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Performance of habitat suitability models for the endangered black-capped vireo built with remotely-sensed data

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ABSTRACT

Identifying suitable habitat is critical to endangered species management and recovery. However, this basic task is often complicated by the rarity of the species in question and the limited availability of high quality environmental data. The endangered Black-capped Vireo (*Vireo atricapilla*) occupies early seral shrub communities generated by fire. The ability to predict vegetation structure is particularly important for mapping vireo habitat because this species occupies transitional, non-equilibrium vegetation types. We use presence data for territorial male vireos collected throughout the Fort Hood Military Reservation, Texas, to construct habitat suitability models using vegetation type (mapped from aerial imagery), soil data, and laser altimetry (LiDAR)-derived measures of vegetation structure. LiDAR produces a three-dimensional, high-resolution representation of vegetation structure across broad spatial scales. We built models that incorporated LIDAR outputs as well as the other habitat predictors using a non-parametric machine-learning algorithm, cforest. Models built using a single predictor class (vegetation structure or type or soil) performed similarly across 25 bootstrapped training and test datasets (median accuracies 76%, 74%, and 79%, respectively). Models incorporating two predictor classes performed better (80–81%) and only slightly worse than the full model (82%). Furthermore, vegetation type and soil data were more important predictors of habitat suitability than structural measures in the full model. Predictive maps suggest that models incorporating vegetation type and soil would be most useful for habitat conservation and management applications on Fort Hood. The addition of LiDAR-derived variables to the model further distinguishes suitable habitats from potentially suitable but presently overgrown areas. In the absence of detailed vegetation data, models based on structural measures performed well when combined with soil data. This could be useful in a broader regional context in which vireos occupy a greater variety of vegetation types with a common structure.

1. Introduction

Vegetation structure (i.e. physiognomy) and species composition are important determinants of habitat suitability for birds (Hutto, 1985; James, 1971; Rotenberry, 1985) as well as predictors of overall avian diversity (MacArthur & MacArthur, 1961). Field-based sampling methods for quantifying vegetation structure and composition are widely used (Barber & Martin, 1997), but may be inadequate for characterizing vegetation across broad spatial extents. Vegetation plot surveys may be combined with air photo interpretation to scale-up results into thematic maps of landscapes (Bergen et al., 2009; Newton et al., 2009). These high-resolution vegetation maps provide a detailed snapshot of vegetation composition and configuration, but may require months to years in fieldwork and image classification. Now widely available, remote-sensing methods such as laser altimetry, also known as LiDAR (light detection and ranging), allow for continuous estimates of vegetation structure (e.g., canopy height and percent cover) across large areas (Lefsky et al., 2002; Vierling et al., 2008). LiDAR datasets can be collected in days or weeks and processed in months, making them attractive for many conservation and management applications. If physiognomy is equivalent or superior to vegetation composition as a predictor of habitat suitability, then rapid habitat assessments using LiDAR-derived datasets may be preferable to field-based methods.

LiDAR is an active remote sensing technology for mapping three dimensional surfaces. A LiDAR device emits laser pulses at regular intervals as it is flown above the target surface. The LiDAR sensor then records the time it takes for the pulses to return. Recording of multiple returns and time delays from millions of laser pulses gives an estimate of surface complexity in three dimensions. Sensors can either record discrete returns or large-footprint waveforms (Lefsky et al., 2002). Both are collected by sensors affixed to an aircraft and can be used for high resolution (0.25–5 m) mapping of terrain and vegetation (Bergen et al., 2009; Lefsky et al., 2002). Terrestrial-based

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LiDAR, in which data are collected from a fixed location, is used in forestry applications and may become appropriate for detailed assessment of micro-scale vegetation structure in the future (Michel et al., 2008).

The potential applications of LiDAR-derived datasets to modeling species-habitat relationships are broad and currently underdeveloped (Bergen et al., 2009; Lefsky et al., 2002; Vierling et al., 2008). To date, LiDAR-derived estimates of vegetation structure have been applied to a range of terrestrial systems, including conifer forests and alpine meadows (Graf et al., 2009; Müller et al., 2010), deciduous woodlands (Goetz et al., 2010; Hinsley et al., 2006), mixed conifer/deciduous forests (Clawges et al., 2008; Goetz et al., 2007), riparian forests (Seavy et al., 2009), forest understory (Martinuzzi et al., 2009), shrub and rangelands (Streutker & Glenn, 2006), and agricultural or mixed-use landscapes (Bradbury et al., 2005; Nelson et al., 2005). Individual-species distributions (Goetz et al., 2010; Graf et al., 2009; Nelson et al., 2005), species diversity (Goetz et al., 2007; Müller et al., 2010; Seavy et al., 2009), and habitat quality (Goetz et al., 2010; Hinsley et al., 2006)have all been modeled using LiDAR-derived measures. One study of avian diversity suggested that LiDAR-derived structural measures performed better than vegetation composition in predicting site diversity (Müller et al., 2010). Again, where this is the case, assessment using LiDAR-derived estimates of vegetation physiognomy may be more time and cost efficient than field-based measurements.

We used LiDAR data to define and map potential habitat for the black-capped vireo (*Vireo atricapilla*) on the Fort Hood Military Reservation, Texas. The black-capped vireo breeds in shrubland habitats historically maintained by fire and shallow soils and persisting 5–30 years (Graber, 1961). These transitional habitats are time-consuming to monitor and map, but initial efforts suggest they may be identifiable with LiDAR surveys (Leyva et al., 2002). Model-based habitat mapping using remotely-sensed data could save considerable effort and aid in the designation and management of critical vireo habitats. Furthermore, the black-capped vireo is endangered and an accurate model of habitat suitability would be useful for designating critical habitat. We constructed and compared predictive habitat models using all combinations and subsets of LiDAR-derived data on vegetation structure, field-derived data on vegetation composition, and soils data. Models were fitted using a machine-learning algorithm and permutation analyses were used to assess variable importance.

2. Methods

2.1. Study area

Fort Hood, an 87,890-hectare military installation in north-central Texas (97°44′W, 31°12′N), supports the largest known population of black-capped vireos under a single management agency (Cimprich & Kostecke, 2006). Fort Hood is located at the intersection of the Edwards Plateau and the Crosstimbers and Southern Tallgrass Prairie ecoregions. Topography includes numerous flat-topped mesas with steep gullies and mesic bottomlands. The installation is covered by woodlands and upland forest (47%), grasslands (34%), and small amounts of shrubland and riparian forest (4% and 3%, respectively).

2.2. Study species

The black-capped vireo is a nearctic-neotropical migrant passerine that breeds in north central Mexico, Texas, and central Oklahoma and winters in west central Mexico (Graber, 1961). In Texas, the vireo nests in shrub thickets comprised primarily of short, deciduous shrub and tree species arranged in clumps on the landscape (Grzybowski et al., 1994). These irregularly shaped thickets are 1–3 m tall, provide 30–60% woody vegetative cover, and are separated by grasslands or rock pavement (Bailey & Thompson, 2007). Shrublands have been observed to persist on Fort Hood in areas with shallow soils or where fires ignited by artillery are common (Pekins, 2006). Otherwise, they represent an early stage in forest succession that will transition into taller shrubs and trees (Cimprich & Kostecke, 2006).

2.3. Data sources

An assessment of vireo presence throughout Fort Hood was conducted in 2002 and 2003. All areas identified from aerial photos as potential vireo habitat were visited during the breeding season (Cimprich & Kostecke, 2006). Areas were searched on foot by walking randomly through potentially suitable vegetation. Song playbacks and multiple visits were used to increase detections. Locations of all calling male vireos were marked with geographic positioning system (GPS) receivers.

We used LiDAR data to generate four variables for modeling vireo habitat (Table 1). LiDAR data were acquired along 42 flight-lines over Fort Hood during a four-day period (Table 2). Raw LiDAR data were processed by the contractor using DASHMap software (Optech Inc., 2006) to create geo-corrected LiDAR point clouds that were used to construct a digital elevation model (DEM). The DEM was quality checked by the contractor against 950 test points to estimate a 95% confidence interval for the DEM of ±0.47 m (Optimal Geomatics, 2009).

We generated maps of canopy height and two measures of woody cover across Fort Hood using the original geo-corrected LiDAR point cloud files (LAS file format) and the GridMetrics function in the FUSION software package (McGaughey, 2009). Estimated height was the mean height of all first returns in a grid cell excluding points with heights less than 1 m to avoid calculating grassland heights (as in Seavy et al., 2009). The first cover estimate was the percentage of first returns between 1 and 30 m out of all first returns and provides an estimate of total woody cover. The second

Table 1
Response and predictor variables and data sources used in constructing black-capped vireo habitat models for Fort Hood, TX.

Variable	Description	Original format	Reference
VIREO	All areas identified as potential vireo habitat were visited in 2002 and 2003 and locations of observed vireos recorded.	Point shapefile	Cimprich & Kostecke, 2006
HEIGHT	Mean height of woody vegetation. Calculated using LiDAR return data from surveys conducted on Fort Hood in March 2009.	LAS files and LiDAR-derived DEM	Optimal Geomatics, 2009
COVER	Percent cover of woody vegetation. Percent of LiDAR returns measuring between 1 and 30 m in height.	LAS files and LiDAR-derived DEM	Optimal Geomatics, 2009
COVER2	Percent cover of woody vegetation less than 3 m tall. Percent of LiDAR returns measuring between 1 and 3 m in height.	LAS files and LiDAR-derived DEM	Optimal Geomatics, 2009
EDGE	Edge density. Total edge length within a grid cell divided by the area of the cell. Edges delineated from the 3 m resolution HEIGHT grid.	HEIGHT grid	
VEG	Manual delineation and classification of vegetation type based on aerial imagery and vegetation sampling data. Sixteen types identified, e.g., shin oak shrubland, shin oak-juniper woodland, riparian woodland, and grassland.	Polygon shapefile	Reemts & Teague, 2007
SOIL	Soil depth to a restrictive layer extracted from the Soil Survey Geographic Database (SSURGO) produced by the US Department of Agriculture Natural Resource Conservation Service	Polygon shapefile	USDA-NRCS, 2007