Great Lakes Fish and Wildlife Restoration Act
FINAL Project Report

Project Title: PREDICTING CLIMATE-CHANGE INDUCED DISTRIBUTIONAL SHIFTS IN GREAT LAKES REGION REPTILES

Project Sponsor: Illinois DNR

FWS Agreement Number: 30181AG189

Principal Investigator(s): Richard B. King

Report Author(s): Richard B. King; Methods and Results coauthored by Michael L. Niiro

Date Submitted: 30 September 2013

Study Objectives: The objectives of this study are to use the maximum entropy method of ecological niche modeling to (1) characterize the association between climatic variables and the current distributions of reptiles of conservation concern in the Great Lakes region, (2) use this information to identify the projected future location of areas of high climatic suitability, and (3) prioritize species and associated management, research, and policy actions based on these projections

List of presentations delivered and outreach activities:

Niiro, M., and King, R. Midwest Partners in Amphibian and Reptile Conservation Annual Meeting, "Predicting Climate-Change Induced Distributional Shifts in Great Lakes Region Reptiles," Pioneer, OH. (2012).

Niiro, M., and King, R. 7th World Congress of Herpetology, "Predicting Climate-Change Induced Distributional Shifts in Great Lakes Region Reptiles," Vancouver, BC. (2012).

Niiro, M., And King, R. International Biogeography Society meeting, "Predicting Future Climatic Suitability for Great Lakes Region Reptiles Using the Maximum Entropy Approach," Miami, FL (2013).

Geographic region project occurred in or effects: Great Lakes region; Minnesota, Illinois, Wisconsin, Indiana, Michigan, Ohio, Pennsylvania, New York and surrounding states and Canadian Provinces

List of reports and peer-reviewed papers completed or in-progress: Copies of this report will be provided to institutions, agencies and personnel listed in Table 1 and to other relevant agencies within the states and provinces included in this study. The work described here will form the basis of an MS thesis by M. Niiro (anticipated fall, 2013) and a manuscript submitted for publication in an appropriate peer-reviewed journal (e.g., Diversity and Distributions, Ecography, Journal of Biogeography).

Executive Summary/Abstract for Project:

Climate change is widely recognized as an imminent threat to native flora and fauna but efforts to address this threat are only beginning. As a group, reptiles may be especially subject to the effects of climate change – their active season is limited by length of the frost-free period and successful reproduction requires access to suitable thermal microhabitats during gestation or incubation. Within the Great Lakes region, mean temperature is expected to increase by ca. 2 degrees C and mean rainfall is expected to increase by ca. 0.2 mm per day by 2060. Among Great Lakes region reptiles are seven snakes and five turtles that are of conservation concern and whose distributions are largely restricted to or broadly encompass the region. The objectives of this study are to use the maximum entropy method of ecological niche modeling to (1) characterize the association between climatic variables and the current distributions of reptiles of conservation concern in the Great Lakes region, (2) use this information to identify the projected future location of areas of high climatic suitability, and (3) prioritize species and associated management, research, and policy actions based on these projections.

Current distributions of reptiles of conservation concern in the Great Lakes region were well predicted by ecological niche models that incorporated four to seven climatic variables. These species consistently showed projected reductions in climatic suitability at locations currently occupied and most showed reductions in climatic suitability within the region more generally. Projected reductions in climatic suitability first became evident in southern and western portions of species' ranges. Reptile species of conservation concern in the Great Lakes region differed in their susceptibility to climate change. Butler's Gartersnake, Eastern and Western Foxsnakes, and Short-headed Gartersnake were least sensitive to climate change; greater than 75% of their known localities were projected to remain climatically suitable in 2050 using the maximum sum of sensitivity and specificity threshold. Furthermore, these species may benefit from the appearance of new areas of high climatic suitability that are not currently occupied. The Spotted Turtle and Northern Map Turtle were somewhat more sensitive; 50-75% of known localities were projected to remain climatically suitable. The remaining species appeared to be more highly sensitive to climate change. Blanding's Turtle, Eastern Massasauga, and Queensnake were projected to have 25-50% of known localities remain climatically suitable and Kirtland's Snake, Wood Turtle, and Bog Turtle were projected to have less than 25% of known localities remain climatically suitable.

High priority species for management, research, and policy actions in response to the threat posed by climate change include Blanding's Turtle, Eastern Massasauga, Queensnake, Kirtland's Snake, Wood Turtle, and Bog Turtle. Management actions include population monitoring especially in areas of decreasing climatic suitability, habitat enhancement, identification and establishment of corridors among habitat fragments, and possible 'rescue' of doomed populations for captive breeding or translocation. Research actions include population viability analysis within areas of decreasing climatic suitability and assessments of colonization ability of newly suitable areas. Policy actions include evaluations of the need for greater legal protection, expanded critical habitat designation, and modified habitat management plans.

Introduction

Climate change is widely recognized as an imminent threat to native flora and fauna (Thomas et al. 2004; Ackerly et al. 2010), but efforts to address this threat are only beginning. For example, just 10% of USFWS recovery plans identify climate change as a threat (124 of 1209 species recovery plans) and only 15 offer substantive analysis of this threat and possible mitigation (Povilitis and Sucklin 2009). Because of the rapidity with which climate change is expected to impact native species (Thomas et al. 2004), analytical methods that allow swift prioritization of species and associated management, research, and policy actions will allow managers and policy makers to address climate change impacts in a time- and cost-effective manner. While the threats imposed by habitat loss, overexploitation, and invasive species are considerable, their resolution typically involves strategies focused on populations within known geographic regions. In contrast, climate change may result in significant shifts in the geographic distribution of environmental conditions suitable for population persistence and as a consequence, management strategies will additionally need to focus on areas not currently occupied by species of concern. The urgency with which climate change impacts need to be addressed is underscored by the observation that pole-ward shifts in species' boundaries are already evident in many species; of 329 animal taxa, an excess of 68% showed distributional shifts consistent with climate change over the 25 years preceding 2000 (Hickling et al. 2006; Thomas 2010).

As a group, reptiles may be especially subject to the effects of climate change – their active season is limited by length of the frost-free period and successful reproduction requires access to suitable thermal microhabitats during gestation or incubation (Deutsch et al. 2008; Doody and Moore 2010). Physiological processes are temperature-dependent (Huey 1982), as is sex determination in many species, particularly turtles (Ewert and Nelson 1991). Furthermore, limited dispersal ability may prevent some reptile species from naturally colonizing new habitats (Araújo and Pearson, 2005).

Within the Great Lakes region, mean temperature is expected to increase by ca. 2 degrees C and mean rainfall is expected to increase by ca. 0.2 mm per day by 2060 (Galatowitsch et al. 2009). Already, climate change is resulting in shifting distributional patterns (e.g., among small mammals, Francl et al. 2010; Myers et al. 2009) and changes in phenology (e.g., among amphibians Brodman 2009; Klaus and Lougheed 2013). Among Great Lakes region reptiles are seven species of snakes and five species of turtles which are of conservation concern and whose distributions are largely restricted to or broadly encompass the region (Figure 1). Most of these species make extensive use of both wetland and upland habitat and have been negatively impacted by habitat loss and degradation resulting from wetland drainage, agriculture, and urbanization (Harding 1997). As a consequence, over much of their range, these species persist in small populations isolated from conspecifics by habitat fragmentation (Bennett et al. 2010; Congdon et al. 2008; Dileo et al. 2010; Shepard et al. 2008; Shoemaker et al. 2013; Willoughby et al. 2013).

The availability of detailed information on species occurrence (e.g., georeferenced locality data from specimen repositories) and local climate (e.g., from NOAA recording stations) makes it possible to characterize associations between current species distributions and individual or composite climate variables. Furthermore, this association can be used in conjunction with climate change projections to predict changes in the location of climatically suitable conditions into the future (e.g., Hijmans et al 2005; Hijmans and Graham2006; Penman et al. 2010; Phillips et al. 2006).). A variety of approaches have been developed for this purpose, (variously referred to as *Climate Matching*, *Climate Envelope Modeling*, *Ecological Niche Modeling,* or *Species Distribtuion Modeling*) and refinements to both the analytical techniques and the interpretation of results are emerging rapidly (e.g., Franklin 2010; Mateo et al. 2010; Tingley and Herman 2009; Thuiller et al. 2009). The objectives of this study are to use the maximum entropy method of ecological niche modeling to (1) characterize the association between climatic variables and the current distributions of reptiles of conservation concern in the Great Lakes region, (2) use this information to identify the projected future location of areas of high climatic suitability, and (3) prioritize species and associated management, research, and policy actions based on these projections.

Climate change may affect Great Lakes region reptiles in different ways. Among species that have restricted distributions, and thus experience a narrow range of climatic conditions, future areas of high climatic suitability may occur in entirely new areas. In this study, such species are represented by the Short-headed Gartersnake, Butler's Gartersnake, and Kirtland's Snake; species whose present distributions encompass portions of just three to seven states and provinces; and the Bog Turtle, a species that occurs within and outside the Great Lakes region but in disjunct areas (Figure 1). For more widely distributed species, future areas of high climatic suitability are more likely to overlap at least part of their current range. However, areas of high climatic suitability may contract, expand, shift in position, or become fragmented. Among the reptiles included here, Eastern and Western Foxsnakes (analyzed as a single entity as explained below), Eastern Massasauga, and Blanding's Turtle are widely distributed within the Great Lakes region but have restricted distributions outside the region (Figure 1). Four other species, the Wood Turtle, Queen Snake, Common Map Turtle, Spotted Turtle, are widely distributed both within and outside the Great Lakes region (Figure 1). Thus, these species provide a test of the way in which current distribution might affect projected impacts of climate change.

More importantly, projected changes in climatic suitability have immediate implications for management, research, and policy actions (Schwartz 2012; Figure 2). For species and areas for which climatic suitability of occupied locations remains constant or increases, management efforts designed to address threats other than climate change (habitat loss, overexploitation, invasive species) are appropriate. Research needs include an evaluation of climate change effects on key interacting species to identify possible indirect effects on species of conservation concern (e.g., prey specialists such as queen snakes are likely to be affected by climate change effects on crawfish). Policy needs include evaluation of the sufficiency of legal protection, critical habitat designation, and habitat management plans, given changes in climatic suitability elsewhere.

For species and areas for which climatic suitability of occupied locations decreases, efforts that also address climate change are warranted (Figure 2). Management needs include population monitoring to facilitate rapid detection of climate change-induced declines and habitat enhancement aimed at increasing local population size and reducing extinction risk. Establishment or enhancement of habitat corridors may be necessary to maintain demographic and genetic health of increasingly subdivided populations (i.e., 'genetic restoration', Hedrick 2005). If populations become too isolated for habitat corridors to be effective, facilitated movement of individuals among population subunits (reciprocal translocation) may be warranted. In the extreme, populations undergoing climate-change induced declines might be targeted for 'rescue' via translocation of individuals to more suitable locations or incorporation into captive breeding programs as insurance against extinction and to provide stock of reintroduction or population augmentation. Research needs include population viability analysis (e.g., Enneson and Litzgus 2009) to assess risk of local extinction, thus informing the need for more active habitat management, translocation, or rescue. Policy needs include evaluation of the need for greater legal protection, expanded critical habitat designation, and modified habitat management plans.

For species and areas for which climatic suitability of unoccupied locations increases, novel policy and research needs arise which take precedence over management (Figure 2). Specifically, the desirability of a conservation policy that includes range expansion needs to be evaluated in light of species status elsewhere and research on availability of suitable habitat within unoccupied areas (e.g., Suzuki et al. 2008, Tigley and Herman 2009) and the potential impacts (both positive and negative) of range expansion on other species (Roemer et al. 2002). This may lead to new policies regarding legal protection, critical habitat designations, and habitat conservation plans. It may also require research to address the potential for natural vs. assisted colonization (Bennie et al. 2013; Travis et al. 2013). Subsequent management needs could include monitoring efforts designed to track changes in distribution, possibly coupled with establishment or enhancement of habitat corridors and assisted colonization efforts (via translocation of individuals from existing populations; Chauvenet et al. 2012;Shirey and Lamberti 2009).

State/ Province	Short-headed Gartersnake	Butler's Gartersnake	Kirtland's Snake	Eastern/ Western Foxsnake	Eastern Massasauga	Bog Turtle	Blanding's Turtle	Wood Turtle	Queen-Snake	Northern Map Turtle	Spotted Turtle
SD				+[1]			+				
NE				+[1]			S[2]				
KS										T	
IA				+[1]	E		T	E		+	
MO			S	+[1]	[3]		E			+	
AR									+	+	
Great Lakes Region											
MN				+[1]	E		T	T		+	
IL			T	+[1]	E		E		+	+	E
WI		T[4]		+[1]	E		T[4]	T	E	+	
IN		E	E	+[1]	E		E		+	+	E
MI		+	E	S[5]	S		S	S	S	+	T
OH	S	+	T	S[5]	E		T		S	+	T
PA	+		E		E	E	S	+	+	+	+
NY	+				E	E	T	S	E	+	S
ON		E		E[5]	T		T	E	E	S	E
QU							S	S		S	S
NB								+			
NS							E	T			
KY			+						+	+	
TN						T			+	+	
WV								S	+	S	S
VA						E		T	+	+	+
ME							E	+			T
NH							E	+			T
VT								S		S	E
MA						E	T	S			+
RI								S			S
CT						E		S			+
NJ						E		T	E	+	+
DE						E		+	+		+
MD						T		+	+	E	+
NC						T			+		+
SC						T			+		T
GA						E			+	S	S
AL									+	+	
FL									+		+

- E Endangered
- T Threatened
- S Special Concern/Greatest Conservation Need
- \+ Present but no special status

[1] Formerly designated Western Foxsnake
[2] Tier 1 at-risk species, Panella 2012
[3] Extant Massasauga populations in Missouri are *S. c. tergeminus* (Gibbs et al. 2010, Kubatko et al. 2011, Ray et al. 2013)
[4] Administrative rule process is underway to delist Blanding's Turtles and Butler's Gartersnakes in Wisconsin
[5] Formerly designated Eastern Foxsnake

Figure 1. Current geographic distribution and conservation status of reptile species that are the focus of this study. Great Lakes states and provinces are highlighted in blue. Species are ordered from fewest (left) to most (right) states and provinces of occurrence. Sources of conservation status information are listed below.

State/ Province	Source of Conservation Status Information (accessed 18 Sept 2013)
SD	http://gfp.sd.gov/wildlife/threatened-endangered/rare-animal.aspx
NE	http://outdoornebraska.ne.gov/wildlife/programs/nongame/Endangered_Threatened.asp
KS	http://www.kdwpt.state.ks.us/news/Services/Threatened-and-Endangered-Wildlife
IA	http://www.iowadnr.gov/Environment/ThreatenedEndangered.aspx
MO	http://mdc.mo.gov/your-property/greener-communities/missouri-natural-heritage-program
AR	http://www.agfc.com/species/Pages/SpeciesEndangeredAbout.aspx
MN	http://www.dnr.state.mn.us/ets/index.html
IL	http://www.dnr.illinois.gov/espb/Pages/default.aspx
WI	http://dnr.wi.gov/topic/endangeredresources/etlist.html
IN	http://www.in.gov/dnr/naturepreserve/4725.htm
MI	http://mnfi.anr.msu.edu/data/specialanimals.cfm/
OH	http://www.dnr.state.oh.us/Home/ExperienceWildlifeSubHomePage/Endangeredthreatenedspeciesplaceholder /resourcesmgtplansspecieslist/tabid/5664/Default.aspx
PA	http://fishandboat.com/endang1.htm
NY	http://www.dec.ny.gov/animals/7494.html
ON	http://www.mnr.gov.on.ca/en/Business/Species/2ColumnSubPage/MNR_SAR_CSSR_SARO_LST_EN.html
QU	http://www.cdpnq.gouv.qc.ca/pdf/Atlas-biodiversite-en.pdf
NB	http://www.registrelep.gc.ca/species/speciesDetails_e.cfm?sid=286
NS	http://novascotia.ca/natr/wildlife/biodiversity/species-list.asp
KY	http://fw.ky.gov/telst.asp
TN	http://www.tn.gov/twra/pdfs/endangered.pdf
WV	http://www.wvdnr.gov/Wildlife/RareSpecList.shtm
VA	http://www.dgif.virginia.gov/wildlife/
ME	http://www.maine.gov/ifw/wildlife/species/endangered_species/state_federal_list.htm
NH	http://www.wildlife.state.nh.us/Wildlife/Nongame/endangered_list.htm
VT	http://www.vtfishandwildlife.com/wildlife_nongame.cfm
MA	http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html
RI	http://www.dem.ri.gov/programs/bpoladm/plandev/heritage/
CT	http://www.ct.gov/deep/cwp/view.asp?a=2702&q=323486
NJ	http://www.nj.gov/dep/fgw/tandespp.htm
DE	http://www.dnrec.delaware.gov/fw/NHESP/information/Pages/Endangered.aspx
MD	http://www.dnr.state.md.us/wildlife/Plants_Wildlife/rte/rteanimals.asp
NC	http://www.ncwildlife.org/portals/0/Conserving/documents/protected_species.pdf
SC	http://www.dnr.sc.gov/species/
GA	http://www.georgiawildlife.com/node/2626
AL	http://www.outdooralabama.com/research-mgmt/cwcs/outline.cfm
FL	http://myfwc.com/wildlifehabitats/imperiled/

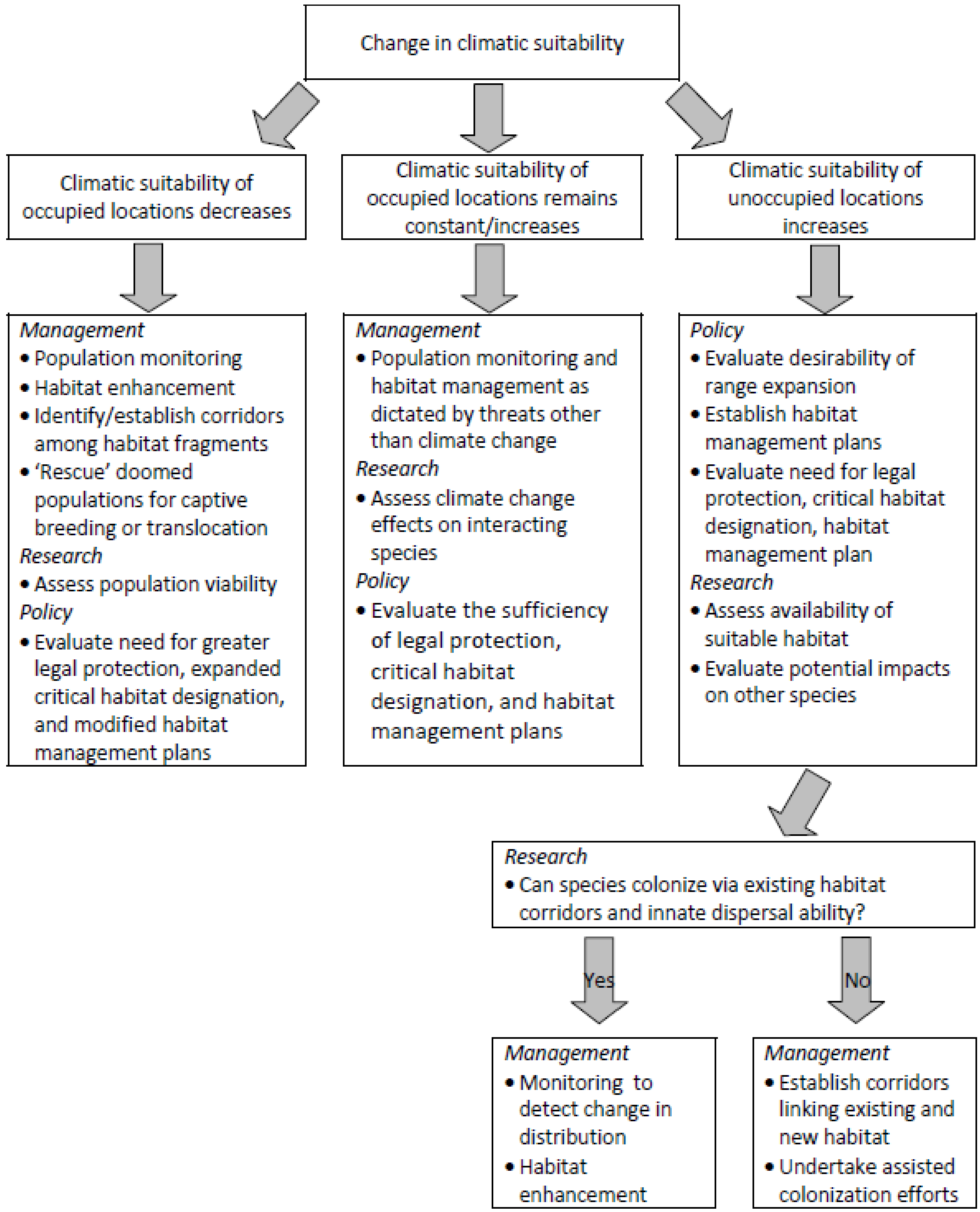


Figure 2. Flow chart linking projected effects of climate change to specific management, research and policy actions.

Methods

Compilation of Georeferenced Locality Data. – Locality records were obtained through queries of the HerpNET network of herpetological collections (http://herpnet.org/) and requests to individual institutions and appropriate state and provincial agencies (e.g., Departments of Natural Resources) and other sources (Table 1). These records were compiled into a searchable database using FileMaker Pro 11. When necessary, geographic coordinates were generated from site descriptions using GeoLocate (http://www.museum.tulane.edu/geolocate/). Records georeferenced using GeoLocate were included only if their associated uncertainty was <10 km (a scale comparable to the spatial resolution of climatic data as described below). Records were mapped using ArcMap 10.1 (www.esri.com) and compared to regional distributional maps (e.g., state and regional field guides) to identify likely erroneous records for subsequent correction or exclusion. To control for possible search effort bias, spatial filtering of records was used to achieve a relatively uniform distribution (Kramer-Schadt et al. 2013, Yackulic et al. 2012). This was accomplished by applying a grid with a square cell size of 15 arcminutes by 15 arcminutes. Within each grid cell, one record was randomly selected for inclusion in the analyses. An exception was made for the case of *Thamnophis brachystoma* where the cell size was 5 arcminutes by 5 arcminutes to account for this species' limited distribution. Following spatial filtering, the number of records retained for analysis ranged from 89-665 among species (Table 2) and exceeded sample size thresholds for acceptable model performance (Wisz et al. 2008).

In general, each species was analyzed in a separate model with its own geographic background. An exception was made for the Eastern Foxsnake and Western Foxsnake, given recent changes in the taxonomy of these two species (Crother et al. 2011, Row et al. 2011). Previously, the Eastern Foxsnake and the Western Foxsnake were considered subspecies, and later distinct species that occupied disjunct geographic ranges (Collins 1991). The Western Foxsnake occurred in South Dakota, Nebraska, Minnesota, Iowa, Illinois, Wisconsin, the upper peninsula of Michigan, and western Indiana whereas the Eastern Foxsnake occurred in northern Ohio, eastern Michigan, and southern Ontario (Conant and Collins 1991). A gap of 250 km in eastern Indiana and western Ohio, where neither species was found, separated the species (Crother et al. 2011, Row et al. 2011). Recent molecular genetic analyses indicate that while two well differentiated Foxsnake clades do exist, their geographic distribution does not conform to previous species designations. These analyses suggest a species boundary and area of sympatry at the Mississippi River (Crother et al. 2011). Because this area of sympatry is poorly characterized and the two species cannot be fully distinguished using morphological characters (Crother et al. 2011), occurrence records could not be assigned unambiguously by species and so Eastern and Western Foxsnakes were pooled in one model.

An exception was also made for the Massasauga Rattlesnake, *Sistrurus catenatus*, for which just the Eastern Massasauga, *S. c. catenatus*, was modeled based on its disjunct distribution (fig. 1 in Kubatko et al. 2011) and strong (species-level) genetic differentiation from the Western Massasauga, *S. c. tergeminus* (Gibbs et al. 2010, Kubatko et al. 2011, Ray et al. 2013).

Exceptions were also made in model construction for the Blanding's Turtle and the Queensnake. Several disjunct populations of these species were excluded from the models to prevent undue influence on the geographic background. Blanding's Turtles occur primarily in the northern states of the Midwestern region of the United States and the southern part of Ontario, Canada (Conant and Collins 1991). A disjunct population occurs in Massachusetts, Rhode Island, Vermont, New Hampshire and Connecticut, but it is separated from the next nearest occurrence by approximately 350 km. Another disjunct population is located in Nova Scotia and is separated from the next nearest occurrence by approximately 300 km. Genetic analyses indicate that these three geographic regions represent separate evolutionarily significant units (Mockford et al. 2007). Queensnakes are found throughout many of the states east of the Mississippi River from as far south as Florida to as far north as New York (Conant and Collins 1991). A disjunct population in Arkansas is separated from the next nearest occurrence by approximately 300 km.

Although the Wood Turtle occurs in both New Brunswick and Nova Scotia, no records for this species were included in the data compilation and so these provinces were excluded from state/province specific summaries for this species.

Model Implementation. – Models were implemented in MaxEnt, a maximum entropy modeling platform that makes use of species presence and background point data to identify environmental variables associated with species distribution (Phillips et al. 2006). The geographic extent from which points are selected in MaxEnt is important to the building of an accurate model (VanDerWal 2009, Rodda et al. 2011, Acevedo et al. 2012). An extent that is too large will result in a highly discriminatory model that is overfit to the data. An undersized extent will result in the model not discriminating at all and being highly underfit to the data. For each species, a buffer was placed around known occurrences and then combined these buffered occurrences into a single continuous polygon in ArcGIS to create the background extent. The resulting polygon was then used to clip the environmental layers in order to restrict the range from which MaxEnt selects its background points. As a default, MaxEnt uses 10,000 randomly selected background points unless the environmental layer has fewer than 10,000 points, in which case MaxEnt uses all points from the environmental layer. A variety of buffer sizes was tested to minimize the mismatch between the known distribution and the area of highest climatic suitability in the MaxEnt model (following VanDerWal et al. 2008). Based upon this testing, a buffer of 250 km provided the model with least mismatch across all species.

Models were trained using climatic data from the WorldClim database representing the time period from 1950 to 2000 with a resolution of 5 arcminutes. At the latitudes of the target species, this corresponds to an approximately square area of ca. 9 km by 9 km. Models were run using 10-fold cross-validation. Under this method, the presence records are split into ten equal folds. Nine folds are used to train the model, and the tenth fold is used to evaluate the model. The model is trained ten times, each time using a different data fold as the tenth fold for evaluating the model. The models are then averaged to produce a final model. In the IPCC Third Assessment Report, a number of different greenhouse gas emissions scenarios were described in the Special Report on Emissions Scenarios (*Special Report on Emissions Scenarios*

2000). These scenarios describe different assumptions about the forces driving climate change. There are 40 different scenarios organized into 4 major scenario families. The A1 and A2 scenario families assume a greater focus on economic development, and thus greater greenhouse gas emissions, whereas the B1 and B2 scenario families assume a greater focus on achieving sustainable practices, and thus comparatively lower greenhouse gas emissions. The A1 and B1 scenario families assume globalization, where new technologies spread rapidly between countries. The A2 and B2 scenario families assume greater regionalization, where development is focused locally and new technologies do not spread as rapidly. The A2a and B2a climate scenarios were selected, as these scenarios are frequently used in environmental niche model analyses (Ihlow et al. 2012, Warren and Seifert 2011). Two different climate scenarios were used to provide differing projections for climate change that better reflect the range of outcomes seen among the 40 climate scenarios from the Special Report on Emissions Scenarios. The data for the A2a and B2a climate scenarios were also more readily available in a variety of formats than the other climate scenarios. Downscaled GCM data from IPCC Fourth Assessment Report was downloaded from the International Center for Tropical Agriculture (CIAT) data portal (Jarvis 2008). Data were downloaded for the A2a and B2a scenarios for the years 2020, 2050, and 2080 from the Hadley Centre's HadCM3, a coupled climate model.

Selection of environmental variables is also an important contributor to model performance and the problem of overfitting (Rodda et al. 2011). A common method is to use the Bioclim variables, a set of 19 bioclimatic variables derived from monthly temperature and precipitation values (Table 3). This variable set was restricted as follows to reduce overfitting of the model (Rodda et al. 2011). Variables Bio8, Bio9, Bio18, and Bio19 were removed *a priori* due to sharp discontinuities that did not correspond with underlying geographic features (King and Niiro unpublished). ENMTools was used to calculate the Pearson correlation coefficient for each pairwise combination of BioClim variables within polygons generated as described above. For all pairwise correlations where $|r| > 0.85$, the variable with fewer strong correlations ($|r|>0.85$) was removed, starting with the highest pairwise correlation. The process was repeated until there were no strong correlations ($|r| > 0.85$) remaining among the selected variables (Elith et al. 2006). While some authors have used lower or higher correlation thresholds (Kumar and Stohlgren 2009, Fang et al. 2013), the use of 0.85 in this study resulted in retention of an intermediate number (4-7; Table 4) of variables (a lower threshold would result in fewer retained variables, whereas a higher threshold would result in more variables) while maintaining moderate potential explanatory variation ($1 – 0.85^2 = 0.28$) as compared to a higher threshold (e.g., $1 – 0.90^2 = 0.19$).

Finally, model performance and overfitting are affected by the complexity of response functions allowed during model selection. This is controlled through the regularization parameter, frequently symbolized as β (Phillips and Dudik 2008, Warren and Seifert 2011). The regularization parameter can be set individually for the different environmental variables but more commonly, a single multiplier is applied to all regularization parameters simultaneously. An example demonstrating the influence of regularization is seen for the Bio13 variable, precipitation in the wettest month, in models run for the Queensnake, *Regina septemvitatta* (Figure 3). In this case, using the default regularization multiplier of 1 resulted in a number of sharp step functions and reversals that do not have emergent biological explanations (Figure 3, left panel). Increasing the regularization multiplier to 1.8 resulted in a simpler function in which probability of occurrence decreases monotonically with increasing precipitation in the wettest month (Figure 3, right panel). Increasing the regularization multiplier reduces the number of parameters included (and hence, reduces overfitting) and results in a model with smoother contours over areas of species' occurrence (Cao et al. 2013). The regularization multiplier was selected empirically through analyses in which regularization was increased by 0.1 increments above the default setting until response curves were approximately monotonic using data for the Queensnake, one of the more widespread species in this analysis. The resulting regularization multiplier, 1.8, was then applied to all species. Response functions were examined to ensure they were approximately monotonic and further adjustments to the regularization multiplier were made on a species-by-species basis.

Models were run without extrapolation, meaning that the logistic-likelihood value was assumed to be zero where the environmental variables exceeded the range of values encountered during the training of the model. This sometimes resulted in hard boundaries in projected areas of climatic suitability, but avoided unrealistic assumptions about the shape of response functions beyond the range of climatic conditions observed among species presences (Owens et al. 2013).

Models and future projections were evaluated using several logistic-likelihood value thresholds distinguishing areas of greater vs. lesser climatic suitability. For thresholds, minimum training presence, 10^{th} percentile training presence, and maximum sum of sensitivity and specificity were selected. The lowest threshold, minimum training presence, is the lowest logistic-likelihood value at which a record used for training the model occurs. Consequently, this threshold envelopes all training records (Cao et al. 2013). The next threshold, 10^{th} percentile training presence, includes the 10^{th} percentile of the training records. The highest threshold maximizes sum of sensitivity and specificity (Cao et al. 2013). To evaluate the loss of suitable habitat, two methods were used. To assess change in climatic suitability at currently occupied locations, the percentage of known species localities used to generate the models that exceeded a given threshold was calculated for each time period. To assess change in climatic suitability within the background area as a whole, the percentage of that area exceeding a given threshold was calculated.

Table 1. List of sources petitioned for data, mode of data request, contact, and number of records received.

Acronym or State/Province	Name	Mode	Contact	# of Records
A. Museums				
	State Museum of Pennsylvania, Harrisburg, PA	direct request	W. Meshaka	26
AMNH	American Museum of Natural History, New York, NY	direct request	D. Dickey, D. Frost, D. Kizirian	1514
AMS	Australia Museum, Sydney, Australia	HerpNet		3
ANSP	Academy of Natural Sciences, Philadelphia, PA	direct request	N. Gilmore	78
APSU	Austin Peay State University, Museum, Clarkesville, TN	direct request	A. Scott	58
ARK	University of Arkansas, Museum, Fayetteville	direct request	M. Suter, N. McCartney	7
AUM	Auburn University Natural History Museum, Auburn, AL	HerpNet		245
BYU	Monte L. Bean Museum, Brigham Young University, Provo, UT	direct request	J. Sites, W. Skidmore	6
CA	Chicago Academy of Sciences, Chicago, IL	direct request	D. Roberts, S. Sullivan	228
CAS	California Academy of Sciences, San Francisco, CA	HerpNet		229
CM	Carnegie Museum of Natural History, Pittsburgh, PA	HerpNet		2760
CMNH	Cleveland Museum of Natural History, Vertebrate Zoology, Cleveland, OH	direct request	R. Muehlheim	150
CU	Cornell University Museum of Vertebrates, Ithaca, NY	HerpNet		375
CUSC	Clemson University, Department of Biological	direct request	S. Miller	30

Acronym or State/Province	Name	Mode	Contact	# of Records
	Sciences, Vertebrate Collections, Clemson, SC			
FMNH	Field Museum of Natural History, Zoology Department, Chicago, IL	direct request	A. Resetar	986
INHS	Illinois Natural History Survey, Champaign-Urbana, IL	direct request	C. Phillips, C. Mayer	922
ISM	Illinois State Museum, Springfield, IL	direct request	M. Mahoney	40
JFBM	James Ford Bell Museum of Natural History, University of Minnesota, Minneapolis, MN	direct request	K. Kozak, A. Luxbacher	376
KU	University of Kansas Natural History Museum, Lawrence, KS	HerpNet		233
LACM	Natural History Museum of Los Angeles County, Los Angeles, CA	HerpNet		43
LSUMZ	Louisiana Museum of Natural History, Baton Rouge, LA	HerpNet		308
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, MA	HerpNet		469
MHP	Sternberg Museum of Natural History, Fort Hays State University, Hays, KS	direct request	C. Schmidt	26
MMNS	Museum of Natural Science, Jackson, MS	direct request	R. Jones	26
MNHSC	Museum of Natural History and Science, Cincinnati Museum Center at Union Terminal, Cincinnati, OH	direct request	H. Mays, J. Davis	171
MPM	Milwaukee Public Museum, Vertebrate Zoology, Milwaukee, WI	HerpNet		582
MSB	Museum of Southwestern Biology, University of NM	HerpNet & direct request	J. Giermakowski, H. Snell	80
MSUM	Michigan State University Museum, East Lansing, MI	HerpNet		339

Acronym or State/Province	Name	Mode	Contact	# of Records
MVZ	Museum of Vertebrate Zoology, University of California at Berkeley, CA	HerpNet		33
NCSM	North Carolina Museum of Natural Sciences, Raleigh, NC	direct request	N. Bradley	592
NIU	Northern Illinois University, Dekalb, IL	direct request	R. King	66
NMC	Canadian Museum of Nature, Ottawa, ONT	Ontario records included in NIHC		
OSM	Ohio State University, Museum of Biological Diversity, Museum of Zoology, Columbus, OH	direct request	A. Nelson	33
OUVC	Ohio University, Vertebrate Collection, Athens, OH	direct request	S. Moody	66
PSM	James R. Slater Museum, University of Puget Sound, Tacoma, WA	HerpNet		5
RM	Redpath Museum, McGill University, Montreal, QUE	Ontario records included in NIHC		
ROM	Royal Ontario Museum, Department of Natural History, Toronto, Ontario	Ontario records included in NIHC		
SBNHM	Santa Barbara Natural History Museum, Santa Barbara, CA	HerpNet		2
SDSNH	San Diego Natural History Museum, San Diego, CA	HerpNet		16
TCWC	Texas Cooperative Wildlife Collection, Texas A&M University, College Station, TX	HerpNet		66
TNHC	Texas Natural History Collections, Texas Natural Science Center, Texas Memorial Museum, University of Texas at Austin, Austin, TX	direct request	D. Cannatella, T. LaDuc	34
UA	University of Alabama Herpetological Collection, Tuscaloosa, AL	direct request	T. Warf, L. Rissler	21

Acronym or State/Province	Name	Mode	Contact	# of Records
UAZ	Amphibian and Reptile Collection, University of Arizona, Tuscon, AZ	HerpNet		25
UCM	University of Colorado Museum, Boulder, CO	HerpNet		40
UF	University of Florida, Florida Museum of Natural History, Gainesville, FL	direct request	K. Krysko	451
UMMZ	University of Michigan Museum of Zoology, Ann Arbor, MI	direct request	G. Schneider, R. Nussbaum	1567
UMNH	Utah Museum of Natural History, University of Utah, Salt Lake City, UT	HerpNet		66
UNSM	University of Nebraska State Museum, Lincoln, NE	direct request	T. Labedz	68
USNM	National Museum of Natural History, Washington D.C.	HerpNet & direct request	J. Jacobs, K. Tighe	1136
UTA	Amphibian and Reptile Diversity Research Center, University of Texas at Arlington, Arlington, TX	direct request	J. Campbell, C. Franklin	282
UWGB	Richter Museum of Natural History, University of Wisconsin, Green Bay, WI	direct request	T. Erdman	41
UWSP	University of Wisconsin Stevens Point, Museum of Natural History, Stevens Point, WI	direct request	E. Wild	58
UWZM	University of Wisconsin Zoological Museum, Madison, WI	direct request	G. Mayer	254
YPM	Peabody Museum of Natural History, Yale University, New Haven, CT	HerpNet		133
B. State/Provincial Natural Heritage Databases				
Alabama	Alabama Natural Heritage Program	direct request	M. Barbour	No records maintained
Arkansas	Arkansas Natural Heritage Commission	direct request	C. Osborne	67

Acronym or State/Province	Name	Mode	Contact	# of Records
Connecticut	Connecticut Department of Energy and Environmental Protection, Bureau of Natural Resources, Wildlife Division	direct request	K. Zyko	No data received
Delaware	Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife, Natural Heritage and Endangered Species Program	direct request	E. Stetzar	No data received
Florida	Florida Natural Areas Inventory	direct request	M. O'Brien	20
Georgia	Georgia Department of Natural Resources, Wildlife Resources Division, Georgia Rare Species and Natural Community Data	online access		60
Illinois	Illinois Natural Heritage Database	direct request	T. Kieninger	186
Indiana	Indiana Natural Heritage Data Center	direct request	R. Hellmich	386
Iowa	Iowa Department of Natural Resources	direct request	D. Howell	193
Kansas	Kansas Natural Heritage Inventory	direct request	J. Delisle	7
Kentucky	Kentucky State Nature Preserves Commission	direct request	S. Hines	No records maintained
Maine	Maine Department of Inland Fisheries and Wildlife	direct request		No records maintained
Maryland	Maryland Wildlife and Heritage Service	direct request		No data received
Massachusetts	Massachusetts Natural Heritage and Endangered Species Program	direct request		No data received
Michigan	Michigan Natural Features Inventory	direct request	Y. Lee, R. Rogers	726
Minnesota	Minnesota Natural Heritage Information System	direct request	S. Bump	
Missouri	Missouri Department of Conservation	direct request	D. Butler	No data received
Nebraska	Nebraska Natural Heritage Program	direct request	R. Schneider, R.	9

Acronym or State/Province	Name	Mode	Contact	# of Records
			Simpson	
New Hampshire	New Hampshire Natural Heritage Bureau	direct request	S. Cairns	880
New Jersey	New Jersey Endangered & Nongame Species Program	direct request	G. Fowles	No data received
New York	New York Natural Heritage Program	direct request		No data received
North Carolina	North Carolina Natural Heritage Program	online access		Data lacks species identifier
Ohio	Ohio Biodiversity Database	direct request	G. Schneider	68
Pennsylvania	Pennsylvania Natural Heritage Program	direct request		No data received
Rhode Island	Rhode Island Natural History Survey	direct request	D. Gregg	No data received
South Carolina	South Carolina Department of Natural Resources	direct request	J. Holling	No data received
South Dakota	South Dakota Department of Game, Fish and Parks	direct request	N. Baker	46
Tennessee	Tennessee Natural Heritage Program	online access		1
Vermont	Vermont Natural Heritage Information Program	direct request		No data received
Virginia	Virginia Natural Heritage Program	direct request		No data received
West Virginia	West Virginia Department of Natural Resources, Wildlife Resources Section	direct request	B. Sargent	49
Wisconsin	Wisconsin Department of Natural Resources	direct request		802
Nova Scotia	Atlantic Canada Conservation Data Centre	direct request	S.H. Gerriets	No data received

Acronym or State/Province	Name	Mode	Contact	# of Records
Ontario	Ontario Ministry of Natural Resources, Natural Heritage Information Centre (NHIC)	direct request	R. Craig	9358
Quebec	Société d'histoire naturelle de la vallée du St-Laurent	direct request	A. Paquet	202
C. Other Sources				
NAFHA	North American Field Herping Association	direct request	D. Becker	772
	B. Gray	personal communication		11

Table 2. List of species standard names, scientific names, abbreviations, number of records obtained, number of georeferenced records , and number of georeferenced records retained in the Maxent model (not all records were georeferenced or met uncertainty criteria for inclusion). Standard and scientific names follow Crother et al. 2008. Species are ordered from fewest (top) to most (bottom) states and provinces of occurrence.

Standard Name	Scientific Name	Abbreviation	Number of Records	Number of Georeferenced Records	Number of Georeferenced Records Retained
Short-headed Gartersnake	*Thamnophis brachystoma*	Thbr	1135	701	125
Butler's Gartersnake	*Thamnophis butleri*	Thbu	1197	856	89
Kirtland's Snake	*Clonophis kirtlandii*	Clki	465	194	98
Eastern and Western Foxsnake	*Pantherophis sp.*	Pasp	3131	2563	326
Eastern Massasauga	*Sistrurus catenatus catenatus*	Sica	3150	2602	284
Bog Turtle	*Glyptemys muhlenbergii*	Glmu	548	232	93
Blanding's Turtle	*Emydoidea blandingii*	Embl	4862	3538	665
Wood Turtle	*Glyptemys insculpta*	Glin	3107	2414	602
Queen Snake	*Regina septemvittata*	Rese	3408	1855	549
Northern Map Turtle	*Graptemys geographica*	Grge	3703	2946	425
Spotted Turtle	*Clemmys guttata*	Clgu	3792	1304	584

Table 3. BIOCLIM variables and descriptions (from Hijmans et al. 2005). BIOCLIM variables marked with * were excluded from variable selection (see text).

Name	Description
Bio1	Annual Mean Temperature
Bio2	Mean Diurnal Range (mean of monthly (max temp – min temp)
Bio3	Isothermality (Bio2/Bio7)(* 100)
Bio4	Temperature Seasonality (standard deviation * 100)
Bio5	Max Temperature of Warmest Month
Bio6	Min Temperature of Coldest Month
Bio7	Temperature Annual Range (Bio5 – Bio6)
Bio8*	Mean Temperature of Wettest Quarter
Bio9*	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18*	Precipitation of Warmest Quarter
Bio19*	Precipitation of Coldest Quarter

Table 4. Bioclim variables selected for modeling in MaxEnt. Species are ordered from fewest (left) to most (right) states and provinces of occurrence. See Table 2 for species abbreviations and Table 3 for definitions of Bioclim variables.

	Species										
	Thbr	Thbu	Clki	Pasp	Sica	Glmu	Embl	Glin	Rese	Grge	Clgu
Bio1	X	X	X	X	X	X	X	X	X	X	X
Bio2	X	X	X	X	X	X	X	X	X	X	X
Bio3		X		X	X		X	X			
Bio4	X	X	X	X	X		X	X			
Bio5											
Bio6											
Bio7	X										
Bio10											
Bio11											
Bio12	X	X	X	X	X	X	X	X	X	X	X
Bio13		X		X	X		X	X		X	X
Bio14				X	X		X		X		X
Bio15	X					X			X		X
Bio16											
Bio17											

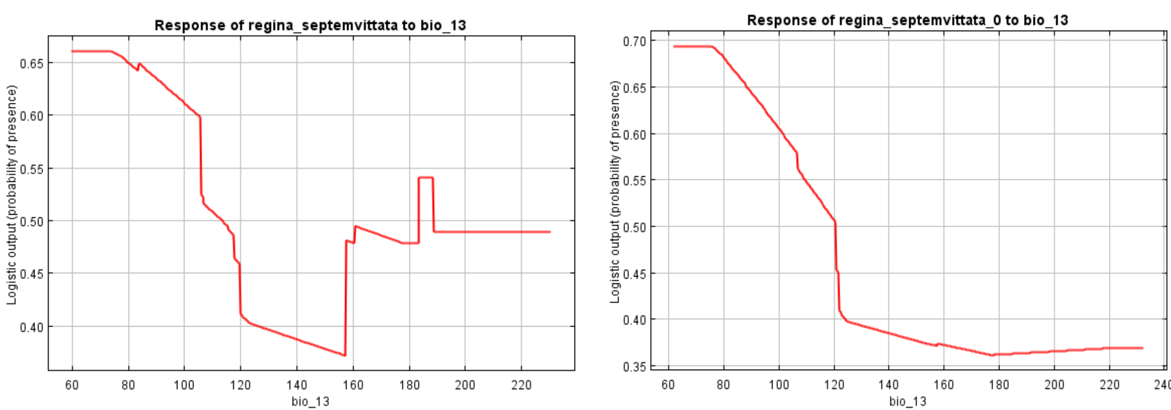


Figure 3. Example of response curves of the Queensnake, *Regina septemvitatta*, to precipitation of wettest month (Bio13) using the default (β = 1, left panel) and adjusted (β = 1.8, right panel) regularization multiplier.

Results

A total of 28,498 records were acquired for all species combined (Table 2). The number of records by species ranged from 465 for *Clonophis kirtlandii* to 4,862 for *Emydoidea blandingii*. The total number of georeferenced records, either from records that had latitude and longitude or from records that could georeferenced using GeoLocate, was 19,205. The total number of georeferenced records retained after applying the spatial filtering method was 3,840. The number of records retained by species ranged from 89 for *Thamnophis butleri* to 665 for *Emydoidea blandingii* (Table 2).

Current Climate (1950 – 2000) Model. – Among the 11 species analyzed, four to seven BIOCLIM variables were retained for analysis following variable selection (Table 4). Annual mean temperature (Bio1), mean diurnal temperature range (Bio2), and annual precipitation (Bio12) were the only BIOCLIM variables included in all of the models (Table 4). Isothermality (Bio3) was included in the models for *Emydoidea blandingii*, *Glyptemys insculpta*, *Pantherophis* sp., *Sistrurus catenatus catenatus*, and *Thamnophis butleri*. Temperature seasonality (Bio4) was included in the models for *Clonophis kirtlandii*, *Emydoidea blandingii*, *Glyptemys insculpta*, *Pantherophis* sp., *Sistrurus catenatus catenatus*, *Thamnophis brachystoma*, and *Thamnophis butleri*. Temperature annual range (Bio7) was only included in the model for *Thamnophis brachystoma*. Precipitation of the wettest month (Bio13) was included in the models for *Clemmys guttata*, *Emydoidea blandingii*, *Glyptemys insculpta*, *Graptemys geographica*, *Pantherophis* species, *Sistrurus catenatus catenatus*, and *Thamnophis butleri*. Precipitation of the driest month (Bio 14) was included in the models for *Clemmys guttata*, *Emydoidea blandingii*, *Pantherophis* species, *Regina septemvittata*, and *Sistrurus catenatus catenatus*. Precipitation seasonality (Bio15) was included in the models for *Clemmys guttata*, *Clemmys muhlenbergii*, *Sistrurus catenatus catenatus*, and *Thamnophis brachystoma*. Maximum temperature of the warmest month (Bio5), minimum temperature of the warmest month (Bio6), mean temperature of the warmest quarter (Bio10), mean temperature of the coldest quarter (Bio11), precipitation of the wettest quarter (Bio16), and precipitation of the driest quarter (Bio17) were never included in any of the models.

Training values for area under the receiver curve (AUC) for the models ranged from 0.74 to 0.95 and testing AUC values for the models ranged from 0.73 to 0.94 (Table 5). Models for species with smaller distributions typically had higher AUC values (Pearson correlation between area within 250 km buffers and testing AUC = -0.805, N = 11, P = 0.003). For example, *Sistrurus catenatus catenatus* and *Graptemys geographica*, two species with particularly large distributions, had testing AUC values of 0.73 and 0.77 respectively. *Thamnophis brachystoma*, an exemplar of a species with a small distribution, had the highest testing AUC of 0.94. Models predicted current distributions of target species well (Figures 4-14; figures are ordered from showing the least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050). Under current climate (1950 – 2000) conditions, greater than 70% of known localities for each species fell within the maximum sum of sensitivity and specificity (SSS) threshold (Table 6). Furthermore, areas of high suitability (above the SSS threshold) were largely restricted to within the 250 km buffer around known occurrences (Figure 4-14). *Clemmys guttata* was an exception in this regard with a significant area above the SSS threshold occurring southwest of the buffer area (Figure 7).

Based on percent contribution and on permutation importance, annual mean temperature (Bio1) was a major contributor to models for all turtle species (Table 5). Other important contributors included mean diurnal range (Bio2) for *Clemmys guttata*, temperature seasonality (Bio4) for *Glyptemys insculpta*, annual precipitation (Bio12) for *Emydoidea blandingii*, precipitation of the wettest month (Bio13) for *Graptemys geographica*, and precipitation seasonality (Bio15) for *Glyptemys muhlenbergii*, (Table 5). For snake species, no single variable emerged as consistently being the highest contributor, although annual mean temperature frequently contributed more than 20% to the models. Other important contributors included mean diurnal range (Bio2) in *Clonophis kirtlandii* and *Thamnophis butleri*; isothermality (Bio3) in *Pantherophis* sp.; temperature seasonality (Bio4) in *Clonophis kirtlandii*, *Pantherophis* sp., *Sistrurus catenatus catenatus*, and *Thamnophis butleri*; annual precipitation (Bio12) in *Pantherophis* sp., *Sistrurus catenatus catenatus*, *Thamnophis brachystoma*, and *Thamnophis butleri*; and precipitation seasonality (Bio15) in *Regina septemvittata* and *Thamnophis butleri* (Table 5). Permutation importance was typically similar to the percent contribution, although relative contributions differed in some species (e.g., *Glyptemys insculpta*, *Pantherophis* sp., *Sistrurus catenatus catenatus*; Table 6). For mean annual temperature (Bio1), all species except *Thamnophis brachystoma* displayed a generally unimodal convex response curve (Figure 15, Table 6); areas of high climatic suitability had intermediate mean annual temperatures. Response curves for other Bioclim variables differed in shape among species (Table 6).

Future Climate Projections. – Most projections indicated loss of climatic suitability originating along the southern and western edges of the species' distributions (Figures 4-14). However, species differed in the patterns of contraction and fragmentation of highly climatically suitable areas (area exceeding the maximum sum of sensitivity and specificity threshold). *Clonophis kirtlandii*, *Regina septemvittata*, and *Sistrurus catenatus catenatus* have single contiguous areas of high suitability under current conditions that are projected to contract and fragment into multiple smaller areas (Figures 10, 11 and 13). *Emydoidea blandingii*, *Pantherophis* sp., and *Thamnophis brachystoma* have single contiguous areas of high suitability under current conditions that are projected to shrink and shift to the northeast (Figures 6, 6, and 9). *Clemmys guttata* and *Thamnophis butleri* have multiple areas of high suitability under current conditions that are projected to merge over time (Figures 4 and 7). *Glyptemys insculpta*, *Glyptemys muhlenbergii*, and *Graptemys geographica* have multiple areas of high suitability that are projected to shrink or be lost (Figures 8, 12, and 14).

To quantify change in climatic suitability, the known species localities used to generate the models were compared to against the threshold values, calculating the percentage of localities that fell within the threshold for each time period. Of the SRES scenarios, the high emission (A2a) scenario resulted in loss of climatic suitability for a greater number of known localities than the medium emission (B2a) scenario (Table 7, 16). This difference between scenarios was evident in all future projections for *Clonophis kirtlandii*, *Glyptemys insculpta*, *Glyptemys muhlenbergii*, and *Sisturus catenatus catenatus* but only in the 2080 projection for *Emydoidia* *blandingii*, *Graptemys geographica*, *Panterhophis* sp., *Regina septemvittata*, and *Thamnophis brachystoma*. Differences between scenarios were negligible for *Clemmys guttata* and *Thamnophis butleri*. In an effort to identify sets of species that might be similarly affected by climate change, species were classified according to the proportion of known localities falling above the maximum sum of sensitivity and specificity (SSS) threshold under the A2a scenario in 2050 (Table 6). By this criterion, *Thamnohis butleri*, *Pantherophis* species, and *Thamnophis brachystoma* were projected to have greater than 75% of known localities remain climatically suitable; *Clemmys guttata* and *Graptemys geogrpahica* were projected to have 50-75% of known localities remain climatically suitable; *Emydoidea blandingii*, *Regina septemvittata*, and *Sistrurus catenatus catenatus* were projected to have 25-50% of known localities remain climatically suitable; and *Clonophis kirtlandii*, *Glyptemys insculpta*, and *Glyptemys muhlenbergii* were projected to have less than 25% of known localities remain climatically suitable. Examining the same criteria in the year 2080, *Thamnophis butleri* falls to 50-75%, *Pantherophis* species and *Thamnophis brachystoma* fall to 25-50%, and *Emydoidea blandingii*, *Regina septemvittata*, and *Sistrurus catenatus catenatus* fall to below 25% of known localities remaining climatically suitable.

A second method of quantifying the change in climatic suitability compared the size of the area satisfying a given threshold value to the size of the geographic background (Table 8, Figure 17). This approach allows for increases in the size of the area deemed climatically suitable. By this method, differences between the A2a and B2a scenarios were generally negligible before 2080 (but see *Thamnophis butleri*; Figure 4). Areas of climatic suitability were projected to increase for *Clemmys guttata*, remain constant for *Graptemys geographica*, first increase and then decrease for *Pantherophis* sp., *Thamnophis brachystoma*, and *Thamnophis butleri*, and steadily decrease for all other species (Table 8, Figure 17).

Neither quantitative measure of change in climatic suitability was correlated with area curreltny occupied by species. Proportion of points above the SSS threshold in 2050 under the A2a scenario was uncorrelated with the size of the geographic background (area with 250 km buffers; Pearson's correlation = -0.152, N = 11, P = 0.689). Similarly, the proportion of the area above the SSS threshold in 2050 under the A2a scenario was uncorrelated with the size of the geographic background (area with 250 km buffers; Pearson's correlation = 0.139, N = 11, P = 0.689).

Table 5. Model AUC values, percent contribution and permutation importance of BIOCLIM variables. Percent contribution was calculated by summing the increases or decreases in regularized gain for each environmental variable; permutation importance was calculated for each environmental variable by randomly permuting the values of that variable among the training points and measuring the resulting drop in training AUC (Phillips et al. 2006). Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050. See Table 2 for species abbreviations and Table 3 for BIOCLIM variable definitions.

	Species										
	Thbu	Pasp	Thbr	Clgu	Grge	Embl	Sica	Rese	Glin	Clki	Glmu
Training AUC	0.86	0.85	0.95	0.79	0.79	0.83	0.83	0.74	0.81	0.86	0.88
Testing AUC	0.85	0.83	0.94	0.78	0.77	0.82	0.80	0.73	0.80	0.84	0.86
Std. Dev.	0.051	0.029	0.030	0.026	0.032	0.019	0.032	0.027	0.023	0.048	0.046
Percent Contribution/Permutation Importance											
Bio1	25.9/21.8	20.1/25.0	13.2/3.0	54.4/44.7	49.3/52.6	34.9/49.5	17.7/24.6	73.1/62.7	46.4/31.0	26.6/21.4	42.1/33.1
Bio2	27.6/24.0	2.6/8.8	0.7/3.1	18.9/22.4	11.2/7.8	17.3/1.8	11.5/0.4	3.9/8.1	6.2/16.6	34.7/44.4	7.2/9.5
Bio3	0.9/0.0	25.6/4.7				7.9/0.0	3.2/7.4		5.3/11.2		
Bio4	5.9/6.0	10.0/27.6	20.9/5.9			7.5/14.9	30.1/39.1		32.2/17.3	35.0/29.8	
Bio5											
Bio6											
Bio7			3.1/0.3								
Bio10											
Bio11											
Bio12	28.3/47.1	19.7/8.6	31.6/37.0	9.4/10.8	12.1/16.5	27.6/26.0	20.7/7.8	0.6/2.5	6.7/12.9	3.7/4.3	6.6/8.6
Bio13	11.3/1.2	7.2/9.4		8.8/6.2	27.4/23.2	1.0/3.8	12.9/7.1		3.2/11.0		
Bio14		14.7/16.0		8.0/11.4		3.8/4.0	3.9/13.5	0.8/3.0			
Bio15			30.5/50.8	0.5/4.5				21.6/23.7			44.1/48.7
Bio16											
Bio17											

Figure 4. Current and future projections of climate suitability for *Thamnophis butleri*. Projections of climate suitability for *Thamnophis butleri* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

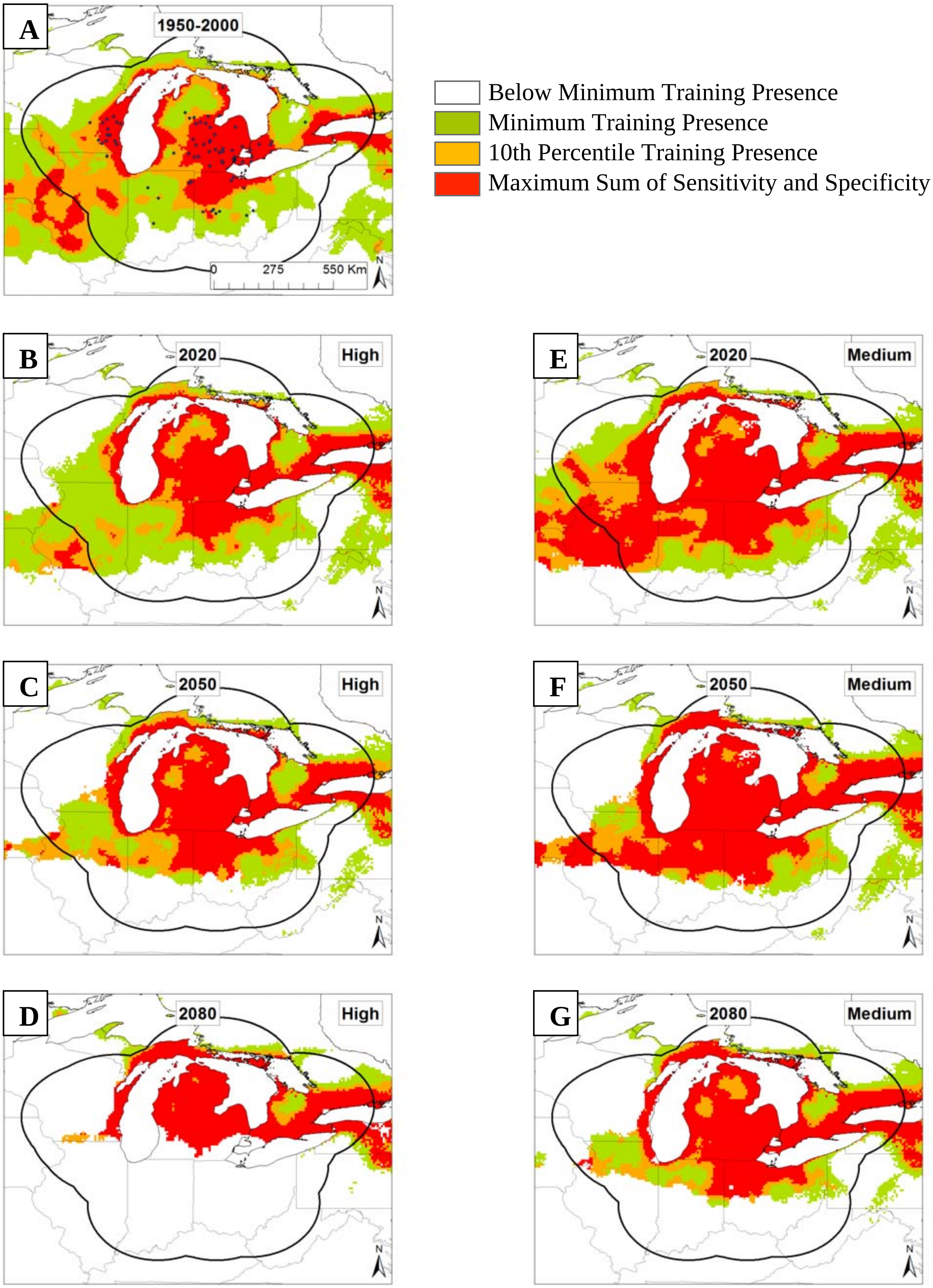

A
1950-2000
0
275
550 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 5. Current and future projections of climate suitability for *Pantherophis sp*. Projections of climate suitability for *Pantherophis* species under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

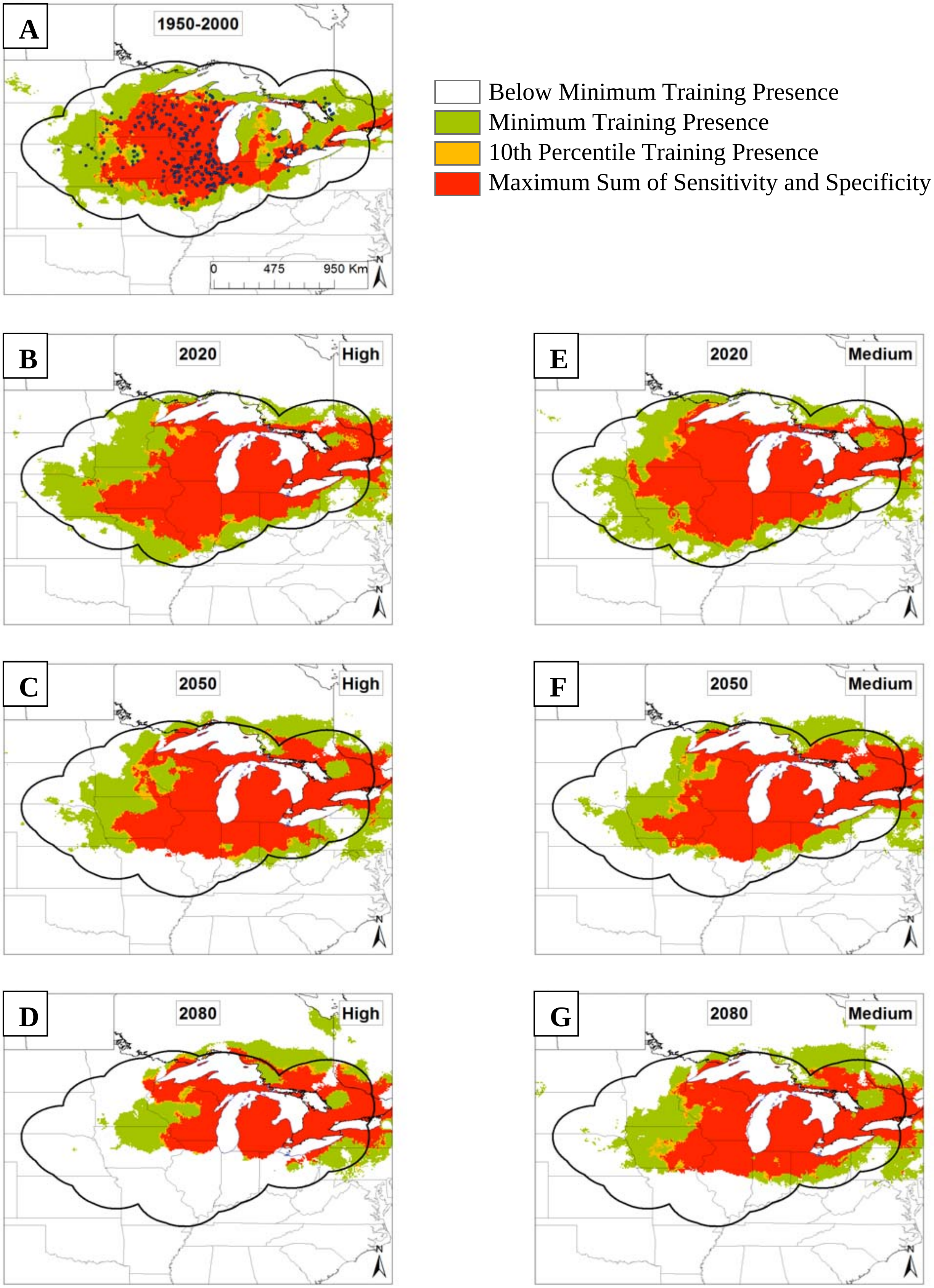

A
1950-2000
0
475
950 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 6. Current and future projections of climate suitability for *Thamnophis brachystoma*. Projections of climate suitability for *Thamnophis brachystoma* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

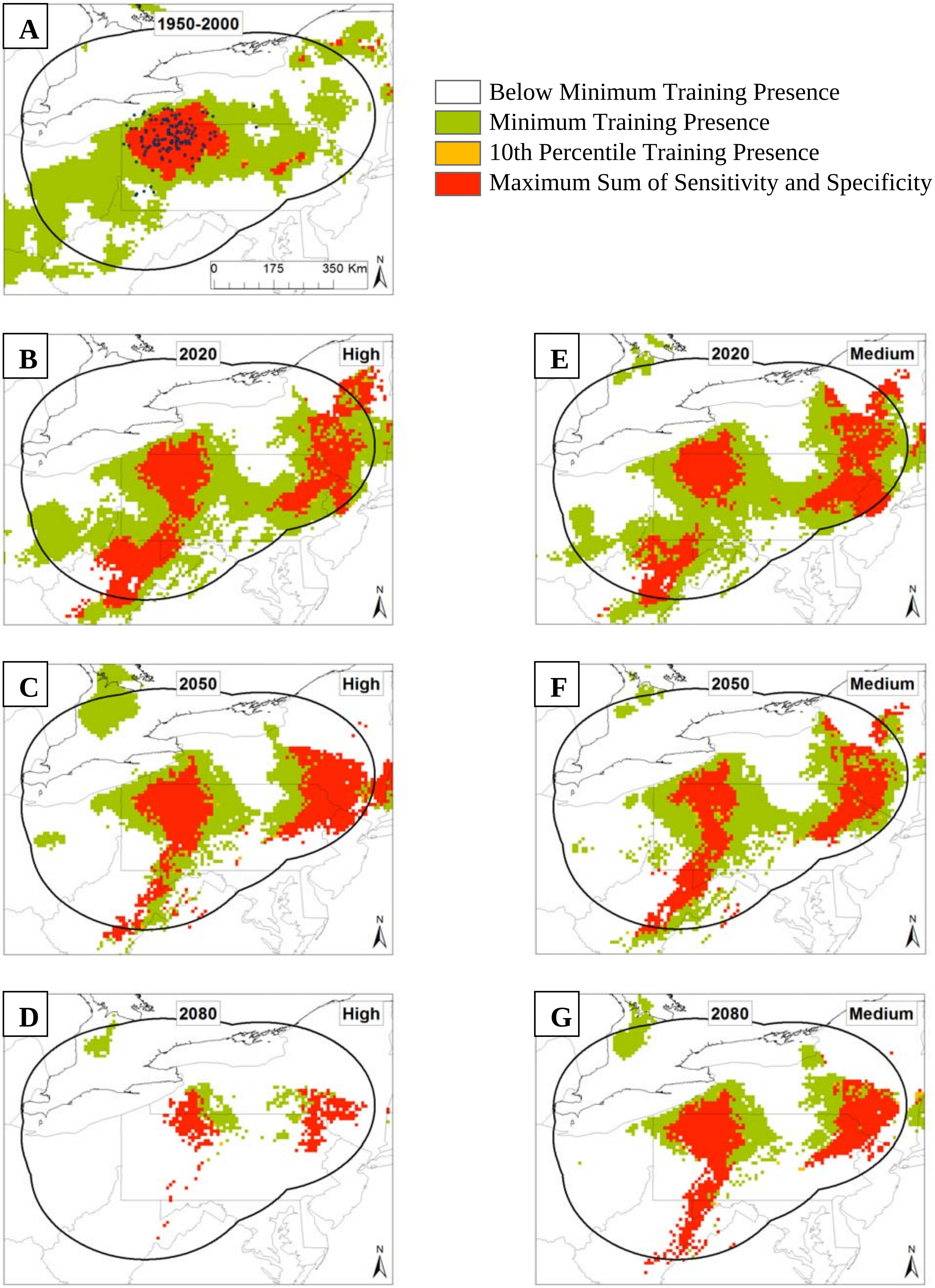

A
1950-2000
0
175
350 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 7. Current and future projections of climate suitability for *Clemmys guttata*.
Projections of climate suitability for *Clemmys guttata* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

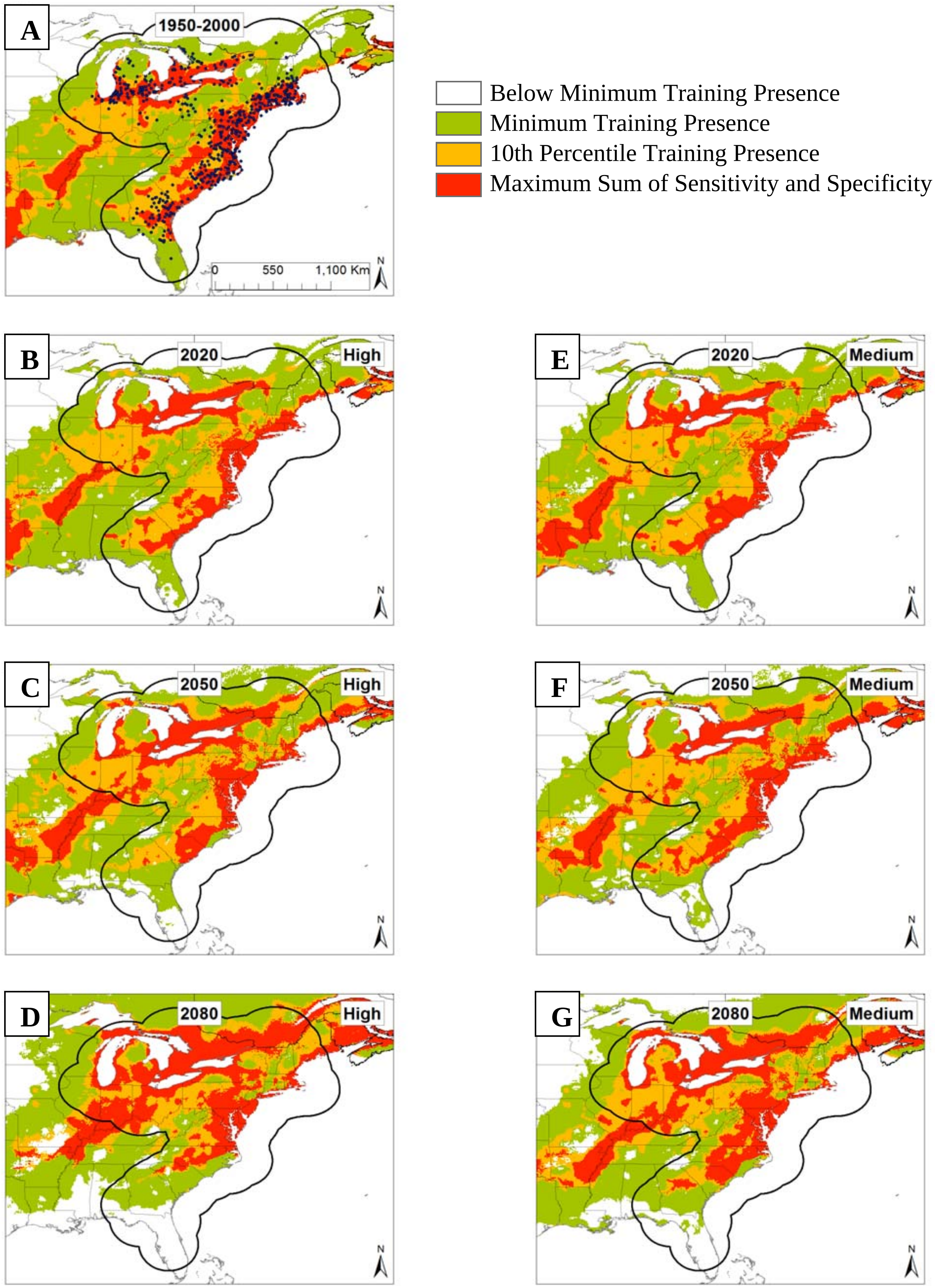

A
1950-2000
0 550 1,100 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 8. Current and future projections of climate suitability for *Graptemys geographica*. Projections of climate suitability for *Graptemys geographica* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

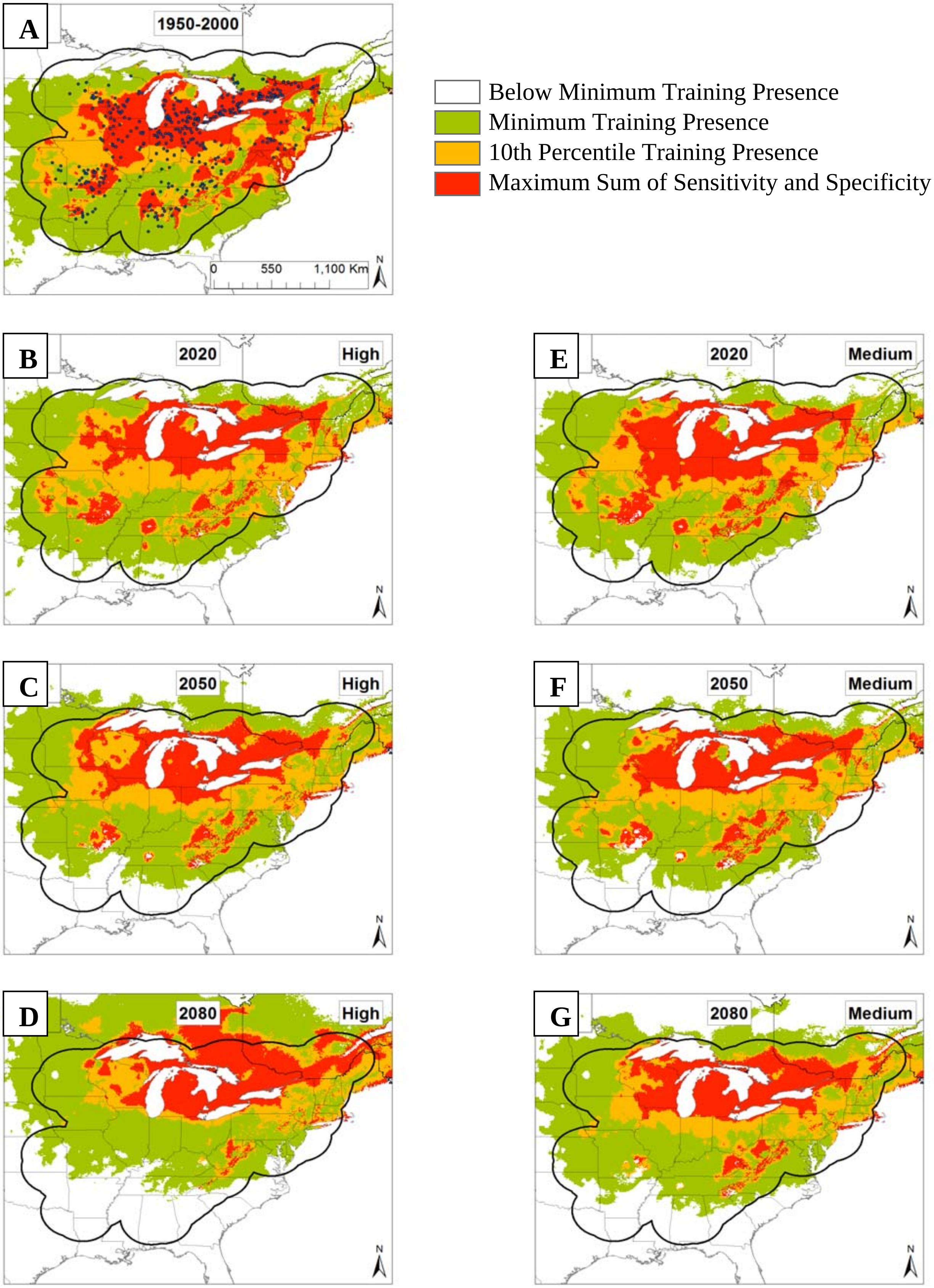

A
1950-2000
0
550
1,100 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 9. Current and future projections of climate suitability for *Emydoidea blandingii*. Projections of climate suitability for *Emydoidea blandingii* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

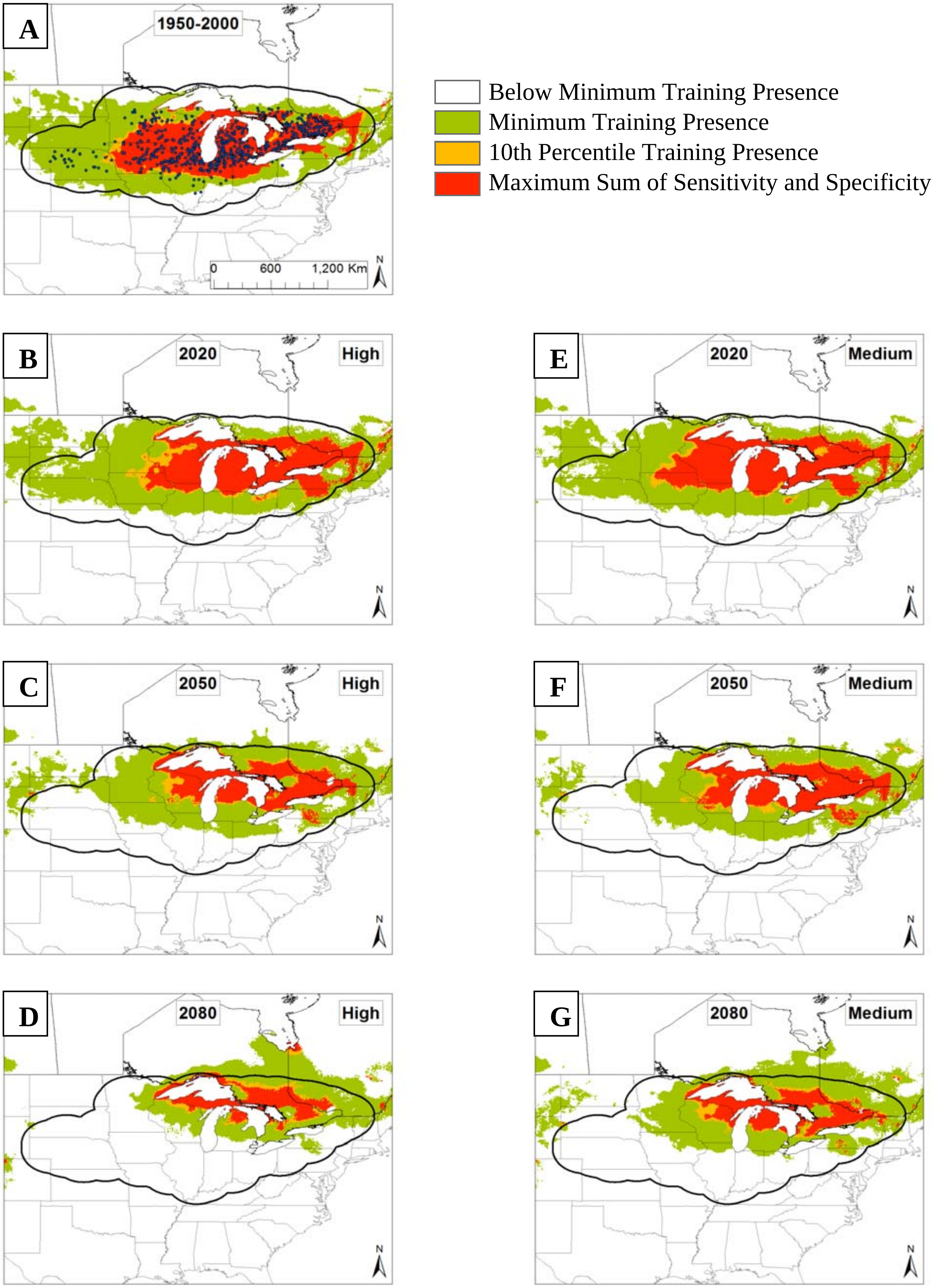

A
1950-2000
0 600 1,200 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 10. Current and future projections of climate suitability for *Sistrurus catenatus catenatus*. Projections of climate suitability for *Sistrurus catenatus catenatus* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

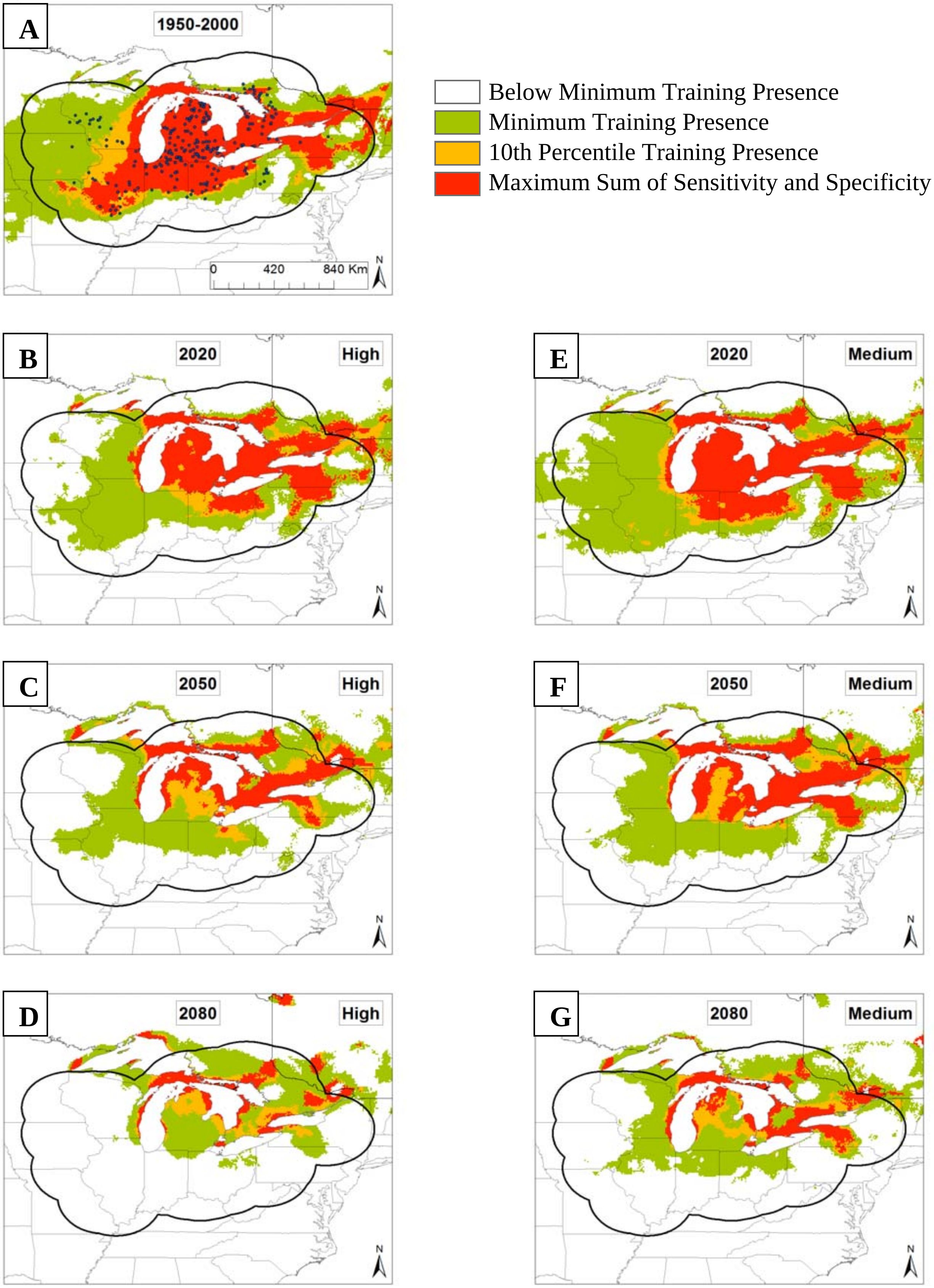

A
1950-2000
0
420
840 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 11. Current and future projections of climate suitability for *Regina septemvittata*. Projections of climate suitability for *Regina septemvittata* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

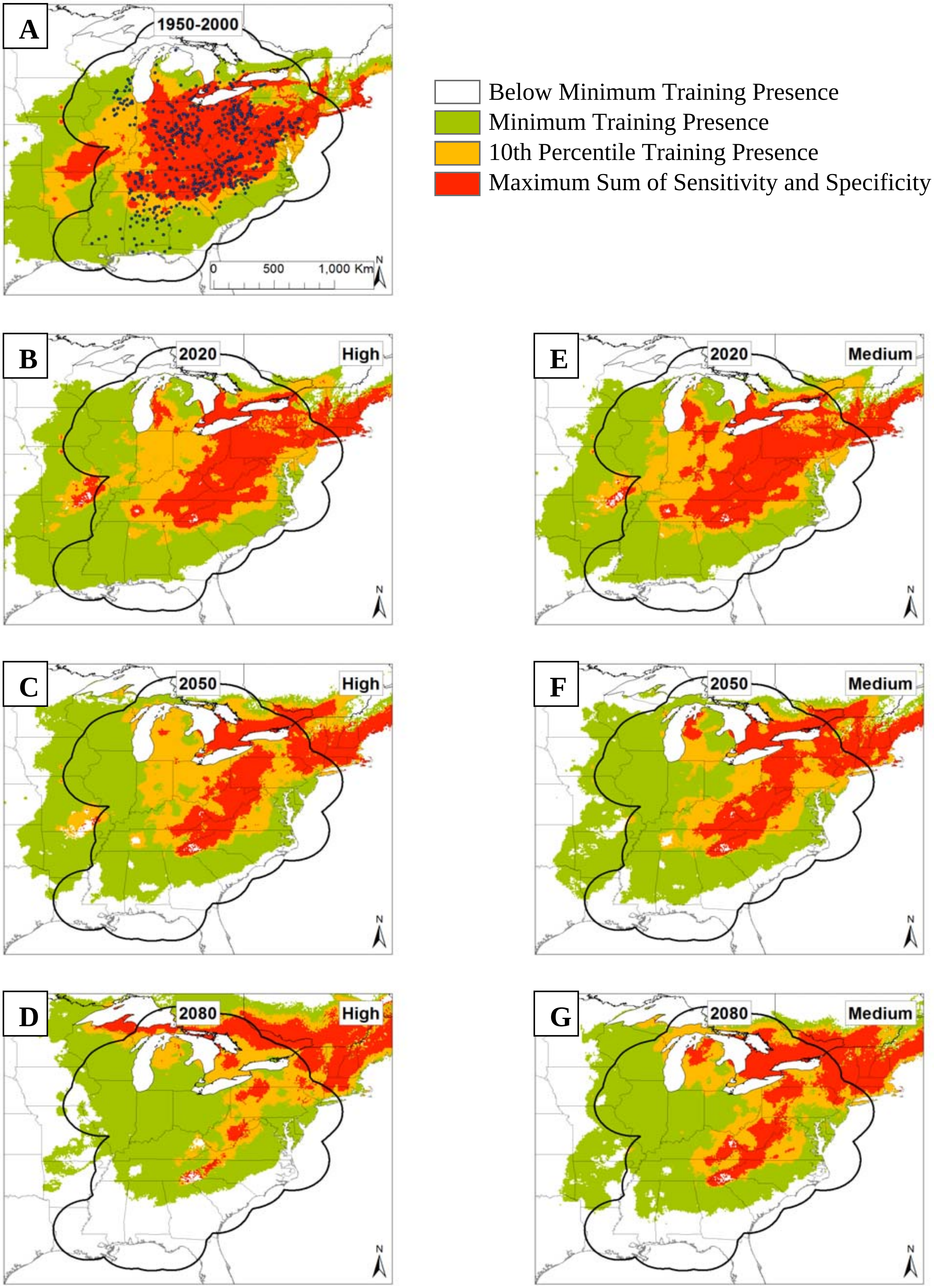

A
1950-2000
0 500 1,000 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 12. Current and future projections of climate suitability for *Glyptemys insculpta*. Projections of climate suitability for *Glyptemys insculpta* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

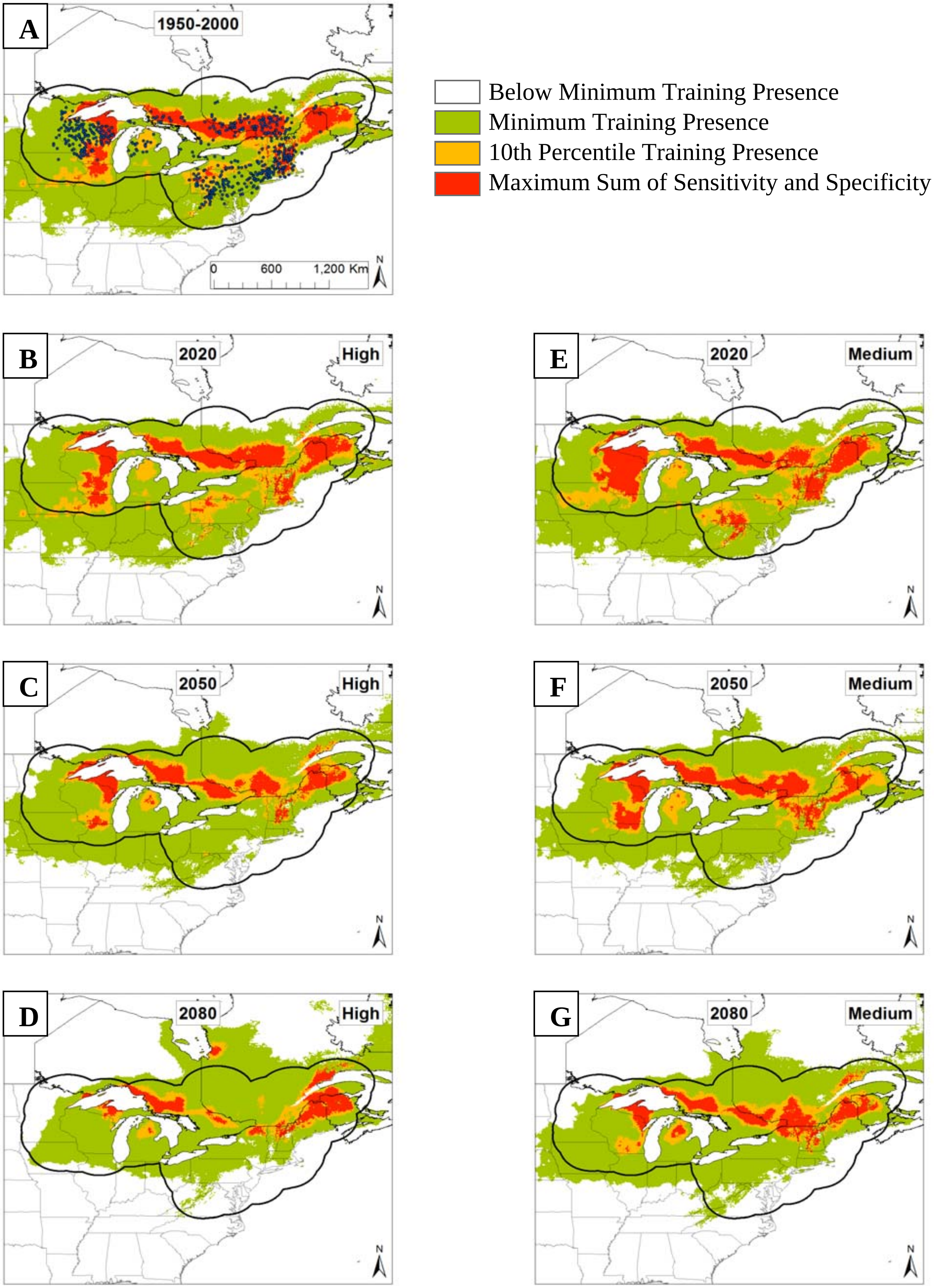

A
1950-2000
0 600 1,200 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 13. Current and future projections of climate suitability for *Clonophis kirtlandii*. Projections of climate suitability for *Clonophis kirtlandii* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

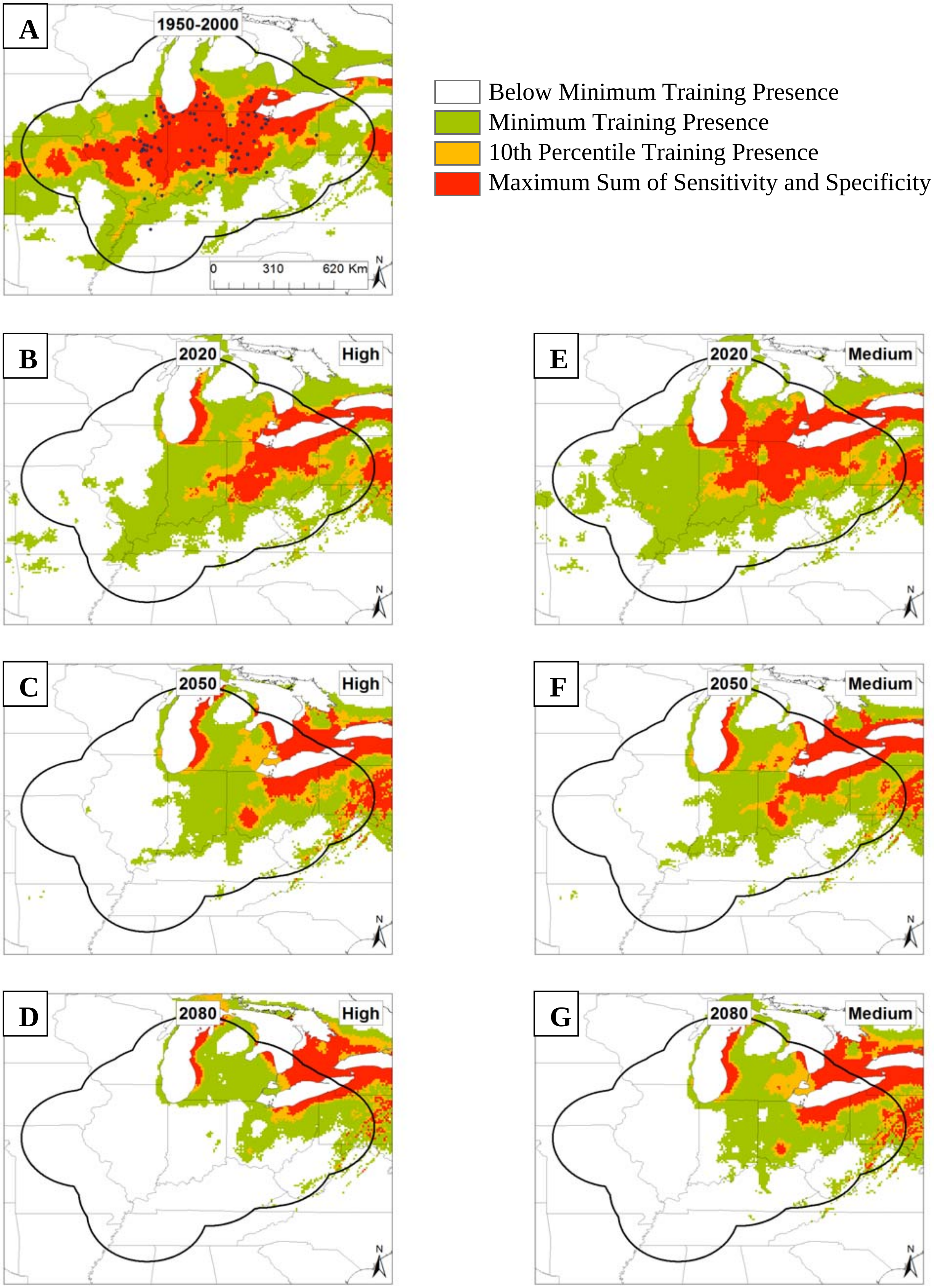

A
1950-2000
0
310
620 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
E
2020
Medium
C
2050
High
F
2050
Medium
D
2080
High
G
2080
Medium

Figure 14. Current and future projections of climate suitability for *Glyptemys muhlenbergii*. Projections of climate suitability for *Glyptemys muhlenbergii* under current conditions (A) 1950-2000, future conditions under the SRES A2a high emissions scenario (denoted 'high') for (B) 2020 (C) 2050 (D) 2080, and future conditions under the SRES B2a medium emissions scenario (denoted 'medium') scenario for (E) 2020 (F) 2050 (G) 2080. In each panel, areas falling above the minimum training presence threshold are green, areas falling above the tenth percentile threshold are gold, and areas falling above the maximum sum of sensitivity and specificity threshold are red. Presence records used in MaxEnt models are show as black dots in panel A. Locations have been 'jittered' by 0.1-0.3 degrees (ca. 10-35 km) to obscure the location of sensitive populations. The solid black line represents a 250 km buffer around presence records.

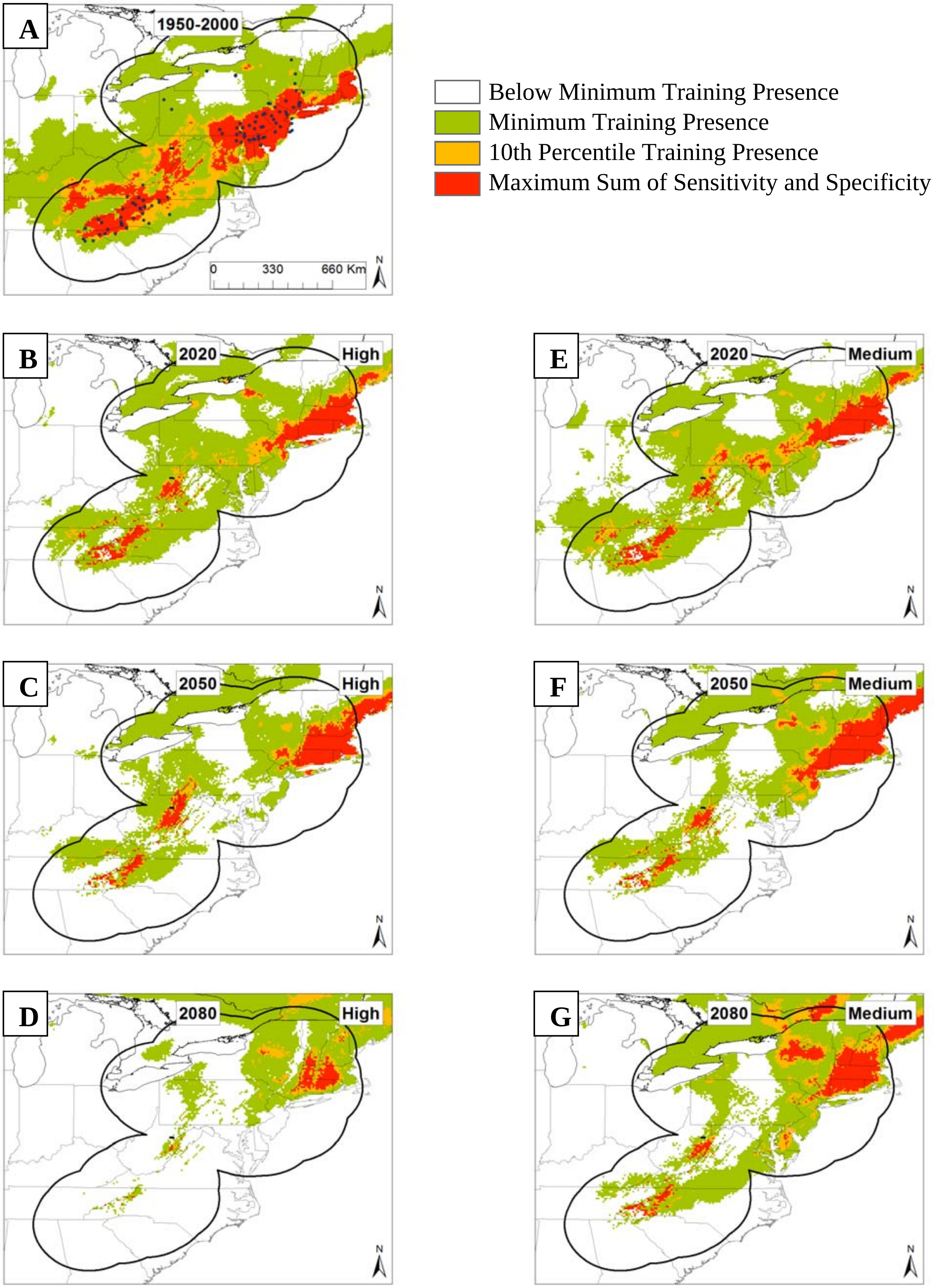

A
1950-2000
0 330 660 Km
N
Below Minimum Training Presence
Minimum Training Presence
10th Percentile Training Presence
Maximum Sum of Sensitivity and Specificity
B
2020
High
C
2050
High
D
2080
High
E
2020
Medium
F
2050
Medium
G
2080
Medium

Table 6. Shape of response curves (change in logistic likelihood with increasing Bioclim variable values). Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050. See Table 2 for species abbreviations and Table 3 for BIOCLIM variable definitions.

	Bio1	Bio2	Bio3	Bio4	Bio7	Bio12	Bio13	Bio14	Bio15
Thbu	Monotonic increase	Monotonic decrease	Monotonic decrease	Unimodal convex		Monotonic decrease	Monotonic increase		
Pasp	Unimodal convex	Unimodal concave	Unimodal convex	Unimodal convex		Unimodal convex	Unimodal convex	Unimodal convex	
Thbr	Unimodal convex	Monotonic increase		Multimodal	Monotonic increase	Monotonic increase			Unimodal convex
Clgu	Unimodal convex	Monotonic decrease				Monotonic decrease	Unimodal concave	Multimodal	Monotonic decrease
Grge	Unimodal convex	Unimodal concave				Unimodal convex	Multimodal		
Embl	Unimodal convex	Monotonic decrease	Unimodal concave	Unimodal convex		Unimodal convex	Monotonic decrease	Unimodal convex	
Sica	Unimodal convex	Monotonic decrease	Monotonic decrease	Unimodal convex		Multimodal	Unimodal convex	Unimodal convex	
Rese	Unimodal convex	Unimodal concave				Monotonic increase		Multimodal	Unimodal convex
Glin	Unimodal convex	Monotonic increase	Monotonic decrease	Multimodal		Monotonic increase	Unimodal convex		
Clki	Unimodal convex	Unimodal convex		Unimodal convex		Unimodal convex			
Glmu	Unimodal convex	Unimodal convex				Monotonic increase			Unimodal convex

Table 7. Number (Obs.) and proportion (P) of known localities falling within minimum training presence (Mtp), 10th percentile (10p), and maximum sum of sensitivity and specificity (SSS) thresholds under the A2a and B2a climate change scenarios. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050.

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Obs.	P	Obs.	Obs.	P	Obs.	Obs.	P	Obs.	P	SSS	P
					Thamnophis butleri							
1950-2000	80	1.00	73	0.91	63	0.79						
2020	80	1.00	71	0.89	61	0.76	81	1.01	79	0.99	76	0.95
2050	77	0.96	75	0.94	65	0.81	78	0.98	76	0.95	75	0.94
2080	44	0.55	43	0.54	43	0.54	71	0.89	69	0.86	61	0.76
					Pantherophis species							
1950-2000	293	1.00	264	0.90	253	0.86						
2020	294	1.00	251	0.86	242	0.83	294	1.00	272	0.93	266	0.91
2050	281	0.96	242	0.83	234	0.80	281	0.96	234	0.80	226	0.77
2080	151	0.52	106	0.36	101	0.35	265	0.90	224	0.77	215	0.73
					Thamnophis brachystoma							
1950-2000	125	1.00	113	0.90	111	0.89						
2020	121	0.97	98	0.78	97	0.78	120	0.96	96	0.77	96	0.77
2050	116	0.93	94	0.75	94	0.75	118	0.94	86	0.69	86	0.69
2080	40	0.32	37	0.30	37	0.30	110	0.88	98	0.78	98	0.78
					Clemmys guttata							
1950-2000	566	1.00	511	0.90	405	0.72						
2020	538	0.95	484	0.86	341	0.60	537	0.95	486	0.86	367	0.65
2050	535	0.95	438	0.77	315	0.56	532	0.94	449	0.79	336	0.59
2080	511	0.90	404	0.71	331	0.59	531	0.94	436	0.77	336	0.59

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Obs.	P	Obs.	Obs.	P	Obs.	Obs.	P	Obs.	P	SSS	P
					Graptemys geographica							
1950-2000	395	1.00	352	0.89	286	0.72						
2020	394	1.00	341	0.86	231	0.59	391	0.99	338	0.86	276	0.70
2050	382	0.97	296	0.76	210	0.53	381	0.97	295	0.75	206	0.52
2080	337	0.85	192	0.50	151	0.38	372	0.94	259	0.66	183	0.46
					Emydoidea blandingii							
1950-2000	632	1.00	569	0.90	543	0.86						
2020	630	1.00	471	0.75	424	0.67	628	0.99	475	0.75	443	0.70
2050	559	0.88	271	0.43	244	0.39	573	0.91	318	0.50	285	0.45
2080	311	0.49	117	0.19	88	0.14	493	0.78	215	0.34	182	0.29
					Sistrurus catenatus catenatus							
1950-2000	257	1.00	232	0.90	214	0.83						
2020	248	0.97	181	0.70	146	0.57	257	1.00	207	0.81	181	0.70
2050	224	0.87	126	0.49	80	0.31	239	0.93	158	0.62	109	0.42
2080	156	0.61	72	0.28	32	0.13	201	0.78	87	0.34	52	0.20
					Regina septemvittata							
1950-2000	536	1.00	482	0.90	395	0.74						
2020	534	1.00	433	0.81	245	0.46	532	0.99	440	0.82	281	0.52
2050	520	0.97	338	0.63	159	0.30	524	0.98	310	0.58	159	0.30
2080	481	0.90	135	0.25	26	0.05	514	0.96	246	0.46	112	0.21
					Glyptemys insculpta							
1950-2000	593	1.00	533	0.90	439	0.74						
2020	588	0.99	355	0.60	191	0.32	591	1.00	421	0.71	264	0.45
2050	560	0.94	214	0.36	122	0.21	589	0.99	259	0.44	159	0.27
2080	504	0.85	90	0.15	33	0.06	567	0.96	194	0.33	108	0.18

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Obs.	P	Obs.	Obs.	P	Obs.	Obs.	P	Obs.	P	SSS	P
					Clonophis kirtlandii							
1950-2000	93	1.00	85	0.91	79	0.85						
2020	80	0.86	45	0.48	28	0.30	93	1.00	59	0.63	53	0.57
2050	67	0.72	20	0.22	13	0.14	66	0.71	28	0.30	14	0.15
2080	31	0.33	6	0.07	3	0.03	61	0.66	13	0.14	10	0.11
					Glyptemys muhlenbergii							
1950-2000	93	1.00	83	0.89	77	.83						
2020	86	0.93	42	0.45	27	0.29	86	0.93	42	0.45	28	0.30
2050	52	0.56	14	0.15	12	0.13	77	0.83	36	0.39	21	0.23
2080	32	0.34	6	0.07	2	0.02	75	0.81	21	0.23	11	0.12

Table 8. Proportion (P) of projected area (km^2) within 250 km buffers that exceeds minimum training presence (Mtp), 10th percentile (10p), and maximum sum of sensitivity and specificity (SSS) thresholds under the A2a and B2a climate change scenarios. Total area included within buffers is provided after species names. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050.

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Area	P	Area	P	Area	P	Area	P	Area	P	Area	P
Thamnophis butleri (1757230)												
1950-2000	956239	0.54	536062	0.31	276651	0.16						
2020	913235	0.52	524056	0.30	354912	0.20	1031052	0.59	800617	0.46	581558	0.33
2050	806366	0.46	599533	0.34	423337	0.24	839215	0.48	695401	0.40	565658	0.32
2080	407652	0.23	361798	0.21	321710	0.18	702136	0.40	544319	0.31	414122	0.24
Pantherophis sp. (3757680)												
1950-2000	2219881	0.59	1191989	0.32	1013733	0.27						
2020	2617731	0.70	1608267	0.43	1497962	0.40	2550677	0.68	1657804	0.44	1548260	0.41
2050	2235898	0.60	1521349	0.40	1440383	0.38	2081798	0.55	1435488	0.38	1354725	0.36
2080	1455829	0.39	1035094	0.28	963272	0.26	1948376	0.52	1331151	0.35	1250969	0.33
Thamnophis brachystoma (755461)												
1950-2000	277914	0.37	59693	0.08	58666	0.08						
2020	349513	0.46	129825	0.17	126862	0.17	340334	0.45	124136	0.16	120944	0.16
2050	253519	0.34	118501	0.16	116131	0.15	262773	0.35	103578	0.14	101294	0.13
2080	63223	0.08	36119	0.05	35776	0.05	187475	0.25	103883	0.14	102390	0.14
Clemmys guttata (5026970)												
1950-2000	3131433	0.62	1795028	0.36	908659	0.18						
2020	3209166	0.64	1878760	0.37	860691	0.17	3245781	0.65	1900314	0.38	876259	0.17
2050	3334835	0.66	2064017	0.41	999951	0.20	3313387	0.66	1989184	0.40	952063	0.19
2080	3290020	0.65	2274849	0.45	1443486	0.29	3349961	0.67	2256236	0.45	1303614	0.26

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Area	P	Area	P	Area	P	Area	P	Area	P	Area	P
Graptemys geographica (6266730)												
1950-2000	4897766	0.78	2909907	0.46	1656560	0.26						
2020	5042901	0.80	2869533	0.46	1346991	0.21	4939668	0.79	2873004	0.46	1575703	0.25
2050	4903273	0.78	2640852	0.42	1339601	0.21	4912291	0.78	2526633	0.40	1261605	0.20
2080	4268411	0.68	2126901	0.34	1243904	0.20	4791620	0.76	2374145	0.38	1230843	0.20
Emydoidea blandingii (4797460)												
1950-2000	3266153	0.68	1563095	0.33	1363595	0.28						
2020	3213298	0.67	1353683	0.28	1130370	0.24	3166952	0.66	1373863	0.29	1207920	0.25
2050	2514564	0.52	879031	0.18	732950	0.15	2498987	0.52	1014759	0.21	857415	0.18
2080	1493242	0.31	583209	0.12	434801	0.09	2077946	0.43	744214	0.16	584859	0.12
Sistrurus catenatus catenatus (3190250)												
1950-2000	1995180	0.63	1118312	0.35	878484	0.28						
2020	1658077	0.52	790725	0.25	639296	0.20	2034127	0.64	901363	0.28	730371	0.23
2050	1374910	0.43	575665	0.18	374673	0.12	1485123	0.47	671654	0.21	490833	0.15
2080	854981	0.27	305765	0.10	156334	0.05	1172306	0.37	415347	0.13	254308	0.08
Regina septemvittata (4566280)												
1950-2000	3251037	0.71	2002944	0.44	1300043	0.28						
2020	3304391	0.72	1779241	0.39	910686	0.20	3234612	0.71	1852087	0.41	1021102	0.22
2050	3126296	0.68	1554747	0.34	646159	0.14	3124742	0.68	1386588	0.30	700141	0.15
2080	2697814	0.59	909140	0.20	269840	0.06	2994204	0.66	1318345	0.29	580151	0.13
Glyptemys insculpta (5600200)												
1950-2000	4020979	0.72	1980897	0.35	1102941	0.20						
2020	3956593	0.71	1546297	0.28	727759	0.13	3962915	0.71	1637680	0.29	829796	0.15
2050	4044537	0.72	1118856	0.20	529364	0.09	3959100	0.71	1265791	0.23	635599	0.11
2080	3607574	0.64	779996	0.14	374926	0.07	3957988	0.71	1051117	0.19	506429	0.09

	A2a						B2a					
	Mtp		10p		SSS		Mtp		10p		SSS	
	Area	P	Area	P	Area	P	Area	P	Area	P	Area	P
	Clonophis kirtlandii (1886810)											
1950-2000	1194698	0.63	613616	0.33	452187	0.24						
2020	892348	0.47	318945	0.17	207059	0.11	1088869	0.58	438227	0.23	338678	0.18
2050	692739	0.37	272957	0.14	175360	0.09	674960	0.36	255958	0.14	167841	0.09
2080	428041	0.23	107126	0.06	73753	0.04	587554	0.31	204961	0.11	128350	0.07
	Glyptemys muhlenbergii (2052120)											
1950-2000	1302633	0.63	513332	0.25	297319	0.14						
2020	1074033	0.52	214484	0.10	122957	0.06	1040039	0.51	249070	0.12	137361	0.07
2050	846576	0.41	175304	0.09	121795	0.06	881995	0.43	226919	0.11	144899	0.07
2080	483137	0.24	84197	0.04	35482	0.02	951995	0.46	258059	0.13	134868	0.07

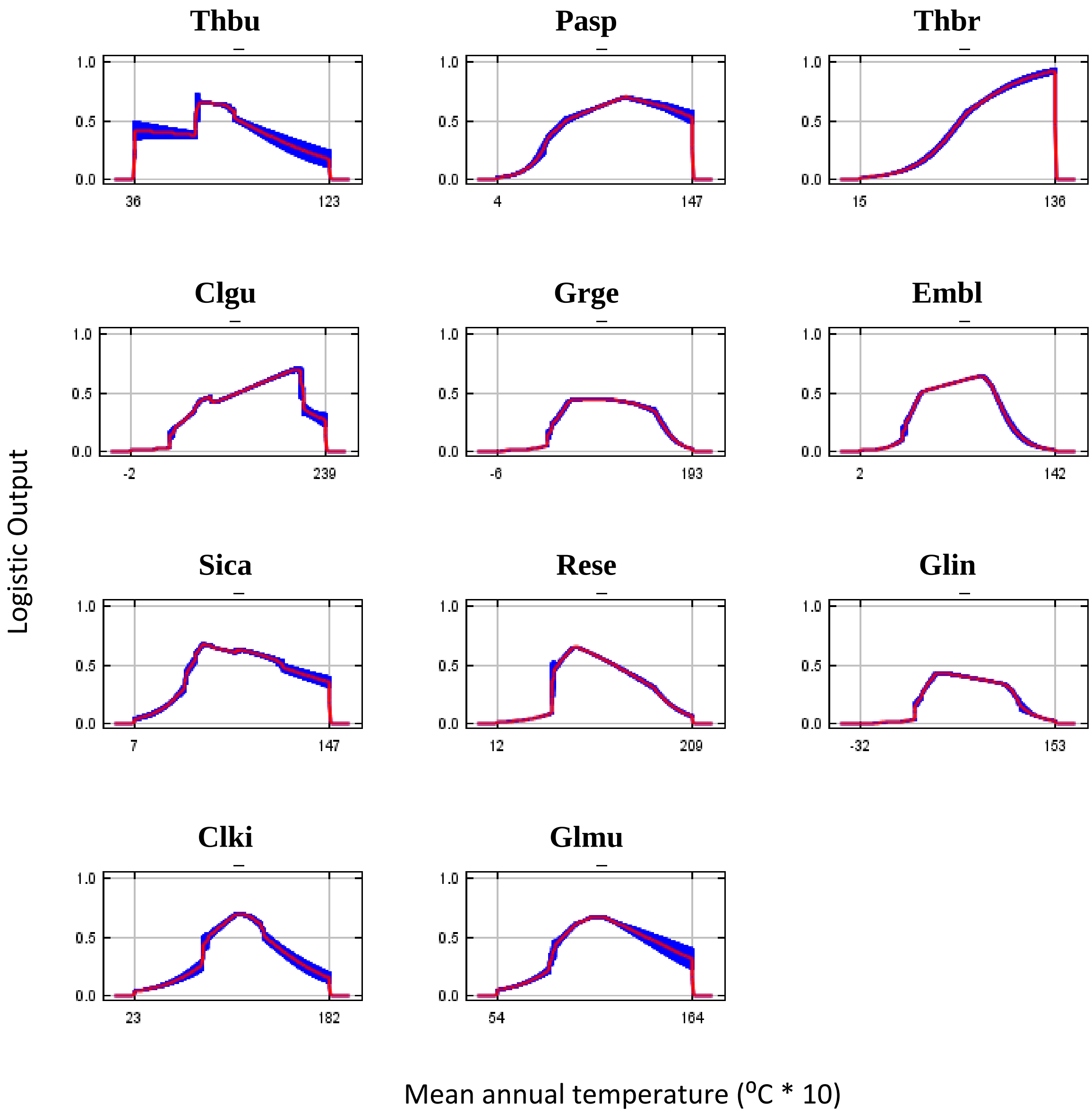


Figure 15. Response curves for mean annual temperature. The red line indicates the response of logistic output to the environmental variable and the blue shaded area indicates the standard deviation of the response curve based on ten-fold cross validation. See Table 2 for species abbreviations. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050.

Figure 16. Temporal change in area of climatic suitability based on the proportion of presence records that fall within areas delineated by MTP (green), 10P (gold), and SSS (red) thresholds under A2a (circles) and B2a (squares) scenarios. Current conditions (1950-2000) are represented by points located at 1990. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050. See Table 2 for species abbreviations.

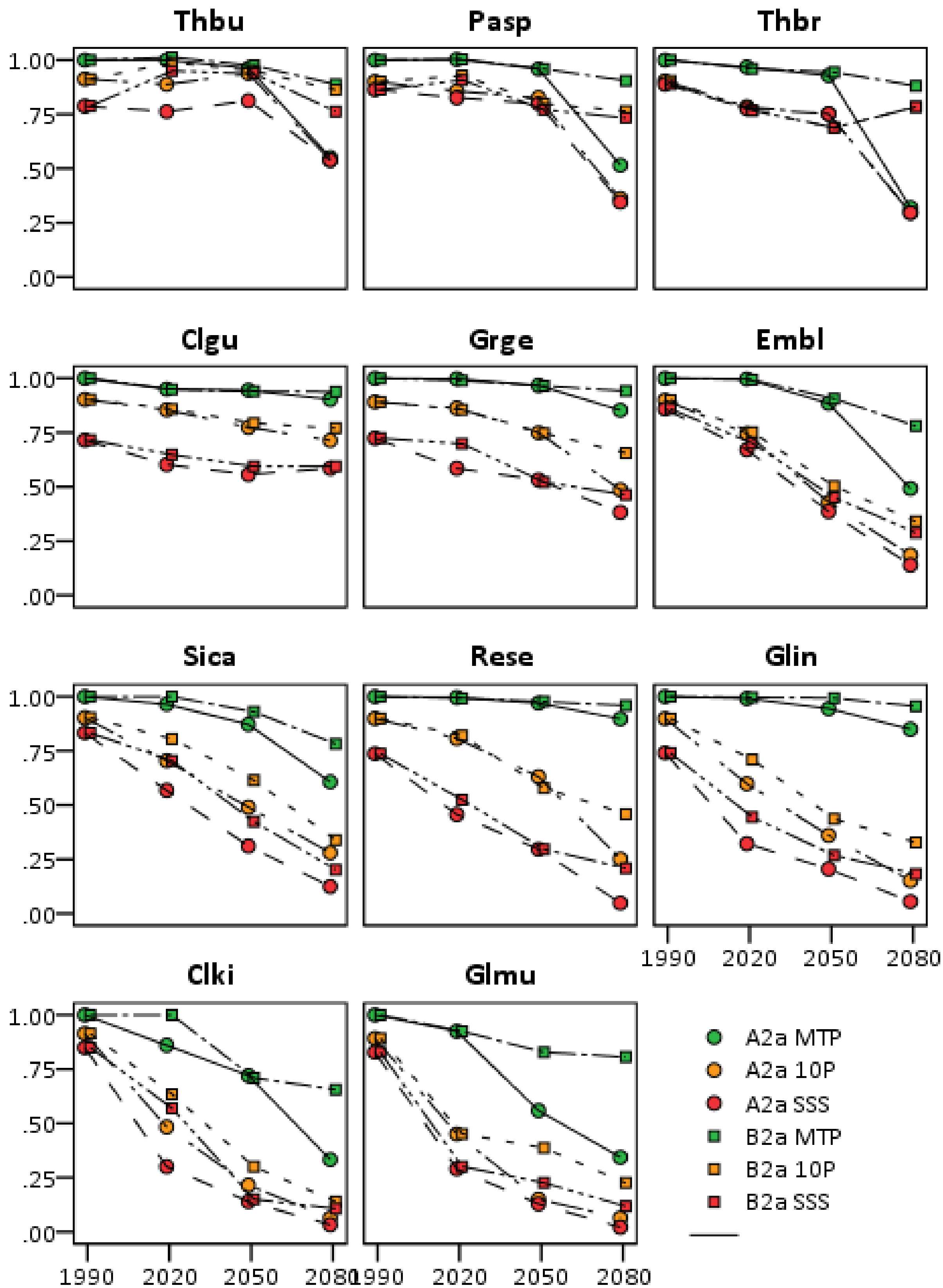
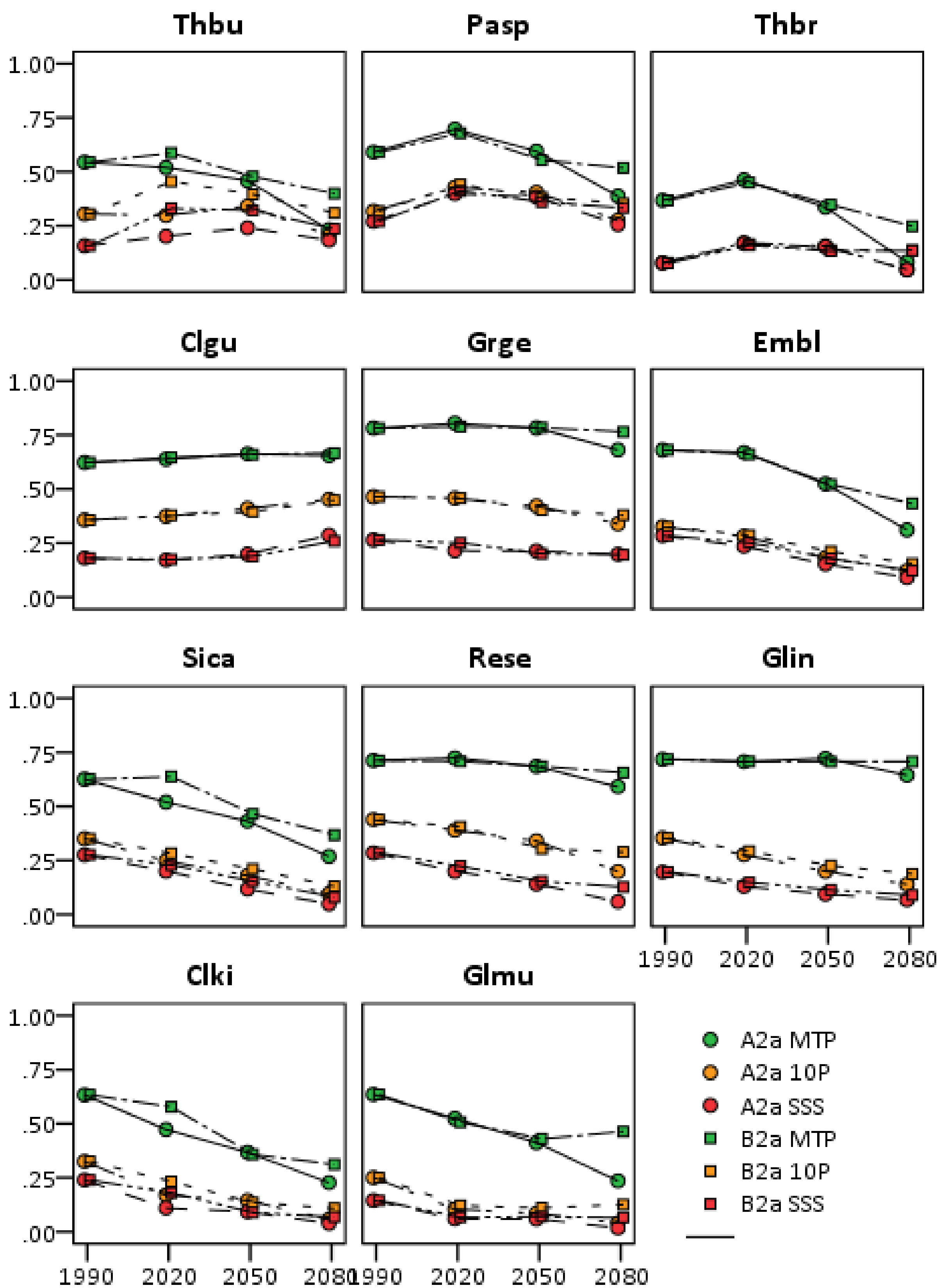

Thbu
Pasp
Thbr
Clgu
Grge
Embl
Sica
Rese
Glin
Clki
Glmu
1.00
.75
.50
.25
.00
1990
2020
2050
2080
A2a MTP
A2a 10P
A2a SSS
B2a MTP
B2a 10P
B2a SSS

Figure 17. Temporal change in area of climatic suitability based on the proportion of background area (presence records with 250 km buffer) that falls within areas delineated by MTP (green), 10P (gold), and SSS (red) thresholds under A2a (circles) and B2a (squares) scenarios. Current conditions (1950-2000) are represented by points located at 1990. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050. See Table 2 for species abbreviations.



Thbu
Pasp
Thbr
Clgu
Grge
Embl
Sica
Rese
Glin
Clki
Glmu
1.00
.75
.50
.25
.00
1990
2020
2050
2080
A2a MTP
A2a 10P
A2a SSS
B2a MTP
B2a 10P
B2a SSS

Discussion

Predicting species' responses to climate change is challenging and consequently, appropriate management strategies are uncertain (Rodŕiguez-Castañeda et al. 2012). Here, this uncertainty was minimized by considering climate change impacts on multiple co-distributed species simultaneously, making it possible to distinguish among species that may be affected by climate change to a lesser or greater degree even if the magnitude of those effects is uncertain. Furthermore, by restricting the geographic scope of analyses, overfitting of environmental niche models was reduces, resulting in more accurate projections of climate change impacts within currently occupied and adjacent locations.

Association between climatic variables and current distributions. – Current distributions of reptiles of conservation concern in the Great Lakes region were well predicted by ecological niche models that incorporated four to seven Bioclim variables (Table 5, Fig. 4-14). For all species, mean annual temperature (Bio1) consistently ranked high among variables included in the models (Table 5). With the exception of *Thamnophis brachystoma*, response curves for this variable were unimodal convex in shape (Table 6, Fig. 15), suggesting that both low and high mean temperatures may limit species distributions. Mean diurnal temperature range (Bio2) and annual precipitation (Bio12) were also included in models for all species but response curves for these variable were inconsistent in shape (Table 5, 6). Temperature isothermality (Bio 3) and several variables relating to precipitation (Bio13 – precipitation in the wettest month, Bio14 – precipitation in the driest month, Bio 15 – precipitation sesonality) contributed to models for some species, but again, the shape of response curves varied among species (Table 5, 6).

Modelers frequently use different sets of candidate climatic variables and this makes it difficult to directly compare results obtained here with environmental niche models for other reptile species. However, variables related to temperature and precipitation are frequent contributors (e.g., red-eared slider, Kikillus et al. 2010; boid snakes, DiCola et al. 2008; smooth snake, Santos et al. 2009; brown tree snake, Rödder and Lotter 2010; Plain-bellied Watersnake, Makowsky et al. 2010; African viperids, Brito et al. 2011; turtles world-wide, Ihlow et al. 2012; a Mediterranean viper, Brito et al. 2011; Burmese pythons, Rodda et al. 2011). Annual degree days, a correlate of mean annual temperature, is an important contributor to an ecological niche model of Orsini's Viper and exhibits a unimodal convex response curve much like seen in this study for mean annual temperature (Lyet et al. 2013).

One species included in the present analysis, the Eastern Massasauga *Sistrurus catenatus catenatus*, was the focus of a previous ecological niche model aimed at understanding niche divergence among *Sistrurus* species and subspecies (Wooten and Gibbs 2011). Four other species were the focus of an analysis of climate change impacts on turtle species world-wide (Ihlow et al. 2012). The percent contribution of Bioclim variables differs somewhat between models for these species (Table 9). However, for the Eastern Massasauga, areas of high climatic suitability correspond closely (compare ther Fig. 2b in Wooten and Gibbs 2011 with Fig. 10A in this report); comparable maps are not available from Ihlow et al. (2012).

Projected future location of areas of high climatic suitability. – Reptiles of conservation concern in the Great Lakes regions consistently show projected reductions in climatic suitability at locations currently occupied (Fig. 16) and most show reductions in climatic suitability within the region more generally (Fig. 17). In general, reductions in climatic suitability first become evident in the southern and western portions of species' ranges (Fig. 4-14).

Species differ in the time-frame over which climate change impacts are projected to occur with some species not showing marked declines in climatic suitability until 2080 (*Thamnophis butleri, Pantherophis* sp*., Thamnophis brachystoma*; Fig. 16). Other species show linear declines in climatic suitability from the present through 2080 (*Clemmys guttata, Graptemys geographica, Emydoidea blandingii, Sistrurus catenatus catenatus, Regina septemvitta*; Fig. 16). Still other species show immediate rapid declines in climatic suitability (e.g., from the present through 2020 or 2050) with a decreasing rate of decline thereafter (*Glyptemys insculpta, Clonophis kirtlandii, Glyptemys muhlenbergii*; Fig. 16).

The degree to which new areas of high climatic suitability arise also varies among species. Areas currently occupied by *Thamnophis butleri*, *Pantherophis* sp., *Thamnophis brachystoma*, and *Clemmys guttata* show decreases vs. constancy or increases in climatic suitability in roughly equal numbers of states and provinces (Table 10). These species are also projected to experience increased climatic suitability outside of their current distribution in a notable number of states and provinces (Table 10). In some cases, these new areas of high climatic suitability appear in states and provinces not currently occupied (*Pantherophis* sp., *Thamnophis brachystoma, Clemmys guttata*; Table 10). Most other species show decreases in climatic suitability in most states and provinces in which they currently occur and relatively few or no unoccupied states or provinces where new areas of high climatic suitability arise (e.g., *Emydoidea blandingii* in parts of Ontario only, *Sistrurus catenatus* in parts of Ontario and Quebec only, *Glyptemys insculpta* not at all; Table 10).

Ecological niche models have been used to predict responses of reptiles to climate change only infrequently. However, declines in climatic suitability similar to that reported here is predicted in the endangered Australian snake, *Hoplocephalus bungaroids* (Penman et al. 2010) in which just 14% of current sites are remain climatically suitable in 2070 under a high warming scenario. Similarly, the Mediterranean viper, *Vipera latasei,* is projected to experience declines in climatic suitability over 57% of its core habitat (Brito et al. 2011). In an analysis of 199 turtle species world-wide, Ihlow et al. (2012) project that 86% of species may experience climate-change induced range contraction by 2080. Similarly, climate change is projected to induce displacement of 11 North American rattlesnake species by 430-2,420 m/yr (Lawing and Polly 2011).

Prioritization of species and associated management, research, and policy actions. – Based on projections presented here, reptiles of conservation concern in the Great Lakes region differ in their susceptibility to climate change. Based on projections of the proportion of known localities falling above the SSS threshold under the A2a scenario in 2050, *Thamnophis butleri,* *Pantherophis* species, and *Thamnophis brachystoma* are least sensitive to climate change; greater than 75% of their known localities are projected to remain climatically suitable (Table 6, Fig. 16). Furthermore, these species may benefit from the appearance of new areas of high climatic suitability that are not currently occupied, at least in the near term (Table 7, Fig. 17). *Clemmys guttata* and *Graptemys geographica* are somewhat more sensitive; 50-75% of known localities are projected to remain climatically suitable and the area of high climatic suitability remains relatively constant (Table 7, Fig. 17). The remaining species appear to be highly sensitive to climate change. *Emydoidea blandingii*, *Sistrurus catenatus catenatus,* and *Regina septemvittata* are projected to have 25-50% of known localities remain climatically suitable and *Clonophis kirtlandii*, *Glyptemys insculpta*, and *Glyptemys muhlenbergii* are projected to have less than 25% of known localities remain climatically suitable (Table 6, Fig. 16). These species also show steadily declining areas of high climatic suitability, whether those areas are occupied or not (Table 7, Fig. 17).

Among the species included in this analysis, projected effects of climate change do not appear to be greater for species with more restricted distributions (e.g., compare *Thamnophis brachystoma*, a species with an extremely limited geographic distribution for which climatic suitability is projected to remain high, and *Regina septemvittata* a species with a broad geographic distribution for which climatic suitability is projected to decrease over much of its range).

In addition to these species-specific projections, it is useful to summarize these trends by state or province because management, research and policy are often set at the state and provincial level (Table 11). One pattern that emerges from such a summary is that most states and provinces listed are home to one or more unprotected species for which climatic suitability is projected to decrease (exceptions include MI, NH, NJ, ON, QU, RI, VT). Another pattern that is evident is that there a number of states and provinces not currently occupied by given species where new areas of high climatic suitability are projected to arise (i. e. KY, MD, NJ, NY, ON, PA, QU, VA, WI, WV).

Species-specific (Table 10) and state/province-specific (Table 11) trends in climatic suitability have immediate implications for management, research, and policy actions identified previously (Fig. 18). High priority species (those projected to be most sensitive to climate change) include *Emydoidea blandingii*, *Sistrurus catenatus catenatus, Regina septemvittata*, *Clonophis kirtlandii*, *Glyptemys insculpta*, and *Glyptemys muhlenbergii*. Because these species are projected to experience decreased climatic suitability in some occupied locations, constant or increased climatic suitability in other occupied locations (except *Sistrurus catenatus catenatus*), and increases climatic suitability in some unoccupied locations (except *Glyptemys insculpta*), a wide range of management, research, and policy actions are warranted across multiple states and provinces (Fig. 18). Importantly, many of these actions (e.g., population monitoring and habitat management) serve 'double duty' in that they represent appropriate responses to threats arising from habitat loss, overexploitation, and invasive species as well as the added threat posed by climate change.

Population monitoring efforts focused on areas where climatic suitability is projected to decline most rapidly would aid in the early detection and timely response to climate change impacts (e.g., *Emydoidea blandingii* in IA, IN, OH,, MN, and NE; *Sistrurus catenatus catenatus* in IL, IN and WI; RESE in AL, GA, KY, IL, IN, and OH; *Clonophis kirtlandii* in IL and IN; *Glyptemys muhlenbergii* in NC, PA, and VA). Recent research provides an incomplete understanding of the degree and mechanisms of climate change induced effects on reptiles but does point to anticipated changes in behavior (Refsnider and Janzen 2012; Refsnider et al. 2013; Weatherhead et al. 2012), offspring sex ratios (Mitchell and Janzen 2010; Refsnider and Janzen 2012; Refsnider et al. 2013), reproductive physiology and phenology (Lourdais et al 2004; Moasterio et al. 2013; Telemeco et al. 2013), and life history (Ujvari et al. 2011). Thus, it would be beneficial to combine monitoring efforts with research on individual- and population-level phenomena (e.g., age- and size-specific growth, reproduction and mortality; realized population growth rates) to aid in refining management strategies. Synergistic effects of climate change and other stressors also warrant consideration (Rohr and Palmer 2013).

Other actions are more specific to the threat of climate change alone. For example, of the high priority species listed above, formal recognition as endangered, threatened, or of special concern is sometimes lacking in some states projected to decrease in climatic suitability (e.g., *Regina septemvittata* in AL, DE, FL, GA, IL, IN, KY, MD, NC, SC, TN, VA, and WV; *Clonophis kirtlandii* in KY; *Glyptemys insculpta* in DE, MD, and ME). For other species, recognition exists but may be insufficient. An interesting example is the Blanding's Turtle, *Emydoidea blandingii*. This species is recognized as threatened or endangered throughout much of its range but only as a species of special concern in Nebraska, where large populations persist in several areas (Congdon et al. 2008). However, this analysis suggests that Nebraska populations are especially vulnerable to climate change (Fig. 9). Blanding's Turtles also appear vulnerable to climate change in Wisconsin (Fig. 9) where an administrative rule process to delist this species is underway (http://dnr.wi.gov/topic/endangeredresources/etlist.html). Even if additional protection were not deemed necessary, including these species in Natural Heritage database compilations of element occurrence records would provide valuable baseline data from which climate change impacts could be inferred.

Identifying new areas of high climatic suitability is a strength of environmental niche modeling and has particular utility for informing conservation management decisions (Schwartz 2012). Here, the projection that new areas of climatic suitability will arise means that a number of states and provinces face the possibility of natural or facilitated colonization of currently unoccupied areas (e.g., *Emydoidea blandingii* in currently unoccupied parts of ON; *Sistrurus catenatus catenatus* in ON and QU; *Regina septemvittata* in NY, ON, and WI; *Clonophis kirtlandii* in NY, ON, and PA; *Glyptemys muhlenbergii* in ON and QU). Policy decisions regarding the desirability of range expansion, together with research on habitat suitability and dispersal mechanisms may be necessary steps in these cases. The extension of existing habitat utilization and suitability models (*Emydoidea blandingii* – Millar and Blouin-Demers 2011, Paterson et al. 2012; *Sistrurus catenatus catenatus* – Bailey et al. 2012; DeGregorio et al. 2011; *Glyptemys insculpta* – Paterson et al. 2012; *Glyptemys muhlenbergii* – Feaga et al. 2012) to new areas of climatic suitability would aid in evaluating the likely success of natural or assisted colonization.

Table 9. Comparison of percent contribution of Bioclim variables to ecological niche models reported by Wooten and Gibbs (2011) and by Ihlow et al. (2012) with those obtained in this study. Dashes ('-') denote variables that were excluded from the candidate variable list of a given study. See Table 2 for species abbreviations.

	Sica		Clgu		Grge		Embl		Glin	
	Wooten and Gibbs	This study	Ihlow et al.	This study	Ihlow et al.	This study	Ihlow et al.	This study	Ihlow et al.	This study
Bio1	14.4	17.7	-	54.4	-	49.3	-	34.9	-	46.40
Bio2		11.5	11.4	18.9	12.2	11.2	21.3	17.3	7.4	6.2
Bio3		3.2	-		-		-	7.9	-	5.3
Bio4	12.8	30.1	-		-		-	7.5	-	32.2
Bio5			-		-		-		-	
Bio6			24.5		19.7		20.2		14.2	
Bio7			-		-		-		-	
Bio8		-	9.1	-	6.5	-	3.6	-	5.3	-
Bio9		-	6.6	-	5.9	-	3.2	-	1.5	-
Bio10	11.0		19.1		12.1		30.3		42.5	
Bio11	22.5		-		-		-		-	
Bio12		20.7	-	9.4	-	12.1	-	27.6	-	6.7
Bio13		12.9	-	8.8	-	27.4	-	1.0	-	3.2
Bio14		3.9	-	8.0	-		-	3.8	-	
Bio15			7.7	0.5	23.6		3.8		10.5	
Bio16			1.5		9.3		5.5		1.7	
Bio17			6.8		5.5		5.3		10.8	
Bio18		-	2.3	-	3.4	-	4.4	-	4.0	-
Bio19		-	11.1	-	1.8	-	2.4	-	1.9	-

Table 10. Species-specific trends in climatic suitability within states and provinces based on projections for 2050 using the A2a scenario. Listed are states and provinces in which the climatic suitability of currently occupied locations decreases or remains constant/increases and states and provinces in which climatic suitability of currently unoccupied areas increases as inferred from Fig. 4 – 14. States and provinces in which species are designated as endangered, threatened, of special concern or in greatest need of conservation are denoted in bold. States and Provinces in which species do not currently occur are italicized. Species are ordered from least to greatest projected decrease in climatic suitability as measured by the proportion of locations falling above the SSS threshold in 2050.

Species	States and Provinces in which Climatic Suitability of Occupied Locations		States and Provinces in which Climatic Suitability of Unoccupied Locations Increases
	Decreases	Remains constant/ Increases	
Thbu	**IN, WI**	MI, OH, **ON**	**IN**, MI, OH, **ON**
Pasp	IA, MN, **MO**, WI, NE	IL, IN, **MI, OH, ON**, SD	IN, **MI, OH**, *NY*, **ON**, *PA, QU*
Thbr	NY, PA	**OH**	*MD, NJ,* NY, PA, *VA, WV*
Clgu	CT, **IN,** FL, **GA**, MA, **MI**, NC, **SC, VA**	DE, **IL,** MD**, ME, NH,** NJ, **NY, OH, ON, QU**, PA, **RI**, **VT**, **WV**	**IN,** *KY*, **ME, NH, NY, OH**, **ON,** PA, **QU**, **VT,** *WI*
Grge	AR, IA, IL, IN, **GA, KS**, MO, NY, OH, PA, VA	KY, **MD**, MI, MN, **ON, QU**, VT, WI, **WV**	MN, MI, **ON, QU**, WI
Embl	**IA, IL, IN, MI, MO, MN, NE, OH,** SD, **WI**	**NY, ON, PA, QU**	**ON**
Sica	**IA, IL, IN, MI, MN, NY, OH, ON, PA, WI**		**ON**, *QU*
Rese	AL, DE, FL, GA, IL, IN, KY, MD, **MI,** MS, NC, **NJ**, **OH, PA**, SC, TN, VA, WV	**NY, ON, WI**	**NY, ON, WI**
Glin	**CT,** DE, **MA,** MD, ME, **NJ**, **NY, PA, QU, RI, VA, WI, WV**	**IA, MI, MN,** NH, **ON**, **VT**	
Clki	KY, **IL, IN, MI, MO, OH**	**PA**	*NY, ON,* **PA**
Glmu	**PA, NY, TN, VA, NJ, DE MD, NC, SC, GA**	**CT, MA**	*ON, QU*

Table 11. State and province-specific trends in climatic suitability by species based on projections for 2050 using the A2a scenario. Listed are species for which climatic suitability of currently occupied locations decreases or remains constant/increases and species for which climatic suitability of currently unoccupied areas increases as inferred from Fig. 4 – 14. Species which are designated as endangered, threatened, of special concern or in greatest need of conservation within a given state/province are denoted in bold. Species which do not currently occur in a given state/province are italicized.

State or Province	Species for which Climatic Suitability of Occupied Locations		Species for which Climatic Suitability of Unoccupied Locations Increases
	Decreases	Remains constant/ Increases	
AL	Rese		
AR	Grge		
CT	Clgu, **Glin**	**Glmu**	
DE	Rese, Glin, **Glmu**	Clgu	
FL	Clgu, Rese		
GA	**Clgu, Grge**, Rese, **Glmu**		
IA	Pasp, Grge, **Embl, Sica**	**Glin**	
IL	Grge, **Embl, Sica**, Rese, **Clki**	Pasp, **Clgu**	
IN	**Thbu, Clgu**, Grge, **Embl, Sica**, Rese, **Clki**	Pasp	**Thbu**, Pasp, **Clgu**
KS	**Grge**		
KY	Rese, Clki	Grge	*Clgu*
MA	Clgu, **Glin**	**Glmu**	
MD	Rese, Glin, **Glmu**	Clgu, **Grge**	*Thbr*
ME	Glin	**Clgu**	**Clgu**
MI	**Clgu, Embl, Sica, Rese, Clki**	Thbu, **Pasp**, Grge, **Glin**	Thbu, **Pasp**, Grge
MN	Pasp, **Embl, Sica**	Grge, **Glin**	Grge
MO	**Pasp**, Grge, **Embl, Clki**		
NC	Clgu, Rese, **Glmu**		
NE	Pasp**, Embl**		
NH		**Clgu**, Glin	**Clgu**
NJ	**Rese, Glin, Glmu**	Clgu	*Thbr*
NY	Thbr, Grge, **Sica, Glin, Glmu**	**Clgu, Embl, Rese**	*Pasp*, Thbr, **Clgu, Rese**, *Clki*
OH	Grge, **Embl, Sica, Rese, Clki**	Thbu, **Pasp, Thbr, Clgu**	Thbu, **Pasp, Clgu**
ON	**Sica**	**Thbu, Pasp, Clgu, Grge, Embl, Rese, Glin**	**Thbu, Pasp, Clgu, Grge, Embl, Sica, Rese**, *Clki, Glmu*
PA	Thbr, Grge, **Sica, Rese, Glin, Glmu**	Clgu, **Embl, Clki**	*Pasp*, Thbr, Clgu, **Clki**
QU	**Glin**	**Clgu, Grge, Embl**	*Pasp*, **Clgu, Grge**, *Sica, Glmu*
RI	**Glin**	**Clgu**	
SC	**Glin**, Rese, **Glmu**		

State or Province	Species for which Climatic Suitability of Occupied Locations		Species for which Climatic Suitability of Unoccupied Locations Increases
	Decreases	Remains constant/ Increases	
SD	Embl	Pasp	
TN	Rese, **Glmu**		
VA	**Clgu**, Grge, Rese, **Glin, Glmu**		*Thbr*
VT		**Clgu**, Grge, **Glin**	**Clgu**
WI	**Thbu**, Pasp, **Embl, Sica, Glin**	Grge, **Rese**	*Clgu*, Grge, **Rese**
WV	Rese, **Glin**	**Clgu, Grge**	*Thbr*

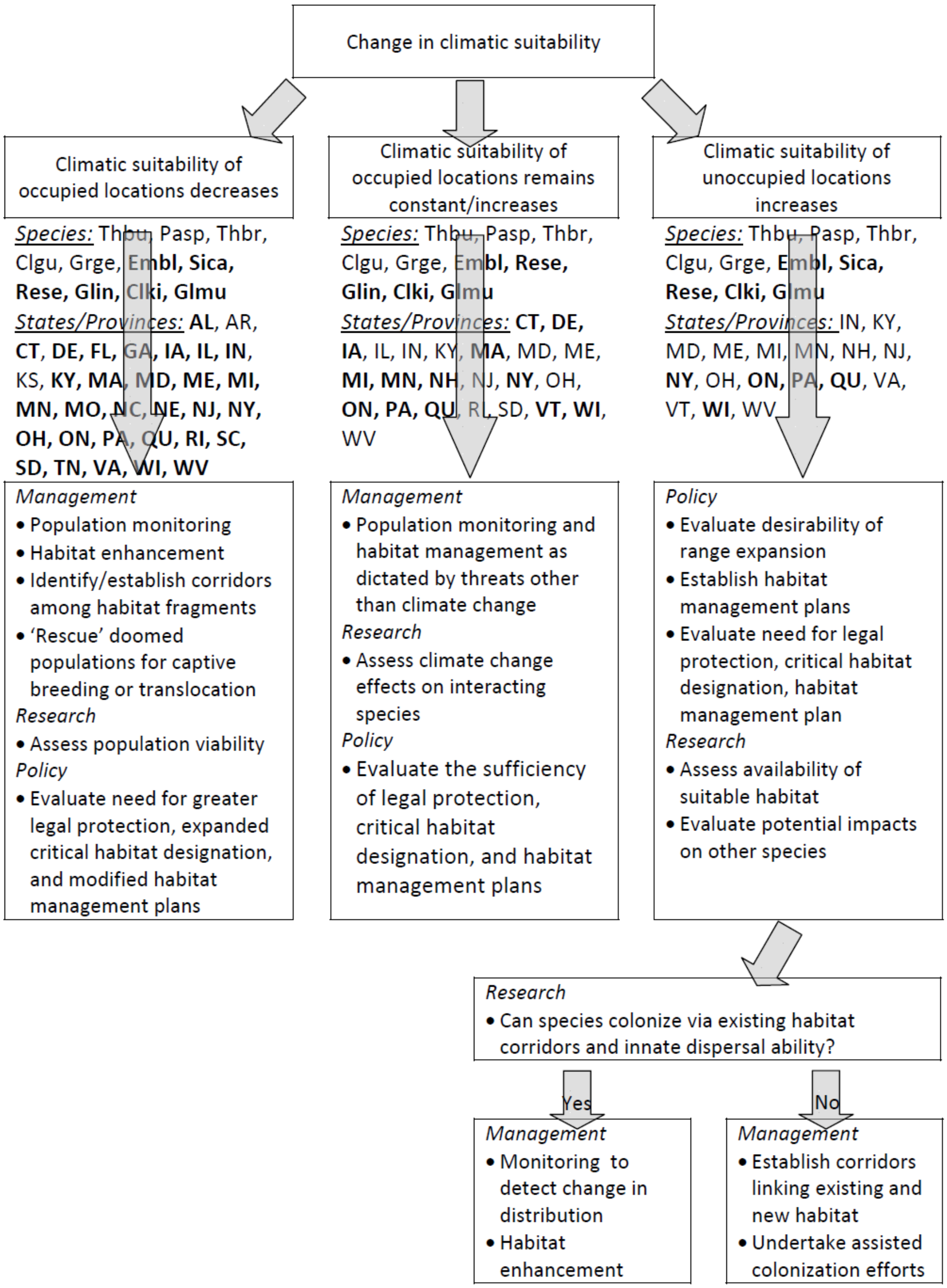


Figure 18. Flow chart linking projected effects of climate change to specific management, research and policy actions (Figure 2) with relevant species and states and provinces identified. Species projected to be most sensitive to climate change and the affected states and provinces are shown in bold. See Table 2 for species abbreviations.

Acknowledgements

A project of this nature is only possible through the cooperation of curators and collections managers of specimen and data repositories and the institutions they represent. Tthe significant contributions of institutions, agencies and personnel listed in Table 1, including N. Baker, M. Barbour, D. Becker, N. Bradley, S. Bump, D. Butler, S. Cairns, J. Campbell, D. Cannatella, R. Craig, J. Davis, J. Delisle, D. Dickey, T. Erdman, G. Fowles, C. Franklin, D. Frost, S. H. Gerriets, J. Giermakowski, N. Gilmore, D. Gregg, B. Gray, R. Hellmich, S. Hines, J. Holling, D. Howell, J. Jacobs, R. Jones, T. Kieninger, D. Kizirian, K. Kozak, K. Krysko, T. Labedz, T. LaDuc, Y. Lee, A. Luxbacher, M. Mahoney, C. Mayer, G. Mayer, H. Mays, N. McCartney, W. Meshaka, S. Miller, S. Moody, R. Muehlheim, A. Nelson, R. Nussbaum, M. O'Brien, C. Osborne, A. Paquet, C. Phillips, A. Resetar, L. Rissler, D. Roberts, R. Rogers, B. Sargent, C. Schmidt, G. Schneider, R. Schneider, G. Schneider, A. Scott, R. Simpson, J. Sites, W. Skidmore, H. Snell, E. Stetzar, S. Sullivan, M. Suter, K. Tighe, T. Warf, E. Wild, K. Zyko are gratefully acknowledged. E. Hileman, C. Jaeger, and G. Rodda provided helpful discussions during the development and completion of this project. Northern Illinois University and the NIU Department of Biological Sciences provided financial and logistic support. Partial funding for this program came from a Grant Agreement from the U.S. Department of the Interior, Fish and Wildlife Service. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

Literature Cited

Acevedo, P., A. Jiménez-Valverde, J. M. Lobo, and R. Real. 2012. Delimiting the geographical background in species distribution modelling. Journal of Biogeography 39: 1383–1390.

Ackerly, D.D., S.R. Loarie, W.K. Cornwell., S.B. Weiss, H. Hamilton, R. Branciforte, and J.J.B. Kraft. 2010. The geography of climate change: implications for conservation biogeography. Diversity and Distributions 16:476-487.

Araújo, M.B., and R.G. Pearson. 2005. Equilibrium of species' distributions with climate. Ecography 28:693-695.

Bailey, R. L., H. Campa, K. M. Bissell, and T. M. Harrison. 2012. Resource selection by the eastern massasauga rattlesnake on managed land in southwestern Michigan. Journal of Wildlife Management 76:414-421.

Bennett, A. M., M. Keevil, and J. D. Litzgus. 2010. Spatial ecology and population genetics of Northern Map Turtles (*Grapytemys geographica*) in fragmented and continuous habitats in Canada. Chelonian Conservation and Biology 9:185-195.

Bennie, J., J. A. Hodgson, C. R. Lawson, C. T. R. Holloway, D. B. Roy, T. Brereton, C. D. Thomas, and R. J. Wilson. 2013. Range expansion through fragmented landscapes under a variable climate. Ecology Letters 16:921-929.

Brodman, R. 2009. A 14-year study of amphibian popualtions and metacommunities. Herpetological Conservation and Biology 4:106-119.

Brito, J. C., S. Fahd, P. Geniez, F. Martínez-Freiría, J. M. Pleguezuelos, and J. –F. Trape. 2011. Biogeography and conservation of viperids from North-West Africa: an application of ecological niche-based models and GIS. Journal of Arid Environments 75:1029-1037.

Brito, J. C., S. Fahd, P. Geniez, F. Martínez-Freiría, P. tarroso, S. Larbes, J. M. Pleguezuelos, and X. Santos. 2011. Climate change and peripheral populations: predictions for a relicth Mediterranean viper. Acta Herpetologica 6:105-118.

Cao, Y., R. E. DeWalt, J. L. Robinson, T. Tweddale, L. Hinz, and M. Pessino. 2013. Using Maxent to model the historic distributions of stonefly species in Illinois streams: the effects of regularization and threshold selections. Ecological Modelling 259:30–39.

Chauvenet, A. L. M., J. G. Ewen, D. P. Armstrong, T. M. Blackburn, and N. Pettorelli. 2012. Maximizing the success of assisted colonizations. Animal Conservation 16:161-169.

Collins, J. T. 1991. Viewpoint: a new taxonomic arrangement for some North American amphibians and reptiles. Herpetolgical Review 22:42–43.

Conant, R. and Collins, J. T. 1991. A Field Guide to Reptiles and Amphibians: Eastern and Central North America (Peterson Field Guides). Houghton Mifflin Company.

Congdon, J. D., T. E. Graham, T. B. Herman, J. W. Lang, M. J. Pappas, and B. J. Brecke. 2008. *Emydoidea blandingii* (Holbrook 1838) - Blading's turtle. In A. G. J. Rhodin, P. C. H. Pritchard, P. P. van Dijk, R. A. Saumure, K. A. Buhlmann, and J. B. Iverson, editors. Conservation biology of freshwater turtles and tortoises: a compilation project of the IUCN/SSC tortoise and freshwater turtle specialist group. Chelonian Research Monographs No. 5, pp 05.1-015.12. Chelonian Research Foundation.

Crother, B. I. (ed.). 2008. Scientific and Standard English Names of Amphibians and Reptiels of North America North of Mexico. Pp 1-84. SSAR Herpetological Circular 37.

Crother, B.I., M.E. White, J.M. Savage, M.E. Eckstut, M.R.Graham, and D.W. Gardner. 2011. A reevaluation of the status of the fox snakes *Pantherophis gloydi* Conant and *P. vulpinus* Baird and Girard (Lepidosauria). ISRN Zoology, Article ID 436049, 15 pages. doi:10.5402/2011/436049.

DeGregorio, B. A., B. J. Putman, and B. A. Kingsbury. 2011. Which habitat selection method is most applicable to snakes? Case studies of the Eastern Massasuaga (*Sistururus catenatus*) and Eastern Fox Snake (*Pantherophis gloydi*). Herpetological Conservation and Biology 6:372-382.

Di Cola, V., G. Cardozo, M. Lanfri, C. M. Scavuzzo, and M. Chiaraviglio. 2008. Modelling the distribution of the Boid snakes, *Epicrates cenchria alvarezi* and *Boa constrictor occidentalis* in the Gran Chaco (South America). Amphibia-Reptilia 29:299-310.

DiLeo, M. F., J. R. Row, and S. C. Lougheed. 2010. Discordant patterns of population structure for two co-distributed snake species across a fragmented Ontario landscape. Diversity and Distributions 16:571-591.

Deutsch, C.A., J.J. Tewksbury, R.B. Huey, K.S. Sheldon, C.K. Ghalambor, D.C. Haak, P.R. Martin. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. PNAS 105: 6668-6672.

Doody, J. S., and J. A. Moore. 2010. Conceptual model for thermal limits on the distribution of reptiles. Herpetological Conservation and Biology 5:283-289.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. McC. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N.

E. Zimmerman. 2006. Novel methods improve predictions of species' distributions from occurrence data. Ecography 29:129-151, 2006.

Enneson, J.J., and J.D. Litzgus. 2009. Stochastic and spatially explicit population viability analysis for an endangered freshwater turtle, *Clemmys guttata*. Canadian Journal of Zoology 87:1241-1254.

Ewert, M. A., and Nelson, C. E. 1991. Sex determination in turtles: diverse patterns and some possible adaptive values. Copea 1991:50-69.

Fang, F. , H. Sun, Q. Zhao, C. Lin, Y. Sun, W. Gao, J. Xu, J. Zou, F. Ge, and N. Lu. 2013. Patterns of diversity, areas of endemism, and multiple glacial refuges for freshwater crabs of the genus *Sinopotamon* in China (Decapoda: Brachyura: Potamidae). PLoS ONE 8: e53143.

Feaga, J. B., C. A. Haas, and J. A. Burger. Water table depth, surface saturation, and drought response in bog turtle (*Glyptemys muhlenbergii*) wetlands. Wetlands 32:1011-1021.

Francl, K. E., K. Hayhoe, M. Saunders, and M. P. Maurer. 2009. Ecosystem adaptation to climate change: small mammal migration pathways in the Great Lakes states. Journal of Great Lakes Research 36:86-93.

Franklin, J. 2010. Moving beyond static species distribution models in support of conservation biogeography. Diversity and Distributions 16:321-330.

Galatowitsch, S., L. Frelich, and L. Phillips-Mao. 2009. Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. Biological Conservation 142:2012-2022.

Gibbs HL, Murphy M, Chiucchi JE. 2010. Genetic identity of endangered massasauga rattlesnakes (*Sistrurus* sp.) in Missouri. Conservation Genetics 12:433–439.

Harding, J. H. 1997. Amphibians and Reptiles of the Great Lakes Region. The University of Michigan Press. Ann Arbor, MI.

Hedrick, P.W. 2005. "Genetic restoration": a more comprehensive perspective than "genetic rescue." Trends in Ecology and Evolution 20:109.

Hickling, R., D.B. Roy, J.K. Hill, R. Fox, and C.D. Thomas. 2006. The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology 12:450-455.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25:1965-1978.

Hijmans, R.J. and Graham, C.H. 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology 12:1-10.

Huey, R. B. 1982. Temperature, phsiolology and the ecology of reptiles. In C. Gans and F. H. Pough (eds.), Biology of the Reptila, Volume 12: Physiology C-Physiological Ecology. Academic Press, London.

Ihlow, F. ,J. Damback, J. O. Engler, M. Flecks, T. Harmann, S. Nekum, H. Rajaei, and D. Rödder. 2012. On the brink of extinction? How climate change may affect global chelonian species richness and distribution. Global Change Biology 18:1520–1530.

Intergovernmental Panel on Climate Change (IPCC) 2007. IPCC Special Report on Emissions Scenarios (SRES) Emissions Scenarios Dataset Version 1.1 New York, NY: Cambridge University Press.

Kikillus, K. H., K. M. Hare, and S. Hartley. 2010. Minimizing false-negatives when predictiong the potential distribution of an invasive species: a bioclimatic envelope for the red-eared slider at global and regional scales. Animal Conservation 13 (Suppl. 1):5-15.

Klaus, S. P., and S. C. Lougheed. 2013. Changes in breeding phenology of eastern Ontario frogs over four decades. Ecology and Evolution 3:835-845.

Kramer-Schadt, S., J. Niedballa, J. D. Pilgrim, B. Schröder, J. Lindeborn, V. Reinfelder, M. Stillfried, I. Heckmann, A. K. Scharf, D. M. Augeri, S. M. Cheyne, A. J. Hearn, J. Ross, D. W. Macdonald, J. Mathai, J. Eaton, A. J. Marshall, G. Semiadi, R. Rustam, H. Bernard, R. Alfred, H. Samejima, J. W. Duckworth, C. Breitenmoser_Wuersten, J. L. Belant, H. Hofer, and A. Wilting. 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. Diversity and Distributions. Doi:10.1111/ddi.12096.

Kubatko LS, Gibbs HL, Bloomquist EW. 2011. Inferring species–level phylogenies and taxonomic distinctiveness using multilocus data in *Sistrurus* rattlesnakes. Systematic Biology 60:393–409.

Kumar, S. and Stohlgren, T. J. 2009. Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. Journal of Ecology and Natural Environment 1:94–98.

Lawing, A. M., and P. D. Polly. 2011. Pleistocene climate, phylogeny, and climate envelope models: an integrative approach to better understand species' response to climate change. PLoS ONE 6: e28554. doi:10.1371/journal.pone.0028554.

Lourdais, O., R. Shine, X. Bonnet, M. Guillon, and G. Naulleau. 2004. Climate affects embryonic development in a viviparous snake, *Vipera aspis*. Oikos 104:551-560.

Lyet, A., W. Thuiller, M. Cheylan, and A. Besnard. 2013. Fine-scale regional distribution modeling of rare and threatened species: bridging GIS tools and conservation in practice. Diversity and Distributions 19:651-663.

Makowsky, R., J. C. Marshall Jr., J. McVay, P. T. Chippendale, and L. J. Rissler. 2010. Phylogenetic analysis and environmental modeling of the plain-bellied watersnake (*Nerodia erythrogaster*) reveals low levels of genetic and ecological differentiation. Molecular Phylogentics and Evolution 55:985-995.

Millar, C. S., and G. Blouin-Demers. 2012. Habitat suitability modeling for species at risk is sensitive to algorithm and scale: a case study of Blanding's turtle, *Emydoidea blandingii*, in Ontario, Canada. Journal for Nature Conservation 20:18-29.

Mitchell, N. J., and F. J. Janzen. 2010. Temperature-dependent sex determination and contemporary climate change. Sexual Development 4:129-140.

Mockford, S. W., T. B. Herman, M. Snyder, and J. M. Wright. 2007. Conservation genetics of Blanding's turtle and its application to the identification of evolutionary significant units. Conservation Genetics 8:209-219.

Monasterio, C., L. P. Shoo, a. Salvador, P. Iraeta, and J. A. Díaz. 2013. High temperature constrains reproductive success in a temperate lizard: implications for distributions range limits and the impacts of climate change. Journal of Zoology 291:136-145.

Moreno-Rueda, G., J. M. Pleguezuelos, M. Pizarro, and A. Montori. 2011. Northward shifts of the distributions of Spanish reptiles in association with climate change. Conservation Biology 26:278-283.

Myers, P., B. L. Lundrigan, S. M. G. Hoffman, A. P. Haraminac, and S. H. Seto. 2009. Climate-induced changes in small mammal communities of the Northern Great Lakes Region. Global Change Biology 15:1434-1454.

Owens, H. L., L. P. Campbell, L. L. Dornack, E. E. Saupe, N. Barve, J. Soberón, K. Ingeloff, a. Lira-Noriega, C. M. Hensz, C. E. Myers, and A. T. Peterson. 2013. Ecological Modelling 263:10-18.

Panella, M. J. 2012. Blanding's Turtle (*Emydoidea blandingii*); a species conservation assessment for the Nebraska Natural Legacy Project. Nebraska Game and Parks Commission, Wildlife Division. 13 pp.

Paterson, J. E., B. D. Steinberg, and J. d. Litzgus. 2012. Revealing a cryptic life-history stage: differences in habitat selection and survivorship between hatchlings of two turtle species at risk (*Glyptemys insulpta* and Emydoidea blandingii). Wildlife Research 39:408-418.

Pearson, R.G., Raxworthy, C.J., Nakamura, M., and Peterson, A.T. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34:102-117.

Penman, T.D., D.A. Pike, J.K. Webb, and R. Shine. 2010. Predicting the impact of climate change on Australia's most endangered snake, *Hoplocephalus bungaroides*. Diversity and Distributions 16:109-118.

Phillips, S. J. and Dudík, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161–175.

Phillips, S.J., R.P. Anderson, and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190:213-259.

Povilitis, A., and K. Suckling. 2010. Addressing climate change threats to endangered species in U.S. recovery plans. Conservation Biology 24:372-376.

Ramirez, J. and Jarvis, A. 2008. High Resolution Statistically Downscaled Future Climate Surfaces. International Center for Tropical Agriculture (CIAT); CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Cali, Colombia.

Ray, J.W., R.B. King, M.R. Duvall., J.W. Robinson, M.J. Dreslik, B.J. Swanson, and D. Mulkerin. 2012. Genetic analysis and captive breeding program design for the Eastern Massasauga *Sistrurus catenatus catenatus*. Journal of Fish and Wildlife Management 4:104-113. Available at http://www.fwspubs.org/toc/fwma/0/0.

Refsnider, J. M., and F. J. Janzen. 2012. Behavioural plasticity may compensate for climate change in a long-lived reptile with temperature-dependent sex determination. Biological Conservation 152:90-95.

Refsnider, J. M., B. L. Bodensteiner, J. L. Reneker, and F. J. Janzen. 2013. Nest depth may not compensate for sex ratio skews caused by climate change in turtles. Animal Conservation 16: DOI: 10.1111/acv.12034.

Rodda, G.H., C.S. Jarnevich, and R.N. Reed. 2011. Challenges in identifying sites climatically matched to the native ranges of animal invaders. PloS One 6(2):e14670. doi:10.1371/journal.pone.0014670.

Rödder, D., and S. Lötters. 2010. Potential distribution of the alien invasive brown tree snake, *Boiga irregularis* (Reptilia: Colubridae). Pacific Science 64:11-22.

Rodríguez-Castañada, G., A. R. Hof, R. Jansson, and L. E. Harding. 2012. Predicting the fate of biodiversity using species' distribution models" enhancing model comparability and repeatability. PLoS ONE 7:e44402. Doi:10.1371/journal.pone.0044402.

Roemer, G.W., C.J. Donlan and F. Courchamp (2002). Golden eagles, feral pigs and insular carnivores: how exotic species turn native predators into prey. Proceedings of the National Academy of Sciences, USA 99: 791–796.

Rohr, J. R., and B. D. Palmer. 2013. Climate change, multiple stressors, and the decline of ectotherms. Conservation Biology 27:741-751.

Row, J. R., R. J. Brooks, C. A. MacKinnon, A. Lawson, B. I. Crother, M. White, and S. C. Lougheed. 2011. Approximate Bayesian computation reveals the factors that influence genetic diversity and population structure of foxsnakes. Journal of Evolutionary Biology 24:2364–2377.

Santos, X., J. C. Brito, J. Caro, a. J. Abril, M. Lorenzo, N. Sillero, and J. M. Pleguezuelos. 2009. Habitat suitability, threats and conservation of isolated populations of the smooth snake (*Coronella austriaca*) in the southern Iberian Peninsula. Biological Conservation 142:344-352.

Schwartz, M. W. 2012. Using niche models with climate projections to inform conservation management decisions. Biological Conservation 155:149-156.

Shirey, P.D., and G.A. Lamberti. 2009. Assisted colonization under the U.S. Endangered Species Act. Conservation Letters 3:45-52.

Shoemaker, K. T., A. R. Breisch, J. W. Jaycox, and J. P. Gibbs. 2013. Reexamining the minimum viable population concept for long-lived species. Conservation Biology 27:542-551.

Suzuki, N., D.H. Olson, and E.C. Reilly. 2008. Developing landscape habitat models for rare amphibians with small geographic ranges: a case study of Siskiyou Mountains salamanders in the western USA. Biodiversity and Conservation 17:2197-2218.

Telemeco, R. S., K. C. Abbott, and F. J. Janzen. 2013. Modeling the effects of climate change-induced shifts in reproductive phenology on temperature-dependent traits. American Naturalist 181:637-648.

Thomas, C.D. 2010. Climate, climate change and range boundaries. Diversity and Distributions 16:488-495

Thomas, C.D., A.Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, BF.N. Erasmus. M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A. Townsend Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Thuiller, W., B. Lafourcade, R. Engler, and M.B. Araújo. 2009. BIOMOD – a platform for ensemble forcasting of species distributions. Ecography 32:369-373.

Tigley, R., and T.B. Herman. 2009. Land-cover data improve bioclimatic models for anurans and turtles at a regional scale. Journal of Biogeography 36:1656-1672.

Travis, J. M. J., M. Delgado, G. Bocedi, M. Baguette, K. Bartoń, D. Bonte, I. boulangeat, J. A. Hodgson, A. Kubisch, V. Pentariani, M. Saastamoinen, V. M. Stevens, and J. M. Bullock. 2013. Dispersal and species' responses to climate change. Oikos DOI: 10.1111/j.1600-0706.2013.00399.x.

Ujvari, B. , R. Shine, L. Luiselli, and T. Madsen. 2011. Climate-induced reaction norms for life-history traits in pythons. Ecology 92:1858-1864.

VanDerWal, J., L. P. Shoo, C. Graham, and S. E. Williams. 2009. Selecting pseudo-absence data for presence-only distribution modeling: how far should you stray from what you know? Ecological Modelling 220:589–594.

Warren, D. L. and Seifert, S. N. 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications 21:335–342.

Weatherhead, P. J., J. H. Sperry, G. L. F. Carfagno, and G. Blouin-Demers. 2012. Latitudinal variation in thermal ecology of North American ratsnakes and its implications for the effect of climate warming on snakes. Journal of Thermal Biology 37:273-281.

Willoughby, J. R., M. Sundaram, T. L. Lewis, and B. J. Swanson. 2013. Population decline in a long-lived species: the wood turtle in Michigan. Herpetologica 69:186-198.

Wisz, M. S., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham, A. Guisan, and NCEAS Predicting Species Distributions Working Group. 2008. Effects of sample size on the performance of species distribution models. Diversity and Distributions 14:763-773.

Wooten, J. A., and H. L. Gibbs. 2011. Niche divergence and lineage diversification among closely related *Sistrurus* rattlesnakes. Journal of Evolutionary Biology 25:317-328.

Yackulic, C. B., R. Chanler, E. F. Zipkin, J. A. Royle, J. D. Nichols, E H. Campbell Grant, and S. Veran. 2013. Presence-only modelling using MAXENT: when can we trust the inferences? Methods in Ecology and Evolution 4:236–243.