

# A proposal to establish the relationship between structure and biodiversity in irregular, conifer dominated stands, in lowland Britain

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## Summary

- There remains a considerable gap in our ecological knowledge of how biodiversity responds to alternative forestry management techniques, such as irregular high forest management, particularly in commercial, conifer dominated stands.
- An excellent opportunity to investigate the response of biodiversity to the structures created by irregular high forest management, in conifer dominated stands, has arisen at the Stourhead (Western) Estate.
- Fieldwork will be undertaken at the ecosystem scale, covering multiple taxonomic groups including vegetation, invertebrates (spiders and moths) and vertebrates (birds and bats).
- Outputs of the project will include peer-reviewed scientific papers, articles in magazines and a report targeted towards foresters and land owners.

## Introduction

Continuous Cover Forestry (CCF), an alternative forestry management technique to clear fell and coppicing, is rising in popularity in the UK and the rest of Europe. The wider concept of CCF includes irregular high forest management (IFM), a management type that creates permanent irregular structures. IFM involves periodically and selectively harvesting individual trees or small groups of trees, creating a permanently irregular structure of mixed size stems. This allows existing trees with good timber potential to expand in size and permits the long-term regeneration and sustainable development of the stand. It also encourages the majority of stems within a stand to develop good crowns and increases resistance to disease and pathogens. Natural regeneration of trees takes place sporadically throughout the stands and increases the chances of continual adaption to changing environmental or climatic conditions. The presence of an under-storey is encouraged as an important silvicultural tool in controlling the condition of the seed-bed (Susse *et al.*, 2011). Irregular silviculture also allows individual retention of trees for other special qualities, such as veterans, elite trees supporting epiphytic flora, and trees of particular historic or landscape value. The overall increase in structural diversity and complexity, displayed in IFM stands, and the retention of veteran trees also increase the potential for carbon sequestration, compared to simpler stand structures (Stephenson *et al.*, 2014; Smith *et al.*, 2017).

Within the UK and Europe there has been a growing interest in IFM which presents a 'closer to nature' form of silviculture than Clear Fell and Replant (CFR), which has been widely used over the last century. CFR involves clearances of stands at regular intervals and stands managed under CFR often consist of a monoculture of one species, even-aged composition of trees, little understorey and poorly developed vertical structure. Within the UK, changes to forestry policy, post-Brexit are likely and could promote systems such as IFM. Beyond policy IFM as an integral pillar of CCF, has the potential to provide many economic, social and ecological benefits. Economically, IFM can produce large quantities of high quality timber, greater resilience against wind-throw and reduced cost of restocking as natural regeneration is integral to this silvicultural system (Susse *et al.*, 2011). IFM has a higher aesthetic value due to the avoidance of highly disturbed ground and provides a number of ecosystem services including water retention and carbon sequestration alongside potentially greater resilience to climate change and disease (Mason *et al.*, 1999; Stokes and Kerr, 2009; Axelsson and Angelstam, 2011; Stephenson *et al.*, 2014). Considering biodiversity, IFM has the potential to be an important land use in connecting areas of semi-natural habitat, acting as buffers and complimenting landscape-scale conservation and re-wilding projects (Bennett and Morgan, 2018).

Managing under IFM principles in commercial woodlands has the ability to deliver for biodiversity, whilst also providing considerable ecosystem service benefits. This has been highlighted in the scientific literature but has been limited to a few well studied taxonomic groups such as birds and a small selection of ecological systems including native coniferous and lowland broadleaf woodland (Calladine *et al.*, 2015; Calladine *et al.*, 2017; Alder *et al.*, 2018). The emerging results from a project at the Rushmore Estate on the border between Wiltshire and Dorset has provided much new knowledge on the relationship between biodiversity and managing semi-natural broadleaf woodland under IFM principles (Alder *et al.*, 2018). The study investigated the abundance and diversity of moths, birds and bats between stands managed under IFM principles, coppice and with limited intervention. Despite the initial findings of the Rushmore project considerable gaps in our knowledge of how IFM delivers for biodiversity remains, particularly in upland systems and those composed primarily of non-native coniferous species.

The Stourhead (Western) Estate, located on the border between Wiltshire and Somerset, initially approached Butterfly Conservation (BC) in 2015 to study the feasibility of re-introducing the Marsh Fritillary into areas of wet grassland. It was found the area of wet grassland was not suitable to support a viable meta-population of the butterfly (Burgin, 2016). The project subsequently evolved to find out more about the Lepidoptera on the estate alongside how the conifer dominated forest stands, managed under continuous cover principles, can deliver for moths and butterflies. So far two seasons of fieldwork has been carried out on the Lepidoptera found at Kingswood Warren, Great Combe and Dropping Gutter (Cook *et al.*, 2018a; Cook *et al.*, 2018b). There is an exciting opportunity at the Stourhead (Western) Estate to build upon these findings and the multi-taxa study at the Rushmore Estate. This will provide much needed ecological information on how IFM in a commercial, coniferous system can deliver for biodiversity at an ecosystem scale. We aim to specifically investigate how biodiversity, at multiple taxonomic levels, is influenced by the stand habitat and structural characteristics created as the estate transition the management of conifer dominated stands towards IFM.

## **Methods**

### *Location*

The study will be undertaken on the Stourhead (Western) Estate located on the border between Wiltshire and Somerset (Figure 1). The estate is a mixture of commercial coniferous forestry, broadleaved woodland and low intensity farmland.

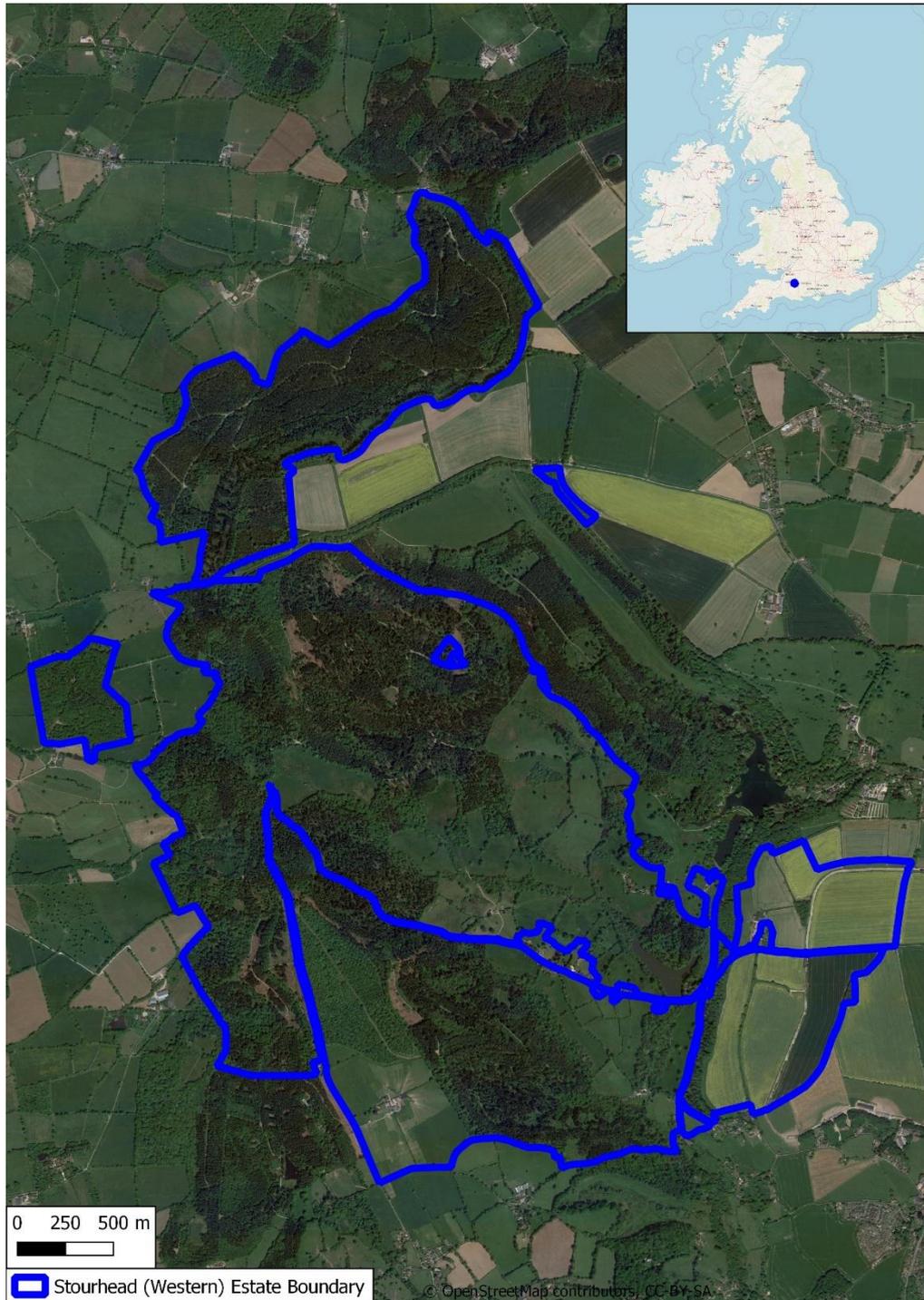


Figure 1. Location of the Stourhead (Western) Estate in the UK.

The commercial stands are composed largely of conifers including Douglas fir and Sitka spruce alongside limited broadleaf elements including ash, alder and oak. The estate began transitioning its stands towards IFM in 1997 and stands can be found at varying points along this continuum from having relatively regular to irregular structure.

### ***Stand Descriptions***

Key stand elements can be defined on a 3-dimensional axis of growing stock and vertical structure, understorey density and broadleaf component (Figure 2; Figure 3). The sample IFM sites will all be found at various points on this 3- dimensional axis. Controls will have

more regular, even aged structure, with a higher growing stock and lack of broadleaf element.

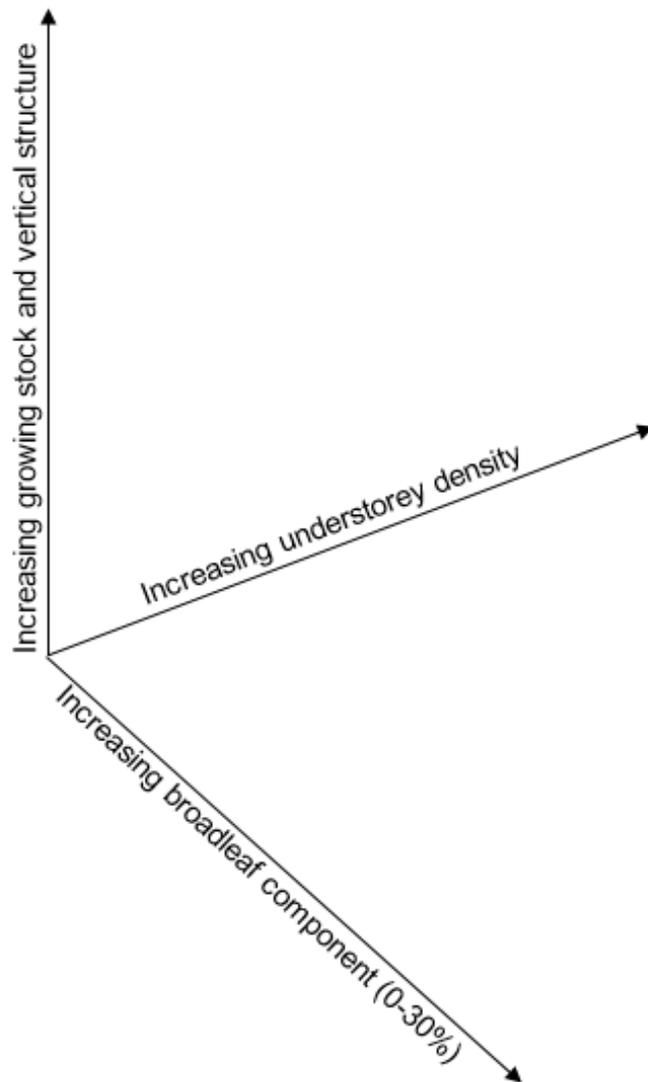


Figure 2. Stand descriptions in this study will fit along a continuum with axes of increasing growing stock, increasing vertical structure and shrub layer and increasing broadleaf component of the stand up to 30%.

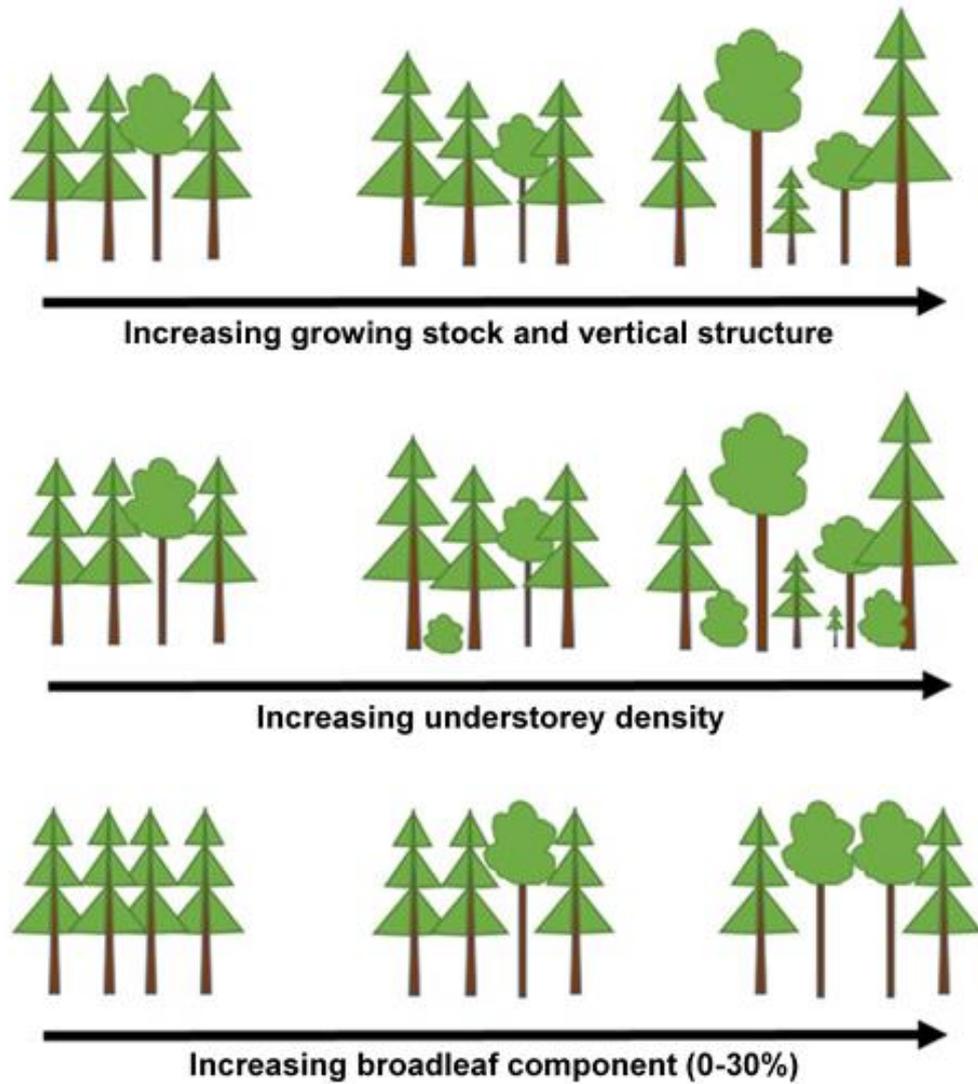


Figure 3. Schematic characteristics of stands under the three axis of variance.

### ***Experimental Design***

The biodiversity project stands comprise stands managed under CCF, that display variability in the factors described in Figure 3. Control areas consist of stands at Kingswood Warren that are at the beginning of transition towards IFM and stands at National Trust Park Hill managed under CFR principles.

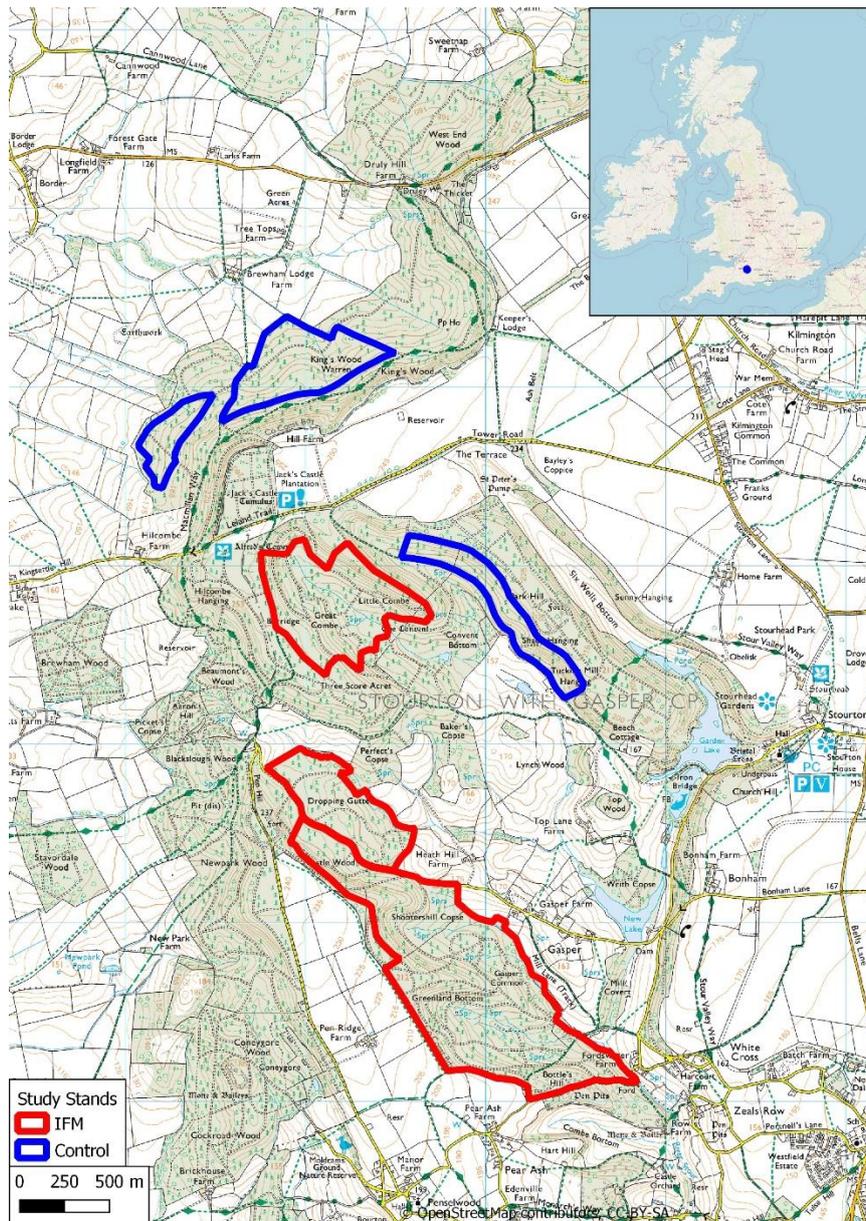


Figure 4. Stands delineated for inclusion in the biodiversity research project.

### **Taxonomic Groups**

All surveys for different taxonomic groups will be nested, at varying levels of resolution, within the boundaries defined in Figure 4. Surveys for habitat characteristics, vegetation, moths and spiders will be undertaken on a plot based system as described in Alder *et al.*, (2018). The 60 m plots in this study ensure coverage of a wide variety of stand elements and have been selected at random using Microsoft Excel. For higher taxonomic groups alternative study methodologies will be undertaken to control for the high level structural and species variation within stands. Full details on the methodologies to be utilised to study individual taxonomic groups are documented in the Appendices. A congruence analysis between the studied taxonomic groups will also be undertaken to understand how biodiversity responds to the structures generated in IFM, at an ecosystem scale. This will be used to report on biodiversity as an ecosystem service and methodologies for exploring this are documented in point 9 of Appendix 1.

## Project Costs

Three costing options have been detailed in Table 1. The three options differ in the methodology and intensity of bat sampling with option 1 being most desirable and option 3 least desirable. The cost of each section of the project has been calculated including BC expenses, contractor expenses and the hire of purchase of equipment.

Table 1. The costs of different sections of the project with three options.

Section of Project	Item	Year 1	Year 2	Year 3	Option 1*	Option 2**	Option 3***
<b>1. Project Management</b>	BC Management/Advice	3000	1300	1600	5900	5900	5900
	BC Report Writing	400	400	1000	1800	1800	1800
	BC Scientific Paper Writing			1000	1000	1000	1000
	Dan Alder Planning/Advice	1200	600	1200	3000	3000	3000
	SelectFor	1500	1500	1500	4500	4500	4500
<b>2. Structural Monitoring</b>	2.1 Plot set up	640			640	640	640
	2.2 Rapid assessment method	4591		4591	9182	9182	9182
	2.3 Preparation of data	720		720	1440	1440	1440
<b>3. Vegetation Monitoring</b>	3.1 DERC Survey	3942			3942	3942	3942
<b>4. Spider Web Monitoring</b>	4.1 BC Survey	600			600	600	600
<b>5. Moth Monitoring</b>	5.1 Equipment	2200			2200	2200	2200

	5.2 BC Survey	1200	1200		2400	2400	2400
	5.3 Contractor (Mike Jeffes) Survey	1828	1828		3656	3656	3656
<b>6. Bird Monitoring</b>	6.1 Set Up and Surveys	4416		4416	8832	8832	8832
	6.2 Preparatory visits x2 to familiarise with site	360			360	360	360
	6.3 Prepare final spreadsheet for analysis	720		720	1440	1440	1440
	6.4 Write up summary results	360		360	720	720	720
<b>7. Bat Monitoring - 2 methods</b>	7.1 Set Up/Surveys - Static units method using 3x SM3 detectors -40 sample nights	2857		2857	11428	5714	
	7.1 Hire of 3 No static recording SM3 units - for 40 sample nights	1800		1800	7200	3600	
	7.1 Processing of acoustic data from static units	800		800	3200	1600	
	7.2 Set Up/Surveys - Transect with spot sampling method	2200		2200			4400
	7.2 Processing acoustic data from transect method	540		540			1080
	7.3 Preparation of data and short report for either 7.1 or 7.2	540		540	1080	1080	1080
<b>8. Data analysis</b>	8.1 BC Statistician	150	150	1500	1800	1800	1800
<b>Totals</b>					<b>76320</b>	<b>65406</b>	<b>59972</b>

\*Option 1 contains bat surveys with two rounds of survey using static detectors, \*\*Option 2 contains bats surveys with one round of surveys using static detectors, \*\*\*Option 3 contains bat surveys where a transect methodology is used.

## Outputs and Outcomes of the Research Project

The key outputs will aim to engage and disseminate information and results to a wide range of audiences through scientific papers, articles and social media.

- Peer reviewed scientific papers will be produced and targeted towards journals such as Forest Ecology and Management. This project had identified and aims to fill a research gap in the biodiversity and forestry literature. The key aim of the project is to determine how the selected taxonomic groups respond in terms of abundance, richness, and diversity to the habitat characteristics of stands managed under IFM principles.
- A congruence analysis across taxonomic groups will be attempted. This will be interesting, novel and inform foresters, land owners and estate owners of how biodiversity responds to this form of management at an ecosystem scale. This is vital to recognising the value of non-timber benefits provided by sustainable forestry, such as biodiversity, a key ecosystems service.
- A final report on the project will summarise the results and suggestions on optimising biodiversity in conifer dominated stands. This will be targeted at foresters and landowners to help engage with management under IFM principles and the biodiversity outputs it will produce. It is hoped that this will help influence and inform forestry policy post-Brexit.
- A report will be produced annually for funders of the project and a meeting held to discuss project progress and developments.
- Articles and newsletters will be targeted towards popular, wildlife, and forestry magazines eg Countrylife, Confor, BC Butterfly Magazine and British Wildlife.
- Conference papers and presentations will be targeted towards forestry conferences and conferences concerning the studied taxonomic groups such as the Butterfly Conservation international symposium.
- Social media will be used to highlight the projects progress, results and any key stories.

## Appendices

### ***Appendix A1. Structure of the Study Stands***

Aim/Background: The structural characteristics of the stands will be sampled with particular regard to canopy and understorey attributes and the species composition of the vegetation will be recorded. These measures will be used to characterise habitat gradients from open to closed canopy, increasing tree and understorey densities and the influence of broadleaved elements in the stands. Such measures will be used to identify how the selected taxonomic groups relate to the habitat structure and composition, and how these are influenced by silvicultural management. Basal area is an important forest measurement which indicates tree biomass and density although it does not indicate variation in tree sizes within a stand. The aim is to characterise through different measurements the structural variation within

each stand area which may be compared with the other stand areas and the measures from sampling other species groups.

Objectives:

1. To measure tree density across size classes
2. To measure the degree of canopy openness
3. To measure variability and structural complexity through vertical profiles
4. To measure the proportion of broadleaf element in each stand area
5. To produce measures for comparison across taxonomic groups

Hypothesis:

Multilevel structural complexity of vegetation increases in woodlands undergoing transformation to an irregular silviculture management.

Methods:

#### Field sampling

1. A plot sampling methodology will be used following a similar approach to that of Hinsley *et al.*(2009) and Alder *et al.*(2018) with a 15 m radius circular plot (0.07 ha).
2. Plots will be used at the sampling locations for bird registrations, moth trapping/spider webs plots and bat sampling locations to characterise the structural elements which can be directly related to the taxonomic group measures at these locations.
3. RAPID ASSESSMENT (see Khanaposhtani *et al.*2012): To provide a comprehensive assessment of vegetation structures present across the stand areas and a comparison between sites used by woodland birds, a total of 170 random sample plots will be set out across the stand area (Figure 5). Plots will be a minimum of 60 m apart to avoid overlap with a neighbouring plot and adjustments will be made where a circle falls outside of a woodland stand. The non-independence and pseudoreplication of plots is a consideration for analysis, see Alder *et al.*(2018). We accept this in our study and have included each stand unit area distinctly within a nested design. Each stand has its own unique ecological signature and our approach has been to consider running a test for both random and fixed effects in our model ANOVA using each stand unit as a covariate in the model. We are testing differences and correlations across fine scale gradients at the stand level which is important because this is the management unit at which forest managers operate. To test for the effects of interaction within a stand as well as between stands a nested design is used. We accept that this study, as with many others, has limitations driven by the

scale, configuration and geographical position of each stand area, which makes it challenging but also particularly interesting ecologically.

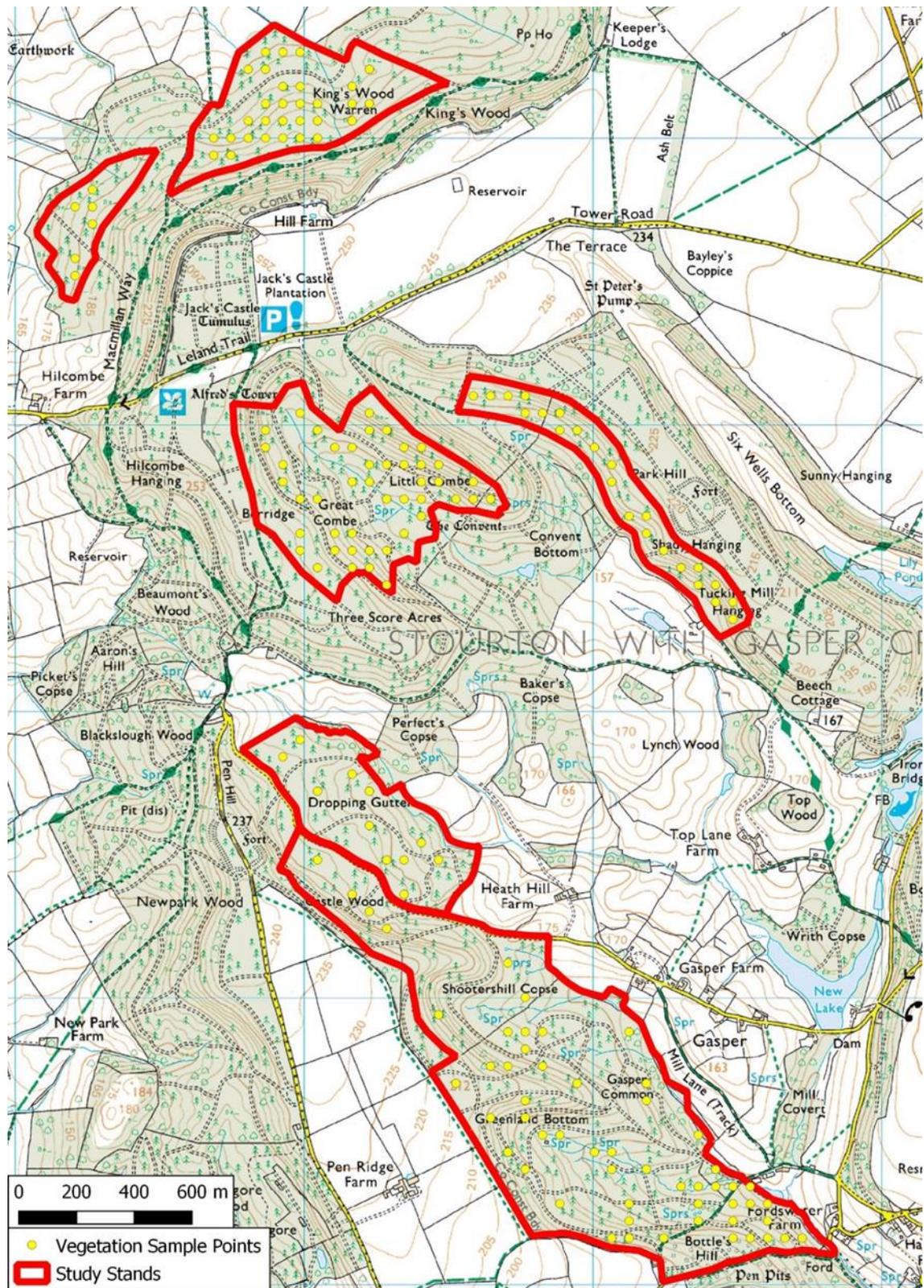


Figure 5. 170 sample points for woodland structural and botanical diversity surveys.

4. At each 15m diameter plot habitat structural measures will include; a) Basal Area b) dbh of the 5 largest trees per plot c) distance to nearest woodland edge habitat e.g. ride d) number and name of tree species e) distance from plot centre to nearest broadleaf canopy tree f) number of stems per plot above 7.5cm dbh g) % broadleaf canopy cover, h) estimate of deadwood on the ground by volume m<sup>3</sup> i) frequency of deadwood snags over 10cm diameter, and j) % canopy openness from a spherical densitometer will be calculated.
5. The nearest neighbour distance for 10-15 trees above 7.5 cm dbh will be measured to test for spatial evenness (or clumping) of trees, and the dbh and standard deviation (as a measure of variability in sizes) will be calculated.
6. Within each 15 m radius circle a habitat complexity profile score will be estimated from four % score categories (0-10% = 0, 10-20% = 1, 20-50% = 2, >50% = 3) to calculate a measure of structural complexity across six height variables. i) canopy layer cover ii) sub-canopy layer cover iii) tall understorey layer 2.5-6m iv) low shrub layer 1-2.5m, v) ground layer 0-1 m. Dominant understorey species and an estimate % cover (including thicket stage conifer and coppice/scrub up to 5m) will be recorded for each 15 m diameter circle.
7. Dominant field layer species will be recorded from % cover of bramble, grass, bracken, forbs and bare ground for the overall 15 m diameter circle.

### Analysis

8. The analysis of structural habitat data can be used to categorise sample points according to the degree of heterogeneity as habitat complexity scores. These scores together with the other structural measures can be assigned to each stand area and the categories of habitat complexity can be compared with measures of abundance, species richness and distributional patterns for moths, birds, bats and spiders.
9. Ordination analysis (e.g. canonical correspondence analysis) can be used to identify the main structural habitat gradients and show correlations of the various taxonomic groups and species along these gradients (factors). Factor scores (+/-) can be used to identify those structural attributes that are most significantly correlated, positively or negatively, to the species or groups of interest. Further statistical testing will be reviewed with a statistician but a key aim is to identify congruence between the different groups from, i) diversity indices ii) abundances and iii) distributions, across canopy gradients.
10. A key issue with this multi-taxon study is that groups vary in the way they relate to habitat influences at different scales, and habitat selection for each should be viewed as hierarchical; from fine-scale, at stand level and up to landscape level. The relationship between sampling points to other landscape features can be considered using the approach of Kirkpatrick *et al.*(2017) which incorporates landscape-scale measures of for example edge to area ratios, water courses, open habitats and habitat patch dominance. These can be measured using GIS from the centroid of the nested sampling points, i.e. by stand unit, so Dropping Gutter may be one nested stand unit. A series of circles can be drawn out from the centre and measures taken

at different distances e.g. 100, 250, 500, 1000, 2000. Diversity indices of habitat heterogeneity can be produced e.g. Shannon-Weiner across these multiple scales.

### **Appendix A2. Botanical Abundance and Diversity of the Stands**

Aim/Background: to identify the flora of the ground, field and shrub layer found within the conifer dominated study stands. This information will be used as in the congruence analysis and as an important co-variate in analysis of data collected from other taxonomic groups, particularly moths.

Methods:

1. A total of 170, 20 m<sup>2</sup> plots, will be sampled based on the same points as the woodland structural measurements (Figure 5).
2. The survey will record the cover of all vascular plants and bryophytes in the shrub, field and ground layer using the DOMIN scale.
3. Bare ground, dead wood and litter will also be recorded alongside photographs of each plot from two different angles.
4. A list of woodland indicator species will be compiled based on those used by NCC for surveys of Ancient Woodland in 1980s (Rose, 1999). The list for South-west England will be used and adapted as necessary.
5. A list of light-demanding and disturbance dependent species will also be compiled. Each of the plant species recorded will be given attributes as detailed in Hill *et al* (2003) for vascular plants and Hill *et al* (2007) for bryophytes.

### **Appendix A3. Surveys of Woodland Guild Moths**

Aim/Background: to identify the woodland macro and micro moth assemblage and investigate differences in the woodland guild (a grouping of species that use the same resource) species richness, abundance and diversity in different stand structure types which are relatable to stand structural characteristics and botanical diversity.

Hypothesis: Stands with a higher degree of structural diversity will display a higher abundance, species richness and diversity of adult moths found in the woodland guild.

Methods:

1. The sampling procedure will be undertaken across 120 sampling points. A 60 m plot system was selected so that individual 6W actinic traps are  $\geq 60$  m apart reducing the possibility of light interference (Merckx and Slade, 2014). The capture rate (number of moths caught) and capture distance (distance moths are drawn to the light) of actinic traps are well known in the scientific literature and this model of moth trap was selected to ensure moth samples are representative of a particular sample point (Truxa and Fiedler, 2012; Bates *et al.*, 2013, Merckx and Slade, 2014).
2. Sample plots were selected using GIS, in order to meet the following criteria (Figure 6). All plots are  $\geq 30$  m away from major ride edges (rides clearly visible from Google Satellite imagery and with a width  $> 8$ m),  $\geq 30$  m away from clear fellings  $> 0.25$  ha which does not represent the usual CCF cycle and  $\geq 30$  m away from streamside vegetation which is characteristically dominated by pure stands of broadleaved trees. A buffer of 30 m was selected as the minimum buffer size to reduce the effects of these confounding variables (Bibby *et al.*, 2000, Alder *et al.*, 2018). All plots were selected randomly using Microsoft Excel within this suitable study area.

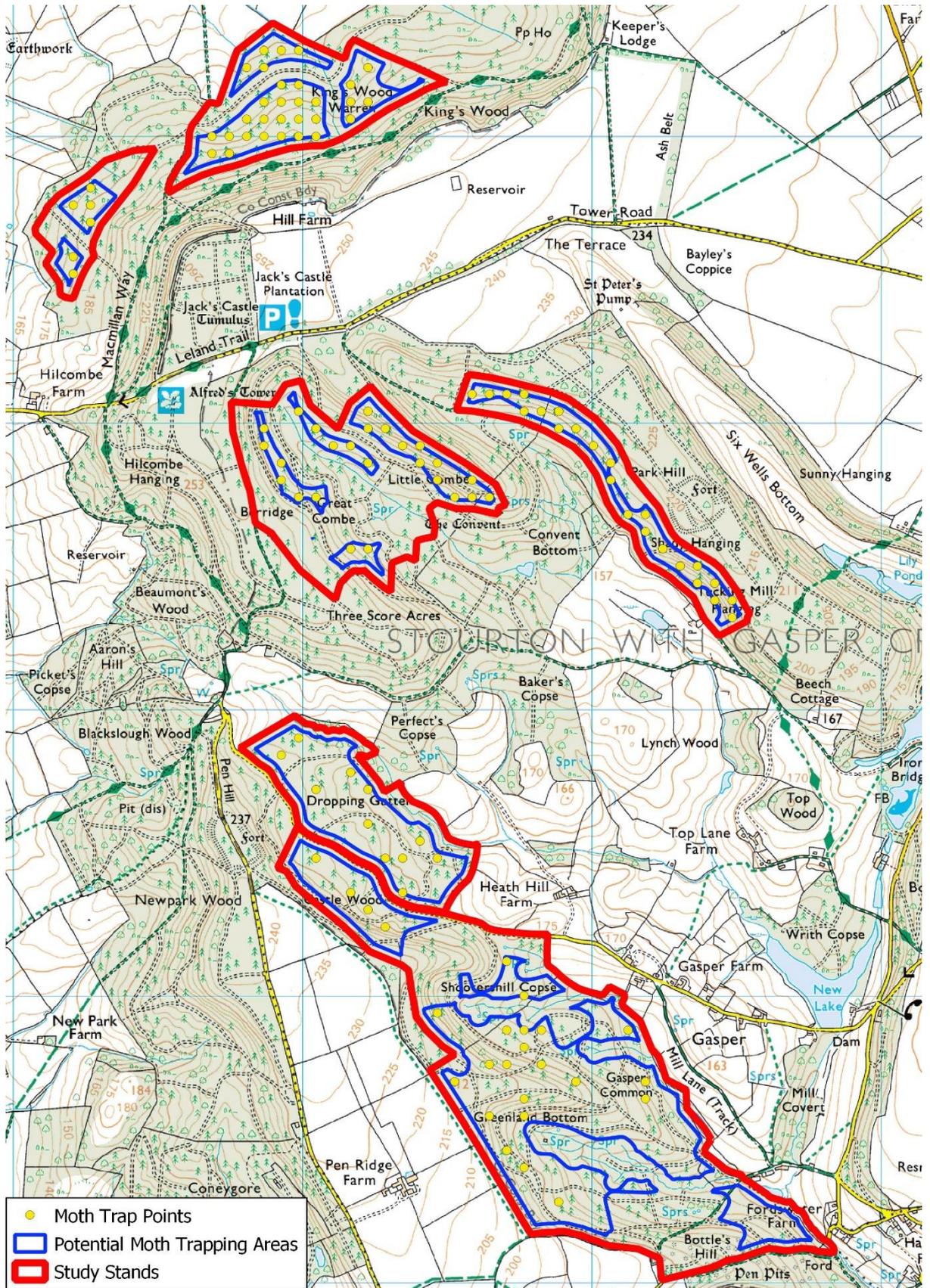


Figure 6. Location of the 120 sample points for moth trapping. The red line delineates the biodiversity study project outline and the blue line delineates areas that meet the strict criteria as being suitable for moth trapping.

3. Variables including aspect, slope, minimum night temperature, stage of moon cycle, cloud cover, wind speed and wind direction will be recorded for each sample plot as each can influence capture rates at light (Yela and Holyoak, 1997; Jonason *et al.*, 2014).
4. Moth trapping will occur in a 2 week period from mid-July, with 60 samples conducted in year 1 and a further 60 in year 2 of the project.
5. 6W Actinic Heath Traps will be deployed between dusk and dawn to temporarily capture adult moths overnight. A total of 10 traps per night will be deployed.
6. Wherever possible individual moths will be identified down to species level. Exceptions to this are large groups of similar species, such as the Coleophoridae, which cannot be determined without genitalia dissection. In such cases records for these species will be aggregated. All moths will be released at their recording locations once identified.
7. Moths will be recorded on a standardised spreadsheet

#### **Appendix A4. Survey of Spiders Webs**

Aim/Background: Spiders are commonplace in woodland habitats and unlike most herbivorous invertebrates, many spider species are much more dependent on the architecture and complexity of the structure of vegetation than they are on the floristic mix. This is because they spin silken webs to trap prey and need structural elements in the wood in order to attach their silk threads. There are many species of spider that do not construct webs and these will be omitted from this study. The survey is designed to examine the shrub layer specifically. Invertebrates are notoriously difficult to study in the field owing to problems of bias from differences in sampling efficiency between treatments. By sampling the artefacts that spiders make, their webs, rather than the spiders themselves, much of that bias can be overcome since the webs are static, remain reasonably intact throughout a sampling period, and are not influenced by presence or absence of sunshine which so many invertebrates are sensitive to.

Hypothesis: There is a difference in spider numbers and diversity, based on counts of webs, between stands with different structural characteristics at Stourhead.

Methods:

1. The methodology to study spider webs is simple, quick and replicable elsewhere. A knapsack sprayer is filled with tap water and a fine mist sprayed in a defined volume of space in each sampling area, and the number and different types of web are counted. It is best to avoid sampling webs on a windy or wet day since webs may be damaged or destroyed by these factors.
2. Only intact webs are counted, as webs formed very recently usually indicate that the spider is still in the vicinity or on the webs. If sampling is undertaken early in the morning in autumn it is not always necessary to spray mist as the webs stand out having acquired a layer of dew overnight. This can speed up sampling until the dew has evaporated.
3. There are three basic types of web to be counted in this way:
  - Orb webs – the classic, round webs with spoke threads attached to vegetation. These are produced by spiders in the families Theridiosomatidae, Tetragnathidae, Netidae and Araneidae.
  - Scaffold webs – these are complex webs of an apparent tangle of threads in three dimensions, sometimes called random webs. They are produced by spiders in the family Theridiidae and Nesticiidae.

- Sheet webs – these are sheets of silk held more or less horizontally, with a complex of anchor threads above and below, and the spider hangs below the sheet. These are characteristically produced by the Linyphiidae (Money Spiders). Random webs are also produced by the Pholcidae (Daddy Long-legs spiders) but these are unlikely to be found in a woodland situation.
4. It is anticipated that at each sampling location, a sub-sample of four, 2 m<sup>3</sup> imaginary boxes will be misted at the ordinal points, 2 m from the sampling location centroid. The recorder will stand in the middle of the imaginary box and spray around the 2 m<sup>3</sup> volume. Intact webs will then be counted, separating them into their distinctive web-types.
  5. The best time of year to survey is end September to mid-October, when many spiders are at peak abundance and are mature adults, and it is proposed that a single sample across all sampling locations is undertaken at this time of year. If a further sampling time is desired then end July is also appropriate as there are species which mature earlier in summer and are no longer adults in the autumn.

### **Appendix A5. Surveys of woodland birds**

Aim: to characterise the woodland bird assemblage at SWE and identify differences in bird distributions across a continuum of stand structures. The sampling procedure will be undertaken across a range of sites representative of the stages through which stands are undergoing transformation to an irregular silviculture. It will include areas of mature even-aged conifer and stands in the early stages of transformation as well as those which are well developed irregular. The method should enable statistical analysis from measures of birds and woodland habitat structure and composition (Hinsley *et al.*2009).

Objectives:

1. To identify the woodland bird community using the conifer dominated stands at SWE.
2. To assess the distribution of woodland birds across differing stand attributes.
3. To compare the relative distributions of woodland birds looking for species specific differences between contrasting stand and habitat characteristics.

Hypothesis: The diversity and abundance of the woodland bird assemblage is positively related to the increasing structural complexity of coniferous stands.

Methods:

1. A territory mapping survey methodology will be used (Bibby *et al.* 2000) during the breeding season which uses registrations of birds to identify clusters of use by individuals and species.
2. A transect will be walked at a steady pace during the breeding season (early March to early June) and the positions of woodland birds will be noted on a map of the stands.
3. Bird registrations will be limited to woodland species (especially those on the Woodland Bird Indicator,( DEFRA 2018)) in the main although in exceptional circumstances open habitat species listed as red or amber on the Birds of Conservation Concern may be included if their use of the woodland habitat appears important.

4. Five or six repeat visits throughout the breeding season will enable individual territories to be mapped; visits will range from early March until the start of June to try and ensure early breeding species e.g. Crossbill, and late arriving summer migratory birds can be recorded.
5. Surveys will not be carried out during persistent or heavy rain and in wind speeds above 4 on the Beaufort scale.
6. Observer bias is a consideration where more than one fieldworker is used. The route walked around the different stands will be the same for each visit although starting and ending locations will be varied to reduce temporal bias.
7. All parts of a stand area will be visited to within at least 50metres while avoiding major changes in habitat e.g. farmland. Rides associated with woodland will be included as edge habitats are an important element in woodland configuration for several bird species.
8. Bird registrations will be used as sampling locations for stand structural habitat measurements. Using the approach from Hinsley *et al.* (2009) individual registrations provide unambiguous samples of habitat use by a species, allowing a high level of precision in matching bird locations with stand habitat characteristics (see B) below).
9. Birds can be categorised to into two main groups; high-forest or canopy dwelling species such as nuthatch and firecrest and shrub dwelling such as willow warbler and wren.

### **Appendix 6. Surveys of woodland bats**

NB: There are two main approaches to sampling bats using acoustic detection; 1) static detectors which record the bats as they fly past a fixed point and 2) manual bat surveys which are based on following a transect walk which takes in the main structural characteristics of each stand area. Method 1 has the potential to generate large volumes of acoustic data which requires subsequent processing using a call recognition classifier and a proportion of manual checking which can take many hours or days to do depending upon the amount of acoustic data. The advantage is clearly related to gaining a full night's sample. Against this must be set the time in processing which method 2 largely avoids. Method 2 can only give a comparative snapshot yet is useful in picking up bat calls throughout a transect. However, to avoid temporal bias carrying out several transect walks in the main period of activity June –August can be productive where increased effort can increase the effectiveness of this method. Both methods are described for a comparison.

Hypothesis: Bat activity in conifer dominated woodland will vary according to stand management which determines structural gradients; bats will avoid dense cluttered stands and be positively associated with open sheltered stands.

#### Method 1 – Static Detectors

Aim: to identify bat species within stand types and identify differences in relative activity between these. Habitat characteristics at the sampling locations can be related to the bat activity and presence/absence.

Objectives:

1. To identify species presence/absence across stand areas.

2. To compare bat activity as a proxy for abundance, from acoustic data.
3. To compare the structural characteristics of stands with measures of bat activity
4. To directly relate bat activity to moth sampling measures

Methods:

5. Bats will be surveyed using acoustic recording units to collect bat calls across each stand area using the same locations (n=120) as those for moth trapping.
6. Weather conditions as for birds.
7. Sampling will involve sampling across each stand type with an equal number of recording units placed in each stand type each survey night to control for temporal bias e.g. 2 detectors each in Close canopy, open canopy and .
8. A suggested number of 4 recording units are used so for two stand types (CCF & even-aged) 2 units are deployed in each. Units will need to be hired.
9. It is suggested that 2 survey periods (total 60 sample nights) are used which reflect bat breeding and post-breeding period; 1) breeding period June to mid July and 2) post-breeding August.
10. Suggest Wildlife Acoustics SM3 units are used with an ultrasonic mic and cable; these are locked to a tree with the mic set 4m above ground facing away from the tree and at least 1 metre away from vegetation which might introduce extraneous sound during breezes and rain, as well as mask bat calls.
11. SM3 units can be configured to trigger at a certain frequency and amplitude and switch on and off at prescribed time around sunrise and sunset respectively. SM3 units can be configured with coordinates so that the on-off timing around sunrise and sunset remains the same each night to account for differences in night length.
12. The bat pass will be used as the measured unit.
13. Bats will be identified using a classifier system Tadarida which runs the acoustic data through the software and pulls out the bat calls and identifies these to species.
14. A print out of passes per species will be produced in excel.
15. A sample (10%) of recordings of each species identified using the Tadarida classifier will be randomly manually checked using a spectrogram such as Sonobat which can load a batch at a time. For rare species with only a few hundred or thousand passes these should be manually checked in Sonobat. Standard references in call parameters such as Russ will be used.
16. Once checked a final spreadsheet of species and passes will be produced for each plot.
17. Comparison between stand area and bat activity can be made using Analysis of Variance tests for main stand types for instance while relationship to habitat structures at the stand level will require multivariate analysis and regression models to test relationships and identify the strongest predictors of stand structural and habitat attributes influencing bat activity.

Method 2 – Transect survey

Aim: To identify species using different stand areas and activity patterns across these. As with method 1 to compare activity and presence or absence of bats with the structural habitat attributes.

Objectives:

1. To identify species presence/absence across stand areas.
2. To compare bat activity as a proxy for abundance, from acoustic data.
3. To compare the structural characteristics of stands with measures of bat activity and presence or absence.
4. To relate bat activity to moth sampling measures.

Methods:

5. A transect route will be used which takes in the stand areas and take in all parts of the stands to be representative of the structural characteristics of the stand (cf. birds).
6. The transect will be surveyed 3 times from 30minutes after dusk for 2 hours in each month between June-August using a full spectrum detector which records the acoustic data from bat echolocations. This is to detect bats using an area to fly through to forage or interact with other bats and avoids activity immediately after dusk when bats are leaving roosts which can skew activity patterns in certain localities (see Kirkpatrick *et al.* 2017).
7. Timed spot sampling of 3 minutes will be undertaken at each predetermined positions along the transect which are representative of the stand structures within a stand area. The locations will be set out in advance and georeferenced for re-finding using a Garmin GPS.
8. Bat activity will be recorded on a field sheet and identified to species if possible with the number of bats if seen. Subsequent review of recordings will be done for species which were not identified in the field using Sonobat spectrogram software.
9. The locations of the bats will be recorded and a summary sheet of species activity produced for each stand area. The definition of bat pass and processing of audio data will be similar to that given in method 1.
10. The relationship between bat activity, stand type and structural habitat attributes will be analysed as in method 1.

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