Biodiversity in Planted Forests

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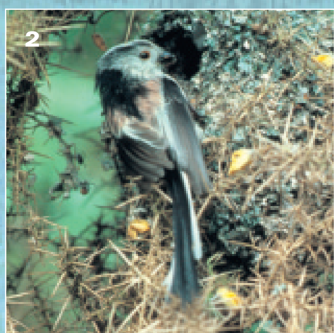
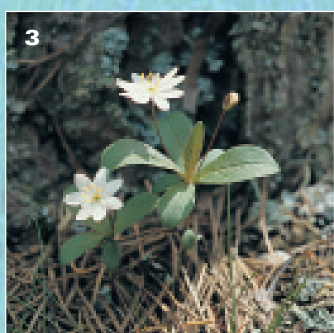


1 Overmature Sitka spruce: a natural reserve to encourage structural diversity and deadwood habitats
2 Long-tailed tit nesting in gorse within a forest ride
3 Chickweed wintergreen, a characteristic herb of northern forests
4 Hoverflies feeding on leopard's bane



Introduction

The majority of planted forests in Great Britain were established in the 20th century, usually on previously open ground with no recent history of forest cover (Hodge *et al.*, 1998), but occasionally through conversion of ancient semi-natural woodland (Spencer and Kirby, 1992). Introduced conifer species such as Sitka spruce *(Picea sitchensis)* and Corsican pine *(Pinus contorta* var. *maritima)* make up a large proportion (66%) of the planted area. Opinions differ as to the potential value of these 'new forests' for biodiversity. Attention has often been drawn to deleterious effects on the flora and fauna of the habitats which forestry replaces or modifies (e.g. Ratcliffe and Thompson, 1989), but there have also been a number of studies which have highlighted the positive value of planted forests for wildlife (e.g. Petty *et al.*, 1995). However, these studies have been mostly site specific, and there have been no comparative studies of plantations of different crop species in contrasting bioclimatic zones, or on a range of varied site types. Similarly, there have been few attempts to compare the biodiversity of planted forests with that of native or semi-natural woodlands. With continuing pressures on forest managers to improve the biodiversity of planted forests, e.g. the Forest Certification process (Anon., 2000), baseline information is urgently needed to provide a quantitative framework for understanding the levels and types of biodiversity currently found in plantations, and to inform the development of biodiversity enhancement strategies.

An additional problem is that the comprehensive assessment of biodiversity is an extremely difficult task. It is rarely cost-effective or practical to conduct a complete census of all taxa within a forest stand, let alone an entire catchment or forest landscape. Therefore, the identity of biodiversity 'indicators' or surrogate measures of biodiversity has become a research priority in recent years (Ferris and Humphrey, 1999). Examples of potential indicators include: deadwood, vertical stand structure, and the occurrence of particular tree species such as birch (*Betula spp.*). However, the link between such indicators and wider biodiversity has not been substantiated to the same degree in British forests as in other countries.

In this article we present results from a 5-year programme of research aimed at:

1. Obtaining baseline information on the types/levels of biodiversity in planted forests.
2. Evaluating the contribution of planted forests to the conservation of native flora and fauna through comparisons with semi-natural woodlands.
3. Identifying potential biodiversity indicators by relating the diversity of range of measured taxa to soil, climate, vegetation and stand structure variables.

Summary data are presented for all taxa analysed to date. Initial results from this programme were presented in *Forest Research Annual Report 1997–1998* (Ferris-Kaan *et al.*, 1998). Ground vegetation, fungi, lichen, bryophyte and selected invertebrate datasets are considered in more detail, and potential indicators of diversity within these groups are discussed. A number of management options for improving habitat quality are identified. A full analysis of the datasets for these and other species groups are presented in a forthcoming Technical Paper based on the proceedings of a symposium held at Harrogate in November 2000 (Ferris and Humphrey, in press).

Study sites

Assessment sites were selected from within the 'lowland', 'foothill' and 'upland' bioclimatic zones of the Ecological Site Classification system (ESC; Pyatt and Suárez, 1997). The zones are defined by annual precipitation totals (lowlands < 800 mm; foothills 800–1500 mm; uplands >1500 mm). Study sites were established in the main crop and semi-natural woodland types within each zone (Figure 1). At the majority of sites, a chronosequence of four 1 ha (100 m x 100 m) permanent sample plots was established in forest stands encompassing different growth stages based on the normal economic rotation (1: pre-thicket, 2: mid-rotation, 3: mature, 4: overmature). Wherever possible, individual chronosequences were established on sites with similar soils, climate and site history.

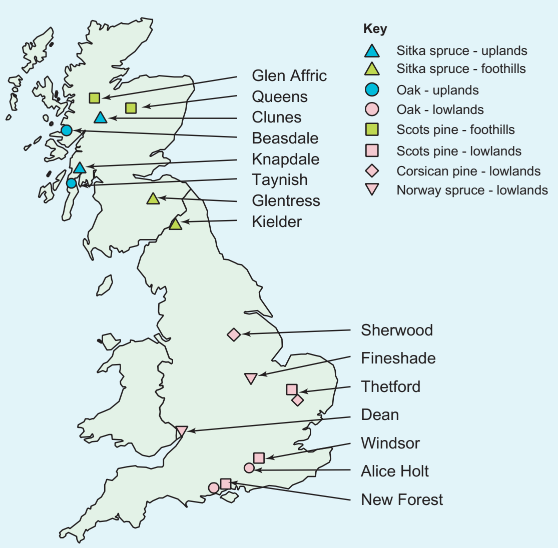


FIGURE 1

Location of biodiversity assessment plots; 52 plots were sampled in total over a 4-year period.

Assessment methods

Plots were selected to minimise heterogeneity in stand structure, species composition, topography and hydrology. A standardised system of assessment was established to maximise potential comparisons between measured attributes and to minimise disturbance during sampling. The plots were permanently marked. Assessments were carried out over a 3–4 year period and covered: structural aspects of biodiversity, such as vertical foliage cover and deadwood; taxa important in ecosystem functioning (e.g. fungi); a range of different groups making up the 'compositional' aspect of biodiversity (e.g. invertebrates).

Practicality and cost also influenced the selection of species groups to assess. Invertebrates were sampled from deadwood and three separate vertical strata (canopy, sub-canopy, ground). Canopy dwelling species were sampled using a canopy insecticide fogging technique (Jukes *et al.*, in press), sub-canopy species by malaise traps (Humphrey *et al.*, 1999), and ground species by pitfall traps (Jukes *et al.*, 2001). The frequency and abundance of vascular plants and fungi were sampled in eight sub-plots within each 1 ha plot (Ferris and Humphrey, in press). Species frequency and abundance estimates were made for lichens and bryophytes growing on individual pieces of deadwood (Humphrey *et al.*, in press). Volume and decay status of fallen deadwood (logs), standing deadwood (snags) and stumps were recorded within each plot. Songbird monitoring was undertaken by point counts and territory mapping (Ferris and Humphrey, in press). Data analysis methods for the various groups are described in full in the publications cited above.

Overview of results

Over 2000 species have been recorded to date (Table 1) with nearly half of these being invertebrates. A surprisingly high number of species were recorded in the planted stands, with lowland Scots pine and Norway spruce stands being the most species-rich of all the crop types. Stands in northern Britain (foothills and upland) had generally less diverse invertebrate and songbird communities than those in the south, but richer lichen and bryophyte communities. It had been expected that the native woodland stands would be considerably more species-rich than the plantations, but this was only the case for some groups such as vascular plants and lichens. These results are due in part to under-sampling of some groups in the native stands (e.g. birds, Table 1), and to a lower number of stands surveyed (e.g. 4 upland oak stands compared to 8 upland Sitka spruce stands). However, the positive value of plantations for groups such as the beetles and hoverflies is substantiated by other studies in

Table 1 Total number of invertebrate, fungi, lichen, bryophyte, vascular plant and songbird species recorded in each forest/climate zone type. Ninety-four coleoptera species (from a total of 474 species records excluding carabids) were recorded in more than one of the three vertical strata (canopy, sub-canopy, ground).

	Lowland				Foothill		Upland		Total species	Red Data species
	Corsican pine	Scots pine	Norway spruce	Oak	Scots pine	Sitka spruce	Sitka spruce	Oak		
Canopy invertebrates										
Coleoptera[a]	71	81	86	66	53	66	47	31	225	2
Sub-canopy invertebrates										
Cicadomorpha[b]	55	68	72	–	35	22	33	–	133	0
Syrphids[c]	27	43	37	15	25	22	29	22	59	4
Coleoptera[d]	76	109	114	80	61	52	52	62	228	4
Ground invertebrates										
Coleoptera (excluding carabids)[e]	36	54	52	25	30	29	35	19	116	1
Carabids[f]	30	21	29	16	18	23	17	18	53	1
Deadwood invertebrates[g]	23	24	21	8	20	14	23	2	64	3
Fungi	94	249	170	181	210	88	232	127	677	29
Lichens	11	29	14	51	100	23	46	102	202	2
Bryophytes	25	35	32	37	31	39	54	60	111	0
Vascular plants	28	34	47	55	27	29	40	60	143	0
Songbirds	18	25	27	–	17	16	15	–	40	0
Totals	494	772	701	534	627	423	623	503	2051	46

[a] Beetles – 37 families; [b] cicalids – 5 families; [c] hoverflies; [d] beetles – 30 families; [e] beetles – 26 families; [f] ground beetles. [g] The deadwood invertebrates category comprises data from a number of insect groups, many of which remain to be analysed. It is anticipated that more species will emerge from the deadwood collected from the oak stands.
– no data available.

planted forests (Humphrey *et al*., 1998). A scattering of Red Data list species were recorded across the majority of species groups, but the most striking result was for the fungi where 29 Red Data list species were recorded, suggesting that plantations provide a particularly valuable habitat for rare fungi. Fungi, however, have been under-recorded in the past compared to other groups, particularly in plantations, so many of these species may be less rare than previously thought.

Ground vegetation

Although ground vegetation diversity was closely related to soil nutrient levels there was also an effect of stand age on vegetation community composition, with the vegetation in most crop types becoming progressively more wooded in character through the stand cycle (increase in woodland similarity coefficient – Table 2). This process is a function of stand age (enough time has elapsed to allow slow-colonising woodland plants to become established in the stand), but may also be related to site history, i.e. whether the stand was established on a site previously occupied by ancient semi-natural woodland. Nevertheless, the plantation coefficients are still lower than those of the semi-natural woodland 'control' plots (oak and overmature foothills Scots pine), and only time will tell whether the wooded character of the vegetation of the overmature planted stands will continue to develop.

Table 2 Changes in the woodland vegetation similarity coefficient in relation to stand stage and crop type. The woodland vegetation similarity coefficient gives a measure of how closely the sampled vegetation is matched to a National Vegetation Classification (NVC; Rodwell, 1991) semi-natural woodland community type relative to a non-woodland vegetation community.

Woodland vegetation similarity coefficient (%)	Pre-thicket	Mid-rotation	Mature	Overmature
Lowland Corsican pine	43.2	32.8	27.4	58.2
Lowland Scots pine	21.9	34.6	34.9	32
Foothills Scots pine	41.3	58.2	69.1	70.8
Lowland Norway spruce	56.6	41.9	51	–
Foothills Sitka spruce	33.3	17.5	25.5	36.8
Upland Sitka spruce	44.7	33.9	49.9	58.6
Lowland oak	–	88.9	60.7	–
Upland oak	–	75.4	79.2	–

– Stand stage not available.

Invertebrates

Carabid (ground beetle) species-richness and community composition were strongly influenced by latitude and canopy structure, and to a lesser extent by soil organic matter and vegetation diversity. Species diversity was greatest in the more open plots, either pre-thicket or overmature, declining with canopy closure. There was a significant increase in the proportion of forest specialist species as the stands matured, with the overmature stands having the highest values (Figure 2).

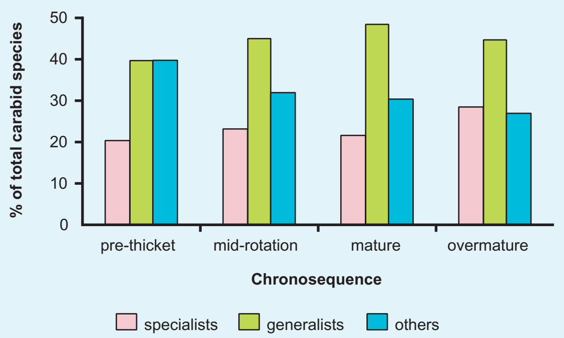


FIGURE 2

The increasing proportion of carabid forest specialists with plantation age, together with a corresponding decline in non-forest species.

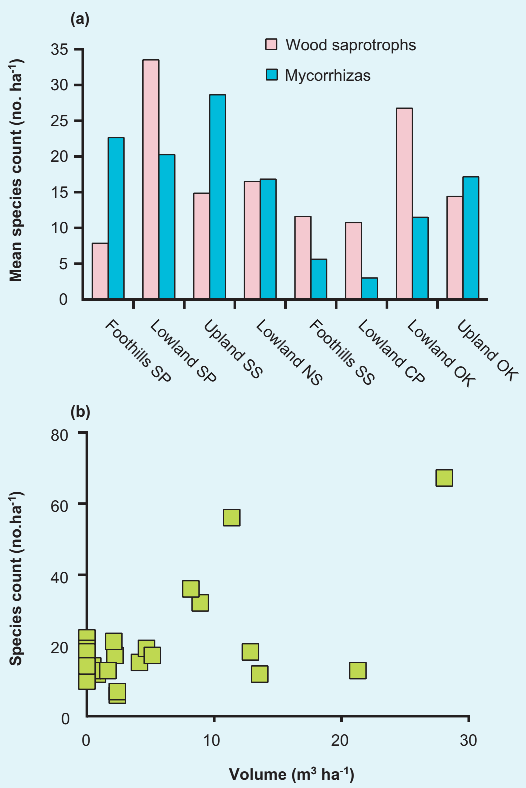
Canopy Coleoptera (beetles) were categorised into the functional groups saproxyles, herbivores, predators and others. The main influences on community composition were tree species and latitude. Saproxylic species showed an increase in abundance with plantation age, but no relationship with fallen deadwood volume was found, possibly due to the narrow sampling window (only one sample per year for 2 years in each plot). Predators were the most abundant group in many plots, particularly spruce, where the predators associated with the green spruce aphid, *Elatobium abietinum*, were dominant. Higher structural diversity in Scots pine stands resulted in a more diverse canopy Coleoptera community, though this relationship was not found in other tree species. A positive relationship between leaf area index and herbivore species richness in pine suggests that as stands are thinned, the loss of canopy cover has a direct effect on the species-richness of canopy Coleoptera.

Large numbers of invertebrates, mainly Diptera (flies) and parasitic Hymenoptera (wasps) were collected from the malaise traps. Hoverflies (Syrphidae), tree hoppers (Cicadomorpha) and beetles (Coleoptera) were identified to species level. Analysis of these data is still in progress, but the key points which have emerged are:

- Hopper and hoverfly species-richness and diversity decreases as mean tree basal area increases.
- Beetle diversity is not related to mean basal area.
- Pre-thicket plots have the highest hopper and hoverfly diversity.
- Sitka spruce canopies support the lowest diversity for all three insect groups.

Fungi

The fungi were broken down into four functional groups: mycorrhizals, parasites, litter saprotrophs and wood saprotrophs. The results shown in Figure 3a are for mycorrhizals (223 species in total) and wood saprotrophs (180 species). Upland Sitka spruce plots had the highest mycorrhizal species counts relating to denser canopy cover. This finding contrasts with those of other studies which have suggested that the fungal flora of conifer stands is often less diverse than that of broadleaved stands (Villeneuve *et al.*, 1989). It is possible that the denser stand conditions associated with spruce are conducive to the development of mycorrhizal communities by affording freedom from competing ground vegetation and providing a higher tree root density for mycorrhizal associations.



F I G U R E 3

(a) Mycorrhizal and wood saprotroph species-richness in relation to crop type. SP: Scots pine, SS: Sitka spruce, NS: Norway spruce, CP: Corsican pine, OK: oak.

(b) Relationship between wood saprotroph species counts and volume of fallen deadwood (lowland sites only).

In the lowland plots, mycorrhizal species-richness was positively correlated with the number of potential host tree species ($P < 0.05$). This confirms recent analyses indicating that many tree species in Britain are associated with distinctive ectomycorrhizal fungi which, in some cases, may be host-specific (Newton and Haigh, 1998). Wood saprotroph richness was strongly correlated ($P < 0.05$) with increases in fallen deadwood (log) volume (Figure 3b), with the lowland Scots pine and oak plots having the highest species numbers and log volumes.

Bryophytes and lichens

There was little distinction between the bryophyte flora of planted stands and semi-natural woodland (Table 1). Bryophyte species-richness was more closely related to crop type than climate, with spruce stands being richer than pine stands, regardless of climate zone. This observation has not previously been recorded in Britain, but is consistent with Fennoscandian literature, where spruce is generally considered a more favourable habitat for bryophytes than pine (Esseen *et al.*, 1997). Bryophytes were less affected by shading, and most spruce stands had a reasonable complement of species in all stand stages. The best stands appear to be those with high values for upper canopy cover (i.e. mature and overmature stand stages). It is possible that these stands offer a better combination of high humidity, adequate light levels and constancy of micro-climate.

Lichen species-richness was much higher in the upland and foothills stands than in the lowland stands (Table 1), substantiating existing views that oceanic conditions (and low pollution levels) in the north and west of Britain provide much better conditions for lichen growth (Rose, 1993). The semi-natural pinewood and oak stands had richer lichen communities than the planted stands, relating to the occurrence of habitat features such as old trees, shaded rocks and cliffs, and a long-continuity of woodland conditions (Plate 1).

PLATE 1

Ancient semi-natural Scots pine wood showing old trees and standing deadwood. (Simon Davey)

Low light levels are considered to be highly detrimental to lichen growth (Rose, 1993). This explains why stand structure had such a significant effect on lichen species-richness, mid-rotation and mature stages having lower species counts than the pre-thicket and overmature stands (Figure 4). The pre-thicket stands are particularly important in the foothills Scots pine plots where stumps support *Cladonia* species. A scarce and important species within the group is *C. botrytes* shown in Plate 2. Bryophyte species-richness was higher on logs and stumps, while snags were more important for lichens (Figure 5). Observations from overseas

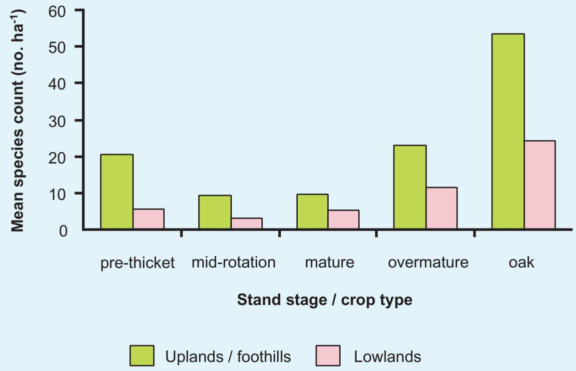


FIGURE 4

Lichen species-richness in relation to stand stage; oak is included for comparative purposes.

PLATE 2

Typical group of pinewood lichens including *Cladonia botrytes* (B) on deadwood; *Vaccinium* berry added for scale. (Simon Davey)

(Kruys *et al*., 1999) tend to support these findings. Larger and more highly decayed material appears to provide a better substrate for lower plant development (Ferris and Humphrey, in press). Snags in native pinewoods provide a key habitat for the rare 'pin-head' lichen group (species of the genera *Calicales* and *Chaenotheca*).

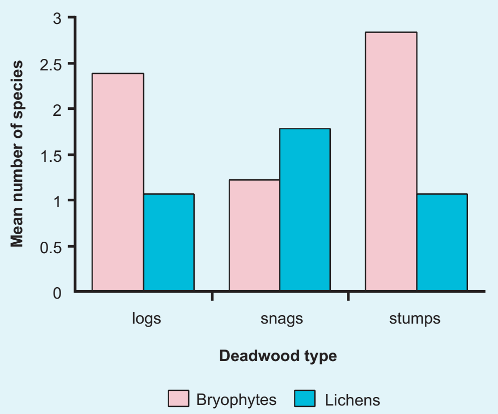


FIGURE 5

Lichen and bryophyte species-richness on different types of deadwood.

PLATE 3

Deadwood is an important substrate for lower plants and fungi especially within natural reserves. (Simon Davey)

Conclusions and implications for management

The project has been successful in meeting its main objective of establishing a baseline dataset of the biodiversity of plantations across Britain. The most significant finding was that stands of non-native conifer species appear to provide suitable habitat for a wide range of native flora and fauna and should be viewed as making a positive contribution to biodiversity conservation in the UK. There were considerable differences in value of different stand ages and crop types for different species groups with no single type providing 'optimal' conditions for biodiversity. Pre-thicket plots and restocks provide habitat for a variety of species-groups common to non-wooded habitats (e.g. heathland). However, the overmature stands, both in native and planted forests, are important for species requiring continuity of wooded conditions and deadwood. Therefore, three contrasting, but not mutually exclusive, management strategies could be considered for plantations:

1. Maintenance of the patch-clearfelling system to ensure provision of early-successional habitat.
2. Extending rotations beyond normal economic felling age and establishing 'natural' (non-intervention) reserves.
3. Managing some stands under continuous cover regimes (sensu Mason *et al.*, 1999).

The latter two strategies would help to maintain and develop mature woodland conditions, including production of old trees, accumulation of deadwood (Plate 3) and diversification of the tree flora.

While wind risk is a significant factor to consider when deciding where to locate continuous cover stands (Mason *et al.*, 1999), site history is also of key importance, as there is a suggestion from the data that plantations established on ancient semi-natural woodland sites (PAWS, e.g. some lowland Norway spruce and upland Sitka spruce stands) have a much higher diversity of woodland fungi, bryophytes and vascular plants than their counter-parts established on previously open ground. Restoring PAWS back to native woodland may not always be of benefit to biodiversity in the short to medium term, particularly if the restoration is done very rapidly. This is especially the case for mycorrhizals where extensive felling of host trees can disrupt mycelial connectivity and reduce the extent of recolonisation after restocking or natural regeneration (Flynn *et al.*, 1998). Even smaller-scale felling can be disruptive (Flynn *et al.*, 1998), and it may be more desirable therefore to identify some PAWS known to have a high number of characteristic species as potential 'natural reserves'.

PLATE 4

Old beech stump. Fresh and well-decayed large logs and stumps provide a range of habitat types. (Entomology Branch, Forest Research)

Based on the results presented above it is clear that measures of stand structure and deadwood have considerable potential as biodiversity indicators in planted forests. For example, the number of host tree species could be used as an indicator of mycorrhizal diversity. The positive correlations recorded between deadwood volumes, and species-richness of wood saprotroph fungi, lichens and bryophytes is also notable. A mix of fresh and well-decayed large diameter logs and stumps should provide a range of habitat types (Plate 4) with volumes in the range of about 40 m^3 ha^{-1} providing for the greatest lower plant and fungal diversity (Ferris and Humphrey, in press).

The biodiversity indicators and management strategies proposed in this article are still tentative and further work is planned in the near future to validate these proposals and analyse additional datasets, looking particularly at the issue of site history.

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