FEATURES

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

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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

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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.

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