gap

KEEPING COMMON SPECIES COMMON

Gap Analysis BULLETIN

No. 16

A Geographic Approach to Planning for Biological Diversity

U.S. Department of the Interior
U.S. Geological Survey

2008

USGS
science for a changing world

Contents

FEATURES

APPLICATIONS

AQUATIC

INTERNATIONAL

continued on back cover

The Gap Analysis Program ... in Brief

The Mission of the Gap Analysis Program (GAP) <http://gapanalysis.nbii.gov> is to promote conservation by providing broad geographic information on biological diversity to resource managers, planners, and policy makers who can use the information to make informed decisions.

As part of the National Biological Information Infrastructure (NBII) <http://www.nbii.gov>—a collaborative program to provide increased access to data and information on the nation's biological resources--GAP data and analytical tools have been used in hundreds of applications: from basic research to comprehensive state wildlife plans; from educational projects in schools to ecoregional assessments of biodiversity.

The challenge: keeping common species common means protecting them BEFORE they become threatened. To do this on a state or regional basis requires key information such as land cover descriptions, predicted distribution maps for native animals, and an assessment of the level of protection currently given to those plants and animals.

GAP works cooperatively with Federal, state, and local natural resource professionals and academics to provide this kind of information. GAP activities focus on the creation of state and regional databases and maps that depict patterns of land management, land cover, and biodiversity. These data can be used to identify "gaps" in conservation--instances where an animal or plant community is not adequately represented on the existing network of conservation lands.

GAP is administered through the U.S. Geological Survey. Through building partnerships among disparate groups, GAP hopes to foster the kind of collaboration that is needed to address conservation issues on a broad scale.

For more information, contact:

John Mosesso
National GAP Director
703-648-4079

Kevin Gergely
National GAP Operations Manager
208-885-3565

FEATURES

Improving the Characterization and Mapping of Wildlife Habitats With Lidar Data: Measurement Priorities for the Inland Northwest, USA

Sebastián Martinuzzi[1], Lee A. Vierling[1], William A. Gould[2], Kerri T. Vierling[3]

Introduction

The development of region- and nation-wide predictive assessments of wildlife species distribution and habitat availability is a major component of the U.S. Geological Survey (USGS) Gap Analysis Program (GAP), which provides critical information for conserving biodiversity in the United States (Scott et al. 1993). Despite continuous advances in predictive modeling tools, the lack of detailed and accurate geospatial data is still a recognized, major challenge to improve species distribution modeling (Guisan and Zimmermann 2000). Current predictions, for example, are based on environmental geospatial data that do not reflect the three-dimensional characteristics of vegetation (Gottschalk et al. 2005; McDermid et al. 2005; Leyequien et al. 2007), an important variable for determining the distribution and abundance of wildlife species (MacArthur and MacArthur 1961; Brokaw and Lent 1999). Modeling species distribution using environmental data that do not adequately represent important species-environment relationships can result in predictions that contain some level of uncertainty and error (Fielding and Bell 1997; Beutel et al. 1999; Guisan and Zimmermann 2000), affecting species conservation and biodiversity assessments such as those made through the GAP.

Light detection and ranging (lidar) is a relatively new source of geospatial data that, contrary to most available remote sensing technologies, provides fine-grained information about the 3-D physical structure of terrestrial and aquatic ecosystems (Lefsky et al. 2002), opening a novel spectrum of possibilities for characterizing wildlife habitats with remote sensing (Vierling et al. 2008). In forested environments, for example, lidar data have been useful for quantifying vegetation structure in terms of biomass (e.g. basal area and tree diameter), percent canopy cover, tree height, tree density, for separating forest successional stages and to characterize subcanopy topography (e.g. Nelson et al. 1988; Harding et al. 2001; Drake et al. 2002; Hofton et al. 2002; Hudak et al. 2006). Recent studies evaluating the utility of lidar for mapping understory shrubs and snag density also yield positive results (Goodwing 2006; Bater 2008). Although lidar data recently have been utilized to investigate local-scale wildlife habitat quality as it relates to avian biology (e.g. Hinsley et al. 2002, 2006; Hill et al. 2004; Broughton et al. 2006; Goetz et al. 2007, Clawges et al. 2008) and fish biology (Jones 2006; McKean et al. 2008), application of lidar data to broad scale species distribution prediction is still in the exploratory stage (see Vierling et al. 2008).

Lidar data acquisitions are typically localized efforts conducted over small areas, and therefore these local efforts have not been ideal for the scales at which GAP work (e.g. state, region, country). However, an increasing number of states currently have or soon plan to have full lidar coverage (e.g. Florida, Iowa, Louisiana, Pennsylvania, North Carolina, Ohio, and Texas). Moreover, as a result of increasing demands from State and Federal agencies, academia, and private industry, the U.S. government is currently evaluating the feasibility and strategy for a national acquisition of high resolution, high accuracy lidar data for all 50 states. This

[1] Geospatial Laboratory for Environmental Dynamics, College of Natural Resources, University of Idaho, Moscow, ID.

[2] International Institute of Tropical Forestry, U.S. Department of Agriculture, Forest Service, Río Piedras, PR.

[3] Department of Fish and Wildlife Resources, University of Idaho, Moscow, ID.

effort is known as the "National Lidar Initiative" (NLI) and is organized by the USGS (Stoker et al. 2007). According to the Center for Lidar Information Coordination and Knowledge (http://lidar.cr.usgs.gov/), the NLI "is currently in the early stages of determining viability, developing what this dataset should look like, what kinds of information contained in a lidar signal are most important for the U.S. people, and what each stakeholders' roles and responsibilities could be".

The objective of this study was to evaluate which habitat structure variables are needed to refine GAP species distribution predictions, in order to identify priorities in developing lidar-derived products. This study was focused on avian and mammal species inhabiting the Inland Northwest, U.S. In this region, previous efforts to predict species distribution with traditional remote sensing data (e.g. Landsat) indicated that the distribution of many wildlife species likely has been overestimated due to the incapability of incorporating information (i.e. constraints) about vegetation structure (Scott et al. 2002). For example, species that are known to occur in closed forests have been predicted to occur in all forests (closed and open) due to the lack of geospatial data about percentage of tree canopy cover. Information from this report has direct implications for further ecological applications of lidar data, including from the NLI, and could have long-term ramifications for improving GAP species distribution predictions and land cover characterization.

Methods

First, we identified the mammal and avian species whose predicted habitat distribution has been overestimated, according to Scott et al. (2002). Scott et al. (2002) also provide information about the type of habitat variables needed to improve the predicted distribution of various species. We refined and expanded the habitat information using published material from habitat suitability models, such as those developed by the U.S. Fish and Wildlife Service. For example, Scott et al. (2002) indicated that the predicted distribution of the pileated woodpecker likely was overestimated due to the lack of geospatial data about the presence of snags, which are a large determinant of the species habitat distribution. According to the habitat suitability model for the pileated woodpecker, not only the size and density of snags, but also the percentage of tree canopy cover, are important variables for predicting the distribution of the species (Schroeder 1982). We then combined all the information about the species whose habitat distribution has been overestimated with the potential habitat variables needed to refine the predictive species distribution models (Table 1).

We included information (i.e. habitat variables) about vegetation structure as well as topography. Scott et al. (2002) indicated that the original topographic data or digital elevation model was not adequate to characterize relevant habitat features for certain species. Lidar, on the other hand, is the best available technology for topographic mapping. In addition, Table 1 lists seven species whose predicted distribution performed well according to Scott et al. (2002), but that may benefit from Lidar data due to the high affinity of the species to structural characteristics of vegetation. Examples of these species are the downy woodpecker and hairy woodpecker, whose presence depends on the availability of snags, among other factors.

Results and Conclusion

We identified a total of eleven variables of habitat structure potentially suitable for refining GAP predictions of species distribution. These variables included, for forests, (1) percent of tree canopy cover, (2) some measure of forest stand biomass, such as the mean tree diameter, basal area, or age, (3) diameter and density of snags, (4) height of overstory trees, (5) diversity of the tree canopy (i.e. number of canopy strata), (6) tree density, and (7) percentage of understory shrub cover. For rangelands, the important variables were the height and percentage of shrub cover, as well as the height of the grasses. Finally, in terms of topography, important variables included rock outcrops (i.e. identification of rocky areas), and morphological measures of streams, creeks, and canyons (Table 1).

The list included a total of 86 species, including 66 avian species and 20 mammal species, equivalent to almost 30 percent and 20 percent of all the avian and mammal species present in Idaho. In addition, 10 of the 86 species are identified as species of greatest conservation need in the Idaho Fish and Game's Comprehensive Wildlife Conservation Strategy. We believe the list of species presented in this study may represent a conservative lower-bound of the actual overall number of species whose predictive distribution models would benefit from the inclusion of lidar-derived data, because the structural habitat preferences of many vertebrate species are either unknown or often not reported.

Table 1. Species and lidar-derived habitat variables.

Common name	Scientific name	Tree canopy cover (percent)	Tree diameter/ basal area/ age	Density and diameter of snags	Overstory tree height	Tree canopy diversity	Tree density	Shrub canopy cover, including understory shrubs (percent)	Shrub canopy height (percent)	Grass height	Rock outcrops	Stream/ creek/ canyon morphology
Avian species												
American dipper	*Cinclus mexicanus*											X
Bald eagle[1]	*Haliaeetus leucocephalus*		X									
Barred owl	*Strix varia*	X	X				X					
Belted kingfisher	*Ceryle alcyon*											X
Black-capped chickadee	*Poecile atricapilla*	X		X	X							
Black-headed grosbeak	*Pheucticus melanocephalus*	X										
Blue grouse	*Dendragapus obscurus*	X						X	X	X		
Blue-gray gnatcatcher	*Polioptila caerulea*	X										
Brewer's blackbird	*Euphagus cyanocephalus*	X										
Brewer's sparrow[1,2]	*Spizella breweri*							X	X			
Broad-tailed hummingbird	*Selasphorus platycercus*	X										
Brown-headed cowbird	*Molothrus ater*	X										
Cassin's finch	*Carpodacus cassinii*	X										
Cassin's vireo	*Vireo cassinii*	X						X				
Canyon wren	*Catherpes mexicanus*											X
Cedar waxwing	*Bombycilla cedrorum*	X										
Chestnut-backed chickadee	*Poecile rufescens*	X										
Chipping sparrow	*Spizella passerine*	X										
Clark's nutcracker	*Nucifraga columbiana*	X										
Common goldeneye	*Bucephala clangula*		X									
Common nighthawk	*Chordeiles minor*	X										
Common poorwill	*Phalaenoptilus nuttallii*	X										
Common raven	*Corvus corax*	X										
Cordilleran flycatcher	*Empidonax occidentalis*	X										
Downy woodpecker[2]	*Picoides pubescens*		X	X								
Dusky flycatcher	*Empidonax oberholseri*	X						X				

Table 1. Species and lidar-derived habitat variables.—Continued

Common name	Scientific name	Tree canopy cover (percent)	Tree diameter/ basal area/ age	Density and diameter of snags	Overstory tree height	Tree canopy diversity	Tree density	Shrub canopy cover, (including understory shrubs) (percent)	Shrub canopy height (percent)	Grass height	Rock outcrops	Stream/ creek/ canyon morphology
Avian species—Continued												
Ferruginous hawk[1]	*Buteo regalis*							X	X	X		
Flammulated owl[1]	*Otus flammeolus*	X										
Fox sparrow	*Passerella iliaca*	X										
Golden eagle	Aquila chrysaetos	X										
Great gray owl	Strix nebulosa	X										
Greater sage grouse[1]	Centrocercus urophasianus	X										
Hairy woodpecker[2]	*Picoides villosus*	X	X	X								
Hammond's flycatcher	*Empidonax hammondii*							X				
Lark bunting	*Calamospiza melanocorys*									X		
Lark sparrow	*Chondestes grammacus*	X										
Lazuli bunting	*Passerina amoena*	X						X				
Lesser scaup[1,2]	*Aythya affinis*							X		X		
Lewis' woodpecker[1]	*Melanerpes lewis*	X		X				X				
Lincoln's sparrow	*Melospiza lincolnii*							X				
Loggerhead shrike	*Lanius ludovicianus*	X										
Long-eared owl	*Asio otus*	X										
Macgillivray's warbler	*Oporornis tolmiei*							X				
Mountain bluebird	*Sialia currucoides*							X				
Nashville warbler	*Vermivora ruficapilla*							X				
Northern flicker	*Colaptes auratus*	X										
Northern goshawk	*Accipiter gentiles*	X										
Northern pygmy-owl	*Glaucidium gnoma*	X										
Northern saw-whet owl	*Aegolius acadicus*	X										
Olive-sided flycatcher	*Contopus cooperi*	X						X				
Orange-crowned warbler	*Vermivora celata*							X				
Oregon (Dark-eyed) junco	*Junco hyemalis*	X										
Peregrine falcon[1]	*Falco peregrinus anatum*	X										
Pileated woodpecker	*Dryocopus pileatus*	X		X								
Red-breasted nuthatch	*Sitta Canadensis*	X										

Table 1. Species and lidar-derived habitat variables.—Continued

Common name	Scientific name	Tree canopy cover (percent)	Tree diameter/ basal area/ age	Density and diameter of snags	Overstory tree height	Tree canopy diversity	Tree density	Shrub canopy cover, (including understory shrubs) (percent)	Shrub canopy height (percent)	Grass height	Rock outcrops	Stream/ creek/ canyon morphology
					Avian species—Continued							
Red-tailed hawk	*Buteo jamaicensis*	X										
Rock wren	*Salpinctes obsoletus*	X									X	
Ruffed grouse	*Bonasa umbellus*								X			
Spotted towhee	*Pipilo maculates*							X				
Townsend's warbler	*Dendroica townsendi*	X	X									
Turkey vulture	*Cathartes aura*	X										
Veery[2]	*Catharus fuscescens*							X	X	X		
Warbling vireo	*Vireo gilvus*							X				
Western tanager	*Piranga ludoviciana*	X										
Wilson's warbler	*Wilsonia pusilla*							X				
Yellow warbler[2]	*Dendroica petechia*							X	X			
	Total	44	6	5	1	0	1	20	6	5	1	3
					Mammal Species							
American beaver[2]	*Castor Canadensis*	X	X					X	X			
American pika	*Ochotona princeps*										X	
Bobcat	*Lynx rufus*	X										
Bushy-tailed woodrat	*Neotoma cinerea*	X										
Coyote	*Canis latrans*	X										
Elk	*Cervus elaphus*	X										
Fisher[1]	*Martes pennant*	X	X			X						
Fox squirrel	*Sciurus niger*	X	X					X				
Golden-mantled ground squirrel	*Spermophilus lateralis*	X										
Hoary bat	*Lasiurus cinereus*			X								
Hoary marmot	*Marmota caligata*										X	
Long-legged myotis	*Myotis volans*			X								
Long-tailed vole	*Microtus longicaudus*	X										
Mule deer	*Odocoileus hemionus*	X										
Northern flying squirrel	*Glaucomys sabrinus*		X									
Pronghorn	*Antilocapra americana*							X	X			
Red-tailed chipmunk	*Tamias ruficaudus*	X										

Table 1. Species and lidar-derived habitat variables.—Continued

Common name	Scientific name	Tree canopy cover (percent)	Tree diameter/ basal area/ age	Density and diameter of snags	Overstory tree height	Tree canopy diversity	Tree density	Shrub canopy cover, (including understory shrubs) (percent)	Shrub canopy height (percent)	Grass height	Rock outcrops	Stream/ creek/ canyon morphology
						Mammal Species—Continued						
Rock squirrel[1]	*Spermophilus variegates*										X	
Southern red-backed vole	*Clethrionomys gapperi*	X	X									
White-tailed jack rabbit	*Lepus townsendii*	X										
	Total	13	5	2	0	1	0	3	2	0	3	0
	Grand total	**57**	**11**	**7**	**1**	**1**	**1**	**23**	**8**	**5**	**4**	**3**

[1] Species of greatest conservation need in Idaho.

[2] Species whose predicted distribution performed well according to Scott et al. (2002), but which may benefit from lidar data.

According to the total number of species associated with each habitat variable (reported at the end of Table 1), the results of this study indicated that the most needed variables are (in order of importance): (1) percentage of tree canopy cover, (2) percentage of shrub canopy cover (including understory shrubs), (3) some measure of stand biomass (mean tree diameter/basal area/age), (4) shrub height, and (5) size and density of snags. Although lidar has been used to successfully quantify tree canopy cover and biomass in different forest types, little is known about the capabilities of this new technology for mapping the distribution of snags, and for measuring the characteristics of the shrub layer (whereas as part of the forest understory or in rangelands) (Goodwing 2006; Bater 2008). More research on these topics would serve to better evaluate the potential of lidar data to characterize wildlife habitats and support predictions of species distribution. In addition, to facilitate ecological and conservation applications of broad-scale lidar data such as those from the NLI, further studies should evaluate the type of information about the structural characteristics of habitats needed to model wildlife species distribution and habitat availability in other regions and across different taxa. For example, while information about vegetation structure is important for birds and mammals, information about microtopography appears to be critical for improving assessments of reptile habitats (C. Peterson, oral commun., 2007). An additional benefit of lidar data is that it allows the development of products and maps at a high spatial resolution, suitable not only for vegetation assessments in upland areas but also in riparian zones, which are important habitat features for wildlife species but are particularly challenging to map with traditional (i.e. 30-m pixel) remote sensing technologies (Goetz 2006).

The impending acquisition of a U.S.-wide lidar dataset has the potential to provide new and relevant geospatial data, suitable for supporting and refining GAP predictions of species distribution and further species conservation assessments for the United States. In order to take maximum benefit from current and future lidar data for GAP related purposes, further studies should evaluate the performance of species distribution models with and without lidar data, and its consequences for GAP assessments of wildlife species distribution and conservation. Finally, we recommend that GAP continue to work in cooperation with a variety of governmental, private and non-governmental organizations to achieve nationwide improvements in remotely-sensed habitat mapping.

Acknowledgments

This work was made possible though funding by the USGS Gap Analysis Program and the USDA Forest Service International Institute of Tropical Forestry (IITF). Two anonymous reviewers provided valuable comments that improved the quality of this paper. Work at IITF is done in collaboration with the University of Puerto Rico.

References Cited

Bater, C.W. 2008. Assessing Indicators of Forest Sustainability Using LiDAR Remote Sensing (Thesis). University of British Columbia, Vancouver, Canada (97 pp.)

Beutel, T.S., R.J.S. Beeton, G.S. Baxter. 1999. Building better wildlife–habitat models. *Ecography* 22:219–223.

Brokaw, N.V.L., and R.A. Lent. 1999. Vertical Structure. Pages 373–399 in M.L. Hunter, editor. *Maintaining Biodiversity in forest ecosystems*. Cambridge, UK, Cambridge University Press.

Broughton R.K., S.A. Hinsley, P.E. Bellamy, R.A. Hill, P. Rothery. 2006. Marsh tit *Poecile palustris* territories in a British broad–leaved wood. *Ibis* 148:744–52.

Clawges, R., K.T. Vierling, L.A. Vierling, E.M. Rowell. 2008. The use of lidar remote sensing to estimate avian species diversity, density, and occurrence in a pine/aspen forest. *Remote Sensing of Environment* 112:2064–2073.

Drake, J., R.O. Dubayah, D.A. Clark, R.G. Knox, B. Blair, M. Hofton, R.L. Chazdon, J.F. Weishampel, and S.D. Prince. 2002. Estimation of tropical forest structural characteristics using large–footprint lidar. *Remote Sensing of Environment* 79:305–319.

Fielding, A.H., and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24: 38–49.

Goetz, S.J. 2006. Remote sensing of riparian buffers: past progress and future prospects. *Journal of the American Water Resources Association* 42:133–143.

Goetz, S., D. Steinberg, R. Dubayah, and B. Blair. 2007. Laser remote sensing of canopy habitat heterogeneity as a predictor of bird species richness in an eastern temperate forest, USA. *Remote Sensing of Environment* 108:254–263.

Goodwing, N.R. 2006. Assessing Understorey Structural Characteristics in Eucalyptus Forests: an investigation of LiDAR techniques (Thesis). University of New South Wales, Sydney NSW Australia (206 pp.)

Gottschalk, T.K., F. Huettmann, and M. Ehlers. 2005. Thirty years of analyzing and modeling avian habitat relationships using satellite imagery data: a review. *International Journal of Remote Sensing* 26:2631–2656.

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

Harding, D.J., M.A. Lefksy, G.G. Parker, J.B. Blair. 2001. Laser altimeter canopy height profiles: methods and validations for closed–canopy, broadleaf forests. *Remote Sensing of Environment* 76:283–297.

Hill, R.A., S.A. Hinsley, D.L.A. Gaveau, and P.E. Bellamy. 2004. Predicting habitat quality for great tits (*Parus major*) with airborne laser scanning data. *International Journal of Remote Sensing* 25:4851–55.

Hinsley, S.A., R.A. Hill, D.L.A. Gaveau, and P.E. Bellamy. 2002. Quantifying woodland structure and habitat quality for birds using airborne laser scanning. *Functional Ecology* 16:851–57.

Hinsley, S.A., R.A. Hill, P.E. Bellamy, and H. Balzter. 2006. The application of lidar in woodland bird ecology: climate, canopy structure, and habitat quality. *Photogrammetric Engineering and Remote Sensing* 72:1399–1406.

Hofton, M.A., L.E. Rocchio, J.B. Blair, and R. Dubayah. 2002. Validation of vegetation canopy lidar sub–canopy topography measurements for a dense tropical forest. *Journal of Geodynamics* 34:491–502.

Hudak, A.T., N.L. Crookston, J.S. Evans, M.J. Falkowski, A.M.S. Smith, P.E. Gessler, and P. Morgan. 2006. Regression modeling and mapping of coniferous forest basal area and tree density from discrete–return lidar and multispectral satellite data. *Canadian Journal of Remote Sensing* 32:126–138.

Jones, J.L. 2006. Side channel mapping and fish habitat suitability analysis using lidar topography and orthophotography. *Photogrammetric Engineering and Remote Sensing* 72:1202–06.

Lefsky, M.A., W.B. Cohen, G.G. Parker, and D.J. Harding. 2002. Lidar remote sensing for ecosystem studies. *BioScience* 52:19–30.

Leyequien, E., C. Verrelst, M. Slot, G. Schaepman-Strub, I.M.A. Heitkönig, A. Skidmore. 2007. Capturing the fugitive: Applying remote sensing to terrestrial animal distribution and diversity. *International Journal of Applied Earth Observation and Geoinformation* 9:1–20.

MacArthur, R.H., and J.W. MacArthur. 1961. On birds species diversity. *Ecology* 42:594–598.

McDermid, G.J., S.E. Franklin, and E.F. LeDrew. 2005. Remote sensing for large–area habitat mapping. *Progress in Physical Geography* 29:449–474.

McKean, J.A., D.J. Isaak, and C.W. Wright. 2008. Geomorphic controls on salmon nesting patterns described by a new, narrow–beam terrestrial–aquatic lidar. *Frontiers in Ecology and the Environment* 6:125–130.

Nelson, R.F., W.B. Krabill, and J. Tonelli. 1988. Estimating forest biomass and volume using airborne laser data. *Remote Sensing of Environment* 24:247–267.

Schroeder, R.L. 1982. Habitat suitability index models: Pileated woodpecker. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS–82/10.39 (15 pp.)

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, J. Ulliman, and R.G. Wright. 1993. Gap Analysis – A geographic approach to protection of biological diversity. *Wildlife Monographs* 123:1–41.

Scott, J.M., C.R. Peterson, J.W. Karl, E. Strand, L.K. Svancara, and N.M. Wright. 2002. A Gap Analysis of Idaho: Final Report. Idaho Cooperative Fish and Wildlife Research Unit. Moscow, ID.

Stoker, J., J. Parrish, D. Gisclair, D. Harding, R. Haugerud, M. Flood, H. Andersen, K. et al. 2007. Report of the First National Lidar Initiative Meeting, February 14–16, 2007, Reston, VA. U.S. Geological Survey Open-File Report 2007–1189.

Vierling, K.T., L.A. Vierling, W. Gould, S. Martinuzzi, R. Clawges. 2008. Lidar: Shedding new light on habitat characterization and modeling. *Frontiers in Ecology and the Environment* 2: 90–98.

Multiple Scale Integrated Range Maps for Modeling Predicted Distributions of Vertebrate Species in the U.S. Virgin Islands

William A. Gould[1] and Mariano Solórzano[2]

Introduction

Biodiversity assessments and conservation management benefit from spatial models that predict species distributions across ranges, interpolating between known occurrences and predicting distribution where suitable habitat occurs within an expected range (Karl et al. 2000, Ferrier 2002, Scott et al. 2002). One of the first steps in a predicted distribution model usually involves development of a species range map used to constrain its distribution. Species range maps have an associated scale and resolution. Occurrences at a point often are extrapolated by attributing a polygon, for example counties, hexagons, or watersheds (Scott et al. 1993; Boykin et al. 2007) using Geographic Information Systems (GIS). Precision and bias of predicted species distributions can be affected by the minimum mapping unit (MMU) used in determining a species range (Stoms 1994, Stockwell and Peterson 2003). Species range maps and distribution models have been developed at many scales and for various uses. There is no consensus about the best range map unit and there is no scale that satisfies all scenarios. This has been described as the modifiable areal unit problem (MAUP) which recognizes a scale effect (Green and Flowerdew 1996). This scale effect is the tendency to obtain different results with the same data (i.e. species occurrence records) when it is grouped at different levels of spatial resolution. A relatively large MMU decreases the amount of information needed to systematically assess species occurrence over an area and develop a range map, but decreases the precision of information. Conversely, a small MMU increases the amount of information needed and may increase the ultimate resolution of the range map, potentially making it a more useful tool for land managers. Typically, the scale selected for an analysis is influenced by size of the area of interest, data availability, and expected use of the predicted distributions.

The Problem

Conservation biologists do a better job of predicting species distributions at coarse scales (continental, regional) than at fine scales (subregional, within reserves or potential reserves) because at coarse scales distributions are constrained by large scale latitudinal gradients as well as other gradients such as climate, seasonality, geography, major vegetation formations, and biome limits. However, land managers and decision makers increasingly are asking researchers for detailed information about the likelihood of particular species presence or absence, species richness, and biodiversity in general for specific land areas as they make management decisions and develop conservation priorities. At fine scales, variability and uncertainty of species distributions becomes more apparent in modeling predicted species distributions and this has an impact on the utility of these predictions as a tool in conservation. Examples of this variability and uncertainty include the amount of area occupied by a species within its range, and the degree of uncertainty about where within its range a species occurs. This variability depends on the ecology of the species, whether the species is a generalist or not in terms of habitat preference, the underlying ecological heterogeneity of the landscape, and the resolution of the range map, (i.e. the size of the minimum mapping unit). The uncertainty of biodiversity assessments is compounded by the variability among species in how they perceive, occupy, and move about the landscape and in the dynamic nature of landscapes at fine scales.

[1] U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, Río Piedras, PR.

[2] U.S. Geological Survey.

Background

The idea behind integrating habitat maps with range maps is that the range map constrains the geographic distribution of a species while habitat maps depict landscape heterogeneity within each minimum mapped unit in the range map. This heterogeneity is ideally described by models of wildlife-habitat relations so that species distribution can be predicted at a fine scale within the known range. A species predicted distribution is often at the scale of meters (i.e. Landsat or other remotely sensed imagery) as opposed to kilometers (i.e. counties, hexagons, watersheds) for range map MMUs. The ideal range map unit is at a scale for which we can assume that where a species occurs within a mapped unit, it occurs throughout that unit, wherever there is habitat available.

As an example of mapping species ranges, most state GAP projects have used a hexagon shape based on the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP) typically used in Gap Analysis (White et al. 1992, Scott et al. 1993). These hexagons have an area of 648 km^2. The 50 U.S. states range in area from 4,000 km^2 to more than 1.7 million km^2 and the mean number of hexagons needed to cover a state is just over 300 (this is a low estimate as hexagons along a state boundary often extend to adjacent states).

In the recently completed Puerto Rico Gap Analysis Project (PR-GAP), we developed range maps for vertebrate species occurring on the islands of Puerto Rico, Vieques, Culebra, Mona, and a number of smaller islands within the commonwealth (Gould et al. 2008). In accomplishing this we addressed the issue of selecting an appropriate MMU for developing range maps. Puerto Rico has an area of 9,000 km^2. Using the 648 km^2 EMAP hexagons recommended as standard GAP protocol (Scott 2007) would have given us few map units and a limited view of the variation in species ranges within Puerto Rico. Additionally, EMAP represents only the conterminous United States and in lieu of EMAP coverage in the Caribbean, we developed the PRGAP-HEX grid with a resolution of 24 km^2 (Figure 1) by tessellating a larger hexagonal grid (an extension of with the EMAP grid to the Caribbean) used in U.S. Forest Service Caribbean Forest Inventory and Analysis (FIA). This hexagon grid covers Puerto Rico and the United States Virgin Islands (USVI) and provides a uniform unit of area to represent the geographic range of vertebrate species across a very heterogeneous landscape—with sharp ecotones over short distances. The final set of 483 hexagons were selected for PRGAP, including 305 occurring only over land, 161 over coastal areas, and 17 over open marine areas with small reefs and cays. The resulting range maps and predicted species distributions have been accepted and used in Puerto Rico by wildlife biologists, students, researchers, land managers, and government agencies.

We are now in the process of conducting a gap analysis of the USVI and have addressed essentially the same question, i.e. "What is the appropriate minimum mapping unit for developing range maps for the USVI Gap Analysis Project?"

Study Area

The U.S. Virgin Islands are located in the Caribbean in the westernmost section of the Lesser Antilles. They include the three main islands of St. Thomas, St. John, and St. Croix. The main islands are surrounded by a considerable number of cays, several of which harbor endemic and endangered species. The total area of the USVI is less than 350 km^2 (Table 1), more than an order of magnitude smaller than the

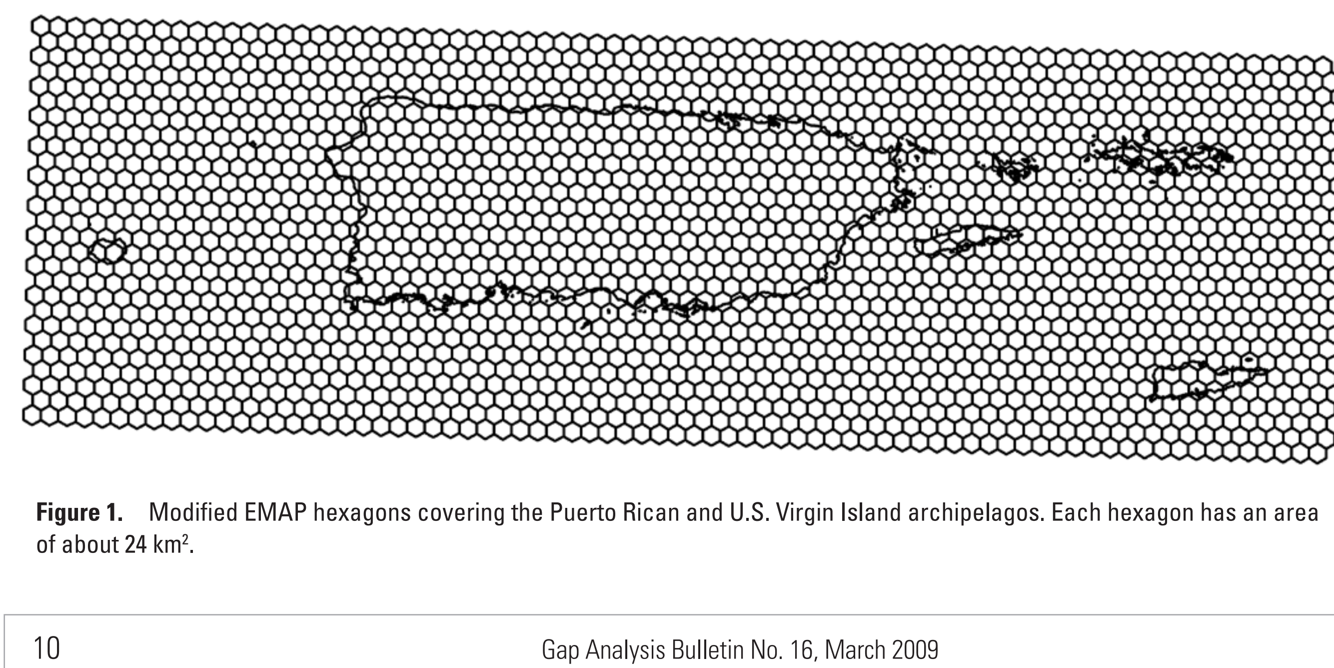


Figure 1. Modified EMAP hexagons covering the Puerto Rican and U.S. Virgin Island archipelagos. Each hexagon has an area of about 24 km^2.

Puerto Rico, yet with relatively high biodiversity (Figure 2) and substantial levels of herpetofaunal endemism for such small islands (Figure 3). As on many other islands of the Caribbean, the USVI natural habitats are under a great deal of pressure from development. Historically, the islands were heavily impacted by agricultural activity (Weaver 2006), with development and urbanization increasing so that a number of species are threatened or endangered locally (Table 2). Distributions of species among the islands and cays are strongly affected by each species' dispersal abilities, human and natural disturbances (i.e. hurricanes), and variability in habitat condition among islands.

Table 1. Minimum map unit size, number of map units, and area in hectares for large and small hexagons and watersheds for St. Thomas, St. John, St. Croix, and the total for the U.S. Virgin Islands.

[**Abbreviations**: HUC, hydrologic unit code; ha, hectare; MMU, minimum map unit; km^2, square kilometer; USVI, U.S. Virgin Islands]

			HUC 10 watersheds		
	Large hexes	Small hexes	With cays	Without cays	Total area (ha)
MMU area (km^2)	24	2	variable	variable	
St. Thomas	21	112	77	13	8,186
St. John	9	55	31	10	5,070
St. Croix	23	155	30	26	21,715
USVI	53	322	138	49	34,972

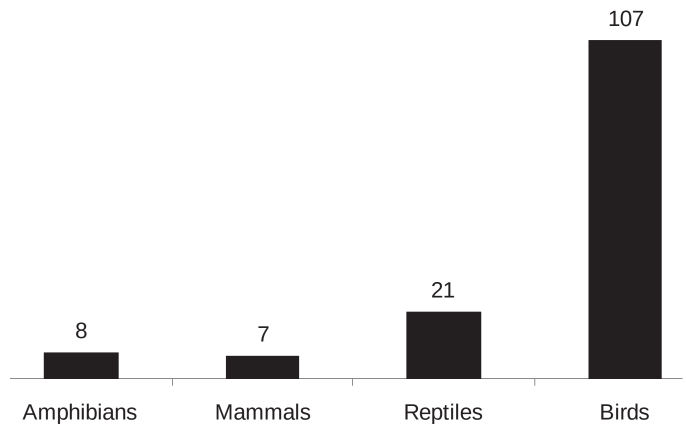


Figure 2. One hundred forty-three species of terrestrial vertebrates occurring in the USVI have been selected for analysis for the USVI GAP project. The majority are bird species, followed by reptiles, amphibians, and mammals.

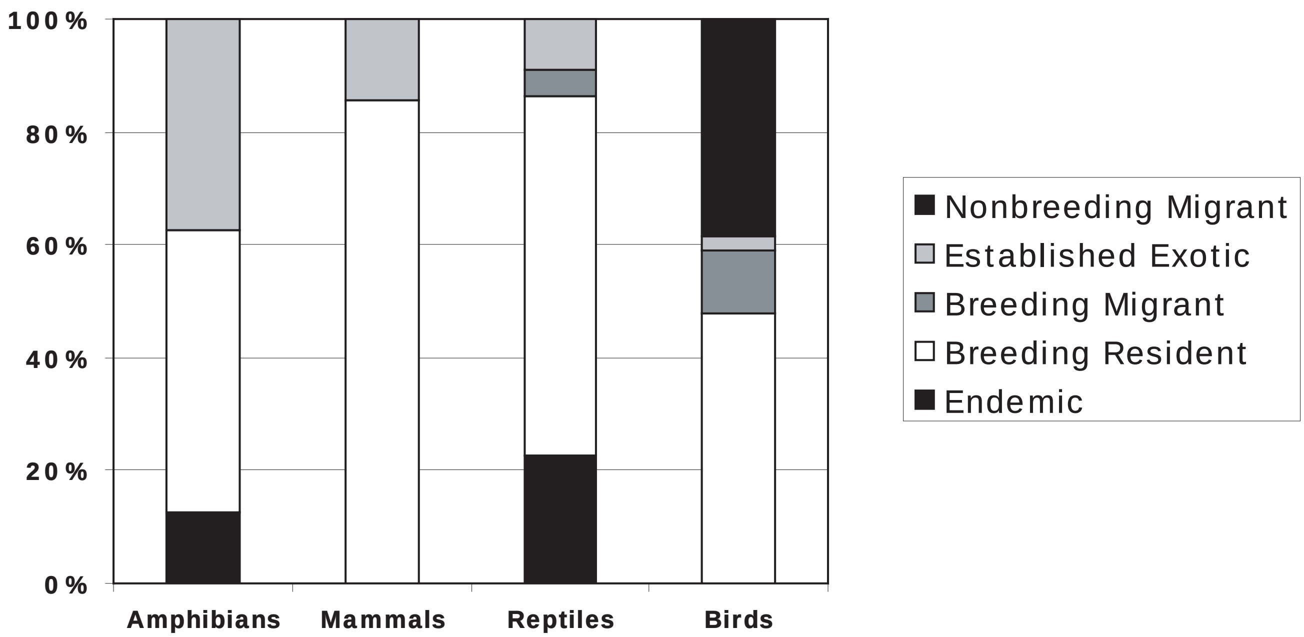


Figure 3. Percentage of number of species which are endemic, breeding resident, breeding migrant, established exotic, or nonbreeding migrant for amphibians, mammals, reptiles, and birds in the USVI. Ten to 20 percent of the amphibians and reptiles are endemic species. The majority of all species are breeding residents. Breeding migrants include a number of bird species and marine turtles (which use terrestrial habitat for nesting).

Table 2. Eight endangered (EN), threatened (LT) species as listed by the U.S. Environmental Protection Agency and 27 endangered (E), territorially endangered (TE), or threatened (T) species as listed by the Virgin Islands Endangered Indigenous Species Act.

[**Abbreviation**: USVI, U.S. Virgin Islands]

	Scientific name	English common name	Spanish common name	Status USVI	
Birds	*Pelecanus occidentalis*	Brown Pelican	Pelícano Pardo	E	EN
	Puffinus lherminieri	Audubon's Shearwater	Pampero de Audubon	TE	
	Otus nudipes	Puerto Rican Screech-Owl	Múcaro Común	TE	
	Chordeiles gundlachii	Antillean Nighthawk	Querequeqúe Antillano	TE	
	Phaethon lepturus	White-tailed Tropicbird	Rabijunco Coliblanco	TE	
	Anthracothorax dominicus	Antillean Mango	Zumbador Dorado	TE	
	Rallus longirostris	Clapper Rail	Pollo de Mangle	TE	
	Catoptrophorus semipalmatus	Willet	Playero Aliblanco	TE	
	Sterna antillarum	Least Tern	Gaviota Chica	TE	EN
	Geotrygon mystacea	Bridled Quail-Dove	Paloma Perdíz de Martinica	TE	
	Patagioenas leucocephala	White-crowned Pigeon	Paloma Cabeciblanca	TE	
	Ardea herodias	Great Blue Heron	Garzón Cenizo	TE	
	Oxyura jamaicensis	Ruddy Duck	Pato Chorizo	TE	
	Anas bahamensis	White-cheeked Pintail	Pato Quijada Colorada	TE	
	Nycticorax nycticorax	Black-crowned Night-heron	Yaboa Real	TE	
	Egretta thula	Snowy Egret	Garza Blanca	TE	
	Fulica caribaea	Caribbean Coot	Gallinazo Caribeño	TE	
	Sterna dougallii	Roseate Tern	Palometa	T	LT
Bats	*Stenoderma rufum*	Desmarest's Fig-eating Bat	Murciélago Rojo Frutero	TE	
	Noctilio leporinus	Greater Bulldog Bat	Murciélago Pescador	TE	
	Brachyphylla cavernarum	Antillean Fruit-eating Bat	Murciélago Cavernícola	TE	
Reptiles	*Ameiva polops*	St. Croix Ground Lizard	Siguana de Santa Cruz	E	EN
	Epicrates monensis granti	Virgin Islands Tree Boa	Culebrón de la Isla Virgin	E	EN
	Dermochelys coriacea	Leatherback Sea Turtle	Tinglado	E	EN
	Eretmochelys imbricata	Hawksbill	Carey	E	EN
	Mabuya mabouya sloanei	Slippery-backed Mabuya	Lucía	TE	
	Chelonia mydas	Green Sea Turtle	Pejeblanco	T	LT

Methods

We developed and followed four guidelines in selecting an appropriate scale for assessing species geographic ranges:

- Map units are large enough that information on species occurrences is available or can be systematically obtained for most map units.
- Map units are compatible with regional (i.e. Caribbean) analyses of species ranges.
- Map units are small enough that we can assume that species occur in the entire suitable habitat within the map unit.
- Map units allow for distinguishing different species ranges—as understood by wildlife biologists, land managers, or other experts—throughout the mapped area.

These guidelines vary with species and ultimately a best fit must be decided upon that is acceptable for most of species within our study.

We integrated our experience from Puerto Rico GAP with ideas and information derived from stakeholders meetings in the USVI to develop a flexible system of creating range maps of different resolutions using documented and probable species occurrence records and we describe that system here. The stakeholders gave us the following suggestions regarding range maps for the USVI:

- Decrease size of hexagon mapping unit to increase accuracy of vertebrate species occurrence mapping. Some species occupy very small regions that may not be adequately mapped with the original hexagon size (24 km^2).
- Include watersheds as distinct entities in analysis due to significant differences in amount of precipitation each collects throughout the year (i.e. we may use watersheds as a surrogate for climatic subregions as they vary predictably in moisture availability and vegetation).

We have decided to use a set of multiple scale integrated mapping units (Figure 4) for mapping species ranges in the USVI.

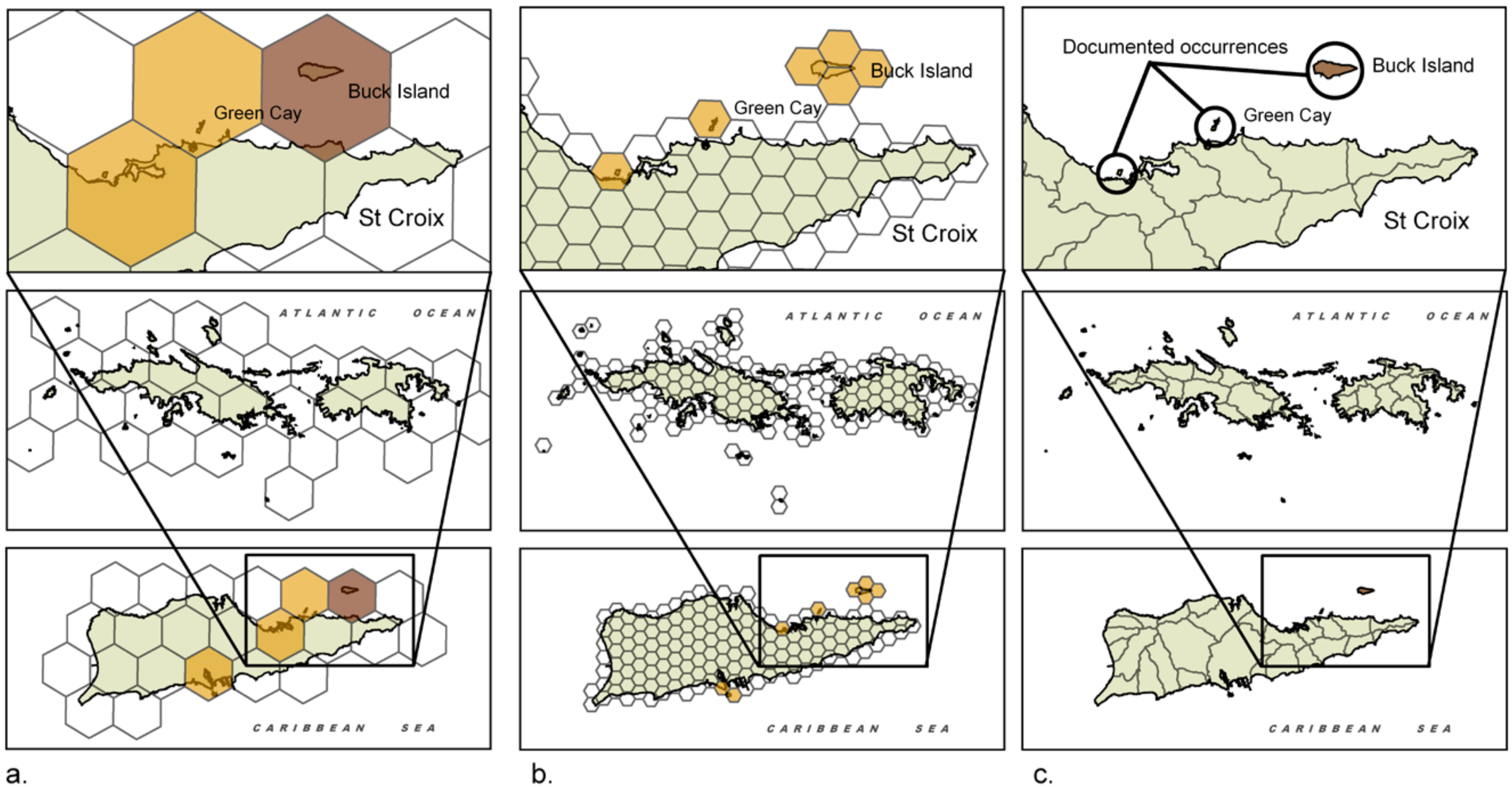


Figure 4. Three sets of minimum map units developed to display species ranges for the USVI. These include the (a) large hexes (24 km^2 area) contiguous with the PRGAP hexagons and range maps, (b) small hexagons (2 km^2 area) nested within the large hexagons, and (c) HUC 10 sub watersheds. This example shows the St. Croix ground lizard (*Ameiva polops*), which occurs on three small cays off the island of St. Croix. The range of the lizard is represented by about 75 km^2 (36 km^2 occurring over land) using the large hexagons, 8 km^2 (2.1 km^2 occurring over land) using the small hexagons, and less than 1 km^2 when restricted to the three cays on which it occurs. In this instance, for a species limited in distribution by the water barrier, we can use the watershed range map to depict its range and restrict its predicted distribution to suitable habitat within that range.

Range Maps

We developed three integrated sets of minimum map units to display species ranges for USVI and model species predicted distributions. These include a grid of 24 km^2 hexagons contiguous with PRGAP hexagons and range maps, a grid made up of 2 km^2 hexagons nested within larger hexagons, and subwatersheds and cays (WRI/NOAA 2005). The subwatersheds are Hydrologic Unit Code (HUC) 14 (NHD 2005). The three sets of map units are integrated in the sense that the occurrence data for any species (confirmed point locations, areas, or probable occurrences based on literature or expert opinion) is intersected with each set of map units to produce three distinct range maps for each species in our analyses. The different range maps have advantages of their own and we hope will subsequently prove useful as we develop species predicted distributions in USVI and products for land managers, research and conservation:

- The 24 km^2 hexagon grid will allow us to assess species distributions for Puerto Rico and USVI as a single integrated dataset. Several species occur across the suite of islands, and for all species we can put their range in a regional perspective. The U.S. Virgin Islands are part of the Puerto Rican bank and share a similar geological history, although St Croix has been disconnected from other islands for a much longer period dating back to at least the Pliocene, around two to five million years ago (Heatwole et al. 1981). In addition, USVI shares many vertebrate species with Puerto Rico. The 24 km^2 hexagon grid, however, was considered too big to map species ranges in USVI by stakeholders. In using this grid the islands are not covered by a significant number of hexagons; for example St John is covered by seven 24 km^2 hexagons. This could lead to excessively overestimating the distribution of some of the species across the islands, especially those of reptiles and amphibians, whose populations are sometimes characterized of occurring in small areas and whose dispersal capabilities are sometimes constrained by habitat segmentation due to roads or other man made barriers.

- In contrast, 2 km^2 hexagons may be more suitable to map species ranges on small islands with significantly mixed ecosystems and topographic diversity. A square kilometer of land surface in USVI may encompass many different types of ecosystems, including mangroves, dry forests, herbaceous wetlands, grasslands, as well as different types of topographic patterns, such as plains, mountains, valleys, and beaches. Smaller hexagons provide a systematically placed, same-sized minimum mapping unit, but on a finer scale which makes resulting range maps more useful to local land managers by allowing greater depiction of range variability within the USVI. A total of 322 hexagons cover the USVI which is manageable in terms of gathering information and developing an occurrence database (Table 1). This method, however, does not avoid the problem of erroneously mapping species distribution across islands (Figure 4), especially because the islands and the cays in USVI are very close together on occasion. In addition, vertebrate occurrence records in the USVI are not abundant, no single agency maintains and manages this type of data, and the information available sometimes does not provide precise location such as coordinates. Thus, a consequence of reducing the size of the hexagon will be that range maps will reflect a greater degree of false absence of species across the landscape.

- Lastly, watersheds offer distinctive habitat characteristics and sometimes harbor different biological communities. For example, some watersheds receive more precipitation than others within the same ecological lifezone. Subwatershed map units have the benefit of delimiting natural boundaries, and allow for greater confidence a species likely occupies the entire suitable habitat within the map unit. USVI is comprised of three main islands with 49 watersheds and numerous cays, 89 of which are included in USVI GAP. There are limitations to using this grid. Because watersheds usually cover a broad elevational gradient, and some species have particular elevational preferences, this method might add additional error to the predicted distribution of these species. Given that the highest elevation in the USVI is 474 m this might not be a problem, but a good effort must be made to identify the elevational requirements of vertebrate species in order to take this into account when modeling predicted habitat distributions.

As an example of the integrated range maps, the St. Croix ground lizard (*Ameiva polops*), occurs on three small cays off the island of St. Croix (Figure 4). Its range is represented by 75 km^2 using 24 km^2 hexagons (a), 8 km^2 using 2 km^2 hexagons (b), and less than 1 km^2 when restricted to the three cays on which it occurs (c). The St. Croix ground lizard is limited by a water barrier between islands and the watershed range map constrains its predicted distribution to suitable habitat within that range. If we use either the 24 km^2 (a) or the 2 km^2 hexagon grid (b), to map its distribution, it appears as though it occurs on St. Croix, which is not the case because it was extirpated from that island, probably through the predatory effect of the introduced Small Indian Mongoose (Platenberg et. al 2005).

In contrast, for a species such as the Great Egret (*Ardea alba*), unrestricted by a water barrier, we might use the 24 km^2 hexagon (Figure 5) to better represent the species range and constrain its predicted distribution within the USVI. These species have the potential of using all suitable habitat within a vast region in the USVI. This option is also more convenient in case there is a lack of occurrence records.

Conversely, the 2 km^2 hexagon range map is more suitable for species that occur in the main islands and whose population are scattered and disconnected. This is the case of some of the amphibians, such as the yellow mottled coqui (*Eleutherodactylus lentus*) (Figure 6). This smaller mapping unit has the advantage of providing a greater resolution in the case that there is an ample set of species occurrence data available.

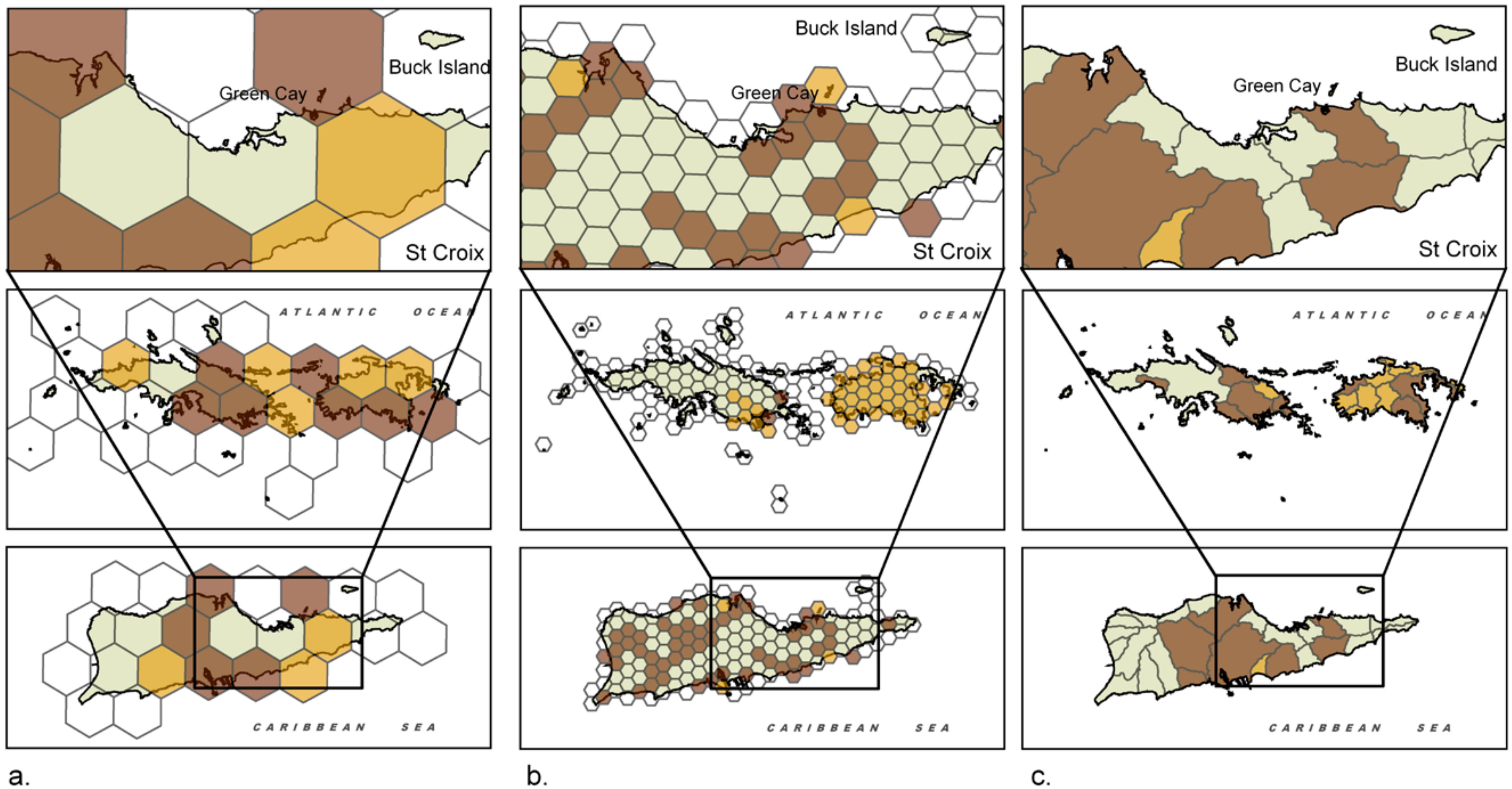


Figure 5. These three sets, similar to those used in Figure 4, show the distribution of the Great Egret (*Ardea alba*). The Great Egret's range is (a) 480 km^2 (209 km^2 occurring over land) when using the 24 km^2 hexagon, (b) 124 km^2 (75 km^2 occurring over land) when using the small 2 km^2 hexagon, and (c) 193 km^2 when using the subwatersheds as mapping units. Mapping the distribution of species that have great dispersal abilities will benefit from the use of a bigger hexagon or the subwatershed units.

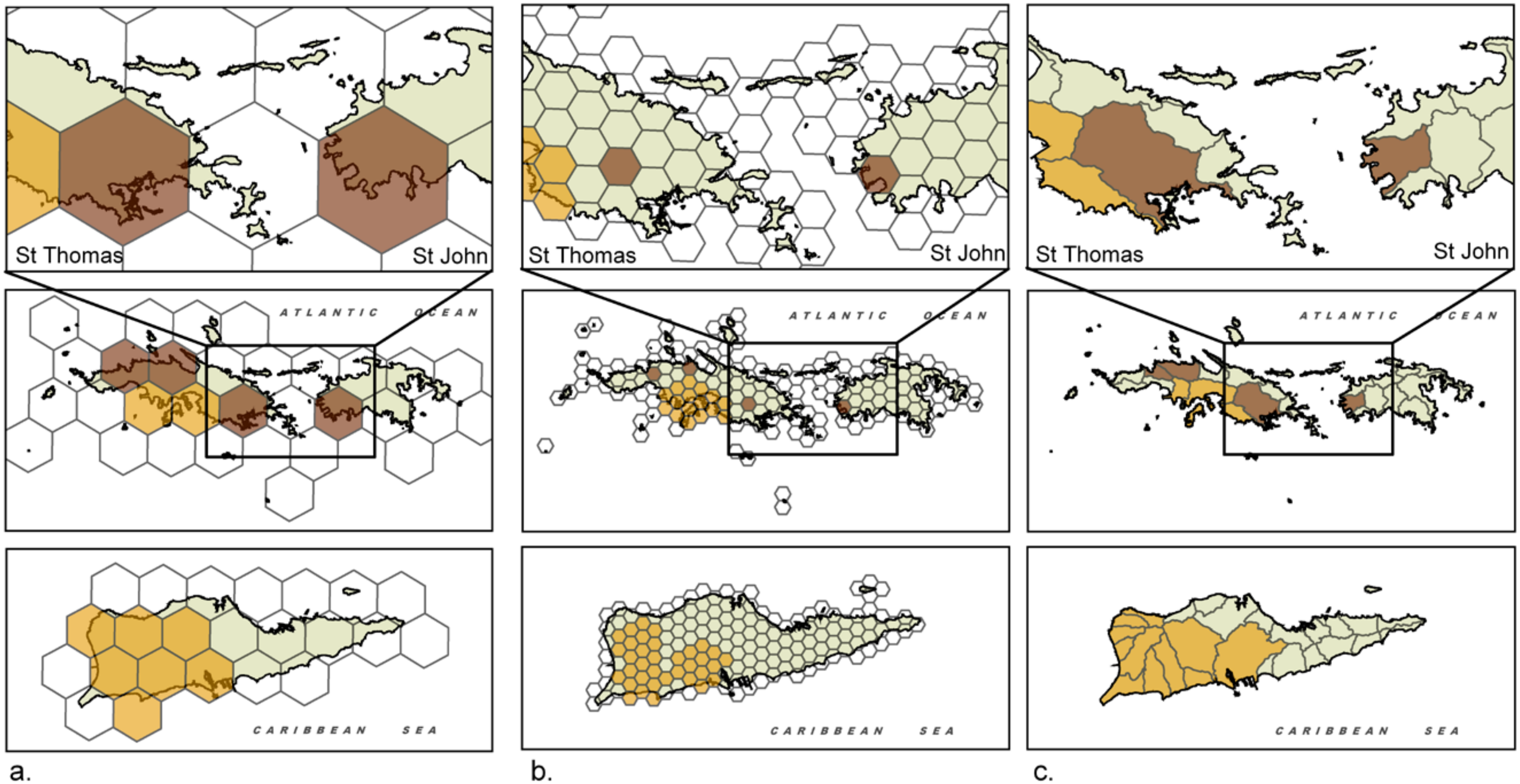


Figure 6. These three sets, similar to those used in Figure 4, show the distribution of the yellow mottled coqui (*Eleutherodactylus lentus*) using the three different grids (24 km^2 hexagon, 2 km^2 hexagon, and subwatersheds). The yellow mottled coqui's range is (a) 312 km^2 (183 km^2 occurring over land) when using the 24 km^2 hexagon, (b) 110 km^2 (87 km^2 occurring over land) when using the 2 km^2 hexagon, (c) 175 km^2 when using the subwatersheds as mapping units. Some amphibians, such as the *E. lentus*, tend to have a patchy distribution because their populations usually are not connected. In these cases mapping the species distribution will benefit from a smaller mapping unit.

Conclusion

The ultimate value of developing a multiple scale system of range mapping will be determined as we begin to use the range maps for modeling species distributions, and as the resulting predicted distributions are used in conservation analyses and land management decisions. Although setting up additional geospatial datasets has represented additional effort, we feel the flexibility of the range mapping system will broaden the applicability and increase the long term value of the USVI Gap Analysis Project datasets.

Reducing the size of the hexagons and taking into account watersheds was considered a significant advantage by stakeholders.

Acknowledgements

This research has been supported by the U.S. Geological Survey Biological Resources Division National Gap Analysis Program cooperative agreement No. 01HQPG0031 and the U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry (IITF) GIS and Remote Sensing Laboratory. Thanks to the National Park Service, the Division of Fish and Wildlife of the USVI Department of Planning and Natural Resources (DPNR), the Coastal Zone Management of DPNR, The Nature Conservancy (TNC), the University of the Virgin Islands (UVI), the Conservation Data Center (CDC-UVI). Thanks to Grizelle González and anonymous reviewers for comments on this manuscript. All research at IITF is done in collaboration with the University of Puerto Rico.

References Cited

Boykin, K.G., B.C. Thompson, R.A. Deitner, D. Schrupp, D. Bradford, L. O'Brien, C. Drost, S. Propeck-Gray, W. Rieth, K.A. Thomas, W. Kepner, J. Lowry, C. Cross, B. Jones, T. Hamer, C. Mettenbrink, K.J. Oakes, J. Prior-Magee, K. Schulz, J.J. Wynne, C. King, J. Puttere, S. Schrader, and Z. Schwenke. 2007. Predicted animal habitat distributions and species richness. Chapter 3 *in* J.S. Prior-Magee, K.G. Boykin, D.F. Bradford, W.G. Kepner, J.H. Lowry, D.L. Schrupp, K.A. Thomas, and B.C. Thompson, eds. *Southwest Regional Gap Analysis Final Report*. U.S. Geological Survey, Gap Analysis Program, Moscow, ID.

Ferrier, S. 2002. Mapping Spatial Patterns in Biodiversity for Regional Conservation Planning: Where to from here? *Systematic Biology* 51:331–363.

Gould, W.A., C. Alarcón, B. Fevold, M.E. Jiménez, S. Martinuzzi, G. Potts, M. Quiñones, M. Solórzano, and E. Ventosa. 2008. The Puerto Rico Gap Analysis Project. Volume 1: Land cover, vertebrate species distributions, and land stewardship. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, Río Piedras, PR: U.S. 165 p.

Green, M., and R. Flowerdew. 1996. New Evidence on the modifiable areal unit problem. Pages 41-54 *in* P. Longley and M. Batty, editors. *Spatial Analysis: Modeling in a GIS Environment*. John Wiley & Sons, Inc, New York.

Heatwole, H., R. Levins, and M.D. Byer. 1981. Biogeography of the Puerto Rican Bank. *Atoll Research Bulletin* 251.

Karl, J.W., P.J. Heglund, E.O. Garton, J.M. Scott, N.M. Wright, and R.L. Hutto. 2000. Sensitivity of species habitat-relationship model performance to factors of scale. *Ecological Applications* 10:1690–1705.

(NHD) National Hydrography Dataset. 2005. *National Hydrography Dataset.* U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency, the U.S. Department of Agriculture Forest Service and other Federal, State, and local partners. Reston, VA.

Platenberg, R.J., F.E. Hayes, D. B. McNair, and J.J. Pierce. 2005. *A Comprehensive Wildlife Conservation Strategy for the U.S. Virgin Islands.* Division of Fish and Wildlife, Government of the U.S. Virgin Islands, St. Thomas. 251 p.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erichia, T.C. Edwards, Jr., J. Ulliman, and R.G. Wright. 1993. Gap Analysis—A geographic approach to protection of biological diversity. *Wildlife Monographs* 123:1–4.

Scott, J.M., P. Heglund, M. Morrison, J. Huafler, M. Raphael, W. Wall, and F. Samson. 2002. *Predicting species occurrences: issues of accuracy and scale*. Island Press, Washington, DC. 886 p.

Scott, J.M. 2007. A handbook for conducting Gap Analysis. Available from http://www.gap.uidaho.edu/handbook/CompleteHandbook.pdf

Stockwell, D.A., and A.T. Peterson. 2003. Comparison of resolution of methods used in mapping biodiversity patterns from point-occurrence data. *Ecological Indicators* 3:213-221.

Stoms, D.M. 1994. Scale dependence of species richness maps. *The Professional Geographer* 46:346–358.

Weaver, P. 2006. Estate Thomas Experimental Forest, St. Croix, U.S. Virgin Islands: research history and potential. U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, San Juan, PR. 62 p.

White, D., A.J. Kimerling, and W.S. Overton. 1992. Cartographic and geometric components of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems* 19:5–12.

(WRI–NOAA) World Resources Institute and U.S. National Oceanic and Atmospheric Administration. 2005. Coastal Data CD for the U.S. Caribbean, Washington, DC.

A Pilot Project to Visualize Kentucky's Modeled Vertebrate Habitat Change

Brian D. Lee[1], Collin D. Linebach[1]

Introduction

Habitat loss and fragmentation are often cited as two of the most important reasons for the decline of biological diversity around the world (Meffe and Carroll 1994). It is an appealing idea to conserve the most biodiversity by maintaining examples of all the natural communities. Several approaches to the spatial identification of biodiversity have been described over the years (Kirkpatrick 1983; Margules et al. 1988; Pressey and Nicholls 1989; Nicholls and Margules 1993). It is important to recognize that a gap analysis is a process to identify landscape areas for potential conservation but does not actually apply conservation measures. The landscape is a changing resource and understanding the changes in relationship to gap analysis is important for planning and management. These changes have ramifications for vertebrate biodiversity as the landscape becomes more fragmented and/or is converted to urbanized or agricultural uses. Identifying and visualizing geographic losses and/or additions to modeled habitat using gap analysis for multiple species simultaneously is potentially valuable for managing vertebrate resources. The goal of this pilot project was to explore an analysis and visualization approach that could aid in understanding modeled habitat dynamics. Specifically, the project was to develop an approach to visualizing habitat, stability or change, at two distinct times across multiple vertebrate species simultaneously using the Environmental Monitoring and Assessment Program (EMAP) hexagons (White et al. 1992) as the landscape unit of analysis. Ultimately, this project has the potential of helping people make decisions about the utilization of limited financial and technical resources for vertebrate species.

Using concepts developed through GAP (Gap Analysis Program 2000; Scott et al. 1993), and specifically the Kentucky GAP Analysis Final Report (2003), this pilot project explored the opportunities and constraints of quantifying terrestrial habitat for several groups of vertebrate species. This effort builds on expertise, methods, and data of the original Kentucky GAP Project as well as utilizing expertise developed during GAP efforts in several states. This work extends the original Kentucky GAP Project by incorporating more recent statewide land cover data and advancements in computing software/hardware technologies while continuing to use EMAP hexagons.

Project Description

When the original Kentucky GAP Project was finalized in 2003, several future needs were identified. The Kentucky GAP team encouraged research that would apply and expand upon the original effort. For example, the results were partially incomplete without a means to compare changes over time according to the final report (Kentucky GAP Analysis Final Report 2003). The original Kentucky GAP did not explicitly include the capability to incorporate temporal landscape change. A second generation of Kentucky GAP that used more current data and explicitly incorporated monitoring of temporal shifts in biodiversity was recommended. The methods developed during this pilot project can potentially be included in land use planning, statewide and regional biodiversity planning, and county based land use planning.

Land cover data based on 1992 Landsat Thematic Mapper (TM) satellite imagery was the most recent available for the original Kentucky GAP Project completed in July 2003. The original Kentucky GAP Project was performed using TM imagery that is now more than 16 years old. Wildlife species distribution maps used in the original Kentucky GAP Project also are outdated. Data and results generated from the original Kentucky GAP have been valuable to state wildlife management efforts. Because of advancements in geographic information systems (GIS) and more current datasets, there was an opportunity to reapply the original Kentucky GAP Project models to visualize how modeled habitat has or has not changed from 2001 to 2005. The approach described in this paper allows for the visualization of temporal and spatial dynamics.

Today, land cover datasets available for Kentucky include the National Land Cover Data (NLCD) 2001 (Homer et al. 2004; Homer et al. 2007) and a compatible dataset

[1] Department of Landscape Architecture, College of Agriculture, University of Kentucky, Lexington, KY.

classifying statewide land cover in 2005 (Kentucky Division of Geographic Information 2007). The 2005 Kentucky Land Cover Change Detection 2001/2005 has Anderson Level II categorization. This dataset produced for the Commonwealth of Kentucky, for the 2005 era, is part one of a two-part dataset that explicitly focused on land cover change detection analysis. The second part of the dataset is a change/no change mask. The goal of the 2005 update project was to provide the Commonwealth of Kentucky with more current and accurate land cover change information since the NLCD 2001. The change detection analysis is based on Landsat Thematic Mapper scenes from 2001 and 2005 (Kentucky Division of Geographic Information 2007). These new land cover data provided an opportunity to update modeled habitat maps. They also provided the opportunity to test for differences in amount, location, and spatial configuration of modeled habitats and to grossly characterize how terrestrial vertebrate species habitat was or was not changing across the state by the EMAP hexagonal grid (White et al. 1992; U.S. Environmental Protection Agency 2008).

Model Development

This pilot project compared standard GAP vertebrate species distribution models from two times to measure changes in habitat. This project generally followed the species model development that was done for the original Kentucky GAP completed in 2003. The habitat characterization, known ranges, and methods were all reviewed by experts for the original Kentucky GAP Project at that time and accepted by the national GAP Analysis Program. By utilizing the original Kentucky GAP approach, comparisons can be made utilizing the newer NLCD 2001 for Kentucky (Figure 1) and the 2005 Kentucky Land Cover Change Detection product (Figure 2) to visualize modeled landscape scale habitat changes across the state for multiple species simultaneously.

Rather than the 365 terrestrial vertebrate species modeled by the original Kentucky GAP Project, this pilot project used a forest dependent species subset of five animals. The species selected were eastern small-footed myotis (*Myotis*

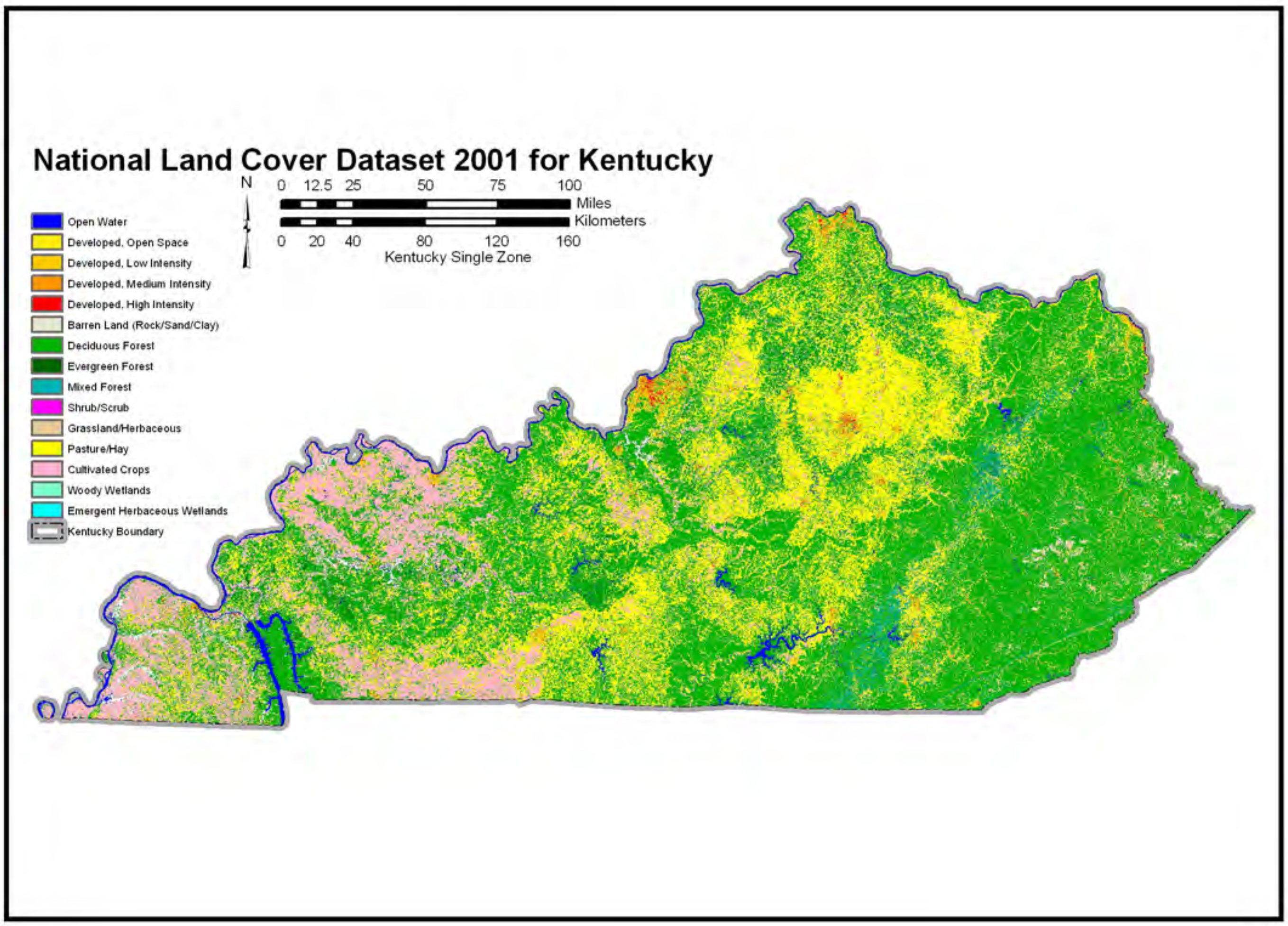


Figure 1. National Land Cover Dataset 2001 for Kentucky.

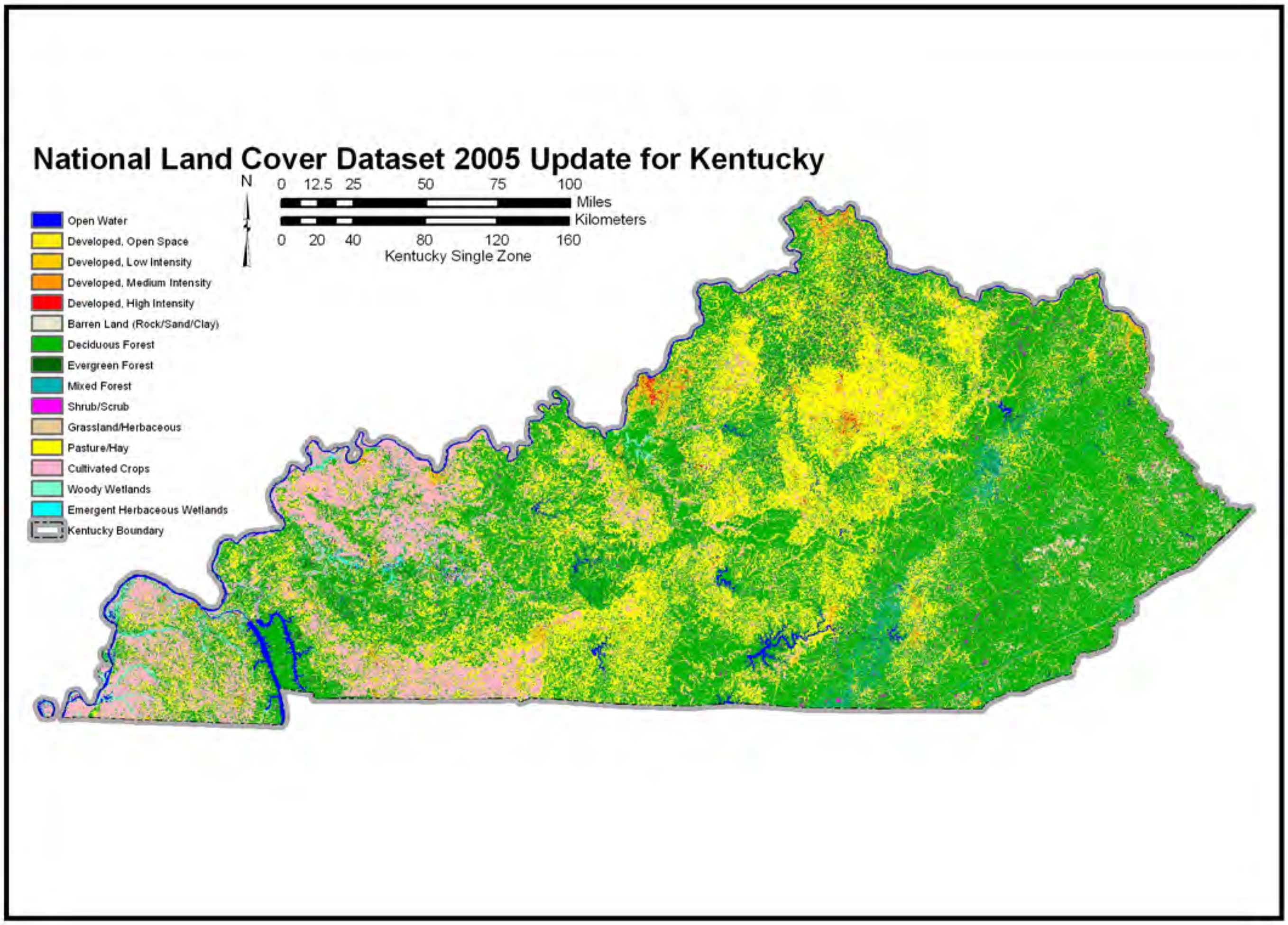


Figure 2. 2005 update to the National Land Cover Dataset 2001 for Kentucky.

leibii), black bear (*Ursus americanus*), eastern spotted skunk (*Spilogale putorius*), Kentucky Warbler (*Oporornis formosus*), and Red-headed Woodpecker (*Melanerpes erythrocephalus*). The species selection was performed by an expert at the Kentucky Department of Fish and Wildlife Resources who was also instrumental in the completion of the original Kentucky GAP Project (2003). A foundation for the expert's species selection was the Kentucky Department of Fish and Wildlife Resources' Wildlife Action Plan (Kentucky's Comprehensive Wildlife Conservation Strategy 2005). The species models were executed using the same procedures for 2001 and 2005 land cover data, which allowed for habitat analysis at the two points in time across the state. The objective was to make comparative analyses of the habitat changes or stability between the two snapshots of land cover. A generalized workflow diagram (Figure 3) shows five major process steps of this approach.

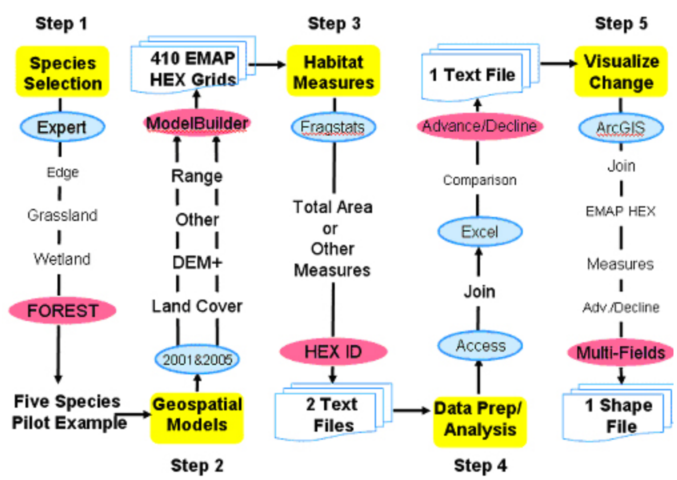


Figure 3. The generalized workflow diagram of habitat modeling and change visualization process used in this project.

The advancement in GIS technology that helped complete this project was the ModelBuilder framework of the Environmental Systems Research Institute's (ESRI) ArcGIS v. 9.2 (SP 4) (ARC/INFO License) (ESRI, Inc. 2007) software package. ModelBuilder provided a graphical framework for designing and implementing the species models. There are several ways in which to assemble the data and processes in ModelBuilder. In this project, a separate ModelBuilder model was created for each species that included the 2001 and 2005 land cover data previously described. An alternative method considered was to develop one ModelBuilder model for each grouping of species for both timeframes. This latter approach did not appear to provide the flexibility to easily consider an individual species efficiently. In addition, as the complexity of the ModelBuilder model increased, computing performance tended to decrease which slowed species model development.

ArcGIS v. 9.2 has the capacity to batch process the models. This feature was particularly useful for repeatedly extracting habitat distributions within many standard areas such as watersheds, the United States Geological Survey 1:24,000 quadrangles, or the EMAP hexagons as was used in this project. In this project, the modeled distribution for 2001 and 2005 were extracted by each hexagon of the hexagonal grid. For Kentucky, 205 hexagons cover the state (Figure 4); this process resulted in 410 ESRI GRID files for each species for subsequent analysis using Microsoft Access (Figure 3 – top of Step 2). An ESRI GRID file is an Environmental Systems Research Institute format for storing raster data defining geographic space and is referred to as GRID in the remainder of this paper. During this pilot project's development, when the batch process capability was utilized, computing performance decreased substantially. Therefore, a separate ModelBuilder model was used exclusively for the purpose of habitat extraction by the EMAP hexagons. This allowed personnel resources to be used more efficiently.

Fragstats v. 3.3 Build 5 was used to analyze each extracted hexagonal GRID for each species at each point in time. Fragstats is a spatial pattern analysis program for

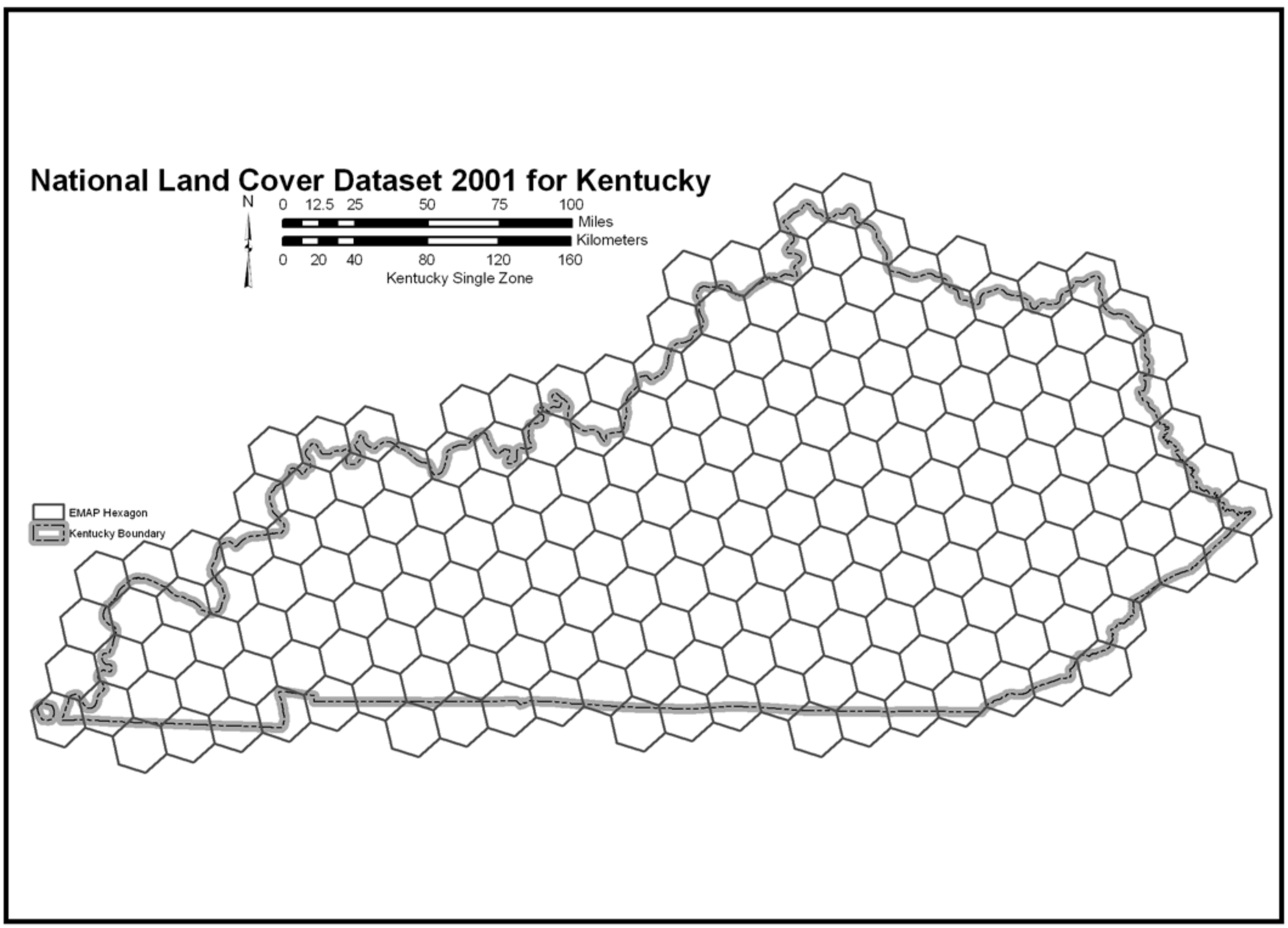
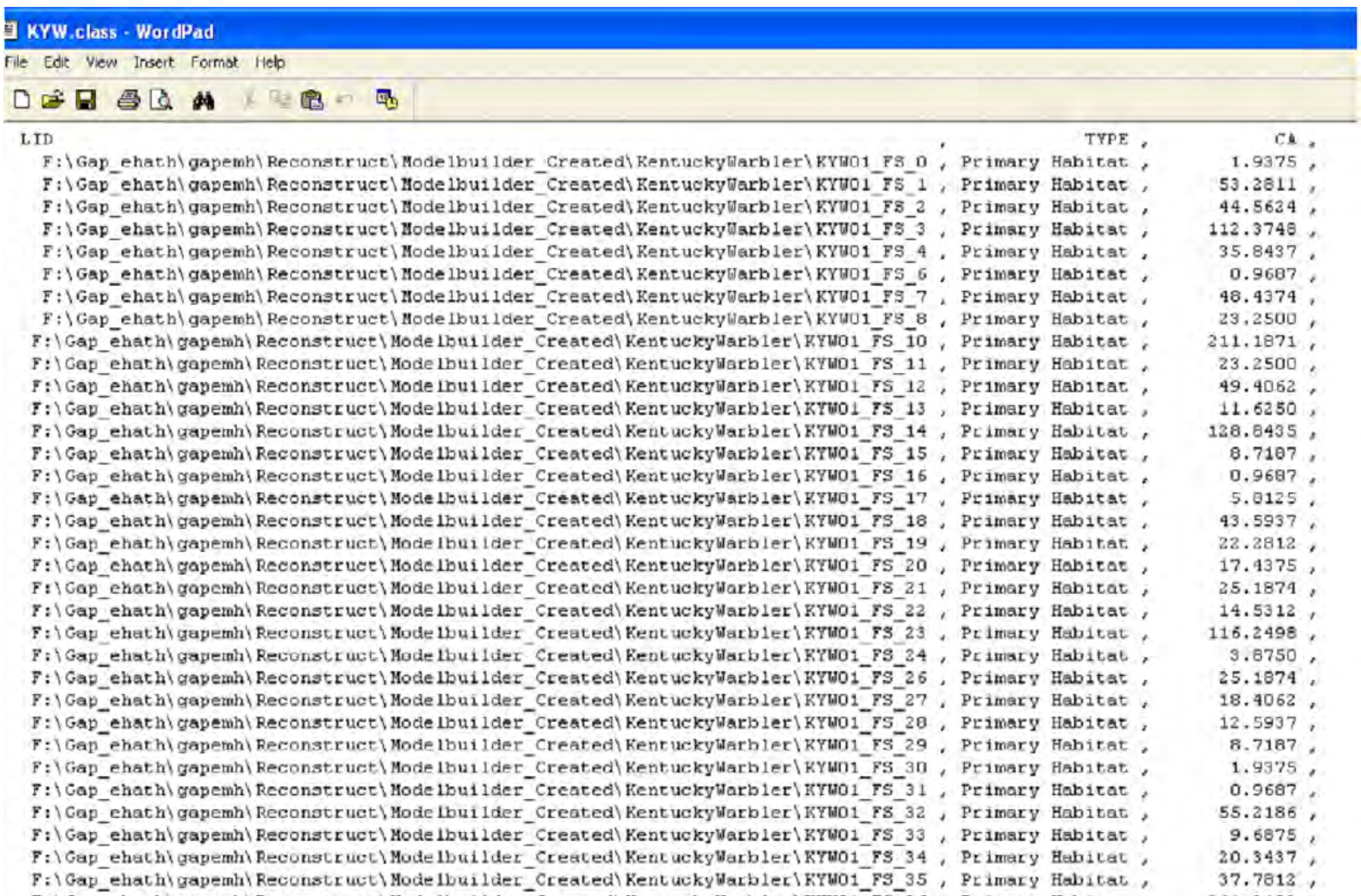


Figure 4. 2005 update to EMAP Hexagons from the National Land Cover Dataset 2001 for Kentucky.

categorical maps (McGarigal et al. 2002). Fragstats has the ability to quantify the area, extent, and spatial configuration of habitat within an area. In this project, each hexagonal GRID extracted was analyzed. Dozens of habitat metrics are capable of being reported by Fragstats including total area, percent of landscape, number of patches, mean/median patch area, nearest neighbor, etc. It is important to note that choosing the appropriate metric(s) to describe habitat is potentially species dependent. McGarigal et al. (2002) places responsibility on the user to understand metric behavior. For the sake of simplicity in describing the general visualization process used in this paper, only the habitat area as reported by Fragstats for each hexagonal GRID was used. Specifically, the Fragstats metric used was TOTAL AREA (CA/TA). The output data from Fragstats were written to a delimited text file (Figure 5) for use in other software applications such as Microsoft Excel and Microsoft Access. Subsequently, the data were joined back to the original EMAP hexagonal grid for visualization following the data manipulation and additional analysis described in the upcoming advancing and declining section (Figure 3 – Steps 4 and 5).

An objective of this pilot project was visualizing habitat, stability or change, as measured by Fragstats metrics at 2001 and 2005 across multiple species simultaneously using the EMAP hexagon extracted habitat GRIDs. The approach used in this pilot project identified each species by each EMAP GRID as to whether it gained habitat (Advancing), lost habitat (Declining), or stayed the same as indicated by TOTAL AREA (CA/TA). Other Fragstat metrics could be used depending on species. Advancing and declining are terms that are often used to describe financial stock market performance (Fosback 1976).




```
LID                                                                          , TYPE            , CA       ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_0  , Primary Habitat , 1.9375   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_1  , Primary Habitat , 53.2811  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_2  , Primary Habitat , 44.5624  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_3  , Primary Habitat , 112.3748 ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_4  , Primary Habitat , 35.8437  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_6  , Primary Habitat , 0.9687   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_7  , Primary Habitat , 48.4374  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_8  , Primary Habitat , 23.2500  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_10 , Primary Habitat , 211.1871 ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_11 , Primary Habitat , 23.2500  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_12 , Primary Habitat , 49.4062  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_13 , Primary Habitat , 11.6250  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_14 , Primary Habitat , 128.8435 ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_15 , Primary Habitat , 8.7187   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_16 , Primary Habitat , 0.9687   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_17 , Primary Habitat , 5.8125   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_18 , Primary Habitat , 43.5937  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_19 , Primary Habitat , 22.2812  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_20 , Primary Habitat , 17.4375  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_21 , Primary Habitat , 25.1874  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_22 , Primary Habitat , 14.5312  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_23 , Primary Habitat , 116.2498 ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_24 , Primary Habitat , 3.8750   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_26 , Primary Habitat , 25.1874  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_27 , Primary Habitat , 18.4062  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_28 , Primary Habitat , 12.5937  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_29 , Primary Habitat , 8.7187   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_30 , Primary Habitat , 1.9375   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_31 , Primary Habitat , 0.9687   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_32 , Primary Habitat , 55.2186  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_33 , Primary Habitat , 9.6875   ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_34 , Primary Habitat , 20.3437  ,
F:\Gap_ehath\gapemh\Reconstruct\Modelbuilder_Created\KentuckyWarbler\KYW01_FS_35 , Primary Habitat , 37.7812  ,
```

Figure 5. Fragstats delimited output text file of metric values by hexagon for 2001 and 2005.

Advancing and Declining Background

Borrowing ideas from broad scale stock market characterization allowed for visualizing modeled habitat changes. The number of stocks that have advanced, declined, or remained unchanged is commonly reported by most news organizations that include financial news as part of their regular coverage. To set the context of using broad scale stock market analysis approaches to characterizing and subsequently visualizing modeled habitat over time, it is important to review some essential points. Fosback (1976) provides detailed examples and discussions of the rationale, limitations, and attributes of using advancing and declining stocks to characterize overall stock market performance. In stock market terms, using price highs and lows or counts of stocks going up or down in price is referred to as market breath analysis (Fosback 1976). If most stocks are increasing in price, the market is generally thought of as having good breath or gaining momentum. If most stocks are declining in price, then the market is thought of as having bad breath or losing momentum (Fosback 1976).

Species Modeled Habitat Advancers and Decliners

The approach described in this paper helps paint a geographic picture of vertebrate species habitat stability or change across the state without relying on direct cell-to-cell comparison of Landsat scenes at two points in time. At this point in the process, there are modeled habitat GRIDS for each species across the state for 2001 and 2005. Once individual species habitat models are completed and EMAP hexagon GRIDS extracted of modeled habitat (Figure 3 – bottom of Step 3), the tabular calculations are completed based on the two observation times (Figure 3 – Steps 4 and 5) resulting in the number of species where total area advanced (Figure 6) or declined (Figure 7). These observations of the models were summed and mapped following a tabular join by hexagon identification code.

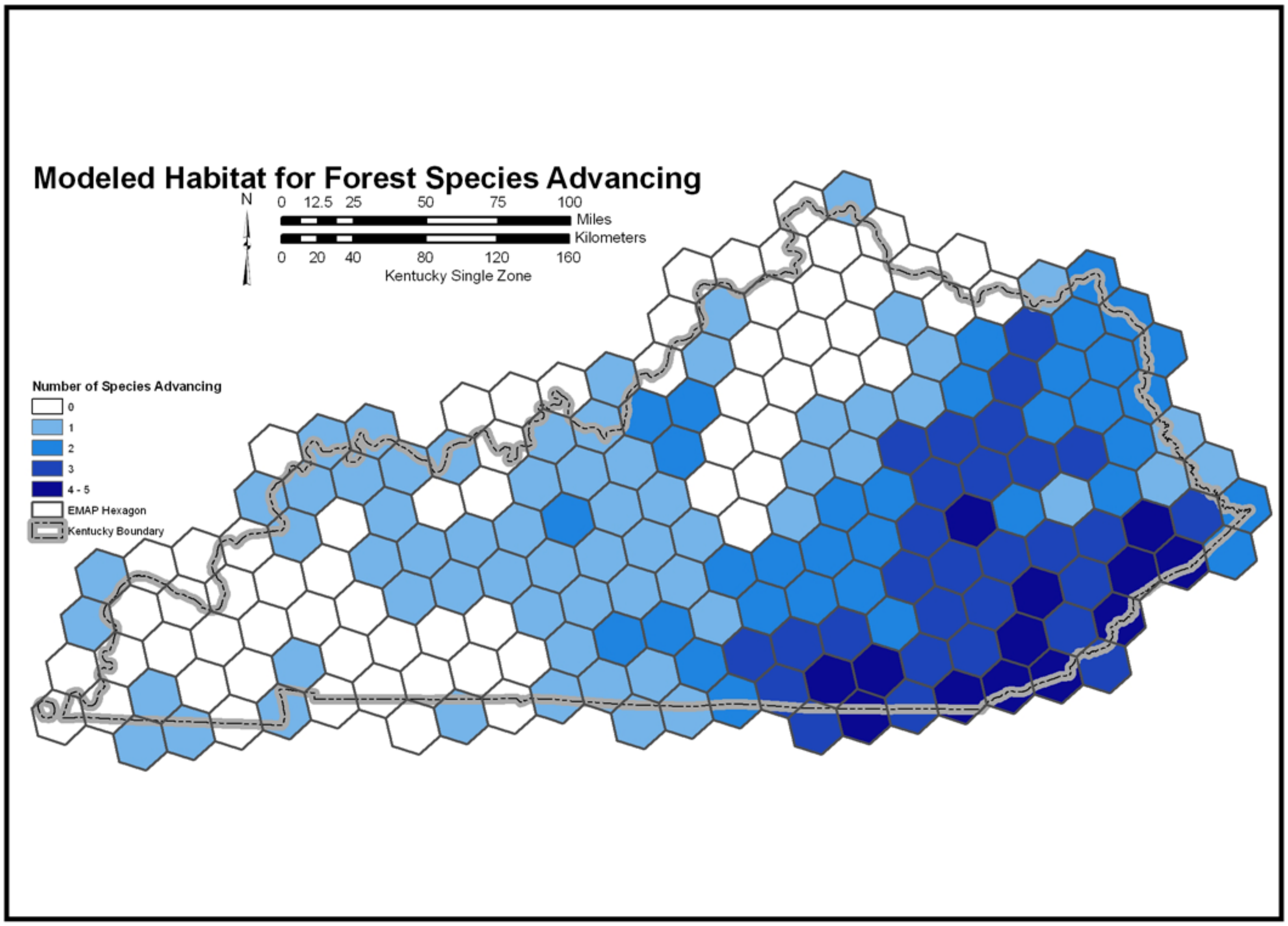


Figure 6. Location and number of species with modeled habitat advances between 2001 and 2005 by hexagon for Kentucky.

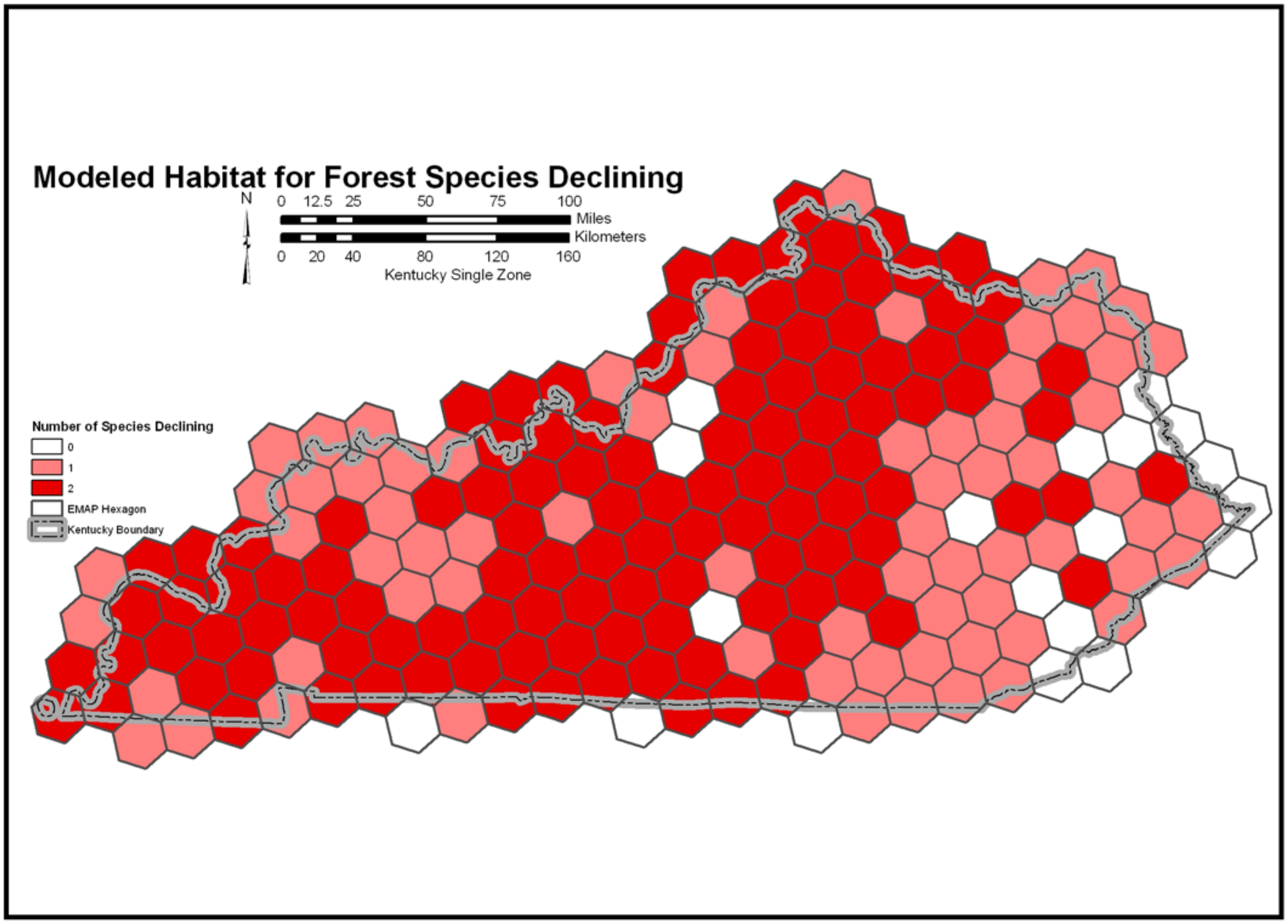


Figure 7. Location and number of species that had modeled habitat declines between 2001 and 2005 by hexagon for Kentucky.

The analysis of Advancers to Decliners or A/D Ratio is considered an indicator of market movement as a whole when discussing stock markets. When the ratio is low, it indicates that the market is moving down. When the ratio is high, it indicates the market is moving up. In the context of this paper, the A/D Ratio is the ratio between advancing modeled habitats and declining habitats for each species in the EMAP heaxagon and was calculated as follows:

A/D Ratio = number of species habitats Advancing / number of species habitats Declining

In wildlife habitat terms, a value of three means that three times as many species modeled habitats advanced as to species modeled habitats declined. Any value less than one means more species modeled habitats declined than species modeled habitats advanced (Figure 8). This characterization was not thought of as the number of habitat types but as total habitat area by EMAP hexagon.

An additional way to visualize modeled habitats across the state is with the Advance–Decline Spread or A–D Spread. This is a variation on the A/D Ratio. Just as its name implies, the A–D Spread charts the difference between the number of advancing modeled habitats and declining modeled habitats in each EMAP hexagon. The formula for the A–D spread is as follows:

A–D Spread = number of species habitats Advancing – number of species habitats Declining

The A–D Spread is an oscillator that revolves around zero. The A–D Spread is interpreted much like any oscillator with overbought and oversold levels near the extremes of the chart when in the context of the stock market. In the context of this paper, when the A–D Spread crosses above zero, this means more species habitats are advancing than are declining, and vice versa.

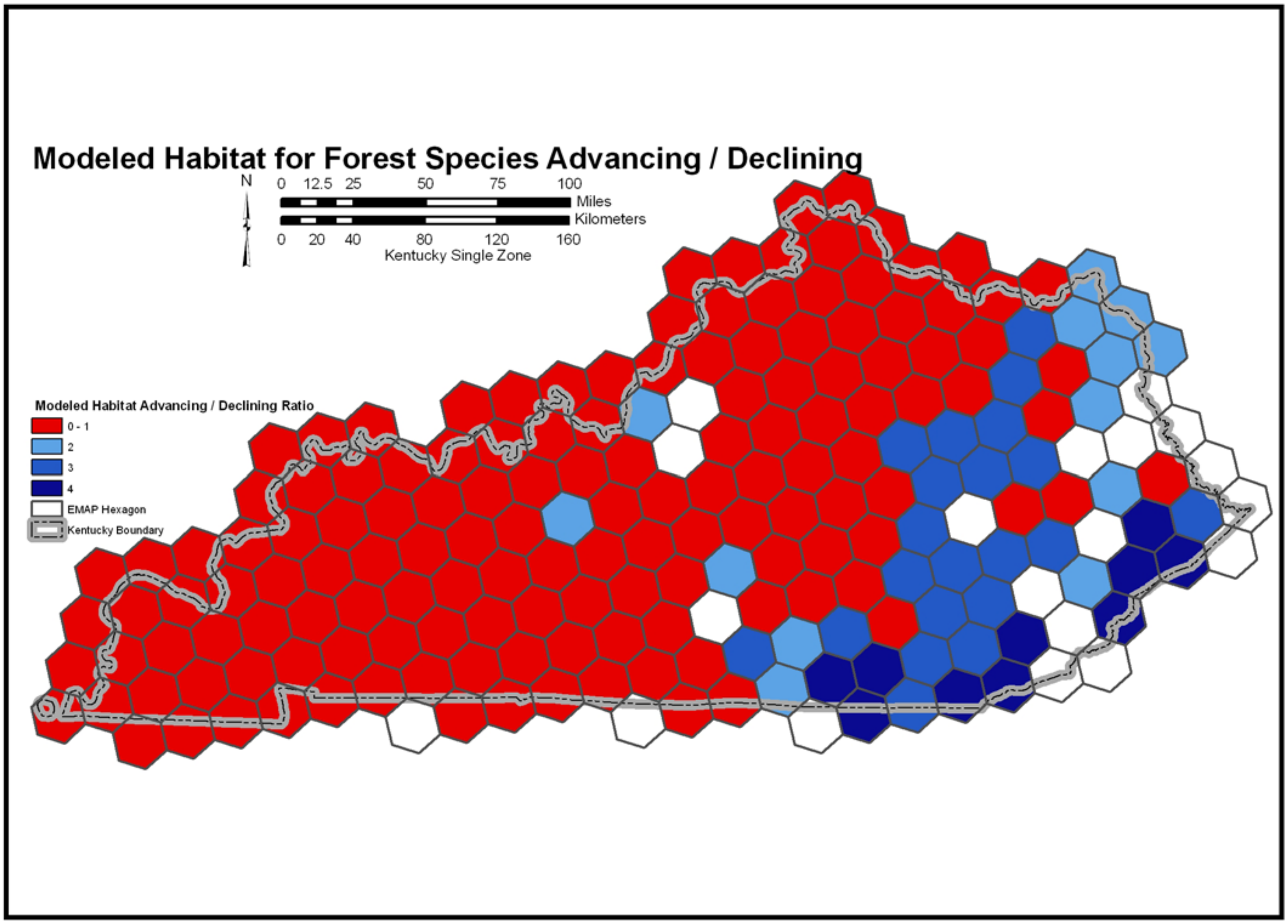


Figure 8. Location and the modeled habitat advance/decline ratio characterization by hexagon for Kentucky.

Discussion and Conclusions

There are strengths, limitations, and needed advancements to the modeling approach described in this paper. The lack of reliance on direct raster cell-to-cell modeled habitat comparisons, which can be difficult to achieve, is an advantage. Another advantage is the various metrics that can be used from Fragstats to quantitatively characterize habitat on a species-by-species decision, although only TOTAL AREA was used in this paper. Another strength is that the ModelBuilder species modeling approach allowed for relatively quick model adjustment and execution without extensive programming knowledge. For example, initially this project was going to use the 1992 and 2001 land cover data; however, the cross-walk between the two datasets was difficult to perform because the classification techniques and class definitions had changed. The comparison did not appear to work effectively upon visual inspection of the modeled habitat results. In addition, the Multi-Resolution Land Characteristics Consortium (MRLC) has cautioned users that direct comparison between 1992 and 2001 is not recommended unless the retrofit product is used (MRLC 2008). The retrofit product uses the Anderson Level I classification, which was not considered sufficient for this project's objectives. During the development of the approach described in this paper, the Commonwealth of Kentucky–Division of Geographic Information led the updating of the NLCD 2001 for Kentucky using 2005 data. The 2001/2005 update project's goal was to provide more current land cover information since the NLCD 2001 (Kentucky Division of Geographic Information 2008). Therefore, the decision to make comparisons between 2001 and 2005 modeled habitats was seen as an opportunity. Advancing and declining characterization can be performed on a variety of mapable units of analysis. EMAP hexagons were used in this paper but additional units could be used that are in keeping with data resolution capabilities. In addition, the modeled habitat characterization could be visualized by various combinations of species or specific groupings, such as only forest interior birds.

There are also some limitations of the approach and opportunities to extend the approach described in this paper. Better decision criteria thresholds for advancing/declining determination need to be established to indicate when the landscape has actually changed in a significant way. At this time, the species model development has relied exclusively on the literature, previous GAP projects, and organizational knowledge of species. The models used in this paper have not been validated with currently known species field occurrences. One approach for improving models could be based on the work of Laurent et al. (2006; 2007), particularly with respect to species model validation of Laurent et al. 2007. The visualization approach described in this paper depends on having individually valid species specific models.

Some geospatial ancillary data for the state are not up-to-date. For example, the state's wetlands and the GAP stewardship shapefiles are years to decades old. The Kentucky topography is believed to be markedly different today due to urbanization and mineral extraction processes; therefore, better topographical and subsequently landscape position data should be incorporated. The need to update the commonwealth's digital elevation data was identified during a 2008 statewide conference entitled "Mapping and Monitoring Land Resource Change: Bridging the Geospatial Divide" as a critical dataset to make available. The process outlined in this paper provides additional reasons to revisit and update those data. Future work will include expanding the species list to include more forest, wetland, grassland/open, or edge/mixed/early successional species before attempting an entirely revised Kentucky GAP Project. An additional opportunity exists by using an approach similar to what Pennsylvania GAP did in terms of the Regional Habitat Insecurity Index (RHII) and Leading Landscapes to identify areas of special conservation concern (Myers et al. 2000).

Biodiversity inventories can be visualized as "filters" designed to capture elements of biodiversity at various levels of organization. One approach is to employ a fine filter of rare species inventory and protection and a coarse filter of community inventory and protection (Jenkins 1985; Noss 1987). Gap analysis is a coarse filter method because it can be used to quickly and cheaply assess the other 85–90 percent of species. It is postulated that 85–90 percent of species can be protected by the coarse filter without having to inventory or plan reserves for those species individually. The approach described in this paper expands on the visualization aspects of the coarse filter with the incorporation of a temporal component.

The findings of the ongoing project are anticipated to improve the ability of planners and other management experts to determine where and by how much habitat resources are expanding, contracting, or staying the same. This approach has value for determining the allocation of limited financial and personnel resources for sustaining wildlife resources in Kentucky and potentially elsewhere. This work also has the potential to help land use planning efforts across the state by identifying critical habitat areas for use in landscape conservation planning. Using relatively few visualization products, planners and managers can discern broad scale patterns of habitat changes. By choosing different groupings of species to include in the advance/decline analysis, preliminary visualization can be used to give direction for more detailed investigations for the causes of increased or decreased habitat. This visualization approach potentially can be used as a landscape warning system of habitat change provided there is a period update to the data required in the species models.

Acknowledgements

M. Keith Wethington provided helpful advice on the species model development. Editorial assistance was provided by Karen Goodlet. The authors wish to thank the anonymous reviewers who provided helpful direction to improve this paper. The material is based on work supported by the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, under Agreement No. 2004-34408-15000. Any opinions, findings, conclusions, or recommendations expressed in this publication/presentation are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

References Cited

(ESRI) Environmental Systems Research Institute, Inc. 2007. ESRI ArcGIS Desktop, Version 9.2. Redlands, CA.

Fosback, N.G. 1976. *Stock market Logic: A Sophisticated Approach to Profits on Wall Street*. Institute for Econometric Research, Fort Lauderdale, FL.

Gap Analysis Program. 2000. A handbook for conducting gap analysis. U.S. Geological Survey Gap Analysis Program, Moscow, ID. Available from http://www.gap.uidaho.edu/handbook/CompleteHandbook.pdf

Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 National land cover database for the United States. *Photogrammetric Engineering and Remote Sensing* 70:829–840.

Homer, C., J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J.N. VanDriel, and J. Wickham. 2007. Completion of the 2001 National Cover Database for the Conterminous United States. *Photogrammetric Engineering and Remote Sensing* 73:337–341.

Jenkins, R.E. 1985. Information methods: Why the Heritage Programs work. *The Nature Conservancy News* 35(6):21–23.

Jennings, M.D. 2000. Gap analysis: concepts, methods, and recent results. *Landscape Ecology* 15:5–20.

Kentucky GAP Analysis Final Report, 2003. Kentucky Department of Fish and Wildlife Resources, Frankfort, KY. Available from http://www.kdfwr.state.ky.us/kfwis/KYGAPWeb/kyreport.pdf

Kentucky's Comprehensive Wildlife Conservation Strategy. 2005. Kentucky Department of Fish and Wildlife Resources, Frankfort, KY. Available from http://fw.ky.gov/kfwis/stwg/

Kentucky Division of Geographic Information. 2007. Kentucky Land Cover Change Detection 2001/2005—Anderson Level II. Kentucky Division of Geographic Information, Commonwealth Office of Technology, Frankfort, KY. Metadata available from http://kygeonet.ky.gov/metadataexplorer/full_metadata.jsp?docId={65E31366-1A04-4BE4-8128-0324E6C672F0} and Dataset available from ftp://ftp.kymartian.ky.gov/kls/KY_LCC0501.zip.

Kentucky Division of Geographic Information. 2008. 2005 Update to the Kentucky portion of the NLCD01. Kentucky Landscape Census Project: Taking GIS and remote sensing to the people of KY with an Open GIS data viewing & distribution system for Kentucky. NASA Cooperative Agreement NCC13-03010. Frankfort, KY.

Kirkpatrick, J.B. 1983. An iterative method for establishing priorities for the selection of nature reserves: An example from Tasmania. *Biological Conservation* 25:127–134.

Laurent, E.J., S.G. Williams, and A.J. McKerrow. 2006. Developing a scientifically rigorous framework for enhancing and evaluating vertebrate models. *Gap Analysis Bulletin* 14:18-23. Available at: http://www.gap.uidaho.edu/Bulletins/14/laurent.htm

Laurent, E.J., S.G. Williams, and A.J. McKerrow. 2007. Evaluating and enhancing GAP predications of birds in western North Carolina. Presentation at the United States Geological Survey GAP Analysis Conference. Asheville, NC. September 11–14, 2007.

Margules, C.R., A.O. Nicholls, and R.L. Pressey. 1988. Selecting networks of reserves to maximize biological diversity. *Biological Conservation* 43:63–76.

McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Fragstats Ver. 3.3 Build 5. Available from http://www.umass.edu/landeco/

Meffe, G.K., and C.R. Carroll. 1994. *Principles of Conservation Biology*. Sinauer Associates, Inc., Sunderland, MA.

(MRLC) Multi-Resolution Land Characteristics Consortium. 2008. National Land Cover Database (NLCD) 1992/2001 Retrofit Land Cover Change Product Multi-zone Download Site. U.S. Geological Survey, U.S. Department of the Interior. Available from http://www.mrlc.gov/multizone.php

Myers, W., J. Bishop, R. Brooks, T. O'Connell, D. Argent, G. Storm, J. Stauffer, and R. Carline. 2000. Pennsylvania GAP Analysis Project: Leading Landscape for Collaborative Conservation Final Report. Available from http://www.orser.psu.edu/PAGAP/PA_GAP_final_report_toc.htm

Nicholls, A.O., and C.R. Margules. 1993. An upgraded reserve selection algorithm. *Biological Conservation* 64:165–169.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories: A Look at The Nature Conservancy (USA). *Biological Conservation* 41:11–37.

Pressey, R.L., and A.O. Nicholls. 1989. Application of a numerical algorithm to the selection of reserves in semi-arid New South Wales. *Biological Conservation* 50:263–278.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards Jr., J. Ulliman, and G. Wright. 1993. Gap analysis: A geographic approach to protection of biological diversity. *Wildlife Monographs* 123:1–41.

U.S. Environmental Protection Agency. 2008. Environmental Monitoring and Assessment Program: About EMAP. United States Environmental Protection Agency, Washington, DC. Available from http://www.epa.gov/emap/html/about/index.html

White, D., J.A. Kimerling, and S.W. Overton. 1992. Cartographic and geometric components of a global sampling design for environmental monitoring. *Cartography and Geographic Information Science* 19:5–22.

APPLICATIONS

Applications of SWReGAP Data to Conservation

Kenneth G. Boykin[1] , William Kepner[2], David Bradford[2]

Introduction

The Southwestern Regional Gap Analysis Project (SWReGAP) provides regional data sets for Arizona, Colorado, New Mexico, Nevada, and Utah, an area that approximates nearly one-fifth of the conterminous United States. These data sets allow for ecoregional analysis of biotic elements and current conservation status. SWReGAP data sets include a 125 class land cover map, 819 terrestrial species habitat models (37 amphibians, 130 reptiles, 437 birds, and 215 mammals), a seamless regional stewardship data set, and gap analysis statistics by state and region (Prior-Magee et al. 2007). SWReGAP was a cooperative effort involving many state and federal natural resource agencies, conservation organizations, tribal resource programs, and universities.

These data can play an informative role in the conservation strategies recently identified in state Wildlife Action Plans (SWAPs) or Comprehensive Wildlife Conservation Strategies (Arizona Game and Fish Department 2005a, 2005b; Colorado Division of Wildlife 2005; Nevada Department of Wildlife 2005; New Mexico Department of Game and Fish 2005, Utah Division of Wildlife Resources 2005). SWAPs provide state and Federal agencies a blueprint for conservation. Incorporation of SWReGAP into these strategies will be mutually beneficial to all involved.

For the past two years New Mexico Cooperative Fish and Wildlife Research Unit provided outreach and expertise in applying SWReGAP data to state, federal, and local cooperators. We worked closely with existing cooperators to provide workshops, expertise, and coordination in using SWReGAP data in conservation applications. We focused on three objectives: (1) conducting workshops for partners; (2) working with partners to incorporate SWReGAP data; and (3) identifying future collaborative projects.

[1] New Mexico Cooperative Fish and Wildlife Research Unit, Department of Fish, Wildlife, and Conservation Ecology, New Mexico State University, Las Cruces, NM.

[2] U.S. Environmental Protection Agency, Office of Research and Development, Landscape Ecology Branch, Las Vegas, NV.

Workshops

We created a workshop focusing on the products and applications of SWReGAP (available at http://swgap.nmsu.edu/SWGAPWorkshops/. Workshops provided participants with background, methods, results, data acquisition, and an opportunity for hands-on use of the data, and were designed around Gap Analysis objectives. State wildlife agencies were targeted including Arizona Game and Fish Department (AGFD), Colorado Division of Wildlife (CDOW), Nevada Department of Wildlife (NDOW), New Mexico Department of Game and Fish (NMDGF), and Utah Division of Wildlife Resources (UDWR). The focus was on identifying potential future collaborative efforts. The 72 participants included bureau and assistant chiefs, recovery coordinators, habitat specialists, biologists, GIS coordinators and specialists, natural heritage coordinators, Wildlife Action Plan coordinators, program managers, conservation stewardship coordinators, and planners. Workshops discussions centered on SWAPs and applying gap data to new applications. Lists of potential applications of SWReGAP data to each wildlife agencies were generated. Focus was on current or planned projects that could be enhanced with SWReGAP data.

Identified projects included methods to identify areas of conservation concern, high priority habitat, conservation focus, and species habitat within these areas (AGFD 2005a, CDOW 2005, NMDGF 2005, UDWR 2005). Other needs included using data to inform Habitat Stamp Programs, land acquisition and property evaluations (CDOW 2005, NMDGF 2005). Agencies also are interested in using this and other data to evaluate oil and gas leases and regulations (CDOW 2005, NMDGF 2005). Data also can be used for species evaluation, monitoring, recovery plans, and potential reintroduction areas (CDOW 2005, NMDGF 2005, UDWR 2005). Projects focusing on more technical aspects included creating a generalized vector land cover data set for an existing tool (AGFD 2005b) and providing data sets for use under limited software and hardware resources (NMDGF 2005). A need also exists to compare SWReGAP data sets to other currently used data sets (AGFD 2005a, CDOW 2005). Other suggestions included additional habitat modeling of subspecies and species not modeled by SWReGAP, and collaborating on modifying and assessing models (NDOW 2005, UDWR 2005).

Federal agencies, including Region 2 U.S. Fish and Wildlife Service (USFWS), also expressed interest in SWReGAP data. SWReGAP data provides baseline information for the nationwide strategic habitat conservation planning effort (National Ecological Assessment Team 2006). Other projects discussed included identifying CRP lands, shinnery oak, sandsage, mesquite, and creosote bush communities for restoration, and using models (e.g. yellow-billed cuckoo) to identify habitat quality and quantity necessary for stable populations.

Workshop participants identified barriers to using gap analysis data. A strategic plan for the Gap Analysis Program with a conceptual timeframe when data sets will be updated was suggested. State agencies expressed concern that analyses and data sets are a snapshot in time with no specific time lines and strategies for future iterations or modifications. There is significant interest in having assistance in using and modifying the data for specific agency purposes. Cooperators were interested in the time lines for the adjacent regional projects including the Northwest, California, Texas, Oklahoma, Kansas, and Nebraska, especially with respect to edgematching. Cooperators were also interested in Aquatic GAP and its products.

Land cover, stewardship, and individual species habitat model data sets are the most frequently used SWReGAP data sets, largely because of ease of use. Agencies expressed interest in the gap analysis statistics but currently do not use analyses. Agencies were interested in modifying the underlying data sets based on either state knowledge or new information. Agency personnel, software, and hardware limit the ability to use data. Web-based applications such as the Gap Ecosystem Data Explorer (GEDE) tool will provide avenues to overcome this barrier.

Applications

Scaling SWReGAP data down for county level application was conducted in an Environmental Protection Agency funded project that addressed the Clark County, NV Multispecies Habitat Conservation Plan (MSHCP)(Clark County Department of Comprehensive Planning 2000; Hiatt and Boone 2003). We revised 37 species habitat models specific to the Mojave Desert Ecoregion (Boykin et al. 2008). Species model modifications varied with corresponding changes in suitable habitat dependent on species. A higher percentage of habitat for these 37 species is in Status 1 and 2 lands within the study area than within the rest of Nevada or the SWReGAP region. We applied the gap analysis approach to a MSHCP management data set to provide better context. We evaluated whether inductive habitat modeling approaches for four species provided better suitable habitat representation. Results varied based on number of species occurrence points, distribution of points, and adequate input data sets (Boykin et al. 2008). Results do suggest that further analysis of this method is warranted.

We are currently working with NDOW on an inductive habitat model for the entire range of the Gila Monster (*Heloderma suspectum*) using Maximum Entropy (Phillips et al. 2006). The species was prioritized as a regional species of concern by the Southwest Partners in Amphibian and Reptile Conservation (SWPARC) and within SWAPS (AGFD 2005b, NDOW 2005, NMDGF 2005, UDWR 2005).

We are currently applying SWReGAP data to several other projects including incorporating SWReGAP data into the NMDGF web-deployed SWAP database. We also assisted in completing a spatial data request from the Western Governors' Association by providing a New Mexico Species of Greatest Conservation Need (SGCN) species richness data set. NMDGF is incorporating SWReGAP data into their online species database (Biota Information System of New Mexico–BISON-M; <http://bison-m.org/>). Data have been used in several county and state agency conservation plans including Bernalillo County, NM, and Pima County, AZ.

Regional Research

We are in the process of comparing "gap species" and SGCN and creating a regional conservation focal area data set. The comparison between "gap species" and SGCN is focused on concordance and discordance between these two lists. This analysis will identify species that should be reviewed for Wildlife Action Plan updates. The conservation focal area analysis uses data sets of identified key habitats, ranking of factors that affect those habitats, SGCN richness, and gap management status to identify areas of potential conservation focus within the entire region (see NMDGF 2005).

Conclusions

State wildlife agencies in the SWReGAP study area were given full day workshops. There is a high level of interest in using these data sets and we identified a need for assistance in application. Application of data sets will be influenced by agency needs and limitations, direction of state wildlife action plans, and developing partnerships with state and Federal agencies (e.g. USFWS). Potential limitations for using SWReGAP data range from operational (hardware and software) to technical (limited GIS capabilities) to philosophical (finer scale focus). Hardware, software, and personnel capabilities vary considerably between potential end users and many personnel work at a finer resolution than SWReGAP data is intended to be used.

SWAPs are obvious connections between SWReGAP and state agencies. Unfortunately SWAPs were completed at the same time as SWReGAP. Three states used SWReGAP land cover (Colorado, Nevada, New Mexico) and two states used stewardship, and habitat models (Colorado, New Mexico). Two states (Arizona and Utah) did not use SWReGAP data within their SWAP. States acknowledged the need to incorporate data sets such as SWReGAP. Regionalization of state SWAPs is necessary and SWReGAP data provides a consistent baseline data set. Other efforts (e.g. SWPARC) are also in search of a regional framework to organize conservation efforts.

References Cited

(AGFD) Arizona Game and Fish Department. 2005a. Arizona's Comprehensive Wildlife Conservation Strategy: 2005-2015. Arizona Game and Fish Department, Phoenix, AZ.

(AGFD) Arizona Game and Fish Department. 2005b. Arizona's Comprehensive Wildlife Conservation Strategy: State of the State (Companion Document B). Arizona Game and Fish Department, Phoenix, AZ.

Boykin, K.G. 2007. Southwest Regional Gap Analysis Project: Application, Outreach, and Education. Technical Assistance Report. New Mexico Cooperative Fish and Wildlife Research Unit.

Boykin, K.G., D. Bradford, and W. Kepner. 2008. Habitat Distribution Models for 37 Vertebrate Species Addressed by the Multi-species Habitat Conservation Plan of Clark County, Nevada. U.S. Environmental Protection Agency.

Clark County Department of Comprehensive Planning. 2000. Final Clark County Multiple Species Habitat Conservation Plan and Environmental Impact Statement for Issuance of a Permit to Allow Incidental Take of 79 Species in Clark County, Nevada. U.S. Fish and Wildlife Service, Reno, NV.

(CDOW) Colorado Division of Wildlife. 2005. Colorado's Comprehensive Wildlife Conservation Strategy. Colorado Division of Wildlife, Denver, CO.

Hiatt, H., and J. Boone (eds). 2003. Clark County Multiple Species Manual. Clark County Department of Comprehensive Planning, Las Vegas, NV.

National Ecological Assessment Team. 2006. Strategic Habitat Conservation: Final Report of the National Ecological Assessment Team. Available from http://www.fws.gov/nc-es/habreg/NEAT_FinalRpt.pdf

(NMDGF) New Mexico Department of Game and Fish. 2005. Comprehensive Wildlife Conservation Strategy for New Mexico. New Mexico Department of Game and Fish, Santa Fe, NM. 526 p. and appendices.

(NDOW) Nevada Department of Wildlife. 2005. State of Nevada Comprehensive Wildlife Conservation Strategy. Nevada Department of Wildlife, Reno, NV.

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

Prior-Magee, J.S., K.G. Boykin, D.F. Bradford, W.G. Kepner, J.H. Lowry, D.L. Schrupp, K.A. Thomas, and B.C. Thompson, editors. 2007. Southwest Regional Gap Analysis Project Final Report. U.S. Geological Survey, Gap Analysis Program, Moscow, ID.

(UDWR) Utah Division of Wildlife Resources. 2005. Utah's Comprehensive Wildlife Conservation Strategy. Utah Division of Wildlife Resources, Salt Lake City, UT.

Using GAP Data in Invasive Plant Ecology and Management

Gary N. Ervin[1]

Introduction

More than 5,000 species of plants introduced to the United States are estimated to have escaped cultivation and exist in some form of sustained wild populations (Pimentel et al. 2001). The potential costs of non-native species invasions has been estimated in the hundreds of billions of dollars per year for control efforts, environmental impacts, and actual commercial losses (Mullin et al. 2000, Pimentel et al. 2001). However, despite the assertions that control efforts during early stages of establishment are likely to be most successful, the focus of invasive species management remains largely within the realm of removal and eradication of well established species (Mullin et al. 2000). This may be the result of numerous factors, foremost of which is that most widespread species usually are of the most substantial economic interest.

A framework that has been proposed for augmenting programs aimed at controlling economically costly and widespread species is the early detection rapid response (EDRR) system. The concept of a nationwide EDRR system was formulated in 2003 (Westbrooks 2005). The concept of EDRR efforts will become more important over time, as ongoing governmental freezes, reductions, and reallocations of state and Federal funds limit the ability of government agencies to keep pace with the spread of invasive species. One potential means of enhancing the efficacy and efficiency of EDRR efforts is the development of probabilistic habitat models for invasive species of concern. These models could guide the limited search and monitoring efforts that currently are possible based on existing funding allocations. Accurate plant habitat models would facilitate efforts at locating, monitoring, and managing existing populations of invasive species as well as identifying adjacent land areas that are at risk of invasion.

Two major research emphases at Mississippi State University that aim to achieve this integration between invasive species research and management are the Cactus Moth Detection and Monitoring Network <http://www.gri.msstate.edu/research/cmdmn/> and the Invasive Plant Atlas of the Mid-South (IPAMS; <http://www.gri.msstate.edu/ipams/>). The IPAMS was established to record the distribution of native and non-native invasive plants within a five-state region of the south-central United States, and to use those data for developing geospatial habitat expectation models (niche models) to aid in guiding management efforts. The present work is part of that effort, but also demonstrates the utility of data available through the U.S. Geological Survey (USGS) Gap Analysis Program (GAP) in informing the development of such models. The case study presented here deals with a native species, *Baccharis halimifolia* L. (Asteraceae), that is believed to be increasing in its distribution within the southeastern United States (Ervin 2008).

Methods

Study Species and Study Area

Baccharis halimifolia L. (Asteraceae) is a shrub commonly known as eastern baccharis, silverling, groundsel-bush, or salt-bush. This species is considered native to the Atlantic and Gulf Coast regions of the United States from Texas to Massachusetts (U.S. Department of Agriculture, Natural Resources Conservation Service 2007; Weakley 2007), where it has historically occurred in upland fringes of coastal marshes and back dune habitats (Krischik and Denno 1990). *B. halimifolia* occurs under a wide range of soil and environmental conditions with respect to factors such as soil pH and nutrient concentrations, and has the ability to survive periodic flooding and drought, as well as fire (Westman et al. 1975).

B. halimifolia is wind-pollinated and produces large numbers of small, wind-dispersed fruit (0.1 mg dry mass per achene; Krischik and Denno 1990). As many as 1.5 million achenes may be produced per plant, and the highest rates of seed production have been observed from plants growing in open-canopied habitats (Westman et al. 1975, Panetta 1977). Available data suggest that germination of non-buried seeds occurs shortly after dispersal. Seedlings are thought to be able to establish during winter, potentially because dormant neighbors have limited capacity to shade the microhabitats where seedlings must establish (Panetta 1977, 1979b).

[1] Department of Biological Sciences, Mississippi State University, Missisippi State, MS.

Despite its historical coastal distribution, *B. halimifolia* is capable of establishing in interior regions of the southeastern United States, particularly in disturbed habitats such as fallow fields and forest edges, as well as arid inland habitats (Krischik and Denno 1990). Areas where *B. halimifolia* has been reported include the interior regions of the coastal plains (Duncan 1954, Krischik and Denno 1990), as well as the Piedmont, Ridge and Valley, Interior Low Plateau, and even in the foothills of the Blue Ridge and Cumberland Plateau (Estes 2004, 2005, Weakley 2007). Duncan (1954) reported that *B. halimifolia* increased its distribution substantially during the first half of the 20th century, and was considered in 1954 to be a weed "of great importance" in Georgia. Outside the United States, *B. halimifolia* has become an invasive weed in Australia, France, Spain, and the Black Sea region of eastern Europe (Westman et al. 1975). The noxious chemistry of its foliage and its preference for disturbed habitats make *B. halimifolia* especially problematic in pasturelands used for cattle production (Kraft and Denno 1982, Boldt 1989, Nesom 2001).

Data Collection

Data for the present study were collected through roadside surveys of *B. halimifolia* in 17 counties of northeastern Mississippi (Figure 1). This region was expected to provide a gradient of *B. halimifolia* density from the southern extent of the region to the Mississippi-Tennessee border. *B. halimifolia* occurs in high densities in the southern portion of this study area, but has only recently been reported in Tennessee (Estes 2004, 2005). Survey routes consisted primarily of state and federal highways, which provided the most direct means of transecting multiple counties in the study area. Those routes also were readily available as georeferenced data layers. Data layers for the highways were obtained from the Mississippi Automated Resource Information System (MARIS; <http://www.maris.state.ms.us/>). The selected routes were digitized in ArcGIS 9.0 (Environmental Systems Research Institute, Inc.), converted to an ArcGIS shapefile, and transferred to an HP iPAQ HX 2110, running Windows Mobile™ 2003 second edition, version 4.21.1088. Navigation along the routes was performed with the assistance of Farm Works Site Mate version 11.40 (CTN Data Service, Inc.) geographic information system (GIS) software and a Holux compact flash card global positioning system (GPS) unit, model GR-271. Digitized routes were corrected for new highway construction after the surveys by visual inspection within GIS and comparison with *B. halimifolia* locations and an independent land cover data layer (National Land Cover Database [NLCD 2001], Multi-Resolution Land Characteristics Consortium: <www.mrlc.gov> [MRLC 2001]). Data handling within ArcGIS was performed in the Albers map projection (USA Contiguous Albers Equal Area Conic, USGS version) and the 1983 North American Datum geographic coordinate system (NAD 1983). However, data collection in the field was performed in the 1984 World Geodetic System datum (WGS 1984), and data were re-projected to NAD 1983 as necessary within ArcGIS.

The roadside surveys, conducted during November and December 2006 (period of fruit production and dispersal), provided 553 presence points for *B. halimifolia* along the survey route (797 km surveyed). To conduct logistic habitat modeling, absence data are required in addition to presences. In this study, absence data were provided by generating pseudo-absence points within 50 m of the survey routes. This was the distance within which it was estimated that *B. halimifolia* patches could be identified readily during the driving survey, as its dense white clusters of flowers and fruit made reproductive individuals readily visible from a few hundred meters in open landscapes. It is possible that pre-reproductive plants could have been overlooked, although the canopy morphology and leaf color and texture are highly noticeable in the surveyed area, especially within 50 m of the road.

Generation of pseudo-absence points is a well established method of creating statistically valid absence data for ecological modeling when true absence records are not available (see Engler et al. 2004 or Chefaoui and Lobo 2008). For this study, pseudo-absence points were generated by creating, in ArcMap, a buffer of 50 m on each side of the survey route. Each recorded *B. halimifolia* point was buffered by a distance of 200 m, and the area of those point buffers was subtracted from the 100-m-wide route buffer. Five hundred random pseudo-absence points were generated within the remaining route buffer area to represent likely points at which *B. halimifolia* was not present, assuming all patches within 50 m of the survey route were observed and recorded. One-half of the presence and pseudo-absence points were selected to form a training data set, the other half were used in model validation, as described below.

Environmental variables hypothesized to be determinants of *B. halimifolia* habitat were soil characteristics and canopy coverage. Soil data included clay content (percent), available water capacity ($cm \bullet cm^{-1}$), bulk density ($g \bullet m^{-3}$), organic matter (percent), pH, cation exchange capacity ($meq \bullet 100g^{-1}$), and permeability ($cm \bullet h^{-1}$). These data were extracted from the USDA NRCS STATSGO data (USDA NRCS 1994). Each variable was represented in the STATSGO database by a high value and a low value for each soil survey mapping unit, and both high and low values were used in the modeling work described here. Canopy cover was obtained from the MRLC National Land Cover Database (NLCD) as 30-m-resolution tree canopy density data (percent cover, to nearest 1 percent). Those data were a USGS Southeastern GAP data product generated initially by the method of Huang et al. (2001).

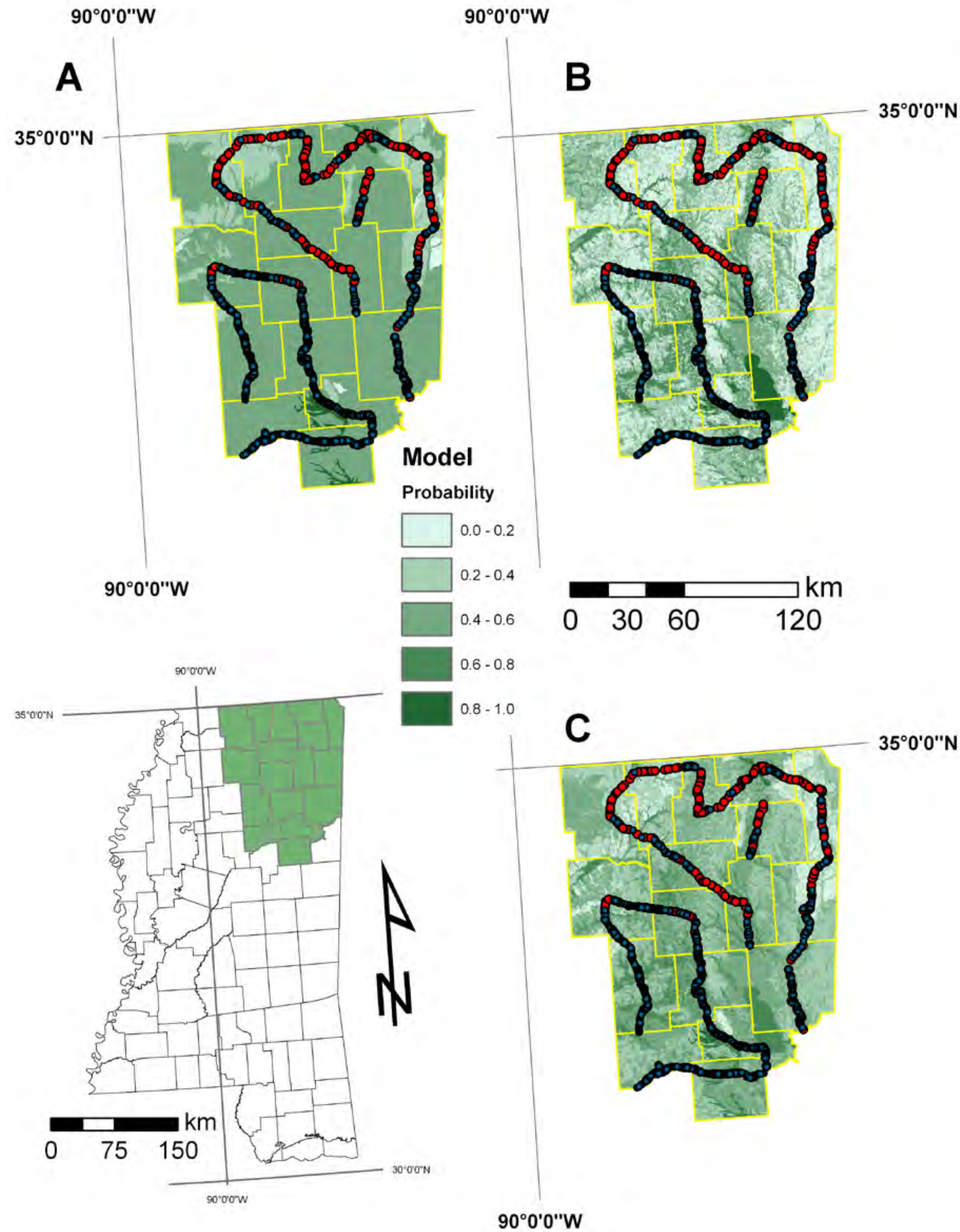


Figure 1. Map of study area and depiction of the three best habitat models from these analyses, in terms of probability of occurrence of habitat suitable for *Baccharis halimifolia*, given environmental data across the area. The Mississippi map in the lower-left shows the location of the study area within the state (shaded northeastern counties). Colored points in the habitat probability surfaces (*A*–*C*) indicate presence (blue) and pseudo-absence (red) points for *Baccharis halimifolia*, along the 797 km survey route. Models are (*A*) minimum soil percent organic matter, soil bulk density model; (*B*) canopy, minimum soil percent organic matter, minimum soil percent clay, pH model; (*C*) averaged model.

Model Development

Presence-absence/distributional models were derived via logistic regression because this approach combines the ability to quantify correlations between predictor and response variables with the utility of incorporating categorical variables, such as the binary presence-absence response variable. The latter feature of logistic regression is attractive for obvious practical reasons but also avoids key statistical issues of ordinary least squares regression, such as failure of dichotomous variables to satisfy assumptions of equal variance, linearity, and normality (Menard 2002).

Logistic regression has been used in successful efforts at modeling species distribution or habitat suitability in several systems. For example, logistic regression was compared with discriminant analysis and artificial neural networks for presence-absence prediction of six bird species on 180 Himalayan streams (Manel et al. 1999). The three methods were found to be equally capable in their overall success at predicting presence or absence. However, logistic regression was described as yielding the most straightforward ability to assess the relative importance of individual environmental variables because of the ability to generate estimated probability of occurrence from regressions on logit-transformed presence-absence data. Manel and colleagues subsequently have used logistic regression in numerous habitat models (e.g., Manel et al. 2000, 2001), as have Buchan and Padilla (2000), Peterson et al. (2003), Underwood et al. (2004), and others.

Derivation and selection of the “best” model(s) of *B. halimifolia* habitat involved two phases. First, the initial set of candidate models to be parameterized consisted only of those containing predictors that were uncorrelated with one another based on simple bivariate correlation analyses (i.e., Pearson correlations). This provided clear indication of the potential explanatory power of each predictor variable independent of other factors. All candidate models then were evaluated by logistic regression and the best models identified by model selection statistics provided through the information-theoretic approach (Burnham and Anderson 2002). Specifically, the log likelihood value from each logistic regression was used to calculate the (corrected) Akaike Information Criterion (AIC_c), from which AIC differences were calculated for use in evaluating the resultant models and for determination of the most influential landscape features, in terms of their correlation with presence and absence of *B. halimifolia*. The corrected Akaike Information Criterion was calculated as:

$$AIC_c = -2\times\left(-\frac{n}{2}\log\left(\frac{RSS}{n-(p+1)}\right)\right)+2K+\left(\frac{2K(K+1)}{n-K-1}\right) \quad , \qquad (1)$$

where

n is the number of sample units (presence and absence points)

RSS is the residual sum of squares from each regression model,

p is the number of predictor variables used in the regression model, and

K is the number of parameters estimated in each model (numbers of predictor variables + 2; includes intercept and variance estimate).

After the initial round of model and environmental factor screening, four additional models were added which included combinations of the most influential, but correlated, environmental factors. Those models were added to permit evaluation of the strength of models with specific suites of soil variables, along with canopy cover. Thus, the tiered approach to developing habitat models incorporated (1) logistic regression to test sets of candidate hypotheses for suites of factors influencing *B. halimifolia* occurrence, and (2) quantitative determination of the model(s) that best represented landscape features associated with distribution of this species, based on the presence-absence data set and *a priori* determined environmental variables thought to be of importance.

During model development and validation, model adequacy also was assessed with a suite of criteria including simple success rate (percent of test points correctly classified) as well as more complex evaluation metrics (Table 1). The AIC_C mentioned above is one such metric that provided information on the relative strength of models, including the efficiency of prediction, as AIC calculation “penalizes” models with larger numbers of variables. Once models were selected for implementation from among those developed with the training data, they were validated with the second half of the data, using the same set of assessment metrics. Manel et al. (2001) evaluated seven assessment metrics for presence-absence models and found that Cohen’s kappa performed best, in part because it was less influenced by prevalence of presence or absence points (i.e., the relative proportion of presence or absence points within the data set). Cohen’s kappa essentially represents the proportion of all possible cases predicted correctly as present or absent by a model after accounting for the effects of chance. Because it is a standardized value, kappa can be used to compare models that include different suites of predictor variables. The True Skill Statistic is suggested to improve upon kappa by having a smaller degree of correlation with prevalence of occurrences versus absences in the data set (Allouche et al. 2006).

Table 1. Model assessment metrics used in this study.

[**Description**: After Δ AIC_c, based on detail provided by Fielding and Bell (1997) and Allouche et al. (2006). **Abbreviation**: Δ, delta; AICc, Akaike Information Criterion]

Assessment metric	Description
Δ AIC_c	Difference in AIC_c between an individual model and the model with the lowest AIC_c value
Success rate	Proportion of points correctly classified as presence or absence
Sensitivity	Proportion of actual presences correctly predicted
Specificity	Proportion of actual absences correctly predicted
Positive predictive power	Proportion of predicted presences that represent actual presence points
Negative predictive power	Proportion of predicted absences that represent actual absence points
Cohen's kappa	"Proportion of specific agreement;" effectively corrects overall accuracy by accuracy expected by chance; see references for details
True skill statistic	(Sensitivity + specificity) - 1

Results

The three best models, based on the Akaike Information Criterion, and as evaluated within the training data set, all included canopy cover as one of the environmental variables correlated with presence of *B. halimifolia* (Table 2). The three models were similar in terms of their performance based on a suite of standard model assessment criteria (overall prediction success, sensitivity, negative predictive power, and Cohen's kappa). However, another set of three models lacking the canopy cover variable performed well when evaluated by specificity, positive predictive power and the True Skill Statistic (TSS). Based on these results, all six of these models were carried into the validation phase of model evaluation.

In validation assessment, the set of six predictive habitat models performed similarly when evaluated against the training data set (Table 2). The models including canopy cover performed better in overall prediction success, sensitivity, negative predictive power, and Cohen's kappa, whereas those without canopy cover exhibited slightly better values for specificity, positive predictive power and TSS. Because of this ambiguity, an additional model was evaluated; that model was based on the average of the logit-transformed predicted probability occurrence determined by the top model in each of the two subsets of models with or without canopy cover (Table 2, bottom row). This model's performance appeared to be influenced heavily by the model that included canopy cover, while values for specificity, positive predictive power, and TSS were intermediate between the two models being averaged.

The best model in each subset of validated models (Table 2, highlighted rows), along with the averaged model are depicted in Figure 1*A–C*. The model that lacked canopy cover (Figure 1*A*) predicted a greater than 50 percent chance of *B. halimifolia* presence for most of the study area. The other two models yielded a more heterogeneous habitat probability surface when projected across the study area in GIS (Figure 1*B,C*). Both models, however, included a large region of high predicted probability of occurrence in the southeastern portion of the study area. As discussed below, that appears to have been an artifact of the resolution of soils data that were used in these analyses.

Table 2. Assessment and validation criteria used in selecting the “best” logistic models to represent suitable habitat for *Baccharis halimifolia* across the survey area.

[Numbers in bold are the highest value for each criterion in each phase of model assessment and validation. The Averaged Model is an average of the two best models from the validation process (highlighted rows); its assessment criteria were highest or equal to the highest for three of the assessment criteria (bold font). **Abbreviations**: Ca, canopy (USGS GAP); OM, minimum soil percent organic matter; Cl, minimum soil percent clay; pH, maximum soil pH; OMx, maximum soil percent organic matter; BD, soil bulk density, in gram per cubic meter]

Environmental variables	Δ AICc	Success rate	Sensitivity	Specificity	Positive predictive power	Negative predictive power	Cohen’s kappa	True skill statistic
				Internal assessment				
Ca, OM, Cl	**0.0**	0.64	**0.62**	0.70	0.83	0.44	0.27	0.32
Ca, OM, Cl, pH	1.2	**0.65**	**0.62**	0.70	0.83	0.44	**0.28**	0.32
Ca, Cl, OMx	2.6	0.64	**0.62**	0.67	0.80	**0.46**	0.26	0.29
OM	39.8	0.61	0.58	**0.79**	**0.95**	0.23	0.18	**0.37**
OM, pH	40.3	0.61	0.58	**0.79**	**0.95**	0.23	0.18	**0.37**
OM, BD	41.8	0.61	0.58	0.78	0.94	0.24	0.19	0.36
				Validation				
Ca, OM, Cl	na	0.61	0.58	0.81	**0.95**	0.24	0.19	0.39
Ca, OM, Cl, pH	na	**0.64**	**0.61**	0.70	0.83	0.42	**0.26**	0.31
Ca, Cl, OMx	na	0.63	**0.61**	0.67	0.81	**0.44**	0.25	0.29
OM	na	0.61	0.58	0.81	**0.95**	0.24	0.19	0.39
OM, pH	na	0.61	0.58	0.81	**0.95**	0.24	0.19	0.39
OM, BD	na	0.62	0.58	**0.82**	**0.95**	0.25	0.21	**0.40**
Averaged Model	na	**0.64**	**0.62**	0.72	0.86	0.41	**0.27**	0.34

Discussion

Natural history information on *B. halimifolia* suggests that canopy cover would be informative in terms of predicting areas of suitable habitat. *B. halimifolia* is wind dispersed, requiring open habitats for long-distance dispersal, and published reports indicate that seeds germinate and establish more readily and that plants produce more viable seed in open canopied habitats than in shaded areas (Westman et al. 1975; Panetta 1977, 1979a). Further, observations before and during the road surveys suggested *Baccharis* is highly correlated with disturbed habitats, another correlate of low canopy coverage (Ervin 2008). Because of these factors, it is not surprising that the canopy cover data provided through the USGS GAP Project were present in the better models resulting from these analyses.

One observation from this exercise that was not expected, however, was the synergy provided by combining the USDA NRCS STATSGO data with canopy cover. The STATSGO data are very coarse-grained, with a mean sample unit of about 640 acres (259 ha). This is in large part explains the homogeneous nature of the predictive surface provided when the model included only soil data (Figure 1*A*). This coarseness also probably contributed to the large, homogeneous high probability region in the southeastern region of Figure 1*B* and 1*C* (although an inadequate number of sample points in that area might also be responsible). Nevertheless, when the coarse-grained soil data were combined with the more detailed and fairly accurate canopy coverage data, the result was a much more realistically heterogeneous probability surface and slightly better performance in assessment criteria (Table 2). Averaging of the two top models further improved upon this performance. Additional improvement likely will be possible with the incorporation of the SSURGO data, which are based on an average soil survey unit of about 64 acres (26 ha). Those data sets were not available for all the study area at the time these models were developed. These data are now available for all the surveyed counties in Mississippi.

This work suggests that the data provided by the USGS GAP project generally can be quite beneficial to efforts at modeling potential habitat for invasive plant species. This project has promise for contributing substantially to early detection-rapid response (EDRR) efforts as part of state and regional invasive species management plans. If accurate predictive models for key invasive plants can be developed, those models will be valuable tools to advise survey efforts contributing to EDRR programs. In addition to guiding detection and monitoring programs, these models can be used to assess the relative importance of different habitat variables, and that information may inform management efforts. In the present work, for example, canopy coverage seemed to be the most influential single variable. This correlates with the known biology of the target species and suggests that programs aimed at managing spread of *B. halimifolia* should focus on open canopied habitats, particularly newly opened areas which would be prone to colonization and development of satellite populations. In light of the biology of this species, the results also suggest that canopy-free land cover, such as transportation corridors and utility rights-of-way, might contribute to spread of *B. halimifolia*. All these pieces of information could prove very useful in monitoring or managing to reduce the spread of *B. halimifolia*, and the approach used here could serve as a template for studying and advising management of other invasive plant species.

Acknowledgments

The work presented here was supported by funding from the U.S. Geological Survey Biological Resources Discipline (04HQAG0135), U.S. Department of Agriculture (2007-55320-17847 and 2008-35320-18679), and the Mississippi Computational Biology Consortium (NSF EPSCoR #EPS-0556308). Assistance in data collection was provided by T. Ervin and G.L. Ervin. Chris Holly provided a very helpful critique of an earlier version of this paper, as did two anonymous reviewers.

References Cited

Allouche, O., A. Tsoar, and R. Kadmon. 2006. Assessing the accuracy of species distribution models: Prevalence, kappa, and the true skill statistic. *Journal of Applied Ecology* 43: 1223-1232.

Boldt, P.E. 1989. Biology and host specificity of *Trirhabda bacharidis* (Coleoptera: Chrysomelidae) on *Baccharis* (Asteraceae: Asterae). *Environmental Entomology* 18: 78-84.

Buchan, L.A.J., and D.K. Padilla. 2000. Predicting the likelihood of Eurasian watermilfoil presence in lakes, a macrophyte monitoring tool. *Ecological Applications* 10: 1442-1455.

Burnham, K.P., and D.R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer, New York.

Chefaoui, R.M., and J.M. Lobo. 2008. Assessing the effects of pseudo-absences on predictive distribution model performance. *Ecological modelling* 210: 478–486.

Duncan, W.H. 1954. More and more weeds in Georgia. *Bulletin of the Georgia Academy of Science* 12:99-103.

Engler, R., A. Guisan, and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. *Journal of Applied Ecology* 41: 263–274.

Ervin, G.N. 2008. Distribution, habitat characteristics, and new county-level records of *Baccharis halimifolia* L. on a portion of its present US range boundary. *Southeastern Naturalist*, accepted.

Estes, D. 2004. Noteworthy collections: middle Tennessee. *Castanea* 69: 69-74.

Estes, D. 2005. The vascular flora of Giles County, Tennessee. *Sida* 21: 2343-2388.

Fielding, A.H., and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24: 38-49.

Huang, C., L. Yang, B. Wylie, and C. Homer. 2001. A strategy for estimating tree canopy density using LANDSAT 7 ETM+ and high resolution images over large areas. *Proceedings of the Third International Conference on Geospatial Information in Agriculture and Forestry*, Denver, Colorado, 5-7 November, 2001. Available from http://www.mrlc.gov/mrlc2k_nlcd.asp

Kraft, S.K., and R.F. Denno. 1982. Feeding responses of adapted and non-adapted insects to the defensive properties of *Baccharis halimifolia* L. (Compositae). *Oecologia* 52: 156-163.

Krischik, V.A. and R.F. Denno. 1990. Differences in environmental response between the sexes of the dioecious shrub, *Baccharis halimifolia* (Compositae). *Oecologia* 83:176-181.

Manel, S., J.M. Dias, S.T. Buckton, and S.J. Ormerod. 1999. Alternative methods for predicting species distribution: An illustration with Himalayan river birds. *Journal of Applied Ecology* 36: 734-747.

Manel, S., S.T. Buckton, and S.J. Ormerod. 2000. Testing large-scale hypotheses using surveys: The effects of land use on the habitats, invertebrates, and birds of Himalayan rivers. *Journal of Applied Ecology* 37: 756-770.

Manel, S., H.C. Williams, and S.J. Ormerod. 2001. Evaluating presence-absence models in ecology: The need to account for prevalence. *Journal of Applied Ecology* 38: 921-931.

Menard, S. 2002. *Applied logistic regression analysis*, 2nd ed. Sage University Papers Series on Quantitative Applications in the Social Sciences, series no. 07-106. Sage Publications, Thousand Oaks, CA.

Mullin, B.H., L.W.J. Anderson, J.M. DiTomaso, R.E. Eplee, and K.D. Getsinger. 2000. Invasive plant species. Council for Agricultural Science and Technology Issue Paper, Number 13, February 2000, 18 p.

(MRLC) Multi-Resolution Land Characteristics Consortium. 2001. National Land Cover Dataset 2001. U.S. Geological Survey, U.S. Department of the Interior. Available from http://www.mrlc.gov/.

Nesom, G. 2001. Groundsel tree – *Baccharis halimifolia* L. USDA Natural Resources Conservation Service Plant Guide. Available from http://plants.usda.gov/factsheet/pdf/fs_baha.pdf

Panetta, F.D. 1977. The effects of shade upon seedling growth in groundsel bush (*Baccharis halimifolia* L.). *Australian Journal of Agricultural Research* 28: 681-690.

Panetta, F.D. 1979a. The effects of vegetation development upon achene production in the woody weed, groundsel bush (*Baccharis halimifolia* L.). *Australian Journal of Agricultural Research* 30: 1053-1065.

Panetta, F. D. 1979b. Germination and seed survival in the woody weed, groundsel bush (*Baccharis halimifolia* L.). *Australian Journal of Agricultural Research* 30: 1067-1077.

Peterson, A.T., M. Papes, and D.A. Kluza. 2003. Predicting the potential invasive distributions of four alien plant species in North America. *Weed Science* 51: 863-868.

Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E. Wong, L. Russel, J. Zern, T. Aquino, T. Tsomondo. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment* 84:1–20.

Underwood, E.C., R. Klinger, and P.E. Moore. 2004. Predicting patterns of non-native plant invasions in Yosemite National Park, California, USA. *Diversity and Distributions* 10: 447-459.

(USDA NRCS) United States Department of Agriculture, Natural Resources Conservation Service. 1994. State Soil Geographic (STATSGO) Database for MS. Available from http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html

(USDA NRCS) United States Department of Agriculture, Natural Resources Conservation Service. 2007. The PLANTS Database. National Plant Data Center, Baton Rouge, LA. Available from http://plants.usda.gov

Weakley, A.S. 2007. *Flora of the Carolinas, Virginia, and Georgia and Surrounding Areas*. UNC Herbarium, North Carolina Botanical Garden, University of North Carolina at Chapel Hill. Available from http://www.herbarium.unc.edu/flora.htm

Westbrooks, R. 2005. Progress on the development of a national early detection and rapid response system for invasive plants in the United States. Abstracts of the Second New England Invasive Plant Summit, September 16-17, 2005, Framingham, MA. Available from http://invasives.eeb.uconn.edu/ipane/summit05/summit05home.htm

Westman, W.E., F.D. Panetta, and T.D. Stanley. 1975. Ecological studies on reproduction and establishment of the woody weed, groundsel bush (*Baccharis halimifolia* L.: Asteraceae). *Australian Journal of Agricultural Research* 26:855-870.

Providing Digital Access to Ancillary GAP Data

Julie Prior-Magee[1]

Introduction

In addition to the standard coverages produced by the U.S. Geological Survey Gap Analysis Project (GAP), a variety of ancillary datasets are developed by state and regional projects. These datasets are used not only for producing the standard GAP coverages, but also can be used as products on their own. Following is a discussion of some of the ancillary datasets and information sources developed by GAP projects, how to access these data products, and current application of these datasets in natural resource management activities. The National Biological Information Infrastructure (NBII) is a cooperator in providing Internet access to a selection of these information resources.

Southwest Regional Gap Analysis Project (SWReGAP) Training Site Photographs

As part of the effort to collect ‘ground-truthed’ training data for the SWReGAP landcover mapping effort, field photos were taken for the majority of the sample plots. A training site database is made available online by the Remote Sensing/GIS Lab at Utah State University. This database includes over 45,000 photos and other data collected during the field effort for SWReGAP. The database can be accessed from <http://earth.gis.usu.edu/swgap/trainingsites.html>. To make the field photographs available to an even larger audience, work is beginning with the NBII Digital Image Library (DIL) to incorporate these photographs and their associated metadata into the DIL <http://images.nbii.gov>. The library contains well-documented images associated with organisms, habitats, wildlife management, and biological research. Images are also linked to metadata that follow the Dublin Core metadata standard. It is anticipated that other regional field photos from GAP will be incorporated into the DIL in the future.

Management Plans

As part of the GAP stewardship mapping effort, management plans are collected to provide information on management intent for various land tracts. Collection of these plans requires searching library collections and agency websites, and contacting agencies directly. In some cases, hundreds of plans may be collected representing a vast resource of consolidated management plan documentation for a region. This collection of management plans can be a useful resource for agencies or organizations interested in researching management actions for various areas.

Recently, an effort to catalogue this collection of management plans has begun in the NBII. The Southern Appalachian Information Node (SAIN) <http://sain.nbii.gov> has catalogued management plans that were collected as part of the Southeast Gap Analysis Project. These management plans are now available from the Resource Management Tools page of the SAIN website. Cataloguing of management plans collected in the Southwest and Northwest will also be completed to provide access to these resources through the NBII.

Other Ancillary Data From SWReGAP

Three ancillary datasets were developed by SWReGAP for use in developing the standard GAP coverages. These datasets are now available from the Remote Sensing/GIS Lab at Utah State University. The Geology dataset is a seamless 1:500,000 scale GIS dataset of surficial geologic formations for the states of Arizona, Colorado, Nevada, New Mexico and Utah. The dataset was compiled and edge-matched from digital versions of the 1:500,000 scale state geologic maps and is currently available from <http://earth.gis.usu.edu/swgap/geology.html>. The Landform dataset consists of 10 landform position classes defined by topographic position and slope gradients that were modeled using a GIS and is available at <http://earth.gis.usu.edu/swgap/landform.html>. Landsat

[1] U.S. Geological Survey, Biological Resources Discipline, Gap Analysis Project and National Biological Information Infrastructure, Las Cruces, NM.

ETM+ Images are available at <http://earth.gis.usu.edu/archive/search.html>. Using this archive one can search for imagery by clickable map, WRS2 Path and Row, by Latitude/Longitude, or by place name. Information is made available from the Intermountain Region Digital Image Archive Center (IRDIAC). The archive stores, processes, and disseminates, through the Internet, remotely sensed information to state and federal collaborators and the public within the Intermountain Region.

Uses of Ancillary Data

Landform and geology datasets produced by SWReGAP were used in the following applications: statewide resource inventories; hydrologic modeling; resource management planning by federal and state agencies; development of a geomorphic dataset; soil erosion modeling; sage-grouse habitat analysis; modeling pygmy rabbit habitat; as part of the soils and geology inventories of the National Park Service's Inventory and Monitoring (I&M) process; providing a geologic base for relating field data spatially; modeling distribution and age-structure of Southwest pinyon-juniper woodland systems relative to abiotic factors; studying the association between landform and cultural resource locations; environmental analysis for highway right-of-way maintenance; and groundwater flow models.

Ancillary Data Currently Available on GAPServe

A variety of ancillary datasets are currently available on the GAP website. The user can search under "Maps, Data, and Reports" then click on "Find GAP Data" and choose to find data by "Theme." Ancillary data is listed under the "Other" category of data themes. Categories of data available include: elevation, slope, lakes, streams and rivers, wetlands, springs, watersheds, roads, cities, county boundaries, soils, and temperature data <http://gapanalysis.nbii.gov/gapserve>

This page intentionally left blank.

AQUATIC

Applications of a Broad-Spectrum Tool for Conservation and Fisheries Analysis: Aquatic Gap Analysis

James E. McKenna, Jr.[1], Paul J. Steen[2], John Lyons[3], and Jana Stewart[4]

Introduction

Natural resources support all of our social and economic activities, as well as our biological existence. Humans have little control over most of the physical, biological, and sociological conditions dictating the status and capacity of natural resources in any particular area. However, the most rapid and threatening influences on natural resources typically are anthropogenic overuse and degradation. In addition, living natural resources (i.e., organisms) do not respect political boundaries, but are aware of their optimal habitat and environmental conditions. Most organisms have wider spatial ranges than the jurisdictional boundaries of environmental agencies that deal with them; even within those jurisdictions, information is patchy and disconnected. Planning and projecting effects of ecological management are difficult, because many organisms, habitat conditions, and interactions are involved. Conservation and responsible resource use involves wise management and manipulation of the aspects of the environment and biological communities that can be effectively changed. Tools and data sets that provide new insights and analysis capabilities can enhance the ability of resource managers to make wise decisions and plan effective, long-term management strategies. Aquatic gap analysis has been developed to provide those benefits.

Gap analysis is more than just the assessment of the match or mis-match (i.e., gaps) between habitats of ecological value and areas with an appropriate level of environmental protection (e.g., refuges, parks, preserves), as the name suggests. Rather, a Gap Analysis project is a process which leads to an organized database of georeferenced information and previously available tools to examine conservation and other ecological issues; it provides a geographic analysis platform that serves as a foundation for aquatic ecological studies. This analytical tool box allows one to conduct assessments of all habitat elements within an area of interest.

Aquatic gap analysis naturally focuses on aquatic habitats. The analytical tools are largely based on specification of the species-habitat relations for the system and organism group of interest (Morrison et al. 2003; McKenna et al. 2006; Steen et al. 2006; Sowa et al. 2007). The Great Lakes Regional Aquatic Gap Analysis (GLGap) project focuses primarily on lotic habitat of the U.S. Great Lakes drainage basin and associated states and has been developed to address fish and fisheries issues. These tools are unique because they allow us to address problems at a range of scales from the region to the stream segment and include the ability to predict species-specific occurrence or abundance for most of the fish species in the study area. The results and types of questions that can be addressed provide better global understanding of the ecological context within which specific natural resources fit (e.g., neighboring environments and resources, and large and small scale processes). The geographic analysis platform consists of broad and flexible geospatial tools (and associated data) with many potential applications.

The objectives of this article are to provide a brief overview of GLGap methods and analysis tools, and demonstrate conservation and planning applications of those data and tools. Although there are many potential applications, we will highlight just three: (1) support for the Eastern Brook Trout Joint Venture (EBTJV), (2) Aquatic Life classification in Wisconsin, and (3) an educational tool that makes use of Google Earth (use of trade or product names does not imply endorsement by the U.S. Government) and Internet accessibility.

[1] Tunison Laboratory of Aquatic Science, Great Lakes Science Center, U.S. Geological Survey, Cortland, NY.

[2] Great Lakes Science Center, U.S. Geological Survey, Ann Arbor, MI.

[3] Wisconsin Department of Natural Resources, Madison, WI.

[4] U.S. Geological Survey, Water Resources Discipline, Middleton, WI.

General Method

The basic development of an aquatic gap “analysis platform” follows the process of (1) data collection and organization, (2) identification and characterization of species-habitat relations, (3) predictive model construction, and (4) application of predictions to each stream reach within each drainage. GLGap is designed for evaluation of habitat condition influence on potential fish distributions at the Aquatic Ecological System (Sowa et al. 2007) (~8- or 10-digit Hydrologic Unit Code (HUC) or combination) or larger scale, but model predictions are made at the stream segment level (confluence-to-confluence). The empirical models designed to represent the species-habitat relations are a significant advancement of our ability to predict where stream conditions should be appropriate for support of various fish species. More than 100 species models have been developed for Great Lakes Basin stream habitats; most are highly reliable, explaining more than 75 percent of variation in the model development data (McKenna et al. 2006; Steen et al. 2006; J. Lyons, Wisconsin Department of Natural Resources, written commun. 2008). The drainage-wide projections provide a map of fish distribution patterns (and data-permitting abundances) and associated habitat conditions. Model predictions and the organized databases provide the analytical platform needed to address many questions about sampling distributions, habitat conditions and suitability, and biodiversity potential at large and small spatial scales. Applications of our model projections have already provided a wide range of benefits to natural resource management agencies, conservation groups, and scientific investigators.

Example Applications

Eastern Brook Trout Joint Venture

The Eastern Brook Trout Joint Venture is a coalition of agencies and organizations attempting to evaluate the status of brook trout (*Salvelinus fontinalis*) throughout its entire native range (EBTJV 2007). The EBTJV is a scientifically-based effort to provide a comprehensive range-wide conservation and education strategy that will assist all partners in effectively addressing common large-scale threats to brook trout and their habitat. Published work, available data, and expert knowledge were used to: (1) estimate the presence of brook trout in major drainage units of the eastern U.S., (2) determine the extant range of heritage strains of brook trout, and (3) identify those populations most in need of conservation (e.g., protection, rehabilitation, and reintroduction). Several specific EBTJV partner objectives are ideally accomplished by use of aquatic gap analysis tools and data, particularly assessing the status, trends, and changes in distribution of brook trout populations and identifying data needed to facilitate species conservation and management. GLGap also may be used to identify threats and potential solutions, assist resource managers in action prioritization based on indices of need, and share information and successes with partners and others. GLGap predictions also provide a reasonable benchmark of habitat potential (to support a particular fish species) with which future changes (restoration-induced or other) may be compared for monitoring and reporting purposes.

EBTJV efforts have been successful from Maine to Georgia. However, knowledge and information gaps remain. Even the most knowledgeable experts were unsure of the presence or status of brook trout within parts of their jurisdictions. For example, within the New York Department of Environmental Conservation (NYDEC) Region 7 (which includes the U.S. Route 81 corridor from Binghamton, NY to Syracuse, NY), there are about 11,000 km of stream habitat, divided into 6,348 stream reaches (defined as confluence-to-confluence based on 1:100,000 scale National Hydrography Data [NHD]). Extensive survey effort has provided samples of fish assemblage composition and brook trout occurrence and abundance from 8 percent of total stream length, within 86 percent of the Region 7 watersheds; brook trout status remains unknown in 14 percent of the watersheds (Figure 1).

The NYDEC and EBTJV are interested in filling those knowledge gaps for brook trout in the most effective way. GLGap’s multiscale model predictions provide both relatively fine- and coarse-scale indices of potential occurrence and relative abundance of brook trout within any stream segment. The GLGap model for brook trout in Central New York accounts for more than 90 percent of variation in brook trout data from the NYDEC Statewide Fisheries Database (McKenna et al. 2006). Preliminary evaluation of those predictions by comparison with field collections and expert review indicate a good correspondence with knowledge of brook trout habitat in selected areas of Central New York. Based on model predictions, past field collections are being evaluated with regard to locations of expected optimal brook trout habitat. The predictions also are being used to allocate field sampling effort, within the “known” regions. Results of field collections will be used to improve the EBTJV assessments and the GLGap brook trout model. GLGap predictions and new information can be used to help the EBTJV develop a Conservation Strategy that identifies current threats to eastern brook trout, propose a general strategy to deal with these threats, monitor improvements, identify priority needs, and outline potential solutions.

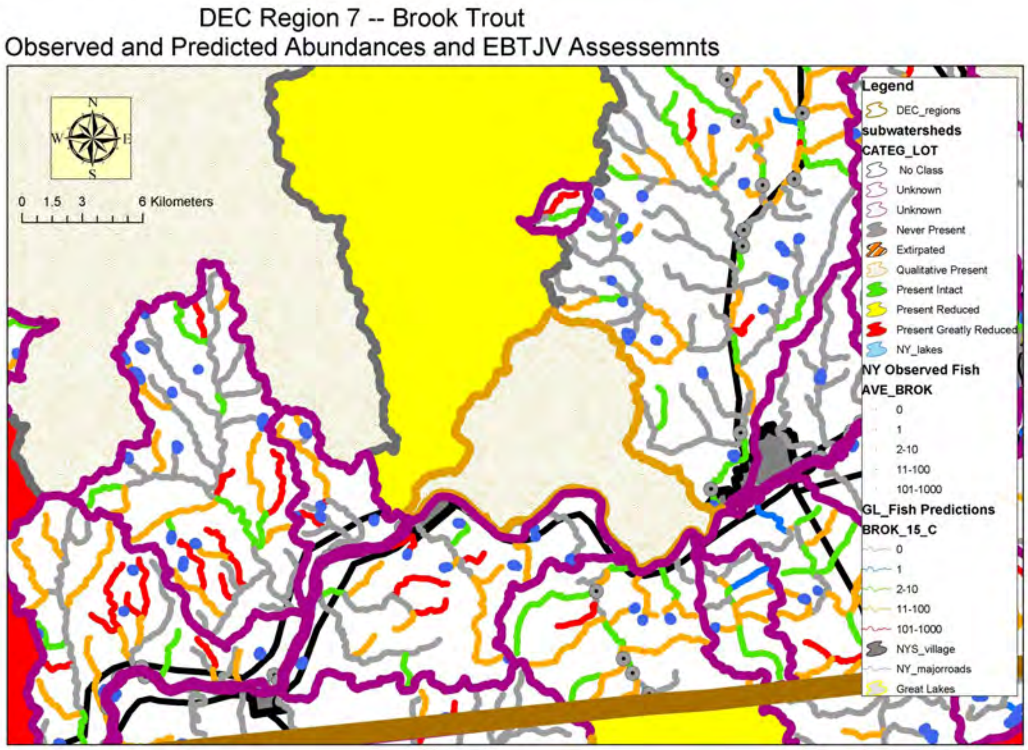


Figure 1. Part of south-central New York within the New York Department of Environmental Conservation, Management Region 7. Shaded polygon areas indicate known brook trout status (e.g., yellow areas are "Present Reduced") based on expert knowledge. Black lines bound 8-digit hydrologic units with unknown brook trout status (white background). Colored lines within those areas indicate GLGap predicted potential brook trout abundance within each stream segment. The greatest potential for good brook trout habitat is in the red and orange reaches.

Aquatic Life Indices for Wisconsin Waters

Wisconsin streams range from icy spring-fed headwaters to the mighty Mississippi River, with an associated diversity of distinctive aquatic communities. In the absence of major human impacts, the occurrence and abundance of fishes and invertebrates in Wisconsin streams (and probably other Great Lakes systems) is determined largely by streamflow and water temperature (Lyons et al. 1988; Lyons 1989, 1996; Wang et al. 2003), particularly minimum summer streamflow and maximum daily water temperature.

Biotic classification can be built on these habitat conditions. However, until recently, broad use of the stream classification has been hampered by the lack of data on stream temperatures and flows for the vast majority of streams in Wisconsin and throughout the Great Lakes Basin. The geographic information system (GIS)-framework (Brenden et al. 2006) and associated water temperature and flow models created for Wisconsin as part of a joint effort between the GLGap Project and the Wisconsin Department of Natural Resources (in conjunction with the Michigan and Illinois Departments of Natural Resources) provide an ideal mechanism to apply the classification to all of the streams in the state. This framework divides all Wisconsin streams into approximately 36,000 discrete confluence-to-confluence reaches. Landscape variables (including geology, topography, channel connectivity, climate, and land cover/use) are associated with each reach at the channel, riparian, and watershed scales. Artificial neural network and multiple regression models were developed from these variables to predict maximum daily mean stream water temperature (Stewart et al. 2006) and annual 90 percent exceedence flow (L. Hinz, Illinois DNR, oral commun. 2006) for each reach. The temperature and flow models are about 67 percent and 70 percent accurate in validation tests, respectively.

The biotic community-habitat relationship was then used to develop a Wisconsin streams classification framework (Table 1). Preliminary trials indicate that this classification is useful for explaining variation in fisheries potential and biotic integrity, designing and implementing field monitoring, and guiding habitat and water-quality management (J. Lyons, Wisconsin DNR, written commun. 2006) (Figure 2). This natural community classification has nine primary classes and two major subdivisions of Coolwater (Cold-Transition and Warm-Transition), providing appropriate precision for fisheries management and other applications.

Table 1. Proposed water temperature and flow criteria for defining natural stream biological communities and the estimated total length of each natural community within the 86,897 kilometers of streams in Wisconsin.

[**Abbreviations**: km, kilometer; ˚C, degrees Celcius; m^3/s, cubic meter per second; <, less than; >, more than]

Natural community	Maximum daily mean water temperature (˚C)	Annual 90 percent exceedence flow (m^3/s)	Estimated length of stream (km)
Ephemeral	Any	0.0	Not estimated
Macroinvertebrate	Any	0.0–0.00085	11,612
Cold headwater	<20.7	0.00085–0.0283	7,020
Cold mainstem	<20.7	>0.0283	1,184
Cool (cold-transition) headwater	20.7–22.5	0.00085–0.085	25,545
Cool (cold-transition) mainstem	20.7–22.5	>0.085	3,499
Cool (warm-transition) headwater	22.6–24.6	0.00085–0.085	19,535
Cool (warm-transition) mainstem	22.6–24.6	>0.085	6,567
Warm headwater	>24.6	0.00085–0.085	4,852
Warm mainstem	>24.6	0.085–3.117	3,789
Warm river	>24.6	>3.117	3,294

With the exception of ephemeral streams, which lack a fully developed aquatic biota, each natural community has a unique aquatic fauna. Only two of the communities, ephemeral and macroinvertebrate, do not consistently support fish. Of the remaining nine, eight apply to wadable streams and one (Warm River) to non-wadable rivers. Trout streams (an existing fish-based stream classification in Wisconsin) fall into six cold or cool, wadable natural communities, and occur from headwater to mainstem habitats. This stream classification system can be used to support Clean Water Act requirements and is being evaluated for implementation and application to Wisconsin natural resource management, as well as Great Lakes issues.

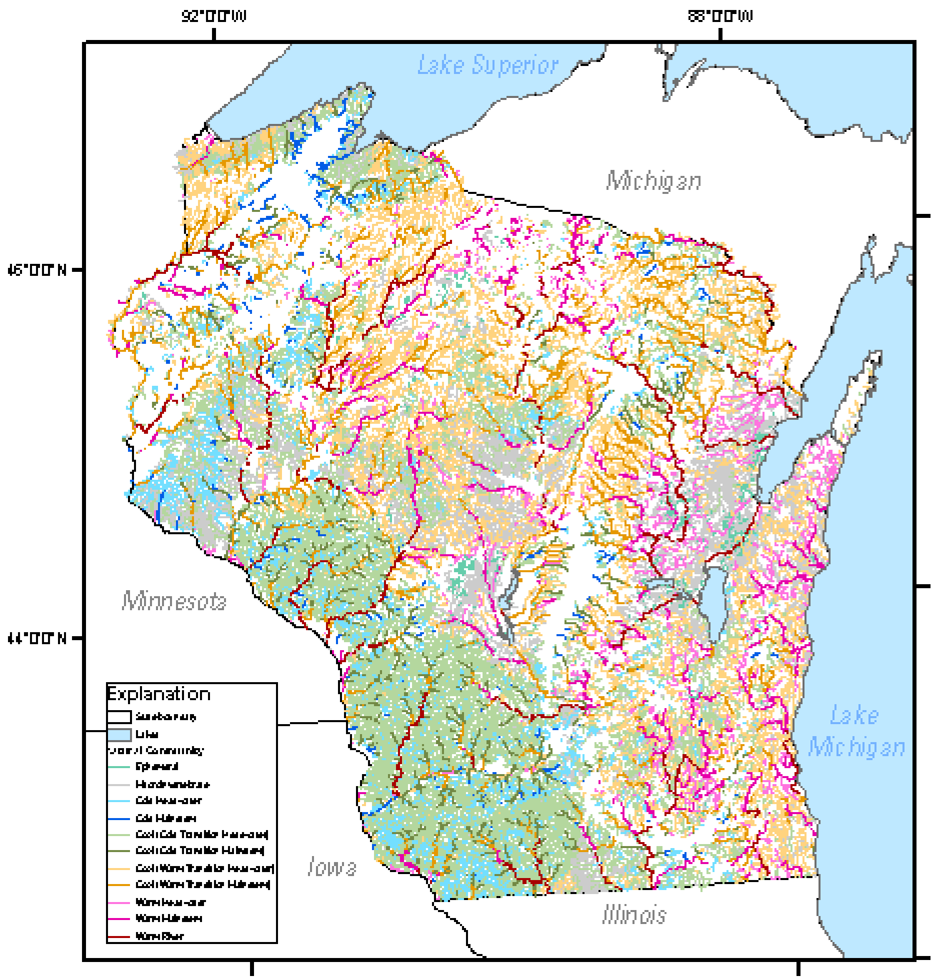


Figure 2. Proposed natural stream biological communities for Wisconsin. The resulting categories are based on predicted maximum daily mean stream temperature and annual 90 percent exceedence streamflow (Stewart et al. 2006; L. Hinz, Illinois DNR, oral commun. 2006). Base from 1:100,000 National Hydrography Data.

Fish in My Back Yard

Our third example demonstrates a means of displaying fish model predictions and informing the public about our tools and analyses. This application extends outreach efforts by using an existing medium (the Internet) and display tool (Google Earth). Google Earth is an interactive map program that allows users to view satellite/aerial imagery projected onto a three dimensional globe <http://earth.google.com/>. Given the sharp image, easy-to-use interface, and freeware nature of the program, Google Earth represents an innovative approach for viewing spatial data without the need to develop a specialized stand-alone mapping application. Groups and organizations can build new content (i.e., information about a topic that can be represented geographically) that can be overlain on top of the baseline satellite/aerial images using a simple text-based coding language called keyhole markup language (KML). KML files contain latitude and longitude points so that features can be spatially located onto the globe in Google Earth.

The GLGap Project has used Google Earth to display predicted fish communities linked to the 1:100K NHD steam network on top of satellite–aerial imagery of the Great Lakes Region. The stream and fish overlays are based on GIS spatial data layers developed as a part of the GLGap Project (Brenden et al. 2006; McKenna et al. 2006; Morrison et al. 2003). Viewing GIS spatial data layers within Google Earth allows a user to clearly see how the stream network falls across the entire landscape. The readily available and viewable satellite–aerial imagery provide a realistic and familiar backdrop that is more informative than viewing individual vector representations (i.e., lines representing the hydrography network, road network, etc.) of the landscape alone. The imagery provides an opportunity to view features of the landscape such as streams, agricultural fields, high density urban development, roads, topographic characteristics, and other landscape or municipal jurisdictions simultaneously in a familiar context. The geographic extent of this pilot study is presently limited to Michigan's Lake Erie watershed. We converted 1:100,000 NHD stream layers to the KML format using a shareware program called Shp2kml <http://www.zonums.com/shp2kml.html>. The centroid latitude and longitude was obtained for each confluence-to-confluence stream reach. A Microsoft Excel macro was built that generated KML code based on the centroid position and fish species presence and absence predictions (Steen et al. 2008). When viewed in Google Earth, this code shows a placemark at each centroid position (Figure 3). Clicking on a placemark will open a popup window that gives a list of the predicted fish species for that particular stream reach, a brief description and picture of the fish species, and links to other websites for related information (Figure 4). The easy-to-use and realistic interface provided by Google Earth, in conjunction with overlays of predicted fish distributions, can help the public better understand the natural communities that surround them and provide awareness of projects like Aquatic Gap Analysis.

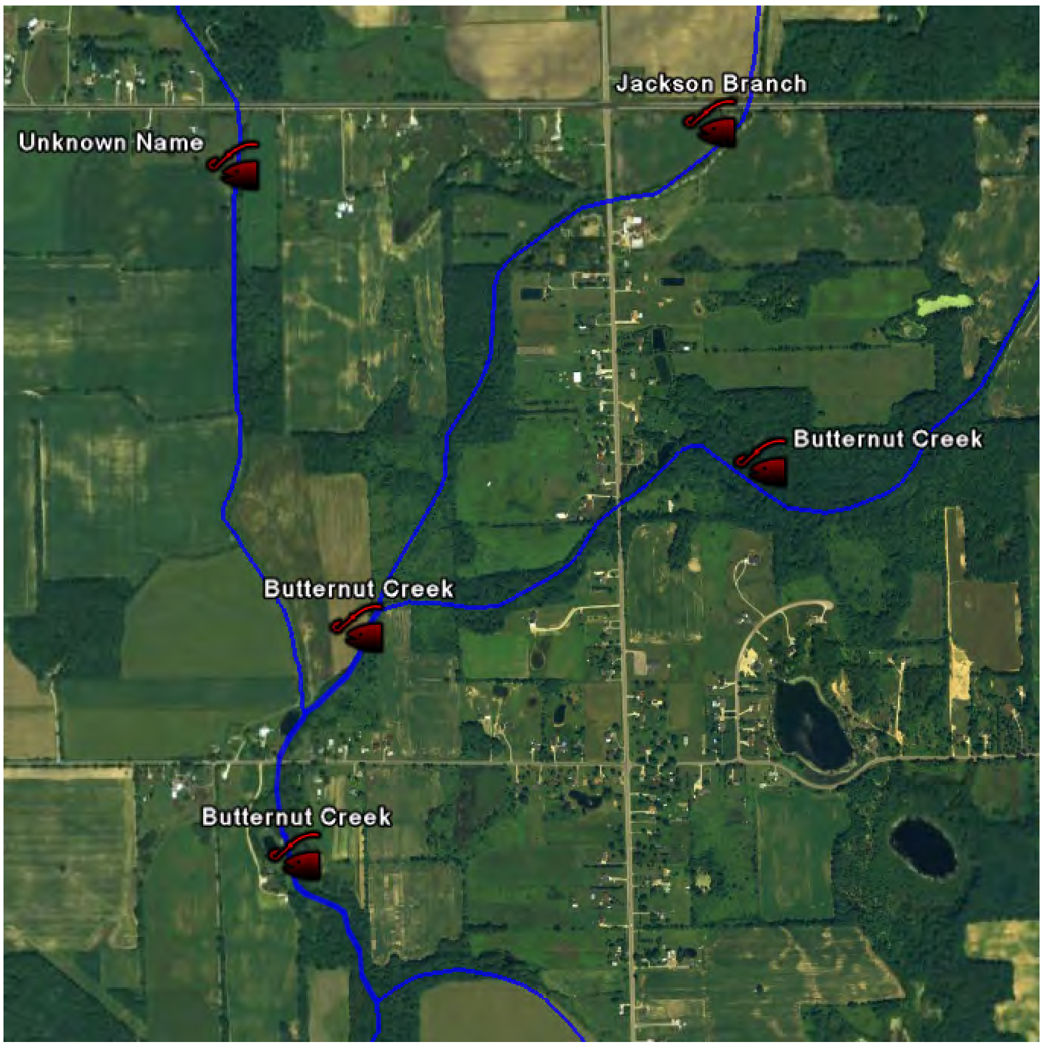


Figure 3. Screen capture from Google Earth over southeastern Michigan landscape, overlaid with 1:100,000 NHD stream network. The fish icons represent placemarks that can be queried. This map displays the utility of combining GIS vector data with satellite/aerial imagery to provide stream ecosystems with high definition and context from their surrounding landscape.

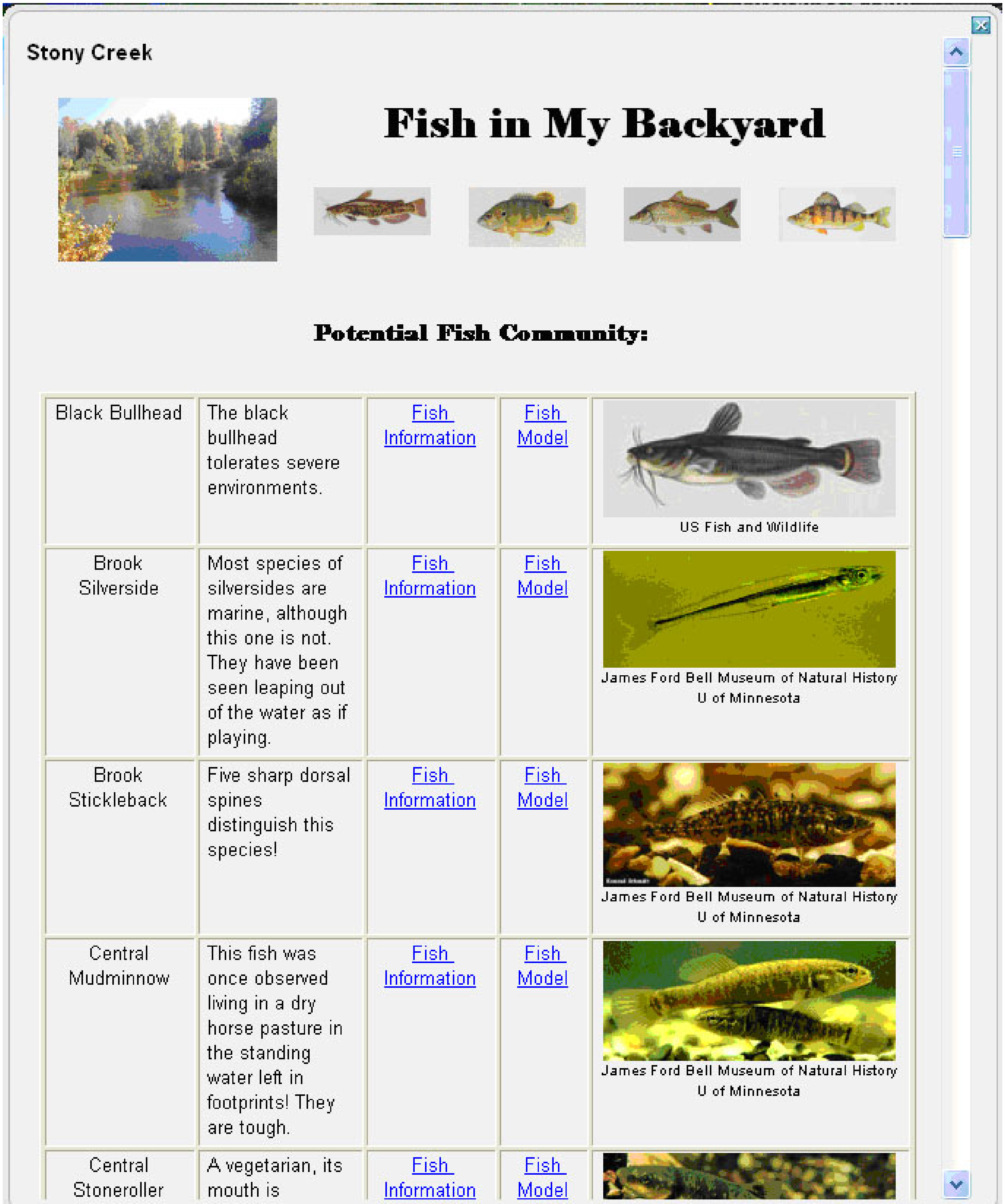


Figure 4. Popup window that provides information on the predicted fish community for a particular stream reach, including a picture, species descriptions, a link to more detailed species information, and a link to information about the predictive fish model used.

Conclusions

We present only a small sample of the potential applications of aquatic gap analysis data and tools. This basic analysis platform greatly extends our ability to examine large-scale ecological conditions in aquatic systems and provides coarse-scale filter and an opportunity to estimate fine-scale (1–10 km) conditions throughout the U.S. Great Lakes Basin. This platform of analytical tools and associated data represent a critical stepping stone to the next generation of data and analytical tools that will allow integration of spatial and temporal dynamics. This system provides the capability to address many real-time and long-term problems natural resource managers face every day.

Acknowledgments

We are grateful to S. Prindle and D. Lemon for initial review of predicted brook trout distributions, to M. Henry for assistance with mapping of New York brook trout status and distribution, and to J. Schaeffer for providing species descriptions for the Google Earth popup window. We would also like to thank the reviewers for their efforts and helpful suggestions. This study was funded by the USGS GAP Analysis Program with additional support of service in-kind by the Institute for Fisheries Research, Michigan Department of Natural Resources, the Wisconsin Department of Natural Resources, and the New York Department of Environmental Conservation.

References Cited

Brenden, T.O., R.D. Clark, A.R. Cooper, P.W. Seelbach, L. Wang, S. Aichele, E.G. Bissell, and J.S. Stewart. 2006. A IS framework for collecting, managing, and analyzing multiscale landscape variables across large regions for river conservation and management. *in* R.M. Hughes, L. Wang, and P.W. Seelbach, editors. *Landscape Influences on Stream Habitat and Biological Assemblages*. American Fisheries Society, Symposium 48, Bethesda, MD. p. 49-74

(EBTJV) Eastern Brook Trout Joint Venture. 2007. Conserving the Eastern Brook Trout: Action Strategies. Prepared by Conservation Strategy/Habitat Work Group, Eastern Brook Trout Joint Venture. Available from <http://www.easternbrooktrout.org/>

Lyons, J. 1989. Correspondence between the distribution of fish assemblages in Wisconsin streams and Omernik's ecoregions. *American Midland Naturalist* 122:163-182.

Lyons, J. 1996. Patterns in the composition of fish assemblages among Wisconsin streams. *Environmental Biology of Fishes* 45:329-341.

Lyons, J., A.M. Forbes, and M.D. Staggs. 1988. Fish species assemblages in southwestern Wisconsin streams, with implications for smallmouth bass management. *Wisconsin Department of Natural Resources Technical Bulletin* No. 161.

McKenna, J.E., Jr., R.P. McDonald, C. Castiglione, S. Morrison, K. Kowalski, and D. Passino-Reader. 2006. A broadscale fish-habitat model development process: Genesee Basin, New York. *Proceedings of the Symposium on Landscape Influences on Stream Habitats and Biological Assemblages*, American Fisheries Society National Meeting, Madison, WI, 2005:533–554.

Morrison, S.S., D.R. Passino-Reader, D.N. Myers, J.E. McKenna, J. Stewart, B.C. Scudder, and K. Lohman. 2003. Great Lakes Regional Aquatic Gap Analysis—preserving biodiversity in the Great Lakes Basin: U.S. Geological Survey-Great Lakes Science Center Fact Sheet 2003-1, 6 p.

Sowa, S.P., G. Annis, M.E. Morey, and D.D. Diamond. 2007. A gap analysis and comprehensive conservation strategy for riverine ecosystems of Missouri. *Ecological Monographs* 77:301–334.

Steen, P.J., D.R. Passino-Reader, and M.J. Wiley. 2006. Modeling Brook Trout Presence and Absence from Landscape Variables Using Four Different Analytical Methods. *Proceedings of the Symposium on Landscape Influences on Stream Habitats and Biological Assemblages*, American Fisheries Society National Meeting, Madison, WI, 2005:513-531.

Steen, P. J., T.G. Zorn, P.W. Seelbach, and J.S. Schaeffer. 2008. Classification tree models for predicting distributions of Michigan stream fish from landscape variables. *Transactions of the American Fisheries Society* 137(4):976-996.

Stewart, J., M. Mitro, E.A. Roehl, Jr., and J. Risley. 2006. Numerically optimized empirical modeling of highly dynamic, spatially expansive, and behaviorally heterogeneous hydrologic systems – Part 2. *Hydroinformatics: Proceedings of the 7th International Conference*, Nice, France, September 2006.

Wang, L., J. Lyons, P. Rasmussen, P. Seelbach, T. Simon, M. Wiley, P. Kanehl, E. Baker, S. Niemala, and P.M. Stewart. 2003. Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 60:491-505.

Using Aquatic GAP Models to Inform Conservation Decisions: A Framework

Elise R. Irwin[1], Kathryn D. Kennedy[2], James T. Peterson[3], Mary C. Freeman[4], Byron J. Freeman[5], and Gareth T. Turner[2]

Introduction

Aquatic systems in the southeast United States harbor the highest levels of biodiversity in North America, with imperilment rates near 28 percent (Warren et al. 2000). Consequently tools to evaluate effects of management and conservation efforts on aquatic fauna are needed. Our Aquatic Gap Analysis projects predicted the distribution of more than 200 species of fish in relation to watershed characters in parts of the Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) river basins (Peterson et al. 2003; Turner et al. 2004; Irwin et al. 2004; Irwin et al. 2007). Using K-nearest neighbor analysis (KNN; SAS 2001) we developed empirical models that related faunal data (presence/absence) from faunal records (post 1970) to landscape features from an extensive GIS database. The basic land unit for model fitting and prediction were 12-digit U.S. Geological Survey (USGS) hydrologic units (mean size about 7,800 ha), defined as watersheds (Figure 1). Important predictive landscape variables included stream reach and watershed characters such as stream order, stream density (km/ha), road density (km/ha) and stream reach elevation (m). In addition, juxtaposition of habitats was important in prediction of species presence, including isolation of stream reach and link magnitude. Finally, Land Use/Land Cover (LULC) variables (e.g., percentage of row crop agriculture or forested land) and parent geology were important variables for predicting presence of many species. Total average model error rates were low (less than 23 percent overall; Peterson et al. 2003; Irwin et al. 2004; Turner et al. 2004; Irwin et al. 2007) and given that error rates are an estimate of the uncertainty in prediction of species occurrence (in the form of a probability), these error rates can be directly incorporated into conservation decision making (Marcot et al. 2006). Our objectives for this paper were to: (1) provide an example framework for conservation decision making for species of greatest conservation need (GCN) using Bayesian belief networks (BBN; see Peterson and Evans 2003 and Kennedy et al. 2006) that incorporate the output from our Aquatic GAP models from the ACT and ACF basins and (2) illustrate how natural resource managers can incorporate uncertainty to make more informed decisions for conservation planning.

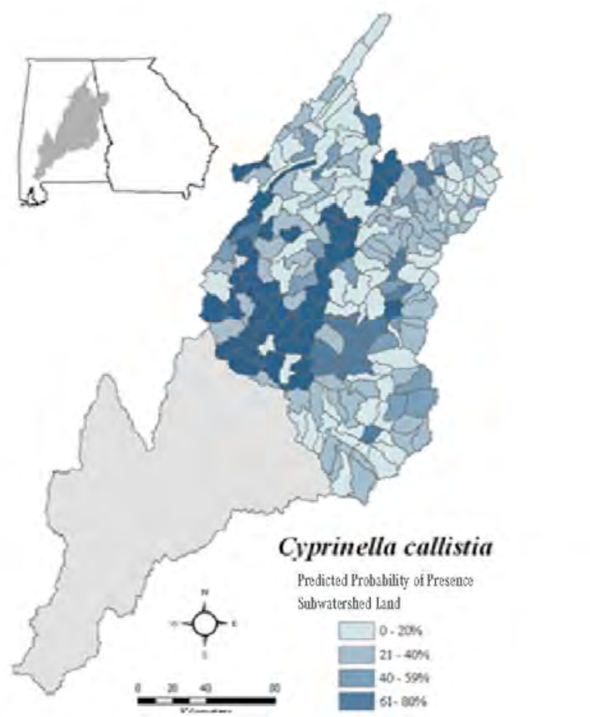


Figure 1. Example of a predicted distribution map from the ACT Aquatic Gap.

[1] U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, AL.

[2] Alabama Cooperative Fish and Wildlife Research Unit.

[3] U.S. Geological Survey, Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia, Athens, GA.

[4] U.S. Geological Survey Patuxent Wildlife Research Unit, University of Georgia, Athens, GA.

[5] Institute of Ecology, University of Georgia, Athens, GA.

Methods

We used the BBN software Netica 1.12 (Norsys Software Corp. 1998) to model a hypothetical conservation decision involving allocation of funds for either the purchase of a land parcel or restoration of a stream reach (“Purchase Land or Restore Stream?”; Figure 2). The primary conservation goal is to maximize protection of GCN species at the least cost to the funding agency. Using conditional probabilities, the network links decision alternatives to state variables, and optimizes the best decision by relating these state variables to appropriate management values, in this case GCN species persistence (“Species Value”; Figure 2) and funding agency expenditures (“Cost”; Figure 2).

Model Structure—The modeled decision considered four decision alternatives: (1) the purchase of land parcel A, an expensive site with high habitat quality in a watershed with low to moderate fragmentation; (2) the purchase of land parcel B, a less expensive site with slightly lower habitat quality in a watershed with low fragmentation; (3) the restoration of stream reach C, a relatively low-cost project at a highly degraded site with minimal fragmentation; and (4) the restoration of stream reach D, another relatively low-cost project, but at a moderately degraded site with moderate fragmentation.

Modeled state variables included degree of fragmentation, colonization probability, current and future GCN species richness, and current and future habitat conditions. To reflect the differences in conditions among areas A–D, we created dependency links (Links “p,” “q,” and “s”; Figure 2) between the decision and corresponding state variables (“Degree of fragmentation,” “Current habitat conditions,” and “Current GCN Species”; Figure 2). In addition, we hypothesized that the decision would influence future habitat conditions, and therefore created a causal link defining this relation (link “t”; Figure 2). Current habitat conditions would also, intuitively, influence future habitat conditions, as is modeled by link “u” (Figure 2). To reflect the hypothesis that degree of fragmentation would influence the ability of species to colonize, we created link “r” (Figure 2). Furthermore, we hypothesized that colonization probability, current GCN species richness, and future habitat conditions would influence future GCN species richness; links “v,” “w,” and “x” reflect these hypotheses (Figure 2).

We linked the management value “Species Value” directly to the future GCN species richness (link “z”; Figure 2). In this model, the faunal measure of success is based exclusively on species richness of GCN species. We linked the management value “Cost” directly to the decision (link “o”;

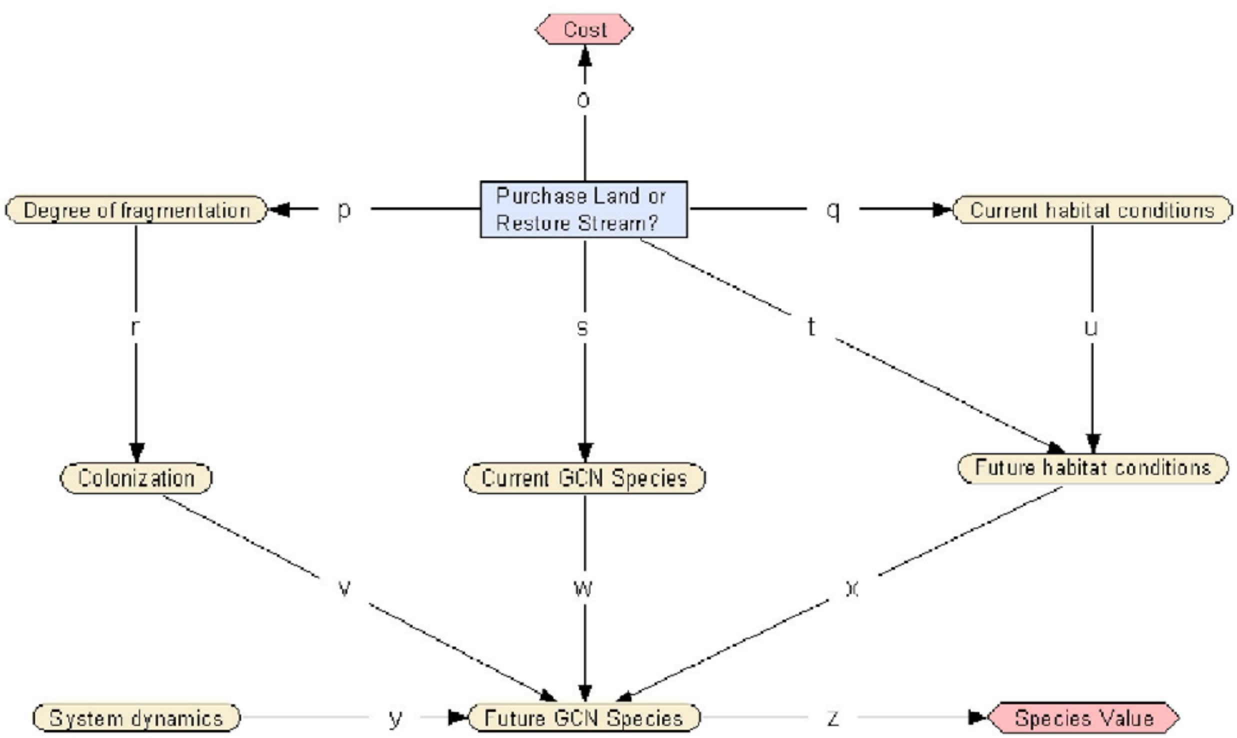


Figure 2. Influence diagram for evaluating options of purchasing or restoring sites for aquatic Greatest Conservation Need (GCN) species. The blue rectangle represents the decision, the yellow rectangles represent state variables, and the pink hexagons represent the conservation values.

Figure 2), as we expect managers to have explicit monetary values associated with the cost of purchasing land or restoring a stream site.

Because we are unsure as to the relative roles that habitat and demographic support (e.g., colonization) have on the persistence and recovery of GCN species, we represented this with an additional uncertainty node that represents two alternative models of system dynamics ("System Dynamics"; Figure 2). Under the habitat model of system dynamics, the future status of GCN species is largely determined by future habitat quality; under the demographic model of system dynamics, the future status of GCN species is largely determined by the ability of species to colonize new areas.

Model Parameterization—Relations among variables in the network were represented by conditional probabilities. Table 1 provides the probabilities describing the condition of sites represented in each decision alternative. The probabilities represent both empirical data and expert opinion. Fragmentation is calculated from various GIS layers (see Irwin et al. 2007), and classification (i.e. into the categories Low, Moderate, and High) is based on distribution of calculated values throughout the region under consideration (e.g. ACT and ACF basins) and model uncertainty. For example, consider the hypothetical site A. If we define moderate as all values between the 25th and 75th percentile, and our fragmentation value falls within this range, we assign a value of 70 under the Moderate category to account for our model confidence in our fragmentation model (70 percent confidence), and distribute the remaining probabilities under the categories "Low" and "High" to account for model uncertainty. These values may shift depending on the percentile under which the value falls. For example, if the value falls closer to the 75th percentile, we may distribute the model uncertainty with a heavier weight in the "High" category.

Current habitat conditions were based on land use/land cover at each site; the probability tables are again populated based on calculated values, model confidence, and expert opinion. Current GCN species richness is derived from GAP models that predict the probability of GCN species at a site. Values are based on both the distribution of species richness data across the region and the additive probabilities of GCN species at the particular site of interest. For example, again consider the hypothetical site A. If the species richness value is above the 75th percentile, and the additive value of GCN species probabilities at this site is 0.70, we would place the value "70" under the "Many" category. The remaining uncertainty (0.3) would be distributed between the "Few" and "Some" categories. Because the species richness value fell above the 75th percentile, most of the model uncertainty weight is placed in the neighboring category "Some," and the remaining uncertainty is placed in the "Few" category.

Table 2 provides the probabilities describing future habitat conditions, as dependent upon current habitat conditions and the chosen decision alternative. "Future" conditions in our model are defined at a 20-year time-step. In our hypothetical decision alternatives, stream restoration has a greater impact on changing future habitat conditions than does land purchase; this is reflective in the conditional probabilities, as the probabilities for improving habitat condition (e.g. changing from "Degraded" to "Moderate" or "Intact") are higher for decisions C and D than for decisions A and B (Table 2).

Probabilities describing colonization probabilities as conditional upon habitat fragmentation are provided in Table 3. These probabilities were based primarily upon expert opinion, and the hypothesis that low fragmentation will lead to high probabilities of colonization, and high fragmentation will result in low colonization rates. Distribution of values across the categories "Low," "Moderate," and "High" is reflective of system uncertainty in the context of this hypothesis.

We assigned the two hypotheses of system dynamics ("habitat" and "demographic support") with equal probabilities (50 percent each). These values would change as data are gathered that support or refute these hypotheses. The conditional probability table describing the future status of GCN species was populated similarly to those described above, with conditional probabilities based on hypotheses relating colonization, future habitat conditions, current GCN species, and system dynamics to future GCN species richness.

Table 1. Conditional probability table describing the condition of sites for decision alternatives.

Decision (site)	Fragmentation			Current habitat conditions			Current Greatest Conservation Need species		
	Low	Moderate	High	Degraded	Moderate	Intact	Few	Some	Many
A	15	70	15	5	10	85	10	20	70
B	70	25	5	5	25	70	10	30	60
C	80	15	5	65	30	5	50	40	10
D	10	80	10	30	65	5	55	40	5

Table 2. Conditional probability table describing future habitat conditions, as conditional upon current habitat conditions and the chosen decision alternative.

Decision (site)	Current conditions	Future habitat conditions		
		Degraded	Moderate	Intact
A	Degraded	70	20	10
A	Moderate	20	60	20
A	Intact	10	30	60
B	Degraded	70	20	10
B	Moderate	20	60	20
B	Intact	10	30	60
C	Degraded	30	30	40
C	Moderate	10	20	70
C	Intact	5	15	80
D	Degraded	30	30	40
D	Moderate	10	20	70
D	Intact	5	15	80

Table 3. Conditional probability table describing probability of colonization, as conditional upon habitat fragmentation.

Fragmentation	Colonization		
	Low	Moderate	High
Low	10	30	60
Moderate	35	40	25
High	50	30	20

Tables 4 and 5 provide the conditional probabilities for the conservation values. Species value was ranked highest (100) when “Many” GCN species were predicted to be present at the site in 20 years (future conditions), and was decreased proportionally for “Some” (value: 66) and “Few” (value: 33; see Table 4). Cost was defined in terms of number of dollars (in thousands) left to be used for other conservation projects. The most expensive land purchase (land tract A) we assigned a value of “0,” assuming that this would take up most (if not all) of available dollars. Site B was assigned a value of “16” (or $16,000), reflective of the lower purchase cost compared to Site A. Sites C and D (the stream restoration projects) were set equal (both “33,” that is $33,000), to reflect the lower, and approximately equivalent, costs of these projects.

Table 4. Conditional probability table describing changes in species value conditional upon future GCN (Greatest Conservation Need) species status.

Future GCN	Species value
Few	33
Some	66
Many	100

Table 5. Conditional probability table describing changes in cost conditional upon the decision alternative.

[Cost is defined in terms of number of dollars (in thousands) left to be used for other conservation projects]

Decision (site)	Cost
A	0
B	16
C	33
D	33

Model Compilation

The optimal decision in a Bayesian belief decision network is determined by examining the expected value associated with each alternative decision, which is the sum of the probability-weighted utility values (see Figure 3; values in blue rectangle). In our example, the optimal decision was to restore site C (sum = 96.85). Although the competing hypotheses of systems dynamics (habitat versus demographic support) are weighted equally in our example, these probabilities could be derived from Akaike weights from alternative models (following Burnham and Anderson 2002) that represent each dynamic and/or expert opinion (Marcot et al. 2006). The actual decision will vary depending on how the decision maker incorporates uncertainty associated with system dynamics. For example, under the “habitat” model for system dynamics (Figure 4; top panel, system dynamics node; habitat = 100 percent, demographic support = 0 percent) the optimal decision is to restore site D (value = 99.73); whereas, the optimal decision is to restore site C (value = 96.53) under the “demographic support” model (Figure 3; bottom panel, system dynamics node; habitat = 0 percent, demographic support = 100 percent).

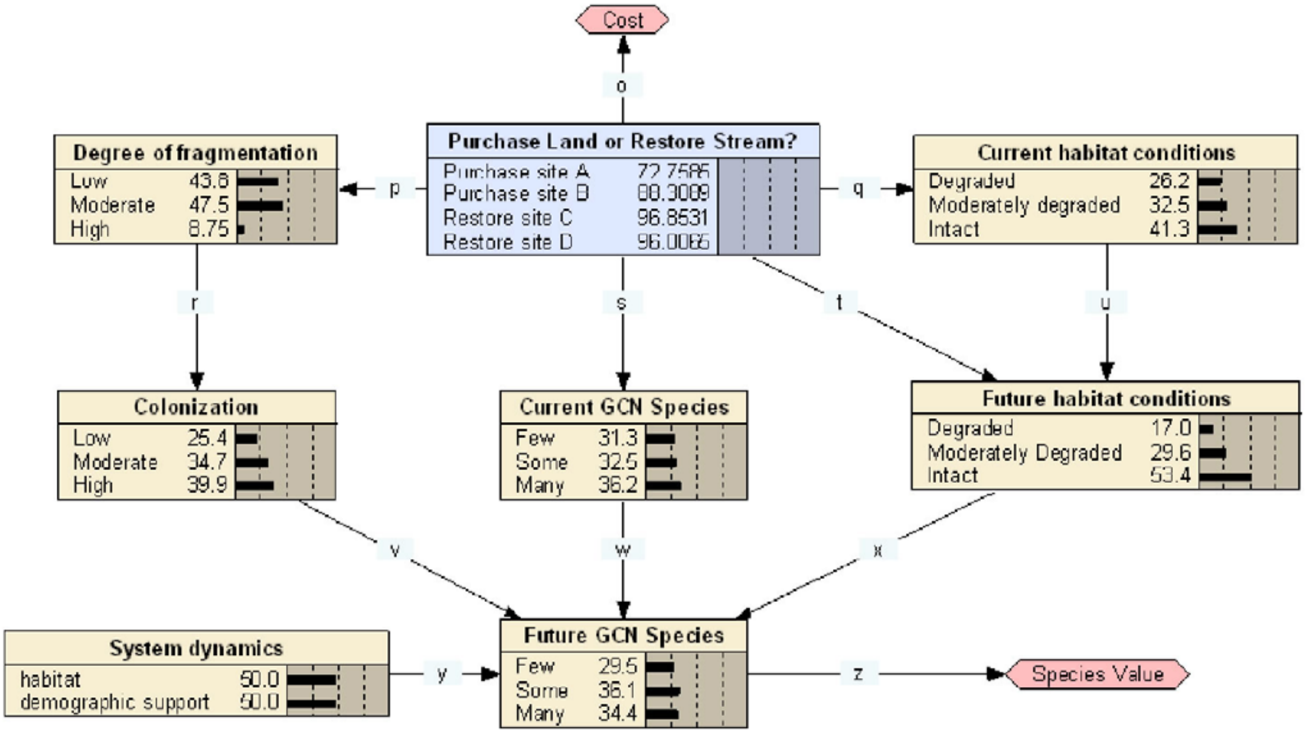


Figure 3. Decision network for evaluating options of purchasing or restoring sites for aquatic GCN (Greatest Conservation Need) species.

Discussion

Our Aquatic GAP models can be used for numerous planning purposes, yet represent only the current system state of species distribution. In addition, our models provide some information on possible mechanisms influencing current distributional patterns (e.g., isolation). However, most conservation planners require more information relative to projected future conditions to make informed decisions. Based on context and stakeholder needs, other state variables could be added to the decision framework. To make predictions relative to how the system state variables will respond to different conservation and/or management actions, data on system dynamics—how habitat condition and species status change through time—will be essential. These data may include either monitoring data, empirical data regarding functional relations among state variables, or, in initial models, expert opinion. For example, Land Use change models have been developed by USGS personnel (P. Claggett, U.S. Geological Survey, unpub. data 2007) and these projections could be used to generate future condition probabilities for habitat quality. Most state Conservation Wildlife Plans (CWPs) call for monitoring of GCN species and management of habitats important to GCN species (e.g., ADCNR 2005); these data also may be used to generate probabilities of system state variables and reduce system uncertainty. Adaptive management frameworks are suggested for many conservation planning efforts; posterior probabilities generated using BBNs can be used to inform future decisions in this iterative process that focuses on reduction of system uncertainty (Walters 1986; Kennedy et al. 2006; Marcot et al. 2006).

For example, if habitat were intact at year 20, and few GCN species were observed (Figure 4; top panel, future habitat and future GCN species nodes), the probability of the "demographic support" model of system dynamics would increase from 0.50 to 0.66 (0.66 = the posterior probability after collecting data). This would suggest that there is greater evidence for the demographic support model over the habitat model for system dynamics. In an adaptive management framework, these posteriors would be the probabilities for the system dynamic node when the next decision is made (Figure 4; bottom panel, system dynamics node). Sensitivity analysis can also be used to assess the influence of changes in each state variable within the decision context. Our proposed framework is flexible and provides a model that integrates the current system state (from Aquatic GAP data) with predicted future conditions, and provides a mechanism for incorporating competing hypotheses of system dynamics, as well as potentially conflicting values of decision makers. The software that we used is user friendly and provides a visual platform for assessing decisions and their potential consequences on state variables and stakeholder values. Such a framework could be used to incorporate the valuable output from our Aquatic GAP programs to potentially meet conservation planning goals within the ACT and ACF basins.

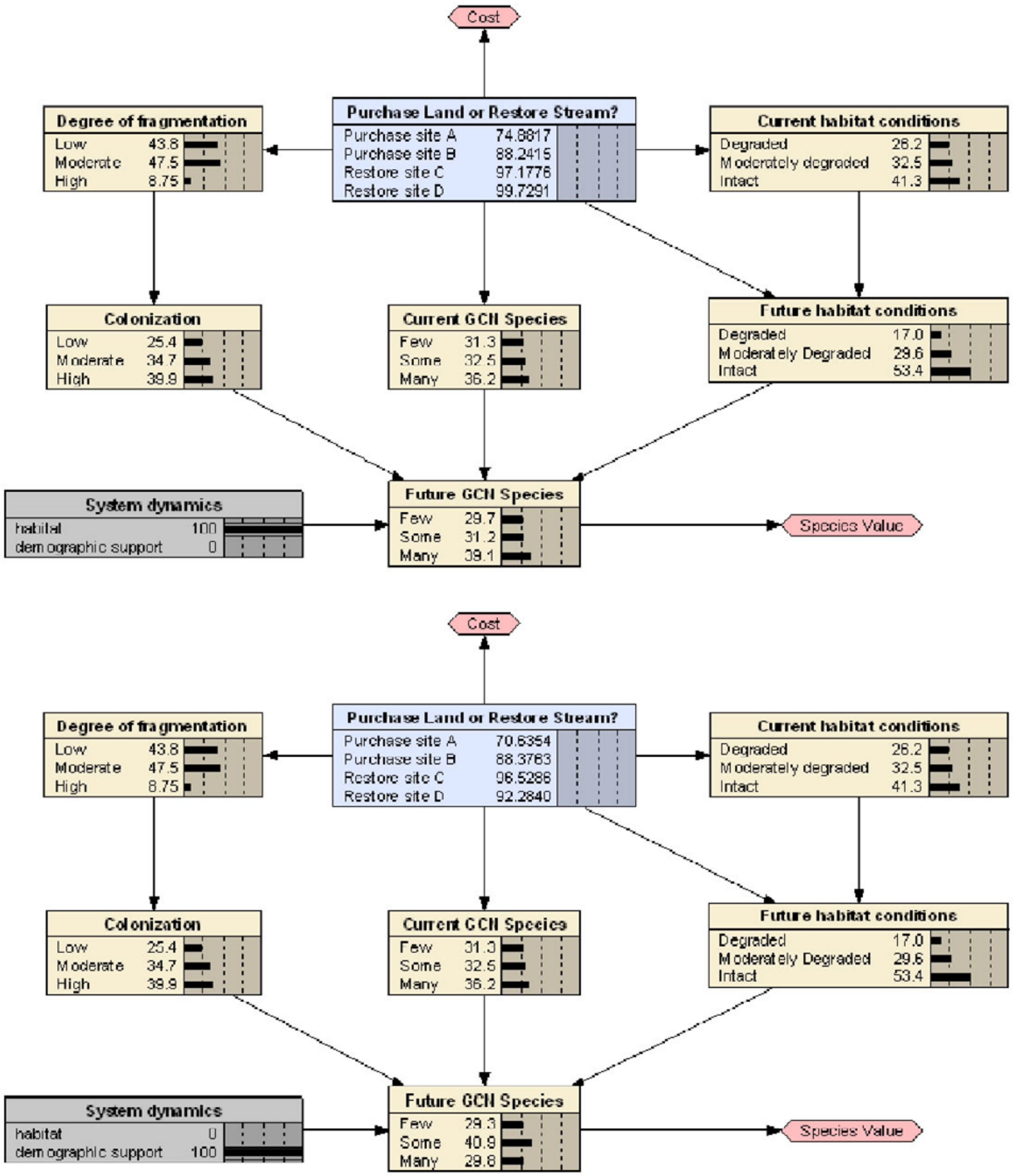


Figure 4. Decision network for evaluating options of purchasing or restoring sites for aquatic Greatest Conservation Need (GCN)species while incorporating system dynamics uncertainty (node highlighted in gray). In the top panel, the "habitat" model is weighted 100 percent and in the bottom panel, the "demographic support" model is weighted 100 percent. Variation in the model weights of the system dynamics node influences the optimal decision.

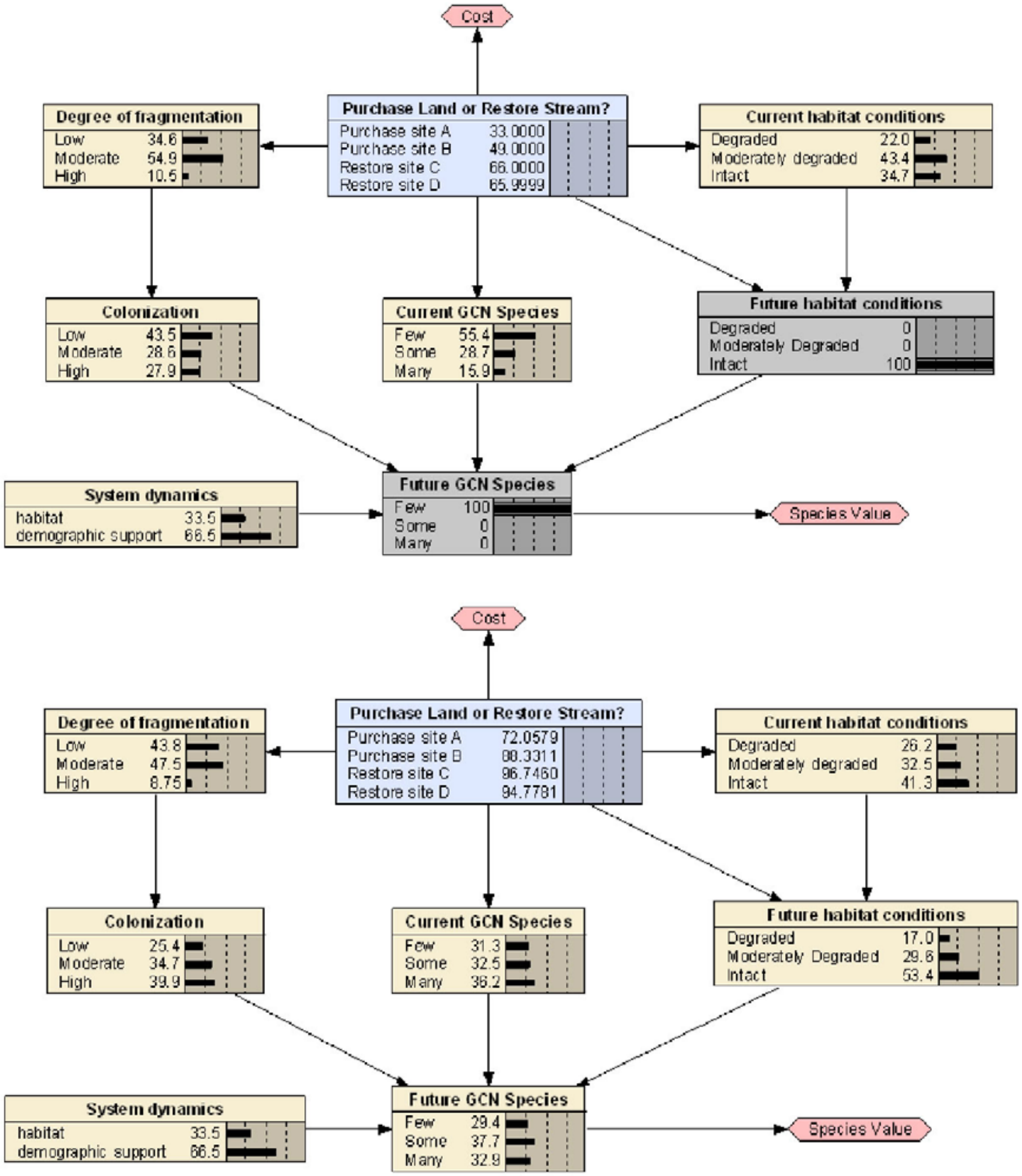


Figure 5. Example of utilizing the decision network for adaptive management. In the top panel, after 20 years we hypothetically observed few GCN species (GCN = Greatest Conservation Need; future GCN species node) and intact habitat conditions (future habitat conditions node). Notice that the weight for the "demographic support" model increased from 50 to 66 percent. The updated probabilities for the system dynamics node can be used as prior probabilities for the next iterative step in adaptive management (bottom panel).

References Cited

(ADNCR) Alabama Department of Conservation and Natural Resources. 2005. Alabama's Comprehensive Wildlife Conservation Strategy. Division of Wildlife and Freshwater Fisheries. Available from http://alapark.com/research-mgmt/cwcs/outline.cfm

Burnham, K. P., and D.R. Anderson. 2002. Model Selection and Multimodel Inference: *A Practical Information-Theoretic Approach*, 2nd edition. Springer-Verlag, New York.

Irwin, E.R., J.T. Peterson, B.J. Freeman, E. Kramer, M.C. Freeman, G. Turner, D. Moosman, K. Mickett, P. Sakaris, C.-A. Hayer, T. Piper, and C. Straight. 2004. Aquatic GAP: Regional Analysis of Biodiversity in the ACT/ACF Basins: Tallapoosa River Basin. Final Report to U.S. Geological Service, GAP Analysis Program, Moscow, ID.

Irwin, E., G. Turner, K. Mickett and T. Piper. 2007. ACT Aquatic Gap and water quality monitoring. Final report to Alabama Department of Conservation and Natural Resources, Division of Wildlife and Freshwater Fisheries, Montgomery, AL.

Kennedy, K.M., E.R. Irwin, M.C. Freeman, and J. Peterson. 2006. Development of a decision support tool and procedures for evaluating dam operation in the Southeastern United States. Science Support Partnership Program Project Final Report to U.S. Geological Survey and U.S. Fish and Wildlife Service.

Marcot, B.G, J.D. Steventon, G.D. Sutherland and R.K. McCann. 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Canadian Journal of Forest Research* 36:3063-3074.

Peterson, J.T., and J.W. Evans. 2003. Decision analysis for sport fisheries management. *Fisheries* 28:10-20.

Peterson, J. T., B.J. Freeman, E. Kramer, E. Irwin, M.C. Freeman, C. Straight, A. Wimberley, and J.C. Ruiz. 2003. Aquatic GAP: Regional analysis of biodiversity in the ACT/ACF basins. Final Report to U.S. Geological Survey, Gap Analysis Program, Moscow, ID.

SAS Institute. 2001. SAS Software for Version 8.1. SAS Institute, Inc., Cary, NC.

Turner, G., E. Irwin, J. Peterson, B. Freeman, M. Freeman, E. Kramer, C. Straight, A. Wimberly, D. Moosman, C. Hayer, and J. Ruiz. 2004. Aquatic GAP: A GIS and modeling approach for analysis of biodiversity in the Tallapoosa River basin, Alabama and Georgia, in S. Ramroop, editor, *Proceedings of the Troy State University GIS Symposium*, Troy State University, Troy, AL.

Walters, C. J. 1986. *Adaptive management of renewable resources*. Macmillan, New York.

Warren, M.L., and others. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries* 25(10):7-29.

INTERNATIONAL

Methodological Approach to Identify Mexico's Terrestrial Priority Sites for Conservation

Tania Urquiza-Haas[1], Melanie Kolb[1], Patricia Koleff[1], Andrés Lira-Noriega[1,2], Jesús Alarcón[1]

Introduction

A significant proportion of the world's species and habitats is in danger of disappearing as human domination continues to gain pace; current rates of extinction are a thousand times higher than background rates throughout earth's life history (Pimm et al. 1995). One of the key strategies implemented by most countries to reduce or halt these trends has been the establishment of protected areas; nonetheless, existing systems of protected areas are seldom designed to conserve biodiversity systematically, and are often inadequate to represent the biodiversity of a given area (Pressey et al. 1994). The imminent declines in biodiversity have triggered considerable efforts to develop methods to select priority sites for conservation (Eken et al. 2004; Sarkar et al. 2006) and the adoption of national and international agreements. The Programme of Work on Protected Areas adopted by the Conference of Parties of the United Nations Convention on Biological Diversity, at its 7th meeting in Kuala Lumpur, Malaysia, in February 2004, is one such example. The aim is not simply to increase the number of protected areas but to ensure that, as far as possible, protected areas should be designed and located in the best places to conserve biodiversity (UNDP 2004). To fulfil these agreements Mexico decided to generate, with solid and technical criteria, an updated and complete assessment of conservation gaps of the protected areas network that will serve as a guide to expand the area comprised by protection decrees, as well as bringing into consideration other complementary instruments for conservation. The National Commission for the Knowledge and Use of Biodiversity (CONABIO), in collaboration with the National Protected Areas Commission (CONANP), several other institutions and specialists have conformed a working group (12 members of the executive group and 28 participants) that decided to broaden the context of this evaluation in a comprehensive manner, incorporating several approaches and spatial scales to identify priority sites for conservation of terrestrial biodiversity. One of the key goals was the identification of precise priority sites at a finer scale than previous prioritization exercises (ie. Mittermeier et al. 2004; Arriaga et al. 2000). In this paper we present the methodological framework used to identify priority sites for conservation of terrestrial vulnerable species and environments.

Methods

Data Sets

Species distribution maps were generated by expert-lead technical groups using the Genetic Algorithm for Rule-set Prediction (GARP; Stockwell and Peters 1999) at a spatial resolution of 1 km^2 (mammals: Ceballos, 2008; birds: Navarro-Sigüenza and Peterson 2007; amphibians and reptiles: Ochoa-Ochoa and Flores-Villela 2006, Flores-Villela 2008; plants in the Mexican red list: CONABIO, unpub. data). GARP is a robust tool that has been successfully tested and used in various fields of research mainly because of its power to extrapolate into unsampled areas, a quality needed when species' ecological niches are reconstructed from incomplete occurrence data (Illoldi-Rangel et al. 2004; Papes and Gaubert 2007) as is the case of many Mexican data sets, while inventory completeness varies greatly across regions and taxa (Ochoa-Ochoa and Flores-Villela 2006; Soberón et al. 2007). In consequence, to assess the conservation status of a great number of species at a national scale, the use of an algorithm like GARP was preferred for its ability to extrapolate into broad unsampled areas (Peterson et al. 2007).

[1] Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Tlalpan, México.

[2] The University of Kansas, Division of Ornithology, Lawrence, KS.

Species geographical distributions were constructed from raw occurrence data obtained from the National Biodiversity Information System (SNIB, CONABIO), the Atlas of Mexican Bird Distributions and The World Information Network on Biodiversity (REMIB). For birds, maps were generated for 936 species, according to the American Ornithologists' Union taxonomy (1998) using 453,540 georeferenced data points. For more information on how these niche models were generated see Nakazawa et al. (2004) and Peterson et al. (2006); see Navarro et al. (2003) for more information on the Atlas of Mexican Bird Distributions. Models for 1,012 amphibians and reptiles species were generated using 181,191 validated georeferenced data points. Species geographic and taxonomic validation followed (Flores-Villela 1993a, 1993b; Flores-Villela and Canseco-Márquez 2004; Frost et al. 2006). Species with more than 10 records were modeled following the "best subsets" procedure using half of the points to build the model and the other half to test the predictive ability, for less than 10 records a soft omission threshold was used. A minimum of five records were used to model the species potential distribution. For more information see Flores-Villela (2008). Ecological niche models for mammals were generated for 213 species, using 37,070 validated georeferenced data points. For plant species in the Mexican red list, 245 models were generated using a database containing 7,709 validated georeferenced data points; models were generated with a minimum of eight data points. Modeling followed similar procedures as the groups previously mentioned.

In all cases environmental data sets (raster GIS data layers) known to affect taxa distributions in Mexico were assembled. Data layers included climatic variables from WORLDCLIM (Hijmans et. al 2008), topographic and hydrologic parameters from Hydro1k (Earth Resources Observation and Science 2008) in addition to thematic national data sets from National Institute of Statistics, Geography and Informatics (INEGI) and CONABIO. Ecological niche models summarize species potential distribution, and as such do not include the effects of historical constraints and limitations on dispersal abilities on species distributions (Soberón and Peterson 2005). To obtain estimates of actual species distribution, all GARP results for vertebrates were edited by experts on Mexican taxa distributions (mammals: Ceballos 2008; birds: Navarro-Sigüenza 2008 and Peterson 2007; amphibians and reptiles: Flores-Villela 2008). Distributions were trimmed with expert knowledge on the species biogeography, the aid of available, coarse-scale range maps (Howell and Webb, 1995, for birds; Ceballos and Oliva, 2005, for mammals) and regionalization maps (e.g. ecoregions). For more information see Navarro and Peterson (2008) and Flores-Villela (2008).

The vast number of plant species and the lack of expert knowledge for most plant groups hindered use of distribution maps for plant species (except species included in the Mexican red list). Moreover, the completeness of sampling is far better at the family and genera level than at the species level (Soberón et al. 2007). Therefore the phanerogamic flora was included using species records of several families (*Asteraceae, Cactaceae, Euphorbiaceae, Poaceae*) and other genera (*Pinus, Quercus*) obtained from the SNIB and REMIB biological database which were then generalized at a higher taxonomic level by means of an index that considers both the number of species and their geographic distribution. This index was constructed by assigning weights to species within a family or genera (*Pinus, Quercus)* using the following formula:

$$Weight_{spi} = (NumPU_{sp} x(-k) + MaxPUxk + 1) \quad , \qquad (1)$$

where

$Weight_{spi}$ is an integer,

$NumPU_{sp}$ is the number of planning units in which the species in question is present,

$MaxPU$ is the number of planning units in which the most widely distributed species is present, and

k is a constant obtained by dividing 22/MaxPU.

MaxPU was divided by 22 to normalize the scale. Total weights and weights within a planning unit for each family or genera were obtained as follows:

Σ $weight_{spi}$, where $weight_{spi}$ is the weight of the *i*th species. (2)

Land use and extent of vegetation types of Mexico were obtained from the INEGI vegetation and land use chart (INEGI 2005a). This map, scaled 1:250,000, is based on Landsat ETM+ satellite imagery interpretation with additional field validation. The map was also used to generate various GIS products and layers related to land use change, fragmentation, loss of habitat, and agricultural activities. In addition, social factors such as population growth (INEGI 1990, 2005b) and size (inhabitants for towns and area for cities) of georeferenced population clusters were derived from official census data (INEGI 2005b). A relatively novel approach was the use of heat points time series as a surrogate for wildfires. For this, a summary of heat points, generated on a daily basis from satellite imagery from 1999 to 2005, was used (CONABIO 2006). Finally, infrastructure like paved highways and dirt roads were incorporated from digital maps (IMT 2001).

Place Prioritization for Biodiversity Conservation

Five expert workshops took place during 2005 and 2006 with the purpose of discussing and defining the criteria to implement prioritization algorithms. Central to the analysis is the size of the planning units, which need to match the available data. The size was set at 256 km^2 (8,045 hexagons) placing a balance between the scale of the input data and computational time.

The identification of priority sites was carried out based on biological variables, and on pressure factors using the simulated annealing algorithm in the marxan software (Ball and Possingham 2000) . The program was run with 1,000,000 iterations and 10,000 runs using the adaptive annealing schedule with normal iterative improvement at the end of each run (Cook and Auster 2005; Chan et al. 2006). The type of data and criteria used in the process of assigning conservation goals to biodiversity elements and cost values to represent pressure factors follow methodology suggested by Groves et al. (2000), Ball and Possingham (2000) and Ulloa et al. (2006).

Biological Data

A total of 2,546 layers were considered, but only 1,450 were selected for the analysis after considering different attributes of their distribution and endangerment status (Tables 1 and 2). The final data set considered plant and vertebrate species, vegetation types, records of phanerogamic flora, and high diversity areas. For terrestrial vertebrates and plants recorded in the Mexican red list, goals were based on different criteria such as the degree of rarity (using as a threshold the last quartile of the geographic distribution range of each taxonomic group), endemism, extinction risk status in the Mexican red list (NOM-059-SEMARNAT-2001) and international red list (IUCN) and pressure from international commerce (CITES). Values assigned to each conservation criteria (Table 2) were summed to obtain the percentage target as follows: 5 percent (∑ = 1–21); 10 percent (41–22); 30 percent (42–63); 40 percent (64–85). Goals for natural and seminatural vegetation were established according to its coverage following criteria described in Table 3a and 3b. For example vegetation types with a critical low coverage of less than 0.75 percent of the national territory (e.g. cloud forests, tall evergreen forest, dry coastal scrub) were assigned the highest conservation goals of 99 percent. The desired conservation goals were expressed in terms of the percentage of geographic range size within the country held by biodiversity elements in relation to the extension of the national territory and goals ranged from 5–99 percent.

Table 1. Selected biodiversity elements to identify terrestrial priority sites.

[**Abbreviations**: SNIB, National Biodiversity Information System; REMIB, The World Information Network on Biodiversity; INEGI, National Institute of Statistics, Geography and Informatics]

Biodiversity elements	Layers	Source of information
Species		
Amphibians	208	Distribution maps
Reptiles	424	Distribution maps
Birds	273	Distribution maps
Mammals	242	Distribution maps
Plant species (Mexican Red list, NOM-059-SEMARNAT-2001)	214	Distribution maps
Plant families	12	SNIB and REMIB records
Natural and seminatural vegetation	68	INEGI (2005), land cover map
Species richness	9	Sum of distribution maps (one-half of the total area with the highest species richness)
Total	**1,450**	

Table 2. Example of conservation goals allocation according to biodiversity criteria values.

[**Abbreviations**: IUCN, international red list; E, possibly extinct in the wild; P, at risk of extinction; A, threatened; Pr, subject to special protection; Cr, critically endangered; En, endangered; Vu,vulnerable. Biodiversity criteria values are shown on the table heading]

	Endemicity	Rarity	Red list	IUCN red list	CITES	Total	Percent goal
	Yes/No 20/0	(Fourth quartile divided in four) 4, 3, 2, 1 20/16/13/10	(NOM-059) E, P, A, Pr 25/25/15/0	Cr/En/Vu 15/10/5	I/II 10/5		
Species 1	20	10	25	5	5	65	40
Species 2	20	0	0	0	5	25	10

Table 3a. Criteria and goal values for natural vegetation types.

[**Abbreviations**: <, less than; >, greater than]

Primary vegetation types or second-growth for vegetation types lacking coverage of primary vegetation	
Mexico's country area (percent)	**Conservation goals (percent)**
<0.75	99
0.75–1.0	70
1.0–2.0	40
2.1–5	20
>5	5

Table 3b. Criteria and goal values for seminatural vegetation types.

[**Percentage of Mexico's country area**: Coverage of second-growth and primary vegetation were summed. **Abbreviations**: <, less than; >, greater than]

Second-growth vegetation	
Mexico's country area (percent)	**Conservation goals (percent)**
<1.1	90
1.0–1.4	60
1.5–2.5	30
>2.6	10

Goals for the phanerogamic flora were set at 25 percent of total families and genera weight (see data set), this percentage was defined by experts criteria during workshops.

Finally, two additional biodiversity elements were considered in the analyses, indicating areas with elevated species richness and areas with a high diversity of endemic species, inferred from the accumulation of distribution model maps by taxonomic group. Conservation goals were assigned for each vertebrate group, depending on the area of coverage of each layer; goals ranged from 5 to 50 percent.

Pressure Factors

Threats to biodiversity were selected based on known impacts on ecological systems, communities and to flora and fauna species. The aim was to use high quality data to characterize pressure factors in order to select sites that could still be valuable to invest in conservation or restoration. The data used by the prioritization algorithm for representing threats is often referred as costs, following the logic that areas suffering from negative impacts are more difficult to protect and require higher conservation investment. Cost information is used to distribute conservation priorities to sites amenable to long-term persistence of conservation features (Chan et al. 2006).

After defining different pressure factors and specifying data availability for representing them in planning units, 19 threat layers were hierarchically grouped, based on the magnitude of their negative impact on biodiversity. The next step consisted in assigning weights to each layer in accordance to its hierarchical level; weights then were used to calculate final cost of each parameter (Table 4). It is well known that land use change is the main driver of biodiversity loss (Sala et al. 2000). Therefore, variables related to habitat loss, deterioration and fragmentation were assigned highest values. Lower values were assigned to dynamic social processes (population growth, recently established settlements) and to infrastructure such as roads, which produces habitat fragmentation and also increases human accessibility for hunting and extraction of other non-timber and timber products (Wilkie et al. 2000). Next in the hierarchical list is the area covered by shrubby and herbaceous secondary vegetation. It was considered important to include secondary vegetation in an early state of succession as a pressure factor, even though some arboreous secondary vegetation types were considered as conservation goals, following the logic that a recent disturbance is thought to indicate an increased human pressure over the area which will result in frequent future disturbances, and thus in lower biodiversity after the intermediate disturbance hypothesis (Connell 1978). Other variables (cities and localities) related to resource overexploitation and pollution represent the end of the hierarchical list. The final cost for each planning unit was obtained by summing up the different weighted values of pressure factors.

Once the algorithm was supplied with the different input data and results were obtained, the terrestrial priority sites were classified into three categories based on the selection frequency performed by the optimisation program. The selection frequency of a planning unit provides a fundamental measure of conservation value for the unit (Stewart et al. 2007) indicating its relative importance to meet given targets. Planning units included in all the marxan solutions are considered irreplaceable, and thus were designated as high priority sites. We ran two site selection scenarios in marxan, the first with goal values as defined in experts workshops, the second was run reducing goals for vegetation types by 20 percent in order to redefine high priority sites as these irreplaceable planning units occupied a large proportion of the country's area in the first run (16.6 percent). The irreplaceability of these units was given in part by high conservation goals (99 percent) given to critical fragmented vegetation types. Irreplaceable planning units in the first and second conservation scenarios were designated as extreme priority sites, irreplaceable planning units in the first scenario were designated as high priority sites, and planning units selected 90–99 percent of all runs in the first scenario were designated as medium priority sites.

Table 4. Allocation of threat values in planning units.

[**Abbreviations**: FAO, Food and Agriculture Organization; x, multiplied by; INEGI, National Institute of Statistics, Geography and Informatics; ha, hectare; CONABIO, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad; #, number; m, meter; IMT, Instituto Mexicano del Transporte ; <, less than; >, greater than]

Threat layer	Calculation	Weight	Data type	Data source
Rate of primary vegetation loss	Rate of land use change for primary vegetation (FAO, 1996) x weight[1]	10, 000	Land use change: destruction of habitat and fragmentation	Land use and cover maps, INEGI 1993, 2005a.
Fragmentation in primary vegetation	Area-perimeter index (Fragstats)[2]	8300	Land use change: fragmentation	Land use and cover map, INEGI 2005.
Secondary vegetation, shrubs	Area (ha) x weight	100	Land use change: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Secondary vegetation, herbaceous	Area (ha) x weight	200	Land use change: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Heat points 2 from satellite images	Area (ha) x weight[3]	7500	Land use change: destruction of habitat and fragmentation	CONABIO 2006.
High impact cattle (goats and lambs)	# points x weight	6700	Livestock farming: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Low impact cattle (bovine and equine)	# points x weight	6100	Livestock farming: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Introduced and cultivated grasslands	Area (ha) x weight	6000	Livestock farming: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Irrigation agriculture	Area (ha) x weight	5800	Agriculture: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Seasonal agriculture	Area (ha) x weight	4000	Agriculture: destruction of habitat and fragmentation	Land use and cover map, INEGI 2005.
Road density (paved roads)	Longitude (m) x weight	3000	Infrastructure: fragmentation and accessibility	IMT 2001.
Road density (unpaved roads)	Longitude (m) x weight	2000	Infrastructure: fragmentation and accessibility	IMT 200.
New localities	# points x weight	1000	Demography and settlements (dynamic): Increased use of natural resources and destruction of habitat and fragmentation	Census data, INEGI 2002.
Population growth (1990-2005)	Rate of geometric population growth x weight	900	Demography and settlements (dynamic): Increased use of natural resources and destruction of habitat and fragmentation	Census data, INEGI 1990, 1995, 2000, 2005.
Localities <1000 inhabitants	# points x weight	10	Increased use of resources and contamination	Census data, INEGI 2002.
Localities 1000–10,000 inhabitants	# points x weight	20	Increased use of resources and contamination	Census data, INEGI 2002.
Localities 10,000–100,000 inhabitants	# points x weight	30	Increased use of resources and contamination	Census data, INEGI 2002.
Localities 100,000–200, 000 inhabitants	# points x weight	40	Increased use of resources and contamination	Census data, INEGI 2002.
Localities > 200, 000	Area (ha) x weight	50	Increased use of resources and contamination	Extract of topographic map 1:250,000, INEGI unknown year.

[1] Only negative values were considered, multiplied by –100 to obtain meaningful positive values.

[2] Mean value per vegetation type was calculated. For each hexagon the maximum value was taken.

[3] Heat points represent the threat of potential wildfires.

Results and Discussion

Conservation of Mexico's extraordinary biodiversity is a great challenge, in particular given spatial patterns of biodiversity and current trends of land use change, habitat degradation, and human population growth (Palacio-Prieto et al. 2000; INEGI 2007). Although it is impossible to represent adequately the full range of biodiversity in a given region or country (Rondinini and Boitani 2006; Sarkar et al. 2006), this study represents a big step towards better identifying conservation gaps in Mexican terrestrial biodiversity. It considered the largest amount of information on Mexican biodiversity which comprises a wide range of biodiversity surrogates including nationally and globally threatened species, restricted-range species (criteria proposed to identify key biodiversity areas, Eken et al. 2004) and habitats (e.g. primary vegetation) that might serve as umbrella to represent a great number of other plant and animal species and to consider important ecological services.

Terrestrial priority sites for conservation detected in the optimisation analysis (Figure 1) cover 594,894 km^2; extreme priority sites (SE) cover 2.18 percent of the continental area, the percentage increases to 16.6 percent of the territory and to 30.6 percent when the sites of high priority (SA) and of high and medium priority (SM) are respectively considered. For more information see CONABIO-CONANP-TNC-Pronatura-FCF, UANL (2007). Currently, protected areas of México cover about 12 percent of the country's continental surface; nevertheless, the existing nature reserve network falls short of effectively representing Mexican terrestrial biodiversity. Only 12.9 percent of priority sites surface is under protection of federal, state and municipal nature reserves (3.91 percent of the country's continental territory). Previous studies have also demonstrated that nature reserves alone are insufficient to protect biodiversity (Brandon et al. 2005; Cantú et al. 2004; see Ceballos 2007; Ortega-Huerta and Peterson 2004). On the whole, protection of 10–12 percent of the land, promoted in the past as a target to be achieved (IUCN 1993) has been proven insufficient to protect biodiversity for a region or a country (Rodrigues et al. 2004; Rondinini and Boitani 2006), and particularly for biodiversity rich countries such as México.

Conservation goals could not be met for all the species and habitat targets; extreme priority sites alone were able to meet conservation goals for 34.9 percent of all the biodiversity elements. When also considering high priority sites, conservations goals were met for 81.2 percent of all the biodiversity elements. In spite of increasing the priority area by twofold when adding the medium priority sites, conservation goals were met for only 90.5 percent of all species and habitat targets. Targets were met with the "best solution" given by the optimisation software; however, this area covers 43 percent of Mexico, which clearly does not help to set conservation priorities. It is therefore not possible to attain the goals for all the biodiversity elements in a reduced area of the country, a fact that reflects the high level of heterogeneity that characterizes Mexico as a megadiverse country.

To represent effectively a larger number of biodiversity elements, extreme and high priority sites should be ideally destined for conservation but it will not be possible to cover these gaps only with protected areas. It is indispensable to have a sustainable management outside the protected areas. New protected areas and other mechanisms for conservation should be preferably determined by a multi-stakeholder process; researchers, technical experts, and other sectors of society should assess priority areas at other scales (i.e. regional, local) in order to promote local conservation actions integrating social data and planning opportunities, so as to effectively address the limited conservation resources. Some successful examples of local and regional conservation actions by organized communities are promising (Ramos-Fernández et al. 2005; Luján-Alvarez et al. 2000; Durán-Medina et al. 2007) for the conservation and sustainable use of biodiversity if adopted throughout the country. Such examples demonstrate that providing alternative sources of income that promote human well-being and biodiversity conservation are essential in order to conserve Mexico's great natural capital on the long term.

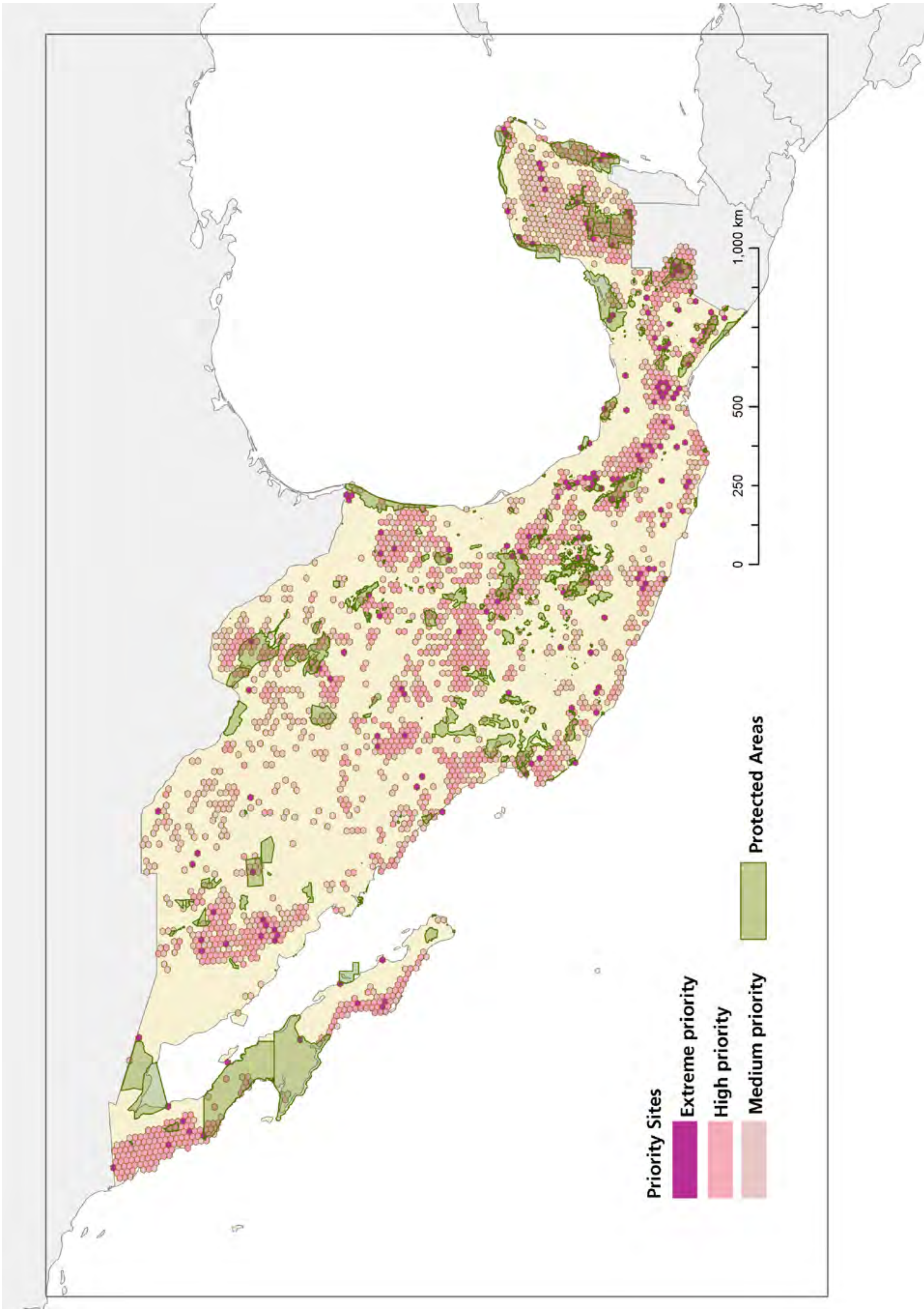


Figure 1. Priority sites and protected areas in Mexico.

Acknowledgments

We would like to acknowledge all the members of the executive board, advisory team and all the workshop participants, without whom this work would not have been possible. Special thanks to Raúl Ulloa for his guidance during workshops, Miguel Murguía and for its guidance with the phanerogamic flora index and to the following people who contributed greatly with their knowledge and work: Cesar Cantú, Gerardo Ceballos, Antony Challenger, Rocío Esquivel, Pedro Maeda, Elizabeth Moreno, Norma Moreno, Adolfo Navarro-Sigüenza, Leticia Ochoa-Ochoa, Marcia Tambutti and Oscar Flores-Villela among many others.

References Cited

American Ornithologists' Union. 1998. *Checklist of North American Birds*, 7nd Edition. American Ornithologists' Union, Washington, D.C.

Arriaga, L., J.M. Espinoza, C. Aguilar, E. Martínez, and E. Loa, coords. 2000. Regiones Terrestres Prioritarias de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México.

Ball, I.R., and H.P. Possingham. 2000. MARXAN (v1.8.2): *Marine Reserve Design using Spatially Explicit Annealing, a manual*.

Brandon, K., L.J. Gorenflo, A.S.L. Rodrigues, and R.W. Waller. 2005. Reconciling biodiversity conservation, people, protected areas, and agricultural suitability in Mexico. *World Development* 33:1403–1418.

Cantú, C., G. Wright, M.J. Scott, and E. Strand. 2004. Assessment of current and proposed nature reserves of Mexico based on their capacity to protect geophysical features and biodiversity. *Biological Conservation* 115:411–417.

Ceballos, G. 2007. Conservation priorities for mammals in megadiverse Mexico: The efficiency of reserve networks. *Ecological Applications* 17:569–578.

Ceballos, G., and G. Olivia, coords. 2005. *Los mamíferos silvestres de México*. CONABIO–Fondo de cultura Económica, México.

Ceballos, G. 2008. *Modelado de la distribución de las especies de mamíferos de México para un análisis* GAP. Proyecto DS006. EcoCiencia S.C. Bases de datos SNIB-CONABIO, México.

Chan, K.M., R.M. Shaw, D.R. Cameron, E.C. Unederwood, and G.C. Daily. 2006. Conservation planning for ecosystem services. *PLOS biology* 4:376–379.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). 2006. *Puntos de calor detectados con imágenes de satélite AVHRR y MODIS nocturnas de los años 1999 al 2005*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México.

CONABIO–SNIB. El Sistema Nacional de Información sobre Biodiversidad de México (SNIB). Available from <www.conabio.gob.mx/institucion/snib/doctos/acerca.html>

CONABIO–CONANP–TNC–Pronatura–FCF, UANL. 2007. *Análisis de vacíos y omisiones en conservación de la biodiversidad terrestre de México: espacios y especies*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Naturales Protegidas, The Nature Conservancy–Programa México, Pronatura, A.C., Facultad de Ciencias Forestales, Universidad Autónoma de Nuevo León, México.

Connell, J.H. 1978. Diversity in Tropical Rain Forests and Coral Reefs. *Science* 199:1302-1310.

Cook, R.R., and P.J. Auster. 2005. Use of Simulated Annealing for Identifying Essential Fish Habitat in a Multispecies Context. *Conservation Biology* 19:876–886.

Durán-Medina, E., J.F. Mas, and A. Velázquez 2007. Cambios en las coberturas de vegetación y usos del suelo en regiones con manejo forestal comunitario y Áreas Naturales Protegidas de México. In L. Merino-Pérez, D. Bray and D. Barry. *Los bosques comunitarios de México. Manejo sustentable de paisajes forestales*. INE, México.

Earth Resources Observation and Science. 2008. HYDRO1k Elevation Derivative Database. U.S. Geological Survey database. Available at http://edc.usgs.gov/products/elevation/gtopo30/hydro/index.html

Eken, G., L. Bennun, T.M. Brooks, W. Darwall, L.D.C. Fishpool, M. Foster, D. Knox, P. Langhammer, P. Matiku, E. Radford, P. Salaman, W. Sechrest, M.L. Smith, S. Spector, and A. Tordoff. 2004. Key biodiversity areas as site conservation targets. *BioScience* 54:1110–1118.

(FAO) Food and Agriculture Organization. 1996. Forest Resources Assessment 1990. *Survey of Tropical Forest Cover and Study of Change Processes*. FAO Forestry Paper 130. FAO, Rome.

Flores-Villela, O. 1993a. Herpetofauna Mexicana. *Special Publications Carnegie Museum of Natural History* 17:1–73.

Flores-Villela, O. 1993b. Herpetofauna of México: Distribution and Endemism in T.P. Ramamoorthy, R. Bye, A. Lot y J.Fa., editors, *Biological diversity of Mexico: origins and distributions*. Oxford University Press, New York, p. 253-280.

Flores-Villela, O. 2008. *Áreas potenciales de distribución y GAP análisis de la herpetofauna de México Proyecto DS009. Base de datos SNIB–CONABIO*, México.

Flores-Villela, O., and L. Canseco-Márquez. 2004. Nuevas especies y cambios taxonómicos para la herpetofauna de México. *Acta Zoológica Mexicana (nueva serie*) 20:115-144.

Frost, D.R., T. Grant, J. Faivovich, R.H. Bain, A. Haas, C.F.B. Haddad, R.O. de Sa, A. Channing, M. Wilkinson, S.C. Donnellan, C. Raxworthy, J.A. Campbell., B.L. Blotto, P. Moler, R.C. Drewes, R.A. Nussbaum, J.D. Lynch, D.M. Green and W.C. Wheeler. 2006. *The amphibian tree of life. Bulletin of the American Museum of Natural History* 297:1-370.

Groves, C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. *Designing a geography of hope: A practitioner's handbook for ecoregional conservation planning.* The Nature Conservancy, Arlington, VA.

Hijmans, R.J., S. Cameron, and J. Parra, P. Jones, A. Jarvis, and K. Richardson. 2008. WORLDCLIM Version 1.4. Museum of Vertebrate Zoology, University of California, Berkeley, CA. Available at http://www.worldclim.org

Howell, S.N.G. and S. Webb. 1995. *A guide to the birds of Mexico and northern Central America.* University Press, Oxford, UK.

Illoldi-Rangel, P., V. Sánchez-Cordero, and A.T. Peterson. 2004. Predicting distributions of Mexican mammals using ecological niche modeling. *Journal of Mammology* 85:658–662.

IMT. 2001. *Red de carreteras. Escala 1:1*. Instituto Mexicano del Transporte, México.

(INEGI) National Institute of Statistics, Geography and Informatics. unknown year. *Carta Topográfica escala 1:250 000. Serie II*. Formato raster. Instituto Nacional de Estadística Geografía e Informática, Aguascalientes, México.

(INEGI) National Institute of Statistics, Geography and Informatics. 1990. *Localidades de la República Mexicana*. Extraído del conteo de población y vivienda. Resultados definitivos, 1990. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

(INEGI) National Institute of Statistics, Geography and Informatics. 1995. *Localidades de la República Mexicana*. Extraído del conteo de población y vivienda. Resultados definitivos, 1995. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

(INEGI) National Institute of Statistics, Geography and Informatics. 2001. *Conjunto de datos vectoriales de lacarta de uso de suelo y vegetación, escala 1:250,000, serie II (continuo nacional).* Instituto Nacional de Geografía y Estadística, Dirección General de Geografía, Aguascalientes, México.

(INEGI) National Institute of Statistics, Geography and Informatics. 2002. *Localidades de la República Mexicana, 2000*. Obtenido de principales resultados por localidad. XII Censo de Población y Vivienda 2000. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). Instituto Nacional de Estadística Geografía e Informática, México.

(INEGI) National Institute of Statistics, Geography and Informatics. 2005a. *Conjunto de datos vectoriales de uso de suelo y vegetación, escala 1:250 000, serie 3 (continuo nacional*). Instituto Nacional de Geografía y Estadística, Dirección General de Geografía, Aguascalientes, México.

(INEGI) National Institute of Statistics, Geography and Informatics. 2005b. *Localidades de la República Mexicana*, 2005. Obtenido de principales resultados por localidad 2005. II Conteo de Población y Vivienda 2005. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

(INEGI) National Institute of Statistics, Geography and Informatics. 2007. Población http://cuentame.inegi.gob.mx/poblacion/habitantes.aspx

(IUCN) International Union for Conservation of Nature. 1993. *Parks for Life: Report of the IVth World Congress on National Parks and Protected Areas*. IUCN, Gland, Switzerland.

Luján Alvarez, C., J.A. Diemer, and M. L. Stanford. 2000. Desarrollo de comunidades forestales sustentables en Chihuahua, México. *Madera y Bosques* 6:29–39.

McGarigal, K., and B.J. Marks. 1995. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Mittermeier, R.A., P. Robles Gil, M. Hoffmann, J. Pilgrim, T. Brooks, C. Goettsch Mittermeier, J. Lamoreux, and G.A.B. da Fonseca. 2004. *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Cemex, México.

Nakazawa, Y., A.T. Peterson, E. Martínez-Meyer, and A.G. Navarro-Sigüenza. 2004. Seasonal niches of nearctic-neotropical migratory birds: implications for the evolution of migration. *The Auk* 121:610–618.

Navarro-Sigüenza, A.G., and A.T. Peterson. 2007. *Mapas de las aves de México basados en web*. Proyecto CE015. Base de datos SNIB-CONABIO, México.

Navarro, A.G., A.T. Peterson, and A. Gordillo-Martínez. 2003. Museums working together: the atlas of the birds of Mexico. *Bull. B.O.C.* 123A:207–225.

Ochoa-Ochoa, L.M., and Flores-Villela O. 2006. *Áreas de Diversidad y Endemismo de la Herpetofauna Mexicana*. UNAM–CONABIO, Mexico, D.F. 211p.

Ortega-Huerta, M.A., and A.T. Peterson. 2004. Modelling spatial patterns of biodiversity for conservation prioritization in North-eastern Mexico. *Diversity and Distributions* 10:39–54.

Palacio-Prieto, J.L., G. Bocco, A. Velázquez, J.F. Mas, F. Takaki, A. Victoria, L. Luna, G. Gómez, J. López, M. Palma, I. Trejo, A. Peralta, J. Prado, A. Rodríguez, R. Mayorga, and F. González. 2000. La condición actual de los recursos forestales en México: resultados del Inventario Forestal Nacional 2000 *Investigaciones Geográficas, Boletín del Instituto de Geografía. UNAM* 43:183–203.

Papes, M., and Gaubert, P. 2007. Modelling ecological niches from low numbers of occurrences: assessment of the conservatiion status of poorly known viverrids (Mammalia, Carnivora) across two continents. *Diversity and Distributions* 13:890–902.

Peterson, A.T., V. Sánchez-Cordero, E. Martínez-Meyer, and A.G. Navarro-Sigüenza. 2006. Tracking population extirpations via melding ecological niche modeling with land-cover information. *Ecological modeling* 195:229–236.

Peterson, A.T., M . Papes, and M. Eaton, 2007. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. *Ecography* 30:550–560.

Pimm, S.L., G.J. Russell, J.L. Gittleman, and T.M. Brooks. 1995. The Future of Biodiversity. *Science* 269:347–350.

Pressey, R.L., R. Johnson, and P.D. Wilson. 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. *Biodiversity and Conservation* 3:242–262.

Ramos-Fernández, G., B. Ayala-Orozco, M. Bonilla-Moheno, and E. García -Frapolli. 2005. Conservación comunitaria en Punta Laguna: Fortalecimiento de instituciones locales para el desarrollo sostenible. 1er. Congreso Internacional de casos exitosos de desarrollo sostenible del Trópico, Boca del Rió, Veracruz, México.

(REMIB) The World Information Network on Biodiversity. Red mundial de información sobre biodiversidad. Available from www.conabio.gob.mx/remib/doctos/remib_esp.html

Rodrigues, A.S.L., S.J. Andelman, M. Bakarr, L. Boitani, T. Brooks, R.M. Cowling, L.D.C. Fishpool, G.A.B. Fonseca, K.J. Gaston, M. Hoffmann, J.S. Long, P.A. Marquet, J.D. Pilgrim, R.L. Pressey, J. Schipper, W. Sechrest, S.N. Stuart, L.G. Underhill, R.W. Waller, M.E.J. Watts and X. Yan. 2004. Effectiveness of the global protected area network in representing species diversity. *Nature* 428:640–643.

Rondinini, C., and L. Boitani. 2006. Differences in the Umbrella Effects of African Amphibians and Mammals Based on Two Estimators of the Area of Occupancy *Conservation Biology* 20:170–179.

Sala, O. E., F. S. Chapin, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall. 2000. Global biodiversity scenarios for the year 2100. *Science* 1770–1774.

Sarkar, S., R.L. Pressey, D.P. Faith, C.R. Margules, T. Fuller, D.M. Storms, A. Moffett, K.A. Wilson, K.J. Williams, P.H. Williams, and S. Andelman. 2006. Biodiversity Conservation Planning Tools: Present Status and Challenges for the Future. *Annual Review of Environment and Resources* 31:123–159.

Soberón, J. and A.T. Peterson. 2005. Interpretation of models of fundamental ecological niches and specie's distributional areas. *Biodiversity Informatics* 2:1–10.

Soberón, J., R. Jiménez, J. Golubov and P. Koleff. 2007. Assessing completeness of biodiversity databases at different spatial scales. *Ecography* 30:152–160.

Stewart, R.R., I.R. Ball, and H.P. Possingham. 2007. The effect of incremental reserve design and changing reservation goals on the long-Term efficiency of reserve systems. *Conservation Biology* 21:346–354.

Stockwell, D.R.B., and D.P. Peters. 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *International Journal of Geographic Information Systems* 13: 143–158.

Ulloa, R., J. Torre, L. Bourillón, and N. Alcantar. 2006. *Planeación ecorregional para la conservación marina: Golfo de California y costa occidental de Baja California Sur*. The Nature Conservancy, México.

(UNDP) United Nations Development Programme. 2004. Programme of Work on Protected Areas. Conference of Parties of the United Nations Convention on Biological Diversity, 7th meeting, Kuala Lumpur, Malaysia. Available at http://www.protectedareas.org/

Wilkie, D., E. Shaw, F. Rotberg, G. Morelli and P. Auzel. 2000. Roads, Development, and Conservation in the Congo Basin. *Conservation Biology* 14:1614–1622.

This page intentionally left blank.

FINAL STATE PROJECT REPORTS

Puerto Rico Gap Analysis Project

William A. Gould[1]

Introduction

The Puerto Rico Gap Analysis Project (PRGAP) began in 2001 to assess Puerto Rico's land cover, vertebrate distributions, land stewardship, and gaps in the conservation of vertebrate species and habitats. The project was instigated by Dr. Jaime Collazo, Assistant Unit Leader, North Carolina Cooperative Fish and Wildlife Research Unit and Professor of Zoology and Forestry at North Carolina State University (NCSU) and has been led by the U.S. Department of Agriculture (USDA) Forest Service International Institute of Tropical Forestry in collaboration with the Puerto Rico Department of Natural and Environmental Resources and NCSU (Gould et al. 2007). PRGAP is based on methods developed by the National Gap Analysis Program to determine the degree to which animal species and natural communities are represented in the current mix of conservation lands. Those species or communities not well represented are considered conservation "gaps." The purpose of PRGAP is to provide geographic and ecological information on the status of the terrestrial vertebrate species and habitats of Puerto Rico. This provides land managers, government planning and policy makers, scientists, students, and the general public with information to make better decisions regarding land management and conservation.

PRGAP has four major components: land cover mapping, documentation of vertebrate species distributions, documentation of land stewardship practices with respect to conservation, and an integrated analysis of these three elements. A number of research publications, reports, and maps have been derived from PRGAP (Gould et al. 2006; Gould et al. 2007; Martinuzzi et al. 2007a–c; Vierling et al. 2007; Gould et al. 2008a–d; Martinuzzi et al. 2008a–c; Parés-Ramos et al. 2008).

Land Cover

We developed a land cover map of Puerto Rico using recent (1999–2003) satellite imagery and information on climate, geology, topography, hydrology, and land use history. We defined 70 land cover classes in a hierarchical classification scheme based on whether the cover was natural vegetation, developed, or agricultural, and on whether the natural vegetation was closed forest, woodland, shrubland, or grassland. Forest and grassland classes were further defined as dry, moist, wet, or flooded. These units were then differentiated as occurring on soils derived from limestone, alluvial, serpentine, or noncalcareous substrates. A number of forest types are further classified as to the forest age (i.e., primary, mature secondary, or young secondary forests). Wetlands were classified as forested or herbaceous, saline or nonsaline, and seasonally flooded or emergent. Finally, where information was available we described the dominant plant communities and species representative of these land cover units.

We classified 53 percent of Puerto Rico as predominantly woody vegetation, 35 percent as grassland or herbaceous agriculture, 11 percent as developed land, and about 1 percent each of water and natural barrens (Table 1). Of the woody areas, low and mid elevation moist forests cover 26 percent, upper elevation wet forests cover 18 percent, dry forests cover 7 percent, and flooded mangrove and *Pterocarpus* forests cover 1 percent of the island. Coastal wetlands cover less than 4 percent of the island. Forty-two percent of the wetlands are saline and 58 percent are freshwater. Mangroves and *Pterocarpus* swamps cover 1 percent of the island, 67 km^2 and 2.6 km^2 respectively. Seventy-four percent of the wetlands are dominated by herbaceous vegetation, and 92 percent of these are seasonally flooded. Of the herbaceous wetlands, 77 percent are nonsaline and 23 percent are saline.

[1]U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry, Río Piedras, PR.

Table 1. Simplified land cover classes from the Puerto Rico Gap Analysis Project land cover mapping.

Land cover	Area		Estimated number of samples	Final number of samples
	Hectare	Percent		
Forest (except mangrove)	345,132	39	125	125
Woodland and shrubland	117,974	13	43	43
Mangrove	8,700	1	3	20
Grassland, pasture, agriculture	312,664	35	113	113
Urban and barren	101,845	11	37	37
Water	8,540	1	3	20
Total	**894,855**	**100**	**324**	**358**

Land Cover Accuracy Assessment

We used island-wide 1-m^2 resolution color IKONOS imagery from 2001–02, including Vieques, Culebra, Mona, and the smaller cays to evaluate the thematic accuracy of the PRGAP land cover map. We concluded that the accuracy assessment should be conducted on the six original classes obtained through the unsupervised classification as they represented the main classes originally separated spectrally. The final 70 PRGAP land cover units were created through modeling of the original classes in combination with geological, climatological, and other auxiliary data. Furthermore, the recoded six land cover classes simplified the accuracy assessment process and helped to reduce image interpretation errors when using the reference IKONOS imagery.

Three hundred fifty-eight sample points were randomly allocated within each of the six land cover classes. Image interpreters did not know which points had been assigned to which classes and the corresponding reference sample points were assessed in the IKONOS imagery and allocated to one of the six classes. ERDAS imagine 9.0 was used to generate an error matrix, accuracy totals, and kappa statistics.

The land cover accuracy assessment (Tables 2 and 3) shows an overall accuracy of 84.92 percent and a kappa value of 0.8, which indicates substantial agreement (Landis and Koch 1977). However, there is significant variability in the producer's and user's accuracy. The producer's accuracy (PA) relates to the probability that a reference sample (IKONOS-interpreted land cover class) will be correctly mapped and measures the errors of omission, whereas the user's accuracy (UA) indicates the probability that a sample from the land cover map matches the reference data and measures the error of commission. The producer's accuracy ranges from 52.54 to 100 percent and the user's accuracy ranges from 72.09 to 95 percent (Table 3). Overall, accuracy assessment for five of the six recoded tended to be in a similar range, from 87 to 100 percent for the producer's accuracy and from 82 to 95 percent for the user's accuracy. However, for the open forest and shrubland class, the PA decreased to 52 percent and the UA decreased to 72 percent, indicating a degree of misclassification. With any land cover classification produced from satellite imagery, misclassification often results from subpixel spatial variability and spatial and spectral resolution limitations.

Table 2. Error matrix of IKONOS-based accuracy assessment of the Puerto Rico Gap Analysis Project major land covers classes.

[Reference data are from IKONOS 2001–02 imagery. The number of correctly identified pixels is in the diagonal part of the matrix and mis-identified pixels are in the row or column of the land cover type in which they occur in the IKONOS imagery]

Land cover class	Error matrix						Total number of pixels
	(1)	(2)	(3)	(4)	(5)	(6)	
(1) Forest (except mangrove)	**108**	9	0	6	2	0	**125**
(2) Woodland and shrubland	8	**31**	0	3	1	0	**43**
(3) Mangrove	0	0	**19**	0	0	1	**20**
(4) Grassland, pasture, agriculture	2	16	0	**93**	2	0	**113**
(5) Urban and barren	0	2	0	1	**34**	0	**37**
(6) Water	0	1	0	0	0	**19**	**20**
Total	**118**	**59**	**19**	**103**	**39**	**20**	**358**

Table 3. Accuracy of land cover classifications of the Puerto Rico Gap Analysis Project.

[**Abbreviations**: RT, reference pixels; CT, classified pixels; NC, number pixels correctly classified; PA, producer's accuracy (samples correctly mapped); UA, user's accuracy (mapped point matches data)]

Land cover class	RT	CT	NC	PA	UA	Kappa
			(percent)			
Forest (except mangrove)	118	125	108	91.53	86.40	0.7971
Woodland and shrubland	59	43	31	52.54	72.09	0.6659
Mangrove	19	20	19	100.00	95.00	0.9472
Grassland, pasture, agriculture	103	113	93	90.29	82.30	0.7515
Urban and barren	39	37	34	87.18	91.89	0.9090
Water	20	20	19	95.00	95.00	0.9470
Total	**358**	**358**	**304**			
Overall Kappa statistics (KHAT value)						**0.8007**
Overall accuracy (percent)					**84.92**	

Terrestrial Vertebrate Distributions

More than 470 vertebrate species have been recorded in Puerto Rico and its adjacent islands including terrestrial and aquatic birds, reptiles, amphibians, and mammals. Of these, 426 are terrestrial vertebrate species. Many of these species are migratory, wintering, accidental, or vagrant species that do not breed regularly or at all on the island. We have developed a database that contains taxonomic information, residence status, and conservation status of all these species. We predicted the distributions of 98 bird, 47 reptile, 18 amphibian, and 14 mammal species including all native resident endemic and endangered terrestrial vertebrates and some introduced species (Figure 1).

Species ranges were mapped by using a network of 24-km^2 hexagons that cover Puerto Rico and its adjacent islands. Each hexagon was attributed with the species probability of occurrence in one of eight categories. Species probability of occurrence information is derived from published literature, unpublished data sets, museum records, and expert opinion.

Species distributions were mapped by identifying predicted habitat within the species range based on literature and expert review. The resulting maps of predicted species distribution are a result of the integration of information from the vertebrate database and land cover mapping. We combined species distribution information to develop species richness maps. The resulting biodiversity patterns indicate that forested parts of the landscape are the habitats with the highest predicted species richness, (i.e., in our analyses forested habitats have higher *alpha* diversity than other habitats) (Figure 2). Urban and barren areas are the habitats with the lowest species richness. Individual taxonomic groups show distinct patterns.

We also looked at the species richness within the network of 24-km^2 hexagons used to document species occurrences. This analysis indicates that the highest levels of habitat heterogeneity (*beta* diversity) and resulting biodiversity are in coastal areas with a mix of wetlands, grassland, and forested coastal hills (Figure 3). The coastal area is also extremely vulnerable to development, because the topography is less steep, it is close to urban areas and existing infrastructure, and nonwetlands on the coastal plain and coastal hills are primarily unprotected. Development is prohibited in the wetlands, but development adjacent to wetlands can destroy the diverse matrix of habitats and affect hydrologic patterns, altering species composition and biodiversity.

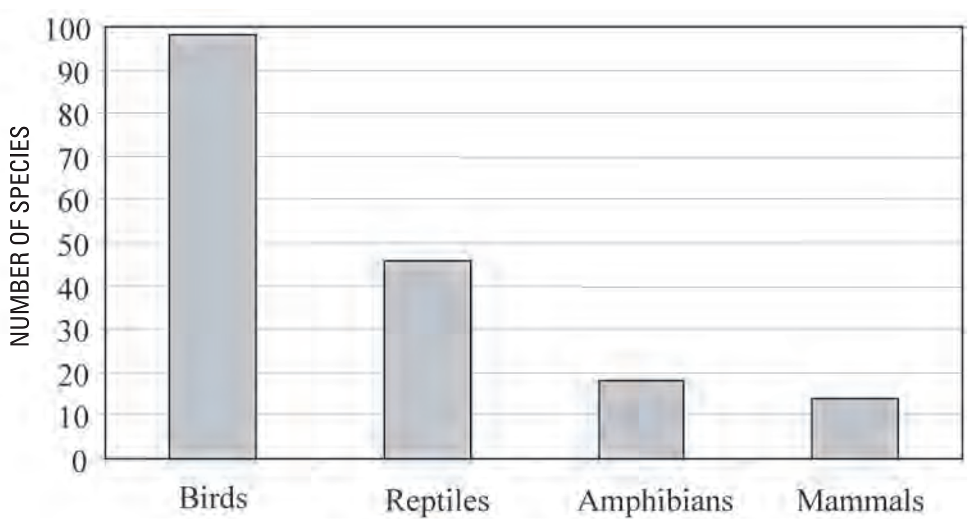


Figure 1. Terrestrial vertebrate species by taxonomic group included in the Puerto Rico Gap Analysis Project.

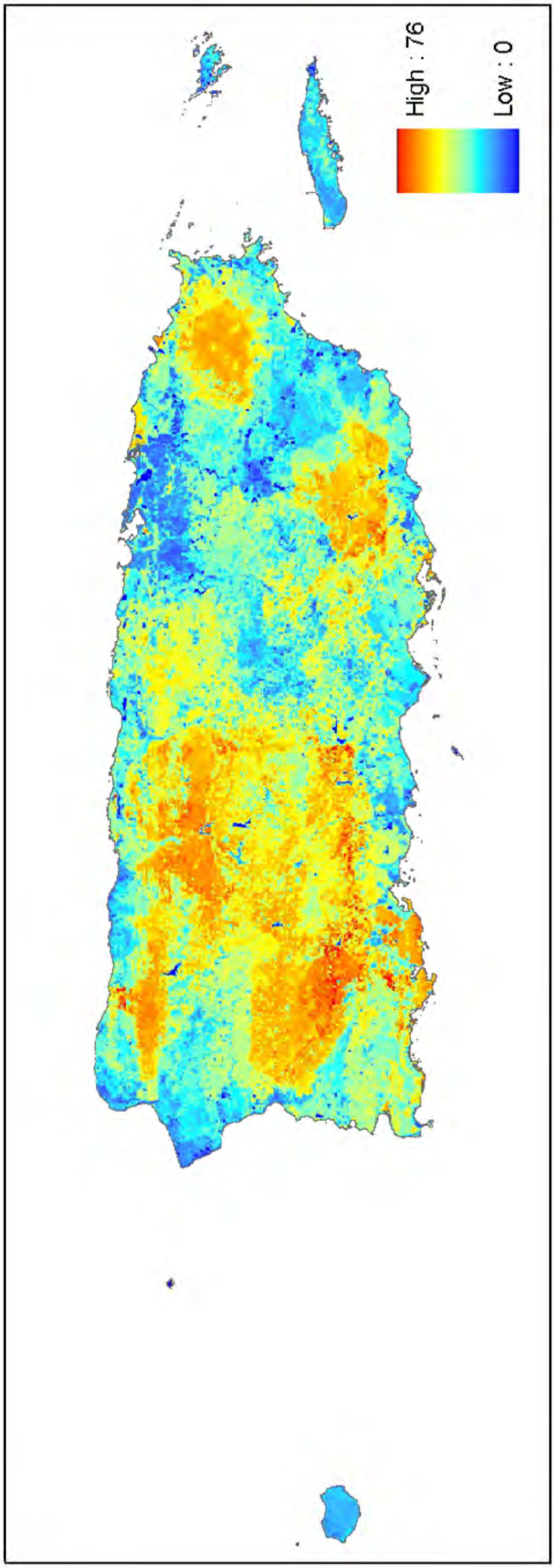


Figure 2. Predicted terrestrial vertebrate species richness per 15 m pixel (225 m^2).

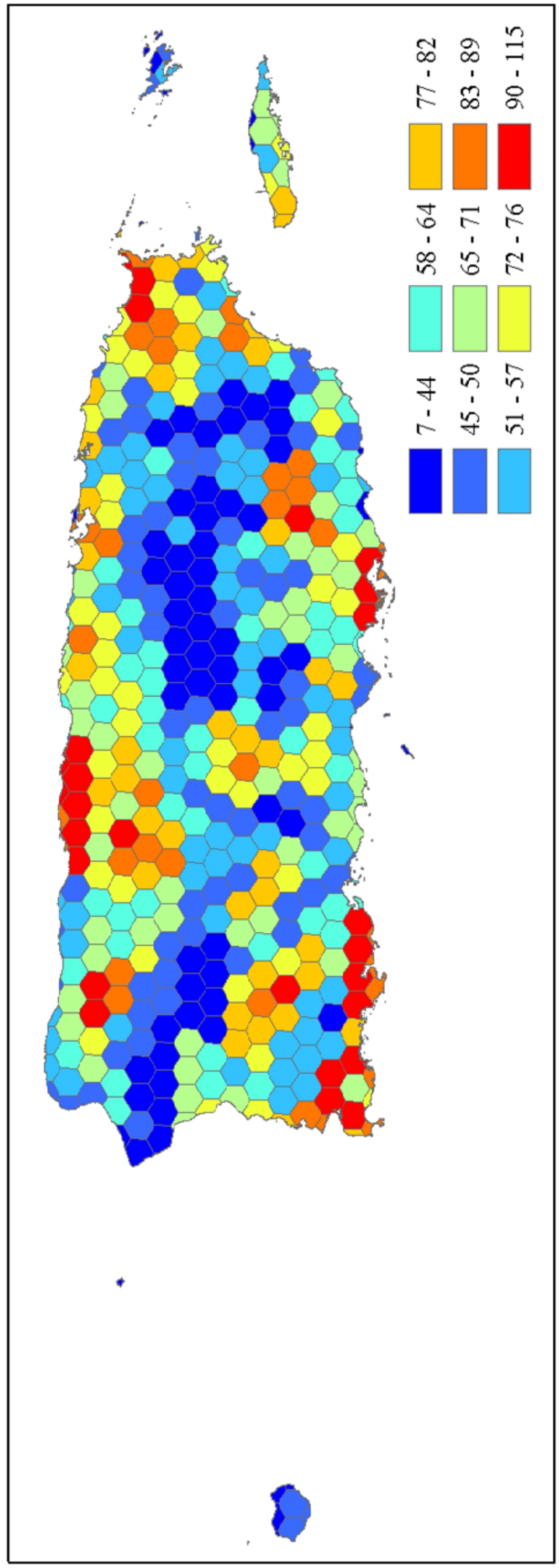


Figure 3. Predicted terrestrial vertebrate species richness per 24 km^2 hexagon.

Land Stewardship

The national GAP currently uses a scale of 1 to 4 to denote relative degree of maintenance of biodiversity for stewardship areas. A status of “1” denotes the highest, most permanent level of maintenance, and “4” represents the lowest level of biodiversity management, or unknown status (Scott et al. 1993).

Although land stewardship, management, and land use are very dynamic, we have identified 77 stewardship areas that receive some management for conservation (GAP status 1 through 3). Land ownership of these areas is shared among 20 organizations with the Puerto Rico Department of Natural and Environmental Resources (DNER) being the primary landowner. Management of land stewardship areas is shared among 20 organizations with the DNER, the U.S. Forest Service, and the U.S. Fish and Wildlife Service being the primary governmental land managers and the Conservation Trust of Puerto Rico being the primary nongovernmental land manager (Figure 4).

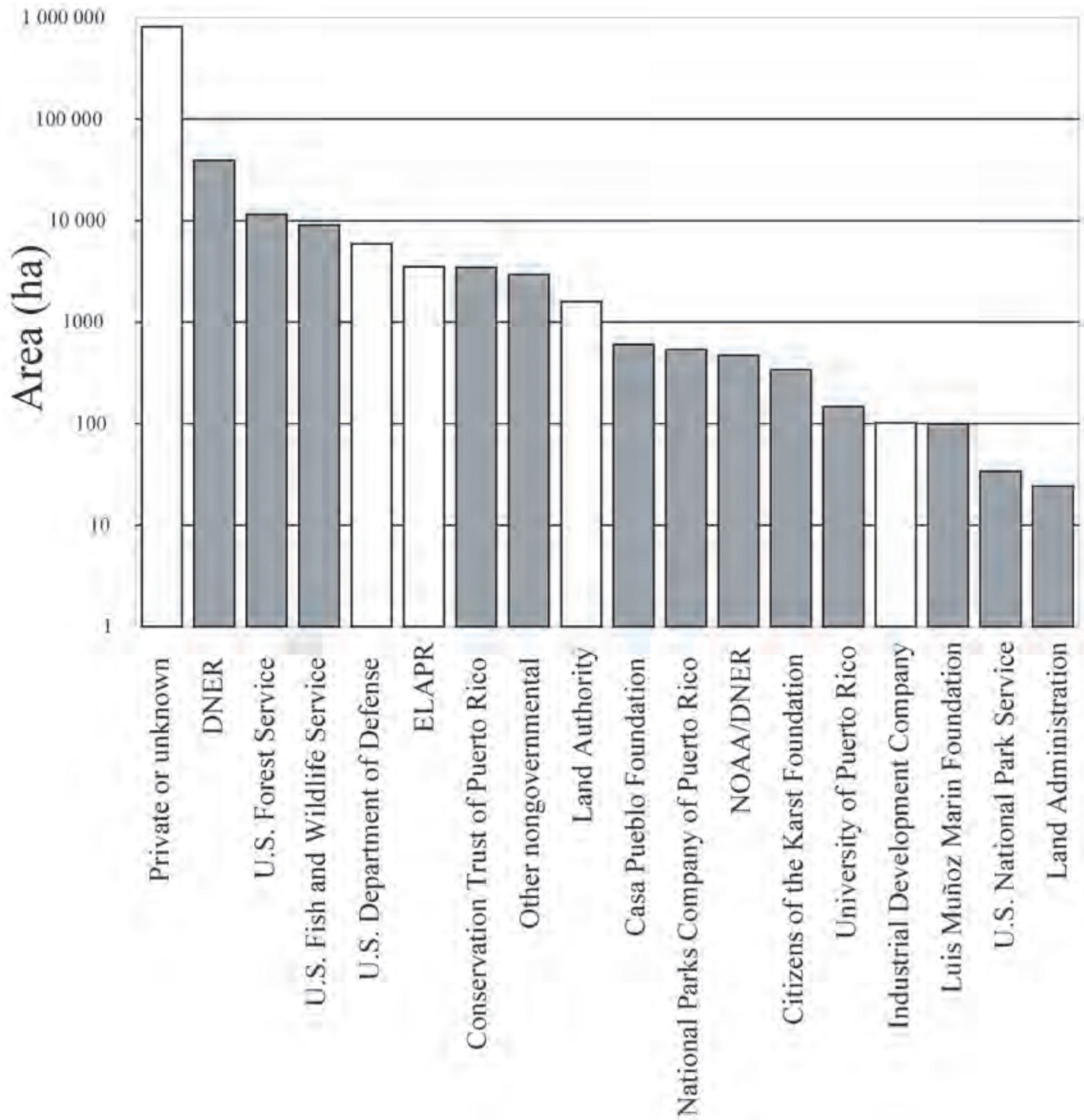


Figure 4. Primary land managers and number of hectares managed in Puerto Rico under GAP management status 1, 2, 3, or 4. Entities with clear bars have no management for conservation (GAP status 4). Entities with dark bars are in part or completely managed for conservation (GAP status 1 through 3). Note the scale is logarithmic. DNER, Puerto Rico Department of Natural and Environmental Resources; ELAPR, Estado Libre Associado de Puerto Rico (the commonwealth government); NOAA, National Oceanic and Atmospheric Administration.

Of the total land area of Puerto Rico, 7.6 percent receives some management for conservation (GAP status 1, 2, or 3) with 7.4 percent of the total land area receiving good management of conservation (GAP status 1 or 2). Fifty-nine percent of the stewardship areas are managed by Commonwealth agencies, 30 percent by Federal agencies, and 11 percent by nongovernmental or private agencies (Figures 5 and 6).

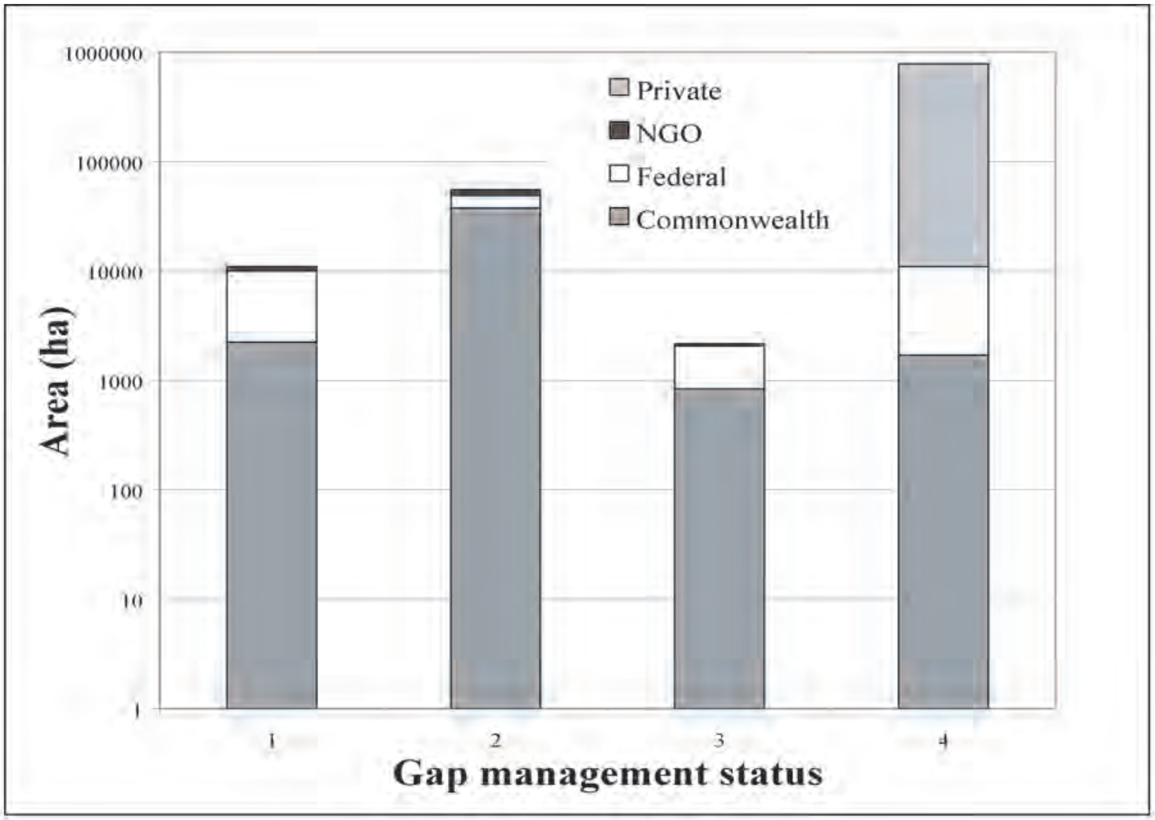


Figure 5. Number of hectares and managing agencies in GAP status 1, 2, 3, and 4 for Puerto Rico. Note scale is logarithmic. NGO, nongovernmental organization.

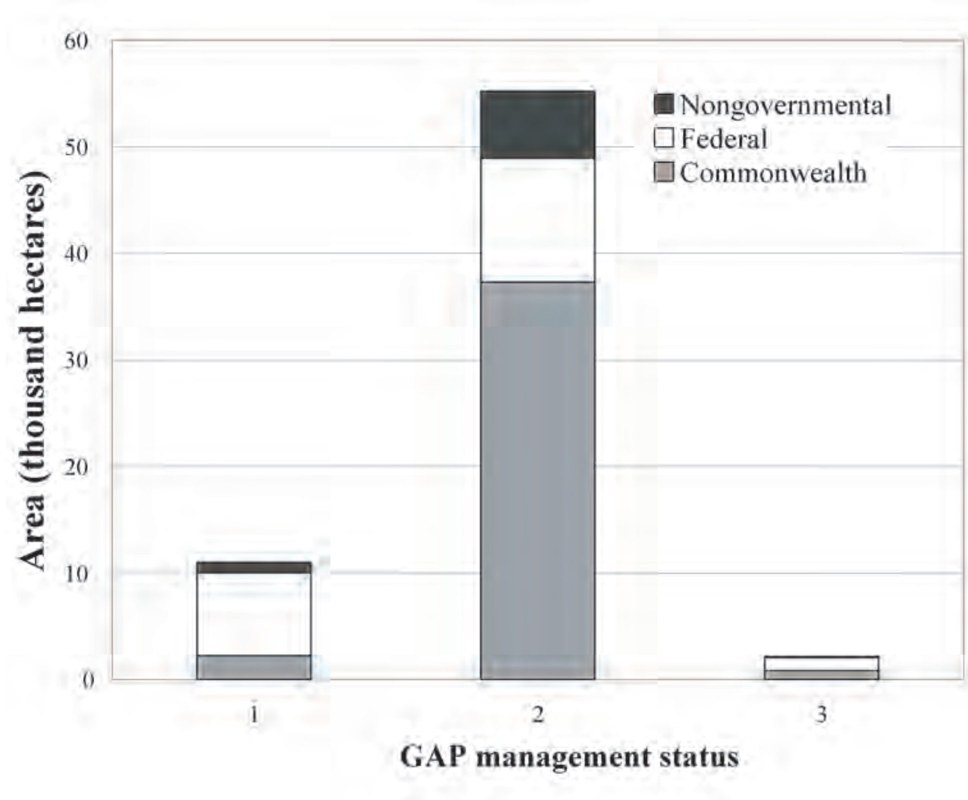


Figure 6. Number of hectares by managing agencies of areas with some management for biodiversity conservation (GAP status 1 through 3).

Gap Analyses–Land Cover

Eight of the 70 land cover classes have less than 1 percent of their area represented in GAP status 1 or 2 conservation areas and cover 43 percent of the island. The conservation areas are primarily subject to human use such as agriculture, housing, and other development. Moist grasslands and pastures cover nearly one-quarter of the island and are primarily active pasture and abandoned agricultural land. Given the resilience of the natural vegetation in Puerto Rico, this land cover type has potential for management for reforestation or as natural grasslands and open space.

Twenty-seven land cover classes have between 1 and 10 percent of their area represented in GAP status 1 or 2 conservation areas. These land cover classes account for 44 percent of the island. They range from an extent of less than 1 percent to more than 6 percent of the island and include a number of young secondary forest and woodland land cover classes, as well as artificial and natural barrens, active and abandoned shade coffee plantations, dry grasslands and pastures, riparian forests, and four mature secondary forest classes.

Four land cover classes have between 10 and 20 percent of their area represented in GAP status 1 or 2 conservation areas. These land cover classes account for 1.7 percent of the island and include two woodland-shrubland classes that typically occur on abandoned agricultural land, dryland riparian forest, and palm plantations.

Fourteen land cover classes have between 20 and 50 percent of their area represented in GAP status 1 or 2 conservation areas and account for 6.1 percent of the island's total area. They include a number of ecologically important areas including beaches and shorelines, mature forests, wetlands, mangrove complexes, and Sierra palm forest.

Seventeen land cover classes are over 50 percent protected under GAP status 1 and 2. They account for 5.1 percent of the island. They include important primary and mature secondary forest types in the Luquillo Mountains, freshwater *Pterocarpus* swamps, forests on serpentine substrates, and a number of dryland habitats unique to Mona Island and the Guánica Biosphere Reserve.

Gap Analyses—Vertebrates

Four species have less than 1 percent of their habitat protected under GAP status 1 or 2. These include two species of gecko common in urban areas, one bird, *Carduelis cucullata*, which is non-native, and *Eleutherodactylus cooki*, the guajón or rock coqui, which has limited habitat none of which is protected.

One recently discovered species not fully included in the PRGAP analysis is the coqui llanero, or plains coqui (*Eleutherodactylus juanariveroii*) (Ríos-López and Thomas 2007). Its habitat is currently unprotected.

Seventy-seven species have 1 percent to less than 10 percent of their habitat protected under GAP status 1 or 2. Many of these unprotected species are widespread although not necessarily common and occur in disturbed habitats. A few, such as the blind snake *Typhlops platycephalus*, have limited habitat (15 percent of the island) and the majority of that habitat (98 percent) is unprotected.

Thirty-two species have 10 percent to less than 20 percent of their habitat protected under GAP status 1 or 2. These species are a mix of those with widespread and those with limited habitat extent.

Forty-three species have 20 percent to less than 50 percent of their habitat protected under GAP status 1 or 2. All these species have habitat extent limited to less than 11 percent of the island. A number of endangered species are in this group, and many are limited to less extensive habitats such as saline and freshwater ponds and wetlands or high mountain areas.

Twenty-one species have at least 50 percent of their predicted habitat protected under GAP status 1 or 2. These include a number of species found only on forest reserves or particular protected satellite islands (Mona and Desecheo). All these species have very limited habitat and none exceed 2 percent of the island.

Forty-seven species are listed as either federally threatened or endangered or given partial status, or are locally listed by the DNER as vulnerable, endangered, critically endangered, or data deficient. The extent of habitat for 70 percent of these species is typically below 5 percent of the island's total area. Eighty-three percent of the species have a habitat extent below 20 percent of the island's total area. *Eleutherodactylus cooki*, the guajón or rock coqui, is the least protected, with no protected habitat. Ten species have less than 10 percent of their habitat protected and 18 species have less than 20 percent of their habitat protected. Five species are found only in reserves with 100 percent of their current distribution protected. Distributions for these species could be expanded outside reserves if suitable habitat is protected or restored and species reintroductions are encouraged.

Conclusions

Puerto Rico is at a crossroads in terms of land use, because much of what was formerly agricultural land is now experiencing more intense, and possibly irreversible, urban development. The current reserve system is well located and protects a number of important habitats and species. However, this system needs to be expanded from 7.6 percent to at least 15 percent of the island's area to be more in line with internationally accepted conservation goals. Our abandoned agricultural land is often a matrix of forested and open green space that serves as habitat for a number of species and buffers older forests, wetlands, riparian areas, and our current reserves. These lands have excellent potential for restoration. Possible restoration plans could include: expanded reserves in the coastal plain, particularly coastal hills and the matrix of wetland and upland vegetation; better regulation of development in the periphery of existing reserves to maintain the integrity of hydrologic systems in wetlands; protection of viable corridors and buffer zones to connect the upland and coastal reserves; development of small and intermediate-sized parks and open space within urban areas that serve as habitat as well as recreational and educational resources for communities; protection of unique habitats such as mountain valleys that shelter the Guajón, *Eleutherodactylus cooki* and the freshwater nonforested wetlands that shelter the Coqui Llanero, *Eleutherodactylus juanariveroii*; and restoration of formerly extensive habitats such as the freshwater swamps or riparian forests of *Pterocarpus officionalis* and the moist lowland Ausubo (*Manilkara bidentata*) forests.

Acknowledgments

This research has been supported by the U.S. Geological Survey Biological Resources Discipline National Gap Program cooperative agreement No. 01HQPG0031 and the U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry (IITF) GIS and Remote Sensing Laboratory. All research at IITF is done in collaboration with the University of Puerto Rico.

References Cited

Gould, W.A., G. González, G. Carrero Rivera. 2006. Structure and composition of vegetation along an elevational gradient in Puerto Rico. *Journal of Vegetation Science* 17:653-664.

Gould, W.A., C. Alarcón, B. Fevold, M.E. Jiménez, S. Martinuzzi, G. Potts, M. Solórzano, E. Ventosa, 2007. *Puerto Rico Gap Analysis Project—Final Report*. U.S. Geological Survey, Moscow, ID and U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry, Río Piedras, PR. 159 p. and 8 appendices.

Gould, W.A., C. Alarcón, B. Fevold, M.E. Jiménez, S. Martinuzzi, G. Potts, M. Quiñones, M. Solórzano, E. Ventosa. 2008a. The Puerto Rico Gap Analysis Project. Volume 1: Land cover, vertebrate species distributions, and land stewardship. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, Río Piedras, PR. 165 p.

Gould, W.A., M.E. Jiménez, B.R. Edwards, G.S. Potts, M. Quiñones, S. Martinuzzi. 2008b. Landscape units of Puerto Rico: Influence of climate, substrate, and topography. Scale 1:260 000. IITF-RMAP-06. U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, Río Piedras, PR.

Gould, W.A., S. Martinuzzi, O.M. Ramos González. 2008c. Developed land cover of Puerto Rico. Scale 1:260 000. IITF-RMAP-10. U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, Río Piedras, PR.

Gould, W.A., S. Martinuzzi, O.M. Ramos González. 2008d. High and low density development in Puerto Rico. Scale 1:260 000. IITF-RMAP-11. U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, Río Piedras, PR.

Landis, J.R.; G.C. Koch, 1977. The measurement of observer agreement for categorical data. *Biometrics* 33:159-174.

Martinuzzi, S., W.A. Gould, and O.M. Ramos González. 2007a. Land development, land use, and urban sprawl in Puerto Rico integrating remote sensing and population census data. *Landscape and Urban Planning* 79:288-297.

Martinuzzi, S., W.A. Gould, O.M. Ramos González, and B. Edwards. 2007b. Development of a landforms model for Puerto Rico and its application for land cover change analysis. *Caribbean Journal of Science* 43:161-171.

Martinuzzi, S., W.A. Gould, and O.M. Ramos González. 2007c. Cloud and cloud-shadow removal in the creation of cloud-free composite Landsat ETM+ imagery in tropical landscapes. IITF-GTR-32.

Martinuzzi S, W.A. Gould, O.M. Ramos González, A. Martinez Robles, P. Calle Maldonado, N. Pérez-Buitrago, and J.J. Fumero Caban. 2008a. Mapping tropical dry forest habitats integrating Landsat NDVI and topographic information. *Rev. Biol. Trop*. 56:625-639.

Martinuzzi S, W.A. Gould, A.E. Lugo, and E. Medina. 2008b. Conversion and Recovery of Puerto Rican Mangroves: 200 Years of Change. *Forest Ecology and Management,* in press.

Martinuzzi S, W.A. Gould, O.M. Ramos González, M. Quiñones, and M.E. Jiménez. 2008c. Urban and rural land use in Puerto Rico. Scale 1:260 000. U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry, Río Piedras, PR.

Parés-Ramos I.K., W.A. Gould, and T.M. Aide. 2008. Agricultural abandonment, suburban growth, and forest expansion in Puerto Rico between 1991 and 2000. *Ecology and Society* 13(2):1. Available from http://www.ecologyandsociety.org/vol13/iss2/art1/

Ríos-López, N., and R. Thomas, 2007. New palustrian *Eleutherodactylus* (Anura: Leptodactylidae) from Puerto Rico. *Zootaxa* 1512:51-64.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, Jr., J. Ulliman, and G. Wright, 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monographs. Onalaska, WI. 123 p.

Vierling, K.T., R.M. Clawges, W.A. Gould, S. Martinuzzi, L.A. Vierling. 2007. Shedding new light on habitat structure. *Frontiers in Ecology* 7:90-98.

Minnesota Gap Analysis Project

Compiled from Final Project Report

Introduction

The Minnesota Gap Analysis Project (WI-GAP) began in 1994 as a part of the Upper Midwest Gap Analysis Project (UMGAP). The Upper Midwest GAP Project was originally initiated by the states of Michigan, Minnesota, and Wisconsin to provide Minnesota's Federal, state, and private land managers with resources that will help them maintain vertebrate species richness within the State.

The objectives were to: (1) map vegetation types; (2) map predicted distribution of terrestrial vertebrates; (3) document occurrence of inadequately represented vegetation types in special management areas; (4) document occurrence of inadequately represented terrestrial vertebrate species in special management areas; and (5) make all information available to resource managers and land stewards in a readily accessible format.

Land Cover

Minnesota has a total area of approximately 217,400 km^2, of which 8.4 percent is water and 91.6 percent is land. Minnesota is the twelfth largest state in the United States and ranks fourth in the nation for amount of water. Individuals and corporations own about three-fourths of the land surface. Governmental units own the remainder. The Federal government owns approximately 1.4 million hectares (7 percent) and the state/county governments own about 3.4 million hectares (17 percent). Federal land ownership is primarily concentrated in the Superior and Chippewa National Forests in northern Minnesota. The State, which owns a large amount of the area covered by water, is the largest landowner in Minnesota. State land ownership is more widely dispersed, but is also more concentrated in the central and northeast areas of the state where numerous State Forests exist (Minnesota DNR 2000).

The Minnesota GAP land cover layer was produced by the Minnesota Department of Natural Resources (MDNR), Division of Forestry, Forest Resource Assessment Unit stationed in Grand Rapids during 1995–2000. This raster dataset is a detailed (1-acre minimum), hierarchically organized vegetation cover map produced by computer classification of combined two-season pairs of early1990s Landsat 4/5 Thematic Mapper (TM) satellite imagery. Landsat Thematic Mapper (TM) scene dates used to create a land cover layer for this project ranged from 1990–95, with the majority being 1991–92. Forty-nine land cover classes were mapped.

Accuracy Assessment

An accuracy assessment of the final statewide land cover layer determined it to be 91 percent accurate at Level 1, 78 percent at Level 2, 65 percent at Level 3, and 58 percent at Level 4. Due to the use of 27 processing units, statewide individual land cover type accuracy numbers were not compiled.

Terrestrial Vertebrate Distributions

Potential distribution maps were developed for 354 terrestrial vertebrate species comprising of 21 amphibians, 28 reptiles, 230 birds, and 75 mammals. This project chose an Ecological Classification System (ECS) to define its primary range extent because it is ecologically based and is part of a nationwide mapping initiative, the National Ecological Unit Hierarchy (Cleland et al. 1997). The Minnesota Department of Natural Resources and the U.S. Forest Service have developed an ECS for ecological mapping and landscape classification in Minnesota following the National Hierarchical Framework of Ecological Units (ECOMAP, written commun., 1993). Ecological land classifications are used to identify, describe, and map progressively smaller areas of land with increasingly uniform ecological features. The system uses associations of biotic and environmental factors, including climate, geology, topography, soils, hydrology, and vegetation. ECS mapping enables resource managers to consider ecological patterns for areas as large as North America or as small as a single timber stand and identify areas with similar management opportunities or constraints relative to that scale. There are eight levels of ECS units in the United States. Six of these levels occur in Minnesota and the first four have been mapped statewide: Province, Section, Subsection, and Land Type Associations.

To address MN-GAP wildlife species informational needs and document literature sources used in this report, information from the MNWRAP database (primarily state occurrence and range extent) was merged with existing framework (i.e. forms, queries, reports, etc.) and data from the Great Plains GAP effort. This Microsoft Access database (MN-GAP Wild) thereby became the data center for all wildlife species information (i.e. range extent, habitat relationships, literature sources, etc.) needed for this report.

ECS Subsection-based range extent maps were developed for all permanent residents that occupy Minnesota year-round, and regular residents were acceptable breeding, nesting, or migrant records exist during at least eight years from 1989 to 1999. Casual/accidental species were also a part of this mapping effort if they had a state status of endangered, threatened, furbearer, or big game species. They were considered casual/accidental if an acceptable record existed during seven or less years from 1989 to 1999.

EMAP hexagon-based range extent maps were created using ECS Subsection-based range extent efforts described above. The conversion from ECS Subsection to the hexagon standard was accomplished by converting the EPA hexagon coverage projected in Lambert Azimuthal Equal Area, re-projecting to the DNR standard, UTM Zone 15N, NAD 83 meters, selecting hexagons that were within Minnesota and converting the new coverage to a new shapefile in ArcView. This shapefile was intersected with Minnesota's ECS Subsection coverage. Each hexagon was attributed to the ECS Subsection in which it fell. Hexagons that overlay two Subsections were attributed to the Subsection in which 50 percent or more of the hexagon's area was located. For a hexagon with three or more Subsections attributed to it, our best professional judgment was used, on an individual basis. Hexagons were assigned a value of "P" (Present) if the species met MN-GAP criteria to for inclusion in that hexagon or "a" (absent) if the species was absent in that hexagon.

Species Richness

Total vertebrate wildlife (n=354) species richness by ECS Subsection ranged from 160 to 250 with a mean of 215±21. The highest diversity of vertebrate wildlife (≥228) is located across east-central to central to northwest Minnesota; lowest (≤206) are located in the southeast, southwest, western and northeastern Minnesota.

Land Stewardship

The Minnesota GAP Stewardship layer was created in two steps. Initial development was handled by the MNDNR's Division of Forestry, Forest Resource Assessment Unit, and completed in 1998. With the start of wildlife species modeling efforts in 2004, it became apparent that the initial land stewardship layer/dataset were lacking in adequate stewardship detail for water areas and there were numerous errors/omissions in land stewardship classes. To adequately address these concerns, the MNDNR Division of Fish and Wildlife undertook an edit of this initial layer/dataset to correct these concerns.

Excluding Lake Superior, Minnesota's total surface area consists of 219,342 km^2. Of this total surface area, 71.3 percent is private, 26.8 percent is public (Federal, State, or county), 1.7 percent is Tribal and 0.1 percent was not. Private lands are primarily concentrated in the agriculture/grassland dominated portions of the state (south and west) while public lands are primarily concentrated in the forested, northern one third of the state. Those public lands that do exist in the south and west areas of the State are scattered and consist primarily of State Wildlife Management Areas, Federal Waterfowl Production Areas, National Wildlife Refuges, County/Regional Parks, and other similar areas. Public lands in the northern areas of the State are in larger blocks and include State Forests, National Forests, County Forests, Boundary Waters Wilderness Canoe Area, Voyagers National Park, and other similar areas. Tribal lands are scattered within the various Indian Reservation and Ceded Territories within Minnesota, but are also primarily concentrated in the north.

Approximately 2.6 percent of Minnesota is within areas designated as management status 1. Most of these lands are public lands in northern Minnesota, with the Boundary Waters Wilderness Canoe Area (3,886 km^2) and Voyageurs National Park (788 km^2) being the two largest contributors to this management status category. Other land units and related land stewards include State Scientific and Natural Areas (Minnesota DNR) and preserves managed by private, non-profit organizations.

Approximately 5.1 percent of Minnesota is within areas designated as management status 2. Most of these lands are public lands such as Forest Service National Forests (8,223 km^2), U.S. Fish and Wildlife Service National Wildlife Refuges and Waterfowl Production Areas (1,743 km^2) and MDNR State Parks (947 km^2). Other land stewards and related units include County and Regional Parks as well as reservoir lands managed by the U.S. Army Corp of Engineers.

Approximately 20.8 percent of Minnesota falls within areas designated as management status 3. Most of these lands are public lands administered by the MDNR (21,815 km^2 in State Forests, other Forestry administered lands, and State Wildlife Management Areas) or various Counties (12,274 km^2 in County Forest or county tax-forfeited). Another major, although temporary, contributor to this category were those private farmlands that were enrolled in Conservation Reserve Program practices (e.g. grassland or tree plantings) that qualified these lands to be included in this management status. Other lands stewards and related units include the Camp Ripley Military Reservation (213 km^2, Minnesota Department of Military Affairs) and various Tribal and related Bureau of Indian Affairs land (3,660 and 691 km^2, respectively).

Approximately 71.4 percent of Minnesota is within areas designated as management status 4. The vast majority of these lands are private lands, primarily farmland in the southern and western areas of the state and corporate forestlands in the north. Management status 4 is also the default code used when adequate information was not available to determine a 1, 2, or 3 management status.

GAP Analysis—Land Cover

A summary of percentage of habitat by wildlife species group and major land stewardship category is listed in Table 1.

GAP Analysis—Vertebrates

Examples from Table 2 include 9.4 percent of amphibian habitat on Federal land, and 62.7 percent is on Private land.

Table 1. Percentage of natural land cover types in management status 1 and 2 for Minnesota.

Land cover type	Percentage of land cover type				
	Less than 1 percent	1 to less than 10 percent	10 to less than 20 percent	20 to less than 50 percent	Greater than 50 percent
Non-Vegetated					
Mixed Developed		1.4			
High Intensity Urban		1.0			
Low Intensity Urban		1.4			
Transportation		1.4			
Barren		4.7			
Grassland					
Cropland	0.6				
Grassland		3.4			
Prairie				21.7	
Shrubland					
Upland Shrub			14.0		
Lowland Deciduous Shrub		9.9			
Lowland Evergreen Shrub			12.7		
Aquatic Environments					
Water (does not include Lake Superior)			14.0		
Floating Aquatic		7.8			
Sedge Meadow		8.3			
Broadleaf Sedge/Cattail			12.8		
Upland Conifer Forest					
Jack Pine				44.4	
Red/White Pine					55.7
Red Pine				25.2	
White Pine/mix				25.6	
Balsam Fir/mix				32.9	
White Spruce			14.4		
Upland Black Spruce					56.3
Upland Northern White-Cedar				24.6	
Red-cedar		3.4			
Upland Conifer			15.5		
Lowland Conifer Forest					
Lowland Black Spruce			19.0		
Stagnant Black Spruce				26.5	
Tamarack		6.7			
Stagnant Tamarack		6.7			
Lowland Northern White-Cedar			11.1		
Stagnant Northern White-Cedar			16.5		
Stagnant Conifer			15.9		
Upland Deciduous Forest					
Aspen/White Birch mix				20.1	
White/Red Oak		2.4			
Northern Pin Oak		3.8			
Red Oak		3.9			
Northern Pin Oak		5.5			
Maple/Basswood mix			11.4		
Upland Diciduous mix			15.0		
Lowland Deciduous Forest					
Black Ash		8.0			
Silver Maple				30.1	
Cottonwood		4.6			
Lowland Deciduous			10.8		
Mixed Forest					
Upland Confer-Deciduous mix			13.8		
Jack Pine-Deciduous mix		9.0			
Red/White Pine-Deciduous mix					64.6
Spruce/Fir-Deciduous mix					70.1
Red-cedar-Deciduous mix		1.3			
Lowland Conifer-Deciduous mix				23.4	

Table 2. Vertebrate wildlife habitat (percent) by major land stewardship category in Minnesota.

Taxonomic group	Federal	State	County	Other public	Tribal	Private conservancy	Private industrial	Private	Unknown
Amphibians	9.4	15.7	7.5	0.1	1.6	0.2	2.8	62.7	0.1
Reptiles	7.6	12.5	5.4	0.1	0.8	0.2	2.1	71.1	0.1
Birds – forest	13.6	18.9	11.3	0.1	1.8	0.1	4.2	49.9	0.1
Birds – open	2.6	10.8	2.2	0.1	0.5	0.2	0.9	82.6	0.0
Birds – water	7.7	12.8	4.9	0.1	2.4	0.2	1.8	70.1	0.1
Mammals	8.1	15.3	6.9	0.1	1.4	0.2	2.6	65.4	0.1

Data Availability

MN-GAP project data will be archived at the Wildlife GIS Program, Division of Fish and Wildlife, Minnesota Department of Natural Resources. We anticipate serving this data through the Minnesota Department of Natural Resources GIS Data Deli <http://deli.dnr.state.mn.us/about.html>, an internet-based spatial data acquisition site.

References Cited

Cleland, D.T., P.E. Avers, W.H. McNab, M.E. Jensen, R.G. Bailey, T. King, and W.E. Russell. 1997. National Hierarchical Framework of Ecological Units: Published in Boyce, M.S., and A. Haney, eds. 1997. Ecosystem Management Applications for Sustainable Forest and Wildlife Resources. Yale University Press, New Haven, CT., p. 181-200.

Minnesota Department of Natural Resources. 2000. Public land and mineral ownership in Minnesota: Minnesota Department of Natural Resources, Division of Lands and Minerals. 34 p.

Ohio Gap Analysis Project

Compiled from Final Project Report

Introduction

The Ohio Gap Analysis Project (OH-GAP) is a regional assessment of the predicted distribution and current conservation status of native wildlife species and natural land cover types in the state. These coarse filter assessments facilitate conservation efforts by proactively identifying areas of potentially high biodiversity that occur outside protected area boundaries as “gaps” in the existing network of conservation lands. This is accomplished through the following five primary objectives, as suggested by the National Gap Analysis Program (GAP): (1) map and describe actual land cover; (2) map predicted terrestrial vertebrate species distributions based on species habitat affinities; (3) document species and land cover types represented in areas managed for the long-term maintenance of biodiversity; (4) provide the compiled information and analysis to the public and those entities charged with land use, research, policy, planning, and management; and (5) build institutional cooperation in the application of this information to state and regional management activities. GAP projects use a data driven approach applying GIS, remote sensing, and other advanced technologies to identify gaps in the representation of biological diversity in areas managed exclusively or primarily for the long-term maintenance of native species and natural ecosystems. OH-GAP was conducted for the entire state of Ohio, encompassing approximately 110,000 km^2 and portions of the Huron-Erie Lake Plain, Eastern Corn Belt Plain, Eastern Ontario Lake Plain, Interior Plateau, and Western Allegheny Plateau ecoregions.

GAP is conducted as state-level projects that are coordinated by the U.S Geological Survey. Cooperative efforts among regional, state, and federal agencies, as well as private groups are encouraged. OH-GAP was conducted in accordance with national GAP standards in cooperation with the U.S. Geological Survey Water and Biological Resources Divisions, The Ohio State University, and the Ohio Division of Wildlife, taking advantage of the expert knowledge and background of many individuals. The Ohio State University Center for Mapping (CFM) was responsible for the production of the land cover map. Animal modeling was conducted through the Department of Evolution, Ecology and Organismal Biology (EEOB) and the Ohio Ecological Services Field Office of the U.S. Fish and Wildlife Service. Mapping of conservation land stewardship for the state was conducted by the U.S. Geological Survey Water Resource Division. Financial support was provided by Ohio Division of Wildlife.

A Biodiversity Overview of Ohio

Landscape patterns of biodiversity are the result of complex interactions, now and in the past, among the geology, climate, and human use of Ohio’s natural resources. Ohio’s border encompasses a wide variety of landscapes within two major landforms: the Central Lowlands and the Appalachian Plateau. Approximately two-thirds of the state’s 44,825 mi^2 of land area makes up the glaciated region, bearing the fingerprint of the last great Ice Age that ended approximately 10,000 years ago. This resulted in a relatively youthful plain with flat to rolling topography covered by glacial till. In contrast, the southeastern hill country remains a rugged, mature landscape dissected by river valleys. These are broken down into five distinct physiographic regions defined by soil type, vegetation, and topography: (1) Huron/Erie Lake Plains, (2) Eastern Corn Belt Plain, (3) Erie/Ontario Lake Plain, (4) Interior Plateau, and
(5) Western Allegheny Plateau.

Lying in the humid continental zone, Ohio experiences a temperate climate with abundant and evenly distributed precipitation. Variations in temperature produce distinct seasonal differences. These variations are the result of topography and the influence of Lake Erie, which exerts a major influence on weather and climate conditions. In the winter, temperatures usually approach or slightly exceed 32°F, but periods of cold weather frequently occur, when temperatures can drop below zero. Summer temperatures normally reach their peak during July, with mean daily maximums ranging from 80–82°F in the northeastern counties to 88°F in southern Ohio.

Ohio receives a moderate amount of total precipitation annually, which varies from 29–33 inches in northwestern counties near Lake Erie to 39–45 inches in northeastern and southern Ohio. Snowfall ranges from more than 50 inches in the northeast to less than 20 inches in south-central Ohio along the Ohio River. The “lake-effect” contributes to large accumulations of snow in the snowbelt, which is east of Cleveland, averaging in excess of 100 inches annually in Geauga County. The overall pattern of annual precipitation reveals that the southeastern Ohio receives more than the northwestern Ohio.

The earliest human inhabitants of what is now Ohio were Paleo-Indian peoples, who lived in the area as early as 13,000 B.C. Later, the Mound Builders, the Adena, and the Hopewell cultures, occupied Ohio from about 100 B.C. to A.D. 500. Ohio was populated by successive groups of Native Americans until European settlement. Population pressure from expanding European colonies on the Atlantic coast compelled several groups to relocate to the Ohio country by 1730. Ohio's chief tribes prior to European exploration were the Wyandot and Ottawa in the northwest, the Erie in the northeast; the Shawnee, ranging north across Ohio; the Miami in the southwest; and the Delaware in the southeast. When the first Europeans began to arrive to the Ohio Country, Native Americans participated in the fur trade.

In the early 1700s, Ohio's pristine environment was described as a predominantly forested landscape with scattered openings, numerous wetlands, and an abundance of wildlife. Ohio's rich natural history and resources drew settlers to the region and make the state economically productive today. However, human settlement has left its mark throughout the state by the clearing, draining, and reshaping of the land to provide for agricultural, industry, and housing. Historically, 95 percent of Ohio's landscape was covered by hardwood forests. The remainder of the state included 5 million acres of various wetland types (bogs, fens, and marshes). The Great Black Swamp in northwestern Ohio stretched 120 miles long and 30 to 40 miles wide. Until it was drained by the end of the 19th century, it was a barrier to early east-west travel and settlement. In addition, it is estimated that approximately 1,000 mi^2 of prairies occupied large forest openings, predominately in the western half of the state. Today, Ohio's landscape is a mosaic of agricultural, suburban and urban areas, and fragmented woodlands. Less than 10 percent of Ohio's original wetlands remain, and original prairie habitat has been lost as a functional ecosystem.

Ohio once was a land of vast mature hardwood forests and wetlands, and coastal beaches and cliff communities, interspersed with prairie and grasslands. Ohio's natural resources provided habitat for numerous species of fish and wildlife. These resources were the foundation for Ohio's current prosperity. The Ohio Gap Analysis project can assist in proactive efforts to protect biological diversity by identifying critical areas where habitat can be preserved or restored in order to ensure that these components remain a part of Ohio's precious natural heritage.

Land Cover Classification and Mapping

The OH-GAP land cover map contains 37 categories, consisting of natural land cover types and human features. Ohio's land cover was mapped to the ecological system (multiple Alliance) level. The alliance level represents vegetation based on species composition of the dominant vegetation type. This map was produced using Landsat Thematic Mapper (TM) satellite imagery at a 30 by 30 meter resolution acquired between 1999–2002. Nine scenes were required to cover the land area of Ohio. In addition, land cover classification efforts incorporated georeferenced digital color aerial photographs, vegetation field samples to validate and ground-truth the photointerpretation, and image processing techniques (supervised classification) to classify all satellite pixels covering the state.

Predicted Vertebrate Species Distributions

The OH-GAP vertebrate species modeling effort produced predicted range and predicted habitat maps for 38 amphibians, 42 reptiles, 176 birds, and 54 mammals that breed in the state. General range maps were produced using existing location data and published range maps. These draft range maps were reviewed by experts who had the opportunity to provide an update based on the most recent occurrence data and their expert knowledge. Predicted habitat maps were created using wildlife habitat relation models for each species. Each model relates the habitat associations of the species to GAP land cover classes and other ancillary datasets. The predicted habitat map for each species was clipped with the general range map, resulting in a spatially explicit map of predicted habitat for each species within its range.

Species richness measured by the number of species present varied geographically for each of the four major taxonomic groups. Amphibian species richness was highest in the central to south central part of the state. Reptile species richness was highest in the south central part of the state. Mammal species richness was highest in the north central part of the state. Bird species richness was highest in the southwestof the state.

Land Stewardship

The land stewardship layer represents the permanence and intent of the management based on information in management plans or agency mandates for specific land units. Status 1 and 2 represent permanently protected lands that are managed for biological diversity, with Status 1 representing the highest level of protection. Status 3 lands are those lands under a management plan that prevents conversion to non-natural cover types but allows either intensive local or extensive resource extraction. Status 4 lands are not managed for biodiversity or are not under a management plan.

The analysis of land stewardship showed that a small proportion of the State is under any sort of protection for biodiversity. In fact, 3.7 percent of the State was under management; and of that, 29.3 percent was federally managed and approximately 50 percent was managed by State agencies.

Lands with high protection for biodiversity (GAP Status 1 or 2) comprised only 0.7 percent of Ohio's land. State Management, primarily the Ohio Department of Natural Resources (ODNR) (43.4 percent) along with The Nature Conservancy (30.3 percent), accounted for the majority of the status 1 and 2 lands. Status 3 lands were managed primarily by ODNR (54.5 percent).

Gap Analysis—Land Cover

Six of the 59 natural cover types in the state have less than 1 percent of their distribution on Status 1 and 2 lands.

Status 1 lands in Ohio are mainly comprised of small parcels dispersed across the state.There is a concentration of Status 1 lands along the Lake Erie coast in Ottawa and Erie Counties, another in Fairfield and Hocking Counties, and a third in Adams and Scioto Counties. In Fairfield and Hocking Counties, Status 1 lands include Central Ohio Metro parks and State Nature Preserves. An example of these, the Clear Creek Valley, is one of the most pristine and secluded natural areas in Central Ohio. Variations of land surfaces, soils and climates have produced habitats that hold more than 800 plant species and 150 species of birds, many of them rare. In Adams and Scioto Counties, Status 1 lands include The Nature Conservancy's "Edge of Appalachia," Shawnee State Forest. This area is one of the most biologically diverse collections of natural systems in the Midwestern United States.

Gap Analysis—Vertebrates

Information System (GIS) analysis of stewardship status for terrestrial vertebrates showed 44 of 177 (24.8 percent) birds, 19 of 54 (35.1 percent) mammals, 12 of 39 (30.7 percent) reptiles, and 3 of 37 (30.7 percent) amphibians have less than 1 percent of their predicted distribution (Table 1) in status 1 or 2 lands.

Only 3 of 177 (3.4 percent) birds, 0 mammals, 1 reptile (2.5 percent), and 0 amphibians have over 10 percent of their predicted distribution in status 1 or 2 lands.

Table 1. Summary of species at different thresholds of biodiversity management in Ohio.

[Biodiversity management is defined as the percent of predicted distribution on GAP Status 1 and 2 lands divided by the total predicted distribution. **Abbreviations:** <, less than; >, more than]

Taxa	Less than 1 percent	1–2 percent	2–5 percent	5–10 percent	Greater than 10 percent	Total number of species
Amphibians	3	19	12	3	0	37
Birds	44	78	46	6	3	177
Mammals	19	25	10	0	0	54
Reptiles	12	13	12	1	1	39
All Species	78	135	80	10	4	307

Vermont and New Hampshire Gap Analysis Project

Compiled from Final Project Report

Introduction

The Vermont–New Hampshire Gap Analysis Project (VT/NH-GAP) began in 1991 as part of what was intended to be a Gap Analysis of New England. The New England project was subsequently divided into three projects–the current project, and one each for Maine and Southern New England (Massachusetts, Connecticut, and Rhode Island)– with each project assuming some regional responsibility for aspects of the other two.

Land Cover

We first developed a land cover map by classifying Landsat Thematic Mapper satellite imagery into general land cover types and incorporating ancillary data (e.g., National Wetlands Inventory maps) where possible. The complete land cover map for VT/NH-GAP features eight general land cover types. The VT/NH-GAP classification uses broad land cover types that reflect modeling requirements, heterogeneity of our study area, and the cost and difficulty of accurately mapping this heterogeneity. A forest shaped largely by extensive human disturbance covered the majority of VT/NH-GAP in the early 1990s. Rather than attempting to map numerous forest types distributed at a very fine scale we classified forest into three broad types. Similarly, many non-forested upland types were lumped together in a class containing many human-altered cover types that change quickly under the influence of natural forces (e.g., succession) or human activity (e.g., agricultural rotation). The eight types in our final classification should crosswalk easily with systems used by other Northeast Gap Analysis projects and with the National Vegetation Classifiaction System (NVCS).

An additional four-class map was developed for use with animals specializing on habitats restricted to the Atlantic coast of New Hampshire. Comparison of mapped cover types with truth data acquired from aerial videography yielded an assessed accuracy of 80.4 percent.

Results

Including forested wetlands, forest cover types accounted for 75.4 percent of Vermont and 82.6 percent of New Hampshire (Table 1). Deciduous forest covers one-half of Vermont and nearly one-half of New Hampshire. Water totals include a small amount of coastal water in New Hampshire, and part of Lake Champlain in Vermont. Additionally, U.S. Geological Survey (USGS) wetlands data were used to add information for coastal habitat types in New Hampshire. Estuarine emergent and shrub wetlands accounted for 28.5 km^2 of non-forested wetlands in coastal New Hampshire; brackish forested wetlands totaled 3.3 km^2. A coastal beach cover type amounting to 1.1 km^2 was substituted, according to habitat modeling needs, for mainly developed/barren but also non-forested and water/wetland cover types along the coast. The USGS data were also used to delineate Isles of Shoals, a cluster of off-shore islands in the Atlantic Ocean. A separate analysis using elevation and distance to roads indicated that 0.5 percent of the developed/barren cover type could be distinguished as remote rock outcrops or similar undeveloped barren cover.

Table 1. Land cover types mapped, their area mapped in the state in square kilometers, and the percent of the states' total area represented by the mapped type.

[Multiply square kilometers by 100 for hectares or 270 for acres]

Cover type	Vermont		New Hampshire	
	Area	Percent	Area	Percent
Non-forested upland	4,690.7	18.8	2,384.2	9.9
Developed/barren	91.2	0.4	306.5	1.3
Coniferous forest	1,677	6.7	2,764.2	11.5
Deciduous forest	12,624.9	50.6	10,688.7	44.5
Mixed forest	3,904.8	15.7	5,250.1	21.8
Water	948.9	3.8	803	3.3
Non-forested wetland	397.2	1.6	700.1	2.9
Forested wetland	599	2.4	1,148.3	4.8
Total	24,933.8	100	24,045	100

Accuracy Assessment

Overall accuracy for the superclass map is 94.0 percent. Overall map accuracy decreased to 80.4 percent when three forest classes are considered separately.

Terrestrial Vertebrate Distributions

Species occurrence records supported the existence of 297 native species in VT–NH at the initiation of the project—196 birds, 56 mammals, 23 amphibians, and 22 reptiles. We created range maps by attributing species to subsection polygons of the National Hierarchical Framework of Ecological Units (ECOMAP 1993). Attributions were made on the basis of occurrence records from species atlases, the Breeding Bird Survey, and state databases. Experts checked and occasionally corrected our draft range maps.

Wildlife habitat relationship models necessary to predict distributions were compiled from an existing database for New and modified with information from further literature review, personal experience, and expert opinion. Elevation, proximity to water, and other ancillary data layers improved predictions for many species. Overall accuracy was 80.5 percent across all sites and taxonomic groups. Accuracy across taxa at individual sites ranged from 70.6 percent at Missisquoi National Wildlife Refuge to 86.0 percent at White Mountain National Forest. Taxonomic group accuracies were reasonably close to 80 percent except for reptiles (52.6 percent).

Land Stewardship

We developed a stewardship lands map by adapting an existing data layer for New Hampshire for use with a cooperative mapping project designed to produce Vermont stewardship data specifically for Gap Analysis. Source data for these projects were generally 1:24,000 scale or better. Stewardship parcels were attributed with owner, managing entity, and management status, among many other attributes. One of four GAP management status codes were assigned to each parcel based on permanency of protection from conversion and degree of disturbance or extractive uses allowed. Status 1 and 2 lands represented the highest levels of protection, and these lands were used for the gap analysis overlays.

Gap Analysis—Land Cover

Federal agencies own the majority of New Hampshire's stewardship lands; U.S. Forest Service holds 60.5 percent. Of the remainder, State government owns 18 percent, and private entities hold 13 percent. Half of private holdings are controlled by the Society of the Protection of New Hampshire Forests (SPNHF). Almost 40 percent of New Hampshire's conserved land falls under management categories 1 and 2. Forest Service tracts account for 84 percent of lands receiving this high degree of protection. State government is the next closest contributor with slightly less than 10 percent of category 1 and 2 lands. Most State holdings in these categories are State Forests or State Parks including four parcels larger than 20 km^2.

Vermont's largest stewardship tracts are concentrated along the spine of the Green Mountains. The arrangement of parcels in this mountainous region provides opportunities for north-south linkages. The narrow Appalachian Trail corridor connects Green Mountain lands with those of the White Mountain National Forest, which nearly spans New Hampshire. Vermont's Northeast Kingdom and the southwestern hills of New Hampshire also have concentrations of large parcels that could provide connectivity among protected lands. Stewardship parcels are few and sparse in lowland areas of both states where proportionately more forest cover has been lost and the pace of development is high. Establishing connectivity in these regions will be a substantial challenge unless more land can be conserved.

Less than 10 percent of New Hampshire and only 3.1 percent of Vermont were categorized as management status 1 or 2. Federal owners accounted for the majority of stewardship lands in New Hampshire, whereas Vermont's stewardship parcels were more evenly distributed among federal, state, municipal, and private owners. We overlaid predicted distributions with stewardship lands to determine level of protection.

Gap Analysis—Vertebrates

Species were identified as gap species if less than 1 percent of their predicted habitat occurred on status 1 and 2 lands. We expanded this criterion slightly by also including species having less than 50 km^2 of habitat in status 1 and 2 lands. In both states, a vast majority of species had less than 10 percent of their predicted habitat represented on status 1 and 2 lands. In Vermont, 15.8 percent of birds and approximately 10 percent of amphibians and reptiles were identified as gap species. In New Hampshire nearly 10 percent of amphibians and over 20 percent of bird species were underrepresented. Judging from the distribution of listed species and other species of known conservation need, the criteria used to identify gap species performed reasonably well but failed to correctly prioritize some species. A tendency of habitat models to either over- or under-predict habitat for certain species might account for some of the perceived discrepancies. Better habitat and species occurrence data would likely improve results of similar efforts in the future.

Despite a scarcity of lands in management status 1 and 2, both Vermont and New Hampshire have substantial areas in management status 3. These lands already have a reasonable level of protection and provide excellent habitat for many species. Efforts to conserve habitat for certain species might focus on potential management changes on less-protected stewardship lands.

References Cited

ECOMAP. 1993. National hierarchical framework of ecological units. Unpublished administrative paper. Washington, DC: U.S. Department of Agriculture, Forest Service. 20 p. Ecoregions of the United States [map, rev. ed.]. Robert G. Bailey, cartog. 1994. Washington, DC: U.S. Department of Agriculture, Forest Service. Scale 1:7,500,000; colored.

Illinois Gap Analysis Project

Compiled from Final Project Report

Introduction

Illinois is known as the “Prairie State,” a part of the vast grassland in central North America that once stretched from Indiana west to Nebraska, south to Texas and north to the Canadian Provinces of Saskatchewan and Alberta with outlying areas in Ohio and Arkansas. The landscape in Illinois once consisted of approximately 21.6 million acres of prairie and 13.8 million acres of forest (Iverson et al. 1989). Today, Illinois is dominated by agriculture.

Our objectives were to: (1) map vegetation types; (2) map predicted distribution of terrestrial vertebrates; (3) document occurrence of inadequately represented vegetation types in special management areas; (4) document occurrence of inadequately represented terrestrial vertebrate species in special management areas; and (5) make all information available to resource managers and land stewards in a readily accessible format.

Land Cover

The land cover classification developed for the Illinois Gap Analysis Project represents the third statewide land cover classification derived from Landsat satellite imagery. The first classification was developed by the Department of Geography at the University of Illinois at Urbana-Champaign from 1978–1981. The second and third classifications were developed by the Illinois Department of Natural Resources (IDNR), Illinois Natural History Survey (INHS), and Illinois State Geological Survey (ISGS) from 1991–1995 and 1999–2000, respectively.

The Land Cover of Illinois 1999–2000 (LCOI 99–00) was developed as part of the Illinois Interagency Landscape Classification Project (IILCP), a cooperative, interagency initiative that began in late 1999 between the U. S. Department of Agriculture National Agricultural Statistics Service (USDA–NASS), the Illinois Department of Agriculture (IDA), and the Illinois Department of Natural Resources (IDNR) aimed at providing statewide land cover information on a recurring basis. The LCOI 99–00 was the primary product of the IILCP initiative and was the result of integrating the directed supervised classification of agricultural lands from the USDA–NASS Cropland Data Layer (CDL) Program (USDA–NASS 2000) and the unsupervised training and maximum likelihood classification of non-agricultural lands. The primary source information for the computer classification was Landsat 5 TM and Landsat 7 ETM+ satellite imagery acquired for three dates (triplicates) during the spring, summer, and fall seasons of 1999 and 2000. Twenty-three classes were delineated. The IILCP established a website in 2003 to provide information pertaining to interactive land cover statistical information on a state, county, and watershed basis, and also provide free download access to several data products developed during the project (IDA 2003). In addition, Illinois Land Cover, a 1:500,000 scale map, was published in June 2005 and has been made available by the Illinois State Geological Survey (ISGS) at <http://www.isgs.illinois.edu/nsdihome/webdocs/landcover/index.html>, and by the Illinois Natural History Survey (INHS) at <http://www.inhs.uiuc.edu/chf/pub/educational_mat.php>.

The IILCP initiative also produced the Illinois GAP land cover classification. The Illinois GAP land cover classification was developed to meet the requirements of Gap Analysis and fulfill the need for a detailed classification of land cover at the vegetation alliance level. A detailed Gap Analysis classification of the vegetated areas of the state was completed using similar methodology to the IILCP, with the notable exception of methodological differences in forested and urbanized areas as required for GAP. The final GAP classification can be aggregated to the IILCP classification, as well as a modified Anderson Level I classification (Anderson et al. 1972). Assessment of the classification accuracy was conducted using independent ground verification samples and standard accuracy assessment analysis and reporting procedures.

Results

The IL-GAP land cover classification distinguishes 29 land cover types; including 7 agriculture cover types, 5 forest cover types, 5 urban or built-up land cover types, 8 wetland types and 4 other categories (Table 1).

Agricultural land represents 11,158,349.61 hectares (ha) or 76.5 percent of the Illinois landscape. The most extensive cover types are comprised of monoculture row crops, principally corn and soybeans, which are typically rotated annually. Together, these two crop types account for 8,876,246.4 ha or 60.8 percent of Illinois' surface area. Because Illinois is dominated by agricultural lands, it was important to separate the agriculture cover categories by specific land use type.

Rural grassland ranks second in surface area with 1,697,106.64 ha, comprising 11.6 percent of Illinois' surface area. This category includes permanent pastureland, roadsides and fence lines, railroad right-of-ways, waterways, prairies, and other grassland cover situated in rural areas.

Five upland forest categories total 11.4 percent of the total surface area. Dry-mesic upland forest is the most common forest type in Illinois, representing 981,992.2 ha or 6.7 percent of the total surface area.

Urban or built-up land makes up the next largest category, occupying a total of 944,843.10 ha or 6.5 percent of the total surface area. Chicago is the largest urbanized area in Illinois and accounts for more than one-half of the total urban land cover.

Eight wetland categories total 555,245.89 ha or 3.8 percent of the land area, including woody and herbaceous types. Surface water makes up 1.7 percent of the total area for a total of 266,631.11 ha. The remaining three categories, barren and exposed land, clouds, and cloud shadows, comprise 0.1 percent of the total land cover classification.

Accuracy Assessment

Accuracy results for the Illinois GAP land cover classification are summarized in three tables in this section. The appropriate accuracy statistic to use depends on the intended use of the classification. Using the modified Anderson Level I of generalization, overall accuracy is 91 percent with FIA data and 96 percent without FIA data. The IILCP LCOI 99–00 Level accuracy is 81 percent and 84 percent, respectively. Finally, the Natural Community Level

Table 1. Illinois Gap Analysis Project land cover codes and cover types.

Land cover code	Land cover type
	Agricultural
11	Corn
12	Soybeans
13	Winter wheat
14	Other small grains and hay
15	Winter wheat/soybeans (double-cropped)
16	Other agriculture
17	Rural grassland
	Forested
22	Dry upland forest
23	Dry-mesic upland forest
24	Mesic upland forest
25	Partial canopy/savanna upland forest
26	Coniferous forest
	Urban and built-up
31	High density urban
32	Low/medium density urban
33	Medium density urban (TM scene 2331 only)
34	Low density urban (TM scene 2331 only)
35	Urban open space
	Wetland
41	Shallow marsh/wet meadow
42	Deep marsh
43	Seasonally/temporarily flooded wetland
45	Mesic floodplain forest
46	Wet-mesic floodplain forest
47	Wet floodplain forest
48	Swamp
49	Shallow water wetland
	Other
51	Surface water
52	Barren and exposed land
53	Clouds
54	Cloud shadows

accuracy is 75 percent or 82 percent, respectively. All but one of the overall accuracy statistics meet the GAP standard of at least 80 percent accurate, and a number of the key individual categories demonstrated much higher accuracy values.

Limitations and Discussion

In the IL-GAP land cover classification, grasslands offered particular challenges because in most cases they are actively managed. Common grassland management practices in Illinois include prairie restoration, the periodic use of fire, grazing, haying, the Conservation Reserve Program (CRP), and the Conservation Reserve Enhancement Program (CREP). The challenge for remote sensing analysts is that the results of the management practices are visible on the landscape and affect the spectral responses viewed by remote sensing devices. The end result is that in many cases management practices may have more effect on the spectral response of a grassland tract than does the species composition. It is difficult, for example, to spectrally distinguish tracts of tall grass prairie and CRP if both have similar management practices. During the time period the land cover was being created, no statewide digital layer representing areas of prairies, CRP, and CREP existed to help separate the grasslands into finer categories. Thus, the final Illinois Gap land cover classification contains one category for grasslands called rural grassland. Future updates of the land cover classification shall incorporate more detailed grassland categories such as CRP, warm season grass, and cool season grass using ancillary data that is now available statewide.

The GAP land cover classification represents the best and most comprehensive land cover layer available to date in order to support wildlife habitat relationship modeling for vertebrates in the State. Generally, the GAP land cover classification is most appropriate for use in regional resource planning at the watershed or county level. In terms of scale, the classification should be used for analysis at a map scale of 1:100,000 or smaller. Often, it will be more appropriate to work in terms of probabilities of occurrence rather than precise occurrence or non-occurrence of a given land cover type. Inappropriate uses would include using the GAP classification to define precise boundaries between mapped features for regulatory purposes or for acquisition; generating specific area measurements for small aerial features; or using GAP data to establish the accuracy of other data.

Due to its level of detail, it is anticipated that the Illinois GAP land cover classification will be used in a wide range of analyses for a diverse group of end users. For example, the GAP land cover classification is being used by CTAP professional scientists to help select yearly monitoring sites in key habitats types (i.e. forests, grasslands, and wetlands) throughout the state. It is also being used by IDNR scientists in support of the Illinois Wildlife Action Plan (formerly the Illinois Comprehensive Wildlife Conservation Plan) to identify and characterize the remaining key wildlife habitats and identify and prioritize areas for conservation and restoration in the state. The GAP land cover classification also is being used by numerous graduate students in Fish and Wildlife Ecology at the University of Illinois at Urbana-Champaign as the major source date layer for identifying and analyzing key habitat areas for their thesis research.

Given the open and public availability of the Illinois GAP land cover classification, its widest dissemination and use is encouraged. All data products, metadata, and accuracy assessment files relating to Illinois GAP land cover classification are available for public download from the Illinois Gap Analysis Project website at the Illinois Natural History Survey <http://www.inhs.uiuc.edu/cwpe/gap/>, as well as the Illinois Department of Agriculture website <http://www.agr.state.il.us/gis/index.html>.

Terrestrial Vertebrate Distributions

The Illinois Gap Analysis Project (IL-GAP) mapped predicted species distributions in accordance with the standards of the National GAP Handbook as of February 16, 2000. The spatial resolution of the models is 30 meters, as provided by the IL-GAP land cover classification. To reduce files sizes and for distribution purposes, all vertebrate models were resampled to a 90 meter spatial resolution. The output of the predicted vertebrate species distributions depended on the input of spatial data; therefore, all ancillary data were formatted to match the IL-GAP land cover classification. GAP products are intended for applications at the landscape scale (Csuti and Crist 2000), thus all predicted species distributions were produced at 1:100,000 scale.

Distributions were predicted for 485 terrestrial vertebrate species. Final predicted species distributions were not created for species with historical or questionable hexagon ranges. A total of 736 predicted distributions were created for 60 mammals, 266 migratory birds, 48 permanent resident birds, 152 summer resident or breeding birds, 111 winter resident birds, 41 amphibians, and 58 reptiles. The total number of models did not equal the total number of species because multiple ranges were created for some bird species.

Mammals

Most mammals have been well studied in Illinois and the distributions were straightforward. Because the distribution of mammals relied on locations from museum collections, research scientist studies, and information gathered from district wildlife biologist mail surveys, the distribution maps likely had higher richness areas where the sampling was conducted (i.e. major universities such as the University of Illinois at Urbana–Champaign). Bats were the most difficult order to model because the habitats they use as roosting sites, such as caves and old buildings, are not represented in the land cover. Thus, only the foraging habitat was modeled for bats. Distributions for fossorial species tend to be overestimated due to the inability to map the understory vegetation in the land cover or to use soil types in the final distribution.

Birds

Museum collections along with observations by amateur and professional ornithologists provided a detailed record of occurrences of bird species across Illinois through 2000. By using such a large number of data sources in the creation of the hexagon range distributions as well as creating multiple distribution ranges (migratory, summer resident or breeding, permanent resident, and winter resident) for each species, the distributions for all birds species have been very well documented. These sources of information probably make the bird distributions models the most complete and up-to-date of all the vertebrate taxonomic groups. The use of model modifiers, especially lakes and habitat edges, greatly improved the distributions for many bird species.

Amphibians and Reptiles

Habitat modeling for amphibians and reptiles was difficult because many species depend on microhabitat features that are not present in the land cover, such as downed logs or suitable hibernacula. Also, many landscape features required by herpetofauna could not be modeled due to unavailable statewide data layers (i.e. water depth, temperature, or vernal pool locations).

The Illinois GAP Project did not conduct an accuracy assessment for the vertebrate habitat modeling process.

Land Stewardship

Public lands (federal, state, non-governmental organization [NGO], and local) comprise approximately 4,477 km^2 (3.1 percent) of Illinois, whereas private lands make up 141,465 km^2 (96.9 percent) of the State. The area of Illinois land in status 1 and 2 is 334 km^2 (0.2 percent) and 1,429 km^2 (1.0 percent), respectively. Protection status 3 lands cover 2,678 km^2 (1.8 percent) of Illinois, and 141,501 km^2 (97.0 percent) are in status 4. Although we have attempted to assess the land stewardship to the best of our ability, the IL-GAP stewardship layer is best considered as a snapshot view of available information.

Gap Analysis—Land Cover

Ten vegetation types have less than 1 percent of their distribution on GAP Status 1 and 2 lands. As expected, these include all agriculture and urban categories (except some urban areas in the Chicago region). Clouds and clouds shadows, which were unable to be removed from the classification, also fall into this category. Seventeen vegetation types have between 1 and 10 percent of their distribution on GAP Status 1 and 2 lands. These include grasslands, upland and floodplain forests, medium and low density urban areas in the Chicago region, barren and exposed lands such as quarries, and most of the herbaceous wetlands. The seasonally/temporarily flooded wetland is the only land cover type with between 10 and 20 percent of its representation on GAP Status 1 and 2 lands. The majority of this cover type occurs along the Illinois and Mississippi Rivers, which have numerous lands owned and/or managed by either federal or state agencies (i.e. U.S. Army Corps of Engineers, Illinois Department of Natural Resources). Swamp is the only land cover type with between 20 and 50 percent of its distribution on GAP Status 1 and 2 lands. The swamp land cover type is located only in southern Illinois and the largest area is in the Cache River area. Much of the Cache River area is owned and/or managed by either federal or state agencies (i.e. U.S. Fish and Wildlife Service or the Illinois Department of Natural Resources). There is no land cover in Illinois that has at least 50 percent of its distribution on protected lands.

Gap Analysis—Vertebrates

Of the 359 vertebrate species assessed by IL-GAP, 88.0 percent had less than 10 percent of their predicted distributions on status 1 or 2 lands. This includes 55 mammals (91.6 percent), 47 permanent resident birds (98.0 percent), 122 summer resident birds (80.3 percent), 36 amphibians (87.8 percent), and 56 reptiles (96.5 percent). The species with less than 1 percent of their predicated distribution in status 1 and 2 lands include 8 mammals, 15 permanent resident birds, 18 summer resident birds, 3 amphibians, and 6 reptiles for a total of 50 species (13.9 percent). Of these 50 species, nine (18.0 percent) are listed as either state threatened (ST) or state endangered (SE) (ST = 3, SE = 6). Three species (two amphibians and one summer resident bird) had predicted distributions that totaled less than 50,000 ha, including the Jefferson salamander (*Ambystoma jeffersonianum*ST), hellbender (*Cryptobranchus alleganiensis*), and Snowy Egret (*Egretta thula*SE). Not only did these species have less than 1 percent of their predicted distribution in status 1 and 2 lands, but their overall distributions were restricted. Three out of the four species with a total predicted distribution less than 50,000 ha are listed as threatened or endangered species in Illinois. These species require special attention if habitats are to be maintained.

Conclusions

In Illinois, wildlife must be conserved on private lands, which will require some new approaches, as well as continuing with some of current approaches already in place at the state level. The Farm Bill, with its incentive programs to conserve erodible lands, and the Wetland Reserve Program, is one already in place in Illinois. In some cases, where particularly valuable wildlife habitat occurs, it is possible for government agencies or non-government organizations to purchase conservation easements on private lands. Other possibilities are cooperative agreements between public and private interests, tax incentives, and education.

References Cited

Anderson, J.R., E.E. Hardy, and J.T. Roach, 1972. A land-use classification system for use with remote sensor data. U.S. Geological Survey Circular 671, 16 p.

Csuti, B., and P. Crist. 2000. Methods for developing terrestrial vertebrate distribution maps for gap analysis. A handbook for conducting gap analysis. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho.

(IDA) Illinois Department of Agriculture. 2003. Geographic Information System. Available from <http://www.agr.state.il.us/gis/index.html>

Iverson, L.R., R. Oliver, D. Tucker, P.G. Risser, C.D. Burnett, and R. Rayburn. 1989. Forest resources of Illinois: An atlas and analysis of spatial and temporal trends. Illinois Natural History Survey, Special Publication 11.

(USDA–NASS) U. S. Department of Agriculture–National Agricultural Statistics Service. 2000. Cropland data layer program. Available from <http://dnr.state.il.us/orc/Wildliferesources/theplan/>

(IDNR) Illinois Department of Natural Resources. 2008. Illinois wildlife action plan. Available from <http://dnr.state.il.us/orc/Wildliferesources/theplan/>

Indiana Gap Analysis Project

Compiled from Final Project Report

Introduction

The Indiana Gap Analysis Project (IN-GAP) was born out of the concern that agencies charged with the protection and restoration of biological resources in the state functioned without the benefit of information at the landscape scale. IN-GAP established goals to:

(1) provide data to the national gap analysis center for the national scale biotic assessment,
(2) support conservation projects underway at the U.S. Fish and Wildlife Service (USFWS) and various partner agencies and organizations,
(3) support the expansion of habitat restoration efforts from the existing scale to a landscape scale,
(4) provide part of the scientific basis for the development of a biodiversity protection and restoration plan for Indiana,
(5) provide useful data to non-partner organizations whose actions and decisions affect biological diversity

We determined, based on national project specifications developed in the early 1990s, that Indiana partners would require products at levels of detail beyond the ability of the National Gap Analysis Project to support. Moreover, it seemed important that IN-GAP pay dividends as soon as possible in the project timeline. The solution we implemented used gap analysis generated products and outside funding to address specific conservation issues of concern. We termed these *metaprojects*. Metaprojects were developed to foster cooperation and acceptance of IN-GAP among the conservation community, generate monetary support to develop detailed data useful for state and regional analyses, demonstrate applications for gap analysis, produce information useful in protecting Indiana's natural resources, and test IN-GAP products.

IN-GAP metaprojects included: a white-tailed deer modeling project with the Indiana Department of Natural Resources, Division of Fish and Wildlife, which used a preliminary statewide landcover map; The Nature Conservancy (TNC) Bioreserve Planning which employed Gap Analysis products and developed additional data as one component in the Blue River Watershed plan; a pilot project to evaluate the utility of gap analysis products for landscape scale wetland restoration with the USFWS Partners for Fish and Wildlife Program; a cooperative project with the USFWS to facilitate listing and recovery of the copperbelly water snake (*Nerodia erythrogaster neglecta*); contaminants investigations involving nesting bald eagles; and the evaluation of Big Oaks (Jefferson Proving Grounds) and Grand Kankakee Marsh National Wildlife Refuges.

Land Cover

The land cover map for Indiana was developed at the Center for Remote Sensing and Geographic Information Systems in conjunction with the Department of Geography, Geology, and Anthropology at Indiana State University (ISU 2006). IN-GAP began in October 1994, before the NVCS was available. Land cover in Indiana was mapped using the spectral characteristics of Landsat 5 Thematic Mapper (TM) imagery to identify 16 distinct classes (Table 1). The majority of these classes are Level 3 types consistent with the sub-class level of the UNESCO (1973) hierarchy.

The majority of Indiana is used for agricultural purposes with 59.5 percent of the landscape classified as row crop agriculture and another 12.5 percent of the state classified as agricultural pasture/grassland cover (Table 1). Agricultural lands are primarily in the northern two-thirds of the state. Forests, more specifically upland deciduous forest (18.7 percent) and wetland deciduous forests (2.2 percent) dominate the landscape in the south-central area of the state (Berta et al. 1998).

Table 1. The land cover types mapped, their area mapped in the state and percentage of Indiana's total area represented by the mapped type.

[**Abbreviations**: km^2, square kilometer; <, less than; >, greater than]

Land cover class	Area covered (km^2)	Area covered (percent)
Developed–non-vegetated	564.3	0.60
Developed–urban, high density	651.3	0.70
Developed–urban, low density	1,697.2	1.81
Agriculture–row crops	55,784.1	59.54
Agriculture–pasture and grasslands	11,693.2	12.48
Terrestrial–shrubland (canopy closure < 50 percent)	356.8	0.38
Terrestrial–woodland (canopy closure 50–75 percent)	613.4	0.65
Terrestrial–deciduous forest (canopy closure > 50 percent)	17,542.9	18.72
Terrestrial–evergreen forest (canopy closure > 50 percent)	511.4	0.55
Terrestrial–mixed evergreen/ deciduous forest	313.0	0.33
Palustrine– deciduous forest (canopy closure > 50 percent)	2,076.7	2.22
Palustrine– deciduous woodland (canopy closure 50–75 percent)	30.6	0.03
Palustrine–shrubland (canopy closure < 50 percent)	322.9	0.34
Palustrine–herbaceous	479.0	0.51
Palustrine sparsely vegetated	86.7	0.09
Water	939.6	1.00
Unclassified–cloud/shadow	34.7	0.04

Accuracy Assessment

The Indiana land cover classification was determined to have an overall classification accuracy of 70.98 percent. The largest class, row crop agriculture, has a user accuracy of 91.89 percent, while upland deciduous forest (75.41 percent), wetland deciduous forests (83.33 percent), and pasture/grassland (12.41 percent) have lower class accuracy statistics.

Terrestrial Vertebrate Distributions

This overall list of Indiana vertebrates includes 300 species, with 38 amphibians, 53 reptiles, 55 mammals, and 154 birds. Gap Analysis Projects model primarily native species. However, IN-GAP chose to model several introduced species including, ring-necked pheasants, rock dove, European starling house finch, Norway rat, and house mouse. It was decided that these speceies should be included in the analysis because they have become naturalized to Indiana and play an important role in the biodiversity of the state, albeit in many cases a negative role. For example, starlings compete with bluebirds and other native cavity nesters for nest sites, and ring-necked pheasants may negatively affect potential prairie chicken reintroduction efforts.

Land Stewardship

Results

Table 2 presents summary statistics of area representation of stewardship and management categories in Indiana. Less than 1 percent of the state is held in GAP Status 1 or 2 lands.

Table 2. GAP percentage of Indiana in various levels of protection.

GAP status code	Acres	Square miles	Hectares	Percentage of state
Status 1	77,234	121	31,256	0.33
Status 2	131,671	206	53,287	0.57
Status 3	457,586	715	185,183	1.98
Status 4	22,489,022	35,140	9,101,183	97.12

Table 3. Land cover types by percentage in GAP Status 1 and Status 2 categories in Indiana.

[**Abbreviations**: <, less than; >, greater than; NWI, National Wetlands Inventory]

Description	0 – less than 1 percent	1 – less than 2.5 percent	2.5 – less than 5 percent	5 – less than 10 percent	Greater than 10 percent
Class 1: Unclassified (clouds and shadows)		2.13			
Class 2: Developed: other (non-vegetated)	0.26				
Class 3: Urban: high density	0.23				
Class 4: Urban: low density	0.13				
Class 6: Agriculture: row crop	0.14				
Class 7: Agriculture: pasture and grasslands	0.22				
Class 8: Deciduous shrubland (canopy closure <50 percent)		1.52			
Class 9: Deciduous woodland (canopy closure 50–75 percent)		1.38			
Class 10: Deciduous forest			3.32		
Class 11: Evergreen forest					5.12
Class 12: Mixed evergreen/deciduous forest			3.63		
Class 13: Palustrine forest			2.85		
Class 14: Palustrine woodland		2.06			
Class 15: Palustrine shrubland			3.08		
Class 16: Palustrine herbaceous		2.39			
Class 17: Sparsely vegetated/unvegetated			2.54		
Class 18: Water bodies (derived partially from NWI)		1.78			

Gap Analysis—Land Cover

Only agricultural row crop and agricultural grasslands had 0–less than 1 percent representation in GAP Status 1 and 2 (not including land cover types with virtually no conservation value like developed non-vegetated, urban low density, and urban high density). Agricultural row crop land has limited biodiversity conservation value, but because of the high percentage of this land cover type in Indiana, some clarification of the role of corn and soy beans in conservation is required. Row crops in Indiana are structurally similar to grasslands; however, because they have essentially no native plant species, they contribute nothing to floristic biodiversity conservation.

In addition to the unclassified class, five land cover classes have between 1 and 2.5 percent of their area in status 1 and 2 lands. These include: deciduous shrubland, deciduous woodland, palustrine woodland, palustrine herbaceous, and open water. Indiana has over 500 natural lakes in the glaciated northern part of the state larger than 2 ha. The largest, Lake Wawasee, covers 1,380 ha. In addition more than 60,000 ha of Lake Michigan covers the extreme northwestern section of Indiana. The open water in Status 1 and 2 categories, however, would mostly comprise Indiana's flood control reservoirs; principal among these are Lake Monroe, Patoka Lake, Brookeville, Mississinewa, and Salamonie reservoirs which total well over 12,000 ha. They are primarily managed by the U.S. Army Corps of Engineers.

Five land cover classes have 2.5 percent to 5 percent of their area in Status 1 and 2 lands. It is likely that upland deciduous forest and mixed evergreen/deciduous have similar profiles. We categorized 3.32 percent of upland deciduous forest and 3.63 percent of mixed forest as Status 1 and 2. The bulk of this would be national and state forest owned and managed land. A significant addition not reflected in the table is the establishment of Big Oaks National Wildlife Refuge in southeastern Indiana that protects over 12,000 ha of upland forest primarily for migratory bird and biodiversity conservation. Although upland deciduous forest emerges as one of the better protected habitat types in the state, fragmentation may affect Status 1 and 2 upland forests, and over 90 percent remains privately held.

Evergreen forest is Indiana's only land cover class with more than 5 percent of its area in status 1 and 2. Evergreen forest occurs as a native community in Indiana as comparatively small patches. Most of the evergreen forest consists of pine plantations grown for forest products or as shelterbelts.

Gap Analysis—Vertebrates

Analysis of IN-GAP data indicates that no amphibian has more than 10 percent of its habitat in Status 1 and Status 2 managed lands. In fact, of the 38 amphibian species modeled, only 3 species have more than 5 percent of their predicted distributions in Status 1 and Status 2 managed lands, and for 8 species, habitat in the top 2 protection categories is less than one percent.

Reptiles in Indiana appear even less secure than amphibians. No reptiles have greater than 5 percent of their predicted distribution in Status 1 and Status 2 managed lands. A disheartening 21 of 55 reptiles have less than 1 percent of their predicted distributions in Status 1 and Status 2 managed lands.

We modeled 154 bird species that breed in Indiana. Of those, only three have greater than 10 percent of their predicted distributions in Status 1 and Status 2 managed lands and 56, more than one-third, have less than 1 percent.

Only 2 of the 55 mammals modeled have greater than 5 percent of their predicted distributions in Status 1 and Status 2 managed lands; no species has 10 percent. Nearly one-half of the species (27) has less than 1 percent of their predicted distributions in Status 1 and Status 2 managed lands.

Limitations Specific to IN-GAP

The results derived from IN-GAP provide insight into the state of biodiversity conservation in Indiana. We envision the various component products of the project (landcover map, vertebrate models, and stewardship coverage) as points of departure for further investigation. It has become apparent, based on early interest in IN-GAP data, that various organizations, government agencies, and private firms recognize utility in these products.

Nevertheless, the conclusions and the component products developed for IN-GAP have some limitations.

Specifically, the Landsat Thematic Mapper satellite images used to develop the land cover map were approximately 10 years old at the release of this report. Because land cover is influenced by natural dynamics, (e.g., succession, beaver dams, storms) and by human alterations, the land cover map becomes less accurate with time. The data available in the mid-1990s were a limited number of 30 m pixel satellite imagery scenes. Moreover, little ancillary data existed in Indiana with which to augment the satellite imagery, which combined with the complexity of Indiana's land cover, resulted in a limited number of land cover classes. The minimum mapping unit (MMU) of the land cover map is one hectare, (i.e., land cover classes in patches smaller than one hectare typically would merge with surrounding larger classes). When IN-GAP began, the goal involved producing products at a scale suitable for analyses at a national or regional scale. Although we modified this approach to the extent possible to address questions at the state scale, many uses (e.g., exclusive reliance on IN-GAP data for municipal environmental planning) were outside the scope of the project.

Vertebrate models reflect not only the limitations of the land cover map on which they are based, but also the incomplete understanding of the life histories of the species they model. In cases for which we have good information on habitat use, our understanding frequently exceeds the data available with which to model (e.g., the presence of snags or specific tree species, or forest maturity). IN-GAP constructed relatively simple habitat relationship models. Users should consider that predicted distribution refers in most cases to habitat where the species would normally reproduce. With respect to a vagile group like birds, for example, some species use backyard feeders, but we did not model suburban habitat unless the species also typically breeds there. Last, habitat may not always be occupied; depending on time of year, population density, habitat quality and numerous other factors, a particular species may or may not be present in any suitable habitat patch.

The stewardship coverage, in large part provided to IN-GAP by the IDNR, Division of Fish and Wildlife reflects the public ownership of land in Indiana circa 1995. We know that the state, counties, non-government organizations and others have continued to acquire land in Indiana for the purpose of natural resource management. Some military reservations also have changed ownership in the ensuing years. These changes by and large are not reflected in the Stewardship coverage. Small, less than one acre sites do not appear in the coverage. In addition, significant efforts like permanent easements through the U.S. Department of Agriculture's Wetland Reserve Program (WRP) do not occur in the Stewardship coverage. Although locally significant, we do not believe that additions to the public land base in Indiana since 1995 have been sufficient to fundamentally alter the results of this report.

The results and conclusions derived from the analysis of the component products of the Indiana Project necessarily carry the burden of the aforementioned limitations of data and analyses.

References Cited

Berta, S., C.M. Cowell, J. Wilson, and D. Wiseman. 1998. State-wide vegetation classification procedures for Indiana—satellite data analysis for the Indiana GAP Project: Abstract Proceedings, Applied Geography Conferences 21:449.

Indiana State University. 2006. Indiana GAP Land Cover Project Summary available at http://web.archive.org/web/20070121131706/baby.indstate.edu/geo/rs/info.htm

UNESCO. 1973. International classification and mapping of vegetation. Paris, UNESCO. 93 p.

This page intentionally left blank.

Northwest Regional Project Report

Northwest Gap Analysis Project

Introduction

The Northwest Gap Analysis Project (NWGAP), which began in September 2004, is updating the land cover, species models, stewardship data, and gap analysis for Washington, Oregon, Idaho, Wyoming, and Montana. A finalized land cover map for the northwest is currently available for download from the NWGAP website at <http://www.gap.uidaho.edu/northwest/data.htm>. Species modeling is progressing with final models to be available in late 2009. Spatial and attribute data are being updated in the land stewardship database with final edits being completed in late 2009. Currently, we are developing a NWGAP mapserver through that data can be downloaded and viewed and queried online.

Land Cover Mapping

The NWGAP has completed 12 draft land cover maps depicting the distribution of Ecological Systems (ES) across Idaho, Washington, Oregon, Montana, and Wyoming (Figure 1). Three mapping teams were involved with mapping NWGAP's 12 map zones; (1) Oregon State University and U.S. Department of Agriculture Forest Service, Corvallis, OR (2) Sanborn Solutions, Inc., Portland, OR, and (3) NWGAP, Moscow, ID. Different modeling approaches were explored to evaluate the effectiveness of each to represent the natural distribution of ES within each map zone and across the region. Oregon State University used Gradient Nearest Neighbor (GNN) and Random Forest modeling techniques, while Sanborn and NWGAP used a Classification and Regression

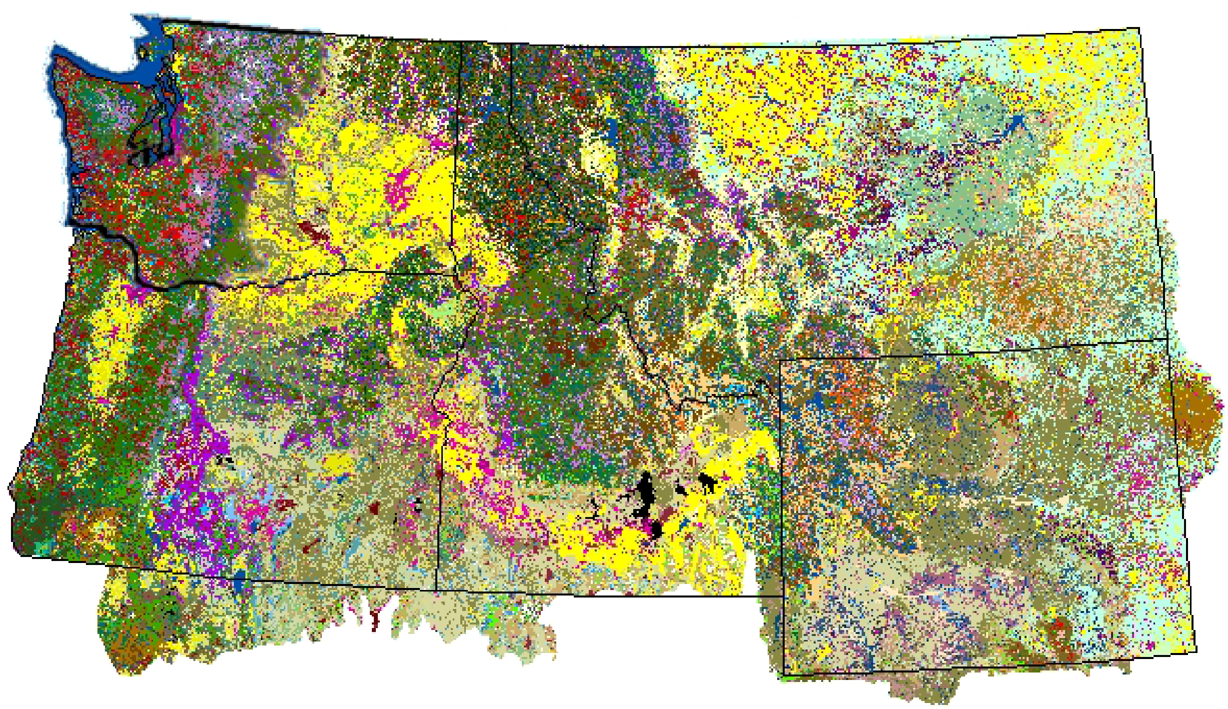


Figure 1. NWGAP draft land cover map showing ecological systems.

Tree (CART) modeling approach. Frequent communication among the mapping teams ensured consistent application of each ES definition and seamless representation across the region.

Collectively, the 12 NWGAP map zones depict the distribution of 173 ES classes and 32 land cover and disturbed classes across the Northwest. Of the 173 ES classes, 24 are barren or sparsely vegetated, 22 are grassland systems, 31 are shrub or steppe systems, 54 are forest, woodland, or savanna systems, and 43 are wetland and riparian systems. The 32 land cover and disturbed classes consist of 15 developed or agricultural lands classes, 7 introduced vegetation classes, 4 harvested vegetation type classes, and 3 recently burned habitat classes. Deterministic accuracy rates for many ES are greater than 80 percent.

The maps were reviewed by Northwestern vegetation ecologists and finalized in December 2008. Draft land cover maps are available for download and online web mapping at <http://www.gap.uidaho.edu/Northwest/data.htm>. The finalized land cover data will be used as one of the primary modeling inputs for NWGAP vertebrate modeling.

Species Modeling

The list of 690 terrestrial vertebrate taxa targeted by NWGAP has been finalized by zoologists in the five northwestern Natural Heritage Programs. Georeferenced occurrence data for all 690 taxa have been compiled and synthesized into a region-wide dataset. These data are currently being processed to cull unreliable and out-of-date records, reduce the spatial bias in record clusters, and apply other criteria that will produce final datasets more appropriate for inductive modeling of a species distribution.

First draft range maps for all target taxa were collected from NatureServe (Arlington, Virginia), tessellated to a common representation as 10-digit Hydrologic Unit Codes (HUCs) and then reviewed by Natural Heritage Program Zoologists in each of the five northwestern states. We anticipate this review to be complete for all taxa by spring 2009.

Initial draft distribution and habitat importance models for all target taxa are currently being compiled with the intent of having all completed by late winter 2009.

Land Stewardship Data

The NWGAP stewardship effort began in January 2008. The intent of this effort is to update the stewardship data from the original five states' data. This involves checking for new and/or updated boundaries and revising GAP status codes based on changes to management from the time the state stewardship data was created.

To date, current spatial and attribute data have been obtained from federal and state agencies. Specifically, 31 National Park Service and 72 U.S. Fish and Wildlife Service property boundaries have been compiled for the entire Northwest. The NWGAP data will be assigned GAP status codes as well as International Union for Conservation of Nature (IUCN) categories, which will match up with attribute data in the rest of the United States. Currently, IUCN categories are being assigned to National Park Service and U.S. Fish and Wildlife Service properties. The remaining federal and state properties are next to be compiled and the entire stewardship database for NWGAP will be completed by September 2009.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
03-31-2009

2. REPORT TYPE
Information report

3. DATES COVERED *(From - To)*
01-01-2008 - 12-31-2008

4. TITLE AND SUBTITLE
Gap analysis—A geographic approach to planning for biological diversity: U.S. Geological Survey Gap Analysis Program Bulletin No. 16, 104 p.

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Maxwell, Jill, Gergely, Kevin, Aycrigg, Jocelyn, and Davidson, Anne, eds.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USGS/BRD/Gap Analysis Program
530 S. Asbury Street, Suite 1
Moscow, ID 83843

8. PERFORMING ORGANIZATION REPORT NUMBER
No. 16

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Geological Survey
Biological Resources Division
Reston, VA 20192

10. SPONSORING/MONITOR'S ACRONYM(S)
USGS

11. SPONSORING/MONITORING REPORT NUMBER

12. DISTRIBUTION/AVAILABILITY STATEMENT
Copies of this publication are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (1-800-553-6847 or 703-487-4650). Copies are also available from the Defense Technical Information Center, Attn.: Help Desk, 8725 John J. Kingman Road, Ste. 0944, Fort Belvoir, VA 22060-6218 (1-800-225-3842 or 703-767-9050)

13. SUPPLEMENTARY NOTES
Published annually

14. ABSTRACT
The 2008 issue of the Gap Analysis Bulletin is the sixteenth in a series of annual publications produced by the Gap Analysis Program. Gap Analysis Bulletin No. 16 features 16 articles on various aspects of gap analysis methods and results. Topics addressed include applications, land cover, and aquatic gap analysis. The Bulletin also includes a section on the current status of each GAP regional project. This issue also contains summaries for completed GAP state projects.

15. SUBJECT TERMS
Biodiversity, conservation biology, Gap Analysis Program, animal modeling, aquatic GAP, land use planning, vegetation mapping

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	SAR	104	Jill Maxwell / 208-885-3550

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Table of Contents continued:

FINAL STATE PROJECT REPORTS

NORTHWEST REGIONAL PROJECT REPORT

USGS Gap Analysis Program
530 S. Asbury, Suite 1
Moscow, ID 83843

RETURN SERVICE REQUESTED

Printed on recycled paper