500	0.019	0.002	0.010	0.663	0.119	0.008	0.031	0.000	0.089	0.034	0.000	0.195	0.247	0.203	0.024
	+1.5-3%	0.323	0.009	0.003	0.020	0.625	0.076	0.147	0.016	0.000	0.056	0.049	0.000	0.220	0.236	0.124	0.028
10 Ha	Baseline	0.250	0.000	0.001	0.000	0.250	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.250	0.000	0.000	0.000	0.250	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.250	0.000	0.002	0.003	0.530	0.089	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.250	0.000	0.000	0.005	0.483	0.053	0.120	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NBRE		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 12.5; PF: 11.3)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.500	0.379	0.242	0.381	0.500	0.187	0.265	0.429	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
	+0.5-1%	0.500	0.470	0.268	0.173	0.500	0.130	0.077	0.078	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.370	0.274	0.043	0.202	0.495	0.058	0.051	0.014	0.183	0.007	0.001	0.000	0.003	0.001	0.000	0.000
	+1.5-3%	0.258	0.205	0.005	0.021	0.495	0.072	0.006	0.039	0.093	0.015	0.000	0.000	0.000	0.001	0.000	0.000
10 Ha	Baseline	0.500	0.325	0.096	0.261	0.490	0.028	0.063	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.500	0.457	0.240	0.147	0.468	0.005	0.027	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.420	0.252	0.063	0.117	0.293	0.011	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.360	0.146	0.001	0.004	0.313	0.013	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WCM		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 0.6; PF: 0.7)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	0.500	0.367	0.313	0.082	0.483	0.132	0.235	0.000	0.500	0.500	0.495	0.487	0.500	0.504	0.496	0.472
	+0.5-1%	0.503	0.439	0.496	0.315	0.750	0.290	0.433	0.032	0.605	0.502	0.503	0.500	0.500	0.481	0.500	0.454
	+1.0-2%	0.500	0.558	0.544	0.522	0.613	0.453	0.513	0.360	0.538	0.705	0.813	0.595	0.500	0.500	0.500	0.500
	+1.5-3%	0.970	0.668	0.619	0.604	1.000	0.894	0.550	0.559	0.983	0.897	0.985	0.676	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.250	0.014	0.001	0.000	0.180	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.007	0.023	0.002
	+0.5-1%	0.250	0.029	0.002	0.000	0.250	0.016	0.001	0.000	0.138	0.000	0.028	0.003	0.000	0.009	0.011	0.004
	+1.0-2%	0.250	0.042	0.043	0.032	0.250	0.005	0.006	0.000	0.153	0.027	0.200	0.079	0.000	0.002	0.006	0.001
	+1.5-3%	0.500	0.274	0.168	0.209	0.500	0.130	0.022	0.004	0.250	0.173	0.324	0.099	0.000	0.014	0.002	0.004
Bauer Cut		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 13.1; PF: 14.2)		18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49	18-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	0.710	0.316	0.206	0.750	0.707	0.579	0.494	0.768	0.769	0.814	0.821	0.998	0.930	0.838	0.876
	+0.5-1%	1.000	0.915	0.899	0.898	0.823	0.877	0.818	0.745	0.635	0.800	0.782	0.812	1.000	0.959	1.000	0.941
	+1.0-2%	1.000	1.000	1.000	0.989	1.000	0.999	1.000	0.931	0.750	0.911	0.843	0.773	0.950	1.000	1.000	0.996
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.750	0.958	0.860	0.846	0.805	0.993	0.923	0.941
10 Ha	Baseline	0.353	0.001	0.000	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.448	0.048	0.007	0.000	0.250	0.047	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.490	0.150	0.150	0.083	0.365	0.144	0.193	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.500	0.190	0.387	0.280	0.480	0.282	0.314	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(A3.b). Northwestern Wisconsin

PuBeet		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 1.2; PF: 0)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	0.988	1.000	1.000	1.000	0.958	0.987	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.435	0.205	0.384	0.456	0.516	0.495	0.536	0.533	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+0.5-1%	0.500	0.292	0.480	0.499	0.412	0.370	0.503	0.495	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.0-2%	0.500	0.454	0.500	0.500	0.336	0.303	0.361	0.406	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.5-3%	0.500	0.455	0.500	0.500	0.391	0.343	0.290	0.385	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
CrCorner		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8.8; PF:1.3)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	0.667	0.664	0.596	0.741	0.898	0.765	0.823	0.995	0.917	0.851	0.812	0.980	0.904	0.773	0.791	0.904
	+0.5-1%	0.566	0.547	0.562	0.572	0.821	0.668	0.785	0.979	0.756	0.851	0.821	0.966	0.909	0.707	0.759	0.797
	+1.0-2%	0.513	0.548	0.505	0.573	0.760	0.572	0.630	0.821	0.668	0.750	0.825	0.893	0.773	0.602	0.653	0.694
	+1.5-3%	0.482	0.535	0.499	0.520	0.573	0.519	0.571	0.645	0.667	0.700	0.655	0.901	0.660	0.550	0.617	0.559
10 Ha	Baseline	0.498	0.500	0.500	0.494	0.483	0.419	0.449	0.500	0.498	0.491	0.483	0.500	0.500	0.500	0.500	0.500
	+0.5-1%	0.461	0.496	0.498	0.484	0.446	0.401	0.402	0.500	0.492	0.495	0.500	0.498	0.500	0.500	0.500	0.500
	+1.0-2%	0.394	0.468	0.458	0.488	0.425	0.297	0.272	0.476	0.500	0.500	0.496	0.493	0.500	0.500	0.500	0.500
	+1.5-3%	0.426	0.353	0.212	0.441	0.232	0.295	0.277	0.385	0.500	0.500	0.473	0.500	0.500	0.500	0.500	0.500
CrNefR		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 0; PF: 0)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	0.999	0.975	0.942	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	0.981	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	0.971	0.932	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	0.997	0.989	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

10 Ha	Baseline	0.251	0.000	0.000	0.000	0.888	0.731	0.884	0.889	1.000	0.959	0.950	1.000	1.000	0.930	0.943	0.998
	+0.5-1%	0.252	0.000	0.000	0.000	0.847	0.714	0.831	0.872	0.901	0.935	0.929	1.000	1.000	0.923	0.950	1.000
	+1.0-2%	0.258	0.000	0.000	0.000	0.836	0.611	0.785	0.803	0.870	0.883	0.895	0.979	1.000	0.950	0.950	1.000
	+1.5-3%	0.402	0.000	0.000	0.000	0.763	0.551	0.584	0.677	0.877	0.795	0.759	0.977	1.000	0.853	0.900	0.952
CrReedE		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 2; PF: 0)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	1.000	1.000	0.786	0.948	0.997	0.877	0.401	0.071	1.000	1.000	1.000	1.000	1.000	1.000	0.950	1.000
	+0.5-1%	1.000	1.000	0.850	1.000	0.983	0.439	0.007	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.950	1.000
	+1.0-2%	0.998	0.797	0.707	1.000	0.642	0.014	0.000	0.000	0.928	1.000	0.963	1.000	1.000	0.950	0.900	1.000
	+1.5-3%	0.576	0.539	0.612	0.785	0.485	0.002	0.000	0.000	0.809	0.802	0.954	0.963	0.750	0.798	0.794	0.900
Crover		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 16.7; PF: 0.4)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	0.083	0.000	0.000	0.000	0.406	0.141	0.287	0.254	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+0.5-1%	0.083	0.000	0.000	0.000	0.227	0.063	0.144	0.168	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.0-2%	0.083	0.000	0.000	0.000	0.187	0.038	0.015	0.048	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.5-3%	0.158	0.000	0.000	0.000	0.128	0.027	0.000	0.000	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.083	0.000	0.000	0.000	0.418	0.162	0.310	0.265	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+0.5-1%	0.083	0.000	0.000	0.000	0.223	0.064	0.177	0.174	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.0-2%	0.083	0.000	0.000	0.000	0.208	0.046	0.029	0.074	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.5-3%	0.146	0.000	0.000	0.000	0.129	0.032	0.000	0.000	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

CrPhant		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 2; PF: 0)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	1.000	0.981	0.999	0.999	1.000	1.000	0.996	1.000	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	0.999	0.840	0.988	1.000	0.998	0.993	0.992	1.000	1.000	1.000	1.000	1.000	1.000	0.950	1.000
	+1.0-2%	1.000	0.961	0.839	0.984	0.993	0.894	0.632	0.680	1.000	0.992	1.000	1.000	1.000	1.000	0.950	1.000
	+1.5-3%	0.824	0.692	0.758	0.925	0.841	0.413	0.061	0.059	1.000	0.982	1.000	0.894	0.917	0.850	0.883	0.987
CrKJM		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 4.2; PF: 0)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.644	0.376	0.466	0.458	1.000	1.000	1.000	1.000	0.987	0.999	0.997	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	0.675	0.485	0.500	0.566	1.000	0.938	1.000	0.978	0.851	0.951	0.946	0.995	1.000	1.000	0.991	1.000
	+1.0-2%	0.828	0.647	0.754	0.823	0.964	0.755	0.789	0.885	0.807	0.875	0.847	0.949	1.000	0.957	0.950	1.000
	+1.5-3%	0.812	0.730	0.841	0.922	0.833	0.598	0.693	0.749	0.730	0.636	0.679	0.875	0.993	0.823	0.848	0.900
St		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 11.1; PF: 4.4)		14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49	14-19	20-29	30-39	40-49
1 Ha	Baseline	0.136	0.021	0.001	0.002	0.192	0.283	0.295	0.448	0.071	0.057	0.009	0.034	0.000	0.000	0.000	0.000
	+0.5-1%	0.195	0.031	0.008	0.009	0.214	0.196	0.200	0.352	0.013	0.069	0.007	0.038	0.000	0.000	0.000	0.000
	+1.0-2%	0.285	0.037	0.005	0.003	0.218	0.203	0.192	0.211	0.000	0.014	0.012	0.029	0.000	0.000	0.000	0.000
	+1.5-3%	0.288	0.099	0.029	0.000	0.191	0.162	0.162	0.236	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

10 Ha	Baseline	0.083	0.000	0.000	0.000	0.167	0.216	0.258	0.405	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.084	0.008	0.001	0.000	0.207	0.191	0.189	0.292	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.086	0.004	0.001	0.004	0.228	0.192	0.195	0.189	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.102	0.013	0.000	0.000	0.188	0.158	0.166	0.237	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(A3.c). Fort McCoy, Wisconsin

A1		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 10.3; PF: 20)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.064	0.000	0.000	0.000	0.071	0.000	0.000	0.000	1.000	1.000	0.970	1.000	0.857	0.764	0.849	0.915
	+0.5-1%	0.047	0.000	0.000	0.000	0.069	0.000	0.000	0.000	1.000	0.999	0.971	1.000	0.926	0.812	0.863	0.914
	+1.0-2%	0.148	0.000	0.000	0.000	0.232	0.000	0.000	0.000	0.992	0.998	0.986	1.000	0.921	0.809	0.857	0.910
	+1.5-3%	0.338	0.010	0.010	0.010	0.534	0.065	0.060	0.060	0.993	0.932	0.977	0.997	0.929	0.822	0.851	0.886
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.004	0.056	0.075	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A5		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 41.8; PF: 32.8)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.002	0.102	0.000	0.000	0.002	0.071	0.017	0.179	0.048	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.021	0.263	0.205	0.000	0.018	0.245	0.193	0.245	0.758	0.700	0.591	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.126	0.391	0.327	0.000	0.094	0.371	0.316	0.344	0.750	0.754	0.867	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.001	0.017	0.090	0.000	0.001	0.011	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.344	0.997	0.791	0.000	0.330	0.999	0.785	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.661	1.000	1.000	0.000	0.700	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

B7		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 4.5; PF: 3.9)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.989	0.938	0.943	0.972	0.897	0.740	0.885	0.944	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	0.892	0.629	0.657	0.783	0.777	0.553	0.644	0.569	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	0.683	0.440	0.458	0.458	0.637	0.417	0.442	0.449	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	0.596	0.357	0.369	0.374	0.566	0.379	0.379	0.376	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.191	0.032	0.026	0.028	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.045	0.131	0.156	0.122
	+0.5-1%	0.076	0.000	0.000	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.107	0.095	0.074
	+1.0-2%	0.071	0.000	0.000	0.000	0.071	0.000	0.000	0.000	0.001	0.002	0.000	0.001	0.254	0.310	0.236	0.188
	+1.5-3%	0.071	0.000	0.000	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.283	0.330	0.321	0.294
B8		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 5.5; PF: 17.1)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.056	0.044	0.039	0.042	0.015	0.000	0.000	0.000	0.254	0.162	0.201	0.229	0.219	0.055	0.145	0.072
	+0.5-1%	0.699	0.395	0.004	0.002	0.357	0.073	0.000	0.000	0.179	0.010	0.050	0.061	0.125	0.019	0.040	0.015
	+1.0-2%	0.691	0.366	0.000	0.000	0.465	0.047	0.000	0.000	0.357	0.073	0.000	0.000	0.088	0.043	0.071	0.031
	+1.5-3%	0.149	0.000	0.000	0.000	0.131	0.000	0.000	0.000	0.024	0.000	0.000	0.000	0.039	0.019	0.024	0.010
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.257	0.218	0.000	0.000	0.040	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.083	0.016	0.000	0.000	0.018	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B13		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 30.6; PF: 34.8)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	+0.5-1%	0.039	0.044	0.058	0.055	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	+1.0-2%	0.015	0.034	0.018	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.002	0.001
	+1.5-3%	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.007	0.006	0.005

10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.009	0.015	0.014	0.014	0.002	0.004	0.007	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.011	0.019	0.026	0.027	0.001	0.004	0.004	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B16		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8.4; PF: 10.6)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.071	0.000	0.000	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.031	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B18		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 13.2; PF: 15.1)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.749	0.539	0.549	0.573	0.980	0.946	0.949	0.952	1.000	0.998	0.961	0.978	1.000	1.000	1.000	1.000
	+0.5-1%	0.641	0.580	0.565	0.632	0.945	0.931	0.937	0.957	0.973	0.999	0.994	0.998	1.000	1.000	1.000	1.000
	+1.0-2%	0.534	0.561	0.683	0.768	0.814	0.886	0.961	0.983	0.754	0.934	0.916	0.949	1.000	1.000	1.000	1.000
	+1.5-3%	0.604	0.661	0.800	0.945	0.796	0.953	0.989	1.000	0.617	0.824	0.853	0.998	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.002	0.005	0.002	0.042	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

C11		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 5.8; PF: 0.3)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.929	0.865	0.942	0.891	0.929	0.806	0.928	0.879	0.603	0.673	0.703	0.708	0.537	0.501	0.532	0.543
	+0.5-1%	0.735	0.751	0.805	0.824	0.705	0.669	0.785	0.746	0.529	0.624	0.642	0.670	0.501	0.500	0.501	0.508
	+1.0-2%	0.654	0.565	0.600	0.705	0.554	0.583	0.573	0.625	0.501	0.515	0.545	0.631	0.500	0.500	0.500	0.500
	+1.5-3%	0.500	0.502	0.500	0.530	0.500	0.508	0.500	0.508	0.500	0.500	0.500	0.512	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.500	0.500	0.500	0.500	0.500	0.500	0.499	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.499	0.499	0.500	0.500	0.500	0.498	0.500	0.497	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.499	0.500	0.500	0.500	0.500	0.499	0.500	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D6		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8.7; PF: 10.3)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.519	0.306	0.259	0.240	0.457	0.275	0.250	0.202	0.634	0.500	0.500	0.500	0.625	0.515	0.530	0.517
	+0.5-1%	0.444	0.204	0.199	0.196	0.391	0.189	0.180	0.188	0.571	0.500	0.500	0.500	0.638	0.534	0.543	0.522
	+1.0-2%	0.359	0.163	0.171	0.204	0.324	0.160	0.178	0.194	0.571	0.500	0.500	0.500	0.624	0.537	0.565	0.515
	+1.5-3%	0.334	0.168	0.153	0.155	0.311	0.126	0.127	0.139	0.571	0.500	0.500	0.500	0.611	0.520	0.543	0.503
10 Ha	Baseline	0.084	0.005	0.005	0.005	0.195	0.054	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.100	0.001	0.000	0.000	0.296	0.063	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.147	0.030	0.007	0.010	0.312	0.107	0.046	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.181	0.104	0.083	0.060	0.348	0.252	0.133	0.130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D4		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 20.9; PF: 11.6)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.501	0.502	0.503	0.507	0.597	0.558	0.552	0.562
	+0.5-1%	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.002	0.500	0.500	0.502	0.504	0.591	0.569	0.559	0.546
	+1.0-2%	0.000	0.000	0.003	0.002	0.000	0.002	0.007	0.024	0.500	0.500	0.500	0.500	0.551	0.541	0.530	0.558
	+1.5-3%	0.026	0.000	0.040	0.008	0.049	0.043	0.130	0.109	0.500	0.500	0.500	0.500	0.515	0.520	0.526	0.529

10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
E131		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 15.4; PF: 12.2)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.535	0.508	0.579	0.672	0.511	0.523	0.641	0.678	0.105	0.057	0.011	0.066	0.500	0.498	0.500	0.500
	+0.5-1%	0.539	0.524	0.556	0.702	0.561	0.616	0.619	0.764	0.316	0.293	0.237	0.231	0.500	0.500	0.500	0.500
	+1.0-2%	0.550	0.500	0.567	0.638	0.632	0.621	0.782	0.769	0.465	0.449	0.450	0.339	0.500	0.500	0.500	0.500
	+1.5-3%	0.688	0.588	0.555	0.528	0.800	0.706	0.708	0.637	0.500	0.497	0.451	0.449	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.007	0.000	0.000	0.003	0.012	0.000	0.001	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.008	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
E132		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 16.7; PF: 16.1)		13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49	13-19	20-29	30-39	40-49
1 Ha	Baseline	0.756	0.840	0.735	1.000	0.244	0.170	0.205	0.201	0.223	0.162	0.061	0.070	0.500	0.500	0.500	0.500
	+0.5-1%	0.445	0.451	0.424	0.747	0.123	0.004	0.004	0.009	0.322	0.369	0.287	0.202	0.500	0.500	0.500	0.500
	+1.0-2%	0.155	0.038	0.060	0.030	0.078	0.000	0.000	0.000	0.451	0.500	0.375	0.251	0.500	0.500	0.500	0.500
	+1.5-3%	0.086	0.001	0.002	0.000	0.091	0.000	0.000	0.000	0.500	0.500	0.422	0.427	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.500	0.500	0.497	0.500	0.360	0.322	0.305	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.498	0.483	0.456	0.466	0.139	0.066	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.469	0.334	0.285	0.126	0.085	0.015	0.014	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.349	0.228	0.216	0.215	0.082	0.005	0.005	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(A3.d). Indiana Dunes National Park

Inland Marsh		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 9; PF: 11)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	0.063	0.000	0.000	0.000	0.102	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.323	0.035	0.070	0.002	0.413	0.331	0.393	0.151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.388	0.422	0.466	0.476	0.481	0.408	0.479	0.463	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.500	0.500	0.500	0.500	0.500	0.498	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.063	0.000	0.000	0.000	0.088	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.261	0.010	0.037	0.001	0.394	0.305	0.371	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.342	0.395	0.425	0.444	0.464	0.383	0.464	0.453	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.500	0.500	0.500	0.500	0.500	0.497	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Marquette Trail		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 1; PF: 0.5)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	0.965	0.494	0.443	0.329	1.000	0.969	1.000	0.993	0.875	0.965	0.855	0.491	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.927	1.000	0.950	0.900	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.384	0.032	0.023	0.058	0.201	0.027	0.143	0.143	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.644	0.645	0.793	0.632	0.469	0.221	0.425	0.331	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.884	0.791	0.980	0.960	0.401	0.211	0.510	0.499	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.948	0.842	0.793	0.970	0.501	0.467	0.505	0.494	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tollestone Dunes		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 12.3; PF: 3.7)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	0.309	0.201	0.110	0.013	0.344	0.218	0.202	0.004	0.502	0.617	0.509	0.350	0.303	0.217	0.195	0.138
	+0.5-1%	0.506	0.483	0.563	0.404	0.450	0.448	0.500	0.260	0.564	0.749	0.717	0.363	0.299	0.168	0.136	0.074
	+1.0-2%	0.464	0.493	0.533	0.518	0.467	0.450	0.500	0.496	0.589	0.620	0.713	0.544	0.248	0.165	0.038	0.004
	+1.5-3%	0.501	0.501	0.500	0.507	0.489	0.479	0.488	0.497	0.467	0.450	0.500	0.496	0.086	0.162	0.037	0.000

10 Ha	Baseline	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.501	0.617	0.509	0.350	0.273	0.207	0.190	0.132
	+0.5-1%	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.524	0.755	0.717	0.373	0.246	0.173	0.133	0.077
	+1.0-2%	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.476	0.616	0.705	0.538	0.189	0.171	0.042	0.003
	+1.5-3%	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.504	0.498	0.231	0.455	0.059	0.160	0.034	0.000
West Beach		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 0; PF: 0)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	0.900	0.366	0.253	0.236	0.966	0.694	0.759	0.702	0.952	0.996	0.880	0.677	0.658	0.777	0.602	0.578
	+0.5-1%	0.951	0.491	0.653	0.605	1.000	0.819	1.000	0.942	0.881	0.968	0.945	0.793	0.612	0.692	0.541	0.570
	+1.0-2%	0.842	0.921	0.989	0.994	0.989	0.947	1.000	1.000	0.591	0.812	0.791	0.754	0.550	0.718	0.545	0.561
	+1.5-3%	0.999	1.000	1.000	1.000	1.000	0.952	1.000	1.000	0.594	0.596	0.517	0.608	0.536	0.605	0.537	0.527
10 Ha	Baseline	0.363	0.093	0.025	0.019	0.343	0.087	0.173	0.103	0.070	0.127	0.019	0.026	0.000	0.000	0.000	0.000
	+0.5-1%	0.472	0.231	0.204	0.208	0.493	0.175	0.448	0.405	0.001	0.154	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.500	0.498	0.500	0.500	0.421	0.374	0.500	0.500	0.000	0.095	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.510	0.501	0.500	0.500	0.500	0.417	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Miller Woods		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8; PF: 11.5)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	0.530	0.439	0.513	0.538	0.461	0.339	0.472	0.424	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.504	0.527	0.500	0.503	0.488	0.385	0.487	0.497	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.499	0.500	0.500	0.501	0.405	0.356	0.448	0.484	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.499	0.500	0.492	0.500	0.317	0.338	0.342	0.426	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.500	0.513	0.479	0.500	0.246	0.106	0.251	0.282	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.500	0.500	0.498	0.500	0.229	0.130	0.191	0.293	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.455	0.500	0.500	0.500	0.121	0.112	0.123	0.136	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.388	0.499	0.438	0.500	0.092	0.067	0.036	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Long Lake		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 6; PF: 0)		12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49	12-19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.968	0.913	0.873	1.000	0.841	0.635	0.790	0.799	0.500	0.502	0.501	0.500	0.500	0.500	0.500	0.500
	+0.5-1%	0.861	0.704	0.872	0.909	0.663	0.615	0.776	0.766	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.0-2%	0.625	0.514	0.720	0.763	0.563	0.475	0.582	0.666	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	+1.5-3%	0.563	0.500	0.500	0.651	0.544	0.500	0.500	0.550	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

(A3.e). Albany Pine Bush, New York

Baron House		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 22.7; PF: 7)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	0.060	0.263	0.413	0.449	0.000	0.000	0.000	0.006	0.500	0.430	0.500	0.500	0.500	0.500	0.502	0.501
	+0.5-1%	0.170	0.466	0.611	0.641	0.000	0.000	0.000	0.000	0.500	0.468	0.500	0.500	0.500	0.500	0.500	0.500
	+1.0-2%	0.420	0.346	0.527	0.768	0.000	0.000	0.000	0.000	0.500	0.475	0.500	0.498	0.500	0.500	0.500	0.500
	+1.5-3%	0.480	0.450	0.510	0.676	0.000	0.000	0.000	0.000	0.500	0.499	0.500	0.500	0.500	0.500	0.500	0.500
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Karner Barrens East		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 9.3; PF: 8.9)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.955	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	0.939	0.812	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	0.828	0.625	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.481	0.451	0.352	0.050	0.183	0.411	0.423
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.390	0.514	0.622	0.260	0.098	0.156	0.408
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.403	0.515	0.642	0.355	0.057	0.201	0.278
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.497	0.500	0.497	0.350	0.146	0.224	0.346
Karner Barrens West		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 37.6; PF: 28.3)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.009	0.005	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.009	0.000	0.000	0.003	0.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
King Road Barrens East		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 4.4; PF: 2.5)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

10 Ha	Baseline	1.000	0.050	0.112	0.437	0.500	0.005	0.011	0.189	0.000	0.007	0.013	0.006	0.450	0.032	0.106	0.166
	+0.5-1%	1.000	0.055	0.017	0.188	0.500	0.120	0.098	0.055	0.115	0.012	0.043	0.027	0.500	0.065	0.158	0.212
	+1.0-2%	0.595	0.040	0.004	0.076	0.500	0.142	0.182	0.216	0.155	0.013	0.028	0.060	0.500	0.096	0.222	0.250
	+1.5-3%	0.500	0.049	0.000	0.024	0.500	0.211	0.255	0.307	0.190	0.022	0.036	0.056	0.500	0.200	0.259	0.265
King Road Barrens West		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 32.2; PF: 16.6)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.010	0.076	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.005	0.070	0.006	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.051	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.094	0.008	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pine Bush Northwest		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8.4; PF: 3.6)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	1.000	0.851	0.123	0.076	1.000	0.418	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	0.972	0.402	0.202	1.000	0.617	0.001	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	0.995	0.639	0.424	1.000	0.616	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	0.994	0.610	0.373	1.000	0.697	0.005	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
	+0.5-1%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
	+1.0-2%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
	+1.5-3%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000

Ping Bush Southeast		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 8.5; PF: 6.7)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+0.5-1%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.0-2%	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	+1.5-3%	1.000	1.000	0.997	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10 Ha	Baseline	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.010	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.015	0.000	0.000	0.000	0.415	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.010	0.000	0.000	0.000	0.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pine Bush Northwest		Whole-Species Change Model				Ecoregion Change Model				Whole-Species Density Model				Ecoregion Density Model			
(PS: 15.9; PF: 2.8)		19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49	19	20-29	30-39	40-49
1 Ha	Baseline	0.010	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.049	0.198	0.145	0.010	0.001	0.008
	+0.5-1%	0.485	0.001	0.000	0.000	0.220	0.000	0.000	0.000	0.000	0.000	0.081	0.177	0.190	0.003	0.004	0.013
	+1.0-2%	0.500	0.009	0.000	0.000	0.385	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.375	0.010	0.024	0.035
	+1.5-3%	0.500	0.054	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.380	0.006	0.013	0.018
10 Ha	Baseline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+0.5-1%	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.0-2%	0.115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	+1.5-3%	0.500	0.001	0.000	0.000	0.205	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A4.a-d. The overlapping of 35 USSE in MN with the areas of high occupancy of the populations in four ecoregions (not including Albany Pine Bush) projected by between-generation change models in 2029, 2039, and 2049 under four *climate scenarios* (baseline, +0.5-1%, +1.0-2%, +1.5-3%) at both *spatial scales* (whole species and ecoregion). The points represent the solar facilities supporting more than 50 Karner blues.

(A4.a). Central Wisconsin

Solar Facility	County	Whole-Species Scale												Ecoregion Scale											
		Baseline			+0.5-1%			+1.0-2%			+1.5-3%			Baseline			+0.5-1%			+1.0-2%			+1.5-3%		
		29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49
Chisago	Chisago					•	•						•												
Cornillie	Chisago					•	•						•												
Johnson 1	Chisago												•												
Johnson II	Chisago												•												
North Star	Chisago					•	•						•												
Sunrise	Chisago					•	•						•												
USS Dubhe	Chisago					•	•						•												
USS Good	Chisago					•	•						•												
USS Nillie Corn	Chisago					•	•						•												
USS Rockpoint	Chisago					•	•						•												
USS	Chisago												•												
Wyoming 2	Chisago									•			•												
Big Lake Holdco	Sherburne	•	•	•	•	•	•		•	•	•	•	•												
Big Lake	Sherburne	•	•	•	•	•	•		•	•	•	•	•												
CF Novel	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Hammer	Sherburne	•	•	•	•	•	•	•	•	•	•		•												
Marmas	Sherburne	•		•	•	•	•	•	•	•	•	•	•												
Sherburne	Sherburne	•	•	•	•	•	•	•	•	•	•		•												
Sherburne North	Sherburne			•	•	•	•		•	•	•	•	•												

Tiller	Sherburne	•	•	•		•	•	•	•	•	•		•												
USS Big Lake 1	Sherburne	•	•	•		•	•		•	•	•	•	•												
B.R. Sartell	Stearns	•	•	•	•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns			•	•	•	•		•	•	•	•	•												
St. Cloud	Stearns			•	•	•	•		•	•	•	•	•												
St. Cloud	Stearns			•	•	•	•		•	•	•	•	•												
St. Cloud	Stearns			•	•	•	•		•	•	•	•	•												
St. Cloud	Stearns			•	•	•	•		•	•	•	•	•												
Blue Lake	Scott			•	•	•	•		•	•		•	•												•
Shakopee Met Council	Scott			•	•	•	•		•	•		•	•												•
Annandale	Wright	•	•	•	•	•	•			•			•												
Monticello	Wright	•	•	•	•	•	•		•	•		•	•												
MN CONX	Anoka	•	•	•		•	•		•	•	•	•	•												
GRE Marshan	Dakota			•		•	•			•		•	•												
St. Paul Intl Airport	Hennepin		•	•	•	•	•	•	•	•		•	•			•									•
Athens MN CONX	Isanti	•		•	•			•			•		•												

(A4.b). Northwestern Wisconsin

Solar Facility	County	Whole-Species Scale												Ecoregion Scale											
		Baseline			+0.5-1%			+1.0-2%			+1.5-3%			Baseline			+0.5-1%			+1.0-2%			+1.5-3%		
		29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49
Chisago	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
Cornillie	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
Johnson 1	Chisago																								
Johnson II	Chisago				•	•	•	•	•	•	•	•	•												
North Star	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
Sunrise	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												

USS Dubhe	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
USS Good	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
USS Nillie Corn	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
USS Rockpoint	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
USS	Chisago				•	•	•	•	•	•	•	•	•												
Wyoming 2	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
Big Lake Holdco	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Big Lake	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
CF Novel	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Hammer	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Marmas	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Sherburne	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
Sherburne North	Sherburne	•	•		•	•	•	•	•	•	•	•	•												
Tiller	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
USS Big Lake 1	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•												
B.R. Sartell	Stearns	•	•	•	•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns	•	•		•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns	•	•		•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns	•	•		•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns	•	•		•	•	•	•	•	•	•	•	•												
St. Cloud	Stearns	•	•		•	•	•	•	•	•	•	•	•												
Blue Lake	Scott	•	•	•	•	•	•	•	•	•	•	•	•									•			
Shakopee Met Council	Scott	•	•	•	•	•	•	•	•	•	•	•	•									•			
Annandale	Wright	•	•	•	•	•	•	•	•	•	•	•	•												
Monticello	Wright	•	•	•	•	•	•	•	•	•	•	•	•												
MN CONX	Anoka	•	•	•	•	•	•	•	•	•	•	•	•												
GRE Marshan	Dakota	•	•	•	•	•	•	•	•	•	•	•	•												

St. Paul Intl Airport	Hennepin	•	•	•	•	•	•	•	•	•	•	•	•							•	•				
Athens MN CONX	Isanti	•	•	•	•	•	•	•	•	•	•	•	•												

(A4.c). Fort McCoy, Wisconsin

Solar Facility	County	Whole-Species Scale												Ecoregion Scale											
		Baseline			+0.5-1%			+1.0-2%			+1.5-3%			Baseline			+0.5-1%			+1.0-2%			+1.5-3%		
		29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49
Chisago	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Cornillie	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Johnson 1	Chisago																								
Johnson II	Chisago	•	•	•	•	•	•	•	•	•	•	•	•												
North Star	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sunrise	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
USS Dubhe	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
USS Good	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
USS Nillie Corn	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
USS Rockpoint	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
USS	Chisago	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•	•	•	•	•	•
Wyoming 2	Chisago	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Big Lake Holdco	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Big Lake	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
CF Novel	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Hammer	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Marmas	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sherburne	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sherburne North	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Tiller	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

USS Big Lake 1	Sherburne	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•
B.R. Sartell	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Cloud	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Cloud	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Cloud	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Cloud	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Cloud	Stearns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Blue Lake	Scott	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Shakopee Met Council	Scott	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Annandale	Wright	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Monticello	Wright	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
MN CONX	Anoka	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
GRE Marshan	Dakota	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
St. Paul Intl Airport	Hennepin	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Athens MN CONX	Isanti	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

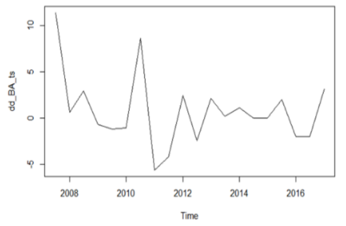
(A4.d). Indiana Dunes National Park

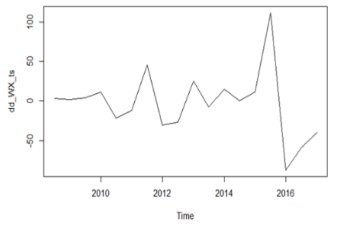
Solar Facility	County	Whole-Species Scale												Ecoregion Scale											
		Baseline			+0.5-1%			+1.0-2%			+1.5-3%			Baseline			+0.5-1%			+1.0-2%			+1.5-3%		
		29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49	29	39	49
Chisago	Chisago		•	•											•	•			•		•	•			
Cornillie	Chisago		•	•											•	•			•		•	•			
Johnson 1	Chisago																								
Johnson II	Chisago																								
North Star	Chisago		•	•											•	•			•		•	•			•
Sunrise	Chisago		•	•						•					•	•			•		•	•			
USS Dubhe	Chisago																								

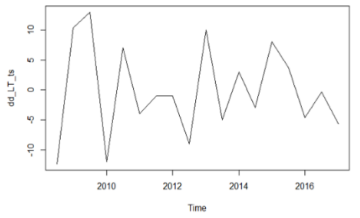
USS Good	Chisago		•	•											•	•			•		•	•			
USS Nillie Corn	Chisago		•	•											•	•			•		•	•			
USS Rockpoint	Chisago		•	•											•	•			•		•	•			
USS	Chisago	•	•	•												•					•	•			
Wyoming 2	Chisago		•	•											•	•			•						•
Big Lake Holdco	Sherburne	•	•	•									•		•	•					•	•			•
Big Lake	Sherburne	•	•	•									•		•	•					•	•			•
CF Novel	Sherburne		•	•			•			•				•	•	•		•	•		•	•		•	•
Hammer	Sherburne		•	•			•			•					•	•			•		•	•		•	•
Marmas	Sherburne																								•
Sherburne	Sherburne		•	•			•			•				•	•	•		•	•		•	•			•
Sherburne North	Sherburne		•	•			•									•					•	•			•
Tiller	Sherburne		•	•			•			•				•	•	•		•	•		•	•			
USS Big Lake 1	Sherburne	•	•	•								•	•		•	•					•	•			
B.R. Sartell	Stearns																								
St. Cloud	Stearns		•	•			•							•	•	•			•		•	•		•	•
St. Cloud	Stearns		•	•			•							•	•	•			•		•	•		•	•
St. Cloud	Stearns		•	•			•							•	•	•			•		•	•		•	•
St. Cloud	Stearns		•	•			•							•	•	•			•		•	•		•	•
St. Cloud	Stearns		•	•			•							•	•	•			•		•	•		•	•
Blue Lake	Scott		•	•			•								•	•		•	•		•	•			
Shakopee Met Council	Scott		•	•			•								•	•		•	•		•	•			
Annandale	Wright		•	•		•	•						•			•			•		•	•			•
Monticello	Wright		•	•		•	•						•			•			•		•	•			•
MN CONX	Anoka		•	•																					
GRE Marshan	Dakota																								
St. Paul Intl Airport	Hennepin						•								•	•		•	•		•	•			
Athens MN CONX	Isanti		•	•			•									•					•	•			•

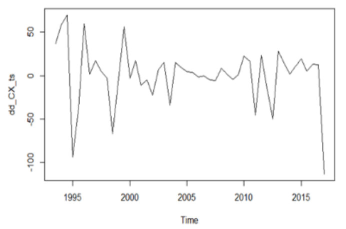
Figure A1. Time-series density dynamics detrended annually and seasonally of all the 48 populations in Central Wisconsin, Northwestern Wisconsin, Fort McCoy (Wisconsin), Indiana Dunes National Park, and Albany Pine Bush (New York).

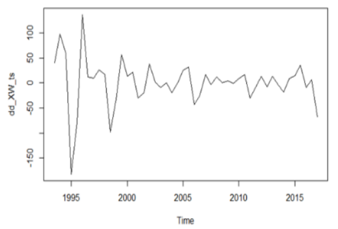
(A1.a). Central Wisconsin

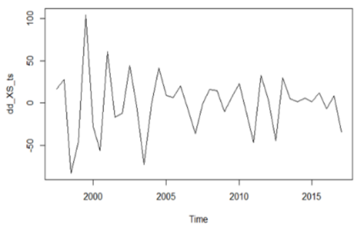


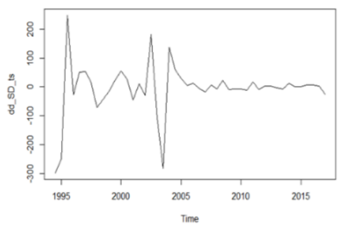


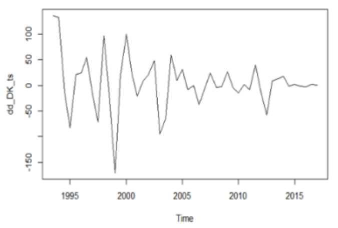


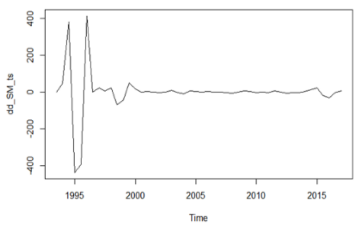


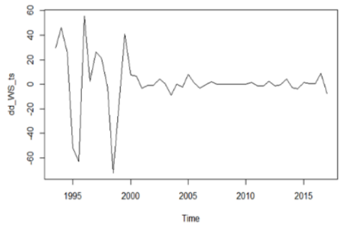


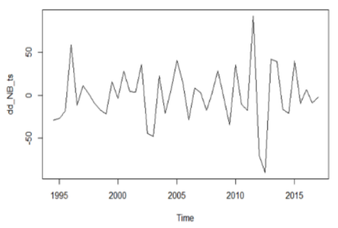


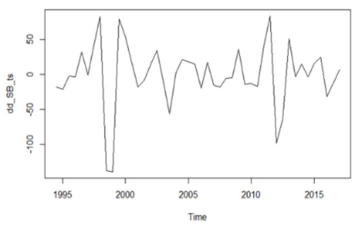


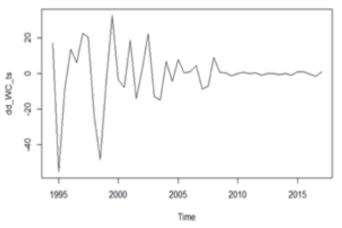




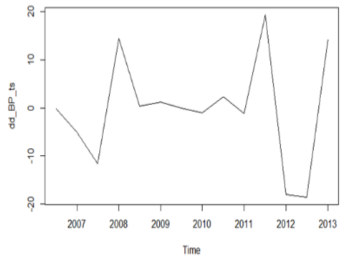


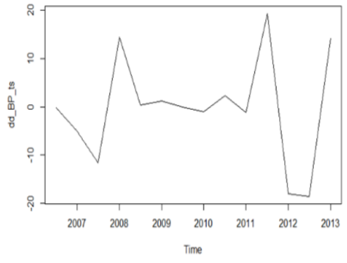


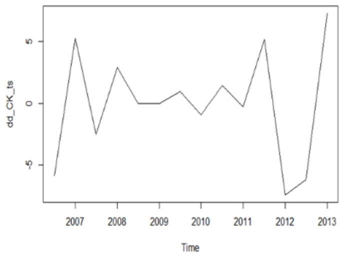


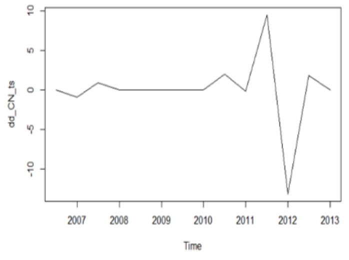


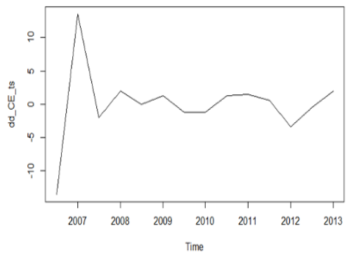
(A1.b). Northwestern Wisconsin

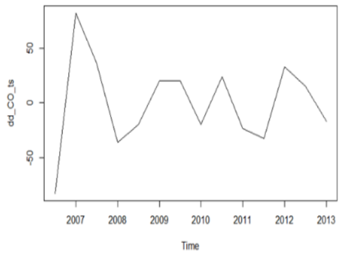


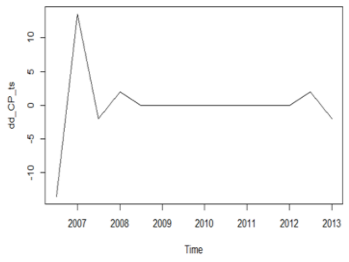


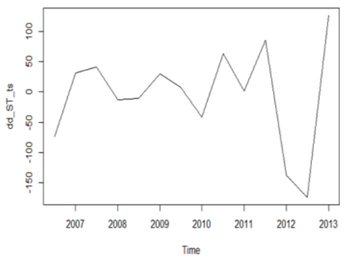




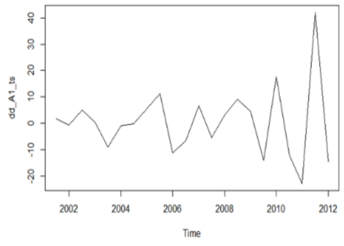


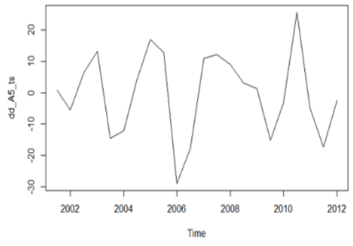


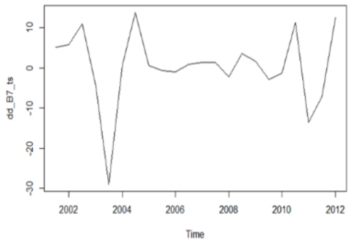


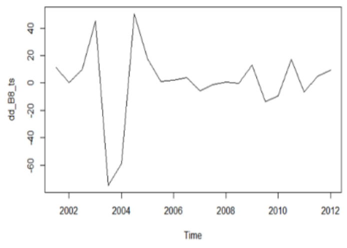


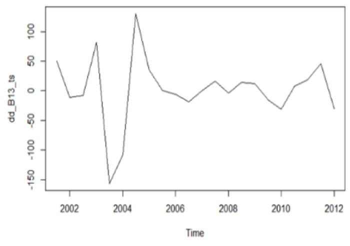
(A1.c). Fort McCoy, Wisconsin

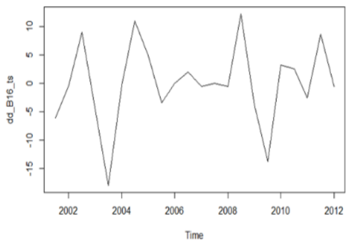


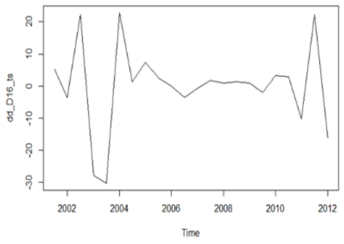
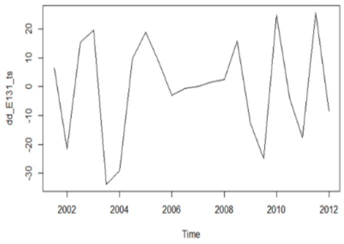
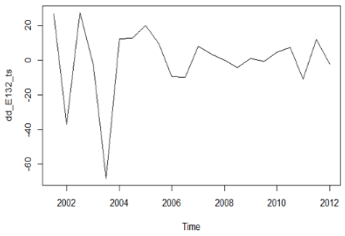
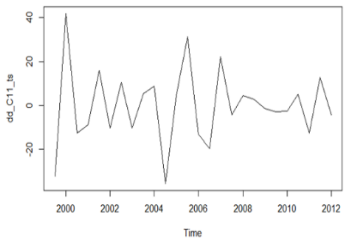
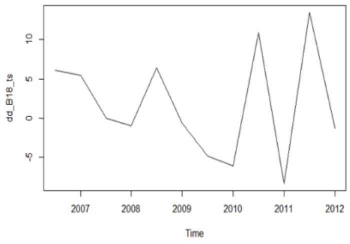
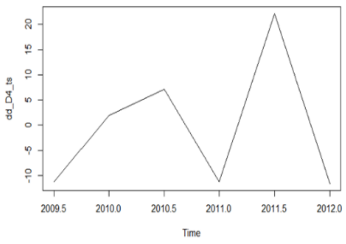




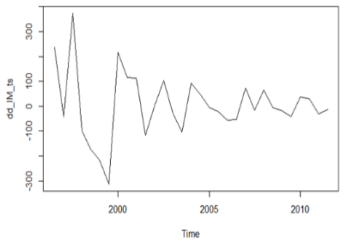
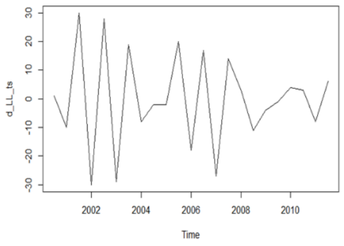
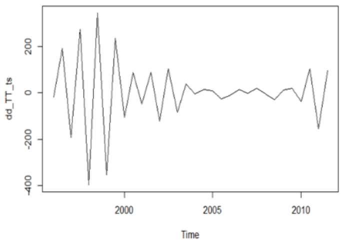
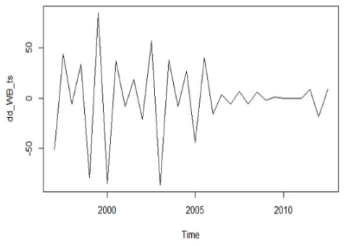
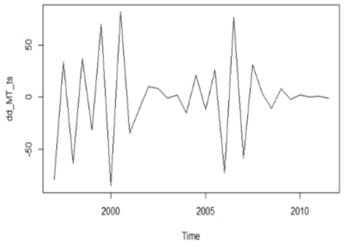
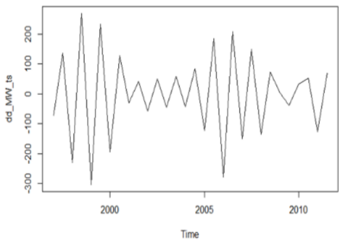




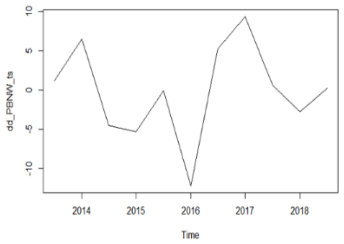


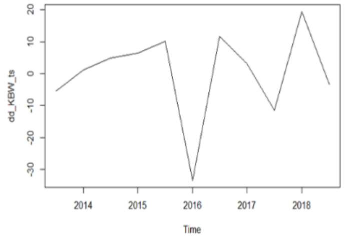
		
		

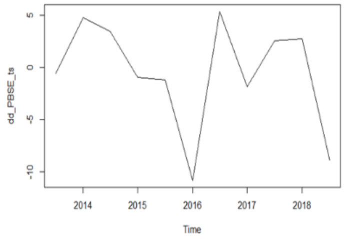
(A1.d). Indiana Dunes National Park

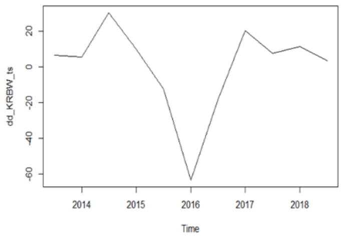
		
		

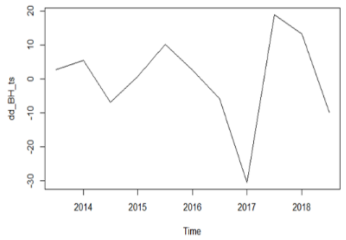
(A1.e). Albany Pine Bush, New York

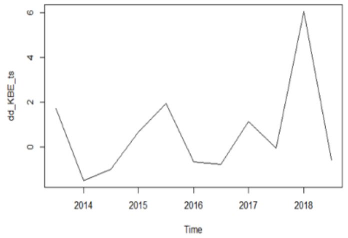


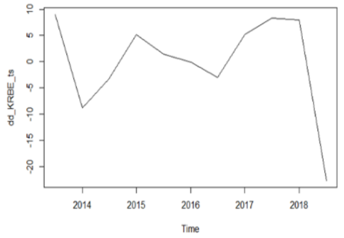












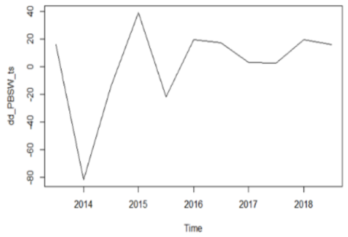
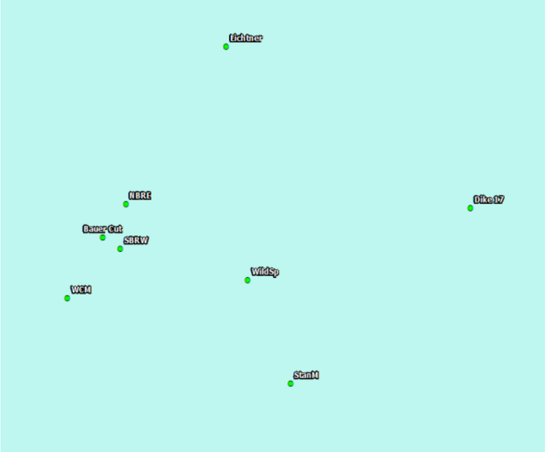
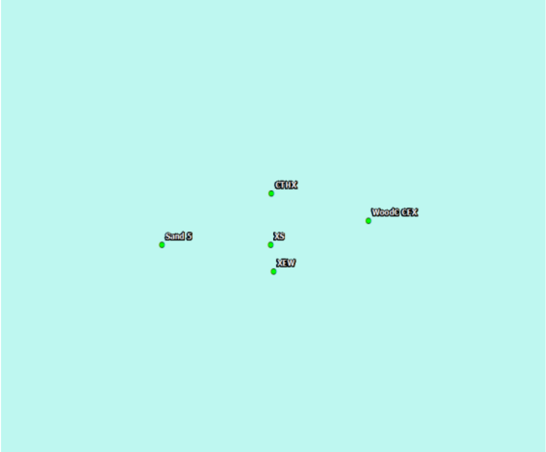


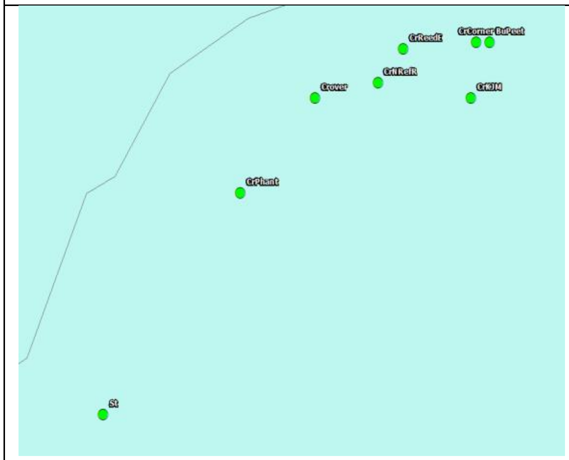
Figure A2. The distributions of all the 48 populations in the five ecoregions.



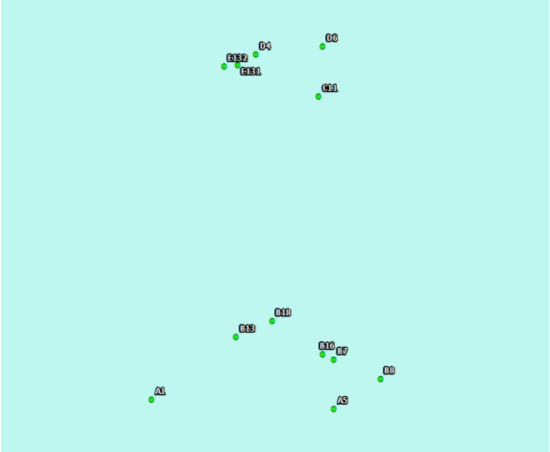
Central Wisconsin (Jackson County)



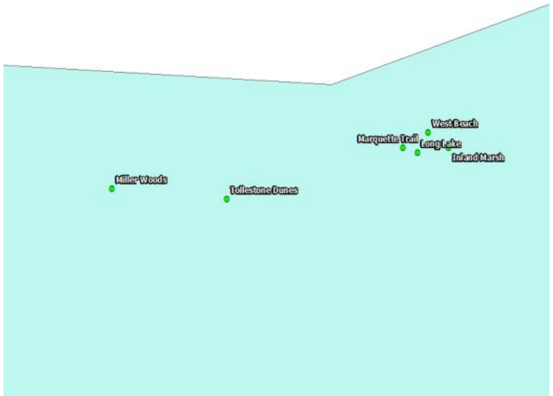
Central Wisconsin (Wood County)



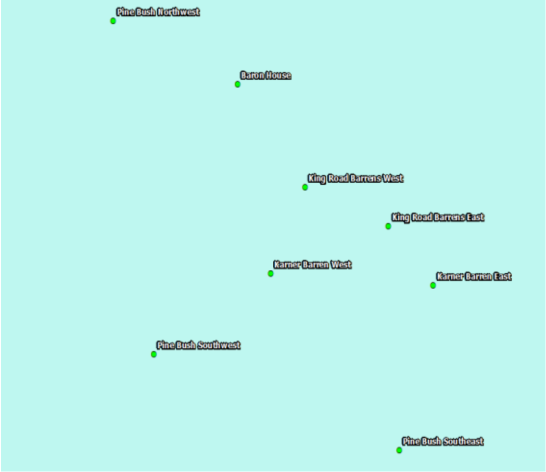
Northwestern Wisconsin



Fort McCoy, Wisconsin



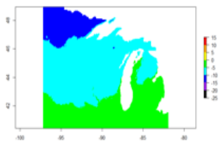
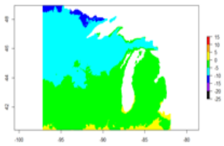
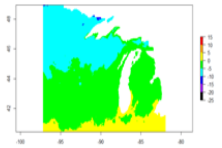
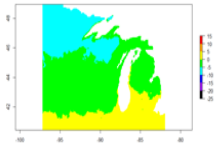
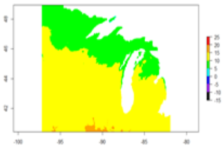
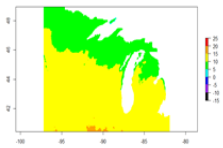
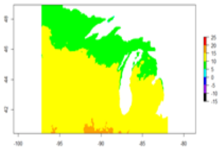
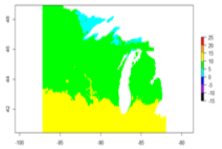
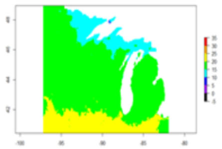
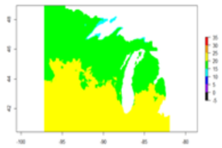
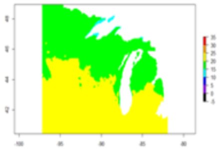
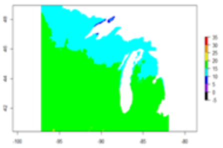
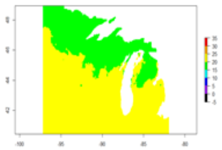
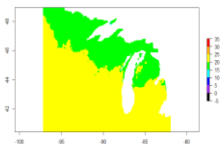
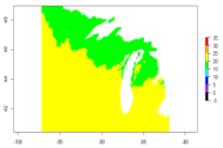
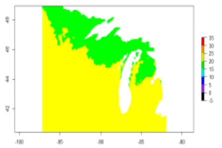
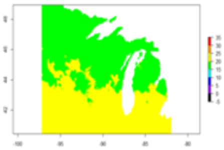
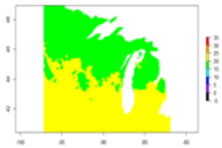
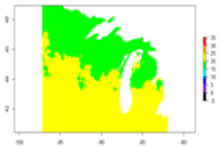
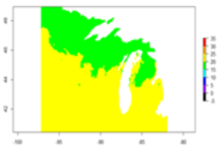
Indiana Dunes National Park



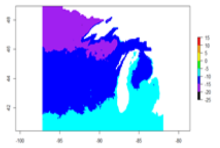
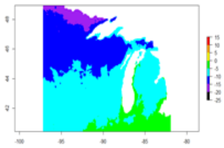
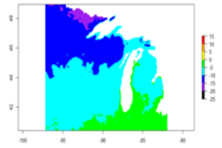
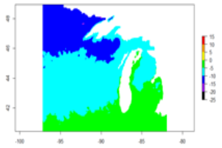
Albany Pine Bush, New York

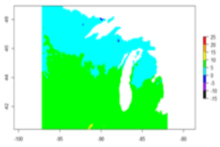
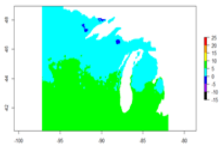
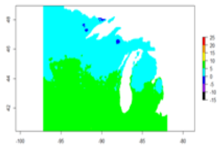
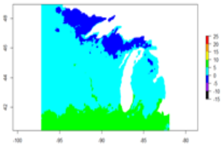
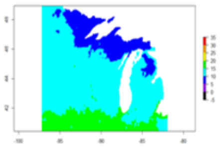
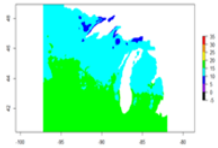
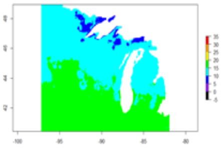
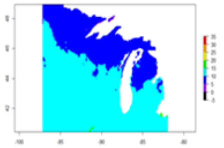
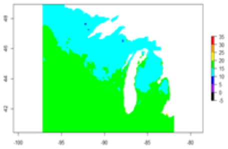
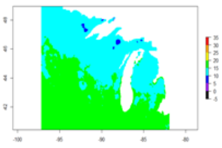
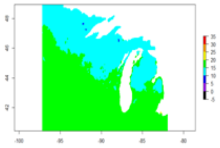
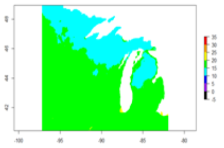
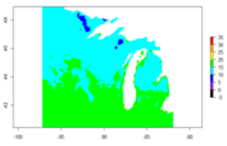
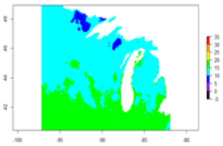
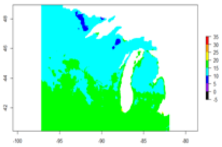
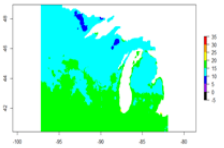
Figure A3.a-d. GFDL-CM3 projected mean, minimum, and maximum temperatures, and total precipitation during overwinter (December to March), spring (April and May), June, July, and August, in 2020, 2029, 2039, 2049 in the upper Midwest.

(A3.a). Mean Temperature

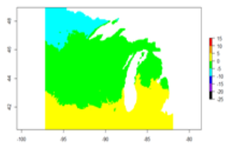
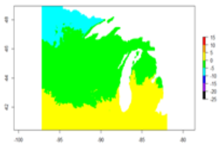
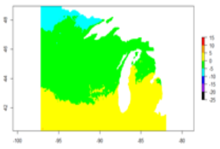
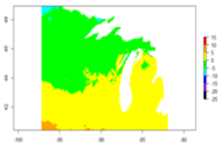
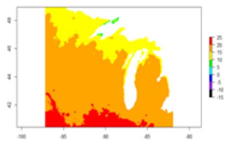
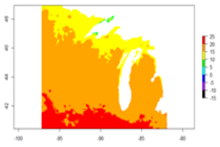
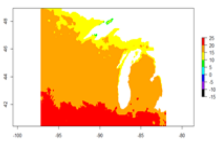
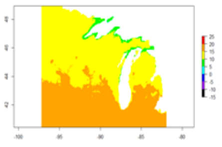
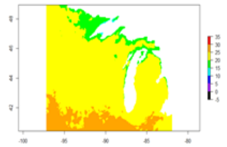
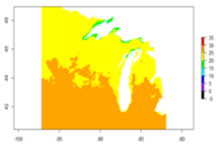
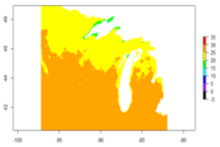
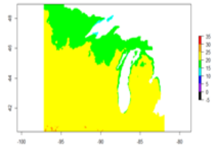
	2020	2029	2039	2049
OW				
SP				
JN				
JL				
AG				

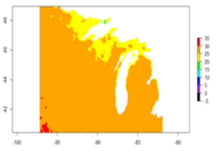
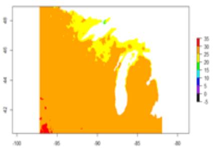
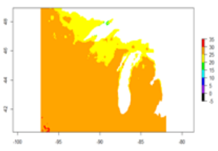
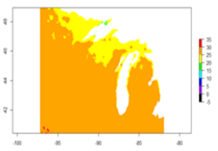
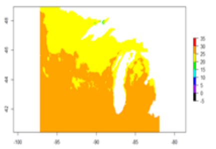
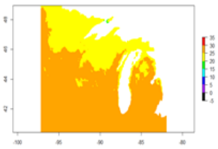
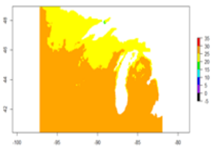
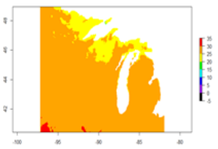
(A3.b). Minimum Temperature

	2020	2029	2039	2049
OW				

SP				
JN				
JL				
AG				

<u>(A3.c). Maximum Temperature</u>

	2020	2029	2039	2049
OW				
SP				
JN				

JL				
AG				

(A3.d). Total Precipitation

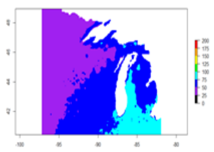
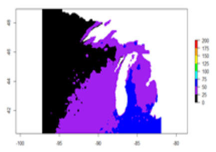
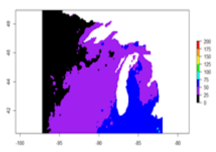
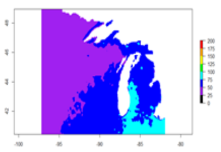
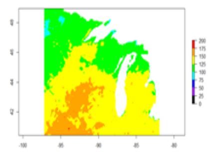
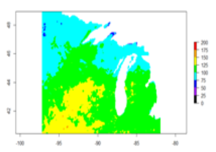
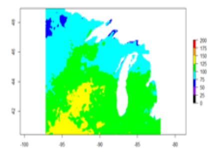
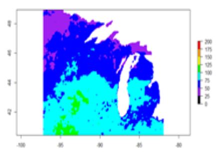
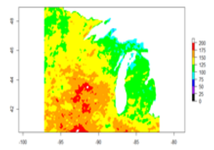
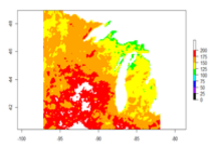
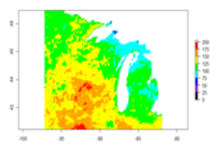
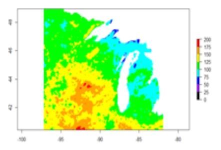
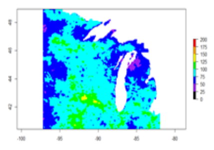
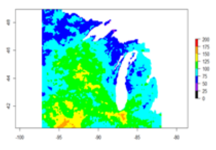
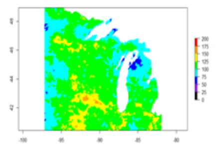
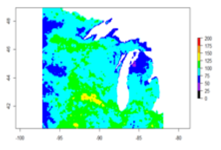
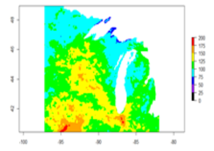
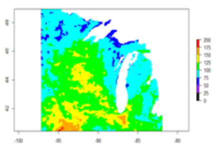
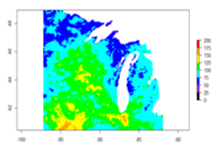
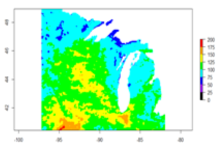
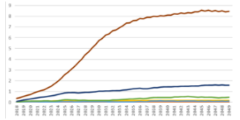
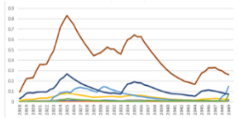
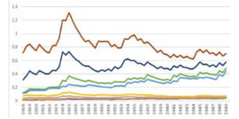
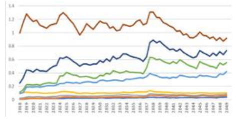
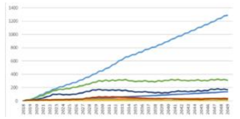
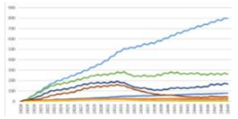
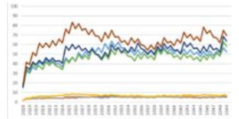
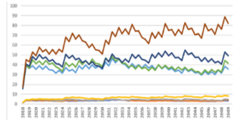
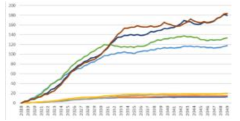
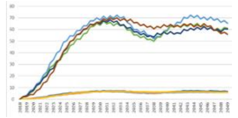
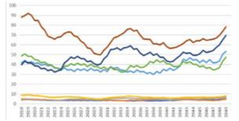
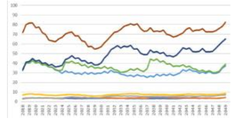
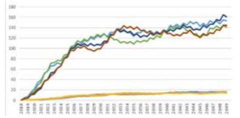
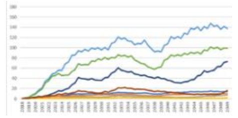
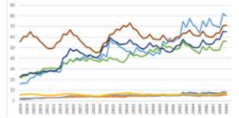
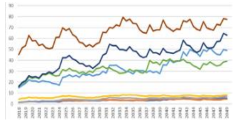
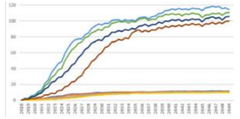
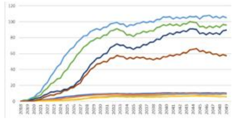
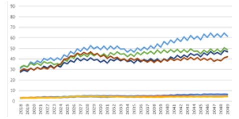
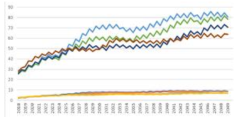
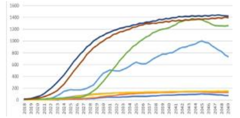
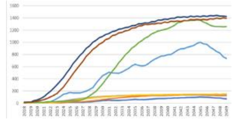
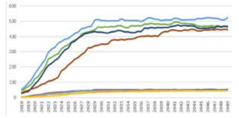
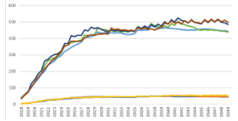
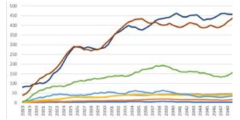
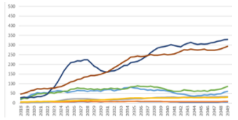
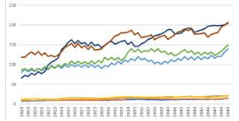
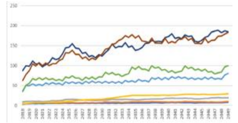
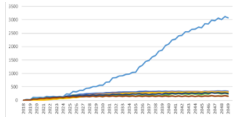
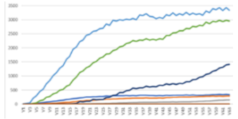
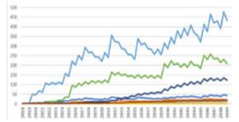
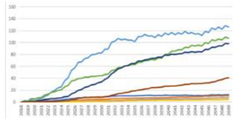
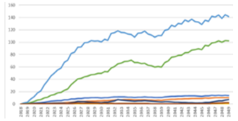
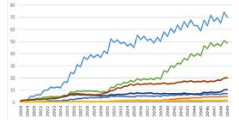
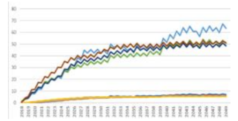
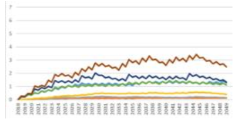
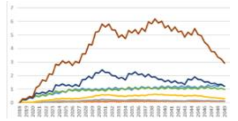
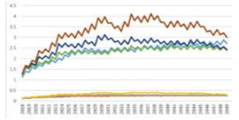
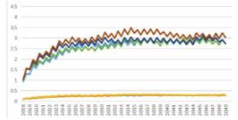
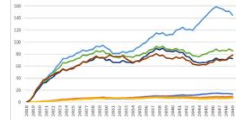
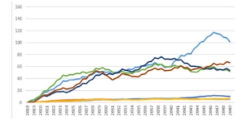
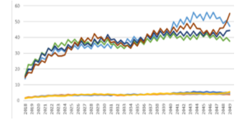
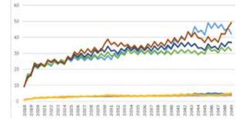
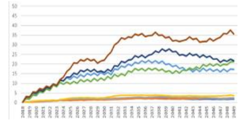
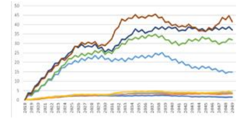
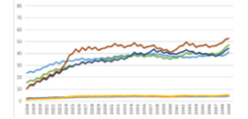
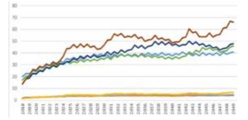
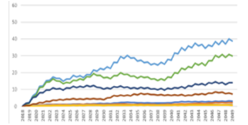
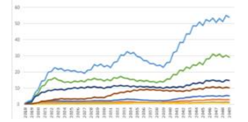
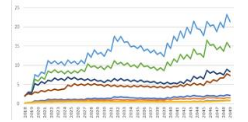
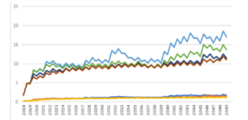
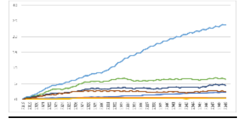
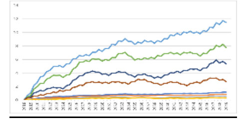
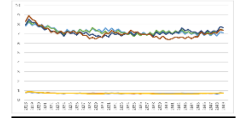
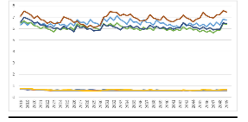
	2020	2029	2039	2049
OW				
SP				
JN				
JL				
AG				

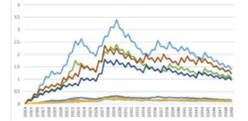
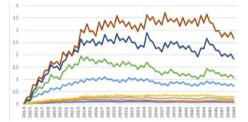
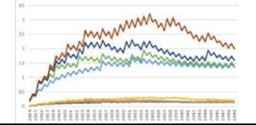
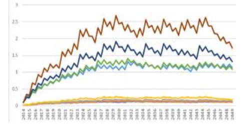
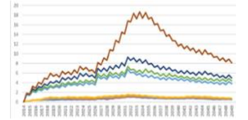
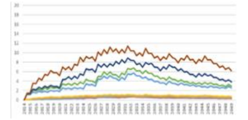
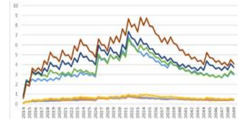
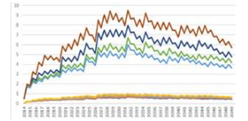
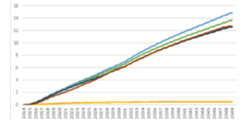
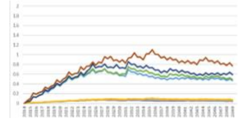
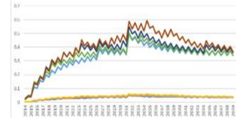
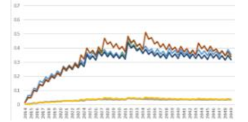
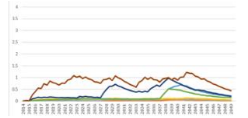
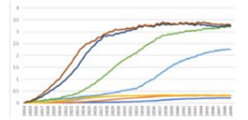
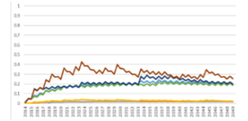
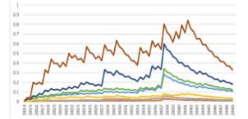
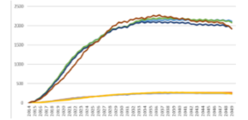
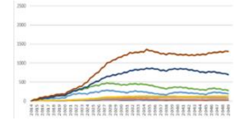
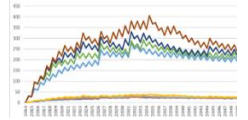
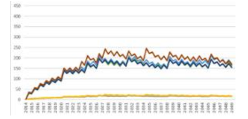
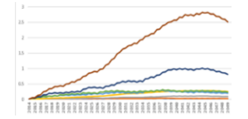
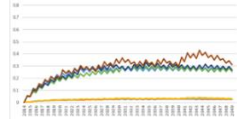
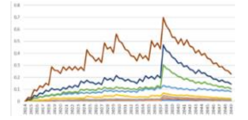
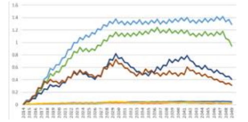
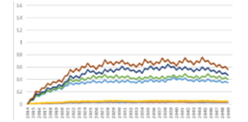
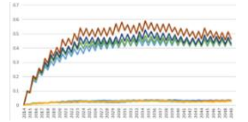
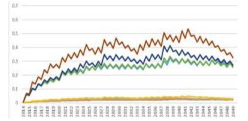
Figure A4.a-e. The predicted trends of all the Karner blue populations in the five ecoregions till 2050 with two *habitat areas* (1 ha and 10 ha) and four *climate scenarios* (baseline, +0.5-1%, +1.0-2%, +1.5-3%) using between-generation change model and density model at both *spatial scales* (whole species and ecoregion), respectively.

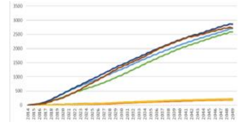
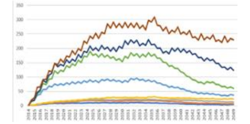
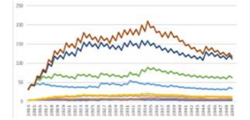
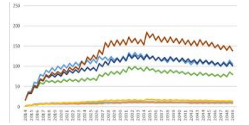
<u>(A4.a). Central Wisconsin</u>

	Whole-Species Change Model	Ecoregion Change Model	Whole-Species Density Model	Ecoregion Density Model
Buena				
Wood-CFX				
CTHX				
XEW				
XS				
Sand 5				
Dike 17				
StanM				
Wild Sp				
Lichtner				

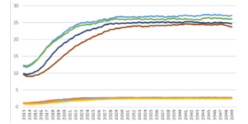
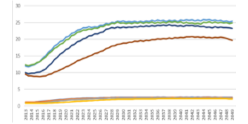
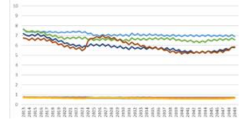
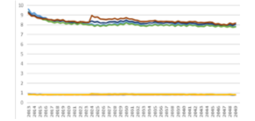
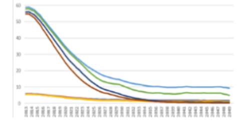
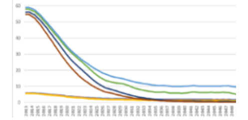
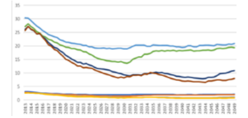
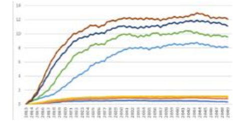
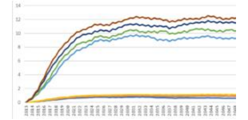
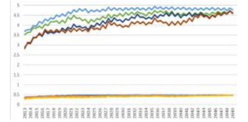
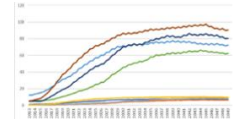
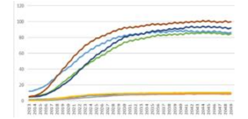
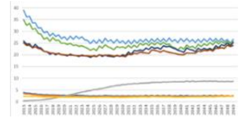
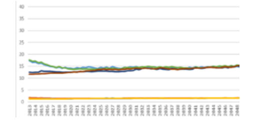
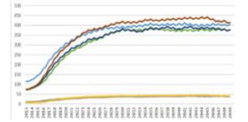
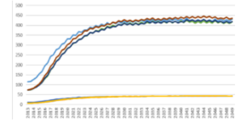
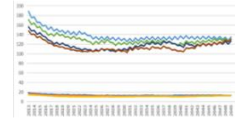
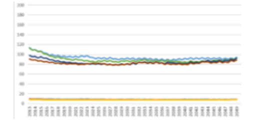
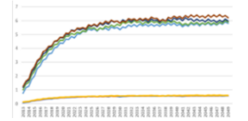
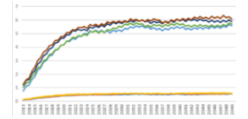
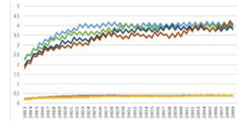
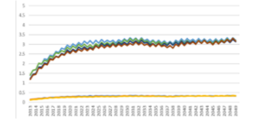
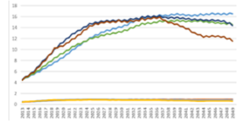
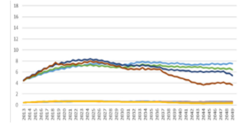
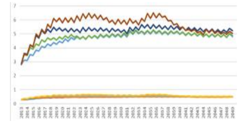
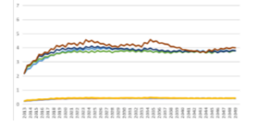
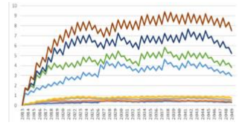
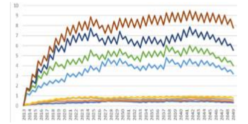
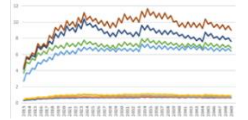
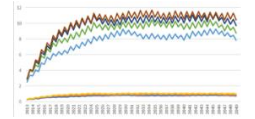
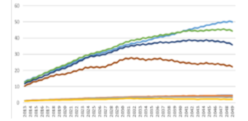
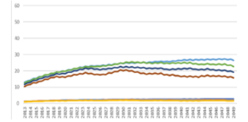
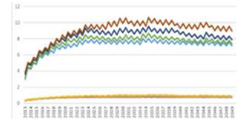
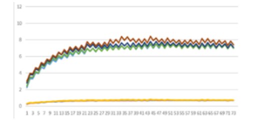
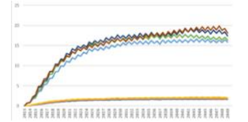
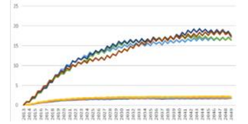
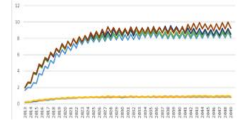
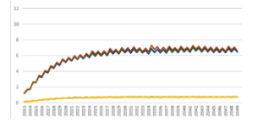
SBRW				
NBRE				
WCM				
Bauer Cut				

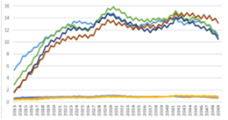
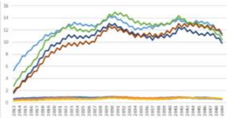
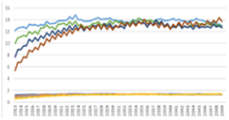
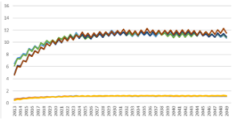
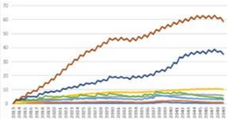
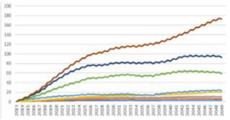
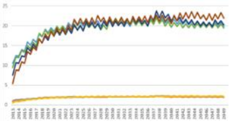
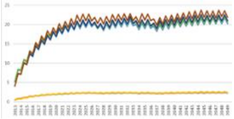
(A4.b). Northwestern Wisconsin

	Whole-Species Change Model	Ecoregion Change Model	Whole-Species Density Model	Ecoregion Density Model
BuPeet				
Cr-Corner				
Cr-NefR				
Cr-ReedE				
Cr-over				
Cr-Phant				
Cr-KJM				

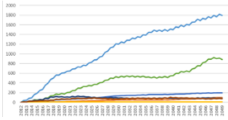
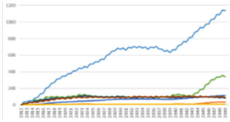
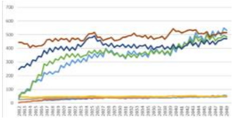
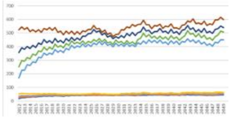
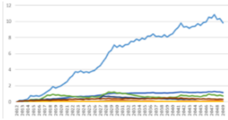
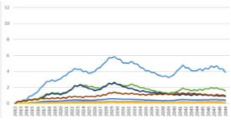
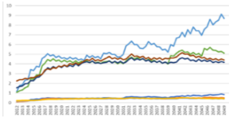
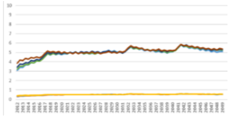
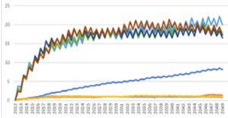
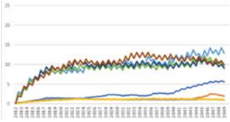
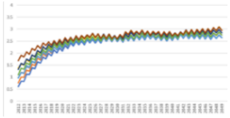
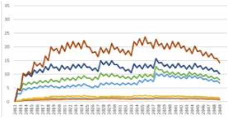
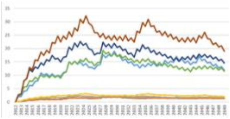
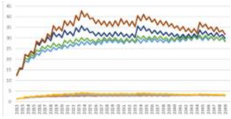
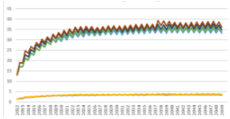
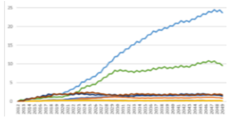
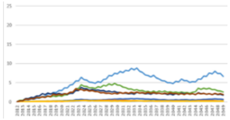
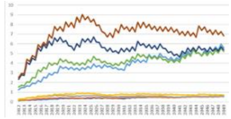
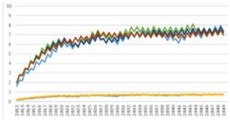
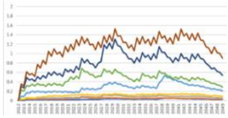
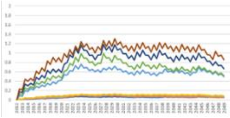
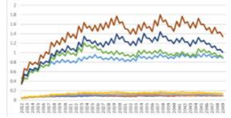
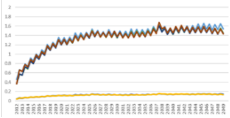
St				

(A4.c). Fort McCoy, Wisconsin

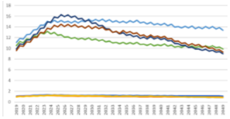
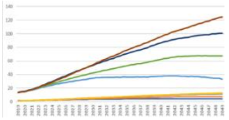
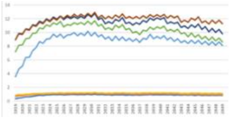
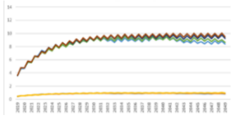
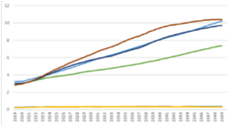
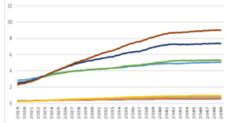
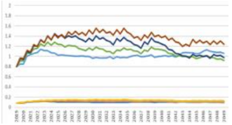
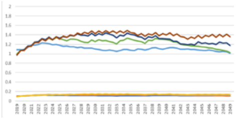
	Whole-Species Change Model	Ecoregion Change Model	Whole-Species Density Model	Ecoregion Density Model
A1				
A5				
B7				
B8				
B13				
B16				
B18				
C11				
D4				
D6				

E131				
E132				

(A4.d). Indiana Dunes National Park

	Whole-Species Change Model	Ecoregion Change Model	Whole-Species Density Model	Ecoregion Density Model
Inland Marsh				
Marquette Trail				
Tolleston Dunes				
Miller Woods				
West Beach				
Long Lake				

(A4.e). Albany Pine Bush

	Whole-Species Change Model	Ecoregion Change Model	Whole-Species Density Model	Ecoregion Density Model
Baron House				
Karner Barren West				

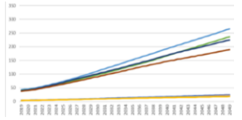
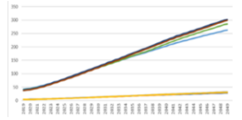
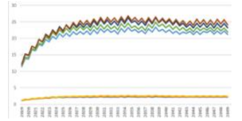
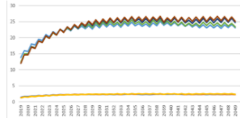
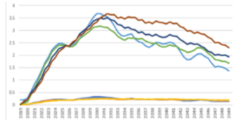
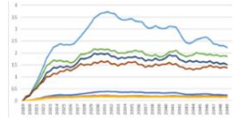
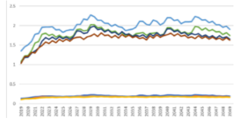
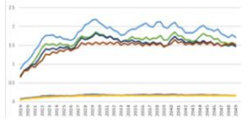
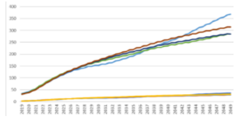
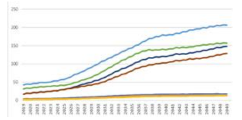
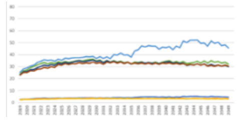
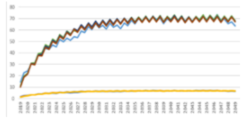
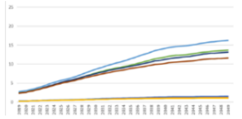
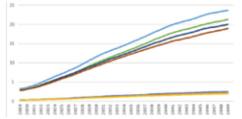
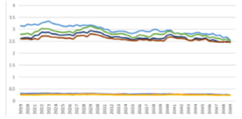
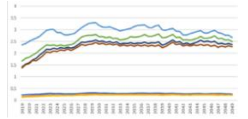
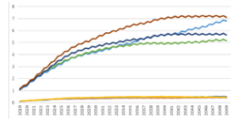
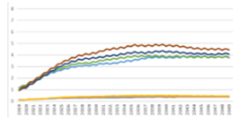
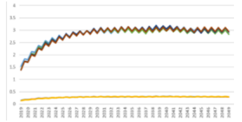
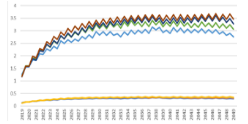
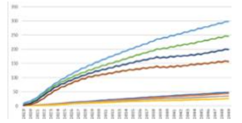
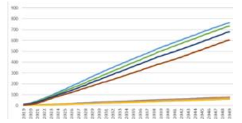
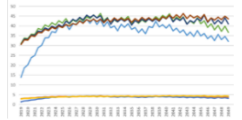
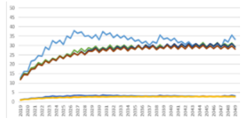
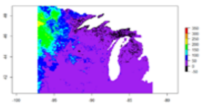
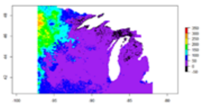
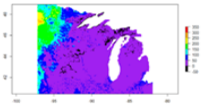
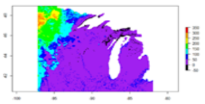
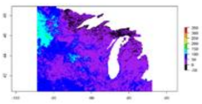
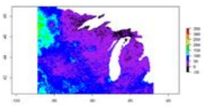
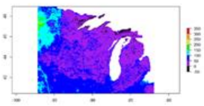
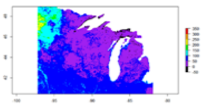
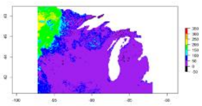
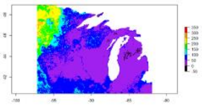
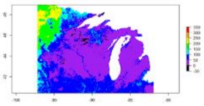
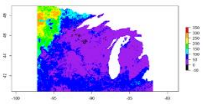
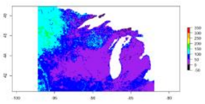
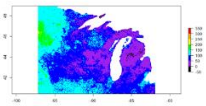
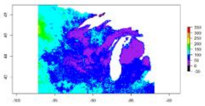
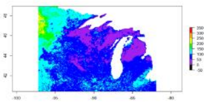
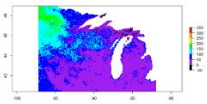
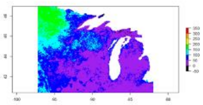
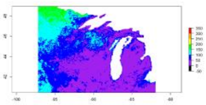
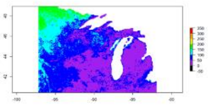
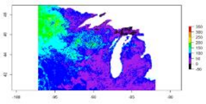
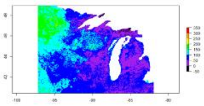
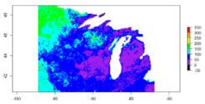
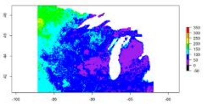
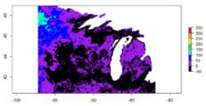
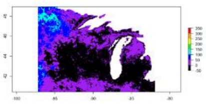
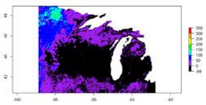
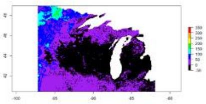
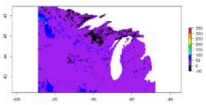
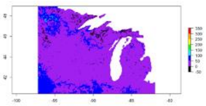
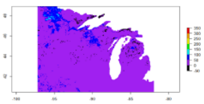
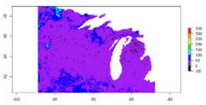
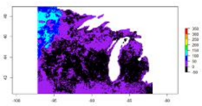
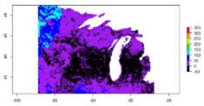
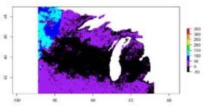
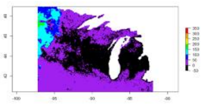
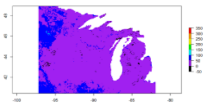
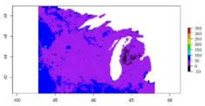
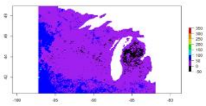
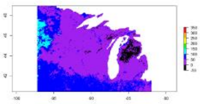
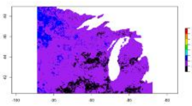
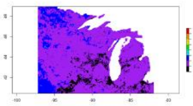
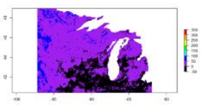
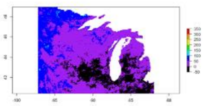
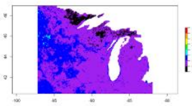
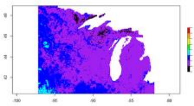
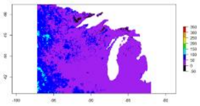
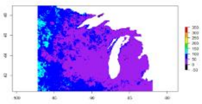
Karner Barren East				
King Road East				
King Road West				
Pine Bush NW				
Pine Bush SW				
Pine Bush SE				

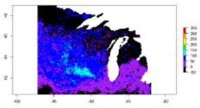
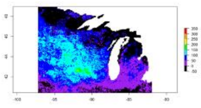
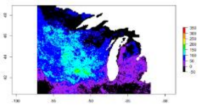
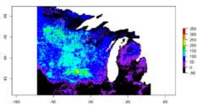
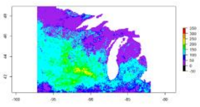
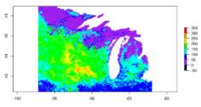
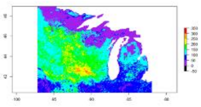
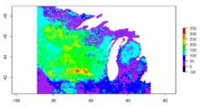
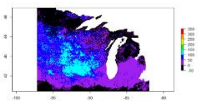
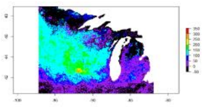
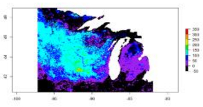
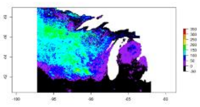
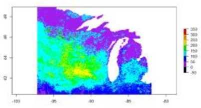
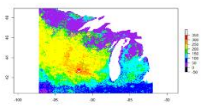
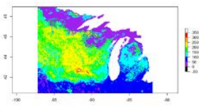
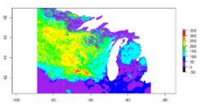
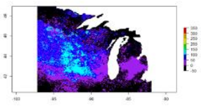
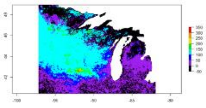
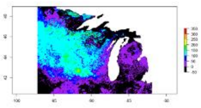
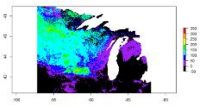
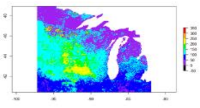
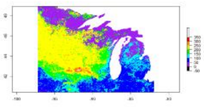
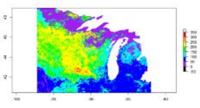
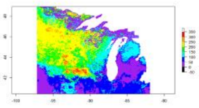
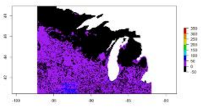
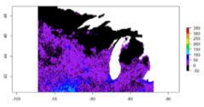
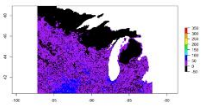
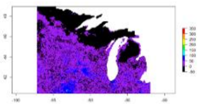
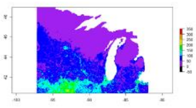
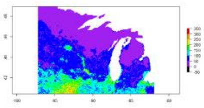
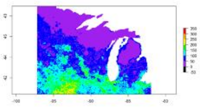
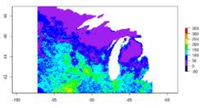
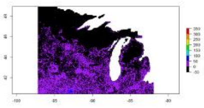
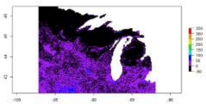
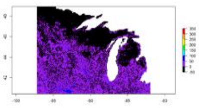
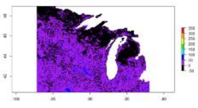
Figure A5.a-d. The projected occupancy of the Karner blue in four ecoregions (not including Albany Pine Bush) during three *predictive windows* (2020-2029, 2030-2039, 2040-2049) under four *climate scenarios* (baseline, +0.5-1%, +1.0-2%, +1.5-3%) using between-generation change model at both *spatial scales* (whole species and ecoregion), respectively.

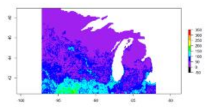
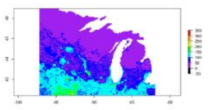
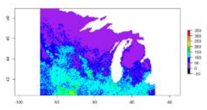
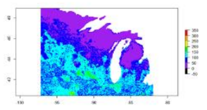
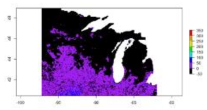
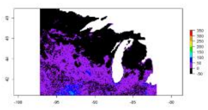
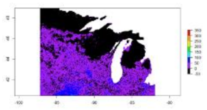
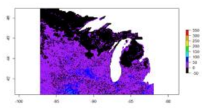
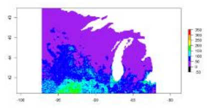
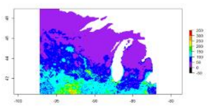
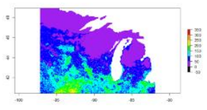
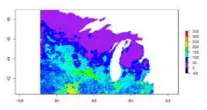
(A5.a). Central Wisconsin

		Baseline	+0.5-1%	+1.0-2%	+1.5-3%
Whole Species 2020 - 2029	G1				
	G2				
Whole Species 2030 - 2039	G1				
	G2				
Whole Species 2040 - 2049	G1				
	G2				
Eco-region 2020 - 2029	G1				
	G2				
Eco-region 2030 - 2039	G1				
	G2				

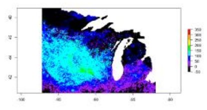
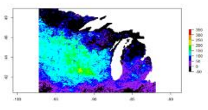
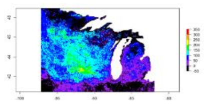
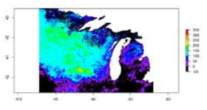
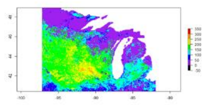
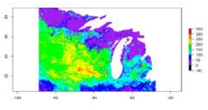
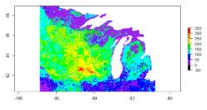
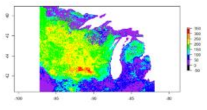
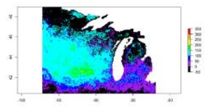
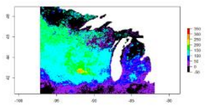
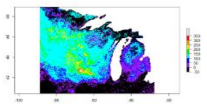
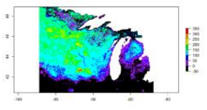
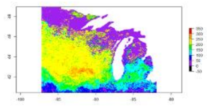
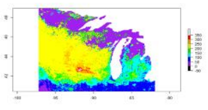
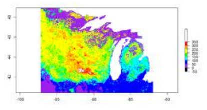
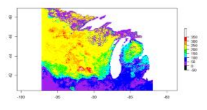
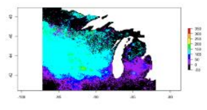
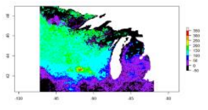
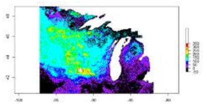
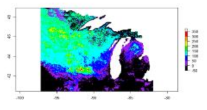
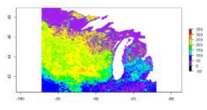
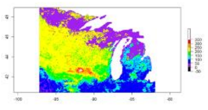
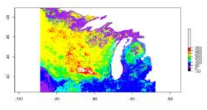
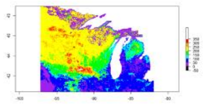
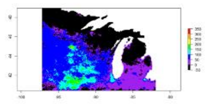
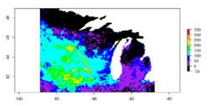
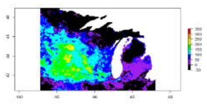
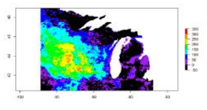
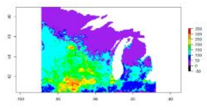
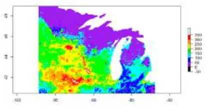
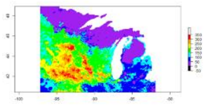
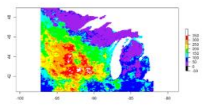
Eco-region 2040 - 2049	G1				
	G2				

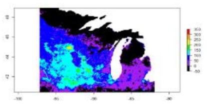
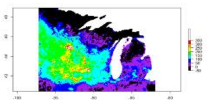
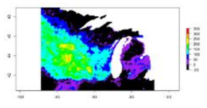
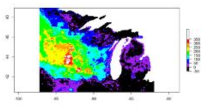
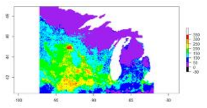
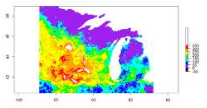
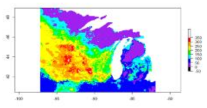
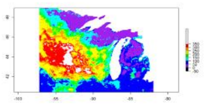
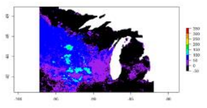
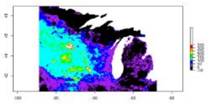
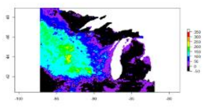
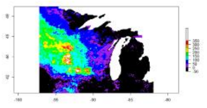
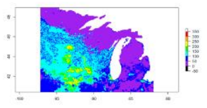
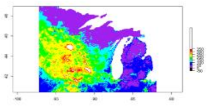
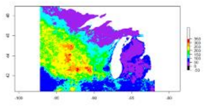
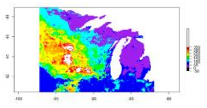
(A5.b). Northwestern Wisconsin

		Baseline	+0.5-1%	+1.0-2%	+1.5-3%
Whole Species 2020 - 2029	G1				
	G2				
Whole Species 2030 - 2039	G1				
	G2				
Whole Species 2040 - 2049	G1				
	G2				
Eco-region 2020 - 2029	G1				
	G2				
Eco-region	G1				

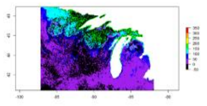
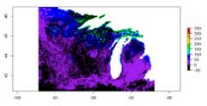
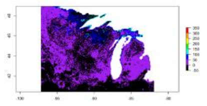
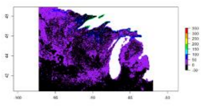
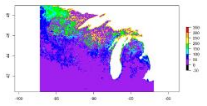
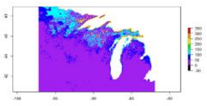
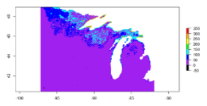
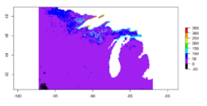
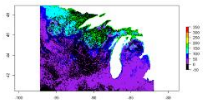
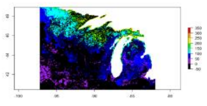
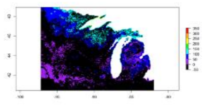
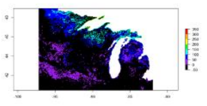
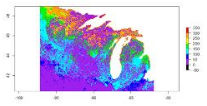
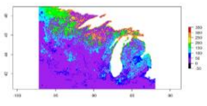
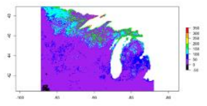
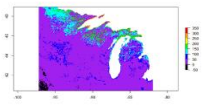
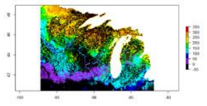
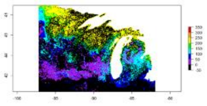
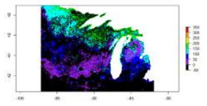
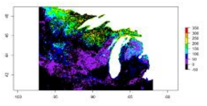
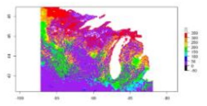
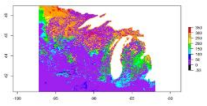
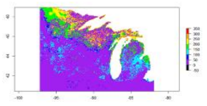
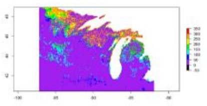
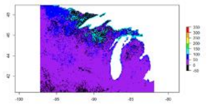
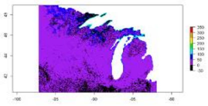
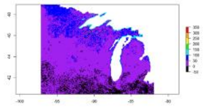
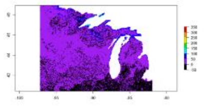
2030 - 2039	G2				
Eco-region 2040 - 2049	G1				
	G2				

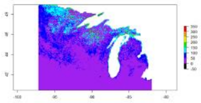
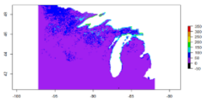
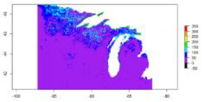
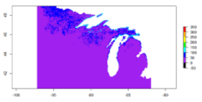
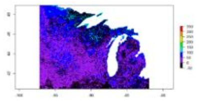
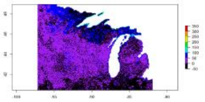
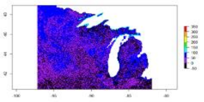
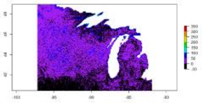
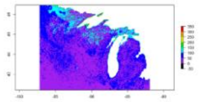
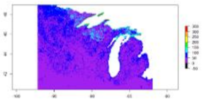
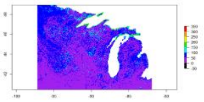
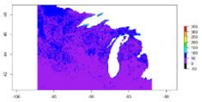
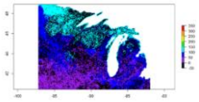
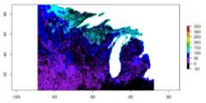
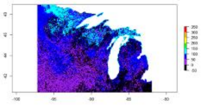
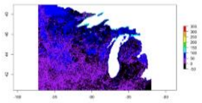
(A5.c). Fort McCoy, Wisconsin

		Baseline	+0.5-1%	+1.0-2%	+1.5-3%
Whole Species 2020 - 2029	G1				
	G2				
Whole Species 2030 - 2039	G1				
	G2				
Whole Species 2040 - 2049	G1				
	G2				
Eco-region 2020 - 2029	G1				
	G2				

Eco-region 2030 - 2039	G1				
	G2				
Eco-region 2040 - 2049	G1				
	G2				

(A5.d). Indiana Dunes National Park

		Baseline	+0.5-1%	+1.0-2%	+1.5-3%
Whole Species 2020 - 2029	G1				
	G2				
Whole Species 2030 - 2039	G1				
	G2				
Whole Species 2040 - 2049	G1				
	G2				
Eco-region	G1				

2020 - 2029	G2				
Eco-region 2030 - 2039	G1				
	G2				
Eco-region 2040 - 2049	G1				
	G2