INTEGRATING MULTIPLE DATASETS FOR THE REMOTE QUANTIFICATION OF WOODLAND BIRD HABITAT QUALITY

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ABSTRACT:

Vegetation structure influences habitat selection for woodland birds and is a key component determining habitat quality. At Scandlaser 2003, and elsewhere, we have demonstrated the application of airborne LiDAR data for organism-habitat modelling. In this paper we review the results of our pilot study which focussed on two species of tits, Great Tit *Parus major* and Blue Tit *Parus caeruleus*, in a mixed broadleaved woodland in lowland England. We showed that reproductive performance can be related to woodland structure, but that this varies temporally in relation to local and regional scale climatic drivers. This paper outlines the planned future direction of this research project. We are examining the integration of airborne and ground-based LiDAR data and the development of analytical techniques to derive information on underlying terrain, canopy height, density, gap fraction, surface roughness and the under-storey shrub layer. We are also examining the integration of LiDAR and multispectral data for mapping thematic classes that combine plant species and canopy structure information. With the acquisition in 2003-04 of remotely sensed data (LiDAR and multispectral) and bird census data (nestbox and territory mapping) for a number of woods in lowland Britain, we will construct and test habitat quality maps to relate species distributions, abundances and patterns of persistence to habitat structure and composition.

1. INTRODUCTION

Vegetation structure is an important component of habitat quality. For terrestrial birds, vegetation structure influences both nesting and foraging habitat quality and thus plays a major role in habitat selection (Fuller and Henderson, 1992; Beier and Drennan, 1997). Structure may affect the ease of movement for foraging birds both physically (Brodmann et al., 1997) and behaviourally (Desrochers and Hannon, 1997) and may influence foraging efficiency through effects on detectability and accessibility of food items (Moorcroft et al., 2002; Whittingham and Markland, 2002).

In work reported previously, we have used LiDAR data acquired with an Airborne Laser Terrain Mapper (ALTM 1210) to measure the vegetation structure of a broadleaved woodland in Cambridgeshire, UK (Hill et al., 2002a, 2002b; Gaveau and Hill, 2003; Patenaude et al., in press). These data were acquired in summer 2000 at a sampling density of 1 laser hit per 4.8 m^2, with elevation recorded for the first and last surfaces illuminated by each laser pulse. We have used these data to show that under certain conditions reproductive performance in Great Tits *Parus major* and Blue Tits *Parus caeruleus* is related to woodland structure, particularly canopy height (Hinsley et al., 2002). For our study area (Monks Wood, Cambridgeshire) in spring 2001, the mean nestling mass of Blue Tits at 11 days of age increased with mean canopy height for a sample area around each occupied nestbox. For Great Tits, an inverse relationship occurred in spring 2001. Both Great Tits and Blue Tits feed their young on tree-dwelling lepidopteran larvae. Canopy structure influenced habitat quality via effects on both food abundance and its availability to parent birds. During the unfavourable weather of spring 2001, the best foraging conditions for Blue Tits occurred where the canopy was tall and well-developed, but for Great Tits a shorter canopy with a more varied height profile was most favourable (Hinsley et al., 2002). The relationship between mean canopy height and mean nestling body mass in spring 2001 was used to generate a map predicting nestling mass for Great Tits, and hence habitat quality, throughout Monks Wood (Hill et al., in press).

Food availability for woodland birds is also influenced by weather conditions, which will affect both food abundance and birds' foraging abilities (Pasinelli, 2001). By examining reproductive data from nestboxes occupied by Great Tits over a 6 year period for the pilot study area we have shown that the nature of the relationship between reproductive success and habitat structure varies temporally in relation to regional scale climate drivers (Hill et al., 2003). When conditions for breeding are poor (e.g. cold, late springs), nestling mass declines with canopy height, but when conditions are good (e.g. warm, early springs), nestling mass increases with canopy height. These relationships between nestling mass and canopy height were statistically significant (at $P < 0.1$) under the 'extremes' of cold and warm experienced in the six year period, but not under the more 'average' conditions. The woodland structure conferring 'best' habitat quality for Great Tits has thus been shown to differ with climate. Habitat selection by Great Tits therefore needs to be flexible and not determined by fixed preferences, and may be predictable in advance (Hill et al., 2003).

The pilot analyses which focussed on two species of tits distributed amongst a maximum of 36 nestboxes across a 157 hectare woodland have thus generated insights into organism-habitat relationships. However, the representativeness, statistical significance, and generality of these results need to be demonstrated more robustly. In addition, whilst vegetation structure is a key variable influencing woodland habitat quality, there are other environmental factors to consider. For example: tree and shrub species composition (Lavers et al., 1996;

Whittingham et al., 2003); spatial characteristics such as size, pattern, fragmentation (Hinsley et al., 1995; Nour et al., 1998); and disturbance and management regimes (Donald et al., 1998; Fuller, 2000). Biotic factors can also be influential, such as: parental quality (Przybylo et al., 2001; Ferns and Hinsley, 2004), and bird population density and resultant competition for nest sites and food (Lack, 1971; Minot, 1981). Of these factors, vegetation structure, plant species composition and spatial metrics can all potentially be derived by remote sensing techniques, whilst issues of bird density and competition can be investigated by examining territories of individual birds.

This paper outlines the planned future direction of this research project. We are examining the integration of airborne and ground-based LiDAR data and the development of analytical techniques to derive information on underlying terrain, canopy height, density, gap fraction, surface roughness and the under-storey shrub layer. We are also examining the integration of LiDAR and multispectral data for mapping thematic classes that combine plant species and canopy structure information (Hill et al., 2002c; Hill and Thomson, submitted). By taking a parcel-based approach this can provide a spatial framework within which bird species distribution, abundances and productivity can be predicted. With the acquisition in 2003-04 of remotely sensed data (LiDAR and multispectral) and bird census data (nestbox and territory mapping) for a number of woods in lowland Britain, we will construct and test habitat quality maps to relate species distributions, abundances and patterns of persistence to habitat structure and composition. The field sites, bird data and remotely sensed data will be described in detail in this paper and the research aims specified.

Figure 1. Location of the study sites: 1. Wytham Woods (Oxfordshire), 2. Sheephouse Wood (Buckinghamshire), 3. Brampton Wood (Cambridgeshire), 4. Monks, Holland, Wennington and four small woods (Cambridgeshire), 5. Bradfield Woods (Suffolk).

2. DESCRIPTION OF THE STUDY SITES

The study sites include eight woodlands in Cambridgeshire (of which Monks, Brampton, Wennington, and Holland Woods are the largest), and in addition, Wytham Woods in Oxfordshire, Sheephouse Wood in Buckinghamshire, and Bradfield Woods in Suffolk (Figure 1).

2.1 Wytham Woods (Oxfordshire)

415 ha. A mixed deciduous woodland of ancient abandoned Hazel coppice with English Oak standards, natural regeneration of secondary woodland (mostly Common Ash and Sycamore), plantations of mostly English Oak and Beech, and areas of scrub, marsh, and semi-natural grass. It is an Environmental Change Network site.

2.2 Sheephouse Wood (Buckinghamshire)

40 ha. Predominantly high forest English Oak. Other canopy trees include Common Ash, Field Maple, Wild Service, Silver Birch and Aspen. The under-storey is principally Hazel and Hawthorn. The wood is managed for timber using the contrasting techniques of clear felling and group felling and thus has a range of physical structures. The wood is a Site of Special Scientific Interest.

2.3 Brampton Wood (Cambridgeshire)

132 ha. A mixed deciduous woodland of Field Maple, Common Ash, English Oak, Silver Birch, Aspen, and ancient abandoned Hazel coppice. There are some blocks of Spruce and Pine spp. Brampton Wood is a Wildlife Trust Nature Reserve. The wood was almost entirely clear-felled in the 1960s and hence has relatively few old trees. A notable feature is the extensive, dense growth of blackthorn and other shrubs.

2.4 Monks Wood (Cambridgeshire)

157 ha. Semi-natural deciduous woodland, dominated by Common Ash and English Oak, but also containing Field Maple, Aspen, and Silver Birch. The woods were affected by felling during World War I and Dutch Elm Disease in the 1970s. As a result, few trees are greater than 80 years old and Small-leaved Elm is relatively uncommon and localised. The under-storey is principally Hazel, Hawthorn and Blackthorn. The wood was declared a National Nature Reserve in 1953 and Hazel coppicing was suspended in 1995 due to excessive damage to regrowth by muntjac deer *Muntiacus reevesi*.

2.5 Holland and Wennington Woods (Cambridgeshire)

72 ha & 26 ha. Mixed semi-natural ancient woods with Common Ash, English Oak and Field Maple dominating the canopy, and Hawthorn, Blackthorn and Hazel dominating the under-storey. Holland Wood also has some large specimens of Scots Pine, Lime and Horsechestnut. One edge has recently been replanted with mixed deciduous trees following clearance of a large Blackthorn thicket. Areas of Wennington Wood where mature Small-leaved Elm trees have died were cleared and replanted with English Oak, Common Ash and Field Maple which combine with regenerating Elm and Blackthorn as open scrub. These two woods are privately owned.

2.6 Riddy, Lady's, Raveley, and Gamsey Woods (Cambs)

9ha, 8 ha, 6 ha, 4 ha. Semi-natural ancient woods with a canopy of Common Ash, English Oak, Field Maple and Elm with a shrubby under-storey of Hawthorn and Blackthorn. There are some scrubby clearings. Riddy Wood is privately owned, whilst the remaining three are leased by the local Wildlife Trust and are managed for nature conservation. Timber extraction in the 1960s has resulted in few large trees remaining.

2.7 Bradfield Woods (Suffolk)

62 ha. An ancient working coppiced woodland dominated by Alder, Common Ash, Silver Birch and Hazel coppice with English Oak, Common Ash and Silver Birch standards. It is a National Nature Reserve, but as an actively worked site, the woods contain large areas of coppice at different stages of growth.

3. DESCRIPTION OF DATASETS

This research project will make use of data gathered as part of long-term bird population monitoring programmes by the British Trust for Ornithology (BTO), Edward Grey Institute for Field Ornithology (EGI) at the University of Oxford, and the Centre for Ecology and Hydrology (CEH) at Monks Wood. This has been supplemented by additional field data collected in spring-summer 2003 and 2004. The project will also use archive airborne remotely sensed data plus additional data collected during 2003-04 by the NERC Airborne Remote Sensing Facility (ARSF). Ground-based laser data were collected in Monks Wood, coinciding with the timing of airborne data acquisition, by the Silsoe Research Institute (SRI).

Avian ecology datasets available from the BTO, EGI and CEH for this project include:

- Monks, Holland, Wennington, Brampton and surrounding Woods: the breeding success of Blue Tits and Great Tits from nestboxes established since 1993, territory mapping in plots and/or transects in Monks and Wennington Woods since 2000, population density estimates from spot counts in Monks, Wennington and Brampton Woods in 2003 (S. Hinsley and P. Bellamy, CEH).
- Wytham Woods: long-term population studies of Great Tits and Blue Tits from nestbox recording since 1947, territory mapping in a 7 ha census plot since 1972, and territory mapping in a 20 ha deer exclosure since 2002 (A. Gosler et al., EGI).
- Sheephouse Wood: full bird population census by territory mapping for 26 species since 1984 (R. Fuller, BTO).
- Bradfield Woods: full bird population census by territory mapping for 39 species in 2003, and territory mapping of Warblers and Nightingales for selected years since 1995 (R. Fuller, BTO).

Remotely sensed data for Monks Wood includes multispectral (CASI and ATM), hyper-spectral (HyMap), LiDAR (ALTM) and RADAR (E-SAR, multi-wavelength and polarisation) from the SHAC campaign of summer 2000. In addition, LiDAR data with a sampling density of 1 laser hit per m^2 and simultaneous CASI and ATM data with a resolution of 2 m were acquired in April and July 2003 for Monks Wood and the surrounding small woods. A sample under-storey dataset with information on location, height and canopy density was also recorded within a week of the airborne LiDAR data acquisitions using a ground-based laser scanner. For Brampton, Sheephouse, and Bradfield Woods, LiDAR data (1 laser hit per m^2) and simultaneous CASI and ATM data (2 m resolution) were acquired in summer 2003, whilst for Wytham Woods a similar dataset will be recorded in summer and winter 2004.

An example of some of the avian ecology and remotely sensed data available for one of the field sites (Riddy Wood in Cambridgeshire) is shown in Figures 2 and 3.

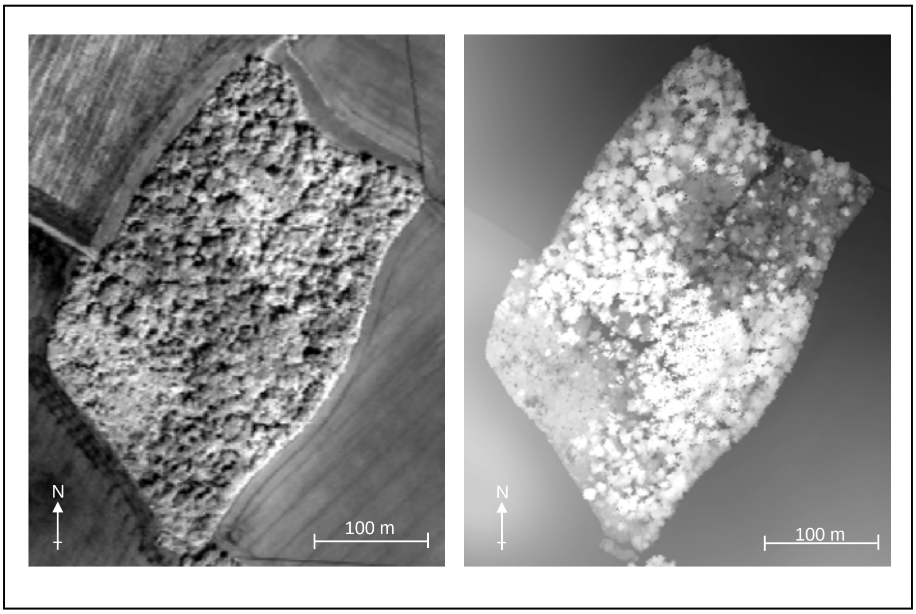

Figure 2. Sample remotely sensed data of Riddy Wood, Cambridgeshire; (left) grey tone image of a near infrared band of CASI data, pixel size is 2 m, (right) Digital Surface Model rendered from first-return LiDAR data interpolated into a 1 m resolution grid.

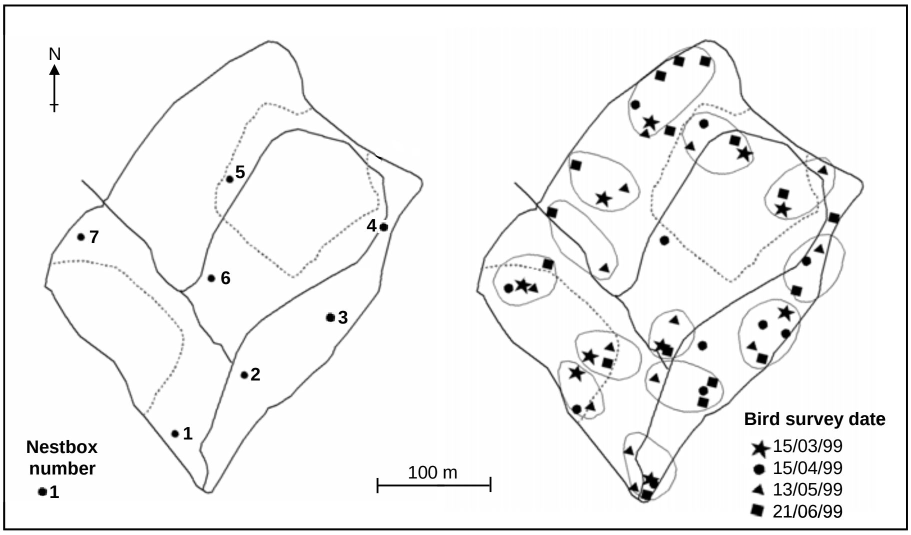

Figure 3. Sample bird data for Riddy Wood, Cambridgeshire; (left) location of the seven tit nestboxes in which breeding success is recorded each year, (right) individual bird registrations for Robin *Erithacus rubecula* recorded on four dates in 1999.

4. AIMS AND OBJECTIVES OF RESEARCH PROGRAMME

This research project seeks to expand on the successful pilot work by analysing a greater number of bird species over a wider diversity of woodland sites. This will build to the integration of diverse remotely sensed and field data using an approach to ecological modelling such as Ecological Niche Factor Analysis (Hirzel et al., 2001; Balzter et al., 2002) or Generalised Linear Modelling (Brotons et al., 2004). The overarching objective is to identify relationships between bird species population dynamics and habitat characteristics, and investigate how these vary over time in relation to external driving mechanisms. This will provide a base-line for the long-term monitoring of bird-habitat relationships, potentially elucidating the causes behind population decline in woodland birds. In addition, the derived models will enable the distribution, abundance, population persistence and breeding success of birds within and between woods to be predicted by remote sensing techniques.

This project contains three work packages, each with a specific aim. The first is to improve our ability to map woodland structural characteristics in small-footprint, discrete-return LiDAR data with a sampling density of one laser hit per m^2. By using the novel approach of combining airborne and ground-based LiDAR data acquired in both summer (full leaf canopy, minimum laser penetration) and winter (no leaf canopy, maximum laser penetration), the objective is to identify the information content regarding the under-storey layer and to devise a method of extracting this information accurately. The second aim of this project is to improve our ability to map woodland species using integrated multispectral and LiDAR data. This will also make use of the distinctions in data acquired in the summer and winter for Monks Wood and Wytham Woods. The third aim of this project is to improve our understanding of habitat quality (defined in relation to abundance and breeding success, territory occupancy and persistence) for a range of woodland bird species and identify how quality is affected by different weather conditions. This will enable the extension and development of the predictive modelling already demonstrated (Baltzer et al., 2002; Hinsley et al., 2002; Hill et al., 2003, in press) for a variety of woodland bird species, across a range of woodland sites with structures representative of UK lowland mixed deciduous woodland, and over several years. Additional data will also enable independent validation of the predictive models.

The specific objectives of this project are:

I. To investigate the proportion of top-canopy, under-storey and ground information in small-footprint, discrete-return LiDAR data (acquired by the ALTM 2033) for deciduous woodland in summer and winter.
II. To develop the current methods of LiDAR data processing to take account of increased laser sampling density and to reduce canopy height under-estimation in the derived value-added products.
III. To devise a method of mapping the under-storey shrub layer characteristics of deciduous woodland in airborne and ground-based LiDAR data.
IV. To investigate the potential to map woodland species composition and biomass using multispectral data (CASI and ATM) and LiDAR data (ALTM).
V. To characterise the canopy structural characteristics associated with individual territories for a range of bird species across 11 deciduous woodlands with structures representative of such habitat in lowland England.
VI. To examine the stability of territory location and distribution within Sheephouse Wood in relation to habitat structure over the period 1996-2004.
VII. To identify detailed relationships between breeding success and vegetation structure for Blue Tits and Great Tits across a range of woodland structures, and to identify how these relationships are influenced by other factors (e.g. tree species composition, woodland size, distance to woodland edge and weather conditions) across the eight Cambridgeshire woods and Wytham Woods.
VIII. To predict the distribution, abundance, persistence and breeding success of woodland birds using ecological models driven by remotely sensed data, and to validate such predictions with independent data.

5. CONCLUSIONS

By taking a unique multi-disciplinary approach that combines rapidly evolving LiDAR technology, multispectral data, leading-edge ecological modelling techniques and detailed time-series bird census and breeding data, the objective of this project is to demonstrate the utility and transferability of organism-habitat modelling in which the distribution, abundance, population persistence and breeding success of woodland birds can be predicted.

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