Ecologically informed bird habitat characterization with airborne laser scanning

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1. Introduction

As forests undergo succession there is a directional change in tree species composition and three-dimensional structure over time (Packham and Harding 1982). Across the landscape of Cambridgeshire, United Kingdom (UK) are many small woods undergoing succession embedded in a broader agricultural context. Within this dynamic environment occur bird species with variable habitat needs. Blue Tit (*Cyanistes caeruleus*) and Chaffinch (*Fringilla coelebs*) are habitat generalists, though preferences for woodland (Redhead et al. 2013) and hedgerow (Fuller et al. 1997) habitats have been noted, respectively. Chiffchaff (*Phylloscopus collybita*) and Willow Warbler (*Phylloscopus trochilus*) are habitat specialists, respectively favouring mature (Hinsley et al. 1996) and early successional (Bellamy et al. 2009) forests. The aim of this study is to characterize the habitat used by these species within a successional context using airborne laser scanning (ALS) data. ALS is suitable for describing forest structure (Lim et al. 2003), including successional contexts (van Ewijk et al. 2011), and is appropriate for characterizing bird habitat as birds use structural cues to select habitat (MacArthur et al. 1962).

2. Data

This study uses ALS data acquired in 2000, 2005, 2012 and 2015, and bird survey data from those same and two subsequent years. ALS were acquired during the leaf-on period and the characteristics are included in Table 1. Bird data were collected along transects across multiple revisits during spring and early summer mornings using a spot mapping method based on the Common Birds Census of the British Trust for Ornithology (Marchant 1983). Woods used in this study include Gamsey (4.9 ha), Lady's (8.4 ha), Raveley (7.2 ha), Riddy (9.4 ha), and two areas adjacent to Monks Wood National Nature Reserve previously used as farmland which were abandoned in 1996 (New Wilderness: 2.1 ha) and 1961 (Old Wilderness: 3.9 ha). These woods are populated by Common Ash (*Fraxinus excelsior),* English Oak (*Quercus robur*), Field Maple (*Acer campestre*) and Elm (*Ulmus spp.*), and shrub species including Common Hazel (*Corylus avellana*), Hawthorn (*Crataegus spp.*) and Blackthorn (*Prunus spinosa*).

Table 1. ALS acquisitions characteristics for all years.

ALS year	Scanner	Flight date	Returns per pulse	Returns per square metre
2000	Optech ALTM 1210	2000-06-10	2	0.27
2005	Optech ALTM 3033	2005-06-26	2	0.45
2012	Leica ALS50-II	2012-09-15	4	10.54
2015	Leica ALS50-II	2015-06-22	4	2.1

3. Methods

Terrain-normalized ALS structural variables describing the full vertical profile (e.g., ground level to top of canopy) and three strata (hereby S1, S2 and S3) were extracted from a circular plot with a 15 m radius

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at locations where the target bird species were present. The three strata correspond to actual levels of vegetation within the canopy (i.e., S1: shrub, <2 m; S2: understorey, 2-8 m; and S3: overstorey: >8 m). Structural variables describing the full profile and for each stratum include skewness, kurtosis, standard deviation, mean, and maximum height. Canopy closure and foliage height diversity metrics were also extracted. Global habitat models for each species were developed using random forest, a machine learning algorithm that generates a collection of decision trees to perform a classification (Breiman 2001), with data across all six woods and all studied years. Random forest output includes variable importance and a measure of out-of-bag (OOB) error (Breiman 2001). The area under the receiver operating characteristic curve (AUROC) was also calculated as a measure of the predictive performance (Fielding and Bell 1997).

4. Results

All four bird species were well modelled and the results are summarized in Table 2, which also includes the range of values characterizing the habitat occupied by each species. Willow Warbler had the lowest OOB error, followed by Blue Tit, Chaffinch, and Chiffchaff. Error associated with presence/absence differed in their magnitude for each species. For Blue Tit, error was relatively even for presence (17.1 %) and absence (16.7 %). Error associated with absence was lower for Chaffinch (16.6 %, versus 19.3 %) and Willow Warbler (7.8 %, versus 12.4 %). For Chiffchaff, error was lower for presence (24.2 %) than absence (33.8 %). AUROC values followed a similar pattern to OOB error, from highest to lowest: Willow Warbler, Blue Tit, Chaffinch and Chiffchaff. Maximum height of the full profile was important to all bird species. Chiffchaff was also associated with structural variables in S3 (maximum height and standard deviation). Willow warbler was associated with S1 (standard deviation and kurtosis). For Blue tit, foliage height diversity and S3 standard deviation were important. The most important variables for Chaffinch were canopy closure and the mean height of the full profile.

Table 2. Top three variables for each species identified by random forest, with model accuracy.

Species	Variable 1 *& range*	Variable 2 *& range*	Variable 3 *& range*	OOB Error	AUROC
Chiffchaff	Maximum height *12.5-18.6 m*	S3 maximum height *12.8-18.8 m*	S3 standard deviation *1.1-2.4 m*	29.0 %	0.79
Willow Warbler	S1 standard deviation *0.5-0.7 m*	S1 kurtosis *1.7-3.2*	Maximum height *4.6-9.6 m*	10.1 %	0.95
Blue Tit	Foliage height diversity *0.8-0.9*	Maximum height *11.3-17.6 m*	S3 standard deviation *1.1-2.3 m*	16.9 %	0.90
Chaffinch	Canopy closure *4-38 %*	Mean height *3.5-9.5 m*	Maximum height *10.1-16.7 m*	18.0 %	0.90

5. Discussion

The ability of ALS-derived variables to describe three-dimensional habitat structure has been shown in previous studies (Bakx et al. 2019; Bradbury et al. 2005; Goetz et al. 2007; Zellweger et al. 2013). Our study demonstrates that there are structural components to the habitat used by Chiffchaff, Willow Warbler, Blue Tit, and Chaffinch that can be quantified with ALS. Our results support ecological descriptors of habitat preferences. For instance, characteristics of the overstorey strata were significant to Chiffchaff whereas it is the shrub strata that is important to Willow Warbler, which is aligned with mature and early successional forest structures. In contrast, we found that Blue Tit and Chaffinch, considered habitat generalists, are not using space equally across the full vertical profile but are discriminating within specific height intervals. Our results also show that species are more specific in the structural components that they are either using (i.e., Chiffchaff) or not using (i.e., Chaffinch and Willow Warbler), suggesting that structural components can act as a deterrent or as an attractor. ALS data provides valuable information regarding the structure of bird habitat and ALS data availability is

increasing. Using ecological knowledge of the habitat structure (i.e., distinct strata), forest succession (i.e., changes over time), and bird species (i.e., habitat preference) to derive meaningful variables aids in result interpretability, and is useful for management and conservation applications.

6. Conclusions

This study uses ecologically informed ALS-derived structural variables to quantify Chiffchaff, Willow Warbler, Blue Tit, and Chaffinch habitat across six woods in Cambridgeshire, UK. All species were accurately modelled and their habitat could be characterized with random forest. Our results support ecological studies examining structural aspects of the habitat used by these bird species (e.g., Fuller et al. 2001), and remote sensing studies using ALS (e.g., Bellamy et al., 2009). A future study will build on these results to identify and quantify habitat across space and over time for each species.

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