# Mapping Species Ranges and Distribution Models across the United States

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In 2008, GAP embarked on an effort to create species distribution models across entire species ranges for a large number of species that occur in the continental US. We began by creating a species list for the US based on the species lists that were developed for the Southwest (SWReGAP), Southeast (SEGAP), and Northwest (NWGAP) GAP regional projects. We then compiled species lists from all the remaining states (e.g., California, Midwestern and Northeastern states). Once a comprehensive list was assembled, each species was verified using the most current information regarding that species (Crother 2008, Wilson and Reeder 2005, American Ornithological Union's 2008 checklist).

We defined a species range as a coarse representation of the total areal extent of a species or the geographic limits within which a species can be found (Morrison and Hall 2002). To represent

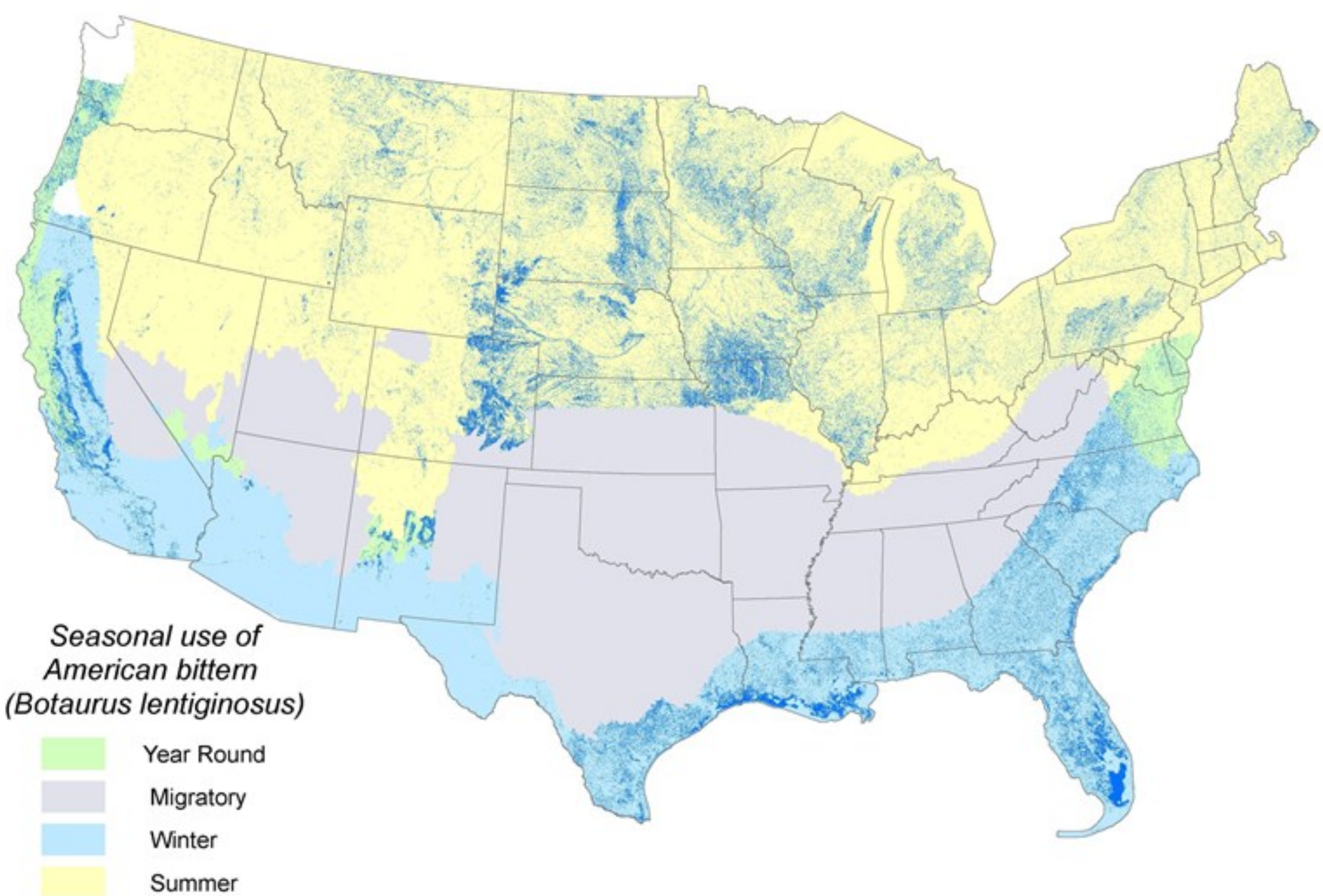


**Figure 1. Range map for the American bittern (*Boraurus lentiginosus*) with predicted distribution in dark blue. The predicted distribution model is based on habitat variables such as land cover classes. A separate predicted distribution was created for summer and winter.**

these geographic limits, we used a national database of standardized 12-digit hydrological units (HUCs). We are using information from NatureServe, SWReGAP, and SEGAP to create our species ranges. The NWGAP species ranges will be incorporated as soon as they are finalized. To date, we have completed national range maps for most of the approximately 700 bird species included on our species list.

We will use each species range to provide the biological context within which to build our species distribution models. We have defined a species distribution as the spatial arrangement of environments suitable for occupation by a species. In other words, a species' distribution is created using a model to predict areas suitable for occupation within that species' range. Our distribution maps, which are the result of our distribution models, are created at a 30m resolution. We are using deductive modeling approaches based on habitat associations and expert input. We will also be starting to collect species point observations for use in inductive modeling as well. Whichever modeling approach is used to create a species' distribution model will be applied consistently across its range. For those species with ranges entirely within the regional extents of SWReGAP, SEGAP, or NWGAP projects, we are using the existing distribution models as our national distribution models for that species.

Our goal is to build species range maps and distribution models with the best available data for use in assessing conservation status, conservation planning, and research (e.g., climate change impacts). This is our first attempt to build species models across a species' entire range rather than stopping at state or regional boundaries. These models will provide a base from which we can iteratively improve the model when new data become available. They will also provide the basis of a national biodiversity assessment.

The next few pages describe species modeling efforts that are contributing towards this national goal. Some of these are regional modeling efforts that were started prior to moving to national scale models (e.g., NWGAP, SEGAP,). Some are regional projects that are already working within the national framework (e.g., NEGAP). Some are modeling efforts based on species groups, such as reptiles or birds, that have a national perspective.

Currently, our main modeling approach is deductive; however, NWGAP and AKGAP species modeling includes inductive modeling. We are focusing our initial efforts on building, expanding, or updating our deductive species models, but we will also expand our inductive modeling efforts over time.

To date, about 200 species ranges and distribution models have been completed by regional GAP projects. Additionally, we have completed about 300 bird ranges and distribution models. These completed species ranges and distribution models will be available via our web site for viewing and downloading (gapanalysis.nbii.gov). As more species ranges and distribution models are completed over the next year; we will continually update our web site. We are currently exploring methods for interactively viewing GAP species data via the web.

Furthermore, through our nationwide bird modeling project, described below, we also have created core datasets needed for conducting national species modeling. These include a national wildlife habitat relationship database on which all our current deductive modeling efforts are based. This database contains wildlife habitat relationships to land cover and other spatial habitat parameters (e.g., elevation, slope) based on literature, taxonomic information (e.g., ITIS codes), and information about the status of the modeling effort for each species (e.g., available model, model spatial extent, partners involved, and projected completion). This database will be integrated into the GAP web site to allow users to check the modeling status for any species. Several key national ancillary data layers (e.g., stream velocity, distance to forest edge) were created through this effort and will be incorporated into other continental scale modeling efforts as described below. These national ancillary data layers will be available from the GAP web site.

GAP's modeling strategy is aimed towards our new national level vision. We believe our strategy over the next 1-2 years will position us well for conducting nationwide biodiversity assessments, while also building and expanding our species modeling data, models, and expertise.

## Species Groups Modeling Efforts

### Mapping Range, Distribution, and Habitat Quality for Vertebrates in the Northwestern United States

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The State Natural Heritage Programs of Wyoming, Montana, Idaho, Oregon, and Washington are mapping range, distribution, and habitat quality for each of 700 vertebrate species (mammals, amphibians, reptiles, and birds) found throughout the northwestern U.S. NWGAP is supported and directed by the National Gap Analysis Program and is anticipated to be complete by winter 2011.

The list of target taxa was derived from a list of all vertebrates that have been documented in the region. Zoology teams from each state culled from this list all vagrant species and other taxa not relevant to conservation in the region. Remaining species that occur in the northwest only during migration will receive range maps, but not distribution or habitat quality maps. A "modeling season" was assigned to each species that occupies different portions of the northwest in summer and winter. Therefore, distribution and habitat quality maps for those species will be specific to the modeling season.

For each species range, documented observations and expert input were combined to attribute each northwestern 10-digit hydrological unit (HUC) by occupation status (e.g., known, suspected), season, and origin (e.g., native, exotic). These maps will undergo a final expert review in fall 2010, which will provide a general quality ranking for each map. The final maps will be delivered in winter 2011.

Physically-suitable environments within a species distribution will be modeled with the MAXENT algorithm, using climatic variables as predictors at points of known species occurrence (Phillips et al. 2004, Phillips et al 2006). Geo-referenced observations of each target species were assembled by project teams and filtered, as needed, to produce a set of reliable and seasonally-appropriate points. For each species MAXENT will summarize the points in terms of six climatic variables that preliminary


**Figure 2: Northwest GAP states.**

analyses indicated are both reliable predictors of presence and also uncorrelated with one another. Each resulting map will be assigned a quantitative quality rank derived from MAXENT output statistics.

Biologically-suitable environments will be land cover types, in the NWGAP land cover dataset, deemed by regional experts as suitable for occupation by each target species. For each species an initial list of suitable land cover types was produced by cross-walking suitable types from each of the five state's previous GAP project to current land cover map types. These initial lists were edited by project teams, and will be further edited by a wider audience of biologists in fall 2010. Resulting maps will be assigned general quality rankings derived from expert review.

The final distribution map for each target species will be the spatial intersection of physically- and biologically-suitable environments. These maps will be assigned general quality ranks derived from the ranks of the two component maps, and will be delivered in winter 2011.

Habitat quality is the degree to which an environment contributes to positive rates of survival and reproduction for a given species. For each species, we will map habitat quality on a *high-medium-low* scale via two modifications of its distribution map. First, the habitat quality of small and isolated patches of suitable environment will be designated *low*, on the general assumption that such patches support low rates of survival and reproduction. Second, we are polling experts on the relative habitat quality of land cover types for each species. This input will allow us to grade all suitable environments by habitat quality; i.e., the two-category (*present, absent*) distribution map will be converted into a four-category (*high, medium, low, absent*) habitat quality map. We anticipate delivery of final habitat quality maps in winter 2011.

## Alaska Gap Analysis Project Species Modeling Update

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The Alaska Gap Analysis Project (www.akgap.info) is a joint project spanning three University of Alaska campuses (Anchorage, Fairbanks, and Juneau). The Alaska Natural Heritage Program, at the University of Alaska, Anchorage, is coordinating the species modeling effort and is responsible for producing and disseminating final models and other project related data products.

The objective of AKGAP is to produce spatially explicit models that predict the range and distribution of Alaska's terrestrial vertebrate species a to support analysis of conservation status. To address some of the challenges associated with deductive modeling techniques that crosswalk species habitat associations to land cover classes, we are using a combination of deductive and inductive modeling techniques and using methods similar to NWGAP (Aycrigg and Beauvais 2008). By combining the strengths of these two modeling techniques, we aim to produce more robust distribution models that are of high utility to resource managers.

During the first year of a 3-year project (2009-2011), we focused on the selection of 435 target species, formation of species-expert and review teams, establishment of a data-gathering framework, collating occurrence data for inductive modeling, and producing preliminary watershed-scale range maps for each of the target species.

In the second year, we have transitioned to the modeling process by focusing on refinement of analytical methods, including development of preliminary inductive and deductive models, populating the habitat-associations database and conducting the cross-walk of habitat descriptions from the literature to ecological systems from the LANDFIRE legend, producing final expert-reviewed range maps, collating ancillary data layers necessary for both deductive and inductive modeling and deriving new layers from existing layers. We conducted a modeling workshop to test the effectiveness of modeling methods and developed techniques to automate the process. We also completed the synthesis of occurrence data, now totaling more than1.5 million records from 650 unique data sources.

During the final year, we will focus on running inductive and deductive models independently and then combining inductive and deductive models to produce draft final distribution models. We will validate the models to assess model accuracy and facilitate a comprehensive expert review process. Lastly, we will incorporate expert comments to produce final distribution maps, prepare associated metadata, and complete a project report.

## Modeling Wildlife Habitat throughout the Western United States: A Prototype for Use in Gap Analysis

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New Mexico State University is currently completing a project combining NWGAP and SWReGAP species models to create western-wide species distribution models. This project is a prototyping effort to identify the process and methods for species habitat modeling over the Western US. The objectives were to identify species to use as prototypes, combine existing species deductive models, obtain species occurrences points for inductive modeling, and conduct inductive modeling using biophysical envelope datasets. Our goal was to compare the deductive and inductive models with regards to modeling technique and effort.

We identified 69 species of greatest conservation need (SGCN) as designated by the State Wildlife Action Plans (SWAPs) as well as species of concern from state wildlife agencies, Partners in Flight, and Joint Ventures. To support the National Gap Analysis Program, we also included deductive models for an additional 70 species to complete their US range.

Using the selected species, we obtained the models from SWReGAP and NWGAP to merge datasets for western-wide and future nationwide application. Consolidation of species ranges was a priority and the National Gap Analysis Program has been incorporating these for the entire nation based on 12-digit HUCs. For initial modeling, we used the SWReGAP habitat modeling database modified to include 283 land cover types identified in the Western GAP land cover dataset. We also created additional datasets of elevation, aspect, slope, distance to springs, distance to lakes, and distance to perennial streams. Data for California was included with use of the California Wildlife Habitat Relationship database. Our process was similar to the SWReGAP process in that we ran models at 240-m resolution to identify general model characteristics and then ran refined models at 30-m resolution.

Inductive modeling requires species occurrence records and environmental variables to define the species habitat relationships. We obtained species occurrence records from NWGAP, state natural heritage programs, and online databases (e.g., Global Biodiversity Information Facility and Arctos). We obtained 550,208 total records with 265,190 (48%) reflecting museum records. Because maximum entropy (MAXENT) was used for NWGAP and applied to a project related to SWReGAP, we used it to model the selected species (Phillips et al. 2004, Phillips et al 2006, Boykin et al. 2008). We reviewed various climate datasets, such as WorldClim, Daymet, and PRISM (Parameter-elevation Regressions on Independent Slopes Model). Based on Daly et al.'s (2008) comparison of these three datasets, we used the PRISM dataset. To maintain temporal relevancy with the PRISM dataset, we only included occurrence records from 1971 to present.

Bioclimatic envelopes were created for each species in MAXENT. Initially, we used 19 bioclimatic variables derived from PRISM and then reduced each model's variables with a standardized procedure, and analyzed the final model using the area under the curve (AUC) metric, omission rates, and fractional area prediction rates.

The inductive models were converted to binary envelopes to combine the final climatic model with the deductive biophysical models and to mask out the biophysical range of the species. Two commonly used thresholds for creating binary envelopes out of the probability surface were used. We are currently comparing species specific models and will complete this project in 2010.

## Southeast Gap Analysis Project Species Modeling Update

**Steve Williams**
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Predicted habitat maps for Southeast Gap Analysis Project (SEGAP) have been created for all terrestrial vertebrate species that breed in the Southeastern U.S. or use habitat there for an important part of their life history. Decisions were made on which species were mapped based on standard GAP guidelines. Species lists were created for each of the nine southeastern states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee and Virginia) by state-level GAP projects; these lists were compiled and pared down to remove some subspecies and domesticated species. Subspecies were only included when supported as distinct and non-overlapping from either the full species or other subspecies. The final list includes 606 species of amphibians, mammals, reptiles, breeding birds, and wintering waterfowl.


All species' geographic known range extents were delineated as single or multiple polygons. Migratory species were primarily represented by breeding season ranges; however, wintering ranges for waterfowl and migratory bats were also delineated (33 species). Processes used to create range polygons were unique because information on the current geographic range of a species varied widely. However, a generalized approach used a variety of sources to develop species' ranges including information in two broad categories: 1) species location records and range maps available digitally or in print, and 2) digital spatial data of environmental parameters including watersheds and ecoregions (Omernik 1987, 1995).

Deductive models of presence/absence for a species' habitat may include a number of spatially explicit data sources. GAP models typically involve land use/land cover data as the primary input. However, other environmental features that make up the landscape constituting species' habitats can be valuable inputs to modeling.

SEGAP attempted to use ancillary data (e.g., soils, elevation, and stream velocity) in addition to land cover to develop species models. Many of these data layers act as surrogates for one or more aspects of a species' habitat that may only be inferred from available, remotely sensed information. The final SEGAP species models are being incorporated into the national data framework of the National Gap Analysis Program.

### Northeast Gap Analysis Project Species Modeling Update

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The Northeast Gap Analysis Project (NEGAP) began in 2008 and is being developed within the newly developed national data framework of the National Gap Analysis Program. It will build upon the national wildlife habitat relationship database, known range dataset, and recently completed national ancillary datasets used in deductive habitat modeling.

Of the 291 NEGAP bird species, 199 draft models have been developed currently. To target species that are of high conservation concern for state wildlife agencies, models for the remaining bird species (92) identified as SGCN by Northeastern SWAPs are also being developed. Subsequently; 248 mammals, reptiles, and amphibians, which are SGCN species, will be modeled. To build upon the national data framework, each species will be modeled throughout its entire known range within the continental US, rather than only for its NEGAP extent. In addition to these targeted SGCN species, other species as identified by conservation partners through joint workshops with the Northeast Landscape Conservation Cooperative and the Atlantic Coast Joint Venture may be added to the initial efforts. The species identified through these workshops will form the basis of a conservation design effort. NEGAP species models are anticipated to be completed in 2011.

## Species Groups Modeling Efforts

### Overview of Nationwide Bird Modeling

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This project, which began in 2009, was the first to begin mapping and modeling species over their entire range, which included up to the entire continental US. This project expanded upon the modeling processes used by SEGAP and SWReGAP, which adopted a deductive modeling approach that was based on information put into a wildlife habitat relationship database and spatial ancillary data, such as land cover, elevation, and slope. The species included in the project were a subset of all the birds included in the national species lists and were considered conservation priority species. We decided to focus on birds for this initial national modeling effort because of conservation interest by Partners in Flight and state partners in the SWAPs. Some of the bird species included had previously been modeled by SEGAP or SWReGAP. This project built upon those models to create models that covered the entire species range.

The initial step was to create species range maps, which were a compilation of SEGAP, SWReGAP, and NatureServe range maps. These were created by attributing 12-digit HUCs within a species' range with origin (e.g., native, introduced), presence (e.g., known, historic), reproductive use, and season (e.g., winter, summer). Each range was reviewed for accurate representation of each species.

We also modified existing wildlife habitat relationship databases from SEGAP and SWReGAP to create a national wildlife habitat relationship database, which is the database that all national species deductive modeling efforts are using. This project populated this database with information on habitat associations from a literature review of peer-reviewed and gray literature for the selected bird species.

Because this was the first project to create national species distribution models, it was also the first to need national coverages of ancillary data. The GAP National Land Cover data were available for use from the National Gap Analysis Program. However, the project team had to create the additional necessary national ancillary data, which included elevation, slope, aspect, distance from forest edge, forest interior patches, percent canopy cover, hydrography (proximity to water, fresh, brackish or salt water, and salinity), stream velocity, and human impacts.

This project was completed in 2010 and produced species distribution models for 322 bird species of conservation concern. It also produced all the national ancillary data needed for additional modeling at the national scale as well as the national wildlife habitat relationship database. This project positioned the National Gap Analysis Program and all its partners well for continuing to produce national level deductive models.

## Overview of Nationwide Reptile Modeling

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NMSU is currently modeling species distributions for 150 reptiles across their entire range within the US. The overall goal is to create, review, and finalize nationwide species distribution models for all reptile species. Specific objectives of this research include: 1) Identify a list of approximately 150 reptile species to model; 2) Research species habitat associations and compile the information in the national wildlife habitat relationship database; 3) Complete deductive habitat models; 4) Review models for accuracy and work with species experts to have these models reviewed; and 5) Continued cooperation with National Gap Analysis Program, state and federal agencies, and non-governmental organizations.

Currently, we are identifying a list of up to 150 reptiles on which to focus our effort. These species will be identified at the species level, unless specific modeling or management issues are identified to warrant the inclusion of subspecies and sufficient data are available to create a representative subspecies model.

Adopting processes used and documented by SWReGAP, SEGAP, and NWGAP efforts and the mapping strategy identified by the National Gap Analysis Program; we are creating habitat models for each species by reviewing literature to include state, regional, and national species accounts, state wildlife agency online databases, and primary literature in order to populate the national wildlife habitat relationship database. Specific notations on each species will include the potential for inductive modeling, additional datasets that could be useful in modeling (e.g. soils), and other informative details to help substantiate the deductive models and provide for further model refinement. Species experts will be contacted when possible to obtain the most recent information.

We are working with the National Gap Analysis Program and North Carolina State University (NCSU) in populating the database, running the models, reviewing the models, and finalizing the models. Extensive cooperation is necessary and leads to constructive feedback on reptile species range maps and models. This project is anticipated to be complete in 2011.

## Incorporating Interspecific Relationships to Map Secondary Cavity User Distributions

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Primary cavity excavators (PCEs) such as woodpeckers are considered to be an ecologically important guild due to their excavation of cavities. Approximately 100 species of birds and mammals are secondary cavity users (SCUs) and utilize cavities for nesting and/or roosting (Aitken and Martin 2007). These secondary cavity users cannot excavate their own cavities, and thus may depend on the cavities that are excavated by woodpeckers in areas where natural cavities are limited.

Although many ecologists have recognized that functional dependencies exist between primary cavity excavators and secondary cavity users, much remains to be learned about the ecological importance of these relationships. Woodpecker-excavated cavities reflect the size of the excavator, and generally, these cavities are only as large as they need to be for users to enter (Jackson and Ouelette 2002, Walters et al. 2002). Secondary cavity users range from small passerines and mammals to large cavity nesting ducks, and not all woodpecker-excavated cavities are likely to provide adequate nest/roost sites. For instance, cavity-nesting ducks in coniferous forests are likely restricted to areas where either Pileated woodpeckers (*Dryocopus pileatus*) or Northern flickers (*Colaptes auratus*) exist; other woodpecker species create cavities that are too small for this group. Therefore, specific relationships between secondary cavity users and primary cavity excavators might exist, and these relationships are important to consider when mapping species distributions of secondary cavity users.

The major objectives of this project are to: 1) Review the peer-reviewed literature to determine the current state of knowledge relative to secondary cavity user dependencies on specific primary cavity excavators, 2) Incorporate those dependencies into GAP maps by intersecting secondary cavity user distributions with specific excavator distributions, and 3) Evaluate how secondary cavity user distributions within and outside of protected lands change with the incorporation of primary cavity excavator distributions.

To date, we have completed the review of peer-reviewed literature to determine the current state of knowledge relative to secondary cavity user dependencies on specific primary cavity excavators (Vierling et al. in prep). These data were based on peer-reviewed literature only, and search terms were not restricted by region. In general, some regions, such as the Southwest, contain more information about PCE/SCU relationships than other regions (Vierling et al. in prep).

In order to assess how secondary cavity user distributions change with the inclusion of primary cavity excavator distributions; we are focusing our initial efforts on the SWReGAP region. Species distribution maps in this region have been recently revised, and multiple studies from this region explicitly describe relationships between secondary cavity users and specific primary cavity excavators. The mapping of secondary cavity user distributions with the incorporation of primary cavity excavator relationships is ongoing and is expected to be completed in 2011.

## Literature Cited


Aitken, K. E. H., and K. Martin. 2007. The importance of excavators in hole-nesting communities: availability and use of natural tree holes in old mixed forests of western Canada. Journal of Ornithology 148: 425-434.

Aycrigg, J., and G. Beauvais. 2008. Novel approaches to mapping vertebrate occurrence for the Northwest Gap Analysis Project. Gap Analysis Bulletin 15: 27-33.

Boykin, K. G., D. F. Bradford, and W. G. Kepner. 2008. Habitat Distribution Models for 37 Vertebrate Species in the Mojave Desert Ecoregion of Nevada, Arizona, and Utah. U.S. Environmental Protection Agency, Office of Research and Development (EPA/600/R-08/117, 124 pp.).

Crother, B. I. 2008. Scientific and standard English names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding. 6th edition. Herpetological Circular No. 37, Society for the Study of Amphibians and Reptiles.

Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. A. Pasteris. 2008. Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States. International Journal of Climatology 28: 2031-2064.

Jackson, J. A., and H. R. Ouellet. 2002. Downy Woodpecker (*Picoides pubescens*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/613.

Morrison, M. L., and L. S. Hall. 2002. Standard terminology: Toward a common language to advance ecological understanding and application. Pages 43-52 in Predicting Species Occurrences: Issues of accuracy and scale. Eds. J. M. Scott, P. J. Heglund, and M. L. Morrison, et al., Island Press.

Phillips, S. J., M. Dudik, R. E. Schapire. 2004. A maximum entropy approach to species distribution modeling. Proceedings of the 21st International Conference on Machine Learning, Banff, Canada, 2004. 655-662.

Phillips, S. J., R. P. Anderson, R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190:231-259.

Vierling, K. T., B. Linkhart, P. Adam, J. Aycrigg, J. Pollock, G. Sadoti, D. Vent, J. Vogeler, and L.A. Vierling. 2010. Evaluating known secondary cavity user dependencies upon cavity excavators: identifying future needs for conservation and management. *In prep*

Walters, E. L., E. H. Miller, and P. E. Lowther. 2002. Red-naped Sapsucker (*Sphyrapicus nuchalis*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/663b.

Wilson, D. E., and D. M. Reeder. 2005. Mammal Species of the World. A Taxonomic and Geographic Reference, 3rd edition. Johns Hopkins University Press.