Integrating Radar Remote Sensing of Habitat Structure: A Pilot Project for Biodiversity Informatics

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Abstract

Mapping for biodiversity informatics requires information on habitat so that known species occurrences may be extrapolated to maps of potential species occurrences. In the case of vegetation requirements for habitat, most current datasets of actual vegetation have been derived from optical (e.g. aerial photography or Landsat) remotely sensed data. These data are largely limited to describing horizontal structure: vegetation community composition and landscape spatial metrics. This paper introduces new radar remote sensors that are more suited to directly measure vegetation height and other multi-dimensional forest structural variables such as density, basal area, and biomass, and to map these as continuous fields over large areas. We discuss this in the context of bird species, one of the taxonomic groups whose habitat preferences may be strongly influenced by multi-dimensional structure. The site for the pilot study is the Michigan Forests Test Site (MFTS) in the Upper Peninsula of Michigan, an area of mixed hardwood and coniferous forest communities. Our study uses two methods, one inductive and one deductive, to investigate the utility of incorporating radar data into biodiversity informatics databases. We evaluate the use of radar alone and also in combination with Landsat data for mapping of bird habitat for biodiversity informatics.

1. Introduction

Mapping for biodiversity informatics requires information on habitat so that known species occurrences may be extrapolated to maps of potential species occurrences (Pennisi 2000). That is, given the conversion of known specimen locations into maps, how can we best predict where additional individuals or populations of that species may occur? In the context of landscape ecology, landscape structure – its multi-dimensional components – is a primary basis for habitat preferences of bird species. Vegetation spatial composition, heterogeneity, variability, and scale are among the variables contributing to the horizontal structure (McGarigal and Marks 1995); while vegetation height, layering, basal area and biomass are examples of variables in the volumetric dimension. Combined together these variables, and others, describe the real multi-dimensional structure of habitat.

Current spatial data, including those derived from remote sensing instruments and used in growing biodiversity informatics databases are largely limited to describing horizontal structure. These two-dimensional models of habitat are artifacts of technology (i.e., remote sensing and contemporary geographic information science), but not necessarily sufficient to fulfill the conceptual needs for biodiversity informatics. Fortunately, the technology has advanced. New radar and lidar sensors can directly measure vegetation height, and can penetrate the vegetation canopy and directly estimate other quantitative variables related to forest structure (Dobson, Ulaby et al. 1992; Bergen, Dobson et al. 1997; Bergen and Dobson 1999). Our work on a NASA test site for the SIR-C/X-SAR spaceborne imaging radar confirmed the ability of radar to directly estimate biophysical variables: height, density, basal area, and trunk, crown, and total biomass, and to map these as continuous fields.

We are developing a pilot demonstration study and evaluation of the contribution of new radar remote sensing instruments to mapping habitat for biodiversity informatics. We will compare the results with models created using multispectral (e.g., Landsat) data alone and in synergy with the radar data, to assess the information content of radar data for biodiversity informatics mapping. We are incorporating an educational outreach component into our project and will produce a demonstration module and presentation on the potential contributions of radar remote sensing to biodiversity informatics.

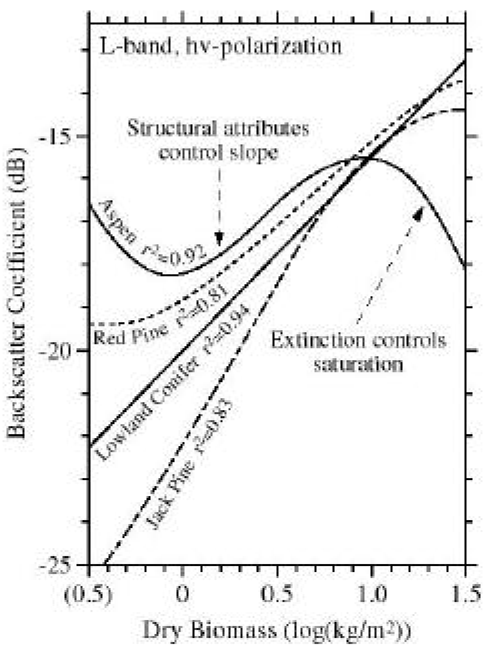

Figure 1. Forest structure controls the slope of the relationship and the saturation level for a given radar wavelength and polarization

2. Scientific Background

2.1 Imaging Radar

Imaging radars are active sensors that propagate their own energy, receive all or part of it back, and form an image. Radars use the longer microwave portion (~1 mm to 1 m wavelengths) of the electromagnetic spectrum and can be described by their frequency(s), polarizations, incidence angles, and spatial resolutions. Radar reflection (backscatter) at a given wavelength and polarization is determined by earth terrain 1) structural or geometric properties, and 2) dielectric properties. The 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 (Dobson, Ulaby et al. 1995). This dependence of radar backscatter on the larger structural properties of vegetation, in addition to the capability of much longer off-nadir wavelengths to penetrate through the vegetation canopy, is the basis for radar's ability to directly estimate multi-dimensional vegetation structural parameters. Numerous studies have now demonstrated the relationship between radar backscatter and vegetation structural parameters height, density, basal area, and trunk, crown, and total biomass (Dobson, Ulaby et al. 1992; Dobson, Ulaby et al. 1995; Bergen, Dobson et al. 1997; Bergen and Dobson 1999) (Figures 1 and 2). Radar interferometry, a related technique, is suited for deriving tree heights. Beginning in 1992 four orbiting radars (ERS-1, ERS-2, JERS-1, and RADARSAT) have provided global coverage and three Space Shuttle missions have carried imaging radars (SIR-C/X-SAR in 1994 and SRTM in 2000). New orbiting radars (ALOS/PALSAR, ENVISAT-1/ASAR, RADARSAT-2) will be launched in the next several years. NASA, the European Space Agency (ESA), and programs such as Global Observation of Forest Cover (GOFC) are encouraging development of radar-derived datasets such as vegetation height and biomass over broad geographic regions.

2.2 Bird Species and Structure

Much has been researched and written on the importance of two-dimensional landscape structure in habitat preference of birds. Other studies have concentrated on particular bird species and their relationship with multi-dimensional vegetation structure. Theoretical models based on field data and habitat suitability databases specify vegetation composition, height (or height/age relationships) and

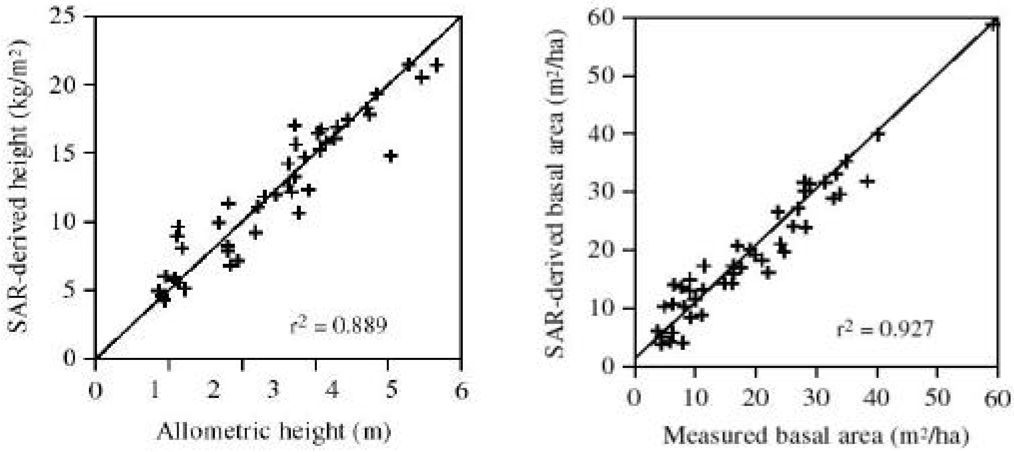

Figure 2. Showing the strong positive correlation between field measurement and radar derived forest structural variables.

density requirements. The NORTHWOODS database, developed at the USDA Forest Service North Central Research Station (NCRS) and derived from field data, is one example.

The multi-dimensional structural habitat of some species has been examined in-depth. In the case of the Northern Spotted Owl (*Strix occidentalis caurina*), researchers determined that structural characteristics of forests preferred for nesting and foraging owls were related to canopy height, dbh (diameter at breast height), basal area, canopy closure, snag presence, tree density, and tree height class diversity, as well as more specific individual tree-based preferences (Buchanan, Irwin et al. 1993). The Kirtland's Warbler (*Dendroica kirtlandii*) is a species that depends on the fire-dominated Jack pine (*Pinus banksiana*) forest communities in northern Michigan for its nesting habitat. The warbler prefers to occupy dense jack pine barrens from 5 to 23 years old and from 1.4 to 5.0 m high, formerly of wildfire origin.

Use of remote sensing for acquiring horizontal or multi-dimensional structure has received less attention than field investigations. Jorgensen (Jorgensen and Nohr 1996) used AVHRR INDVI (Integrated Normalized Vegetation Index) to estimate biomass production over the Sahel and as an indicator of biological diversity, noting this is useful primarily in landscapes with large heterogeneity in the horizontal plane like the Sahel. Researchers in Yellowstone National Park used Landsat and a geographic information system (GIS) to categorize habitats a priori and then determined the relationship between remotely sensed habitat categories and species distribution patterns (Debinski, Kindscher et al. 1999). Bayesian modeling was used to predict probability of occurrence for 14 Maine land bird species. The relationships between bird survey data and the spectral values of Landsat bands 4 and 5 plus texture were used (Hepinstall and Sader 1997). Applications of active sensors that directly interrogate vegetation structure are even more rare.

One previous study focused on radar mapping of vegetation structure and bird habitat (Imhoff, Sisk et al. 1997). Airborne multi-frequency polarimetric radar showed that 1) radar was successful in discerning structural differences relevant to bird habitat within otherwise similar community composition, and 2) the abundance of individual bird species were observed to change significantly across both floristic and structural gradients. The authors concluded, "these results suggest that efforts to map bird diversity should focus on species-specific habitat relationships and that some measure of vegetation structure is needed to understand bird habitat".

3. Research Approach

Our approach involves the implementation and evaluation of two modeling methodologies. We are: 1) integrating radar-derived variables of multi-dimensional vegetation structure with a priori rule-based habitat models and producing maps of potential habitat, 2) using the same radar data with a sample of known species locations and genetic algorithm software (GARP) to predict potential habitat, 3) evaluating the results from the two methods compared with use of multi-spectral (e.g., Landsat) imagery alone and in synergy.

3.1 Study Site

NASA established the Michigan Forests Test Site (MFTS) in the eastern Upper Peninsula of Michigan for radar ecology in 1990. The site has several physiographic regions that support a cross-section of communities: upland conifers, northern hardwoods, lowland conifers, lowland hardwoods, forested and herbaceous wetlands, rangeland, and agricultural lands. Much of the site is in the Hiawatha National Forest. Seventy 4-ha forest calibration stands representing the range of communities, ages, and densities were measured (Bergen 1997), as were fifteen rangeland and agricultural fields. Available imagery includes SIR-C/X-SAR, ERS, JERS, Landsat, and SPOT. All images were orthorectified, georegistered, filtered (radar), and classified. Spatial biophysical datasets (for forests composition, height, basal area, trunk, crown, and total biomass) have been derived from SIR-C by the authors. All results have been carefully validated. GIS data include test stand locations and attributes, topography, and hydrology.

The NCRS supports the NORTHWOODS database of species habitat preferences. The Hiawatha St. Ignace District Office has research reports and observation datasets for bird species that they study or monitor as part of their a) regional forest sensitive species list, b) management indicator species, and/or c) research projects with university faculty and students. We have selected the bird species we will model based on a) the importance of the species to the USFS, b) the available data on species habitat structural requirements, and c) the types of habitat that the species uses. The species currently included in the study are Sharp-tailed Grouse (*Tympanuchus phasianellus*), Kirtland's Warbler (*Dendroica kirtlandii*), Black-throated Blue Warbler (*Dendroica caerulescens*), Northern Goshawk (*Accipiter gentiles*), and Spruce Grouse (*Dendragapus Canadensis*).

3.2 Computational Methods

First, we are applying a deductive approach using our derived data for both habitat structure description and bird species habitat requirements. The remote sensing datasets include mapped vegetation composition, height, basal area, and trunk, crown and total biomass derived from SIR-C radar imagery of an approximately 20 by 50 km area in the MFTS. The bird habitat dataset is the NORTHWOODS database that contains summary habitat requirements for 389 species of birds and other animals derived from original field sighting data. The models are standard Boolean procedures, and may be simple or more complex. We are implementing these in the Modeler module in ERDAS Imagine. This software is designed for interactive model development on multi-layer thematic or continuous datasets.

Second, we are also implementing a complementary (i.e., inductive) modeling method for mapping predicted species habitat. We are using the GARP genetic algorithm software, associated with the Biodiversity Workshop: http://biodi.sdsc.edu/Doc/GARP/ (Payne and Sotckwell). Our overall approach is to run the program for the selected species of interest using observation data from the Hiawatha, the radar-derived data, and any ancillary data employed in the first method as the environmental input datasets. The output datasets will be maps of potential suitable habitat. Our rationale for using the derived radar datasets is 1) this will allow us to compare the two modeling methods, and 2) radar-derived datasets of e.g. vegetation height and biomass are likely to be increasingly available.

To do an evaluation of the added utility of radar data, first we will use Landsat-derived data and compare model results based on two-dimensional structure information only (i.e., the current state-of-the-art) with results from model runs that also include multi-dimensional structural information derived from radar images. Second, by comparing the rule-based deductive model of species presence and preference with the genetic algorithm-based inductive approach, holding input data constant, we will develop an understanding of the degree of variability in model results that is attributable to modeling method.

4. Future Work

Building on the important biodiversity efforts of museum curators and biodiversity managers, remotely sensed data facilitates extrapolation of known locations to potential locations. Further, because of the repeat observation capabilities of remote sensing, the influence of change in species habitat due to land-use change or natural disturbances can be monitored. Radar remote sensing can be used to map and monitor several environmental variables, including land cover, moisture, and multi-dimensional landscape structure. All are important and their importance varies by taxonomic group. Multi-dimensional structure is a landscape characteristic that is key to major taxonomic groups. This project is developing a sound understanding of the complementarities and/or advantages of incorporating radar data into biodiversity informatics systems using appropriate modeling methodologies. In addition to the core informatics applications developed here, the data, once incorporated, may also be used to answer biodiversity research questions such as those related to variability and diversity across multi-dimensional landscapes and to enhance visualizations of landscape structure.

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