Abstract

Habitat losses are a major threat to avian biodiversity. In order to preserve habitat, patterns of biodiversity must be understood. Habitat structure is a key factor influencing biodiversity, however the relationships between structure and richness are not fully understood and methods for characterizing habitat structure over broad extents are lacking. I will develop methods to quantify horizontal and vertical vegetation structure at broad scales, and I will test hypotheses on the relationship between structure and richness. Landsat-derived texture measures will be used to characterize horizontal structure, while vertical structure will be quantified by lidar data, including texture measures thereof. In addition to the separate analysis, these two methods will be integrated to examine if the approaches are complementary. Based on the Landsat texture approach, I will produce nationwide maps of predicted avian species richness of several functional avian guilds. Finally, I will simulate lidar data from NASA's upcoming DESDynI mission, and evaluate the ability of these data to explain variability in avian species richness. This project will advance NASA's goals of improving ecosystem models and advancing methods to characterize horizontal and vertical habitat structure in the context of conservation and biodiversity.

Overview

Human-driven land use change and associated habitat losses are major threats to biodiversity (Manne et al. 1999, Pimm et al. 1995). With increasing development pressure on many of the Earth's ecosystems, the identification and preservation of high-value habitat is crucial. Biodiversity hotspots have been identified at global scales (Reid 1998), but less effort has been focused regionally, where management decisions are more often applied. Habitat structure, climatic stability, and productivity are the major factors determining species richness patterns (Gaston 2000, MacArthur 1972, Rosenzweig 1995). To identify important habitat, these factors must be quantified over large extents. Remotely sensed measures of climate and productivity are relatively mature, while there is no consensus on measuring habitat structure. There is a crucial need for methods to quantify both vertical and horizontal habitat structure over broad scales. My aim is to establish these methods and advance understanding of factors influencing biodiversity. NASA has recognized the characterization of horizontal and vertical habitat structure to aid conservation assessments of habitat and biodiversity as a specific goal of the upcoming DESDynI Radar/Lidar Space Mission (DESDynI 2007). In addition to the technical aspects of characterizing habitat structure, I will explore hypotheses about the impact of habitat structure on avian richness patterns.

Horizontal structure, the spatial arrangement of vegetation over an area, has long been recognized as an important factor in species habitat requirements (Wiens 1974, Cody 1981, Mcgarigal and Mccomb 1995). For instance, some species thrive on edges, transitions between vegetation types, while others require contiguous areas of one vegetation type. Because measures of horizontal structure must incorporate contextual information over large areas, field-based measurements are logistically difficult. I will use texture measures derived from Landsat imagery to quantify horizontal habitat structure.

Vertical habitat structure has been recognized as especially important in determining bird species diversity (MacArthur and MacArthur 1961, Wiens and Rotenberry 1981). Standard methods for measuring vertical vegetation structure in the field are labor intensive, limiting coverage to small areas. Lidar is emerging as the most promising tool for characterizing vertical structure with nearly continuous sampling over relatively broad extents. I will evaluate the ability of lidar, including simulated DESDynI data, to characterize vertical habitat structure in a manner meaningful to bird biodiversity.

My project has 3 primary goals: (1) evaluate several approaches of characterizing habitat structure from remotely sensed data, (2) enhance understanding of how habitat structure affects avian species richness, and (3) produce maps of predicted avian species richness on a national scale. I will take three approaches to characterizing habitat structure. First, I will analyze the ability of texture measures from Landsat imagery to quantify horizontal structure. Second, I will utilize lidar data to characterize vertical habitat structure. Third, I will combine the two approaches to determine their relative effectiveness. In each case I will evaluate the effectiveness in capturing habitat characteristics relevant to avian species richness overall, and for several functional guilds. As part of this analysis, several hypotheses will be tested about the relationship between avian richness and habitat structure. Based on these models, I will produce a nationwide map of predicted avian richness. Lastly, I will simulate data from the lidar sensor on DESDynI, and evaluate the effectiveness of these data in explaining variation in avian species richness. The following questions will be specifically addressed:

1. Measures of horizontal structure derived from Landsat imagery:
   1.1. Which texture measures are most effective at predicting species richness of specific bird guilds, and do these relationships vary between ecoregions?
2. Measures of vertical structure derived from lidar:
   2.1. Can avian species richness be modeled from lidar-derived measures of forest structure?
   2.2. Can avian species richness be modeled directly from lidar data, including first- and second-order texture measures?
3. Integration of horizontal and vertical measures of habitat structure:
   3.1. Are Landsat- and lidar-derived measures of habitat structure complementary in explanatory power of spatial patterns in avian species richness?
4. Exploration of simulated DESDynI lidar data
   4.1. Can avian species richness be modeled from simulated DESDynI lidar data?

Background

Geographic patterns in biodiversity have long been recognized. Positive relationships exist between biodiversity and area sampled (Williams 1943), habitat structure (MacArthur 1972, MacArthur and MacArthur 1961), available energy or productivity (Wright 1983, Currie 1991), and environmental stability (Fjeldsa and Lovett 1997, Fischer 1960). Biodiversity is negatively associated with elevation (Stevens 1992) and latitude (Fischer 1960, Wallace 1878). Understanding the causes of spatial patterns in biodiversity is still one of the most pressing challenges for ecologists (Gaston 2000). Many of the observed trends are encompassed by Macarthur's (1972) hypothesis that biodiversity is a function of habitat structure, productivity, and climatic stability. This framework is especially amenable to studies using remotely sensed data over very broad (regional or national) extents.

Remotely sensed measures of productivity and climatic stability are relatively mature, and broad-scale analyses of these factors on biodiversity have been carried out (e.g. Currie et al. 2004, Rowhani et al. 2008). In contrast, relatively few studies have attempted to measure habitat structure over broad extents for biodiversity modeling. Some studies have had success relating landscape metrics to species richness (Atauri and de Lucio 2001, Farina 1997, Donovan and Flather 2002), however, landscape metrics characterize the composition and configuration of land cover types, ignoring within-class heterogeneity (Turner et al. 2001). Other approaches have attempted to characterize horizontal habitat structure directly from passive, optical remote sensing data (Kayitakire et al. 2006, Tuttle et al. 2006).

One promising approach is the calculation of first- and second-order texture measures (Haralick et al. 1973). First-order (occurrence) measures are summary statistics calculated from the spectral values of pixels in a moving window. Second-order measures are based on the gray-level co-occurrence matrix (GLCM) (Haralick et al. 1973), a matrix representing the relative frequency at which certain gray-tone levels occur in adjacent pixels. Second-order measures of texture are more commonly used than first-order (Coburn and Roberts 2004), because they take into account information about the spatial distribution and dependencies of spectral values.

Measures of texture derived from satellite imagery have successfully modeled habitats for greater rheas in grasslands of Argentina (Bellis et al. in press) and avian species richness in the Chihuahuan desert (St-Louis et al. 2006, St-Louis et al. 2008). Because of the high availability of satellite imagery, it is important to assess whether this technique can be effective over broad extents and in habitats with more complex vertical structure, such as forests.

Lidar offers an unprecedented opportunity for synoptic measurement of vertical habitat structure. Because of its ability to penetrate into lower canopy strata, lidar has the potential to characterize the vertical habitat structure in ways optical remote sensing cannot. Lidar has already been found an effective tool for measuring canopy height, cover, and standing biomass (Hyde et al. 2005, Hyde et al. 2006). The vertical distribution of canopy elements derived from lidar imagery can be effective in predicting avian species richness in eastern forests (Goetz et al. 2007).

Study Area

My study will be consider three areas. Image texture analysis will encompass the entire continental United States while the lidar analysis will study the Baraboo Hills region of Sauk County, Wisconsin, as well as Oconto County, Wisconsin. The Baraboo Hills are noteworthy for their contiguous forest cover and diverse natural communities. The field sampling encompasses approximately 6,000 acres in Devil's Lake State Park and The Nature Conservancy's land (Fig.1) in the Baraboo Hills and nearly 130,000 acres of National and County Forest in heavily forested Oconto County (Fig. 2).

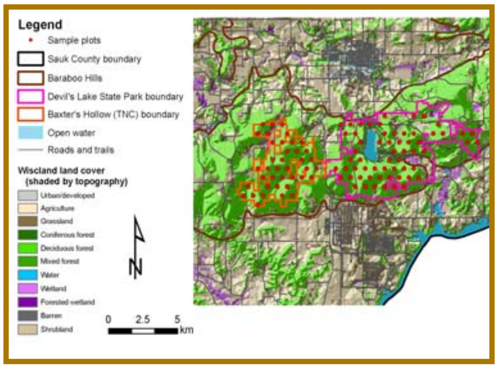

Figure 1. Baraboo Hills Study Area

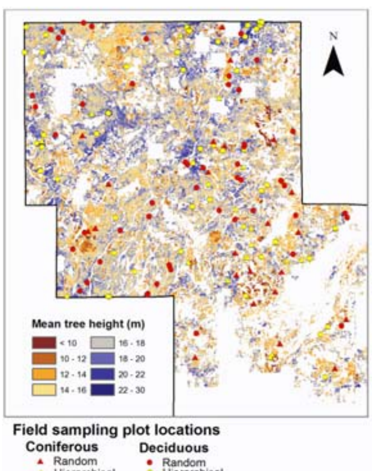

Figure 2. Oconto County Study Area

Approach

1.1. Which texture measures are most effective at predicting species richness of specified bird guilds, and do these relationships vary between ecoregions?

Avian species richness estimates will be inferred from the Breeding Bird Survey (BBS, USGS PWRC 2008), an annual survey of approximately 3,000 routes across the U.S. Along each 39.4 km route, fifty 3-minute point counts are conducted, and all birds heard or seen are recorded. To account for underdetection, I will use the software COMDYN (Hines et al. 1999) to estimate richness from the point count data.

A suite of first- and second-order textures will be calculated from a mosaic of Landsat images covering the continental United States. Surface reflectance images from the year 2000 made available by the LEDAPS project (http://ledaps.nascom.nasa.gov/) will be utilized. If variation is present in the phenological stage of the LEDAPS imagery, preference will be given to texture measures that are more robust to phenological variation (Culbert et al. in review). A 20-km radius buffer will be created around the center of each BBS route, and the mean and standard deviation of each texture will be calculated within each of these buffers. The buffer size encompasses the route and roughly corresponds to the dispersal distance of fledgling birds (Sutherland et al. 2000). Models of species richness, within functional guilds (e.g. forest, grassland, Neotropical migrants, short-distance migrants, and permanent residents) will be created for each ecoregion (Bailey 1995). Based on these models, regression kriging (Odeh et al. 1995) will be used to produce nationwide maps of avian richness by guild.

As a preliminary analysis, textures were calculated from a Landsat mosaic of Wisconsin, and species richness was estimated from 91 BBS routes. Multivariate linear models of simple first-order texture measures (3x3 variance, multiple bands) explained 63% of variation in richness of Neotropical migrants.

Hypotheses: Both first- and second-order texture measures will be useful in explaining species richness, with a general pattern of higher variability corresponding to higher richness. The most effective textures and the directions of the relationships will vary among ecoregions. Habitat guilds will exhibit a stronger relationship with texture measures than migratory guilds.

Outcome: I will produce nationwide maps of avian species richness by guild. These maps will provide assessment of habitat structure and aid land managers in making decisions about habitat preservation. A manuscript of these results will be submitted to Ecological Applications.

2.1. Can avian species richness be modeled from lidar-derived measures of forest structure?

Lidar has been successful in estimating forest stand attributes (Naesset et al. 2004). Since these attributes are related to vegetation structure, it may be possible to model species richness from them. I will be using Lidar-derived measures of forest structure from a recently completed study (Hawbaker et al. in review, Hawbaker et al. in press). Lidar data were collected over the Baraboo Hills and Oconto County study areas using a small-footprint, discrete-return Leica ALS50 flown in leaf-off conditions during May 2005. At 119 field plots (Fig. 2) in the Baraboo Hills and 111 plots in Oconto County, ground truth data were collected measuring tree density, dbh, basal area, mean tree height, and total volume and shrub cover. Regression models were derived to estimate these forest stand attributes from the lidar signal. At each Baraboo Hills study plot, two songbird point counts (Ralph et al. 1993, Buckland et al. 2001). I will conduct point counts at the Oconto County plots following the same protocol.

Lidar-derived measures of vegetation height and height variability have been used with moderate success to explain variability in avian richness (Goetz et al. 2007) as well as the distribution of breeding skylarks in an agricultural setting and the breeding success of great tits and blue tits in broad-leaved woodland (Bradbury et al. 2005). I will create a model to explain avian species richness at each plot as a function of timber attribute measures estimated from the Lidar data. Close attention will be paid to shrub and sapling structure, as understory layers are important habitat to many bird species. I will also create a model using the ground truth data from each study plot in order to evaluate the influence of error in the lidar-derived estimates. Separate models will be derived at each study site (Baraboo and Oconto) to compare the relationships, and a full model will also be created with pooled data from both sites.

Hypotheses: Avian species that nest in the canopy and midstory vertical strata will have the greatest richness in forests with lower tree density and higher basal area. There will be greater richness of species that nest in early successional habitats in areas with higher tree density and lower basal area.

Outcome: I will determine if any commonly used lidar-derived forest stand attributes are useful in predicting avian species richness. A manuscript will be submitted to Conservation Biology.

2.2. Can avian species richness be modeled directly from lidar data, including first- and second-order texture measures?

In the Baraboo Hills study area, basic lidar measures were significantly correlated with avian species richness (Lesak et al. in review). I will build on this approach by including the second study site (Oconto County) and adding texture measures of lidar data. First-order measures of texture have been used in a supervised land-cover classification of lidar data (Charaniya et al. 2004), however, to the best of my knowledge, no studies have explored second-order texture measures for lidar data, and lidar-derived texture has not been used in the context of habitat or biodiversity modeling. I will create rasters of the study area using the difference between the first and last return of the lidar pulses, as well as returns binned to correspond to specific vegetation layers. I will then calculate first- and second-order texture measures of these surface rasters. These texture measures will capture vertical structure as well as horizontal structure (spatial arrangement of vertical structure). Each texture will be summarized for a buffer around the plot corresponding to the effective distance of the bird point count. I will then model species richness of each plot as a function of that plot's textures.

Hypothesis: Texture measures calculated from lidar data will be effective at predicting species richness, because they will characterize the vertical structure of the forest as well as the horizontal spatial arrangement of this structure.

Outcome: I will determine if texture measures derived from lidar data are effective in predicting avian species richness. A manuscript will be prepared and submitted to Remote Sensing of Environment.

3.1. Are Landsat- and lidar-derived measures of habitat structure complementary in explanatory power of spatial patterns in avian species richness?

Texture derived from Landsat imagery has the advantage of a large catalog of imagery, both spatially and temporally. Landsat imagery is limited though in its ability to capture vertical habitat structure. In contrast, lidar is well suited to measure vertical structure but limited in its ability to detect differences among vegetation types. The question is how the two types of remotely sensed data could be integrated to better capture vegetation structure, especially as it relates to avian biodiversity. Over the Baraboo Hills and Oconto County study areas, I will use multiple linear regression to model avian species richness as a function of Landsat- and lidar-derived texture measures. Because performance of these measures will likely differ with forest type, I will see if improvement is made by including Anderson level II (Anderson et al. 1976) forest type from the 2001 NLCD (Homer et al. 2004). Through model selection techniques I will compare the performance of both Landsat and lidar data and determine to what degree the two approaches are redundant or complementary in their ability to quantify habitat structure.

Hypothesis: In modeling bird species richness, models including both Landsat- and lidar-derived measures will be superior due to their combined ability to capture both horizontal and vertical structural information.

Outcome: I will determine how effective Landsat- and lidar-derived texture measures are at measuring habitat structure relevant to birds, and whether these two approaches are complementary or redundant. A manuscript will be prepared and submitted to Remote Sensing of Environment.

4.1. Can avian species richness be modeled from simulated DESDynI lidar data?

A major difficulty in the use of lidar data is the limited geographic extent of most lidar data sets. The planned development of the DESDynI radar/lidar sensor (DESDynI 2007) will help alleviate this problem. In order to evaluate the ability of the DESDynI's lidar sensor to characterize habitat structure, I will aggregate the returns in the lidar data for my two study sites to simulate 25 m spatial resolution waveform data (Blair and Hofton 1999). When generating simulated datasets, I will use multiple vertical bin sizes and introduce noise to simulate several accuracy levels. Because DESDynI will not provide wall-to-wall lidar coverage, I will take a transect approach to analyzing the data, and calculate measures of image texture from the 1-dimensional vector of lidar response data (as compared to the 2-dimensional matrix approach used in question 2.2).

Hypothesis: Texture measures of the simulated DESDynI lidar data will explain some variation in avian species richness, though due to the 1-dimensional transect nature of the data set, results will be inferior to texture measures derived from wall-to-wall lidar data.

Outcome: I will determine the effectiveness of a texture-based analysis of simulated DESDynI lidar data. A manuscript will be prepared and submitted to the Journal of Geophysical Research.

Timeline

Year	2009	2010				2011				2012		
Quarter	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Question 1.1	DA	AN	AN	MP								
Question 2.1			DA	AN	AN	MP						
Question 2.2					DA	AN	AN	MP				
Question 3.1								DA	AN	MP		
Question 4.1										DA	AN	MP

DA – Data Acquisition, AN – Analysis, MP – Manuscript Preparation

Significance

Preserving levels of biodiversity is crucial, particularly as land-use change reduces available habitat. To maintain current levels of biodiversity, we must be able to recognize areas of high species richness. We must also understand the habitat factors that determine these hotspots, and currently, methods to characterize habitat structure over broad extents are lacking. My study will have positive impacts on three levels, basic science, methodology, and management. I will further the understanding of the relationship between habitat structure and avian biodiversity. I will advance methodologies by exploring measures of horizontal and vertical structure, integrating texture and lidar, and evaluating the performance of simulated data for the lidar sensor of the upcoming DESDynI satellite. Most importantly, my results will have implications for biodiversity conservation and management. I hope to make a significant contribution to all three of these areas by completing this project that helps fill the need for applied research in the field of biodiversity conservation.

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