Relationships between hedgerow characteristics and bird communities:: a multivariate approach

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RELATIONSHIPS BETWEEN HEDGEROW CHARACTERISTICS AND BIRD COMMUNITIES: A MULTIVARIATE APPROACH.

by

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LIST OF FIGURES

LIST OF TABLES

CONTENTS

ABSTRACT

Fifty 100m hedge transects were selected within 10km of Durham City, North England. The bird community of the hedge transects was censused six times between May and July, and characteristics of the hedge and surrounding landscape were recorded. The data was analysed using multivariate methods to determine the importance of the microstructure of the hedge in relation to aspects of the bird community.

Stepwise Multiple Regression selected the scores of the first axis of a Detrended Correspondance Analysis of shrub abundance data (related to the height and width of the hedge) as the best predictor of Bird species richness and density. Individual species were related to different aspects of the hedge microstructure. The use of transformed independant data improved the predictive value of most of these relationships.

A Detrended Correspondance Analysis found that major source of variation in the bird species abundances was due to the number of trees in the hedge. Canonical Correspondance Analysis was used to analyse how a community responds to a set of external factors. The CANOCO first axis was related to an increase in the area of nearby woodland in the positive end and an increase in the number of trees in the negative end. The position of the species scores in relation to these environmental gradients was analysed.

The habitat preferences of 4 common species of bird was explored using "sector" analysis, whereby the mean density of the species is plotted against the major sources of variation in the environmental variables. different habitat preferences between species are apparent.

The importance of trees to the bird community was elucidated using Linear Discriminant Analysis. The analysis was carried out with hedges with no trees and hedges with 3 or more trees as the two *a priori* groups. Eighty-three percent of the sites were placed in the correct groups, using 14 common bird species as variables.

The importance of the microstructure of the hedge to the bird community is discussed.

1 INTRODUCTION

Quantitative relationships between elements of bird communities and vegetational parameters, following the classic paper of MacArthur & MacArthur (1961), have been reported by many workers. Research has concentrated on woodland communities (eg. MacArthur, Recher & Cody 1966; Orians 1969; Recher 1969; Abbot, Abbot & Grant 1977; Raebnold 1978; Cody 1983; Karr & Freemark 1983; Howe 1984 and Opdam, Rijsdik & Flustings 1985), but others have been studied eg. Karr (1968) on strip-mined land, Pianka & Huey (1977) for desert communities, Rotenberry & Wiens (1980) for shrub steppe communities in North America. Little work, however, has been carried out on the ecological relationships between hedgerows and birds.

Estimates of the length of hedgerow in Great Britain vary from 804,000km to 1 million km (Locke 1962; Moore 1962; Pollard, Hooper & Moore 1974). New agricultural techniques since 1945 have caused a substantial disappearance of hedges (O'Connor & Shrubb 1986). Williamson (1967) estimates loss at 2.5m/ha in England and Wales between 1963-66, this figure varies geographically; Baird & Tarrant (1973) give a figure of 1.4m/ha loss in Norfolk between 1946-1970. Total hedge loss from 1954-1970 was between 3800km and 5800km per annum (Pollard, Hooper & Moore 1974).

The importance of hedges as a habitat for birds has not been clear. Moore (1970) considered hedges to be essential to the agricultural bird community; Pollard, Hooper & Moore (1974) considered them to be nationally unimportant and Murton & Westwood (1974) concluded that hedges were a sub-optimal habitat for birds and thus of little significance. However, Snow & Mayer-Gross (1967) found the proportion of nests fledging at least one young was higher in farmland than woodland for four common species of bird. Krebs (1971) concluded, for Great tits (*Parus caerulas*), that less eggs were laid and more chicks were predated by birds living in hedges compared to birds resident in woodland. Hedges are a poor quality habitat for some bird species (Williamson 1969, Batten &

Williamson 1976, Osborne 1984).

Recent quantitative studies on birds in the agricultural landscape have tended to confirm the importance of hedges to local bird communities. Morgan & O'Connor (1980) have related the density of Yellowhammers (*Emberiza citrinella*) to the length per area of hedgerow on 65 farms. Wyllie (1976) found that 70% of the species of bird and 70% of the total number of territories were to some extent dependant on the hedges and trees within a Huntingtonshire parish. Bongiorno (1982) considered modern large scale agriculture in Galacia, Spain, to support an impoverished bird community compared to traditional small scale farming practices. Osborne (1982) and Arnold (1983) found local habitat features, particularily hedgerow, to be correlated to bird density. The loss of hedgerow in the agricultural landscape can cause a loss of bird density and diversity (Hooper 1970; Evans 1972 and Moore 1970) or a change in species composition (Watnough 1974; Bull, Mead & Williamson 1976).

The characteristics of hedges are important to the avifauna. Lack (1988) noted a 1.7 times increase in the density of birds at hedge T-junctions compared to linear lengths. Morgan & O'Conner (1980) found that hedges with trees have a greater density of Yellowhammers compared to hedges without trees. Williamson (1967) considered Hawthorn (*Crataegus monogyna*) dominated hedges to be a better resource for birds than Beech (*Fagus sylvatica*) or Elm (*Ulmus glabra*). Arnold (1983) concluded that any feature which increased the three dimensional stucture of the hedge eg. ditches and trees, tended to increase the species richness of the bird community. Parslow (1969) suggested that hedges over 1.2m were of greater value to breeding birds as they offered greater protection from predation. Similarily, Rands (1982) proposed that an increase in dead grass at the bottom of the hedge decreased the predation pressure on partridges.

Most studies have concentrated on hedges as one component of the agricultural landscape, little work has however been done on hedges *per se*. Ibrahim (1985) has related the physical characteristics and shrub species diversity of hedgerows to bird diversity and density using multiple regression. Osborne (1982) considered the effect of the loss of Elm (*Ulmus glabra*) trees due to Dutch Elm disease (*Ceratocystis ulmi*) to the bird community in hedges in Dorset. Osborne (1984) used a variety of multivariate techniques in an intensive study of 42 hedges on a Dorset farm to appreciate relationships between the birds and their hedges.

This study will use various multivariate techniques so as to appreciate the multiplicity of parameters and multidimensional character of biological systems. This approach has been used for terrestrial bird communities e.g. by James (1971); Cody (1978); Rotenberry & Wiens (1980); Collins, James & Risser (1981) and Meents, Rice Anderson & Ohmart (1983). This study aims to clarify the important hedge parameters associated with bird density and species richness for the whole community and the density of some common hedgerow species. The data were collected from 50, one hundred metre sections of hedge within a 10km radius of Durham, England.

2 METHODS

2.1 Selection of hedgerow sites

Fifty, one hundred metre long hedge sites, termed in this study a "transect", were selected within 10km of Durham City, northern England, using the following criteria:-

1. The hedges appeared subjectively, to represent the major types of variation in hedges , in both structure and shrub species composition, around Durham City..

2. The land type on both sides of the hedge was either road, cereal, rape or pasture. Roadside hedges were only selected if, on the opposite side of the road, there was another hedge. For cereal, rape and pasture, the land-type had to be constant along the whole length of the hedge on both sides, for a minimum distance of 20m perpendicularly from the hedge. Surrounding landscape pairs were chosen to achieve the largest possible set of combinations of the landscape categories, so as to include as much of the natural variation as possible.

3. The 100m lengths of hedgerow selected were linear and at least 15m away from intersections of two or three hedges, or other non-linear features. If gaps or gates were present in the 100m hedgerow transect, they had to total less than 10% of the 100m study length. The total length of gaps in the hedge in the 100m transect was added to the end of the transect. Thus, a hedge with 5m of gaps along the 100m length would, in total measure 105m ie. 100m of hedgerow and 5m of gaps. Each transect thus consisted of 100m of hedgerow vegetation, but could measure up to 110m long.

4. Hedgerow sites did not have a house within 100m, and had no significant urban areas within 500m.

2.2 Hedgerow parameters

At each of the 50, 100m transects of hedge a standard data sheet was filled out.

Information taken at each of the 50 transects was as follows:-

a) The surrounding landscape category (road, cereal, rape or pasture) on the side of the bird census and the opposite side of the hedge.

b) The height and width of the hedge at 10m intervals along the 100m length. The ten widths and heights were classed into 0.5m categories

c) The presence of shrub species (ie. those with woody stems) in 20 evenly spaced (ie. every 5 metres) 1m quadrats of the hedge were recorded for each transect.

d) If trees were present within the hedgerow transect, the species and the diameter at breast height (dbh) were recorded in 5cm categories, from 15cm to 40cm, for each individual tree.

e) From a large scale map, the area of woodland within a radius of 200m and 500m of the 100m hedgerow transect was measured.

2.3 The bird census

Much work on birds uses the mapping method (Enemar 1959, Williamson & Homes 1964, or for hedges see Osborne 1982) whereby the spatial position of each bird observed in the study area is recorded over repeated censuses. Areas within the study area which tend to have aggregations of recordings of a bird species are delimited and considered to be the territory of a single male. A mosaic of the spatial use of the study area by the bird community, with respect to territories, can thus be built up.

However, two factors make this the mapping approach to the study of hedgerow birds inappropriate (Osborne 1984). Firstly, the study area used in this work is small, only 100m of hedge, in comparison to bird territories which may span over several hedges. Secondly, the usage of a territory by the owner might not be constant over its area. Thus, the accuracy of delimitation of territories by this method would and lack clarity.

Instead of the mapping method, the total number of registrations of each species of bird in the hedge for the 6 censuses was recorded. Results would thus tend to indicate the density of usage of the hedge by the birds, as opposed to the mapping method which gives an indication of the number of territories within the censused area. The results of both methods should be highly inter-correlated, particularily for large study areas.

The number of visits required at each study plot to reach a certain level of accuracy in the estimation of the number of territories for a set area, using the mapping method, depends on two factors. Firstly, the efficiency of the observer ie. what proportion of the birds present are actually recorded by the observer. Secondly, the acceptance level for each cluster of registrations that constitute a territory ie. the minimum number of registrations of a bird of a certain species in a localised area that is used as a criterea for delimiting a territory.

An accuracy of 80-90% territories found is used by the International Bird Census Commitee, this can be achieved by 6 visits with a visit efficiency of 50% and an acceptance level of 2 (Svensson 1978). Svensson further, recomends between 5 and 8 visits for each site per year for the Common Bird Census (Svesson 1978). In this study a visit number for each site of 6 was selected. This was considered to be a suitable compromise between accuracy of censuses and time spent in the field. The accuracy of the censuses was analysed (see results).

At each of the 50 sites a census was carried out 6 times, constituting a total of 300 censuses or 30km of censuses. The censuses were carried out between May and July, 1990; sites were censused three times between 0500-0800 and three times between 0800-1100, on two or more days. No activity by the observer, around the hedge, for at least one hour before a census was permitted. No censuses were carried out on days when it was windy enough to make observation of birds difficult, or on when it was raining.

A census involved slowly walking along the full 100m length of the hedge transect, on the same side of the hedge for all 6 censuses. Any bird in the hedge that was observed or recognised by song was recorded. A check was constantly kept over the part of the hedge already censused for birds that might have been missed or "frozen" due to the approach of the observer. The birds observed in the trees within the 100m transect of hedge were recorded seperately. Birds that appeared to be flying into the hedge but dramatically changed direction at the last moment, due to the presence of the observer, were also recorded. If any bird was unable to be indentified it was recorded as an unknown.

2.4 Multivariate analysis

The relationships between the bird species and the hedegrow were explored by a triad of complimentary multivariate techniques;

1. Stepwise Multiple Regression (Least Squares). This method selects the variable that is most closely related to the bird density, then the remaining variation in the density of the bird is related to the remaining parameters, the variable that can explain the most of the residual variation is selected. This is repeated until all the variables that are related significantly to the dependant variable are selected. The use of simply transformed data allowed the allowed non-linear relationships to be explored. Such relationships are present, "curvilinear relationships between birds and vegetation are important" (Meents, Rice, Anderson & Ohmart 1983). Multiple Regression allows the importance of the factors that determine the Hutchsonian (multidimensional) niche (Rotenberry & Wiens 1980) to be isolated on both the macro (community) and micro (species) level (Anderson 1981) and an appreciation of the niche-gestalt, the importance of environmental parameters within the perceptual field of the species, is also possible (James 1971).

2. Ordination techniques.

a. Detrended Correspondance Analysis (DCA). This method searches for axis of maximum variation within the data. DCA gives scores for both the sample and the species, thus the relationship between both the species and the sites can be analysed from the same analysis.

DCA is based on Reciprocal Averaging ordination but overcomes the problems of compression of the ends of the axis and quadratic arch distortion, common in many ordination techniques (Gauch 1982). The second and further axis are "detrended" by segments, rather than just being orthognal, so no systematic relationship between axis 1 & 2 is permitted. The arch distortion is overcome in DCA by rescaling, achieved by equilibration of average within sample dispersion of scores along the axis. Hill & Gauch (1980), after extensive comparative testing with other ordination techniques, have shown "DCA results at least as good as, and usually superior to other ordination techniques". DCA has been used effectively for description of bird niches (Sabo 1980).

b. Canonical Correspondance Analysis (CCA). This method involves the integration of ordination and regression to produce a multivariate direct gradient analysis method. The relationship of the variables to the species scores can be displayed on a plot of two ordination axes. The biplot arrows show the direction of variation of the variables in relation to the species, the length of the arrow being related to the importance of the variable.

3. Sector Analysis of the hedgerow DCA with bird density.

Sector Analysis has been used to determine the niche breadth of shrubsteppe bird communities (Rotenberry & Wiens 1980). The scores of each site using the hedge descriptor variables in a DCA are related to the species density. The mean density of the bird along these ordination axis describing the variation in the environment, is plotted. If the density of the bird changes greatly along the axis, then the bird species is expressing preference for a certain type of the environment. If the species shows little trend in density over the sectors of the DCA, then the bird shows little preference for the variable(s) that the axis is related to.

3 RESULTS

3.1 Hedge shrub composition

The presence of shrub species was recorded in 1000 one-meter quadrats (20 for each of the 50 hedge transects) in hedges around Durham City. The number of species of shrub that each hedge transect contained (SSPP) was calculated as the total number of species present in all the 20, 1m quadrats for that 100m hedge transect (Fig. 1.). The most common number of species in a 100m length was 5 shrub species (12/50 transects). The most shrub species that a hedge contained was 10 (3/50). A near normal distribution of number of species of shrub in hedge sites is apparent (Fig. 1.), with 5 being the mean. Hedges with 4, 5 or 6 shrub species consist of over half (56%) of hedge sites surveyed.

A total of 19 shrubby species were recorded as being constituent shrubs of hedges in this study (Table 1.). The species vary from trees eg. *Quercus robur*, to small shrubs such as *Calluna vulgaris*. Many tree species that are common in the County Durham landscape are also found as small trees in hedges eg. *Ulmus glabra, Fagus sylvatica, Acer pseudoplatanus and Sambucus nigra. Crataegus monogyna* was the most common hedge shrub species, being found in 903/1000 (90%) of 1m quadrats. It was present in every hedge surveyed (Table 2.), and was present in 10 or more quadrats in each hedge in 47 out of 50 hedges

The five most common species of shrub in the hedge sites after hawthorn were *Rosa canina, Fraxinus excelsior, Rubus fruticosus, Sambucus nigra* and *Prunus spinosa*, respectively (Fig. 2.). Some species were found only in one hedge (eg. *Salix alba, Calluna vulgaris and Sorbus aucuparia*), or two (eg. *Salix viminalis*). The DCA scores for each species in each hedge transect were tabulated (Table 2.) as a basis for further analysis.

A Detrended Correspondance Analysis (DCA) (Hill & Gauch 1980)) was carried out on the shrub species abundance data to elucidate the relationships between the 50 hedge transects using the shrub abundance scores. The DCA gives both species and sample scores.

Fig.1. The frequency of occurence of hedges with different shrub species diversity, from 50 transects.

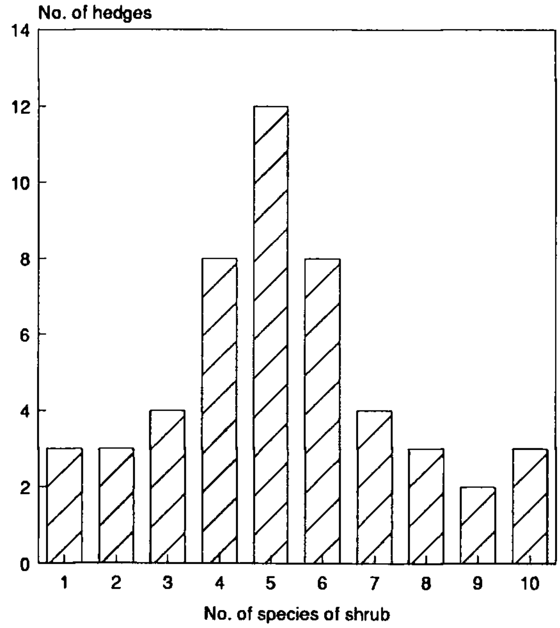
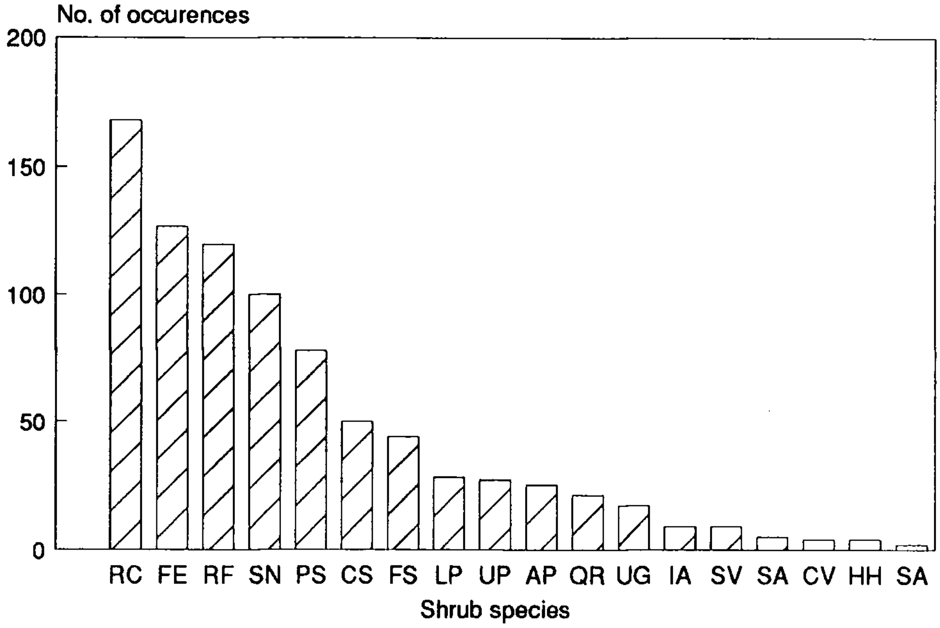


Fig. 2. Frequency of presence of shrub species (excluding Hawthorn) in hedge study sites.



Hawthorn score= 903

Table 1. The shrub species recorded in the 50 hedge sites, the Latin binomial and the abbreviation used in this study.

Common name	Binomial	Abbrev.
Hawthorn	*Crataegus monogyna*	CM
Elderberry	*Sambucus nigra*	SN
Ash	*Fraxinus excelsior*	FE
Rose	*Rosa canina*	RC
Bramble	*Rubus fructinosus*	RF
Dog wood	*Canus sanguinea*	CS
Gorse	*Ulex europaeus*	UE
Holly	*Ilex aquifolium*	IA
Sycamore	*Acer pseudoplatanus*	AP
Blackthorn	*Prunus spinosa*	PS
Ivy	*Hedera helix*	HH
Honey-suckle	*Lonicera pericylmenum*	LP
Beech	*Fagus sylvatica*	FS
Elm	*Ulmus glabra*	UG
Oak	*Quercus robur*	QR
Salix	*Salix viminalis*	SV
Willow	*Salix alba*	SA
Heather	*Calluna vulgaris*	CV
Rowan	*Sorbus acuparia*	SA

Table 2. Frequency of shrub species (presence or absence) in 50 hedge sites.

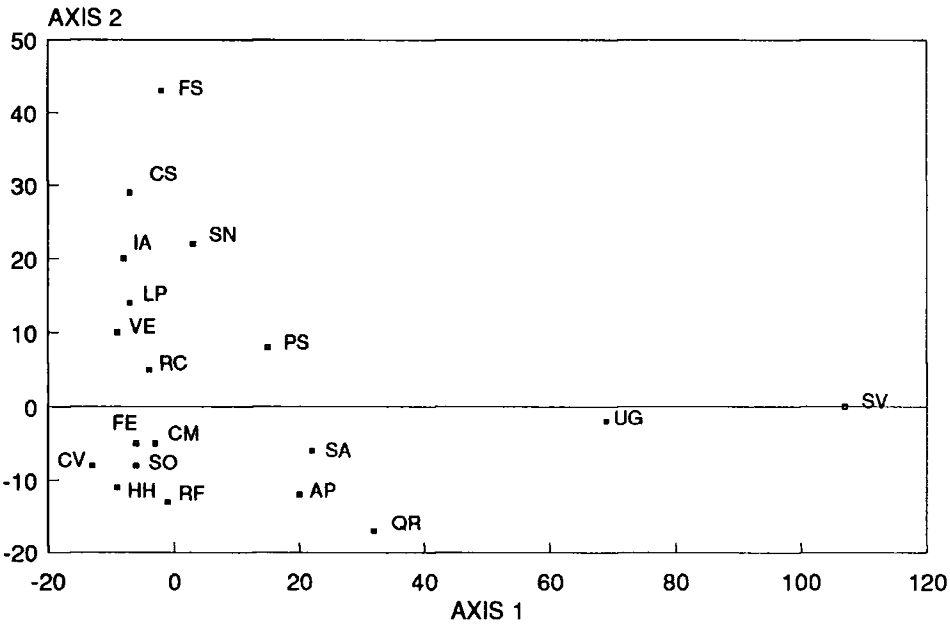
SITE	CM	SN	FE	RC	RF	CS	UE	IA	AP	PS	HH	LP	FS	UG	QR	SV	SA	CV	SA
1	20	12	7	3	1														
2	20	4	9	6		3													
3	20																		
4	20	2																	
5	20																		
6	14	1	4	3		5													
7	20		7	9		5	3	1	1										
8	19		6	3	1		2			6									
9	20		4	8						9									
10	20	7	1	7	3	4	2			4	1	5							
11	11		1	6	1				1	11			2						
12	19	1		1									2						
13	17	1	4	14	10					2									
14	16	1		12	5	2				10		2							
15	14		1	6						11		4							
16	14		6	11		2				2		5							
17	4	18		12		9				7		20							
18	20		7	8	3				2	1	2	5							
19	20	1		11		4				2	1		10						
20	20				3	4													
21	19			4	8	10													
22	20		2																
23	19		13	7	9					2									
24	18		5		2				13										
25	18		2	6										1					
26	20		6	1					1										
27	20		3	2				1											
28	20	1		4	4														
29	20			7	4														
30	10	6			1				8	1				5	1	1			
31	5			1	1					6			9	5	8	1			
32	4	6			6					15				11					
33	20		2	9											2		1		
34	20		3	2	5										5				
35	20																		
36	19	3		1											4				
37	20		5	9							1				1				
38	20				5	6						2							
39	13	1	5	7	6					5									
40	18		2	10															
41	20	11	2	12								2	7						
42	16	2	1	5	12		3	3		1		2							
43	20			6	11			1		2		3							
44	19	2		8	11		1		2	2									
45	15	2	4	9	3				1	1	4		1	1					
46	10	1	19	5	9			3		4		3						4	
47	20																		
48	20	2		4			6												
49	10			7	2					1									2
50	19	5	2	1										1					

A plot of the species scores (axis 1 & 2) shows two predominant gradients (Fig. 3.). The first axis is associated with an increase in size of the hedge, the second major axis of variation is associated with the addition of species to hawthorn dominated hedges. *Crataegus monogyna* *a*ppears central to both axis.

In a plot of the DCA of shrub abundance data a majority of the samples scores lie close to the origin of axis 1 and axis 2 (Fig. 4.). This is due to the commoness of hawthorn in the samples (see Fig. 2.), which has a species score situated close to the origin (Fig. 3.). Some points are outliers to this central hawthorn dominated group of sample scores. Using the species scores to interpret the sample scores, the reason for some transect scores being outside this set of core point is apparent. For example, transect 17 has little hawthorn (4/20) but is dominated by *Sambucus nigra* (18/20) and with *Rosa canina* (12/20) and *Canus sanguinea* (9/20) present. The position of this point in an ordination would thus tend to have a high positive score on the second axis. Similarily, transect 31 has a relatively large amount of *Ulmus glabra* and *Salix vibrium* present, it thus tends to lie at the positive end of the first axis.

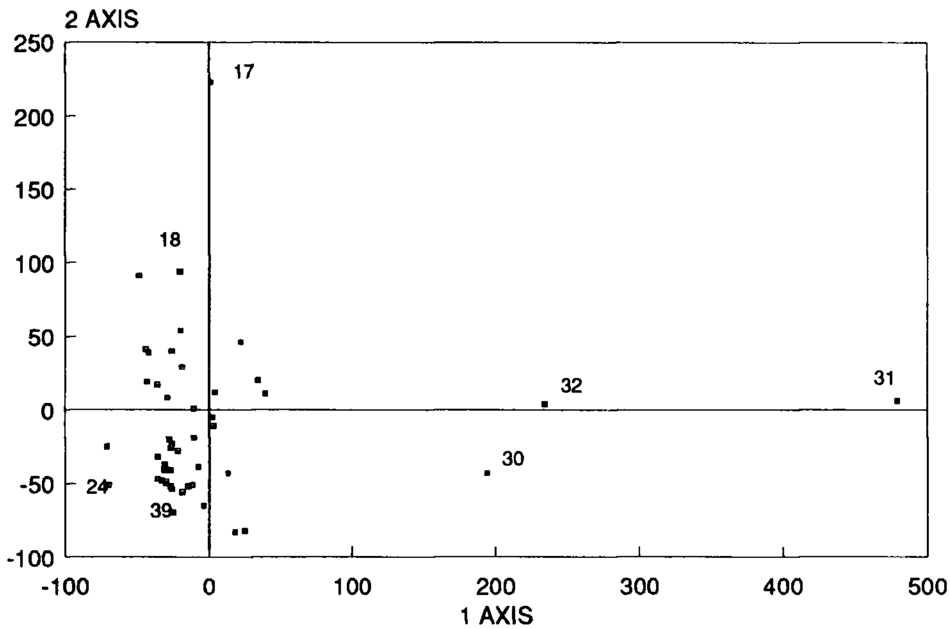
The presence of the central core of transects surrounded by a set of outliers (hedges with non-hawthorn dominated shrub species composition or uncommon species present) make an appreciation of the subtle pattern of the central hedges difficult to interpret. Therefore, the most outlying points in the plot were sequentially removed until a plot of just the core sites was observed. This involved the removal of 7 outlying points (17, 18, 24, 30, 31, 32 and 39), shown on Fig. 4. The new plot of hedge shrub composition of just the hawthorn dominated transects (Fig. 5) produces a greater scatter of points in both axis one and two.

Fig.3. Ordination (DCA) of species scores of shrub abundance data for 50 sites (axis 1 & 2).



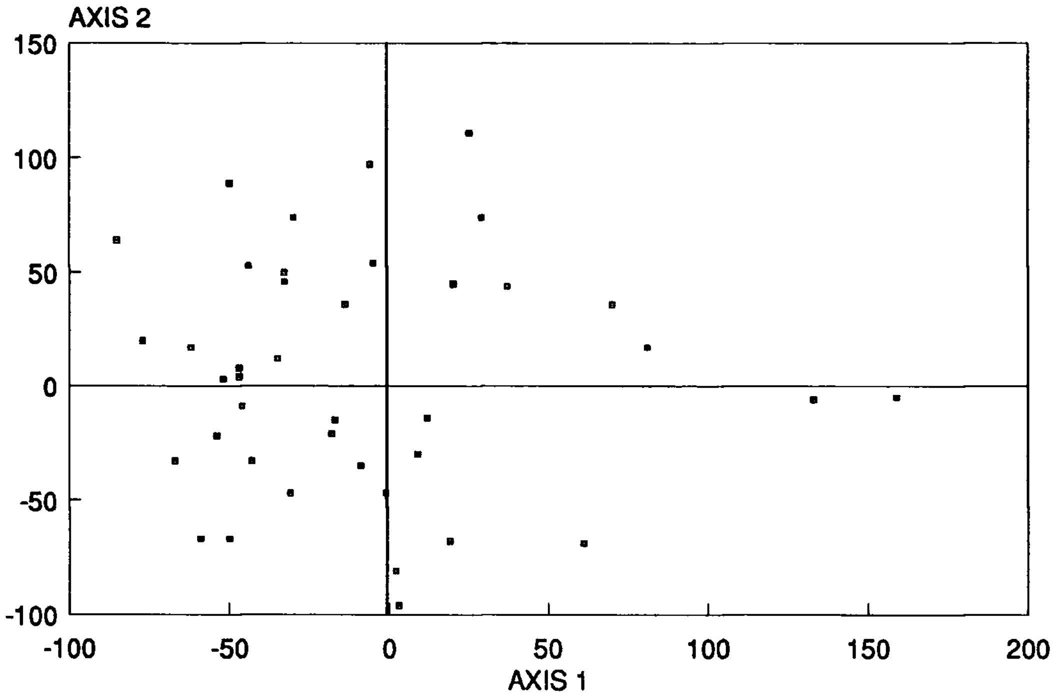
Eigenvalue: axis 1, 0.42; 2, 0.29.

Fig. 4. Ordination (DCA) of sample scores of shrub abundance data for 50 hedge sites (axis 1 & 2).



Eigenvalues: axis 1, 0.42; 2, 0.29

Fig. 5. Ordination (DCA) of shrub abundance data, without 7 outlying points (axis 1 & 2).



Eigenvalues: axis 1, 0.24; 2, 0.20

3.2 Hedge physical characteristics

The height of hedges in this study varied from under 1m to over 5m tall. The frequency of distribution of different hedge heights indicates two peaks, one at 1.5-1.99m and the other at 3.5-3.99m (Fig. 6.). It appears that the distribution ofhedges tailed around 1.5-1.99m are the hedges that are consistently managed by the tenant. This height provides a suitable height to keep stock in. The second distribution peaking at 3.5-3.99 is of hedges that have been left to grow unmanaged. The shrubs commonly grow to this height as well as showing lateral extensions. A statistically significant correlation between the height of the hedge and the width of the hedge was found ($r=0.85$, $df=50$, $P<0.000$) (Fig. 7.). Hedge height and width are thus intercorrelated variables. The width of the hedge is approximately 2/3 of the height of the hedge.

A tree in a hedge was defined as an individual tree whose vegetation had emerged from the mean hedge height ie. the bulk of the trees vegetation was seperated from the hedge vegetation. Using this criterion, 28 of the sites had one or more trees in the 100m transect. Eight of these 28 transects with trees had only one tree in them, these trees having probably grown out of the hedge. Other hedges had from 2-23 trees, some of these were equally spaced and obviously planted. The number of species of tree in a hedge transect (TSPP) varied from 1-5, about 2/3 of the hedges having only one species.

The amount of woodland within 200m of the 100m hedge transect (200m) varied between 0 (28 transects) and 47,000m^2. This was correlated to the amount of woodland within 500m of the hedge transect (500m) ($r=0.31$, $df=50$, $P<0.05$).

Fig. 6. Frequency of different hedge heights (average of 10 samples for each site) for 50 hedge transects.

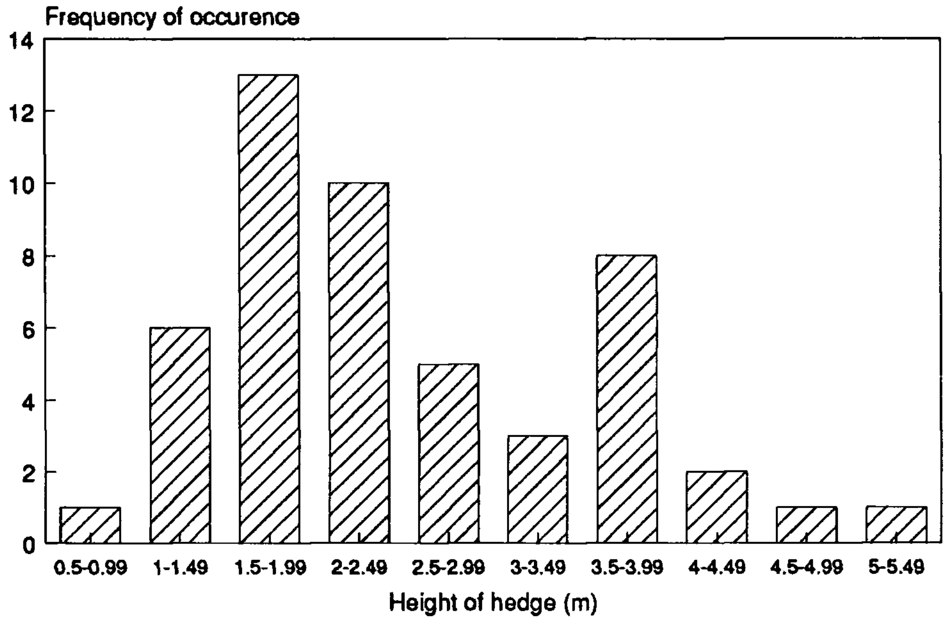
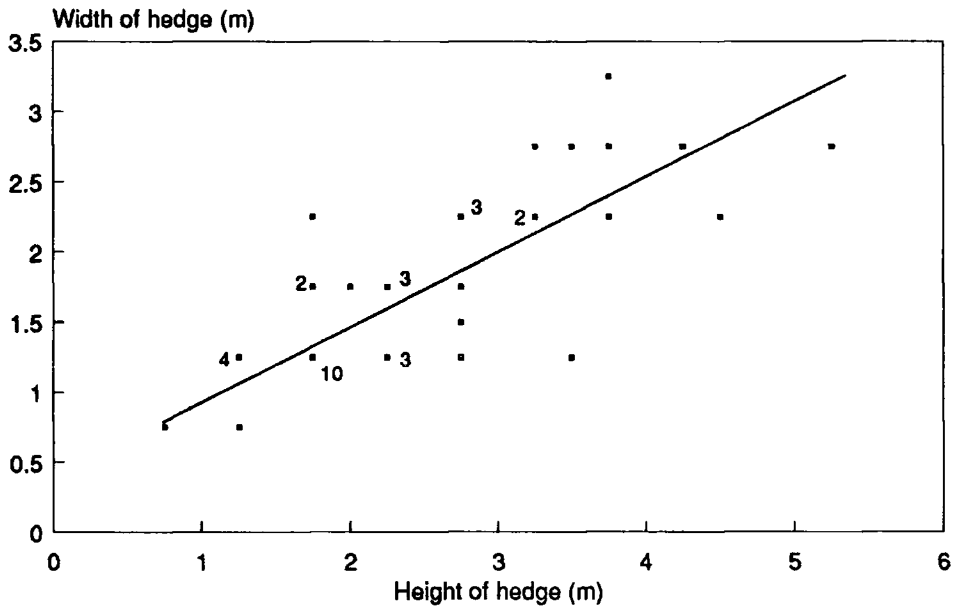


Fig. 7. Relationship between the height and width of the 50 hedge transects ($r=0.848$, $df=50$, $P<0.0001$).



Values at points are number of points at this position.

Table 3. Spearmans Rank Correlation Coefficient for hedgerow descriptive variables.

	FAS	SAS	TAS	HT	WD	200m	500m	10-25	25+
SAS	-								
TAS	-	-							
HT	-	-	-						
WD	-	-	-	***					
200m	***	-	-	*	**				
500m	-	*	-	***	***	***			
10-25	-	-	-	-	-	**	-		
25+	-	-	-	-	-	-	-	**	
TSPP	-	-	-	-	-	-	-	***	***

Significance levels; P>0.05 *, P>0.01 **, P>0.001 ***.

Table 4. Correlation Coefficients (linear) between hedgerow descriptive variables.

	FAS	SAS	TAS	HT	WT	200m	500m	10-25	25+
SAS	-								
TAS	-	-							
HT	*	-	-						
WD	**	-	-	***					
200m	-	-	-	**	**				
500m	-	*	-	**	**	*			
10-25	-	-	-	-	-	-	-		
25+	-	-	-	-	-	-	-	-	
TSPP	-	**	-	-*	-	-**	-	-	-

Significance levels; P>0.05 *, P>0.01 **, P>0.001 ***.
-*, or -** denotes negative correlation.

3.3 Inter-correlation of hedge vegetational and morphological characteristics.

The variables used to describe the hedges, HT, WT, 200m, 500m, 10-25, 25+ and the first, second and third DCA scores of the shrub species ordination (FAS, SAS and TAS), were correlated with each other. Two correlation coefficients were used. The first Spearmans Rank Correlation (r_S) (Table 3.), a non-parametric test, uses just the rank value of the two variables, it thus recognises curvilinear relationships as being significant. The second coefficient, Correlation Coefficient (r), uses the values of the two correlating variables, and lends significance only to relationships that approximate to linear

If many of the correlations are significant using r_S, but not with the r coefficient, then many of the relationships would appear to be non-linear. Out of a possible 45 correlations, 12 have significant r_S values (Table 3.) and 12 have significant r values (Table 4.). Of these correlations 8 are the same ones with r and r_S values, 4 are different with each test. Although many variables are correlated in a linear fashion, some relationships have a non-linear nature. Probability theory suggests that 5% of relationships between random data sets would be correlated ($P>0.05$ or higher) by chance alone. These data have 12/45 (27%) of relationships at a significance level of $P<0.05$ or higher. The correlations between variables are thus likely to be real, rather than statistical artifacts possible from two random data sets (Osborne 1984).

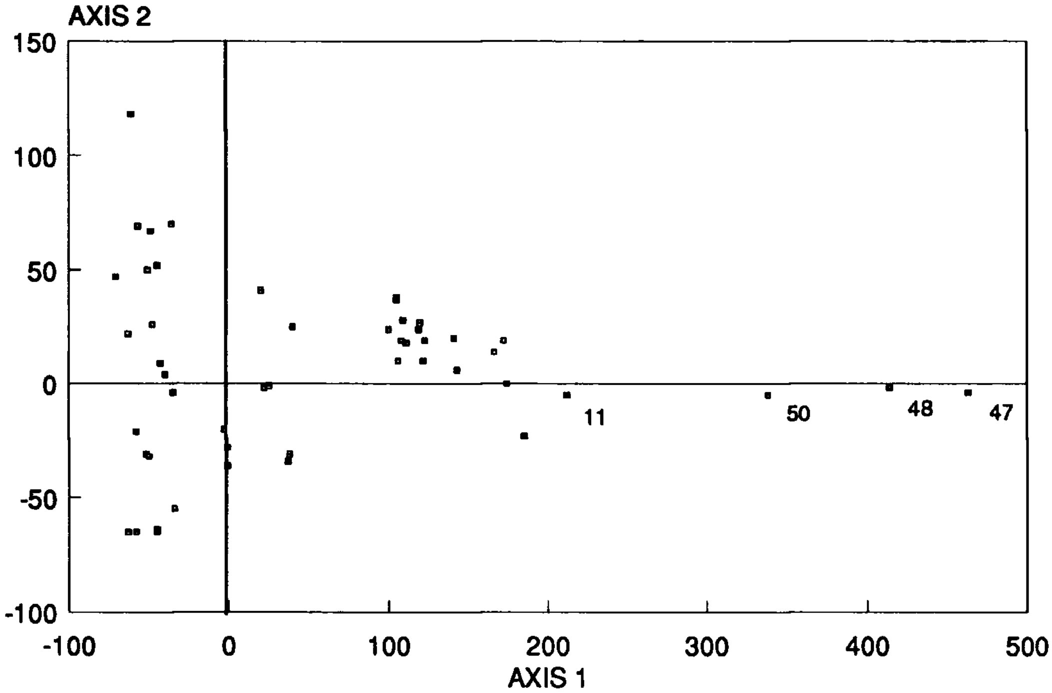
3.4 Ordination of hedge sites using descriptive parameters

A DCA was carried out using the hedge descriptive variables. The scores of the shrub abundance DCA were not used in this analysis. It was considered that an ordination of the sample scores, already from an ordination, was liable to produce results that would be difficult to interpret biologically. Thus, instead of the scores from the DCA of shrub abundance (FAS, SAS and TAS), just the total number of species of the hedge (SSPP) in the transect was used for this analysis. The variables entered into the DCA were thus;

SSPP	Total number of shrub species
HT	Height of the hedge
WD	Width of the hedge
200m	Area of woodland within 200m of the hedge
500m	Area of woodland within 500m of the hedge
10-25	The number of trees in the hedge with dbh between 10 and 25cm.
25+	Number of trees with dbh 25cm or greater.
TSPP	Total number of species of tree in the hedge.
R	Road beside hedge
P	Pasture beside hedge
C	Cereal beside hedge
RA	Rape beside hedge

The DCA of these hedgerow variables (Fig. 8) shows a long gradient along the first axis and a shorter gradient on the second axis. The first axis is associated with an increase in the number of trees in the hedge. The species loadings for the tree variables are 25+ (10), TSPP (17) and most importantly 10-25 (62). The sites with the highest number of trees are placed with high positive scores along the first axis ie. site 47, 48, 50 and 11 respectively. Those sites with few or no trees are distributed lower down the first axis. Shrub species richness (SSPP) has a small positive loading (12) and a small negetative loading is given by the variables 200m and 500m on the first axis. The second axis has a high positive loading for 200m, sites with a positive score thus tend to have woodland within 200m of the hedge. The major pattern of variation in these data is thus number of trees, particularly small trees,

Fig. 8. Ordination of hedgerow sites
using hedge descriptive parameters
(Axis 1 & 2).



Eigenvalue: axis 1, 0.53; 2, 0.19

along the first axis and area of woodland within 200m on the second axis; the eigenvalues are 0.53 and 0.19 respectively.

3.5 Bird Census Data

A total of 1082 birds of 23 species were recorded in censuses of 50 hedge sites from May-July (Table 5 & 6.). The mode of the total number of birds recorded in 6 censuses in each hedge was 10-19 (18/50 transects) (Fig. 9.). Over 80% of the transects had between 5-29 individuals recorded in them.

The number of new species observed in each of the 6 censuses was plotted against increasing census number for the first 10 transects (Fig. 10a. & 10b.). This shows that in nine out of ten censuses, no new species species of bird were likely to be observed in the 7^{th} census if it were carried out. Thus, the estimate of species richness of the hedge after 6 censuses was considered to be representative of the species richness of common birds of the hedge.

The commonest birds observed in the transects were Chaffinch, Yellowhammer, Blue-tit, Blackbird, Whitethroat and Willow Warbler respectively. Five species of bird were observed in less than five occurences; they were Wheatear, House sparrow, Cuckoo, Jay and Tawny owl.

A DCA of the bird species scores was carried out for the 50 hedge transects. The major source of variation is in the first axis (eigenvalue 0.47) (Fig. 11b.), the second axis being very minor. Using the species scores (Fig. 11a.) to interpret the sample scores, the bird species with negative scores on the first axis tended to be those that are foundmore commonly in hedges with trees eg. Rooks, Blackbirds and Wood-pigeons. Positive scores tend to be related to species that are found in simple hedges eg. the Whitethroat and Dunnock. Yellowhammer and Chaffinch are found centrally in the first axis gradient and are commonly found in all types of hedges. The first axis thus represents the variation in birds

Table 5. The bird species recorded in the 50 hedge sites, the Latin Binomial and the abbreviation used in this study.

Common Name	Latin binomial	Abbreviation
Whitethroat	*Sylvia communis*	WT
Dunnock	*Prunella modularis*	DN
Willow warbler	*Phylloscopus trochilus*	WW
Chaffinch	*Fringilla coelebs*	CF
Yellowhammer	*Emberiza citrinella*	YH
Blue tit	*Parus caeruleus*	BT
Song thrush	*Turdus philomelos*	ST
Great tit	*Parus major*	GT
Wood pigeon	*Columba palumbus*	WP
Magpie	*Pica pica*	MP
Linnet	*Acanthis cannabina*	LN
Patridge	*Perdix perdix*	PT
Robin	*Erithacus rubecular*	RB
Tawny owl	*Strix aluco*	TO
Blackbird	*Turdus merula*	BB
Rook	*Corvus frugilegus*	RK
Wheatear	*Oenanthe oenanthe*	WE
House sparrow	*Passer domesticus*	HS
Cuckoo	*Cuculus canorus*	CK
Wren	*Troglodytes troglodytes*	WN
Greenfinch	*Carduelis chloris*	GF
Blackcap	*Sylvia atricapilla*	BC

Table 6 The abundance of bird species in the 50 hedge sites (total of all 6 censuses).

	WT	DN	WW	CF	YH	BT	ST	GT	WP	MP	LN	PT
1	11	6	4	3	1							
2	19	4	3	7	1	1						
3		3		1	2		1					
4		3	2	15	5			2	5	2	2	
5	3	4	3	5	3				1		8	1
6	7	4	2	7				1				
7	3	2	2	5		1		5			1	
8				13	5	5						
9		1	1	5	5	4						
10	1			10	3	1						
11				4	2							
12		1		6	2	4						
13				4	3							
14		1		4	3						1	
15			1	11	3							
16	4	3		13	2						4	
17	5	1		9	1							
18	12	2		1	1							
19	1	2		7	2							
20					3							
21				4	6		3					
22				3	1		1					
23				4			1					
24				5	3					1		
25				6	3					1		
26			5			1						
27		1	6			3						
28		1		1	5							
29		1		10	1		2		5			
30			2	8	1	3	1	7	2	2		
31					3	2		3	3			
32		2		10	4	1			2			
33			1	2								
34	1	3	12	2	2	29	2	3				
35			2	2		15		5		1		
36		1	1	5		20	2	5	4			
37				4	3							
38				2	15							1
39	5			1		8		2				
40	3	3	1	5	6						2	
41	3	4		2	1							
42		3	6	9	5		1	1			14	
43		2	10		11		3				1	
44		2	4	4	8		1					
45			3	2	8		1					
46	1		6	2	1		1					
47			2	8	2	12		5	5	3		
48			1	2	1	8				1		
49		1		3	1	6						
50			1	6	1	6						

	RB	TO	BB	RK	WE	HS	CW	WN	GF	BC	JY
1											
2											
3											
4											
5	2	1									
6											
7	5										
8			1								
9	1		1								
10											
11				3							
12	1		4								
13											
14					1						
15											
16						1					
17											
18											
19					1						
20			2								
21											
22											
23											
24			1			1					
25											
26											
27						2					
28											
29	1		2	2		1					
30			5	2			2				
31			6	8		1	2	1			
32	5		4					2	16	6	
33			6								
34	5		10				1	1			
35			2	2			1				
36			7								
37								2			
38	1										1
39			6					9			
40			2								
41			2								
42			9					2			
43			2								
44			2								
45				1							
46			4								
47			3			1					
48											
49			2								
50			2								

Fig. 9. The frequency of sites with different numbers of total birds observed in all 6 censuses.

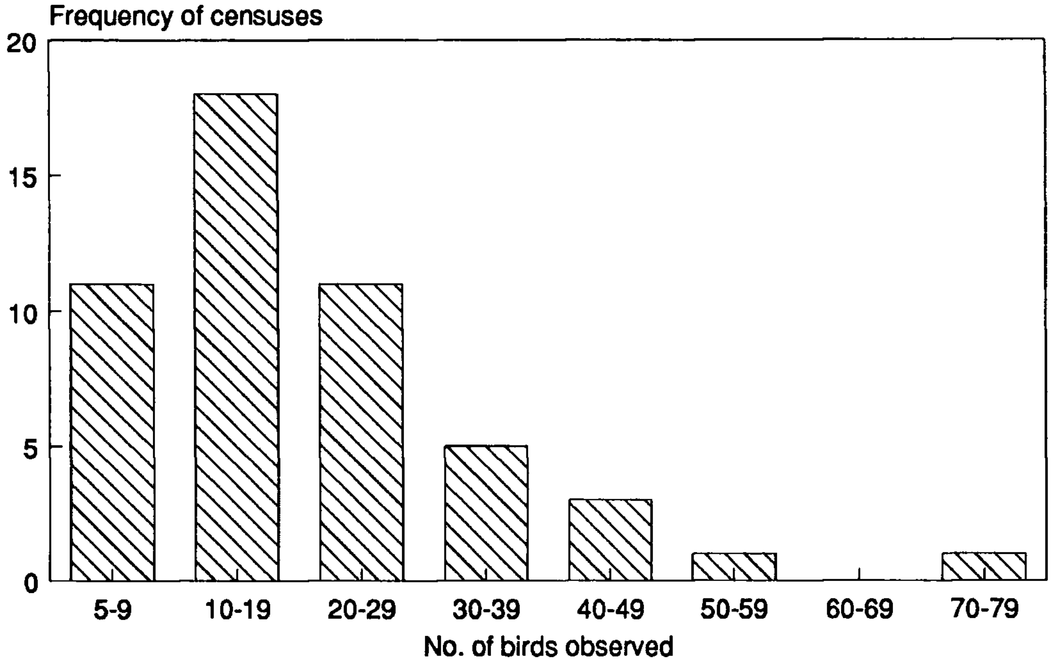


Fig. 10 a. The number of new bird species observed against the number of censuses carried out (sites 1-5).

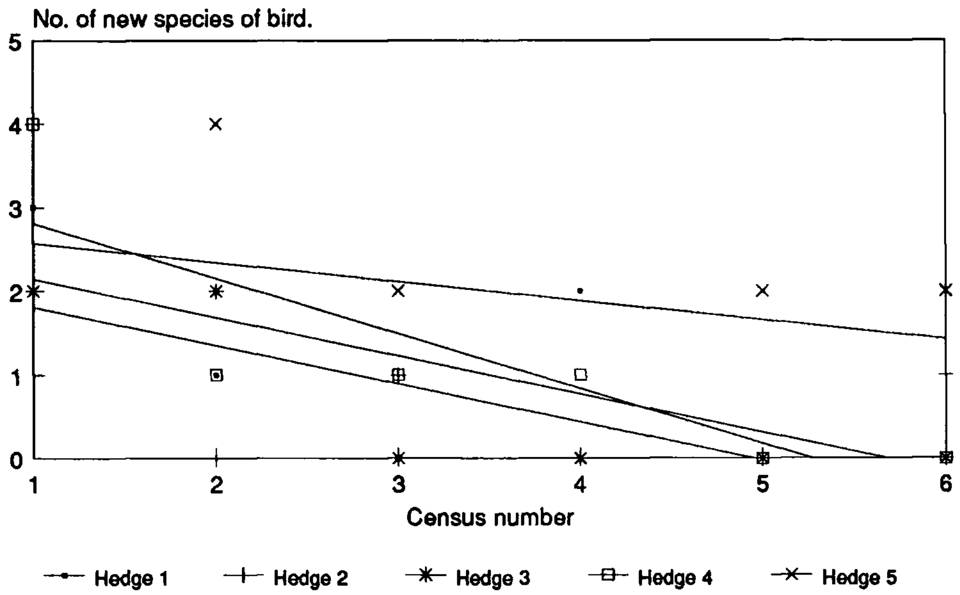


Fig. 10b. The number of new species of bird observed with increasing number of census (Hedges 6-10)

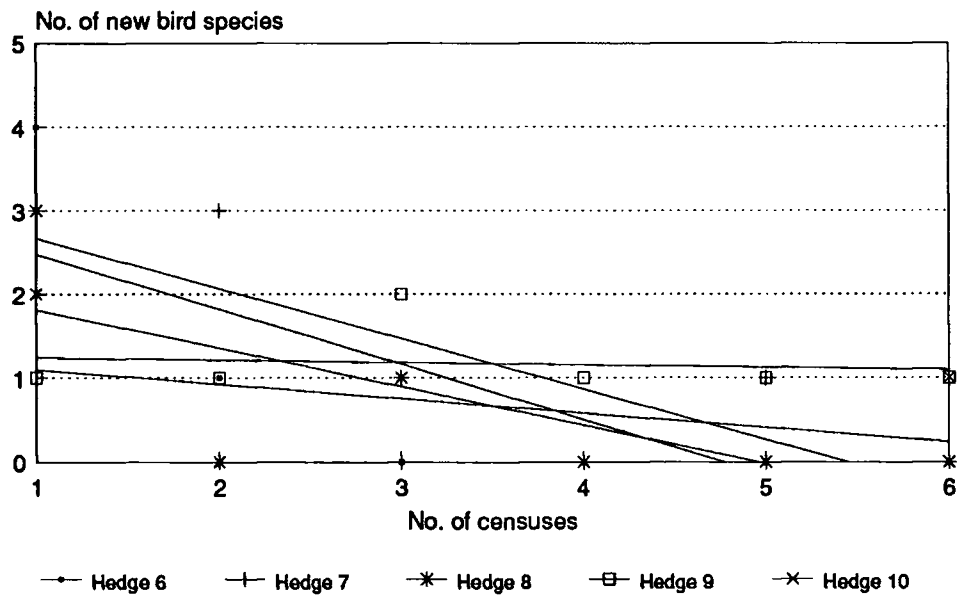
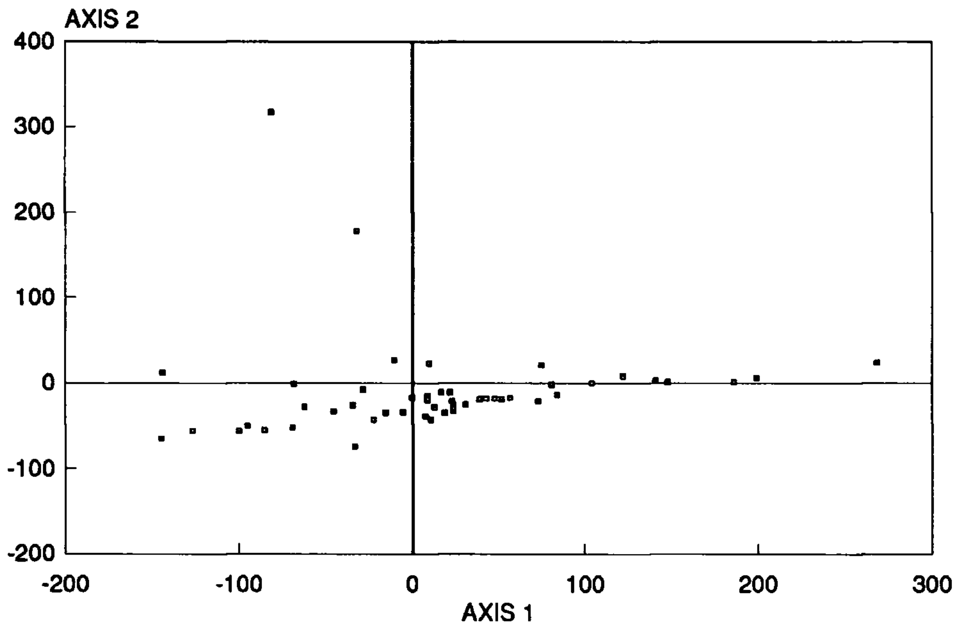
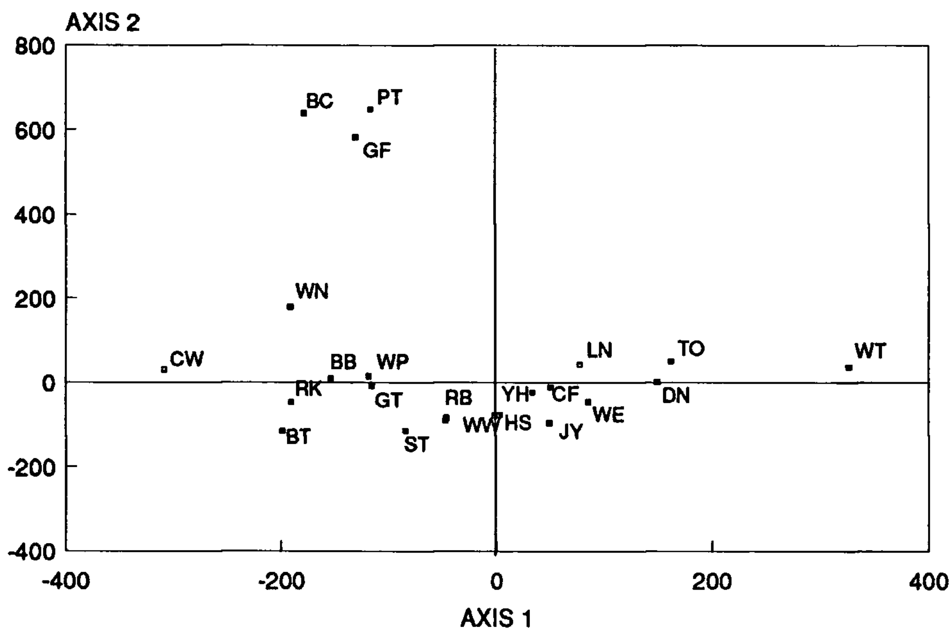


Fig. 11a. DCA of sample scores of bird abundance data for 50 sites (Axis 1 & 2).



Eigenvalue: axis 1, 0.47; 2, 0.41.

Fig. 11b. Ordination of bird species scores from the 50 hedge transects (axis 1 & 2).



Eigenvalue: axis 1, 0.47; 2, 0.41.

that are recorded, from those of complex hedges in the negative end of the gradient to birds found in simple (managed) hedges in the positive end of the spectrum.

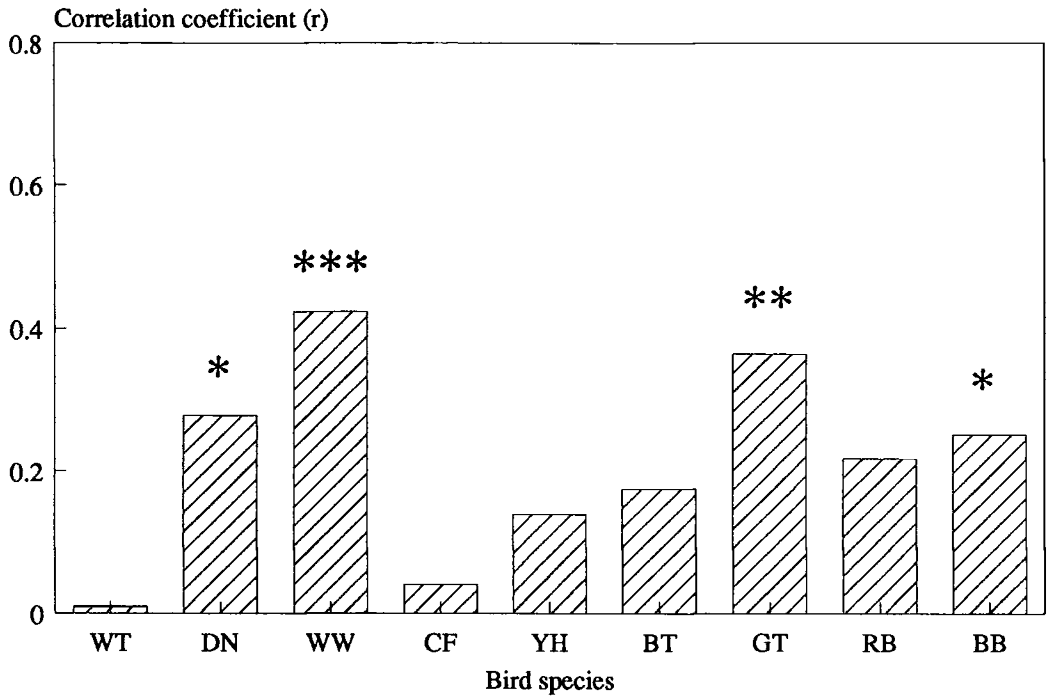
Correlations were carried out between the total density of birds recorded in the 50 hedge sites and the density of each common bird species. To ensure that the two variables were independant of each other (a requirement for correlations) the density of the species under consideration was subtracted from the total density of birds. Thus, species "A" was correlated to the density of species B......W (for 23 species), and species "B" was correlated to A+C.....W. Of the nine common bird species (those with over 40 records in the censuses), 4 were significantly correlated to the total density of birds; the Dunnock, Willow warbler, Great tit and the Blackbird (Fig. 12.). The Robin was nearly correlated significantly to total density of birds (r_s= 0.22, P=0.065). The other 4 common species that were not significantly correlated to the total density of birds were Whitethroat, Chaffinch, Blue tit and Yellowhammer.

3.6 RELATIONSHIPS BETWEEN BIRD AND HEDGE DATA

3.6.1 Simple correlations

Correlation Coefficients were calculated between the hedge variables and the density of common birds, total bird density and bird species richness for the 50 hedge transects (Table 7.). Willow warblers, Chaffinches and Yellowhammers are not correlated significantly to any hedge descriptive variable. However, Blue-tits and Great-tits were correlated to 4 variables; Whitethroats, Robins and Blackbirds to two variables and Dunnock

Fig. 12. Correlation coefficients (r) of density of some common bird species with total density of birds for 50 hedges.



* P<0.05, ** P<0.01, *** P<0.001.

Table 7. The independant variables of hedge characteristics that correlate significantly with the density of common birds and community density and diversity.

DEPENDANT VARIABLE	INDEPENDANT VARIABLES			
Bird spp. richness	FAS	HT	10-25	
Bird density	FAS	HT	WD	
Whitethroat	SAS	200m		
Willow warbler	-			
Chaffinch	-			
Yellowhammer	-			
Bluetit	SAS	10-25	25+	TSPP
Greattit	FAS	HT	WT	25+
Robin	WD	25+		
Blackbird	200m	25+		

to one variable. The total density of birds was related to 3 variables (FAS, HT and WD), and the total species richness was related to FAS, HT and 10-25. A total of 19% (21/110) of relationships were above the $P<0.05$ significance level.

3.6.2 Stepwise multiple regressions

Stepwise multiple regression was used to ascertain the importance of each of the hedge descriptor variables significantly related to the dependant variables. Least squares regression was used as the main source of error was in the independant variable. This method helps to clarify the intercorrelations among variables because once a variable has been chosen in the regression another intercorrelated variable is not selected, unless it can explain a significant amount of the remaining variation in the residuals. The variation in the dependant variable that it can explain has already been explained by an intercorrelated variable.

A summary of the variables chosen in stepwise multiple regressions was constructed (Table 8a.). With Whitethroat, Chaffinch and Yellowhammer no significant relationships were found with descriptor variables. Three bird species have their densities explained initially by the variable 200m (area of woodland within 200m of the hedge). The first variable selected by the regression to explain the density of robins is WD (width), for Blue-tits 25+ (number of trees with dbh 25cm+) and for Great-tits it is FAS (scores of axis 1 of the shrub abundance data).

3.6.3 Polynomial treatment of variables in Stepwise Multiple Regressions

Multiple Regression (using Least Squares) considers the prediction of the dependant variable from the independant variables in terms of linear, straight line relationships. No

Table 8a. The variables selected by a Stepwise Multiple Regression to describe aspects of the bird community, in ranked order.

DEPENDANT	INDEPENDANT VARIABLES		
WT	200m	SAS	
DN	200m		
WW			
CF			
YH			
BT	25+	10-25	
GT	FAS	25+	HT
RB	WD	25+	
BB	200m		
TSSP	FAS	25+	
AVNO	FAS		

Table 8b. The variables selected by a Stepwise Multiple Regression with the variables squared, square-rooted and logged, in ranked order.

DEPENDANT	INDEPENDANT VARIABLES			
WT	200m	SAS		
DN	200m			
WW				
CF	HTS	500MSQ		
YH				
BT	10-25LN	SASLN	SASSQ	SAS TASLN
GT	FAS	10-25	HT	
RB	WDS	10-25LN	WD	
BB	200mLN			
TSPP	FASSQ	10-25LN		
AVNO	FASLN			

Variables squared suffix "S"
Variables Square roots suffix "SQ"
Variables natural log suffix "LN"

provision is made for non-linear relationships (ter Braak 1987). Thus, to determine if relationships between the hedge descriptor variables and the bird data would be more accurately explained by transformed variables, the independant data was transformed.

The data was transformed in 3 ways:

1. Natural log (ln)
2. Squared (s)
3. Square root (sq)

The variables as well as the transformed variables were entered into a Stepwise Multiple Regression to predict the density and diversity of facets of the bird community.

A total of 20 independant variables were selected by the Regressions (Table 8b), this is 6 more than with untransformed data. 70% of these variables selected were transformed. Twelve out of the 20 independant variables selected were in the same position as with transformed data, however two-thirds of these variables were transformed. The availability of transformed data in the Stepwise Multiple Regression increased the r^2 of most of the regression lines, and thus the predictive value.

3.7 Multivariate direct gradient analysis of birds in hedges

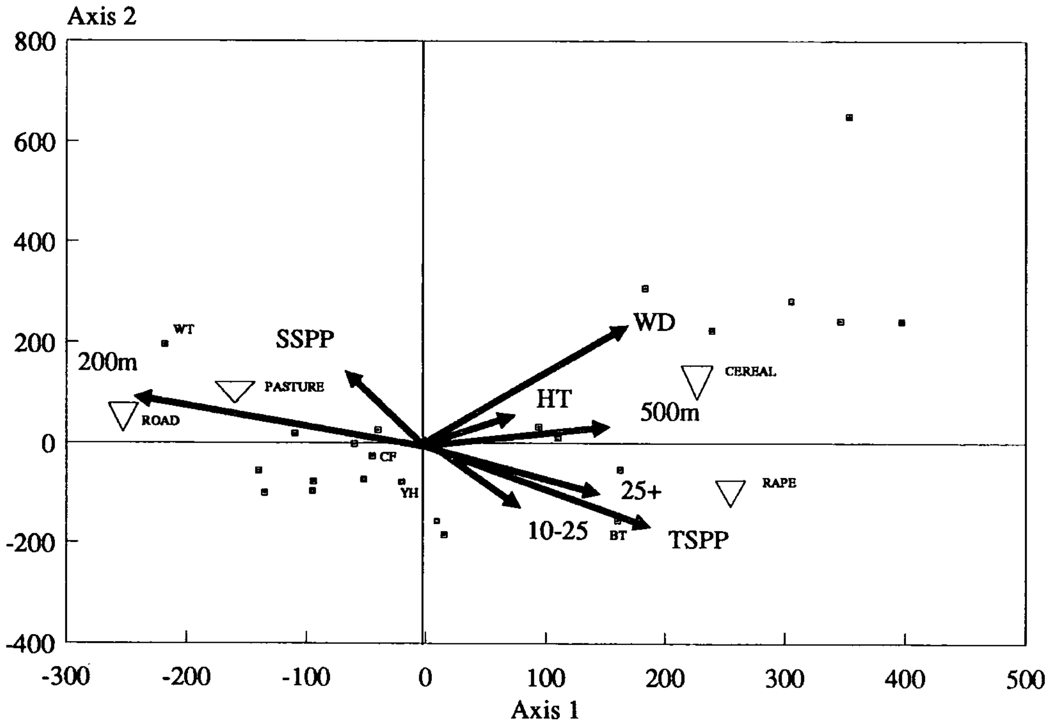
Regression analysis, as well as being limited to linear relationships, is confined by its ability to consider only one species at a time. For non-linear and/or non-monotonic (ie. complex multi-step curves) responces of a community, less powerful methods involving "indirect" gradient analysis (Whittaker 1967) eg. ordination, had to be used. However, regression and ordination have been fused to produce a new breed of multivariate analytical methods; multivariate direct gradient analysis methods ie. canonical ordination. One method, available as part of the CANOCO programme, is Canonical Correspondence Analysis (CCA). CCA can analyse how a community of species respond to a set of external factors, while not assuming linearity and detecting unimodal relationships. The analytic process can be divided into two steps (Gauch 1982):

1. Extraction of the dominant pattern of variation in the species data by ordination.
2. Determination of the relationship of this pattern to environmental variables.

Species data (bird hedgerow abundance data) and environmental data (hedge descriptor variables) were entered into a CCA within the CANOCO programme. A plot of the species scores and the environmental bi-plot (shown as arrows) was constructed (Fig.13.). The arrows represent the direction, or axis, of variation in the variables over the whole dimension of the ordination. The length of the arrow is related to the rate of change in that variable, important environmental variables are therefore represented by longer arrows. The direction of variation in some of the variables is similar to that of others eg. TSPP, 10-25 and 25+. Due to this intercorrelation of variables an attempt to remove the minor variables that correlated with other major variables was made. The programme was rerun with just 4 variables; 200m, TSPP, SSPP and WD, the major variables from the bi-plot with all the environmental variables. These 4 variables were representative of the amount of woodland in the surrounding area, the number of species of trees in the hedge, the number of species of shrub in the hedge and the width of the hedge. Although the eigenvalue decreased with the decrease in the number of environmental variables used in the analysis (from 0.35/0.18/0.13 to 0.28/0.14/0.08 for axis 1, 2 and 3 respectively) this was considered to be acceptable. The decrease in the number of variables improved clarity of the plot and thus aids interpretation.

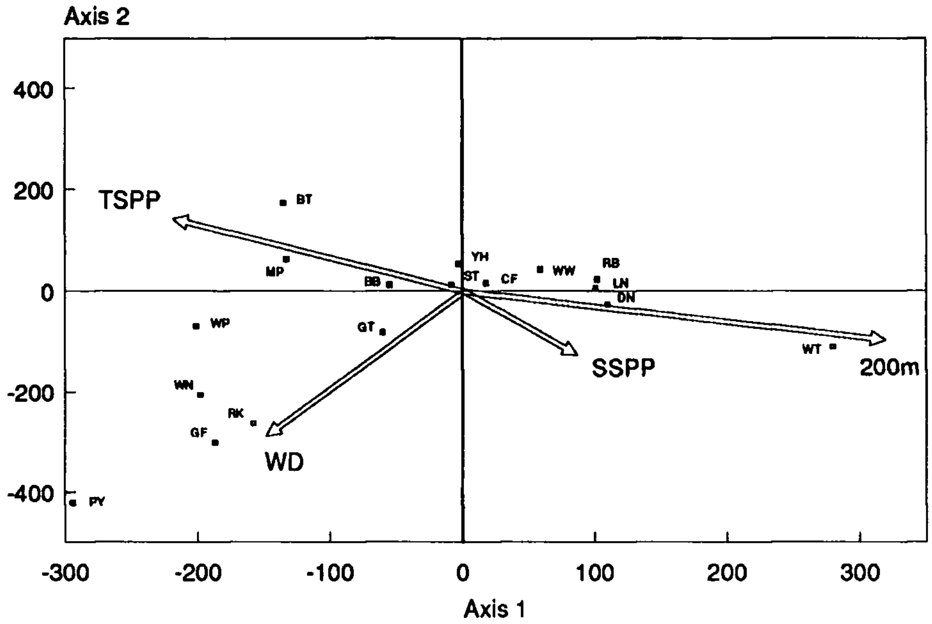
The relationship of the 4 environmental variables to the major axis of variation in the bird species can be observed (Fig. 14a.). The first axis is associated with an increase in the amount of nearby woodland in the positive region and with an increase in the number of species of tree in the negative region. The second axis is primarily concerned with a decrease in the width of the hedge with increasing scores, and the third related to shrub species richness (Fig. 14b.). Whitethroats can be seen to lie at the extreme positive end of the first

Fig. 13. CCA diagram for hedge birds
with variable gradients as arrows.



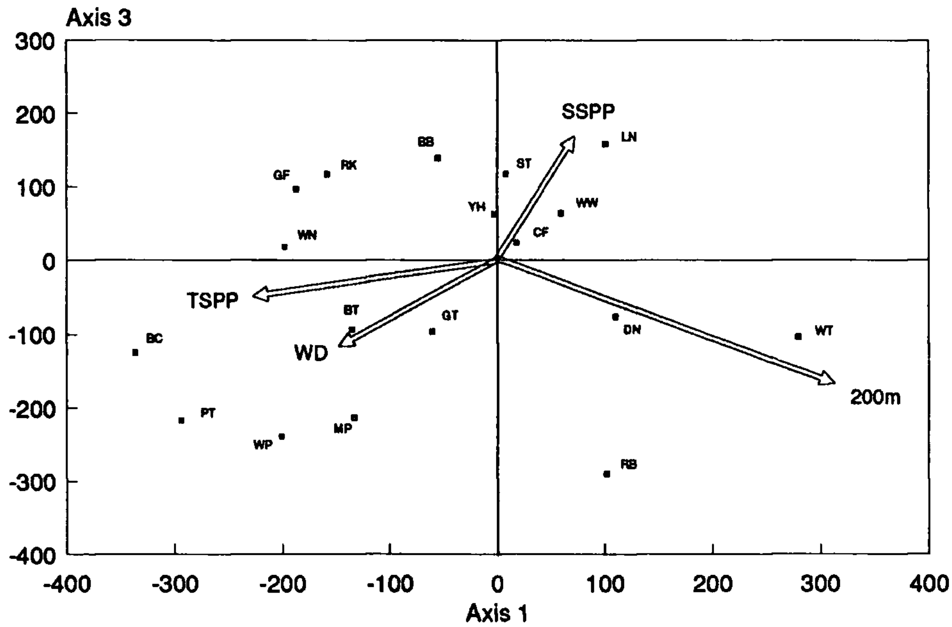
Eigenvalue: axis 1, 0.33, axis 2, 0.18.

Fig.14aCCA ordination diagram for hedge birds with variable gradients shown as arrows (axis 1 & 2).



Eigenvalue: axis 1, 0.28; 2, 0.14.

Fig. 14b. CCA of ordination of hedge birds with variable gradients as arrows (Axis 1 & 3).



Eigenvalue: axis 1, .14; 3, .08.

axis, with a very small negative score on the second axis. This species, thus, is found in greater abundance in hedges with a sizeable component of nearby woodland but with few trees. The Blue-tit, on the end of the first of the axis is primarily related to the number of tree species in the hedge. Similar analysis can be carried out for the other species of bird, the responce of the species constituting the community can thus be appreciated in relation to the descriptive variables.

3.8 Mean density of bird species in sectors of the hedge DCA

The magnitude of the "niche" of a species can be indicated using indices of niche breadth. Levins (1968) proposed the use of an index, where "B" was the recriprocal value of Simpsons index (Simpson 1949). Other authors have suggested using the Shannon-Weiner information index (Colwell & Futuyma 1971) or Smiths measure (Smith 1982). However, in this study the data was not considered to be suitable for such a degree of determinism. Instead, a more graphical method was used, to show trends in resource relationships for exploratory purposes. This method is termed "sector analysis".

To establish the relationship between the major axis of variation in the hedge descriptor variables and the densities of birds, a plot of the mean density for four bird species against bulked scores of the hedge DCA (Fig. 8.), was constructed (Fig. 15). The first and second axis of the shrub DCA was divided into 4 sectors (Axis 1; sector 1, (-100)-(-1); 2, 0-99; 3, 100-199; 4, 200+: Axis 2; sector 1, (-100)-(-51); 2, (-50)-(-1); 3, 0-49; 4, 50+). Then the mean density of one bird species from the bird censuses of the sites (from the shrub DCA) that lay in axis 1, sector 1 was calculated. This was repeated for sector 2,3 and 4 of axis 1, and for the 4 sectors of axis 2. The mean density of the 4 species in the eight sectors was plotted (Fig 15.). This was only done for the 4 commonest species of bird in the censuses (chaffinch, yellowhammer, blue tit and whitethroat).

Fig. 15. The mean density of four common species of bird in different sectors of the hedge ordination (axes 1 & 2.)

Fig. 15a. Chaffinches

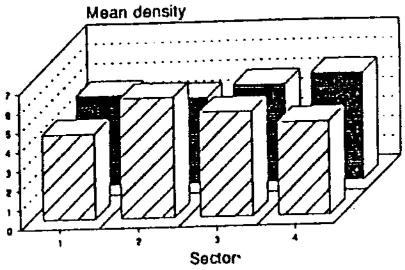


Fig. 15b. Yellowhammers

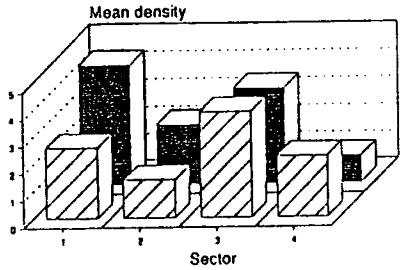


Fig. 15c. Blue-tit.

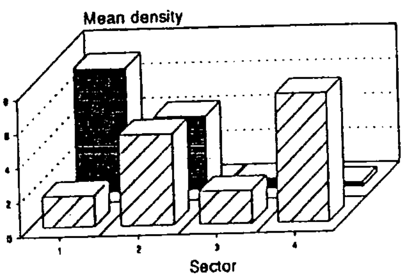
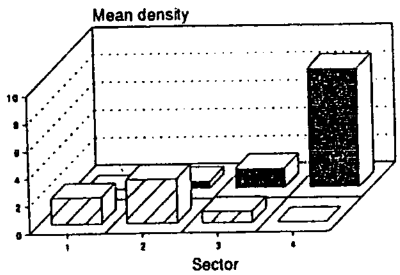


Fig. 15d. Whitethroat.



The 4 sectors in axis 1 represent a gradient of increasing number of trees (particularly those of dbh 10-25cm) with increasing sector number. Birds species that tend to have high densities in the higher number sectors would be associated with hedges with trees. The 4 sectors in axis 2 represent a gradient of increasing area of woodland within 200m of the hedge. These two gradients are the two major axis of variation in the hedge descriptor variables.

The density of chaffinches (Fig. 15a) is similar over the whole range of axis 1 and 2. It is thus appears to be associated with all types of hedges. A variation in the density of Yellowhammers (Fig. 15b.) over the two axis is apparent, however it tends to follow no particular trend. There is a strong trend in the second axis of the blue tit (Fig. 16c.), an increase in the density of the blue tit is related to a decrease in the amount of woodland within 200m of the hedge. The Whitethroat, however, has the opposite trend, its density increases with an increase in surrounding woodland. Whitethroat densities tend to decrease with an increase in the number of trees in the hedge.

3.9 Individual responses of species of birds to their hedge environment.

The results from the triad of mulivariate methods can build up a picture of the type of habitat in which a species of bird tends to be found in higher densities. This is done for 3 common species of bird; Whitethroat, Blue tit and Chaffinch.

Whitethroat: A Stepwise Multiple Regresssion selected 200m as the first variable and SAS as the second, no third variable was selected. The area or woodland explained 30% of the variation in the density of Whitethroats (Coefficient of Determination[r^2]= 0.29), SAS increased this to 0.47. The multiple r value was 0.69. With the use of polynomial independant variables, the same linear variables were selected. The DCA of bird species (Fig. 11b) places the WT at the opposite end of the first ordination axis away from the species that tend to be found in hedges with trees. The CCA diagram of the Whitethroat places the species again on the extreme positive end of the first axis very closely related to the 200m biplot arrow. The niche of the Whitethroat determined by sector analysis shows that the bird is found in hedges with few trees (axis 1) but is strongly associated with hedges with woodland nearby (axis 2).

These different methods of analysisng the data all point towards the same type of hedge in which the Whitethroat is found in greater densities. Higher densities of the bird are found in hedges with a significant area of hedge in the surrounding area, they tend to avoid hedges with trees. The similarity in the definition of the "niche" of the WT from these various multivariate methods suggests that the results are real, rather than artifacts of analysis, and are produced from actual relationships within the data set.

Chaffinch: The Chaffinch is found centrally in the DCA of the bird species (Fig. 11b.) and the CCA (Fig. 14). Stepwise Multiple Regression of the variables with the density of the CF did not select any variable, however polynomial treatment of the variables caused height of the hedge squared and the square root of 500m to be selected. Sector analysis shows similar densities in the four sectors of both axis one and two (Fig. 16a.). The Chaffinch, the most common bird recorded in the hedges, seems to have little preference for the type of hedge that it inhabits.

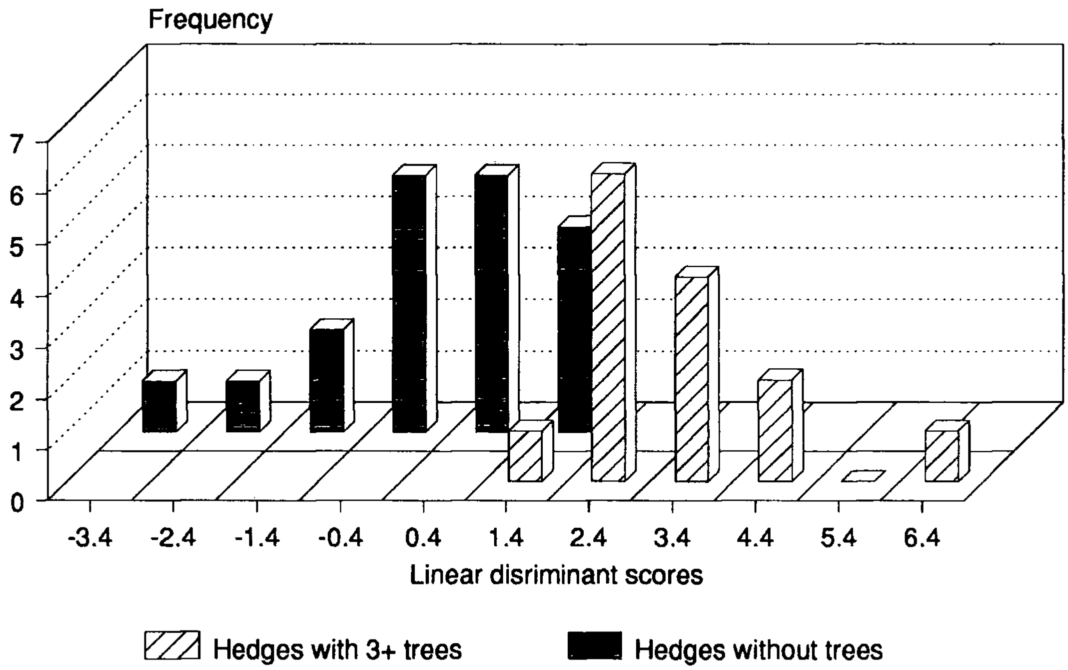
Blue tit: The species score for the BT is found towards the end of the DCA (axis 1) where tree associated species are found (Fig. 11b). On the CCA diagram (Fig 14a.) the Blue tit is closely related to the TSPP biplot arrow, and also the width of the hedge with a plot of axis 1 with 3 (Fig. 14.). Variables selected in the Stepwise Multiple Regression are, respectively, trees with a dbh 25+cm and 10-25cm and the natural log of 10-25 the second and third shrub sample scores (SAS, TAS). With sector analysis a trend towards living in hedges with trees is apparent and a dislike of hedges with surrounding vegetation nearby. The major variable that the BT selects for in hedges is trees, the larger trees being more important than smaller trees.

3.10 The effect of trees in hedges on the bird community

Of the fifty transects studied, 28 had trees present and the remainder had no trees. To determine the differences in the bird community of hedges with and without trees, a Linear Discriminanat Analysis (LDA) was carried out (using DISCRIM). This analytic test searches for variables that discriminate, or distinguish between, two *a priori* (predetermined) groups. In this case, the two *a priori* groups were hedges with and hedges without trees. The variables used to distinguish between the two groups were the bird species. Initially, all the bird species were used in the LDA, however the LDA did not accept the data as too many "0" counts were present in these data.

The test was repeated with only 12 common species of bird as discriminating variables, and limited to hedges with 3 or more trees present in the 100m transect (13 transects) and those hedge transects with no trees (22 transects). The probability that the two *a priori* groups were from the same normal distribution was 0.32, this was not significantly different (Analysis of Variance of the Linear Discriminant Function, F=1.2, P=0.32, with 12 and 21 degrees of freedom). However, it is not important if the two *a priori* groups are not significantly different as long as the results are biologically interpretable (Rice, Ohmart & Anderson 1983). The estimated probability of misclassification of the transects, based on the Mahalanobis distance (D^2) was 0.21, and actual classification success was 83% (85.3% for hedges with trees, and 82% for hedges without trees). The mean discriminant function of the hedges with trees was 3.35, and 0.64 for hedges without trees (Fig. 16.).

Fig. 16. Frequency distribution for LDA between hedges with 3 or more trees and hedges without trees.



Total classification success= 83%

The percent added to the discrimination function by the 12 variables is shown below:

Blue tit	33.6
Chaffinch	21.9
Robin	21.7
Dunnock	12.6
Magpie	10.2
Blackbird	5.9
Linnet	3.1
Whitethroat	2.7
Great tit	0.42
Yellowhammer	-0.9
Willow warbler	-2.0
Woo~~o~~d pigeon	-9.0

The Blue tit, Chaffinch and Robin supply nearly 75% of the discriminant power of the LDA. They are the variables that are most important when discriminating between hedges with and hedges without trees. The bottom ranked species, Wood pigeon, Willow warbler and Yellowhammer take away discriminant ability fom the discriminant function because they have negative scores.

The value in this test is not to be able to determine if a hedge has trees in it, using the bird community. Wether a hedge has trees in it or not is really rather obvious, and a census of the bird community is unnecessary! However, this LDA does show that the birds in the two *a priori* groups are different, though not significantly; that one can discriminate between these two hedges with an accuracy of 83% using bird species; and, which species are most important in distuinguishing between the two groups.

4 DISCUSSION

4.1 Variation in hedge transects

Bailey (1979) found, from a survey of 620 hedge samples from around Durham, that Hawthorn was dominant in 94% of transects. The 6 most abundant shrub species he found in Durham were the same 6 most abundant species in Warickshire and Wiltshire . The mean number of species of shrub in the hedges surveyed was approximately two, seven being the maximum. This study has an average number of 5 shrub species for each hedge. The difference can partly been explained by the difference in transect length. Bailey used 27m transect lengths (following Pollard, Hooper & Moore 1974) whereas this study used 100m lengths. However, my criterea was to sample the greatest possible range of variation in the hedgerows, whereas Bailey used randomly selected sites. Species rich sites were thus chosen preferentially to the "common" hawthorn hedges (94% of hedges, Bailey 1979).

A similar picture concerning the width and height of the hedge sample emerges when comparisons with Bailey's work are made. He found that 60% of the randomly selected hedges were below 1.5m, 25% 1.5-2.1m, and 15% over 2.1m. The frequencies of these hedge heights in this study are 14%, 26% and 60% (Fig. 6.). This difference is again due to selection of "prime" hedges in this study.

The sites used in this study are not a typical group of hedges from County Durham, they are bigger and more diverse than random samples. Despite inclusion of as much variation as possible, they are still relatively similar in some respects, for example the dominance of hawthorn in the shrub species composition.

Helliwell (1975), using coefficients of variation, found four parameters varied the most in Shropshire roadside hedges. These were, listed in order of decreasing importance:

1. Number of trees per length of hedge.

2. Number of shrub species in the hedgerow.

3. Density of woods in the surrounding square mile.

4. Distance of hedge from nearest wood.

This study shows similar types of variation in the hedge parameters. The first two axes of an ordination (DCA) of the hedge descriptive parameters, the axes of maximum variation in the samples, are explained respectively by the number of trees in the hedge and the area of woodland near to the hedge, these two parameters being the first and third most important parameters in Helliwell's study. The number of shrub species in the hedge, Helliwell's second most variable parameter, has been shown to be similar in the transects selected in this study, with nearly 60% of the hedge sites having 4,5 or 6 species of shrub. The 50 selected hedges represent more of the variation in County Durham than if the sites were chosen randomly. The main areas of variation are similar to those of Shropshire hedges (Heliwell 1979), except that the shrub species richness is less variable.

4.2 Different requirements for different species

It is apparent from this work that different species of bird are related to different aspects of the environment. For example, the Whitethroat is associated with the amount of woodland close to the hedge, the Blue tit to the number of trees in the hedge while the Chaffinch seems to show little preference for the variables measured in this study. The amount of hedge *per* area, as used by previous workers (Moore 1974, Murton & Westwood 1974, Wyllie 1976, Morgan & O'Conner 1980, O'Conner & Shrubb 1980) would thus not be an optimal predictor of the density of different species of birds. The subtler attributes of the hedge, rather than just the length, would need to be considered.

4.3 Similar requirements for the whole community

Four out of the nine common species in this study were significantly related to the total density of the bird community . This means that as the density of birds increases so does the density of these four species of bird. Thus, these species must all be increasing in a similar manner as the hedge becomes "better" for birds. The other species were related to a different aspect of the environment and thus do not follow the community density. For example, the density of the whitethroat is strongly related to the amount of woodland within 200m of the hedge. Thus,there would appear to be a hedge community that increases as the hedge becomes generally "better", while other species of bird need specific requirements to be met before they inhabit the hedge.

4.4 What makes a good hedge for birds?

A "good" hedge for birds, can be described as a hedge that has a high density of birds. If this is the case, then this study suggests that good hedges would be those with trees within their length, with large height and width and nearby woodland. Williamson (1971) described "good" hedges as those that were mature as opposed to low cut hedges. Osborne (1984) found that large hedges with trees and nearby scrub had the highest density birds.

The addition of trees to the hedge increases the Foliage Height Diversity of the area, and thus following the model of MacArthur & MacArthur (1961) the species diversity of birds would increase. This study shows that an increase in diversity in the bird community would be coupled with an increase in density, as diversity and density are positively related ($r=0.88$. $n=50$, in this study).

An increase in the size of the hedgerow would lead to an increase in the potential for foraging in the hedge. The greater the amount of woodland in the nearby area (ie. the territory), the "greater the opportunity hedgerow birds may have to commute to richer food supplies" (O'Connor & Shrubb 1986).

This approach, however may be somewhat simplistic, it assumes that the local density of a species is positively correlated to habitat quality. van Horne (1983) proposes that this relationship may not hold if:

1. Habitat use during Winter is the critical factor determining density of the species.
2. There is multi-annual variability in the variability of local population densities.
3. Social interactions prevent sub-dominant individuals entering the area.

O'Connor (1981) suggests that density is a good measure of habitat quality in years of low density, but poor in high density years. He analyses data from 1961-1980 (O'Connor 1986) on the habitat use by the mistle thrush (*Turdus visivorus*) in Britain. A decrease in the population to approximately one quarter of their population was experienced after the severe Winter of 1962-63. The recovery of the bird species followed aspects of the habitat hierachy model of Brown 1969 (O'Connor & Fuller 1985) (see also the model of Fretwell & Lucas 1970). In Brown's model, early in the population recovery, following a dramatic decline, new types of habitat are colonised by the expanding population. However as the population increases further, established breeding areas are more densely utilised. A hierachy of preferred habitats is thus apparent, form "core" breeding areas utilised in times of low population to low quality habitats utilised only when the prime habitat areas have a high density of birds.

Any single census that was carried out early in the recovery would tend to suggest that the thrush was limited to a few habitat types ie. relatively specialist. Only long term data would show this is not the case, and that the habitats used are dependant on overall density of the species (O'Connor 1986).

Evidence for habitat hierachies also come from Kluijver & Tinbergen (1953) with titmice in woodland, and Glas (1960) with chaffinches in different types of woodland. Osborne (1980) found the Chiffchaff (*Phylloscopus collybita*) utilised hedges up to 1km away from copses when the population was high. Osborne (1984) found similar habitat expansion in wrens, however expansion caused no change in abundance across habitats. Batten & Williamson (1976) show that the "Buffer hypothesis" (Brown 1969) is compatible with Common Bird Census data.

In this study, a census was repeated across different types of hedge types, but was not repeated across years. However, from predictions of the partly verified Fretwell & Lucas (1970) model, it could be suggested that a hierachy exists among hedge types.

This habitat hierachy concept can be considered on two scales:

1. Intra-habitat.
2. Inter-habitat.

In both cases it is argued that if such hierachies exist, the implications of them do not invalidate this study.

1. Intra-habitat hierachy; because the bird is present in the hedge, it would tend to be found in the areas where the habitat is most suitable for it. Even at low densities, the bird species would still tend to be related to the aspects of the micro-environment that it responds to (Anderson 1981). Thus, the major variables of the hedge that it is associated with would still be related to its density. Loss in the clarity of the habitat relations of the bird would come from the hedge character of the low hierachy, sub-optimal sites which it might not be present in. Intra habitat discrimination has been shown for wrens in hedges (Osborne 1984).

2. Inter-habitat hierachy; for the wren, at low population densities the bird inhabits woodland. Only when the population builds up to a certain level do some of the birds leave the wood and move to hedgerows (Williamson 1969, Osborne 1982). Hedges, for the wren are thus all less preferred habitats. This situation is probably common for most song birds found in the hedge, most of whom are primarily woodland species (Pollard *et al* 1974). Hedges are thus a sub-optimal habitat for most species. The presence of these species in the hedge would suggest that the populations are in the "filling in" stage rather than the

colonising stage of the Fretwell-Lucas model. Thus, the birds would tend to be finely related to those habitat variables that are important to them, even those of lesser importance. Thus, due to the presence of bird species in sub-optimal habitats (hedges), the concern over a poor relationship between density and habitat quality (suggested by van Horne 1983) is unsupported.

4.5 The importance of the hedge microstructure to the bird community

Not all hegdes are equally valuable to birds (O'Connor 1985). Certain aspects of the hedge microstructure (Anderson 1981) make the hedge more desirable to live in for certain species e.g. trees (O'Connor 1985), three dimensional diversity (Arnold 1983) and shrub species composition (Pollard *et al* 1974). Osborne (1982, 1983) suggests that the ornithologically best hedges are those with a large basal area and many tree species including some dead timber. Basal area was calculated by Osborne by multiplying the average width with the length of the hedge.

This study does not use area as a descriptor variable because the length of the transect was constant over all the censuses (100m). All previous studies of hedge birds have used an unstandardised hedge length as the census length. As transect length is constant, and the hedge was selected to be homogeneous along its short length, the major variable noted by Osborne is controlled. Thus, the variables describing the microstructure of the hedge become the sole variables used to describe aspects of the bird community.

In this study, the major axis of variation in the hedges was trees, the primary axis in the variation of birds was trees. Trees were thus considered to be the major variable in the hedges that the birds were associated with. Thus a Linear Discriminant Analysis (LDA) was carried out between hedges with 3 or more trees in their 100m transect length and those transects without trees (Fig. 16).

A measure of the success of an LDA is the classification successs (Rice *et al* 1983). In this case the success of classification between hedges with/without trees was 83%. Although the two *a priori* groups were not significanlty different (P<0.32), they were different enough for an LDA to be successfull. Most species had positive scores for their standadised lambda, this means that they tended to be found in hedges of group one i.e. hedges with 3 or more trees. Robin, Chaffinch and Blue tit, the three most discriminating bird species with positive lambda scores, accounted for over 75% of the LDA discriminating power. Birds species that discriminated for hedges without trees were Whitethroat, Dunnock and Linnet. The predominant discriminatory power comes from those species that are found soley in hedges with trees (95%), rather than those species that are found only in hedges without trees (15%).

If a hedge was planted with trees the bird community would tend to move, over time, to the more positive end of the discriminant axis (Fig. 16.). This would entail the addition of species such as Robin, Chaffinch and Blue tit, at the expense somewhat of the Whitethroat and the Dunnock. The presence of trees in a hedge increases the density of birds in the hedge, however this increase in density is produced predominantly by the addition of species (those with strong positve lambda scores) rather than a replacement of the species with more tree liking species (little discrimination by those species with negative scores). Therefore, the addition of trees to a hedge would tend to increase the mean density of birds and the diversity of birds by the addition of species.

It has been shown that the density of the Whitethroat, Chaffinch, Yellowhammer, Blue tit and Robin are not related to the total density of birds in the hedge. However, the density of the Dunnock, Willow warbler, Great tit and Blackbird, the "community" birds are significantly related to the total density of birds (Fig. 12.). The "community" birds are the species that tend to be found in hedges without trees, the addition of trees would lead to an increase in their density. The other species are present in hedges without trees and change little with the addition of trees, thus they would not be related to the total density of birds.

These two analytic methods, LDA and regression with the total density of birds suggest there are two general types of common species in hedgerows:

1. The "community" species that increase in density with the community, and tend to be present at higher densities when trees are present in the hedge.

2. The species that are related to certain specific aspects of the hedge characteristics and do not increase with an increase in the total density of birds eg. the Whitethroat that is found predominantly be found in hedges with no trees but with nearby wooodland; the Blue tit that is found only in hegdes with trees.

Although the density of the Whitethroat and the Dunnock are not associated with trees in the hedge, they are associated with the area of surrounding hedgerow. They both have the variable 200m (area of woodland within 200m) of the hedge selected first in a Stepwise Multiple Regression (with both linear and polynomial variables). They are thus correlated to the amount of trees, but in the surrounding habitat not within the hedge. However, Bishton (1986) from an intensive study of the foraging behaviour of the Dunnock, notes that "hedgerows are the most important feeding habitat". The relevance and importance of the nearby woodland as a resource for the Dunnock (this study) is not apparent as most foraging is carried out within the hedge (Bishton 1986). Further research is needed to elucidate this relationship.

The Yellowhammer, another common species of bird not related to the total bird density, has been shown to use woodland as an overflow habitat when agricultural densities become too high (O'Connor 1980), this is opposite to most hedgerow bird species. Morgan & O'Connor (1980) found that length of hedgerow explained about 15% of the variation in the density of Yellowhammers from 65 farms from the Common Bird Census. Other landscape factors were related to the density of the Yellowhammer, however little of the variation in the Yelowhammer was explained. In this study, no factors were significantly related to the Yellowhammer. Mabye, because hedges within the farm are an optimal habitat (O'Connor 1980), all these sites are fully utilised wether they are "good" or "bad" hedges. In the sub-optimal habitat of the woodland, there is enough unused area for the yellowhammer to exhibit within habitat preferences.

4.6 The importance of hedges as a habitat for birds

This study has shown that hedges are a habitat utilised by a variety of species of bird. Hedges are however only one feature of the agricultural landscape. Hedges can be utilised by birds for a variety of reasons eg. breeding sites, foraging areas or for predator avoidance. From a sample of 57 common farmland species of bird, the abundance of 52% of the species was correlated to the local density of hedgerow (O'Conner & Fuller 1985). Many bird species are thus found in significant numbers in hedges.

Murton & Westwood (1974) write however, that, "hedgerows appear to be suboptimal habitats which have become a red herring so far as the real issues affecting the welfare of birds in Britain are concerned". Pollard, Hooper & Moore (1974) considered them to be unimportant nationally, and Westwood (1974) viewed hedges as insignificant. There appears to be an contradiction; how can hedges be "unimportant" when the abundance of over half the common agricultural bird species are related to the length of hedgerow?

The answer to this paradox lies in the scale that the author considers. Locally, hedges are an important resource for birds as many birds are found in the hedge (an average of 10-19 for 6 censuses in this study) or correlated within a single farm to the length of hedge e.g. Morgan & O'Connor (1980) for the Yellowhammer. However, hedges are nationally unimportant to birds as they are suboptimal habitats for most species (O'Connor 1984). They act as overflows from "core" areas such as woodlands (Pollard *et al* 1974), and thus the loss of hedgerow habitat would not threaten the existence of the species as it would still be present in the core areas (assuming that they were still intact).

The possibility for invasion from other areas has been shown. Edwards (1977) removed some bird species from hegdrows in Hampshire, and showed that reinvasion occured in some species (Blackbirds, Dunnock and Song thrush) but not in the Chaffinch. However, the density of the species of birds after 60 days was below the density prior to removal. These results can be used to support the idea of habitat hierachies (Fretwell-Lucas model), however the origin of the invading birds was not known.

Krebs (1981) has shown that the removal of Great tits in woods can lead to an influx from hedges. Hedges are thus important on a local scale to the bird species, nevertheless the national welfare of most species is not threatened by the removal of hedges as long as the core areas are left intact. The core areas maintain the population and provide a pool of individuals for invasion into new areas.

This study has shown that the microstructure of the hedge is important in determining aspects of the bird community. Some common species, that are related to the total density of birds, tend to be found in higher densities in hedges with trees, these species have been termed the "community" species. Other species are related to more specific aspects of the hedge eg. amount of woodland nearby, presence of trees, or are commonly found in all types of hedgerow and thus, exhibit little habitat preference.

The differing habitat requirements for different species means that the microstructure of the hedge is an important determinator of aspects of the bird community. The value of the hedges to birds should not be considered just in relation to the length of hedge per area, more subtle attributes must be considered such as number of trees in the hedge or area of nearby woodland. The bird community in different types of hedges is not the same, thus an appreciation of the character of the hedge is necessary before its value to the bird community can be assessed.

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