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Modeling Activity of the Indiana Bat (*Myotis sodalis*) at Mammoth Cave National Park Using Remotely-Sensed Descriptors of Forest Canopy Structure

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Abstract

We sought to identify forest canopy characteristics useful for predicting activity of the Indiana bat (*Myotis sodalis*), an endangered species found at Mammoth Cave National Park (hereafter, the Park). To do so, we used Airborne Laser Scanning (ALS) to quantitatively describe understory, mid-story, and canopy structure across the Park (Dodd et. al 2013). Concurrent with the collection of remotely-sensed data, we conducted surveys for bat activity from August 2010 through October 2011 using acoustic detectors (Anabat II) deployed along geo-referenced transects (Dodd et al. 2013). These acoustic surveys were conducted before the detection of White-nose Syndrome at MACA (USNPS 2013).

Analysis of acoustic data was carried out using Echoclass v.1.1, and echolocation pulses classified as belonging to the Indiana bat were considered per detector / night as our response variable. We then derived a suite of forest canopy descriptors for our acoustic survey points using the ALS data set. This suite of variables incorporated descriptors based on the absolute measurements of ALS hits at 10-m increments throughout the forest canopy, as well as measurements for total canopy height and canopy gap. Our suite also incorporated predictive variables developed by Lesak et al. (2011), which apportioned the incidence of ALS hits throughout the forest canopy by collapsing ALS data into 10 proportionate bins scaled to the height of the canopy. All descriptors were based on a 15-m radius centered on an acoustic survey point.

These descriptive variables included:

- Total Density (sum of all ALS-derived CHP from the ground to the top of the canopy)
- Gap Index (percent of open air space >3 m in height without vegetative structure)
- Canopy Height (height of canopy at the 90th percentile of ALS hits aboveground)
- Understory Density (sum of ALS-derived CHP from the ground to 10-m aboveground)
- Midstory Density (sum of ALS-derived CHP from 10 to 20-m aboveground)
- Overstory Density (sum of ALS-derived CHP from 20 to 30-m aboveground)
- Legacy Density (sum of ALS-derived CHP > 30-m aboveground)

- $P_{Understory}$ (percent of ALS-derived CHP in the bottom 2 bins of scaled data)
- $P_{Midstory}$ (percent of ALS-derived CHP in intermediate 3rd through 6th bins of scaled data)
- P_{Canopy} (percent of ALS-derived CHP in the upper 7th through 10th bins of scaled data)
- $R_{Understory}$:Midstory (ratio of $P_{Understory}$ to PMidstory)
- $R_{Understory}$:Canopy (ratio of $P_{Understory}$ to PCanopy)
- $R_{Midstory}$:Canopy (ratio of $P_{Midstory}$ to PCanopy)
- R_{Total}:Understory (ratio of total density to understory density)

We used multiple linear regression in conjunction with Akaike's Information Criterion (AIC) model rankings (Burnham and Anderson 2002) to identify the most parsimonious models for predicting activity of the Indiana bat. We derived *a priori* canopy structure models to be evaluated for the response variable. These models corresponded to specific portions of the forest canopy (understory, midstory, and overstory), as well as a model describing the entirety of clutter (hereafter, "total clutter").

Component predictor variables for the models were as follows:

- total clutter: total returns, gap index, canopy height
- overstory: overstory density, legacy tree density, P_{Canopy}
- midstory: midstory density, $P_{Midstory}$, $R_{Understory}$:Midstory, $R_{Midstory}$:Canopy
- understory: understory density, R_{Total}:Understory, $P_{Understory}$, $R_{Understory}$:Canopy

We used AIC scores relative to the smallest AIC value (ΔAIC) and Akaike weights (w_i) to assess the suitability of habitat models (Burnham and Anderson 2002, Arnold 2010). For models with strong support, we identified significant parameter estimates to elucidate which canopy descriptors within a model best described the variation observed for activity of the Indiana bat.

In summary, a total of 836 detector-nights from 109 survey locations were used for model development. From these, 35,872 echolocation files were recorded and 790 files were classified as belonging to the Indiana bat. Resulting models were significant for total clutter, understory, midstory, and overstory (Table 1).

Table 1: Akaike's Information Criterion scores (AIC), difference in AIC values (ΔAIC), Akaike weights (w_i), and number of parameters (K) developed for multiple linear regressions modeling activity of the Indiana bat (*Myotis sodalis*) using ALS-derived descriptors of vegetation throughout the forest canopy at Mammoth Cave National Park, 2010-2011. Models with an asterisk were significant ($P \leq 0.05$).

Response Variable	Model	AIC	ΔAIC	w_i	K
Indiana Bat Pulses (n = 836 detector-nights)	Understory*	7525.05	0.0	0.99	6
	Midstory*	7537.94	12.9	< 0.01	6
	Overstory*	7541.34	16.3	< 0.01	5
	Total Clutter	7546.81	22	< 0.01	5

Considering AIC rankings, however, only the understory model received support. Parameter estimates of this model suggest the Indiana bat was more active in areas with proportionately less clutter in the understory (Table 2). Based on these data, we would hypothesize that management activities that promote a long-term reduction of understory clutter (e.g., prescribed fire or silvicultural thinning) will complement efforts to provide useful foraging habitat for this endangered species.

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Table 2: Parameter estimates (β) and standard errors (SE) for ALS-derived descriptors of the forest canopy used in models of bat activity (Indiana bat pulses) at Mammoth Cave National Park, 2010-2011. Parameter estimates indicated by an asterisk were significant within a model (P ≤ 0.05).

Model	Canopy Descriptor	β ± SE
Total Clutter	Total Density	2.7 ± 5.1
	Gap Index	95.2 ± 57.3
	Canopy Height	2.4 ± 0.8*
Overstory	Overstory Density	-1.8 ± 7.2
	Legacy Tree Density	140.4 ± 37.4*
	P_{Canopy}	-20.4 ± 19.3
Midstory	Midstory Density	-2.7 ± 6.1
	$P_{Midstory}$	-72.7 ± 44.9
	$R_{Understory}$:Midstory	-1.4 ± 1.3
	$R_{Midstory}$:Canopy	30.0 ± 7.7*
Understory	Understory Density	-19.2 ± 11.1
	R_{Total}:Understory	-2.5 ± 48.9
	$P_{Understory}$	-172.2 ± 44.6*
	$R_{Understory}$:Canopy	46.5 ± 8.4*

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