Chapter (non-refereed)

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Guidelines for managing woods in Aberdeenshire for song birds

D D FRENCH, D JENKINS and J W H CONROY
Institute of Terrestrial Ecology, Banchory

1 Introduction
This paper uses data on song bird populations and habitat features from woods in Deeside, Aberdeenshire, to define some forest management practices that are likely to enhance the richness of the song bird populations in these woods in spring and summer. We analyse the relationships between song bird populations and the structural characteristics of the woods to test the ways in which forest structure and tree type affect song bird populations. We then derive from these relationships our recommendations for woodland management.

Our main emphasis is on the whole song bird population, especially numbers of birds, numbers of species, and species diversity, and secondarily on groups of species which occupy similar habitat types. We do not consider in detail the needs of most individual bird species, as these are not often likely to be catered for by simple adaptations of normal forest management.

Our results are most relevant to the management of established woods, rather than the early stages of a new wood. We do not, therefore, consider new plantings, except to the extent that the pattern of planting will affect the eventual structure of the established (mature) wood. Our sample does, however, include a young (<*c*40 yr maximum age) conifer plantation and an area of young birch (*Betula* spp.) of similar maximum age colonizing a former heather (*Calluna vulgaris*) moor.

2 Methods
We initially surveyed a number of semi-natural woods to test the general idea that forest structure and tree type both affected song bird populations. Later, we took selective samples, mainly in plantations, to test in more detail the effects of mixed tree species and the presence of a tall-shrub layer on numbers of birds and species. We have also monitored changes in bird populations following changes in forest management.

2.1 Study areas (sites)
Single census plots, mostly about 10 ha, were established in 14 woods during 1980–84 (Figure 1, Table 1) as our basic sampling units. A further 2 plots were set up in 1985, partly to test our ability to predict their song bird populations, so data from these plots are omitted from most of the more general analyses. Including these 2 woods, there were 6 conifer stands, 3 birch/aspen (*Populus tremula*), 1 oak (*Quercus* spp.)/birch and 6 mixed broadleaf/conifer stands, of which one was mainly conifer, 2 mainly broadleaf trees, and 3 approaching equal proportions of the 2 tree types.

At the oak/birch plots (J), a tall-shrub layer of rhododendron (*Rhododendron ponticum*), covering about one-third of the total area, was removed between 1980 and 1982. At 2 of the mixed woods (N and O), selective felling, mainly of pine (*Pinus* spp.) at N and of birch at O, removed much or all of one tree type from part of the site, leaving the rest unaltered. At these 3 'experimental' sites, we examined the changes resulting from the manipulations in more detail than in the general comparative analysis of whole census plots. Similarly, we examined within-site variation in those sites which had both a tall-shrub layer and an upper canopy.

2.2 Bird counts
Most census plots were rectangular, with the ratio of long and short sides never more than 2.5 : 1. Each was marked out in a regular grid of 40 m x 40 m squares to aid mapping of bird sightings.

For mapping bird territories, we used the standard Common Bird Census methods of the British Trust for Ornithology (Marchant 1983), plotting the positions of all birds heard or seen on each of several visits between March–April and June, then deriving territory boundaries for each song bird species from the resulting maps. If a territory overlapped the plot boundary, it was scored as a half, unless there was good evidence that more than three-quarters of it was outside (score 0) or inside (score 1). Where territory boundaries were doubtful, we used the arrangement which gave the minimum score. Crossbills (*Loxia curvirostra*) were not counted, as they were not normally territorial during the period of the counts (their young were already hatched), neither were game birds, corvids, nor birds of prey. Differences between observers were assessed by duplicate counts at a number of sites, and found to be negligible.

For subsequent analyses, the counts were first corrected to territories 10 ha^{-1}. (Throughout the paper, number of 'birds' means number of territories mapped). Bird species were classified in the following ecological groups according to their use of habitat, after Thomson (1910), Komdeur and Vestjens (1982), Haapanen (1965), and our own field observations.

i. *Open ground* Birds of large open areas with little or no tree or shrub cover only occurred in

Table 1. List of sites, with median altitudes (to nearest 10 m), brief descriptions, top heights and sampling dates (for locations see Figure 1)

A	Strone. 220 m asl. Young (<40 yrs) pine plantation, plus some later natural regeneration, top height *c*9 m, sampled 1980–83.
B	Gairney. 260 m asl. Uniform stand of tall pine, possibly regenerated after fire, *c*140 yrs old, top height *c*20 m, sampled 1980–83.
C	Allachy. 260 m asl. 'Caledonian' pine forest, >150 yrs old, rather open, a little juniper near one end, top height *c*20 m, sampled 1980–83.
D	Drum. 320 m asl. 'Caledonian' pine, >150 yrs old, very open, many spreading trees, some juniper, but mostly short, top height *c*18 m, sampled 1980–83.
E	Glassel Road. 120 m asl. Mature pine plantation, with some broadleaf understorey and shrub layer, relatively dense upper canopy, top height *c*21 m, sampled 1985.
F	Glen Dye. 100 m asl. Mature pine plantation, *c*80–90 yrs old, rather open, very tall trees, with gaps, including a large area of natural regeneration acting as a tall-shrub layer, top height *c*25 m, sampled 1984–85.
G	Dinnet Roadside. 160 m asl. Young birch (<40 yrs) colonizing heather moor, very open, and grazed by cattle, includes areas of bog/marsh, top height 8 m, sampled 1980–83 and 1985.
H	Huntly Road. 170 m asl. Birch colonizing moor, similar to G but more older trees and generally denser, includes a little bog and a small pond, top height *c*10 m, sampled 1985.
I	Ord Hill. 170 m asl. Birch/aspen, mixed age but few really old trees, *c*½ in small clumps, of all ages and spp., the rest nearly all young birch, top height *c*15 m, sampled 1980–83.
J	1. Dinnet Oakwood. 170 m asl. Old oak plantation *c*⅓ with mixed-age birch/aspen/cherry, and another ⅓ with dense rhododendron shrub layer, sampled 1980–81. 2. as above, after removal of rhododendron, top height *c*19 m, sampled 1982–85.
K	Potarch. 160 m asl. Mixed wood, mainly mixed-age/spp. conifer, plus some birch and cherry, height very variable, top height *c*14 m, sampled 1984–85.
L	Braeroddach. 210 m asl. Mixed wood, mainly birch + some pine, both medium-age, grazed by cattle, some bog areas, top height *c*14 m, sampled 1983–85.
M	Craigendarroch. 180 m asl. Mixed wood, mainly oak, plus birch/pine, on steep slope with many boulders, generally fairly uniform except in mixed areas, top height *c*20 m, sampled 1982–85.
N	1. Cambus o' May. 210 m asl. Mature-old birch + many large old pines + small areas of oak and (?) coppice birch + edge of mixed-conifer plantation, grazed by cattle, rather open, top height *c*18 m, sampled 1983–84. 2. As above, after felling/removal of some pine and birch during winter 1984–85, more even distribution of pine/birch, sampled 1985.
O	1. Corsedardar. 210 m asl. Half very young conifer, half an intimate mixture of Douglas fir with medium-age/semi-mature birch and rowan + a few scattered large pine and beech, top height 5–8 m in young part, *c*14 m in mixed part, sampled 1984. 2. as above, after removal of nearly all birch/rowan from half the mixed area, sampled 1985.
P.	Crathie. 280 m asl. Very mixed wood. Several ages of birch + some other broadleaf trees + a wide range of mature-old conifers, juniper abundant both under birch and in gaps, as well as several other shrub-types. A long-established, well-developed wood, top height *c*20 m, sampled 1981–84.

appreciable numbers at one site, so were ignored in all analyses of habitat groups: skylark (*Alauda arvensis*), sedge warbler (*Acrocephalus schoenobaenus*) (might also be put in group (ii) or (iia)), meadow pipit (*Anthus pratensis*).

- ii. *Shrub + open* Birds using shrubs or similar cover, usually plus some small open gaps: song thrush (*Turdus philomelos*), ring ouzel (*T. torquatus*) (a single territory, on a craggy area at the top of a hill, but also using shrubby areas in the site), blackbird (*T. merula*), dunnock (*Prunella modularis*), greenfinch (*Chloris chloris*), bullfinch (*Pyrrhula pyrrhula*), yellowhammer (*Emberiza citrinella*).
- iia. *Ground cover* Wren (*Troglodytes troglodytes*) (needing tall ground vegetation or similar low cover, or shrubs. Similar to group (ii), and incorporated for some analyses).
- iii. *Stem and air* Birds mainly of more open, mature woodland, stem/hole nesters, or stem feeders, or air feeders, or requiring high, open song stations, or canopy nesters but ground foragers: woodpeckers (*Picus viridus* and *Dendrocopus major*), tree creeper (*Certhia familiaris*), mistle thrush (*Turdus viscivorus*), redstart (*Phoenicurus phoenicurus*), wood warbler (*Phylloscopus sibilatrix*), spotted flycatcher (*Muscicapa striata*), tree pipit (*Anthus trivialis*).
- iv. *Tall shrub (+ canopy)* Birds preferring a fairly dense tall-shrub layer (or, in some cases, cover at equivalent height), usually also a canopy of some kind in addition: wood pigeon (*Columba palumbus*), long-tailed tit (*Aegithalos caudatus*), blackcap (*Sylvia atricapilla*), redpoll (*Acanthis flammula*).
- iva. *Tall shrub* Canopy more or less irrelevant, but otherwise similar to group (iv) and combined for some analyses: robin (*Erithacus rubecula*), willow warbler (*Phylloscopus trochilus*).
- v. *Canopy* Birds either of actual canopy or of 'tops' of trees or shrubs: blue tit (*Parus caeruleus*), coal tit, (*P. ater*), goldcrest (*Regulus regulus*), siskin (*Carduelis spinus*).
- vi. *Whole profile* Birds either requiring cover at all levels or able to use almost any level: great tit (*Parus major*), chaffinch (*Fringilla coelebs*).

These ecological groups are essentially related to forest structure. They do not take into account preferences of some bird species for particular tree species or types; for example, great tit is usually only found where broadleaf trees are present, and goldcrest only with conifers. The effect of tree type is, however, examined in the consideration of mixtures.

Another common distinction which we have not made is between 'seed eaters' and 'insect eaters', as this distinction does not normally apply during the nesting period when the counts were done.

The diversity indices 'bird species diversity' (BSD), using numbers of each species, and 'habitat group

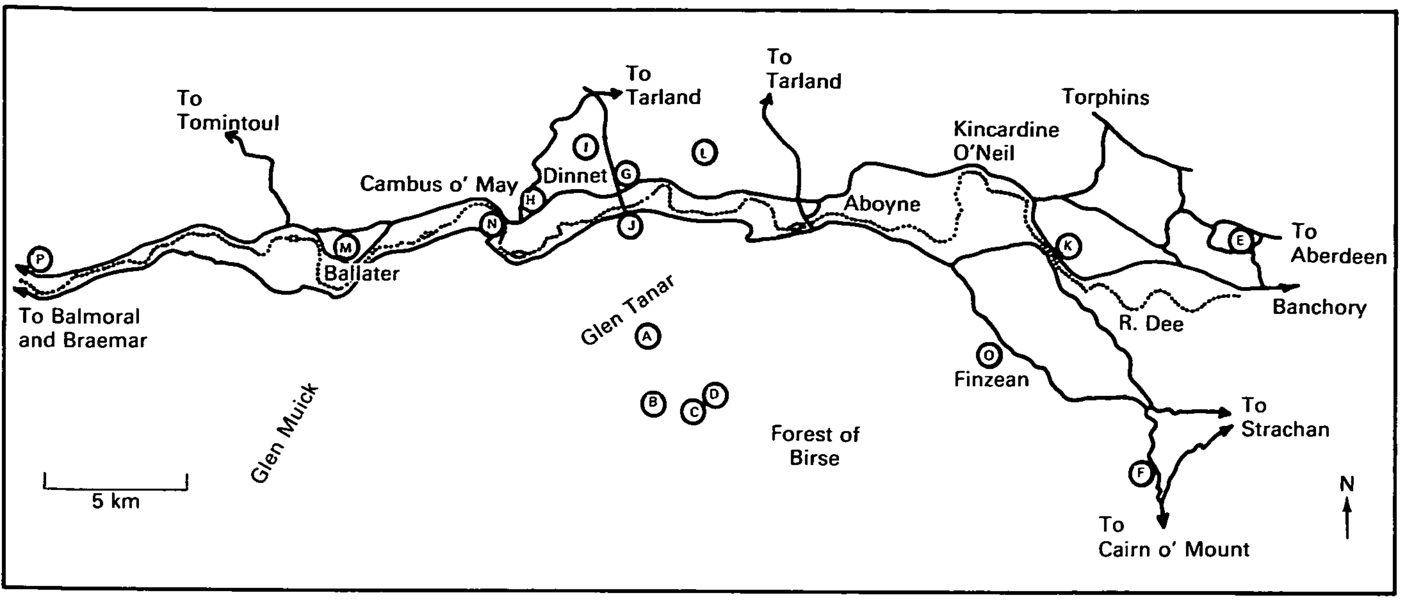

Figure 1. Approximate site locations. Site codes as in Table 1

diversity' (HGD), using numbers in each ecological group, were both calculated using the Shannon Index:

$$-\Sigma[p_i \times \ln(p_i)]$$

where p_i is the proportion of the ith species or group in the population or sample (Shannon & Weaver 1949).

2.3 Habitat survey

This survey was done mainly to obtain measures of forest structure parameters (cover of different layers, and general structural diversity), especially vegetation profiles (cf Moss 1978). Initially, all distinct 'habitat types' (ie areas with distinctive structure, species composition, height, density, etc) found in the census plot were mapped. Within each habitat type, we recorded the cover of vegetation at heights of 0–0.25 m, 0.25–0.5, 0.5–1, 1–2 and thereafter at intervals according to presence of cover, to the nearest metre. Plots of 10 m x 10 m were placed in randomly selected grid squares within each habitat type, near a corner of the square chosen (i) to avoid boundaries of habitat types, and (ii) to be a 'representative' sample of the type, and were moved within the square or to an adjacent square if necessary to satisfy these conditions. Three further constraints were that (i) as far as possible all separate areas of any type should be sampled at least once, (ii) sampling intensity in any habitat type should be approximately proportional to its area, and (iii) the total number of plots in any site should be not more than about 35, but always at least 20.

At each height, cover was estimated to the nearest 10%, with under 5% scored as 'present'. The resulting cover profiles were then examined graphically. Habitat types which did not have distinct profiles were combined, and an average profile was calculated for each profile/habitat type. The overall profile for the census plot was calculated as the weighted mean (proportionally, by relative area) of the average profiles of the recognized habitat types. From the vegetation profiles, we extracted 'total cover' (sum of all layers), cover at 0–1 m (ground layers and low shrub), 2–6 m (tall shrub), 7–12 m (low canopy), 13–18 m (mid-canopy), 19–25 m (high canopy), and 13–25 m ('upper' canopy = average of mid and high). From these data, we calculated foliage height diversity (FHD) using ground, shrub, lower and upper canopy as the constituent groups expressed as the Shannon Index, and the number of distinct profile types (NPT).

FHD measures only the vertical heterogeneity of the vegetation. We also used a reduced version of the transect method of van Berkel (1979) to estimate horizontal heterogeneity (Opdam & van Bladeren 1981). This measure is defined (per transect of 50 points) as $\log_{10}$[1 + (no. of groups with +ive score) x (no. of different-sized groups +ive) x (no. of different-sized gaps)] for each layer (herb, shrub, lower canopy, upper canopy) separately. These values were then averaged over 6–8 transects, and the resulting mean values for each layer were summed to give an index of total horizontal heterogeneity (HET) over all layers for each site. From the transect data, we also estimated the relative cover of different tree types in the canopy, and the average size of gaps.

2.4 Analyses

Our analyses were in 2 parts. First, from the general survey, we assessed the effects of the following 'vegetation parameters':

— structural composition (cover of different layers) and diversity (FHD, NPT and HET) } profile and heterogeneity parameters

— age or stage of development of the stand
— canopy tree type (ie broadleaf, conifer, mixed)
— a tall-shrub layer

on these 'bird parameters':

— number of birds using different parts of the profile (the 'ecological groups' defined above)
— number of birds
— number of species
— the 2 diversity indices
} bird summary parameters

Second, using especially our later selective samples and 'experimental' sites, we attempted to define an 'optimal' size for gaps, to derive a minimal 'useful' proportion of secondary types in mixtures, and to suggest the best distribution of tree types within a mixture. We also assessed in greater detail the effects of different combinations of tall-shrub layer and canopy types.

3 Results

3.1 Basic data and general description of bird populations

Table 2 lists the numbers of territories 10 ha^{-1} of species in the 8 ecological groups, plus bird summary parameters for each study area. All song bird species from Newton's (1986) list were present, except for redwing (*Turdus iliacus*) and chiffchaff (*Phylloscopus collybita*) (both seen but never shown to hold territory), whitethroat (*Sylvia communis*) and pied flycatcher (*Ficedula hypoleuca*), which are all uncommon in north-east Scotland. The variety of bird species was therefore much as expected for the area generally.

Numbers in our plots were within Newton's (1986) range of numbers of (territorial) birds, ie 15–150 10 ha^{-1}, varying from 22 at Dinnet Roadside (site G) to 118 at Crathie (site P). Numbers in our conifer woods were generally similar to or higher than those of Moss (1978) and Moss *et al.* (1979) for plantations in southern Scotland.

Data in Table 2 are mean counts over all available years at each site. Variation between years was moderately high, eg total number typically ranged ± 10% of the mean count over 3–5 years. In a few sites the range was wider (>20%).

There was a general trend of increasing number of species with number of birds. However, there were several sites with many birds but few species, eg Strone, site A, or *vice versa,* eg Allachy, C, or Braeroddach, L (Table 2).

Usually, there were fewer bird species in birch and conifer woods than in oak or mixed woods. Some species also were either restricted to, or more numerous in, particular tree types. With the exception of siskins, which were found with all tree types, and reached their highest density (in 1981) in the oakwood (site J), our data were not inconsistent with Newton's (1986) general observations on individual species or groups.

3.2 Whole-wood (general survey) analyses

Correlations and regressions with profile and heterogeneity parameters were calculated using the mean

Table 2. Numbers of birds (territories) 10 ha^{-1} in 8 ecological groups, and bird summary parameters, in 16 Deeside woods (source: original unpublished data

Site	Ecological groups (i)	(ii)	(iia)	(iii)	(iv)	(iva)	(v)	(vi)	Number of Birds	Number of Species	Bird species diversity	Habitat group diversity
A	0	0	1.9	0	0	22.1	8.9	8.3	41.6	6.2	1.66	2.73
B	0	0	6.9	6.1	0	1.4	8.7	14.0	37.1	8.0	1.73	2.71
C	0	0	3.9	6.1	0	3.2	6.1	9.7	29.0	11.3	2.07	4.88
D	0	0	5.2	3.9	0	6.9	7.6	13.4	37.2	8.3	1.83	4.64
E	0	0.6	1.2	13.2	3.0	3.6	10.2	10.8	42.6	11.0	2.13	6.26
F	0	1.5	4.5	18.5	3.7	7.6	11.7	15.6	62.9	15.0	2.39	7.53
G	7.5	0.5	0	0	0	9.6	2.0	2.3	22.1	8.2	1.62	2.04
H	0	2.2	3.0	5.9	1.5	21.6	5.2	11.9	51.3	11.0	2.01	5.90
I	0	2.1	4.0	3.1	2.3	17.0	3.7	13.3	45.6	13.0	2.11	5.97
J1	0	4.9	4.2	12.2	1.1	13.6	10.5	18.5	64.9	16.0	2.43	7.48
J2	0	2.7	0.3	15.5	0.3	9.6	9.0	14.6	52.0	14.3	2.35	4.83
K	0	7.6	1.6	10.9	3.9	12.7	7.5	18.0	62.0	17.5	2.54	8.09
L	0	1.1	0.5	3.1	1.5	7.0	5.8	11.9	30.9	12.0	2.09	4.75
M	0	4.4	0.6	9.4	3.0	9.3	11.1	20.6	58.4	16.5	2.36	6.40
N1	0	4.4	0	13.2	0.8	6.5	12.2	19.6	56.9	16.0	2.43	5.20
N2	0	3.1	0.5	9.3	0	3.6	15.1	14.6	46.2	16.0	2.42	3.54
O1	1.1	5.1	0	2.2	0	32.7	5.0	10.0	56.1	13.0	1.91	3.30
O2	0.6	3.4	1.1	0.6	1.1	33.8	12.1	13.3	66.0	14.0	2.01	3.82
P	0	10.6	4.4	16.0	11.9	33.3	16.0	26.4	118.6	19.0	2.53	7.99

All figures are mean scores for the site over all available years. Site codes as in Table 1
Ecological groups – birds of: (i) open ground, (ii) shrub + open, (iia) ground cover (wren), (iii) stem and air, (iv) tall shrub (+ canopy), (iva) tall shrub, (v) canopy, (vi) whole profile

Table 3. Vegetation profile and heterogeneity parameters for 16 Deeside woods (source: original unpublished data)

Site	Ground cover (0–1 m)	Tall shrub (2–6 m)	Canopy: Lower (7–12 m)	Canopy: Mid (13–18 m)	Canopy: High (19–25 m)	Canopy: Upper (mean of mid and high)	Foliage height diversity	Number of distinct profile types	Horizontal heterogeneity
	Total % cover (summed over 1 m intervals) of:								
A	248	140	13	0	0	0	0.77	3	6.14
B	126	23	90	38	2	20	1.23	1	3.82
C	129	17	53	16	1	8	1.07	4	6.53
D	139	21	48	9	0	4	0.98	3	5.85
E	119	36	97	150	8	79	1.36	4	6.57
F	117	22	14	36	27	31	1.29	5	7.53
G	86	21	2	0	0	0	0.59	3	5.02
H	136	90	11	0	0	0	0.82	2	5.23
I	110	86	86	10	0	5	1.20	4	7.85
J1	159	139	149	68	0	34	1.34	5	7.97
J2	107	118	172	58	0	29	1.32	4	7.64
K	140	103	51	1	0	1	1.05	7	6.99
L	109	73	139	2	0	1	1.10	4	7.11
M	52	56	189	69	2	36	1.25	4	6.37
N1	96	77	149	29	0.5	14	1.26	7	6.80
N2	93	69	129	19	0.5	10	1.24	6	6.75
01	156	99	27	1	0	1	0.94	4	7.22
02	163	72	21	1	0	1	0.88	4	6.99
P	139	102	97	31	1	16	1.29	7	8.26

Site codes as in Table 1

data in Table 2. Effects of age, tree type and shrub/canopy combinations were calculated using data from individual years.

3.2.1 Vegetation profiles and horizontal heterogeneity

Correlations of bird parameters (Table 2) with profile and heterogeneity parameters (Table 3) indicated strong relationships between number of birds, number of species and diversity indices, and several vegetation parameters, especially FHD, NPT and HET (Table 4). Ecological groups (iii) and (vi) were also well correlated with many vegetation parameters, but otherwise correlations between individual ecological groups and site characteristics were generally low. Even those that were high (eg group (ii), ground + shrub birds, with NPT) were all of the group with some general expression of habitat diversity, rather than with anything more specific.

In an attempt to convert these correlations to predictive equations, and to obtain more immediately measurable predictive parameters, we computed a series of multiple regressions, using a step-up procedure, and avoiding FHD, NPT and HET unless they were necessary to produce any significant regression. The predictive values of the best regression equations for each bird parameter were tested by comparing observed and expected values at the 2 sites omitted from the analyses (Table 5). About two-thirds of the predicted values are reasonable for both woods, but

Table 4. Correlation matrix of bird parameters *vs* profile and heterogeneity parameters in Deeside woods (source: original unpublished data)

Ecological groups (i)	(ii)	(iia)	(iii)	(iv)	(iva)	(v)	(vi)	Number of Birds	Number of Species	Bird species diversity	Habitat group diversity	
−0.55	0.39	−0.07	0.40	0.15	0.15	0.42	0.54	0.41	0.39	0.47	0.35	Total cover
−0.21	−0.05	0.21	−0.31	−0.06	0.51	0	−0.19	0.11	0.36	−0.35	−0.15	Ground cover
−0.30	0.50	−0.29	0.12	0.17	0.51	0.19	0.28	0.42	0.32	0.31	0.23	Tall shrub
−0.40	0.26	−0.16	0.46	0.09	−0.34	0.35	0.57	0.16	0.48	0.57	0.30	Lower canopy
−0.30	0.20	0.19	0.67	0.16	−0.28	0.43	0.57	0.31	0.41	0.50	0.42	Mid-canopy
−0.09	−0.12	0.27	0.48	0.19	−0.17	0.21	0.10	0.14	0.14	0.21	0.34	High canopy
−0.30	0.16	0.24	0.74	0.19	−0.30	0.45	0.55	0.32	0.42	0.51	0.47	Upper canopy
−0.67	0.36	0.30	0.80	0.35	−0.26	0.55	0.77	0.45	0.64	0.76	0.62	FHD
−0.24	0.76	−0.28	0.61	0.55	0.17	0.52	0.63	0.63	0.84	0.84	0.66	NPT
−0.38	0.58	−0.16	0.46	0.49	0.44	0.30	0.48	0.61	0.71	0.70	0.67	HET
−0.39	0.74	−0.13	0.77	0.58	0.06	0.63	0.77	0.67	0.89	0.93	0.73	FHD × NPT
−0.56	0.55	0.08	0.77	0.51	0.08	0.49	0.73	0.62	0.79	0.86	0.77	FHD × HET

For definition of ecological groups, see Table 2. Cover categories as in Table 3

FHD = foliage height diversity, NPT = number of profile types, HET = horizontal heterogeneity

$r=\pm$ 0.47, $P<0.05$; $r=\pm$ 0.59, $P<0.01$

Table 5. 'Best' regression equations of bird parameters on vegetation parameters, and tests of their predictive ability (source: original unpublished data)

			Site E		Site H	
Bird parameter	Regression	R^2	Observed	Expected	Observed	Expected
Ecological group* (ii)	1.39 × NPT − 3.12	.58	1.0	2.5	1.5	0
Ecological group* (iia)	0.04 × (tall shrub) − 0.04 × (lower canopy) + 0.09 × (upper canopy) − 1.06	.47	1.5	3.5	3.0	2.0
Ecological group* (iii)	20.2 × FHD + 0.29 × (high canopy) − 15.2	.72	13.0	15.0	4.0	2.0
Ecological group* (iv)	NPT − 2.668	.31	3.0	1.5	1.5	0
Ecological group* (iva)	0.17 × (tall shrub) − 0.09 × (lower canopy) + 8.88	.50	4.0	6.0	21.0	23.0
Ecological group* (v)	7.3 × FHD + 0.85 × NPT − 2.9	.41	10.5	10.5	5.0	5.0
Ecological group* (vi)	1.29 × NPT + 15.82 × FHD − 8.85	.72	11.0	18.0	12.0	7.0
Number of birds	6.25 × FHD × NPT + 20.9	.45	43	55	51	31
Number of species	1.93 × NPT + 4.65	.71	11	12	11	9
BSD	0.12 × FHD × NPT + 1.53	.87	2.13	2.18	2.01	1.73
HGD	0.66 × FHD × HET + 0.02	.59	6.26	5.92	5.90	2.85

Regressions were calculated omitting sites E and H, then the expected bird parameters for each site were calculated from the regressions
All regressions are significant at $P<0.05$
BSD = bird species diversity, HGD = habitat group diversity (Shannon Index)
Shrub and canopy variables are total cover (summed at 1 m intervals) over the range 2–6 m (tall shrub), 7–12 m (lower canopy) and 19–25 m (high canopy), and the mean of 13–18 m and 19–25 m (upper canopy)
FHD = foliage height diversity (Shannon Index), NPT = number of profile types, HET = horizontal heterogeneity (Opdam & van Bladeren 1981)
*See Table 2

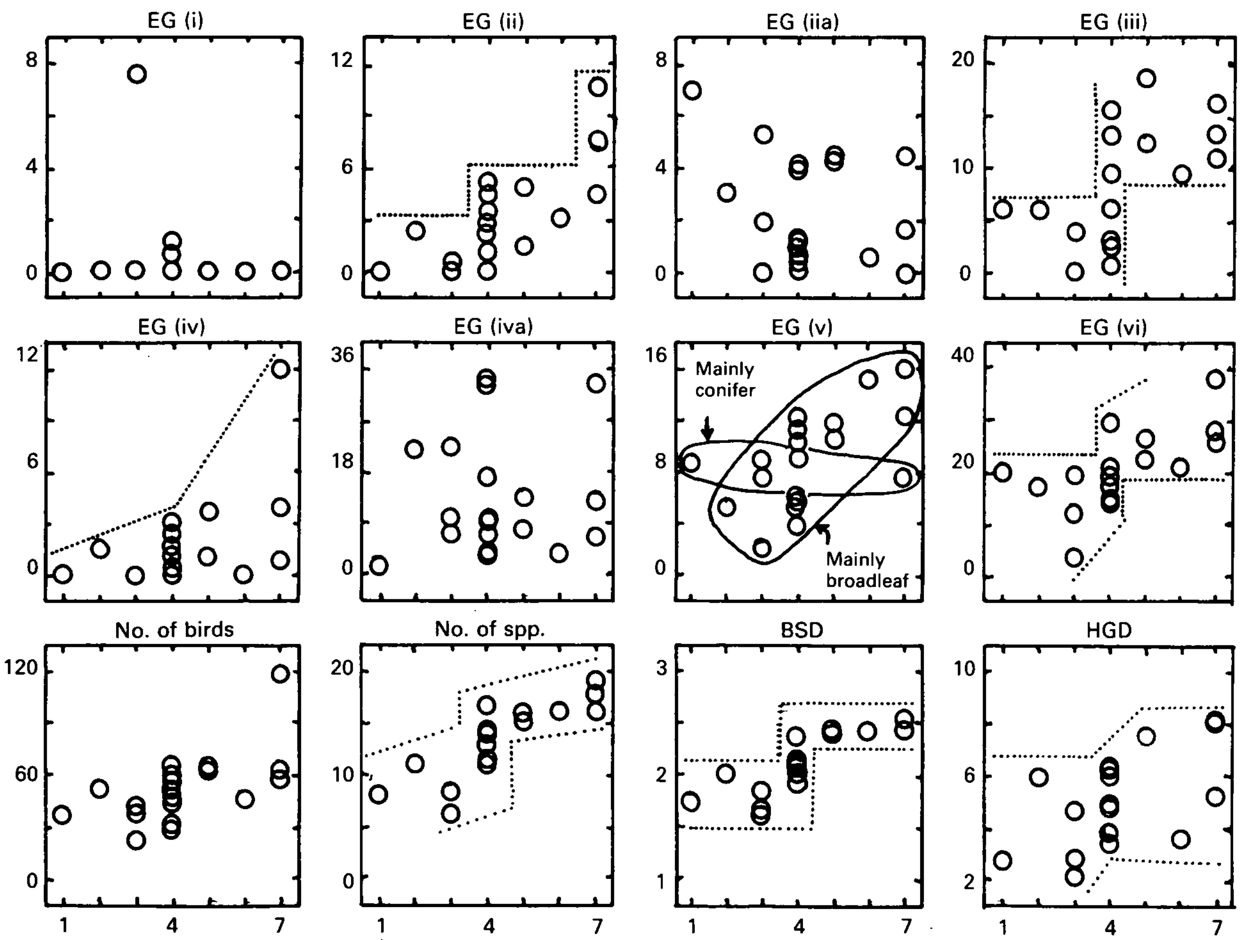

Figure 2. Relations between bird parameters and number of profile types (NPT). Dotted lines indicate step or threshold at NPT=4. EG = ecological group (see text and Table 2) (source: original unpublished data)

the prediction of habitat groups cannot generally be called 'good', neither can the prediction of number of birds. Number of species and BSD, however, were both well estimated and, together with prediction of habitat groups taken as a whole, the regressions provide a fairly good measure of the overall value of a wood for song birds.

We also found that, if plotted against bird parameters, the number of distinct profile types (NPT) frequently showed a step or threshold relationship, in which 4 profile types was the threshold above or below which a wood could be classed as 'good' or 'bad'. This threshold held true for number of birds, number of species, BSD, and ecological groups (ii), (iii) and (vi). Group (v) was related to NPT in broadleaved and mixed woods, but not in coniferous woods (Figure 2). Groups (i), (iia) and (iva), on the other hand, seem to depend more on the actual amounts of particular layers than on any kind of structural heterogeneity.

3.2.2 Age/development of wood

Four classes were defined: young (before canopy closure), medium age (with at least lower canopy), old (with full canopy, <100 years old or, if older, then first generation), and very old (>100 years old, or a multiple-age wood established for several generations). Preliminary analyses of variance suggested that the only major division was between young woods and all others. For tall-shrub birds (group (iv) + (iva)), medium-age woods appeared to be best, and old woods, with little understorey, worst, while canopy birds (group (v)) divided between old and very old woods (best) and the rest. Jonckheere's S-test (Jonckheere 1954) confirmed these orderings of bird parameters between age classes (Table 6i). The ranking of age classes was very similar over all bird parameters. A Kendall coefficient of concordance (see, eg, Siegel 1956) confirms this similarity (W=0.62, P<0.001), indicating that, after canopy closure, the actual age of a wood is relatively unimportant in determining its

Table 6. Tests of ranking of wood types for birds (Jonckheere's S-test) (source: original data)

i. Age/development								
	Young	Medium	Old	Very old			S	z
Number of birds	1	3	3	3			260	3.20***
Number of species	1	3	3	3			310	3.82***
Ecological group (cf Table 2)								
(ii) + (iia)	1	3	3	3			308	3.79***
(iii)	1	3	3	3			376	4.63***
(iv) + (iva)	2.5	4	1	2.5			372	3.31***
(v)	1.5	1.5	2.5	2.5			350	3.49***
(vi)	1	3	3	3			368	4.53***
BSD	1	3	3	3			342	4.21***
HGD	1	3	3	3			368	4.53***
ii. Tree type								
	(a)	(b)	(c)	(d)	(e)	(f)	S	z
Number of birds	2.5	1	4.5	4.5	2.5	6	594	5.23***
Number of species	1.5	1.5	3.5	5.5	3.5	5.5	602	5.40***
Ecological group								
(ii) + (iia)	3.5	1.5	3.5	5.5	1.5	5.5	376	3.31***
(iii)	2.5	1	5	5	2.5	5	526	4.69***
(iv) + (iva)	3	3	3	3	3	6	228	2.94**
(v)	3.5	1	3.5	3.5	3.5	6	536	5.23***
(vi)	2	1	4	4	4	6	578	4.91***
BSD (1)	1.5	1.5	4.5	4.5	4.5	4.5	544	5.12***
BSD (2)	1.5	1.5	4.5	6	3	4.5	614	5.49***
HGD	4	1	4	4	4	4	280	3.45**
iii. Tall shrub/canopy combinations								
	(a)	(b)	(c + d)				S	z
Number of birds	3	2	1				622	5.69***
Number of species	3	2	1				554	5.07***
Ecological group								
(ii) + (iia)	3	2	1				446	4.08***
(iii)	3	2	1				524	4.79***
(iv) + (iva)	3	2	1				418	3.82***
(v)	3	2	1				284	2.59**
(vi)	3	2	1				546	4.99***
BSD	3	2	1				574	5.25***
HGD	3	2	1				404	3.69***

**P<0.01, ***P<0.001

Ranks in each row give the group orders tested against the data for each bird parameter. A high rank indicates a high value of the corresponding bird parameter. z is the normal approximation

BSD (1) and (2) in (ii) are alternative orders tested against the same data

For definitions of age classes and of groups, (a)–(f) in (ii) and (a)–(d) in (iii), see text overall song bird populations. Data for sites E and H all fell within the range expected for their groups.

3.2.3 Tree type

Bird parameters were compared between different tree types, by analyses of variance and Jonckheere's S, in the same way as for age. Six classes of tree types were defined, according to canopy composition, ie ignoring understorey/shrub layer: (a) conifer, (b) birch/aspen, (c) oak (± other broadleaves), (d) mixed (mainly conifer), (e) mixed (mainly broadleaves) and (f) mixed (equal). Woods were assigned to mixture classes (d, e, f) according to whether there was more or less than 25% of the secondary tree type. The rankings (Table 6ii) appear slightly more variable than for age classes, but the coefficient of concordance is still high ($W=0.72$, $P<0.001$), indicating a significant agreement in overall ranking, in the order: birch<conifer≤mixed (mainly broadleaves)<oak<mixed (mainly conifer) <mixed (equal). Particularly consistent are the ranking of birch/aspen woods (always worst) and mixed (equal) woods (always best). The generally low ranking of broadleaved types other than oak is also notable. Again, data for sites E and H are as expected.

These rankings partly contradict the generally held view that broadleaved trees always support more birds and species than conifers. For example, Newton (1986) states that 'with similar soil and field layer, breeding birds are more abundant in birch/oak than in spruce, and more abundant in spruce than pine', while from our data the order is oak> conifers>birch. This result may be because of uncritical comparison between tree species which confounds tree species with structural characteristics, or because of the tendency to combine all broadleaved species, or not to distinguish between single-species stands and mixtures of species of the same tree type (broadleaf/conifer). While insufficient for a detailed comparison, our data also suggest that pine is not necessarily the worst tree species for song birds. Indeed, one of our richest sites (Glen Dye, site F) was pure pine.

3.2.4 Tall-shrub layer in relation to canopy

We expected woods with both mature canopy and a tall-shrub layer to have richer song bird populations than woods with only one of these layers. We also expected that, where both canopy and tall-shrub layer were present, their spatial distribution would affect the composition of the bird population. We tested these 2 ideas by Jonckheere's S-test, dividing the woods into 4 groups:

a. woods with at least one-third of the census plot containing a tall-shrub component, and at least one-third of the area with upper canopy, especially high canopy, and with canopy and tall-shrub both together and separately (F, J1, P);
b. woods with both upper canopy and tall-shrub layers, shrub over less than one-third of the area but still more than 15%, and/or with less than all 3 possible combinations of tall shrub and/or canopy (I, J2, K, M);
c. woods with no significant upper canopy (A, G, O);
d. woods effectively without a tall-shrub component (B, C, D, L, N).

Even though we thought that the tall-shrub + canopy combination would be important, the results of the tests surpassed all our expectations. Every bird parameter tested gave the ordering (c, d)<(b)<(a) (Table 6iii: $W=1$, $P=0$).

3.2.5 Altitude and fertility

Altitude seemed to be relatively unimportant to woodland song birds on Deeside in spring. Both the best and worst of our woods were found at or near both altitudinal extremes. Only at one site (D) might a combination of altitude and exposure be extreme enough to depress the bird populations. Better soils supported more birds, but fertility had little or no effect on numbers of species, confirming Newton's (1986) conclusion.

3.3 Detailed analyses of specific patterns or relationships

3.3.1 Horizontal heterogeneity; is there an 'optimal' gap size?

Woods with a uniform closed canopy did not support a rich song bird population (ie high numbers and many species), while large open areas did not normally contain many woodland birds (cf Tables 2–3). Somewhere between these extremes there must be an optimal range of gap sizes (a 'gap' being any space between tree crowns that is at least the size of a single crown). How wide or narrow is this range? What proportion of the total area should be gaps? To answer these questions, we examined the relation between BSD, percentage of total area covered by gaps >15 m wide, and mean size of gaps >15 m. We chose 15 m as the minimum size because gaps smaller than this will be present in almost any canopy where there has been even a small amount of thinning, removal of dead trees, or simply lack of establishment of a tree in a particular position. Fifteen metres is about the smallest gap likely to be created by removal of a group of trees from the canopy, and is therefore the minimum size to be considered in manipulating forest structure.

If we take a BSD of 2 or less as indicating a poor wood for song birds, 2–2.3 as moderate and >2.3 as good, and plot the range of these bands against percentage cover of gaps >15 m and mean size of gaps >15 m, a clear pattern emerges (Figure 3). The best woods all lie within a quite narrow range, both of percentage cover of gaps and size of gaps, ie 10–35% cover, and mean width 20–35 m. The only 'bad' woods to lie within this range are Strone and Gairney, which both had exceptionally simple profiles. Also, within both the moderate and good groups, the highest BSDs all clustered about 20% cover of gaps, irrespective of gap size, decreasing both above and below this line.

All distributions of gap sizes within woods were highly

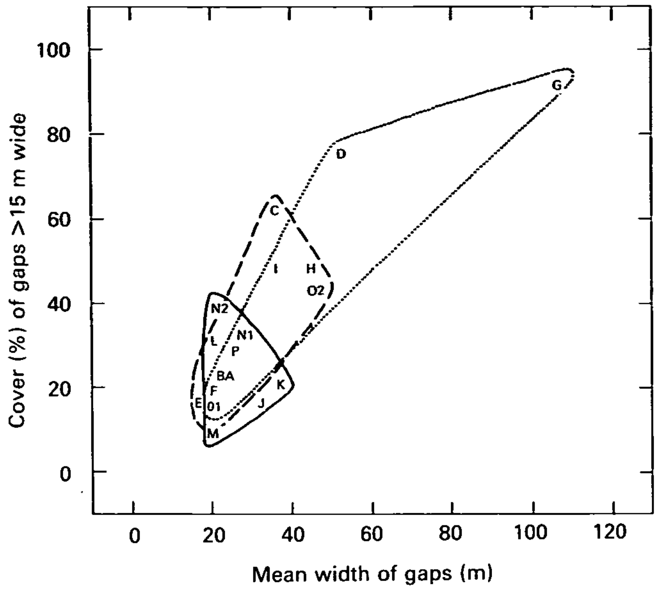

Figure 3. BSD in relation to percentage cover of gaps ⩾15 m (in canopy) and mean width of gaps. Data plotted are the range of cover and gap size for 3 groups of woods: —— BSD>2.3, – – – 2.0 ⩽BSD ⩽2.3, - - - - BSD <2.0. A–P are site codes (see Table 1)

skewed, so a mean gap size of 20–35 m implies a maximum gap of perhaps 150 m x 100 m once in 10 ha, or, say, 50 m x 100 m or equivalent 2 or 3 times 10 ha^{-1}.

3.3.2 Optimal composition of mixed woods

What is the minimum proportion of the secondary tree type in broadleaf/conifer mixtures that will markedly improve the value of the wood for song birds? Is there an optimal spatial distribution of tree types in mixtures, eg are clumps better than an even scatter of individual trees?

In 2 sites, selective felling of one component of a mixed canopy, within a single coherent area, had changed the composition of the mixture over part of the site, in both cases with a comparable, coherent area left unchanged. At Cambus o' May (site N), many old pines and some birch were felled in winter 1984–85, changing an area originally containing similar amounts of pine and birch to predominantly birch (+ a few pine), while another part of the site, originally also birch (+ a few pine), remained unaltered. At Corsedardar (site O), also in 1984–85, nearly all birch and rowan (*Sorbus aucuparia*) were removed from about half of the mixed area, where they had previously accounted for 30–50% of the total canopy cover (cf Table 1).

If these changes in proportion of the tree types had affected the bird populations, we would expect, in both sites, a general decline in both numbers and species richness in the felled areas, relative to the corresponding unfelled areas. After correcting all counts to a constant area within each site, we compared overall changes in numbers of each bird species, between years, in felled and unfelled areas (Wilcoxon signed-ranks test), and also noted presence or absence of marked changes in some bird summary parameters (Table 7).

At Cambus o' May, there was no evidence for any effect of removing the old pines, as there was a highly significant decline in numbers of most species in both felled and unfelled areas, both in 1983–84 and 1984–85 (Wilcoxon test). The aggregate parameters 'number of birds' and BSD also declined in the felled area both before and after felling. The 2 areas (felled and unfelled) appeared to be changing differently, but the differences cannot, so far, be attributed to changes in tree type composition.

Table 7. Comparison of bird summary parameters, and overall changes in numbers of individual species, between felled and unfelled areas at 'experimental' sites. Felling was between 1984 and 1985 (source: original unpublished data)

i. Cambus o' May (site N)

	Unfelled			Felled		
Year	1983	1984	1985	1983	1984	1985
Number of birds	17.5	17.5	15	29	16.5	11.5
Number of species	11	12	10	12	12	10
BSD	2.00	2.14	2.09	2.14	2.09	2.01

Wilcoxon test of overall changes in individual species between years		Unfelled 1983–84	Unfelled 1984–85	Felled 1983–84	Felled 1984–85
	T	5.5	3.5	2.5	2.0
	N	12	11	13	10
	P	<0.01	<0.01	<0.01	<0.01

ii. Corsedardar (site O)

	Unfelled		Felled	
Year	1984	1985	1984	1985
Number of birds	21	31	20	22
Number of species	8	11	10	9
BSD	1.52	1.88	1.66	1.74

Wilcoxon test of overall changes in individual species between years		Unfelled 1984–85	Felled 1984–85
	T	10	24
	N	12	11
	P	<0.01	NS

Table 8. Bird summary parameters compared with canopy composition of mixed woods (source: original unpublished data)

Mixture type	Site	Proportion of secondary tree type (%, to nearest 5%)	Distribution of secondary type	Number of birds	Number of species	Bird species diversity
Mainly broadleaves	(L)	15	clump	31	12	2.09
	(N2)	20	clump	46	16	2.42
	(M)	10	clump	58	16	2.36
Mainly conifers	(K)	23	clump	62	17	2.54
	(E)	15	even	43	11	2.13
Approx 'equal'	(N1)	30	clump	57	16	2.43
(primary : secondary ratio	(P)	25	clump	119	19	2.53
3:1)	(O1)	30	even	56	13	1.91
	(O2)	20–25	even	66	14	2.01

'Even' in 4th column indicates a more-or-less even scatter of single trees or very small clumps (2 or 3 trees at most)
'Clump' indicates that the secondary tree type has an appreciably clumped distribution, ie a larger scale of pattern

At Corsedardar, there was no obvious change between years in anything except BSD in the felled area, but all bird parameters tested improved markedly in the unfelled area, suggesting that in this case there was some detrimental effect of removing part of the mixture. The remaining birch in the mixed area is due to be felled before 1986, which should provide a further test of the effect of removing a tree type from the mixture.

If, however, we compare whole mixed woods, rather than sub-plots, for differences in song bird populations related to canopy composition and clumping of tree types (Table 8), 2 trends can be seen. First, with the possible exception of the mixed oak/pine/birch plot at Craigendarroch (site M), woods with less than about 20% of the secondary tree type had fewest birds and bird species, and lower BSD. Second, a clumped distribution of the secondary tree type was better than an even scatter of individual trees. We did not sample any woods with very large (2 ha or more) clumps so cannot say whether these would be better or worse than smaller clumps.

3.3.3 Combinations of tree and shrub types

We have data from 4 sites where there were distinct areas with and without a tall-shrub layer. At 3 (Glassel Road, Glen Dye and Potarch), we can simply compare the summary bird parameters over the 2 areas (Table 9). In nearly all cases (the only exception was number of birds, not the most important parameter, at Potarch), areas with a tall-shrub layer, as expected, consistently contained more birds of more species, with higher BSD, than areas without one.

At the fourth site, Dinnet Oakwood, we monitored the consequences of removal, in 1980 and 1981, of a shrub layer of rhododendron, which formerly covered about one-third of the area. The census plot consisted of 3 blocks of almost equal areas. These were: oak with rhododendron in 1980–81 (but not thereafter); oak always without rhododendron; and oak (also without rhododendron) mixed with birch, aspen and bird cherry (*Prunus padus*). Comparing successive pairs of years (one pair before/during treatment and 2 after) within each of these areas, there was a drastic decrease in the richness of the bird population in the former rhododendron area after its removal (Table 10). The apparent partial recovery (indicated by number of species and BSD in 1984–85) was entirely due to a small influx of stem and air (group iii) and canopy (group v) birds, all in low numbers and, from examination of the territory maps, usually only holding parts of their territories in the area from which rhododendron

Table 9. Bird summary parameters in areas with and without a tall-shrub layer within 3 woods, showing the general increase in the richness of the song bird population with the presence of a tall-shrub layer (source: original unpublished data)

Site	Bird parameter	With tall shrub 1984	With tall shrub 1985	Without tall shrub 1984	Without tall shrub 1985
Glassel Road (E)	Number of birds		20		16
	Number of species		11		7
	BSD		2.17		1.74
Glen Dye (F)	Number of birds	41	40	33	38
	Number of species	13	13	11	10
	BSD	2.37	2.37	2.18	2.05
Potarch (K)	Number of birds	38	45	43	34
	Number of species	16	17	12	12
	BSD	2.56	2.62	2.07	1.86

Table 10. Bird summary parameters, and overall changes in numbers of individual species between successive pairs of years in 3 sub-plots in Dinnet Oakwood (site J) (source: original unpublished data)

		Oak originally with rhododendron[1]			Oak always without rhododendron[2]			Oak with other broadleaf spp. and without rhododendron[3]		
2-year period		1980–81	1982–83	1984–85	1980–81	1982–83	1984–85	1980–81	1982–83	1984–85
Number of birds		20.5	5	8	12	16	17	20.5	23	20
Number of species		12	6	11	15	13	13	11	12	15
BSD		2.43	1.71	2.18	2.34	2.36	2.32	2.54	2.23	2.39
Wilcoxon tests of overall changes in individual species (between years)	T	4	9.5		23	42		46	40	
	N	13	9		13	14		14	14	
	P	<0.01	NS		NS	NS		NS	NS	

[1]Area with rhododendron present in 1980–81, removed thereafter

[2]Area of oak with rhododendron never present

[3]Area with much birch/aspen/bird cherry mixed with the oak

(2, 3) These 2 areas provide partial controls for comparison with the rhododendron area, to assess the effects on the bird population of removing the shrub layer between 1980 and 1982

had been removed, the territories being centred on adjacent areas. In the other 2 areas, there was no significant change between periods. Further monitoring will show whether the loss of the original (largely shrub-related) species will eventually be offset by an increase in species using the more open air space in the cleared area.

The within-wood analyses, therefore, confirm the original survey conclusion of the great importance of a tall shrub + canopy combination. Can we also say whether any particular type of shrub or canopy, or combination, is better for song birds than another? We have data for several woods, all with approximately equivalent amounts of tall shrub, in all combinations of conifer and broadleaf (deciduous), plus one wood with a broadleaved (evergreen) shrub layer (Dinnet Oakwood before rhododendron removed), and one (Crathie) with a mixture of broadleaved and conifer types in both shrub layer and canopy. In the results below: (a) = conifer under conifer (Glen Dye), (b) = conifer under broadleaves (Potarch), (c) = broadleaved deciduous under conifer (Glassel Road), (d) = broadleaved deciduous under broadleaf (Dinnet Oakwood 1982–85), (e) = broadleaved evergreen under broadleaf (Dinnet Oakwood 1980–81), and (f) = mixed under mixed (Crathie). Jonckheere tests on number of birds, number of species, and BSD indicate the following rankings:

Number of birds
(c)<(d)<(a,e,b)<(f) S=76, z=3.94 P<0.001

Number of species
(c)<(d,a,e)<(b,f) S=52, z=2.88 P<0.002

BSD
(c)<(d,a,e)<(b,f) S=42, z=2.31 P<0.01

Combining these groups gives an overall ranking of (c)<(d)≤(a,e)≤(b)≤(f); ie an evergreen shrub layer (whether conifer or broadleaf) was consistently better (for song birds) than a deciduous shrub layer, and a mixed shrub layer, at least in combination with a mixed canopy, better than either. The relatively high ranking of Glen Dye, in which both canopy and shrub layers were entirely pine, indicates that the structural characteristics of the shrub/canopy combination were probably more important than their species composition.

4 Discussion

The generally low ranking of birch/aspen woods and of mixtures where the main component was broadleaved species, indicating that they were relatively poor habitat for song birds, is perhaps surprising. However, because both birch and aspen tend to colonize in fairly homogeneous even-aged blocks, structural diversity is likely to be low in these woods. Also, they rarely develop a distinct tall-shrub layer of sufficient extent and density to support many shrub-living birds (ecological groups (ii), (iv) and (iva)). Similarly, in mixtures, a small proportion of broadleaved species, if suitably clumped, may contribute a greater number of additional species to those of pure conifer stands than *vice versa*.

The importance of structural diversity has been emphasized in our results, supporting the suggestions of MacArthur and MacArthur (1961), with the major proviso that, as well as FHD, it is also necessary to take into account some measure of horizontal heterogeneity (eg NPT or HET). Our observed variation among tree types does not indicate tree species effects, but rather effects of differences in the cover profiles characteristic of those types.

Mixtures (of tree types) increase species richness (of bird populations), not only by increasing structural diversity but also by providing habitat for birds specific to, or most common in, each individual tree type (eg goldcrest in conifers, blue tit in broadleaves). At least some aggregations of the secondary tree type should be large enough to support complete territories of the type-specific birds. From observed territory sizes, we can suggest that, for most bird species 'preferring' a particular tree type, a single clump of 50–100 m diameter, or a cluster of smaller clumps of equivalent total area, will provide sufficient of the correct tree type to enable establishment of at least one territory. This will not be sufficient markedly to improve overall species richness in a 10 ha total area, as many of the 'type' species will be competing for the suitable habitat and only one or a few birds will successfully hold territory. Nevertheless, it does give some indication of a possibly optimal clump size in mixtures .

Indicators of a wood with a structure attractive to many song bird species include the number of distinct profile types. While this number appears to be a good general guide, it is an index that is not always easy to define precisely. Especially, differences in canopy height, if mainly within the same canopy class (low, mid, high), are not likely to matter to most song birds. (Crossbills, however, seemed to require high canopy.) Also, differences in actual amounts of cover in the tall-shrub range were generally more important than the same differences in canopy layers, and may be further confused by the intermingling of low canopy with the tops of tall shrubs. However, in practice, most profile types seem to be distinguishable from each other on the ground, and we had little or no difficulty in assessing this parameter in our woods. One point to note is that profile types covering only very small areas (<40 m x 40 m) should usually be ignored or, alternatively, combined with whichever other type they most resemble.

5 Conclusions

From our data and analyses, we can state a series of '*desiderata*' for a rich song bird population, as a guide to the sort of woodland structure for which a forester should aim in order to encourage a wide variety of song birds. These '*desiderata*' are not all entirely compatible with maximizing an economic crop, but most can be achieved at little cost. Given that many foresters are willing to 'give up' about 10% of the total area of a forest to 'conservation purposes', it would, for example, be possible to establish a near-optimal structure over 10 ha in a forest one km^2, leaving the rest entirely for intensive timber growing. A potentially more fruitful approach, however, would be to spread the '10%' more widely and attempt to integrate it into the more general management of the forest. The first method might provide an extremely rich wood in a small area, but would have little or no effect on the rest of the forest. The second, while almost certainly never attaining the same maximum richness anywhere, might still make the whole forest significantly richer in birds, and the total effect could be much greater. What combination of these methods is best for any particular forest must be decided by the forester, taking into account any existing features of the area, such as topography, water bodies, open areas, as well as his own management requirements.

The '*desiderata*' (all apply primarily to a 10 ha area) are as follows.

1. The wood must be already established, with at least one-third mature or old trees. There is little a forester can do with a very young wood to encourage woodland song birds, because the necessary habitats simply are not there. Three options for improving the structure of the ensuing mature wood, however, are (i) to stagger plantings, in order to generate as wide a variety of ages as possible and provide some degree of 'edge' habitat, (ii) to use existing older trees as a 'nurse crop' for under-planting, and (iii) to plant mixtures of tree types, in suitable-sized blocks. Much of the possible management for song birds, though, starts with first thinnings and fellings, and with the second and subsequent rotations.
2. The wood must contain at least 4 distinct profile types. This is another essential feature, and may at first seem a difficult one to attain. However, a single tree species, at 2 ages more than 15 years apart, and with and without a shrub layer, or at different spacings, or thinned and unthinned, immediately provides at least 4 distinct profiles, possibly more. Clearings immediately add 1 to the number of profile types.
3. It should have a tall-shrub layer (not necessarily a dense one) over about one-quarter to one-third of its area. This layer can be of genuine shrubs (eg juniper (*Juniperus communis*), rose (*Rosa* spp.), elder (*Sambucus nigra*), hazel (*Corylus avellana*), rhododendron, and perhaps bramble (*Rubus* spp.)) or small trees (preferably evergreen of some sort, including young conifers), and may be achieved by planting, by coppicing (where appropriate), or simply by not removing regeneration.
4. It should have an 'upper canopy' (>12 m), preferably including some 'high canopy' (>20 m), over at least one-third of its area. This simply means that there should be about one-third or more 'pole' and 'high forest'. Ideally, pine in some areas should be left to grow beyond about 80 years old, spruces 60 years, birch 60–90 years, and other trees to equivalent ages, albeit in a well-thinned stand, possibly acting as a 'nurse' for under-plantings or natural regeneration (see also 5).
5. Shrub layer and canopy should overlap over about one-third of their respective areas. Maximum bird richness requires canopy and shrub, both separately and together. The combination is, however, easily achieved by (i) planting or restocking next to pole or mature forest, (ii) not removing regeneration, especially at the edges of mature thinned stands (the understorey will always extend a little way in), and (iii) underplanting.
6. There should be gaps >15 m wide in the canopy, covering about 20% of the total area, mostly ≤50 m wide, but with one or a few (10 ha^{-1}) up to 100 m wide. Gaps larger than 100 m should

preferably include some 'shrubs'. The extent to which this layout is attainable will depend very much on the practicability of appropriate thinning and felling regimes. Basically, it implies a small-scale thinning/extraction programme, analogous to efficient muirburn. Long corridors, eg rides, are not an adequate substitute for genuine gaps, but a length: breadth ratio of up to about 5:1 is probably acceptable for widths of up to 40 m, especially if there is some shrub or understorey in the gap. Generally, the proportion of gap is more critical than the size of gaps, especially in relatively dense stands. In mature stands, already well thinned, a few larger gaps would probably be sufficient, especially if there was also some regeneration or under-planting (see 3–5 above).

7. The canopy should be a mixture of tree types (broadleaf/conifer) in a ratio between about 3:1 and 5:1 (in either direction), the secondary type mostly arranged in clumps or blocks not less than 25 m wide, and with some clumps or aggregates of clumps totalling ⩾*c*1 ha. Like number of profile types, this requirement may appear at first almost impossible. However, remembering the 2 methods of 'giving 10% to conservation' noted above, a forester wanting to cut broadleaved planting to the absolute minimum could, if he chose the first method, limit broadleaved species to as little as 2% of the total plantings in one km^2, though ornithologists would probably consider that to be a distinctly 'suboptimal' strategy. Additionally, readily colonizing broadleaved species such as birch and rowan could be encouraged, or at least not immediately removed, especially in cleared areas (before subsequent replanting), and even used as a nurse for young conifers, probably after some initial thinning.
8. Large-scale even-age planting, and clearfelling in large blocks (≫*c*5 ha) should be avoided.
9. Some dead wood (not too small, ie large branches, stumps and stems) is useful to encourage woodpeckers, tits and other hole-breeders (lack of nest holes is often a limiting factor to some bird species). Often less than 0.5% (ground cover), or just 2 or 3 dead trees and a few stumps or fallen branches, is sufficient. Total removal of all dead wood may even be counter-productive, as many hole-breeding species, particularly great spotted woodpecker, will make their holes in dead or rotten wood by preference but, if that is denied them, may then start to attack live wood. Against this factor, however, must be set the (small) risk of potential pathogens, if too much dead wood is left in a stand.

The end result of forest management according to the above *desiderata* should be a wood something like that shown in Figure 4, and the 3 most important general strategies for achieving it are as follows.

1. Planting, thinning, extraction and restocking in small blocks or strips, generally not more than *c*200–250 m wide, but with a length: breath ratio that can be up to 5:1. Initial plantings can be on a much larger scale, provided subsequent thinning, etc, reduces the final scale of pattern to the above ratio or less.
2. Encouragement (or non-removal) of natural regeneration of all kinds, together with some under-planting, to provide a tall-shrub layer and, in conjuction with strategy 1 and with a variety of planted age classes, to multiply the variability produced by 1.
3. Planting (including under-planting and replanting), or encouraging regeneration, in mixtures (conifer + broadleaf), with the secondary tree type suitably clumped.

Finally, comparison of the pine plantation at Glen Dye, and the mixed conifers at Potarch, with the 'Caledonian' pinewoods at Glen Tanar shows clearly that plantations need not be poorer than 'natural' woods in song birds and can, indeed, be considerably richer, if the above guidelines are followed.

6 Summary

In 16 woods in Deeside, we analysed the relationships between song bird populations and structural characteristics of the woods, with the aim of deriving recommendations for woodland management to enhance song bird populations.

Bird populations were assessed by a mapping method (British Trust for Ornithology Common Bird Census), and bird species were assigned to one of 8 'ecological groups', according to their nesting and foraging habits. These groups, and the summary parameters, 'number of birds', 'number of species' and 'bird species diversity' (BSD), were compared with vegetation profiles and diversity/heterogeneity parameters, derived from detailed surveys of the census plots.

The main conclusions, from regressions of bird parameters on vegetation parameters, and statistical comparisons among different ages of woods, tree types, and amounts and distributions of tall shrubs, were as follows.

1. The quality of habitat for woodland song birds generally improved with age of wood.
2. Birch was the 'worst' single type for song birds and oak the 'best', with conifers intermediate. Mixtures of conifers and broadleaved species were usually 'better' than pure stands of a single tree type, and mixtures with the main component conifer were 'better' than those that were mostly broadleaved trees. The secondary tree type in mixtures needed to be at least 20% of total canopy to be effective. It also should be concentrated in clumps or similar aggregations, rather than evenly spread or in thin lines.

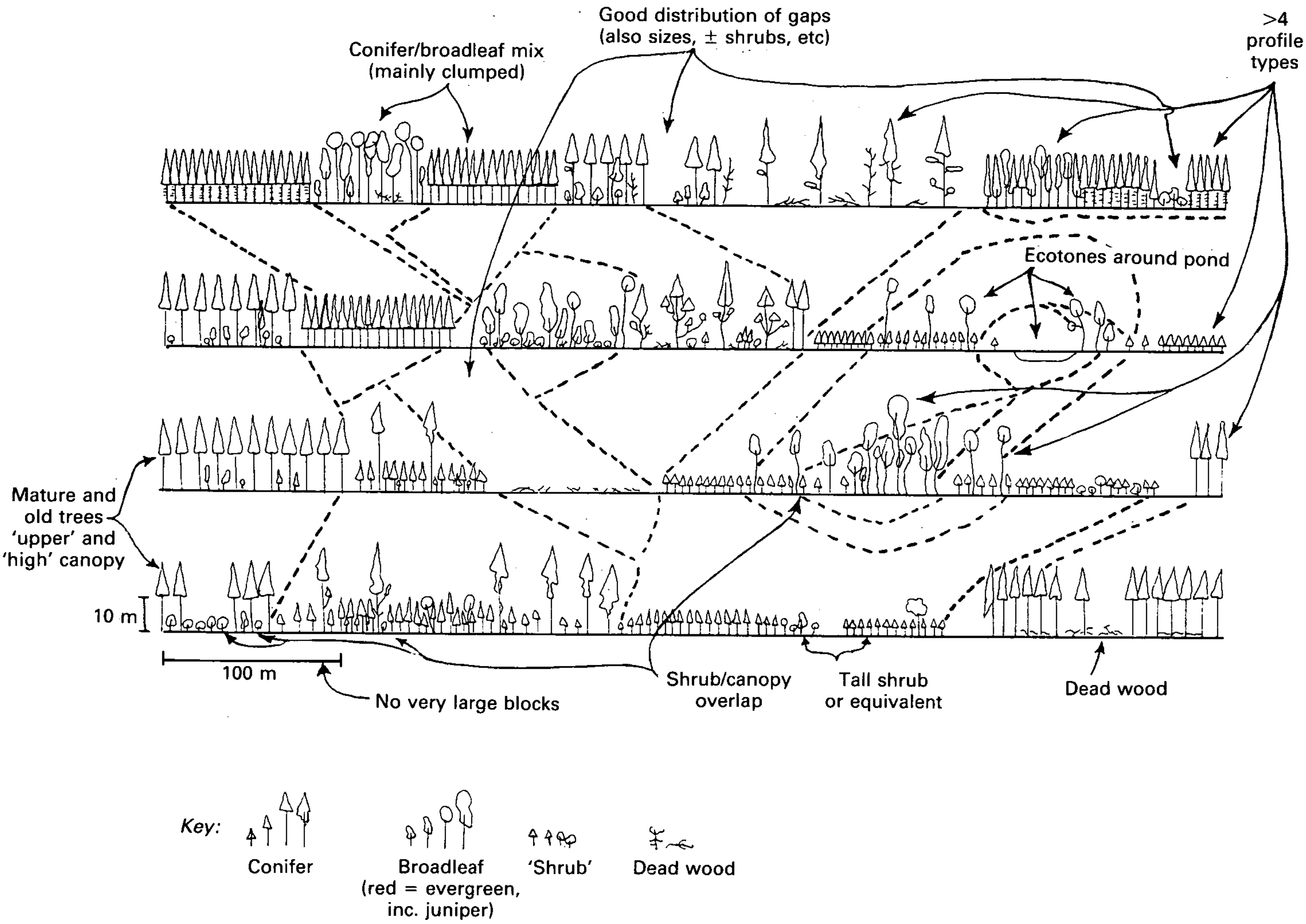

Figure 4. Schematic representation of a desirable forest structure. The Figure represents 4 parallel transects over a total area of c15 ha, and stand densities are all drawn half-size, in relation to broadleaves and 'shrub', for greater clarity

3. The combination of canopy >12 m high, especially where some trees were >20 m, with a tall-shrub layer or equivalent, was especially conducive to a rich song bird population. The structural aspect was much more important than the tree/shrub species involved, though evergreen 'shrubs' (including young conifers) appeared to be 'better' than deciduous broad-leaved types.
4. The number of distinct vegetation/cover profiles in a wood was a fairly good general guide to its attractiveness to many song bird species. More than 4 distinct profiles 10 ha^{-1} usually indicated a 'good' structure, favouring a rich, diverse, song bird population, and less than 4 a 'poor' structure, supporting few species.
5. Small gaps (15 m ⩽gap size ⩽50 m) in the canopy were important.

From our analyses, we derived the following '*desiderata*', which are further discussed in terms of their practicability (often they are far more practicable than appears at first sight).

— The wood must contain at least one-third mature or old trees, and a variety of other age classes.

— It must contain at least 4 distinct profile types in 10 ha.

— It should have canopy over about one-third of its area, with a tall-shrub layer over a similar proportion, and these should overlap over about half their range.

— There should be gaps ⩾15 m wide in the canopy, over about 20% of the total area, mostly small (⩽*c*50 m wide) or, if larger than 100 m, including shrubs or young trees.

— There should be a mixture of tree types, suitably clumped. Uniform, large-scale, even-age blocks (≫*c*5 ha) should be avoided.

— A small amount of dead wood should be allowed to remain in the stand.

An example of a 'desirable' woodland structure is given, and strategies are suggested for achieving the above '*desiderata*'.

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