ASSESSING RELATIONSHIPS BETWEEN LIDAR-DERIVED VEGETATION STRUCTURE AND BUTTERFLY DENSITY TO IMPROVE BUTTERFLY HABITAT MAPPING

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ABSTRACT

The assessment of both local and landscape level vegetation features is essential when comparing species presence and density to habitat characteristics. LiDAR remote sensing provides highly detailed information quantifying vegetation structural parameters that are often indicative of habitat quality at both local and landscape scales. Previous studies using LiDAR data for habitat assessment have compared vegetation structure to various species, but few have integrated both local and landscape scale data. This study evaluates the efficacy of pairing LiDAR data with field-based habitat measurements to characterize species-habitat relationships for four butterfly species in Northern Idaho, USA. LiDAR data was employed to characterize landscape-scale forest structural attributes, and field measurements were taken to quantify local habitat characteristics that may influence the butterfly species under investigation. According to a non-metric multi dimensional scaling ordination, the four butterflies addressed in this study are distributed into two groups, one more associated with LiDAR-derived vegetation metrics and the other more associated with percent cover of host plant and landscape-scale landcover characteristics. We conclude that incorporating LiDAR data in habitat-species relationship studies may allow for more in-depth evaluations of habitat quality and structure across large spatial extents.

KEYWORDS: LiDAR, butterfly habitat, species-habitat relationship, vegetation structure, ordination.

INTRODUCTION

Developing our understanding of species-habitat relationships can improve habitat models and lead to improved management and conservation strategies. However, investigating species-habitat interactions across large spatial extents is challenging. Indeed, characterizing vegetation structure at spatial scales that are biological meaningful to wildlife can be difficult (Seavy et al., 2009). However, in recent years the assessment of vegetation structure at larger spatial scales has been facilitated through the use of remotely sensed data. The continual development of remote sensing systems that are sensitive to three-dimensional vegetation structure (e.g., Light detection and ranging (LiDAR)) are further improving large area species-habitat studies.

LiDAR data have demonstrated utility in assessing three-dimensional vegetation characteristics that are important for wildlife, such as bird habitat (Martinuzzi et al. 2009; Seavy et al., 2009; Bradbury et al. 2005), beetle habitat (Müller and Brandl, 2009), and more recently, spider habitat (Vierling et al., In Press). Vierling et al. (In Press) assessed the use of LiDAR-derived variables to describe spider species distributions and community characteristics, finding that the predictive power of the LiDAR-derived variables was equal to or greater than that of ground measurements. Similar studies are likely to generate valuable insights into species-habitat dynamics and may ultimately aid in the development of more effective conservation strategies.

The primary objective of this study was to evaluate the use of LiDAR data for characterizing butterfly habitat in Latah County, Idaho, by integrating field measurements of local-scale habitat quality with LiDAR derived measurements of vegetation structure. We ask if LiDAR-derived measurements of vegetation structure can be combined with ground-measurements to quantify local-habitat quality and explain variation in butterfly density across a structurally diverse ecosystem.

METHODS

Study Area

This study was conducted on the Palouse Range in North Idaho USA, on the western extent of the Clearwater Mountains of Idaho (Figure 1). The landscape is characterized by the boundary between the mostly-forested Clearwater Range of the Rocky Mountains and the grasslands of the Palouse Prairie Region of Eastern Washington. Forests are dominated by: *Pinus ponderosa* C. Lawsom var. *scopulorum* Englem., *Pseudotsuga menziesii* (Mirb.), *Lariz occidentalis* Nutt, *Thuja plicata* Donn ex D. Don, Franco var. *glauca* (Beissn.) Franco, and *Abies grandis* (Douglas ex D Don) Lindl. The sharp interface between forests and grasslands in this study area is ideal for assessing the utility of characterizing butterfly habitat with remote sensing and ground measurements.

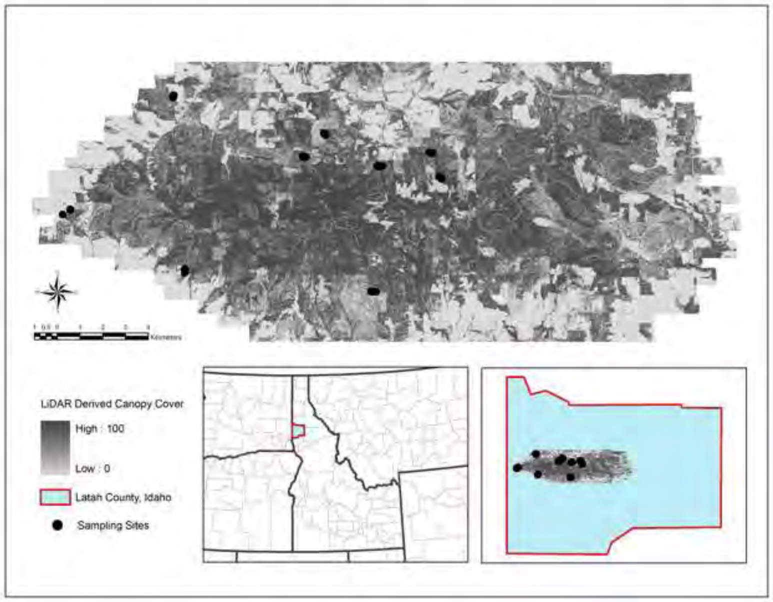

Figure 1. LiDAR data and butterfly density sites in Latah County, Idaho. LiDAR data is represented by derived canopy cover (in grey shades).

Field Data

Butterfly Density Data: Butterfly density and local-scale habitat characteristics were measured in the field across three transects at nine sites across the Palouse Range. Butterfly surveys were conducted five times per year in 2004 and 2005 using the distance sampling method (Buckland et al., 2004). The focal butterfly species of this study are *Coenonympha tullia*, *Celastrina ladon*, *Cupido amyntula* and *Vanessa cardui*, selected to represent two open forest and two grassland species.

Table 1. Field measurements from Pocewicz et al. (2009). Habitat measurements include larval host plant for all four butterfly species, as well as total nectar plant availability and amount of forest and grassland cover surrounding the site.

Field Measurement Habitat Variables (From Pocewicz et al. 2009)	
Reference Name	**Environmental Variable Desciption**
HCPazure	Percent cover of larval host plant for *Celastrina ladon*
HCPpainted	Percent cover of larval host plant for *Vanessa cardui*
HCPringlet	Percent cover of larval host plant for *Coenonympha tullia*
HCPtailed	Percent cover of larval host plant for *Cupido amyntula*
N.C.all	Overall vegetation canopy cover of potential nectar sources
all.forest.500	The area of forest cover, in ha, within 500m
all.grass.500	The area of grassland cover, in ha, within 500m
all.forest	The area of forest cover, in ha, within 1km
all.grass	The area of grassland cover, in ha, within 1km
favorable.5	The area of meadow, prairie, and young forest within 500m
favorable.1	The area of meadow, prairie, and young forest within 1km

Field Habitat Measurements. Vegetation sampling was conducted over a six-week period in 2004 and included measurements of percent cover of vegetation, including nectar and host plant cover, and forest stand structure (Table 1). Land use types and area of forest and grassland cover were classified from digital orthophotos.

Remote Sensing Data

Discrete return LiDAR were acquired during the summer of 2003 across the Palouse Range study area, using Optech ALTM30 system. The Multi-scale Curvature Classification algorithm (Evans and Hudak, 2007) was used to classify LiDAR returns into ground and non-ground returns, and a high-resolution (2 m) digital elevation model was created from the classified ground returns. Numerous LiDAR metrics characterizing vegetation structure and surface topography were calculated at a 20 m spatial resolution and summarized along each butterfly transect (Table 2).

Table 2. LiDAR derived forest structure and topography attributes from Falkowski et al. (2009). Attributes include canopy cover, forest structure characteristics calculated by mean and standard deviation, and forest slope and aspect.

LiDAR Derived Forest Structure and Topography Metrics (From Falkowski et al. 2009)

Reference name	Environmental variable desciption
MEAN_canopy	Mean Canopy Cover (vegetation returns/total returns x 100)
MEAN_cti	Mean Compound Topographic Index (Tarboton, 1997)
MEAN_elev	Mean Elevation (m)
MEAN_hmax	Mean Maximum Height
MEAN_hmean	Mean Height
MEAN_mcnab	Mean Landform Index (McNab, 1992)
MEAN_slp	Mean Slope (%)
MEAN_str0	Mean Percentage of Ground Returns = 0 m
MEAN_str1	Mean Percentage of Non-Ground Returns > 0 m and ≤ 1 m
MEAN_str2	Mean Percentage of Vegetation Returns > 1 m and ≤ 2.5 m
MEAN_str3	Mean Percentage of Vegetation Returns > 2.5 m and ≤ 10 m
MEAN_str4	Mean Percentage of Vegetation Returns > 10 m and ≤ 20 m
MEAN_str5	Mean Percentage of Vegetation Returns > 20 m and ≤ 30 m
MEAN_str6	Mean Percentage of Vegetation Returns > 30 m
MEAN_trasp	Mean Transformed Aspect (°) (Roberts and Cooper, 1989)
STD_canopy	Standard Deviation Canopy Cover (vegetation returns/total returns x 100)
STD_cti	Standard Deviation Compound Topographic Index (Tarboton, 1997)
STD_elev	Standard Deviation Elevation (m)
STD_hmax	Standard Deviation Maximum Height
STD_hmean	Standard Deviation Mean Height
STD_mcnab	Standard Deviation Landform Index (McNab, 1992)
STD_slp	Standard Deviation Slope (%)
STD_str0	Standard Deviation Percentage of Ground Returns = 0 m
STD_str1	Standard Deviation Percentage of Non-Ground Returns > 0 m and ≤ 1 m
STD_str2	Standard Deviation Percentage of Vegetation Returns > 1 m and ≤ 2.5 m
STD_str3	Standard Deviation Percentage of Vegetation Returns > 2.5 m and ≤ 10 m
STD_str4	Standard Deviation Percentage of Vegetation Returns > 10 m and ≤ 20 m
STD_str5	Standard Deviation Percentage of Vegetation Returns > 20 m and ≤ 30 m
STD_str6	Standard Deviation Percentage of Vegetation Returns > 30 m
STD_trasp	Standard Deviation Transformed Aspect (°) (Roberts and Cooper, 1989)

Data Analysis

Ordination. An unconstrained non-metric multi-dimensional scaling ordination analysis (NMS) was conducted in PC-ORD (McCune and Mefford, 1999) to identify the important habitat features influencing the density of four butterfly species. Ordination was run on autopilot with a random starting configuration using the Sørensen's (Bray-Curtis) similarity coefficient. Significant environmental variables were determined by calculating Pearson's Correlation Coefficients (r) and p-values between axis scores and environmental variables. Environmental variables with a correlation of $r \geq 0.4$ and a p-value ≤ 0.01 for at least one axis were considered significant variables and chosen for further examination.

Correlation analysis between significant variables and butterfly density. Relationships between butterfly densities and important environmental variables (as identified by the ordination) were evaluated via a correlation analysis. Transformations were conducted on butterfly population data using log transformations to meet assumptions of linearity and homoscedasticity. Correlation analysis was then conducted between each butterfly density species and significant environmental variables.

RESULTS AND DISCUSSION

The first (λ = 0.391) and second (λ = 0.380) ordination axis explained 77.1% of the dimensional space, with 98% orthogonality. The NMS completed forty runs with real data and fifty runs with randomized data. A total of 54 entities and 1431 entity pairs were used in the correlation A total of 81 iterations were completed for the final solution, with a final stress of 17.634 for a 2-dimensional solution.

Important variables identified by the ordination included percent cover of larval host plant; cover of meadow, prairie, and young forest; canopy cover; maximum height; density of LiDAR ground returns; density of LiDAR non-ground vegetation returns between 0m and 1m; and percentage of LiDAR vegetation returns between 1 m and 2.5 m, and between and 10 m and 20 m (Figure 2). Overall, *C. tullia* and *C. amyntula* were highly associated with LiDAR-derived vegetation structure characteristics while *C. ladon* was highly associated with host plant cover and the availability of nectaring sites. *V. cardui* was associated with both forest structure and nectar plants (Figure 2).

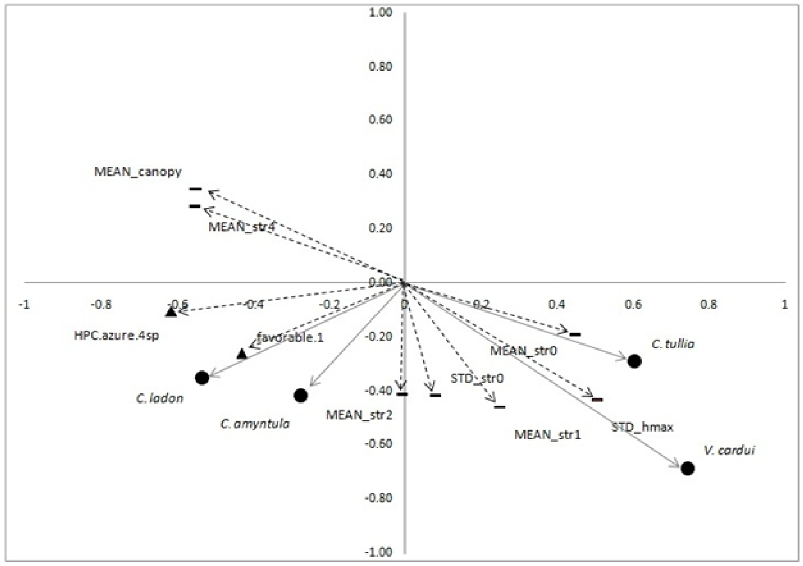

Figure 2. The ordination (axis 1 and 2) distribution of four butterfly species (represented by black squares and solid lines). Significant environmental variables with > 0.04, and p-value ≤0.01 include LiDAR metrics (represented by bars and dashed lines, and Field Measurements, represented by triangles and dashed lines).

C. ladon was most closely related to the percent cover of larval host plant for *C. ladon*, and the cover of meadow, prairie, and young forest within a 1km radius, while *C. tullia* was most closely related to mean canopy height and the percentage of ground returns. *C. amyntula* was most closely related to the density of LiDAR returns between 0m and 1 m, as well as the percent cover of larval host plant for *C. ladon*, the cover of meadow, prairie, and young forest within a 1 km radius, mean canopy cover, and the density of vegetation returns between 1m and 2.5 m. *V. cardui* was most closely related to the standard deviation of maximum canopy height, and the mean percentage of non-ground returns between 0m and 1m.

According to the correlation analysis, strong relationships were found between butterfly density by species and significant environmental variables (Table 3). There was a strong, inverse relationship between the density of *C. tullia* and canopy cover (r = -0.624, p = 0.004), and a strong, direct relationship between the density of *C. tullia* and the density of ground returns (r = 0.48, p = 0.037). This suggests that *C. tullia* prefers areas with little to no tree cover. *C. amyntula* density demonstrated a strong, positive relationships between the density of non-ground LiDAR returns between 0 m and 1 m (r = 0.689, p = 0.001), the mean percentage of vegetation returns between 1 m and 2.5 m (r = 0.574, p = 0.008), the percent cover of larval host plant for *C. ladon* (r = 0.483, p = 0.031), and the cover of meadow, prairie, and young forest within a 1 km radius of the transect (r = 0.533, p = 0.016). *C. amyntula* density also had a strong, inverse relationship with mean canopy cover (r = -0.465, p = 0.039). These results suggest that that *C. amyntula* prefers areas of low-lying vegetation with nectar plant availability, and especially large amount of nectar areas, such as meadows and prairies. *C. amyntula's* relationship with the host plant of *C. ladon* suggests that *C. amyntula* may display a preference for this host plant, and/or may share a dependency on this plant with *C. ladon*. *C. ladon* density was positively correlated with both percent cover of its larval host plant (r = 0.426, p = 0.005), and the cover of meadow, prairie, and young forest within a 1km radius (r = 0.439, p = 0.004), suggesting a strong relationship to its host plant, as well as a preference for areas high in nectar plant cover. Lastly, *V. cardui* density was strongly and positively correlated with the density of non-ground LiDAR returns between 0 m and 1m (r = 0.537, p = 0.001), as well as the standard deviation of maximum canopy height (r = 0.575, p < 0.000). This suggests

V. cardui density increases as canopy complexity increases, and that *V. cardui* shows a preference for understory vegetation.

Table 3. Correlations and P-values based on relationships between butterfly density and significant environmental variables. Strong relationships (r>0. 4 and p-value <0.05) are shown in boxes.

Environmental variables	*Celastrina ladon*		*Coenonympha tullia*		*Cupido amyntula*		*Vanessa cardui*	
	r	*P-value*	*r*	*P-value*	*r*	*P-value*	*r*	*P-value*
HPC.azure.4sp	0.426	0.005	-0.404	0.086	0.483	0.031	-0.088	0.620
favorable.1	0.439	0.004	-0.194	0.425	0.533	0.016	0.192	0.277
MEAN_canopy	0.145	0.366	-0.624	0.004	-0.465	0.039	-0.264	0.131
STD_hmax	-0.058	0.718	0.319	0.183	0.390	0.089	0.575	0.000
MEAN_str0	-0.314	0.046	0.480	0.037	0.249	0.291	0.170	0.336
STD_str0	0.152	0.344	0.186	0.445	0.295	0.202	0.322	0.063
MEAN_str1	0.082	0.610	-0.242	0.318	0.689	0.001	0.537	0.001
MEAN_str2	0.134	0.402	-0.245	0.312	0.574	0.008	0.246	0.161
MEAN_str4	0.111	0.490	-0.362	0.128	-0.381	0.097	-0.323	0.062

CONCLUSIONS

This study demonstrates that combining LiDAR metrics and ground-data measurements can be used to identify vegetation characteristics that are important for butterfly habitat. This strongly suggests that the utilization of LiDAR allows for a more detailed, larger-scale evaluation of butterfly habitat. Based on the findings of this study, we recommend the use of LiDAR remote sensing in the assessment of vegetation structure that can then be extrapolated across the landscape, the evaluation of species-habitat relationships where species are strongly associated with vegetation structure, and in associated conservation management practices.

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