ECOLOGICAL INFORMATICS 2 (2007) 9–22

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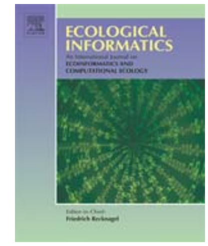

Multi-dimensional vegetation structure in modeling avian habitat

*Kathleen M. Bergen**, *Amy M. Gilboy*, *Daniel G. Brown*

University of Michigan, United States

ARTICLE INFO

Article history:
Received 31 December 2006
Accepted 2 January 2007

Keywords:
Bird habitat
Forest structure
Landscape structure
Radar
Landsat
GARP

ABSTRACT

The goal of this study was to evaluate the contributions of forest and landscape structure derived from remote sensing instruments to habitat mapping. Our empirical data focused at the landscape scale on a test site in northern Michigan, using radar and Landsat imagery and bird-presence data by species. We tested the contributions of multi-dimensional forest and landscape structure variables using GARP (Genetic Algorithm for Rule-Set Production), a representative modeling methodology used in biodiversity informatics. For our multi-dimensional variables, radar data were processed to derive forest biomass maps and these data were used with a Landsat-derived vegetation type classification and spatial neighborhood analyses. We collected field data on bird species presence and habitat for northern forest birds known to have a range of vegetation habitat requirements. We modeled and tested the relationships between bird presence and 1) vegetation type, 2) vegetation type and spatial neighborhood descriptions, 3) vegetation type and biomass, and 4) all variables together, using GARP, for three bird species. Modeled results showed that inclusion of biomass or neighborhoods improved the accuracy of bird habitat prediction over vegetation type alone, and that the inclusion of neighborhoods and biomass together generally produced the greatest improvement. The maps and model rules resulting from the multiple factor models were interpreted to be more precise depictions of a particular species habitat when compared with the models that used vegetation type only. We suggest that for bird species whose niche requirements include forest and landscape structure, inclusion of multi-dimensional information may be advantageous in habitat modeling at the landscape level. Further research should focus on testing additional variables and species, on further integration of newer radar and lidar remote sensing capabilities with multi-spectral sensors for quantifying forest and landscape multi-dimensional structure, and incorporating these in biodiversity informatics modeling.

1. Introduction

Biodiversity and ecosystem informatics is an emerging field that has been defined as “the creation, integration, analysis, and understanding of information regarding biological diversity” (Biodiversity Informatics, 2004). A core need of biodiversity informatics is the capability to produce maps not only of known locations of biological species occurrences, but also potential locations of these the same species based on similar habitat properties (Pennisi, 2000). To accomplish this, biodiversity informatics increasingly relies on inductive methods and models to map habitat and range of species. Several modeling approaches, including GARP (Genetic Algorithm for Rule-Set Production) use museum or field species presence data in conjunction with environmental layers. To construct realistic models and output habitat maps, input environmen-

* *Corresponding author.*
E-mail address: kbergen@umich.edu (K.M. Bergen).

1574-9541/$ - see front matter
doi:10.1016/j.ecoinf.2007.01.001

tal layers describing essential habitat requirements or range characteristics are required.

At landscape to regional scales, landscape structure is increasingly believed to be a primary factor determining the habitat preferences of species (Dunning et al., 1992; Wiens, 1995; Boulinier et al., 2001). In addition to vegetation type, landscape patch metrics such as shape, size, and edge, are among the variables contributing to a quantitative definition of landscape structure (McGarigal and Marks, 1995), but spatially continuous geostatistical methods and neighborhood-based descriptions for categorical or continuous data may also be employed (Gustafson, 1998). This component of landscape structure has a largely horizontal definition. Quantifying vertical or volumetric structure creates a multi-dimensional description. For example, tree canopy height, biomass, density, understory presence, and/or canopy layering are also important structural variables for many forest bird species (Morgan and Freedman, 1986).

Biodiversity informatics uses spatial data of land cover and vegetation derived from remotely sensed datasets (Gottschalk et al., 2005). The capabilities of multi-spectral passive optical sensors such as Landsat, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), SPOT (Systeme Pour l'Observation de la Terre), or MODIS (MODerate Resolution Imaging Spectroradiometer), are useful for discriminating vegetation type and horizontal structure. Newer radar and lidar sensors have the capability to directly quantify vertical and volumetric dimensions of vegetation structure. The fusion of radar or lidar capabilities with widely available optical data, such as that from Landsat, and interpreting them for multi-dimensional structural characteristics is generating significant interest for describing forest and landscape structure (Bergen et al., 2006).

1.1. *Study objectives*

Our goal was to assess the value of integrating radar and optical remote sensing data to model multi-dimensional habitat space. We used empirical data at the landscape scale for a test site in Northern Michigan, using SIR-C radar and Landsat imagery and bird species data observed in the field to map bird habitat characteristics. Our primary modeling methodology was based on GARP, a representative modeling method used in biodiversity informatics. Our specific objectives were to: 1) create multi-dimensional vegetation structure and bird species datasets; 2) develop models and test for the influence of forest and landscape structure on habitat predictions, 3) assess output model accuracies, and 4) interpret the usefulness of forest and landscape structure environmental layers for habitat mapping.

1.2. *Background*

Birds can be particularly responsive to characteristics of forest multi-dimensional structure. While some bird species are generalists, many species have narrower ecological niches. Along with the composition of vegetation, niche discriminating characteristics can include the amount and configuration of horizontal patches (James and Wamer, 1982; McGarigal and McComb, 1995; Flather and Sauer, 1996), patch area (Howe, 1984; Boecklen, 1986; Freemark and Merriam, 1986), edge effects (Flaspohler et al., 2001; Chalfoun et al., 2002), and forest cover and fragmentation (Trzcinski et al., 1999).

Observations have also shown that suitable habitat for a bird species may be based on volumetric and vertical characteristics of the vegetation (Morgan and Freedman, 1986). These include stand age, height or biomass (Probst and Weinrich, 1993; Green and Griffiths, 1994; Nelson and Buech, 1996; Buchanan et al., 1999), shrub versus forest structure (Goransson, 1994), structure of a shrub layer within forests (Reid et al., 2004), and effects of forest thinning (Siegel and DeSante, 2003). One prior study focused on radar-based mapping of vegetation structure and bird diversity, where bird species and abundance were observed to change across both vegetation type and structural gradients. The authors concluded that some measure of vegetation structure is needed to understand how birds perceive habitat (Imhoff et al., 1997).

Both optical and radar image data are potentially suitable for classifying land cover and vegetation and providing maps of horizontal landscape structure. However, classifications derived from optical remote sensing instruments such as Landsat at fine (30 or 60 m) spatial resolutions (Vogelmann et al., 2001), and MODIS at coarser (1 km) spatial resolutions (Friedl et al., 2002; Hansen et al., 2005) are more widely available. Of these, the sensor used is determined by the spatial scale of the question, e.g. landscape, regional or global. Vegetation classifications derived from 30 m Landsat data are appropriate for landscape to regional-scale analysis and, in forested areas, are often produced at a level of detail equivalent to forest communities (Anderson Level II), and sometimes to species or species groups (Anderson Level III; (Anderson et al., 1976). Land-cover and vegetation classifications may also serve as the basis for calculating metrics of landscape horizontal structure.

Of all sensor types, the active sensors radar and lidar have the greatest capabilities for directly describing vegetation vertical and volumetric structure. Active sensors transmit and receive their own energy rather than relying on reflected sunlight to form an image, and radar sensors do so in the longer microwave portion (~1 mm to ~1 m wavelengths) of the electromagnetic spectrum. Radars are described by their wavelengths (e.g. C-band at approximately 6 cm, L-band at approximately 23 cm); transmit-receive polarizations (horizontal or vertical propagation of radar waves); energy incidence angles with respect to Earth's surface; and spatial resolutions (Lillesand et al., 2004). Radar reflection (called backscatter coefficient, or $\sigma°$, in decibels) at a given wavelength, polarization, and incidence angle is determined by earth terrain structural properties and electrical properties. In the case of forest vegetation, structural properties are the dominant factor; where the specific contributing structural properties of vegetation canopies are 1) size distribution of components (for trees main stem, branches, and foliage) relative to wavelength, 2) orientation of components, and 3) number of reflecting components (Ulaby et al., 1986).

This dependence of radar backscatter on the structural properties of vegetation, in addition to the capability of long off-nadir wavelengths to penetrate through the vegetation canopy, is the basis for radar's ability to provide direct estimates of vegetation structure (Pierce et al., 1998).