Forestry Commission

Research Note

Implications of lowland broadleaved woodland management for the conservation of target bird species

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This research consisted of a literature review and field study which investigated woodland management for birds within lowland broadleaved woodlands in Britain. The research considered the effect of woodland management (silvicultural intervention and control of deer browsing) on vegetation structure, and the relationships between vegetation structure and woodland birds. Based on habitat–bird relationships, a classification of six woodland stand structures (A–F) related to their value to birds, and a framework to help understand and manage woodland development to deliver these structures were created. The field study, which was conducted in England and Wales, showed that woodlands are predominantly mature or late thicket stands, with low structural heterogeneity (type E – closed canopy, few strata), and silvicultural interventions are primarily mid to late rotational thinning. Such interventions lead to a uniform stand structure and reduced stem and understorey density. High deer browsing pressure also reduces understorey density. Study results showed these vegetation structures to be less favourable to the target bird species who were instead found to be associating with the structures predicted from the literature as being favourable. This suggests that vegetation structures for birds can be described, and if provided, bird populations could be enhanced. The frequently occurring woodland structure type E is of least value to woodland birds. Woodland managers are encouraged to move type E stands towards other types to help meet bird conservation objectives.

Introduction

Woodlands support a range of different bird communities, which vary according to woodland type and geographical location. Trends in breeding bird populations are used as one of the key indicators (the 'bird index') of the state of the UK's biodiversity and woodland bird populations remain of conservation concern and a policy priority. The woodland bird index fell by nearly 20% between 1970 and 2012, with declines especially pronounced for birds in southern broadleaved woods, but with an opposite trend seen in Scottish populations since 1994 (Balmer *et al*., 2013; Scottish Natural Heritage, 2015). There is particular conservation concern for a number of bird species, including 17 species which are the focus of the present study: Nightjar, Lesser spotted woodpecker, Willow tit, Marsh tit, Wood warbler, Willow warbler, Garden warbler, Song thrush, Spotted flycatcher, Nightingale, Pied flycatcher, Redstart, Dunnock, Tree pipit, Lesser redpoll, Bullfinch and Hawfinch. Several factors may drive the declines (Fuller *et al*., 2005), including pressures on birds during migration or when on wintering grounds outside the UK. Within the UK, climate change and impacts on land use outside woodlands may be affecting food resources, while increased predation pressure and competition between species may also be occurring. In woodlands, there have been changes in vegetation structure in recent decades, with a large proportion of lowland broadleaved woodlands becoming shadier due to canopy closure and many woods being increasingly heavily browsed by deer (Mason, 2007).

Vegetation structure can be altered by woodland management, both by the timing and type of silvicultural interventions applied and by management of deer browsing pressure. Based on our understanding of the resource requirements of the target bird species (Table 1), structural changes to vegetation could alter habitat suitability for birds, including many understorey-dependent birds, for example by altering the foliage within 2 m of the ground, an area that provides nest sites, food and cover.

A review of European literature showed that the relationships between woodland management and target bird species have been relatively well studied in coppice systems but information is sparser on the influence of woodland management on the target bird species in high forest systems (Table 2). The review also showed that, although early stages of growth in rotationally managed woodland may be valuable to several bird species, conventional stand thinning may have little positive effect on habitat suitability. There is strong evidence for the impact of deer on vegetation: deer browsing reduces vegetation in the low shrub layer (below 2 m), reduces the herbaceous component of the field layer and leads to an increase in coarse grasses and sedges (Gill and Fuller, 2007; Cooke and Farrell, 2001; Gill *et al*., 1996). Impacts on young coppice regrowth are particularly marked. However, there is a lack of knowledge about the direct effects of deer browsing on woodland birds in high forest systems and the links between habitat change and bird species response requires further study.

The research aimed to address knowledge gaps in those forest systems where the 17 target bird species are showing the greatest declines, by conducting:

- A field study in high forest, lowland broadleaved woodlands in England and Wales to test relationships between:
  - woodland management (both silviculture and deer) and woodland structure
  - birds and woodland vegetation structure features.
- A synthesis of knowledge on the resource requirements of woodland bird species and woodland habitat features to identify woodland structures likely to support the full range of woodland bird species.

Lowland broadleaved woodland field study

Design and survey methods

We established a selection of study areas where the effects of recent silvicultural intervention could be examined within woodlands of varying deer densities.

The field study was conducted on a sample of 300 woodland plots, selected as representative of woods in two regions of lowland Britain – southern England and the Welsh Marches (Figure 1). Based on prior knowledge of the status of deer in each study region, there was considered to be a gradient of deer density from 'High' to 'Low' in the two study regions (Figure 1). Roughly half of the plots within each region had been subject to silvicultural interventions in the last 20 years. Plots were not stratified by stand stage/structure. Study plots were chosen to be internally homogeneous with respect to the application of silvicultural interventions and broad structure. Their median area was 3.31 ha. All 300 plots (150 in each region) were subject to an extensive survey of birds and habitat, and a subset of 40 plots (20 in each region) were intensively surveyed for deer population density and vegetation structure.

For the extensive (300 plot) survey, birds were assessed using a four-visit territory mapping method (Hewson *et al*., 2007). Vegetation structure and composition was assessed using a suite of quantitative and qualitative measures in a Rapid Vegetation Assessment (RVA) (for details see Fuller *et al*., 2014, Appendix 3).

Table 1 Summary of resource requirements for 17 target bird species (migrant species indicated in **bold**). These relate to nesting, feeding and territory requirements as well as broader habitat associations and behaviour likely to be relevant in determining responses to changes in woodland structure. Principal food outside breeding season refers mainly to the UK rather than in migrants' wintering grounds. This summary is based on published information (for details see Fuller *et al*., 2014, Appendix 1).

		Hawfinch	Redstart	Pied flycatcher	Spotted flycatcher	Marsh tit	Willow tit	Lesser spotted woodpecker	Bullfinch	Lesser redpoll	Dunnock	Song thrush	Garden warbler	Tree pipit	Willow warbler	Wood warbler	Nightingale	Nightjar
Broadleaved	Woodland type	✘		✘		✘	✘	✘					✘			✘	✘	
Conifer										✘								
Young	Stage of woodland development						✘			✘	✘	✘	✘	✘	✘		✘?	✘
Mature		✘?	✘	✘	✘	✘		✘								✘		
Varied									✘									
Dense lower shrub layer	Woodland structure								✘		✘	✘	✘				✘	
Dense upper shrub layer						✘	✘								✘			
Sparse understorey			✘	✘										✘		✘		
Open canopy			✘		✘									✘	✘			
Closed canopy																✘		
Large trees		✘			✘			✘										
Open space														✘				✘
Unknown																		
Ground or near-ground	Nest site location													✘	✘	✘	✘	✘
Tall field layer or shrub layer									✘	✘	✘	✘	✘					
Canopy or tree cavities		✘	✘	✘	✘	✘	✘	✘										
Ground	Main foraging sites	✘	✘							✘	✘	✘		✘			✘	
Shrub layer							✘						✘					
Canopy		✘						✘		✘					✘	✘		
Aerial					✘													✘
Varied				✘		✘			✘									
Invertebrates	Principal food in breeding season	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘
Seeds		✘							✘									
Buds and flowers		✘							✘									
Invertebrates	Principal food outside breeding season																	
Seeds		✘				✘	✘		✘	✘	✘							
Fruit					✘							✘	✘				✘	

Woodland type = species not marked with an 'X' show no marked preferences. 'X' in grey means resource used to a lesser extent by species.

In the subset of 40 plots, deer population density was estimated by distance sampling, based on observations of deer made at night using thermal imaging (Gill *et al*., 1997). Half of the plots were in areas considered *a priori* as 'High' deer density and half were in areas considered *a priori* as 'Low' deer density. Vegetation structure was assessed by ground-based laser scanning (for details see Fuller *et al*., 2014, Appendix 4). This method creates a three-dimensional reconstruction of the woodlands, documenting foliage density and stem material across the entire vertical span of the canopy.

Results of the field study

Stand structures

Overall, 81% of the plots were classified as mature or late thicket stands. Other stand types, particularly the younger stages, were relatively rare in these long rotation high forest broadleaved systems. Only 21 plots (12 in the south and 9 in the Marches) were classed as recent plantations and 35 plots (20 in the south and 15 in the Marches) as recent natural regeneration. Overall,

Table 2 Summary of literature review findings on effects of woodland management on birds. Bird habitat features and their response to silvicultural interventions are listed by silvicultural system and stand stage/condition, the target bird species benefited and strength of available evidence. European literature was reviewed.

Silvicultural system	Intervention	Stand stage / conditions	Habitat response	Target bird species benefited	Evidence[1]
Coppice	Harvesting on a short rotation	Stem initiation / prior to coppice regrowth	Temporary open ground increase	Tree pipit	STRONG
		Stem exclusion / young woodland growth stages	Dense low / young woody vegetation provided	Nightingale, Willow warbler, Garden warbler, Dunnock, Song thrush, Bullfinch	
Clearfell	Harvesting and restocking	Early stem initiation / post-harvesting	Temporary open ground increase	Tree pipit, Nightjar	STRONG (but from conifer systems)
		Late stem initiation to stem exclusion	Dense low shrubby vegetation (bramble and birch + crop trees) – increase	Willow warbler, Garden warbler, Dunnock, Song thrush, Lesser redpoll, Bullfinch	WEAK (for variation of scale of intervention)
	Thinning c. 30–40% canopy	Stem exclusion to understorey re-initiation	Shrub layer – no change/ decrease Damaged and dead trees – decrease	No change in bird populations / lower numbers of ground- and shrub-nesting species compared to unthinned stands	MEDIUM
Low-impact silvicultural systems	Variable density thinning (<40% of canopy removed)	Stem exclusion to understorey re-initiation	Shrub layer – no change Mature trees – little change	Dunnock, Song thrush	WEAK
	Variable density thinning (>80% of canopy removed)	Stem exclusion to understorey re-initiation	Dense low shrubby vegetation – increase Mature trees – little change	Bullfinch, Hawfinch, Lesser redpoll, Garden warbler	
Restoration of planted ancient woodland sites	Thinning to remove non-native trees (when low % non-native trees)	Stem exclusion to understorey re-initiation	Dense low shrubby vegetation – no change Mature trees – little change	Dunnock, Bullfinch, Song thrush	WEAK
	Thinning to remove non-native trees (when high % non-native trees)	Stem exclusion to understorey re-initiation	Temporary open ground – increase Dense low shrubby vegetation – increase	Tree pipit, Willow warbler, Garden warbler, Dunnock, Song thrush, Bullfinch	

[1]Criteria defining classes of evidence strength:

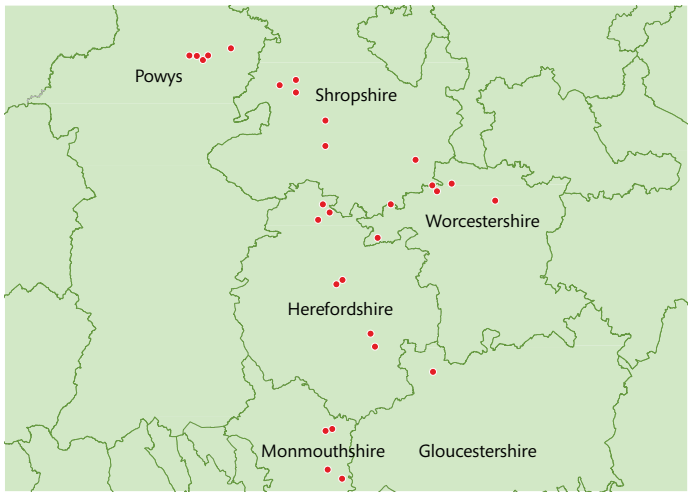
STRONG EVIDENCE – results were based on studies which between them fulfilled most of the following criteria.
1. Studies which include suitable comparisons between different stand types.
2. Based on several sources, the results of which concur.
3. Most studies from UK.
4. Studies have recorded impacts on vegetation structure and birds.
5. Studies with good replication of sites and/or studied over suitable timescales.

MEDIUM EVIDENCE – results were based on studies which between them fulfilled most of the following criteria, but may also include some of the criteria for strong evidence.
6. Based on few studies.
7. Results may include inference from studies of other forest types, e.g. boreal and Mediterranean forests.
8. Few studies include effects on birds, with further inference drawn from vegetation effects.

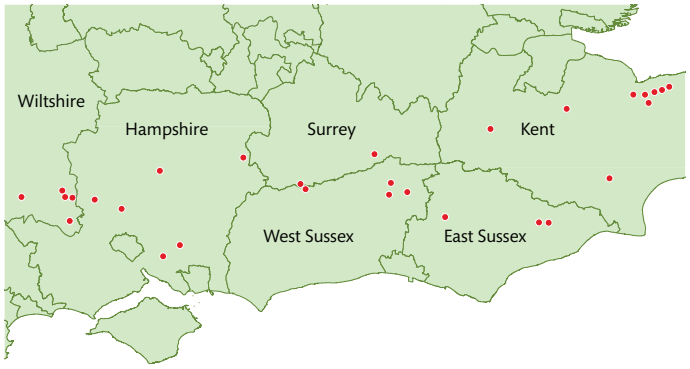
WEAK EVIDENCE – results were based on studies which between them fulfilled most of the following criteria, and may include some of the criteria for medium evidence but none of the criteria for strong evidence.
9. Information is based on anecdotal information.
10. Results from different studies are contradictory.
11. Little or no direct evidence for birds with inference drawn from effects on woodland structure.
12. Based on a single study that does not include replication or suitable comparisons.

Figure 1 Approximate locations of sites in southern England and the Welsh Marches that were sampled in the extensive field study of lowland broadleaved woodland. A total of 150 plots were studied in each area. These were located within 30 large woodland blocks, as shown on the maps below. The sites were distributed across a gradient of deer abundance (Area A – relatively high in the west and relatively low in the east, Area B – relatively high in the south and relatively low in the north).

Area A



Area B



25% of the plots were within PAWS restoration sites, with similar numbers in each region. The most commonly applied interventions appeared to be mid to late rotation thinning, rather than end of rotation harvesting and restocking. Consequently, only a restricted range of the full variety of stand structures possible within a high forest system were available for this study.

Bird species

Forty-nine bird species were recorded in the study plots in sufficient numbers to enable their analysis. Blackbird, Blue tit, Great tit, Robin, Woodpigeon and Wren were recorded from almost all the plots. Of the target species, Song thrush and Marsh tit were the most frequently recorded, occurring in half or more of the study plots. Dunnock, Spotted flycatcher and Bullfinch were the next most abundant (recorded in a quarter to a third of the plots), followed by Willow warbler, Garden warbler, Redstart and Pied flycatcher (10–25% of plots). The least frequent target species were Wood warbler, Lesser spotted woodpecker, Tree pipit, Nightingale, Lesser redpoll, Nightjar, Willow tit and Hawfinch, the latter four being encountered too infrequently for inclusion in the analysis.

Deer species encountered during the field survey were mostly roe and fallow deer, with muntjac deer being recorded in much smaller numbers. No red or sika deer were seen.

Effects of woodland management

Woodland management is here taken to mean silvicultural intervention and control of deer browsing. The effects on woodland habitat structure attributable to silvicultural intervention were investigated through a number of tests of association using data from the extensive (300 plot) and intensive (40 plot) surveys.

Associations between woodland habitat structure and silvicultural intervention were found from the extensive survey data but were not clear from the intensive survey. Plots with recent silvicultural interventions appeared more uniform in structure, with a reduced stem number and understorey cover, and a tree canopy that contained less birch compared to the plots without recent silvicultural intervention.

The effects of deer on vegetation were considered for the 40 intensive survey plots only (20 'High' and 20 'Low' deer density class), as deer density class was validated by population density estimates for these plots. Strong associations were found for the effects of deer density on vegetation with reduced foliage and stem density, and reduced understorey cover recorded where deer density was higher.

Bird abundance and habitat features

Tests for the relationships between habitat features and abundance or presence–absence of individual bird species encountered in the extensive survey were conducted in two different ways:

1. Empirical habitat–bird relationships: analyses conducted using only the data collected in the field study.
2. Hypothesis testing of habitat–bird relationships: habitat–bird relationships indicated from the literature review (Table 1) were tested using the field study data.

Empirical habitat–bird relationships

Separate analyses were undertaken for individual species. The important structural habitat features for target species for which valid models could be constructed are summarised in Tables 3 and 4. Table 3 shows that the combinations of habitat features were highly species-specific. For example, both Bullfinch and Marsh tit abundance was positively associated with tree height and understorey cover occurring between 2 m and 4 m above the ground, and negatively associated with understorey cover below 2 m, but showed contrasting response to grass cover.

Table 4 indicates which structural habitat features were the

Table 3 An overview of positive (+) or negative (–) effects of structural habitat features based on multivariate model weights for the target species for which there were sufficient data for analysis. Dots mean no effects were detected. Data were collected in a field study in lowland broadleaved woodlands in England and Wales.

Species / Habitat feature[1]	Understorey cover <2 m	Understorey cover 2–4 m	Understorey density at 0.5 m	Understorey density at 1.5 m	Canopy cover	Tree height	Semi-woody cover	Bracken cover	Grass cover	Herb cover	Bare ground	Number of stems	Stem diversity	Basal area
Bullfinch	–	+	·	·	·	+	·	·	–	·	–	+	–	·
Dunnock	·	–	·	·	·	·	·	+	–	·	·	·	·	+
Garden warbler	·	·	+	+	·	·	–	–	–	–	–	·	·	·
Marsh tit	–	+	·	+	·	+	+	·	+	·	·	·	·	·
Spotted flycatcher	·	–	·	·	+	·	·	·	–	+	·	·	–	·
Song thrush	·	·	–	·	–	·	+	–	–	·	–	+	–	–
Willow warbler	+	·	·	·	·	·	·	·	·	·	·	·	·	–

Table 4 Numbers of bird species for which associations with individual structural habitat features (variables) were identified. Relationships could be either positive or negative. Importance of the relationship for each species was determined by a summed variable-specific model weight of greater than 0.5 indicating the relationship was significant. The total number of bird species examined was 26. Data were collected in a field study in lowland broadleaved woodlands in England and Wales.

Habitat feature[1]	Number of species with weight >0.5:		
	All	Negative only	Positive only
Stem size diversity	17	4	13
Basal area	14	4	10
Semi-woody cover in field layer	13	3	10
Understorey cover[1] occurring <2 m above ground	12	8	4
Understorey density[2] at 1.5 m above ground	12	2	10
Grass cover	12	9	3
Canopy cover	11	0	8
Bare ground	10	8	2
Tree height	9	1	8
Herb cover	9	5	4
Understorey cover[1] occurring between 2 m and 4 m above ground	8	3	5
Understorey density[2] at 0.5 m above ground	8	5	3
Bracken cover	8	6	2
Number of stems	6	3	0

[1] 'Understorey cover' refers to the density of vegetation when viewed from above.
[2] 'Understorey density' refers to the density of vegetation when it is assessed horizontally.

most important across all bird species examined. Stem diversity (of trees) was the most frequently important feature, having a model weight greater than 0.5 for 17 species (65% of the total examined), for which 13 relationships were positive. Other significant habitat features (i.e. having a model weight greater than 0.5) and relating to ten or more of the bird species were: basal area, semi-woody cover, understorey cover and density, grass cover, canopy cover and bare ground. Associations between these structural habitat features and birds were more frequently positive than negative, with the exception of understorey cover at less than 2 m, grass cover and bare ground, which were consistently negatively associated. Relationships of bird species with plant composition were also highly individual.

Hypothesis testing of habitat–bird relationships

Of particular interest are associations between different habitat features and birds where prior knowledge can be used to hypothesise about possible relationships. These hypotheses were established on the basis of the results of the species requirements review (Table 1). Tests of single habitat features (the predictor variables) were conducted for hypotheses, where the data allowed successful model fitting (Table 5). For example, Song thrush abundance is hypothesised to increase or presence to be more likely with an increase in bare ground and with an increase in cover of shrub layer (at 0.5–4 m above ground level).

Effects were only detected for half of the associations hypothesised to occur between birds and habitat features (Table 5). Lack of support does not necessarily mean that the hypothesis is inappropriate, because there may have been insufficient variation in the habitat feature concerned or insufficient numbers of birds to undertake an adequate test. Where effects were seen, three-quarters were in the expected direction, i.e. supporting the hypothesis. Hypotheses for shrub cover in the height range 0.5–4 m, shrub and tree diversity, and tree size and height were most strongly supported. As predicted, Dunnock, Garden warbler, Blackcap, Song thrush and Willow warbler were all associated with higher levels of understorey cover while Tree pipit avoided such areas. The hypothesised negative effects of tree size, tree height and canopy cover appeared to be supported for a number of species and most of the species associated with more complex understorey vegetation also avoided closed canopy areas.

Table 5 Target bird species[1] for which negative (–) or **positive** (+) effects[2] of increasing amounts of habitat features were detected consistently across study regions (Welsh Marches and southern England). Habitat features are those which were hypothesised to affect habitat suitability for the selected species based on existing knowledge. Support (or not) of the hypothesis is indicated.

Habitat attribute	Species number[3]	Hypothesis supported[4]	Hypothesis not supported[5]	Variable response hypothesised[6]
Tree size (basal area) and height	10	**Spotted flycatcher(+)** Garden warbler(–) Nightingale(–) Willow warbler(–)		**Blackcap(+)**
Number of tree stems	1			
Shrub and tree diversity	2	**Bullfinch(+)**		
Birch cover	1	**Willow warbler(+)**		
Oak cover	4			
Canopy cover	13	Dunnock(–) Garden warbler(–) Willow warbler(–)		**Spotted flycatcher(+)** Blackcap(–)
Understorey cover 0.5 m to 2 m	4	**Dunnock(+)** **Garden warbler(+)**		
Understory cover 0.5 m to 4 m	9	**Blackcap(+)** **Song thrush(+)** **Willow warbler(+)** Tree pipit(–)		
Bare ground	6	Wren(–)	Pied flycatcher(–)	

[1] In addition to the target species, Blackcap and Wren were included because these relatively common species are likely to be sensitive to understorey structure and may therefore provide useful insights.
[2] Bird species are listed where significant $P<0.05$ and near-significant $P<0.07$ relationship was detected.
[3] Number of bird species hypothesised to be affected (positively or negatively, linearly or non-linearly) by habitat attribute. Lack of support for these does not necessarily mean that the hypothesis is inappropriate, because there may have been insufficient variation in the habitat variable concerned or insufficient numbers of birds to undertake an adequate test.
[4] Species for which significant relationship was in direction hypothesised.
[5] Species for which significant relationship was in opposite direction to that hypothesised.
[6] Species whose abundance/presence was hypothesised to vary as habitat attribute increased but which showed a significant positive or negative response.

Resource requirements and woodland features for the target bird species

Methods

Links were made between birds and woodland habitat features that would deliver resource requirements of the target bird species. This information was used to define the set of 'characteristic stand structures' occurring in lowland broadleaved woodlands and their value to the target bird species. The habitat features were derived from the habitat–bird models using the field study data. For completeness (and to represent lowland broadleaved woodlands more widely in Britain), these were supplemented from the literature by habitat–bird data for woodland structures not encountered in our field study. The characteristic stand structures have been set in context of the stand development stages that woodland is expected to pass through (Harmer *et al.*, 2010). This interpretation incorporates stocking density gradient (high–medium–low), and also the likely impact of deer on achieving stand structures. Management recommendations for delivering the different stand structures have been developed with reference to their likely development trajectories.

Results

Characteristic stand structures for woodland birds

Six characteristic stand structures were defined and are referred to as:

A – dense low shrub layer
B – dense high shrub layer
C – open understorey
D – open canopy
E – closed canopy, few strata
F – closed canopy, multiple strata.

Figure 2 provides a visual and text summary of the key features of these six structures. The text summary contains:

- Resource definition available to the bird species in the breeding season, e.g. low complex dense vegetation of shrubs and woody plant structures typically within 2 m of the ground (resource definitions were produced from a synthesis of the available literature on bird ecology).

- Bird species and the level of association with the set of listed resources, e.g. Bullfinch, Lesser redpoll, Marsh tit, Willow tit

Figure 2 Characteristic stand structure types (A–F).

A. Dense low shrub layer

Resource definition: Low complex dense vegetation of shrubs and woody plant structures typically within 2 m of the ground.
Strong association: Dunnock, Garden warbler, Nightingale, Song thrush, Willow warbler.
Weak/moderate association: Bullfinch, Lesser redpoll, Marsh tit, Willow tit.
Stand features:
- High density of low understorey <2 m (ideally stands where horizontal visibility below 1.5 m is <6 m)
- High numbers of small stems
- Low tree height and low diversity of stem sizes
- High ground cover possibly including high bramble cover

Silvicultural notes
This type of stand structure typically develops following canopy disturbance, usually after clear felling at the end of a rotation or when group felling takes place. It is a short-lived stand structure comprising shrubs and small regenerating trees. It forms part of the stand initiation phase of stand development, but it may occur during later stages if basal area is low. Unless actively managed to restrict height growth it will develop into stand structure B.

B. Dense high shrub layer

Resource definition: Complex dense vegetation structures in the upper shrub layer typically 2–5 m above the ground.
Strong association: Bullfinch, Marsh tit, Song thrush, Willow tit.
Weak/moderate association: Hawfinch.
Stand features:
- High understorey cover up to 4 m above ground (ideally >60% cover)
- High density of stems
- Broken canopy (canopy cover no more than 80%)
- Low bracken cover
- Some grass cover
- High hazel cover

Silvicultural notes
This stand structure develops as shrubs in type A increase in height. It is a short-lived stand structure comprising shrubs and sapling trees, low growing shrubs (e.g. bramble) are likely to be less abundant. It occurs during the later stages of the stand initiation phase and may extend into the early phase of stem exclusion. If basal area is low it may persist into the later stages of stand development. At medium and high basal areas it will only occur when stands are managed as all-sized stands (Table 6).

C. Open understorey structure

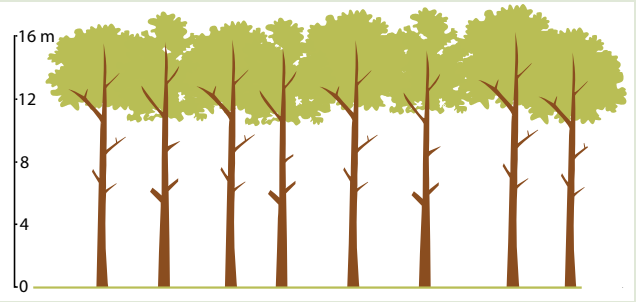
Resource definition: Stands with no or little low shrub or woody vegetation (i.e. <5 m of the ground).
Strong association: Pied flycatcher, Redstart, Tree pipit, Wood warbler.
Weak/moderate association: Spotted flycatcher.
Stand features:
- Negligible low vegetation 0.5–4 m tall but with moderate or patchy ground flora
- Little bracken or bare ground (often grassy ground cover)
- Taller trees in mature stands

Silvicultural notes
Stands with this structure are not found during stand initiation, but can occur at all other stages of stand development (Table 6). At high stocking densities the shade cast by the overstorey will maintain the open understorey conditions but at lower densities, grazing (or heavy browsing by deer) will be necessary. Generally has good overall canopy cover with more trees and smaller gaps between them than type D, grazed upland oak woods are a typical example of this type.

D. Open canopy structure

Resource definition: Woodland with significant gaps between the crowns of individual trees. Such trees may be open-grown with spreading canopies and often have relatively high amounts of dead/decaying wood.
Strong association: Lesser spotted woodpecker, Pied flycatcher, Redstart, Spotted flycatcher, Tree pipit.
Weak/moderate association: Nightjar, Wood warbler.
Stand features:
Within our sample we had few or no stands of this type and it was not possible to identify stand features from analyses of the data.
Silvicultural notes
Stands with this structure are only found at low stocking densities within the understorey re-initiation and all-sized stages of stand development (Table 6). Typical wood pasture where grazing (or heavy browsing by e.g. deer) will be necessary to maintain open understorey conditions.

E. Closed canopy – few strata



Resource definition: Stands where the canopy layer is relatively simple often associated with single-aged mid-growth phases.
Strong association: Wood warbler.
Weak/moderate association: Hawfinch, Lesser spotted woodpecker, Pied flycatcher, Redstart, Spotted flycatcher.
Stand features:
- Negligible understorey <2 m above ground (horizontal visibility more than 10 m)
- Low basal area
- Little bracken or bare ground (often grassy ground cover)

Silvicultural notes
Found during the stem exclusion and early understorey re-initiation phases of development in medium and highly stocked stands (Table 6). Is often the typical structure throughout much of the rotation for stands managed using a thin and clearfell system. Not a desirable structure for the target species of woodland birds but suitable management can transform these stands into others having greater variety in the shrub and understorey strata.

F. Closed canopy – multiple strata

Resource definition: Stands where the canopy layer is relatively complex forming several foliage strata often associated with more mature growth phases. Multiple strata could be derived from mixtures of trees of different ages or from high canopy depth within individual trees.
Strong association: Hawfinch, Lesser spotted woodpecker, Pied flycatcher, Spotted flycatcher, Wood warbler.
Weak/moderate association: Marsh tit, Redstart, Song thrush.
Stand features:
- High canopy cover (>90%)
- Tall mature stands with high diameter at breast height
- Little bracken
- Good herb ground cover

Silvicultural notes
Only found in stands with medium and high stocking density during the late understorey re-initiation and all-sized management phases of development (Table 6). Such structures are likely to arise when using methods of continuous cover forestry which create conditions allowing the development of a patchwork of shrubs and regenerating understorey trees beneath the overstorey.

– weak/moderate association (levels of association with resources were produced from a synthesis of the available literature on bird ecology).

- Stand features reflecting the key, and most biologically meaningful, variables identified in the statistical models (see 'Lowland broadleaved woodland field study' section) which correlate with the associated bird species, e.g. high numbers of small stems (stand features are based on the field study data).

The silvicultural notes (Figure 2) and Table 6 provide the context of the stand development stage, the influences of stocking density and capture management recommendations. Stand structures of type A (dense low shrub layer) and type B (dense high shrub layer) are developed in young stands at stem initiation stage but type A can be maintained through later stages of stand development with management, if stand basal area is low enough (<10 m^2/ha). Structure C (open understorey structure) can develop in stands with high basal area (>20 m^2/ha) in stem exclusion and understorey re-initiation stages and in old-growth stands, and only in these stages in stands with lower basal area when grazed or heavily browsed. Structure D is found in typical wood pasture where grazing is necessary to maintain open conditions. Stand type E is individually of least value for woodland birds and is a widespread and typical structure in much current lowland broadleaved woodland. Many of the 300 stands examined in the field survey approximated stand type E or that of stand type C, although with rather more understorey vegetation in many cases. Structure F (closed canopy, multiple strata) is only found in stands with medium and high basal areas and during the late understorey re-initiation and old-growth management phases of development. Such structures are likely to arise when using methods of continuous cover forestry. Between them, characteristic stand structures A–F should provide breeding season resources for all the target species and most other species of woodland birds.

Discussion and conclusions

The sites sampled in this study were a representative sample of broadleaved lowland woodlands in England and Wales. We found that the majority of study plots were late thicket (stem exclusion stage) or mature (understorey re-initiation stage) stands. The stands that had received recent silvicultural interventions were more uniform in structure, with a reduced stem number and understorey cover. Deer pressure on woodland habitats was clear from the intensive vegetation survey, and findings were consistent with what is known of deer impacts on vegetation. The greatest impacts were on the reduction of understorey density.

Table 6 Occurrence of the six characteristic stand types in different stages of stand development.

Stage of stand development					
Stocking	**Stem initiation**		**Stem exclusion**	**Understorey re-initiation**	**Old-growth**
	Early	**Late**			
Low Basal area <10 m^2/ha		A ⟶ B1	A2 B (early) (C)	A2 B (C) D3 G (late)	A B (C) D3 G
Medium Basal area 10–20 m^2/ha		A ⟶ B1	B (early) (C) E4	(C) E4 (early) F (late) G (late)	B (C) F G
High Basal area >20 m^2/ha		A ⟶ B1	B (early) C E4	C E4 (early) F (late) G (late)	B C F G

Six characteristic stand types are:
A – dense low shrub layer, B – dense high shrub layer, C – open understorey, D – open canopy, E – closed canopy, few strata, F – closed canopy, multiple strata.
Stem exclusion includes pole stage.
Old-growth – death of overstorey trees and replacement of these with younger trees developing from the understorey.
(early)/(late) – only occurs early or late in the stage of stand development.
(C) – will only occur when grazed or heavily browsed.
G – cavities within stems/trunks etc. although not a stand structure type it is an important structural resource.
1 – If the shrubs in stand type A are all low growing, such as bramble, then will not develop into B.
2 – Suitable management to regenerate the understorey will be needed to maintain this structure.
3 – Wood pasture with open canopy structure not represented in survey.
4 – Stand type E does not appear to favour target woodland bird species..

In total 49 bird species were recorded from the study plots. This includes all 17 target species, although Lesser redpoll, Nightjar, Willow tit and Hawfinch were encountered too infrequently for inclusion in the analysis. We found that higher understorey density at 1.5 m, increased stem size (basal area), greater diversity of stem sizes, canopy cover and tree height were related positively to the abundance of the target bird species. However, silvicultural thinning decreased stem size diversity and tree species density and reduced understory density (at 1.5 m and above 4 m); high deer browsing pressure also reduced understory density (at 1.5 m and 4 m). We conclude that silvicultural thinning, as normally practised in late thicket and mature stage stands, does not improve the habitat for target bird species, whereas management of deer browsing does. These findings are supported by evidence from the literature which suggests that thinning (as currently practised) decreases the shrub layer and reduces the number of dead or damaged trees, with consequent negative effects on numbers of ground- and shrub-nesting birds, and brings no benefits overall to bird populations.

Using the field survey data, we detected differences in the abundance or presence of individual bird species in relation to habitat features hypothesised to be important from the literature. For example, certain bird species were associated with or avoided habitat features of shrub cover up to 4 m tall, tree size and height and canopy cover, in a predictable way. This suggests that within the typical lowland broadleaved woodlands in England and Wales, target bird species are associating with the expected habitat features. Increasing the provision of these features will potentially lead to increases in target bird species abundance. Certain types of stand management are reported in the literature (mostly on conifer systems) to deliver these habitat features and benefits for birds. Harvesting and restocking initially creates conditions of temporary open ground benefitting, for example, Tree pipit, and later on results in increases in dense low shrubby vegetation, which was shown to be of benefit to six of the target species.

The uniform stand structures encountered in our study reinforce the view that a very high proportion of lowland broadleaved woodland in England and Wales lacks structural heterogeneity. Creating a more diverse structure through woodland management could lead to increased resource provision for the target species. Tailoring management for each species may prove challenging, as this research demonstrates that the combination of required habitat features is highly species-specific. Instead we propose that woodland management for birds (and potentially for other biodiversity) is focused on delivering a mixture of different stand structures at the landscape scale. Six characteristic stand structures have been described for lowland broadleaved woodlands based on the findings of this research. Together they should deliver breeding season resources for all the target species and most other species of woodland birds. Stand structures are possible at only certain stand development stages and their occurrence can be further influenced by basal area of the stand and grazing/browsing pressure. Silvicultural intervention can maintain structures, e.g. type A (low dense shrub layer) in stands developed beyond stem initiation (establishment) stage or encourage their development, e.g. type F (closed canopy, multiple strata) by using methods of continuous cover forestry. The most frequently occurring structures found currently in lowland broadleaved woodlands in England and Wales (stand type E), are of least value to woodland birds. By using silvicultural management to move stand type E towards other stand types, there is scope to increase the area of woodland that would potentially provide resources for a wider range of woodland birds, including several declining species. Maintaining a range of stand structures will also benefit other woodland species, for example structure types D and F will support 60% of the priority (Forestry Commission, 2011) non-avian species, such as Invertebrates, Lichens and Bryophytes associated with lowland broadleaved woodland (see Fuller *et al*., 2014, Appendix 7).

As well as strengthening our knowledge base, this research has provided new insights into woodland management for birds in lowland broadleaved woodlands in Britain and underpins a classification of characteristic stand structures. The characteristic stand structure classification provides a framework to understand and manage woodland development with the aim of delivering breeding season resources for woodland birds.

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