Climate Envelope Models in Support of Landscape Conservation

Final Report

September 2012

U.S. FISH AND WILDLIFE SERVICE AGREEMENT NO: F11AC00028 (UF PROJECT #91389)

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SUMMARY

Successful conservation strategies in the face of climate change will require careful consideration of how changing climate will affect wildlife and habitats. Development of innovative, data driven, accessible tools will assist in understanding and planning for those effects. This document serves the final report for U.S. Fish and Wildlife Service (USFWS) project # F11AC00028 that provides tools that enhance the U.S. Fish and Wildlife Service's (and others) climate change toolbox. This project was funded to (1) develop climate envelope models and associated prediction maps for 26 federally threatened and endangered terrestrial (T&E) vertebrate species occurring in peninsular Florida; (2) provide a technical guidebook for use and interpretation of climate envelope models; (3) develop visualization and social networking tools that will allow natural resource managers and the general public to view our models, and (4) create a searchable database of species traits for use in developing vulnerability assessments and other biological planning documents. A summary for each of these deliverables is provided here with links to associated reports, publications, and web pages that provide more detailed information.

ACKNOWLEDGEMENTS

We thank the Mazzotti lab group at the University of Florida for assistance with literature searches, reading papers, extracting data, proofing, and editing. This project is a cooperative effort among University of Florida, U.S. Fish and Wildlife Service (South Florida Ecological Services and Washington Office of Science Advisor), U.S. Geological Survey (Greater Everglades Priority Ecosystem Science), and the National Park Service (Everglades and Dry Tortugas National Park). Funding from U.S. Fish and Wildlife Service, U.S. Geological Survey and National Park Service was through the South Florida and Caribbean Cooperative Ecosystem Studies Unit.

Suggested Citation: Watling, James, I., Laura A. Brandt, Allison Benscoter, David Bucklin, Carolina Speroterra, Frank J. Mazzotti, and Stephanie S. Romañach. 2012. Climate Envelope Models in Support of Landscape Conservation. Final Report to U.S. Fish and Wildlife Service agreement F11AC00028. Fort Lauderdale Research and Education Center, University of Florida, Davie, FL.

INTRODUCTION

Climate change will accelerate threats that challenge our ability to restore, preserve, and protect natural ecosystems and the species that depend on them. Successful conservation strategies will require an understanding of climate change and the ability to predict how it will affect species and habitats at multiple scales.

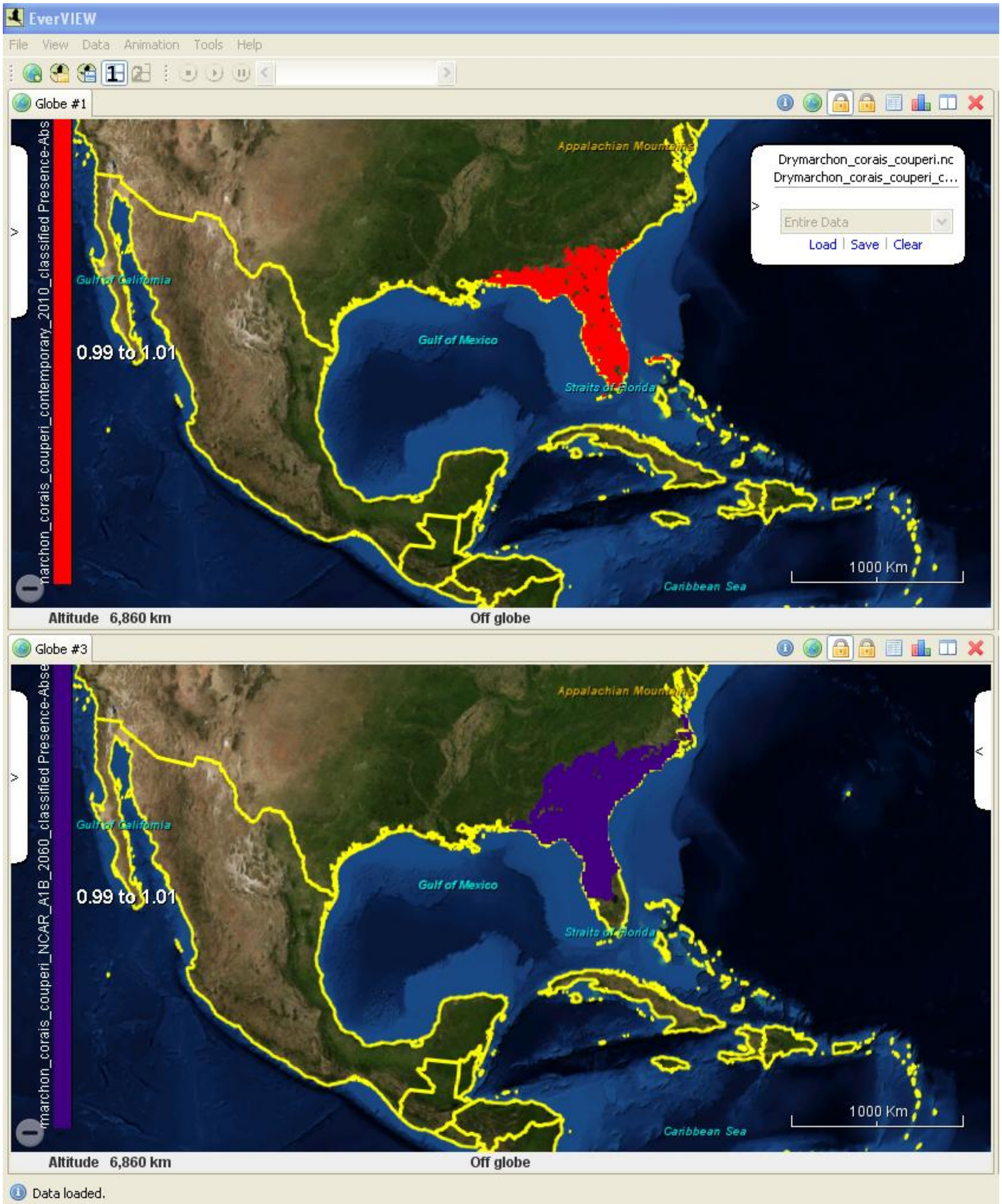
U.S. Fish and Wildlife Service (USFWS) and National Park Service (NPS) have developed strategic plans for climate change response that include three elements: adaptation, mitigation, and education. In order to implement effective adaptation strategies, natural resource managers need to understand which climate parameters are likely to change, what the magnitude of that change may be, and how natural resources (e.g., species, habitats, and ecosystems) are likely to respond to climate change. Modeling both potential changes in climate and responses of species and habitats can help increase certainty in management decisions by helping managers to understand the range of possible species and habitat responses under different alternative futures.

Climate envelope modeling, a subset of species distribution modeling (SDM), is one type of modeling that can be useful in understanding species and habitat responses to climate change because they identify key links between drivers of change (e.g., climate) and relevant responses. Climate envelope models describe relationships between species' occurrences and bioclimate variables derived from temperature and precipitation data to define a species' climate niche (envelope). Relationships derived from contemporary climate conditions and distributional data can be projected to the future using estimates of anticipated climate change. Models describing hypothesized changes in a species' future climate envelope then may be used in association with spatially explicit projections of land use change and sea level rise to estimate how species' distributions may respond to multiple interactive drivers of global change.

The objective of our project was to develop modeling methods and products that will allow natural resource managers to examine potential effects of climate change on species' geographic ranges in the context of ecosystem and landscape planning. In addition to delivering final products such as output of models, reports, and publications we are committed to making available the information and data that we use to create those products and will provide those in electronic form.

This project consists of four parts: (1) developing climate envelope models and associated prediction maps for 26 federally threatened and endangered terrestrial (T&E) vertebrate species occurring in peninsular Florida; (2) providing a technical guidebook for use and interpretation of climate envelope models; (3) developing visualization and social networking tools that allow natural resource managers and the general public to view our models, and (4) creating a searchable database of species traits for use in developing vulnerability assessments and other biological planning documents. This report provides a summary for each of these deliverables with links to associated reports, publications, and web pages that provide more detailed information.

I ***Develop climate envelope models and associated prediction maps for 26 federally threatened and endangered terrestrial (T&E) vertebrate species occurring in peninsular Florida***



Climate envelope models describe relationships between species' occurrences and bioclimate variables derived from temperature and precipitation data to define a species' climate niche (envelope). Relationships derived from contemporary climate conditions and distributional data can be projected to the future using estimates of anticipated climate change. These projections are useful for examining where climate may be suitable for species in the future. They also can be combined with other information on land use change, sea level rise, and species dynamics to get a more complete picture of how species may respond global change. More information on climate envelope modeling can be found in "Use and Interpretation of Climate Envelope Models: A Practical Guide", the guidebook produced during this project (see SectionII).

Climate envelope models were created for 26 federally threatened and endangered terrestrial (T&E) vertebrates occurring in peninsular Florida (Table 1) by combining georeferenced data on species presence and absence with spatially-explicit temperature and precipitation data. Georeferenced species occurrences were obtained from a variety of sources including online museum databases, the primary literature, and field sampling. Contemporary climate data included average monthly temperature and precipitation observations from two global climate data sets: WorldClim and the Climate Research Unit. Observations from the two data sets were averaged to create a 'consensus' layer for analysis. More details on species occurrence data used in this project can be found in Watling et al. 2010.

For each species, the contemporary modeling domain was defined based on a modification of the target group approach (Phillips et al. 2009) wherein we drew the minimum convex polygon around occurrences of phylogenetically closely related species. This approach reduces some of the arbitrariness of using political or other boundaries to determine the geographical space in which models are constructed. Presence data were incorporated from throughout the geographic range for all species. Within the target group domain for each species, 10,000 points were selected at random as 'pseudo-absences' and incorporated into the model. Between 2—19 individual monthly climate variables were used for modeling for each species. Variable selection was done by selecting the subset of variables from the total pool of 24 climate predictors (12 mean monthly temperature variables and 12 monthly precipitation variables) that resulted in the models with the best classification ability using the random forest algorithm.

Projections of future climate conditions were obtained from data downscaled by Tabor & Williams (2010) from the World Climate Research Program's CMIP3 multi-model dataset, which was used for the Intergovernmental Panel on Climate Change's 4^{th} Assessment report (CITE). Three global circulation models (GCMs) were used for our projections: GFDL CM2.0, NCAR CCSM3 and UKMO HADCM3. Two relatively high CO2 emissions scenarios were modeled using data from each GCM: the A1B and A2 scenarios from the IPCC family (CITE). Projection climate data for the period 2041—2060 (hereafter 2060) were used to create maps of future climate suitability for species. For eight species with a coastal distribution (*Microtus pennsylvanicus dukecampbelli*, *Oryzomys argentatus*, *Peromyscus gossypinus allapaticola*, *Peromyscus polionotus niveiventris*, *Peromyscus polinotus phasma*, *Sterna dougallii dougallii*, *Crocodylus acutus and Nerodia clarkia taeniata*), projection maps only show areas within two grid cells of the coast.

Species	AUC	Cohen's kappa	Sensitivity	Specificity
Mammals	Mean ± 1 SD	Mean ± 1 SD	Mean	Mean
Puma concolor coryi	0.963 ± 0.027	0.842 0.059	0.909	0.996
Odocoileus viriginianus clavium	0.999 ± 0.001	0.884 0.083	1	0.998
Sylvilagus palustris hefneri	0.964 ± 0.076	0.843 0.155	1	0.999
Eumops floridanus	0.962 0.089	0.337 0.295	0	0.999
Microtus pennsylvanicus dukecampbelli	0.999 0.011	0.940 0.096	0.800	1
Neotoma floridana smalli	0.999 0.001	0.942 0.104	1	1
Oryzomys argentatus	0.999 0.001	0.840 0.113	1	0.998
Peromyscus gossypinus allapaticola	0.901 0.129	0.647 0.211	1	0.999
Peromyscus polionotus niveiventris	0.963 0.069	0.717 0.179	0.667	0.999
Peromyscus polionotus phasma	0.996 0.020	0.895 0.099	0.800	1
Birds				
Ammodramus maritimus mirabilis	0.999 ± 0.001	0.841 ± 0.131	0.75	1
Ammodramus savannarum floridanus	0.960 ± 0.056	0.710 ± 0.156	0.667	1
Aphelocoma coerulescens	0.999 ± 0.001	0.881 ± 0.030	0.941	0.998
Charadrius melodus	0.963 ± 0.005	0.642 ± 0.024	0.790	0.951
Sterna dougalli dougalli	0.641 ± 0.135	0.127 0.181	0	1
Mycteria americana	0.967 ± 0.004	0.748 0.016	0.788	0.962
Polyborus plancus audubonii	0.999 ± 0.003	0.882 0.031	0.950	0.996
Rhostramus sociabilis plumbeus	0.999 ± 0.001	0.857 0.041	0.96	0.998
Grus americana	0.980 ± 0.055	0.632 0.155	0.50	0.999
Picoides borealis	0.984 ± 0.005	0.705 0.020	0.930	0.964
Amphibians and Reptiles				
Ambystoma cingulatum	0.872 ± 0.076	0.220 ± 0.150	0.125	1
Crocodylus acutus	0.966 0.017	0.468 0.060	0.593	0.990
Eumeces egregius lividus	0.995 0.020	0.672 0.193	0.600	1
Neoseps reynoldsi	0.990 ± 0.036	0.475 0.174	0.75	0.999
Drymarchon corais couperi	0.997 ± 0.002	0.879 0.023	0.899	0.990
Nerodia clarkii taeniata	0.999 0.001	0.480 0.080	1	0.996

Table 1. Classification of model performance. Red indicates models with poor ability to classify species presences, green indicates models with good ability to classify presences, and yellow indicates models with moderate classification ability.

We used a red, yellow, green (stoplight) color scheme to summarize both model performance as well as projected species responses to temperature and precipitation conditions in 2060. We used four criteria to evaluate model performance: AUC, Cohen's kappa, Sensitivity and specificity. Briefly, AUC ranges from 0—1 with higher scores indicating models that more accurately discriminate climate conditions at presence and absence sites; Cohen's kappa also ranges from 0—1, with higher values indicating models that better classify presences and absences; sensitivity measure's a model's ability to accurately classify presences, and specificity measures a model's ability to accurately classify absences (see "Use and Interpretation of Climate Envelope Models: A Practical Guide", the guidebook produced during this project and described in Section II for more details on model evaluation). All evaluation criteria were calculated by training a model with 75% of the available occurrence (presence/absence) data and testing it with the remaining 25% of occurrences. Values of AUC and Cohen's kappa reported are the average of 100 random partitions of the occurrence data into training and testing subsets, whereas sensitivity and specificity were calculated once for each of 26 species models. We focused on sensitivity to classify models using the stoplight approach, with green indicating 'good' models with sensitivity ≥ 0.900, yellow indicating models with moderate performance (<0.900 and >0.500), and red indicating 'poor' models with sensitivity ≤ 0.500 (Table 1). Overall, we estimate that approximately 12/26 (46%) of models are good, 8/26 (31%) show moderate performance, and 6/26 (23%) show poor performance.

To categorize species responses to climate change, we calculated how many times smaller the future climate envelope is projected to be relative to the contemporary climate envelope (Table 2). In the second column of Table 2, numbers indicate the relative size of the contemporary climate envelope relative to the projected climate envelope in 2060 (i.e., the area of the 2060 climate envelope for the Florida panther, *Puma concolor coryi* is 12% that of the contemporary climate envelope, whereas the size of the future climate envelope for the Key Deer, *Odocoileus virginianus clavium* is over 15 times greater than the contemporary climate envelope). We convert numbers to categories such the green indicated species for which the area of the climate envelope is projected to increase by at least 25% by 2060, yellow indicates species experiencing only small changes in the area of the climate envelope (< 25%), and red indicating species for which the climate envelope is expected to get much smaller in 2060 relative to today's climate envelope (at least a 25% decrease).

Overall, the size of the climate envelope decreased for 13/26 (50%) of species, stayed about the same for 3/26 (12%), and increased for 10/26 (38%) of species. If we just consider responses for species for which model performance was judged to be good (Table 1), 50% of those species are projected to experience an expansion in the area of the climate envelope, 8% will experience little change in area of the climate envelope, and 42% will experience a contraction in area of the climate envelope.

Of course, models are just one piece of the puzzle when planning for climate change adaptation. We stress that the models presented here represent responses to climate only and do not take into account all factors that can determine where a species will occur in the future. We are currently working on adding additional variables, particularly land cover, to models, and expect that more holistic models will provide greater insight into potential responses of species to climate change. We also have not included any effects of rising sea levels in our models, which will certainly have implications for species range shifts in response to climate change.

All climate envelope models are available for download at http://crocdoc.ifas.ufl.edu/projects/climateenvelopemodeling/ under the section 'NetCDF files'. The NetCDF files are formatted for use with EverVIEW software available at www.jem.gov.

Please contact the authors for more information before using the model results presented here for any kind of biological planning.

Species	Relative size of future climate envelope	Status
Mammals		
Puma concolor coryi	0.12	Decrease
Odocoileus viriginianus clavium	15.45	Increase
Sylvilagus palustris hefneri	0.21	Decrease
Eumops floridanus	4.82	Increase
Microtus pennsylvanicus dukecampbelli	0.11	Decrease
Neotoma floridana smalli	309.40	Increase
Oryzomys argentatus	0.07	Decrease
Peromyscus gossypinus allapaticola	0.02	Completely lost*
Peromyscus polionotus niveiventris	0.58	Decrease
Peromyscus polionotus phasma	0.55	Decrease
Birds		
Ammodramus maritimus mirabilis	34.59	Increase
Ammodramus savannarum floridanus		Completely lost
Aphelocoma coerulescens	1.94	Increase
Charadrius melodus	5.61	Increase
Sterna dougalli dougalli	0.10	Decrease
Mycteria americana	5.58	Increase
Polyborus plancus audubonii	0.38	Decrease
Rhostramus sociabilis plumbeus	0.82	Slight loss
Grus americana	0.88	Slight loss
Picoides borealis	4.22	Increase
Amphibians and Reptiles		
Ambystoma cingulatum	.17	Decrease
Crocodylus acutus	0.78	Slight loss
Eumeces egregius lividus		Completely lost
Neoseps reynoldsi		Completely lost
Drymarchon corais couperi	1.47	Increase
Nerodia clarkii taeniata	10.66	Increase

Table 2. Classification of species responses to projected climate change. Red indicates species experiencing a reduction in the area of the climate envelope, green indicates species projected to experience an expansion in the area of the climate envelope, and yellow indicates species for which the size of the climate envelope is projected to experience little change. The asterisk * indicates a species for which only a single suitable grid cell remained during the 2041—2060 period.

II *Provide a technical guidebook for use and interpretation of climate envelope models*

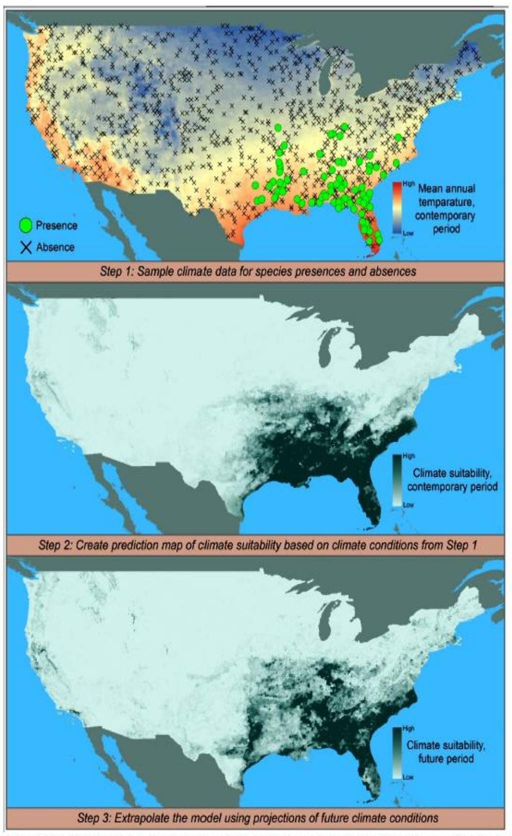


Figure 1. Conceptual overview of the climate envelope modeling process. In step one, climate data are compiled at sites where a species exists, as well as sites where species are absent or their status is unknown. In step two, a mathematical equation is used to extrapolate an estimate of climate suitability for the species using the same climate data as in step one. In step three, using the same species-climate relationship as in step two, climate suitability is extrapolated to a new (future) period based on future climate conditions.

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both climate envelope and mechanistic models alone were not as successful in predicting occurrences of the Eastern fence lizard (*Sceloporous undulatus*) as a hybrid approach combining elements of both modeling approaches. Recently-developed extensions of mechanistic modeling such as dynamic range models (Pagel & Schurr 2012; Shurr et al. 2012) focus special attention on dispersal, an important characteristic that is missing entirely from traditional climate envelope models. Because data inputs for climate envelope models are much less demanding than for mechanistic models, we expect that climate envelope modeling will continue to be used for modeling of species for which detailed demographic or physiological data are lacking, even as approaches for mechanistic modeling become more user-friendly. We reiterate, however, that models of any type should only be part of the decision-making toolbox, and not the sole basis for conservation planning.

What are the differences between climate envelope and mechanistic models, and what are you likely to learn from each of them? In general, mechanistic models are more data intensive, because they require detailed information on how individual fitness varies as a function of climate (e.g., survival growth and reproductive output under different temperature or precipitation conditions). These data are generally used to fit specific equations describing things like physiological response curves. Since we do not usually have that kind of data for many species, you are much more likely to hear about a physiological model for one or a few species, whereas people often use climate envelope models to create predictions for many different species (e.g., almost 3000 species of terrestrial vertebrates in the North and South America, Lawler et al. 2009). Because the outputs of mechanistic models include information on how fitness traits vary across climate gradients, you are more likely to learn about how climate affects specific aspects of an organism's life history in a presentation or paper on mechanistic models than in a presentation on climate envelope models. However, because climate envelope models can be easily modified to include data on other types of environmental conditions (land cover, elevation, etc), you are more likely to learn about the relative importance of climate in determining species range limits or range shifts when reading a paper on climate envelope models than in a paper on mechanistic models. In general, it probably makes sense to think about climate envelope models as being focused on broad patterns and limiting factors for species, often in the context of a relatively coarse-filtered screening tool for evaluating species susceptibility to climate change. Mechanistic models, on the other hand, give much more insight into how climate change affects demography of individual species and are probably more likely to be used for species already known to be at risk for negative effects of climate change or that are of particular economic or cultural importance (e.g., waterfowl and sport fish).

How are climate envelope models created?

Creating a climate envelope model is fairly straight forward in concept. A researcher gathers occurrence data and contemporary climate data to establish the relationships between species occurrence and climate variables. The relationship is calculated using one or more **algorithms**, and the researcher evaluates the results. Once the relationship has been determined, a researcher can use that relationship with projections of future climate to describe the future climate envelope for the species. The modeling process can vary quite a bit, depending on factors such as the algorithm and statistical software used for modeling and the extent to which input data are pre- or post-processed. Since it is not practical to include

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There are many factors to consider when developing and interpreting climate envelope models. As with many models there is no one “right” answer to some of the choices that are made in development of the model. We developed this guidebook with input from U.S. Fish and Wildlife Service personnel to help conservation professionals and natural resource managers who do not do climate envelope modeling understand some of the major issues and topics in climate envelope modeling. We address topics from a practical perspective, using minimal jargon to explain and illustrate some of the many issues that one has to be aware of when using climate envelope models.

The 50 page document is written for a non-expert, and is presented as a series of questions that one may ask when confronted with information from climate envelope models. The guidebook covers a range of topics such as ‘What is a climate envelope model?’, ‘How are climate envelope models created?’, ’What are some of the assumptions underlying climate envelope modeling?’, and ‘Can models be extrapolated anywhere or anytime?’. We wrote the guidebook with minimal jargon, and provide a glossary to define technical terms. The guidebook is illustrated liberally so that key points are reinforced in both words and pictures. We drew on both our own work and the work of others to provide examples and ground the guidebook in ‘real world’ applications.

The guidebook is included as a pdf file with this report, and is available for download at: http://crocdoc.ifas.ufl.edu/projects/climateenvelopemodeling/. It is intended to be widely circulated in the US Fish and Wildlife Service and beyond. Please feel free to share the guidebook with colleagues, and email the authors if you have questions or suggestions about the content of the guidebook.

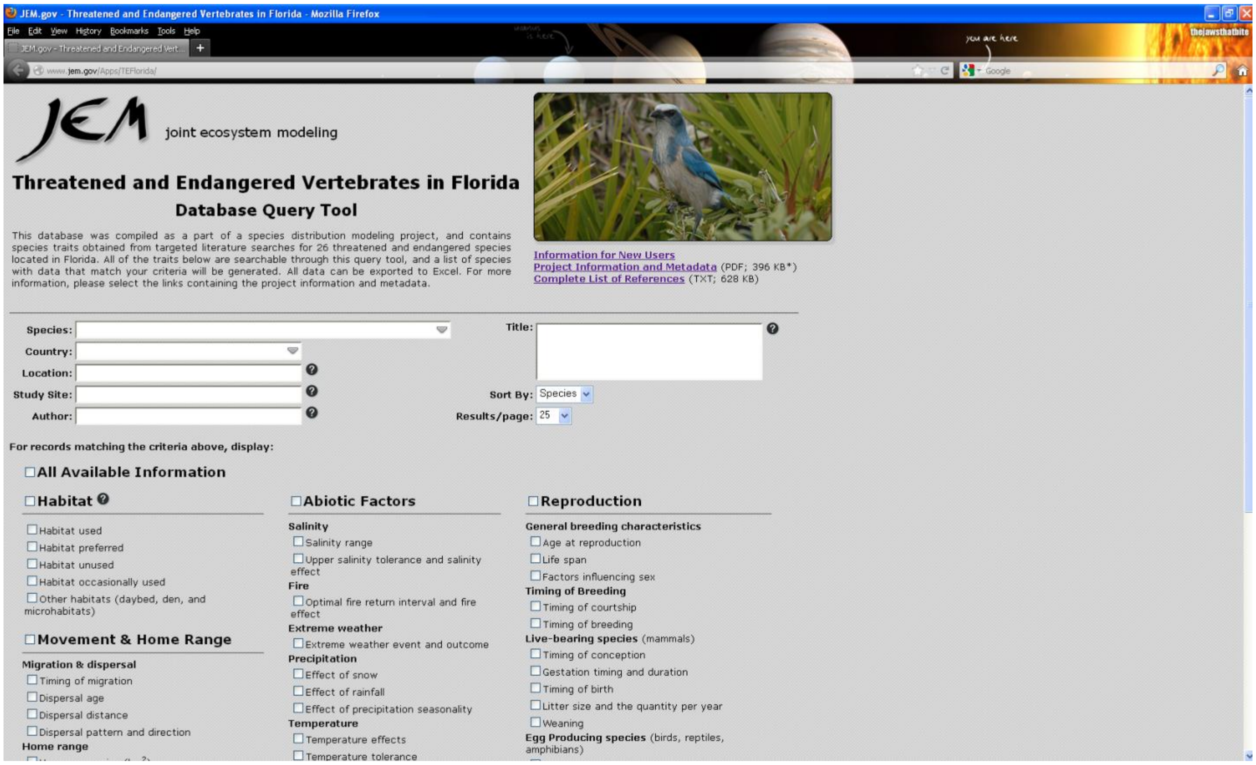
III *Develop visualization and social networking tools that will allow natural resource managers and the general public to view our models*

One of the goals of our project is to make our results accessible to a wide range of audiences including other researchers, natural resource managers, and the general public. To do this we have been working with software developers at the U.S. Geological Survey, National Wetlands Research Center, Spatial Analysis Branch, Advanced Applications team to package our output in a format (NetCDF) that can be read by others and used in a readily available data visualization program, EverView. EverView, a U.S. Geological Survey desktop model visualization platform (http://jem.cr.usgs.gov/pages/EverVIEW/EverVIEW.aspx) is built on the JAVA version of NASA's World Wind API, which enables EverVIEW to visualize geospatial data from anywhere on Earth. We have pilot tested a tool for converting map files into NetCDF format (the data standard for use in EverVIEW) and this data converter is now online and available for download at www.jem.gov.

In addition we have worked with software developers to develop additional tools for EverVIEW that will help users extract information from these climate envelope models and other geospatial model output. Additional charting and reporting tools that allow users to perform simple calculations and plot change across multiple maps through time are slated to be including in upcoming EverVIEW releases.

To share model results with the public we have developed a webpage (http://crocdoc.ifas.ufl.edu/projects/climateenvelopemodeling/) that currently provides output for the 26 species models. We also use this site to share other products, including the guidebook, fact sheets, and journal articles resulting from out work.

IV *Create a searchable database of species traits for use in developing vulnerability assessments and other biological planning documents*



One of the steps in our data-driven approach to developing and interpreting climate envelope models was to collect the most up-to-date information on our species of interest and organize it in a way that would be easily retrievable. We also wanted to make the information available to others who may use it for conducting vulnerability assessments or updating documents such as recovery plans.

We recognized that collecting all information for every species was beyond the scope of this project, and thus narrowed and prioritized our data collection goals to include the following: first, information that would inform selection of climate variables for use in our modeling; second, information that would help us interpret output of the models; and third, information that might help interpret the models and would also be of use in vulnerability assessments. The resulting database therefore contains some, but not all, data needed to conduct a vulnerability assessment using a tool such as that developed by NatureServe. The database contains almost 10,000 lines of data describing a range of traits and conditions such as movement and home range, habitat, reproduction, and responses to temperature, precipitation and fire for 26 endangered species and subspecies in Florida, as well as their non-endangered parent species (for subspecies only).

Work on the database was done by our research group as well as software developers at the U.S. Geological Survey, National Wetlands Research Center, Spatial Analysis Branch, Advanced Applications team . The traits database went live in May 2012 and is hosted at the Joint Ecosystem Modeling (JEM) website (http://www.jem.gov/Apps/TEFlorida/). The database has been accessed over 250 times since it was launched in May, with users representing a variety of stakeholder groups (e.g., county governments, the Florida Department of Environmental Protection, the U.S. Environmental protection Agency, DOI agencies, various public school districts and universities, and people from seven different countries.

More information on development of the database can be found in Watling et al. 2010 and in documents on the Joint Ecosystem Modeling (JEM) website (http://www.jem.gov/Apps/TEFlorida/).

V. *Reports, publications, fact sheets, web pages, and presentations resulting from this work.*

In addition to the specific deliverables highlighted in this report, we have produced a number of other products during the completion of this project. Many of these are available at http://crocdoc.ifas.ufl.edu/projects/climateenvelopemodeling/. Please contact the authors if you have questions about any of these products.

Reports

Watling, James, I., Laura A. Brandt, Frank J. Mazzotti, and Stephanie S. Romañach. 2010. Climate envelope modeling for evaluating anticipated effects of climate change on threatened and endangered species. September 2010 update. Fort Lauderdale Research and Education Center, University of Florida, Davie, FL.

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Publications

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Abstracts & presentations

Watling, James, I**.**, Laura A. Brandt, Stephanie S. Romañach, Ikuko Fujisaki, Yesenia Escribano, Emily Pifer, Michelle J. Curtis, Frank J. Mazzotti, Don DeAngelis, and Leonard G. Pearlstine. Climate-based distribution models for the American Crocodile, *Crocodylus acutus*: Illustration of methodological challenges and management opportunities. Poster presentation at Ecological Society of America Meeting August, 2010, Pittsburgh, PA. Presented by James Watling.

Watling, James I, Laura A. Brandt, Stephanie S. Romañach. Climate envelope modeling: A piece of the puzzle. Presentation at Florida Fish and Wildlife Conservation Commission workshop on species vulnerability to sea level rise. January 2011. St. Petersburg, FL. Presented by Laura A. Brandt.

Watling, James I, Laura A. Brandt, Carolina V. Speroterra, Frank J. Mazzotti, Stephanie S. Romañach. Species at risk from climate change: the case of Florida Keys endemics. Poster presentation at: Sea Level Rise Adaptation in the Florida Keys, Conserving Terrestrial and Intertidal Natural Areas and Native Species, May 2011, Hawks Cay Resort, Florida Keys. Presented by James Watling.

Watling, James I, Laura A. Brandt, Stephanie S. Romañach. Developing climate envelope models for threatened and endangered vertebrates in peninsular Florida. Oral presentation at: Everglades National Park, Krome Center, Homestead, FL, May 2011. Presented by James Watling.

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<u>Fact Sheets</u>

Planning for climate change in south Florida. Climate envelope modeling for threatened and endangered species. Laura A. Brandt, Stephanie S. Romanach and Frank J. Mazzotti.

Science Support for Climate Change Adaptation in South Florida. Laura M. early and Rebecca G. Harvey.

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