

Modelling the effects of forest fragmentation on certain species of forest-breeding birds

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Summary

The influence of forest fragmentation was assessed on the abundance of six forest-breeding bird species. The study area (2327 sq Km) was located in south-west France. The forest cover, extracted from a Landsat **MSS** scene, was first reduced to a grid of 5865 quadrats, each 650 by 650 m. Two values were attributed with each quadrat: Quadrat Forest Cover (QFC), expressed in percent; and a local measure of forest fragmentation – the Neighbouring Forest Cover (NFC) – expressed on a 0–1000 scale. The distribution of six forest-breeding species was sampled on 556 quadrats.

For each species, the local abundance appears to be more correlated with the fragmentation-oriented NFC value than with the local QFC value. For three species out of six (song thrush, robin, chaffinch) an incidence model, based on the Logistic regression, was built. A correct fit was obtained.

An incidence map of these species was then built up over the whole study area. Their regional status was then estimated, for a sampling cost of less than 10% of censusing all the area.

1. Introduction

Habitat fragmentation has become a problem of general concern. Formally the fragmentation concept encompasses two aspects:

- (1) reduction of the total area, and
- (2) scattering of residual formations in a mosaic

in which the remaining individual elements are disjointed.

Defined in such a way, the fragmentation concept appears to be scale-free: it addresses no particular scale because the phenomena can occur at all scales. Also the definition addresses no particular kind of habitat because the fragmentation can occur in most types of habitat.

The biological end-results of habitat fragmentation are now known through a lot of studies con-

cerning specific situations and/or taxas (*e.g.* Lynch and Whigham 1984; Lovejoy and Bierregaard 1986; Van Dorp and Opdam 1987). General reviews as well as theoretical investigations (Wilcove *et al.* 1986; Burgess and Sharpe 1981; Harris 1984; Verner *et al.* 1986) have allowed the extent and the biological importance of habitat fragmentation to be identified: 'Habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis' (Wilcox and Murphy 1985).

The mechanisms by which habitat fragmentation impoverishes the biological diversity have been lucidly summarized by Harris (1988). The author's concern is mostly related to forest fragmentation. The main effect of forest fragmentation is, as stated by Harris, the 'Faunal relaxation', that is the selec-

tive extinction of some species followed by a compensating rise in common species.

The extinction of 'sensible' taxa, induced by fragmentation could arise from several causes, frequently acting simultaneously.

The relation linking area with species richness has been known for a long time. The first studies, started in 1922 (Gleason 1922) were followed by numerous papers, out of which those of Preston (1962), MacArthur and Wilson (1967), Connor and MacCoy (1979) are of great importance.

The two concepts of 'Minimum Dynamic Area' and 'Area Sensitive Species' (Crowley 1978) enable one to understand how, under a critical area threshold, some species become extinct. Hamel *et al.* (1982) give an illustration of this effect in their study of the influence of diminishing forest areas on the selective extinction of Passerine birds in the Southeastern United States.

The relatively large body of data available on the effects of forest fragmentation is now taken into account by wildlife planners and managers. One of the main goals of biological conservation is to maintain the identity and the integrity of some biota to guarantee the presence of some communities. Because some species are sensitive to the area of the biotope in which they live, special attention has to be given to the overall architectural design of the habitat that is to the landscape itself.

To make this task easier, quantitative models of species must be available. In general, however, these models do not exist for a large number of species, biotopes and scales (Verner *et al.* 1986).

The present paper aims to model the response of certain species of breeding birds to forest fragmentation.

Firstly, forest habitats can easily be characterised and described in quantitative terms. We will use, in this study, a forest model obtained from processing a Landsat MSS scene. Secondly, the local abundance of forest-breeding passerine birds can easily be measured. The species are conspicuous and sampling strategies for the breeding avifauna are well defined.

So the present study was possible since it was restricted to species that are very dependant on forest cover.

The hypothesis under test is that the fragmentation of the forest cover, above all, determines the local abundance of forest-breeding species. For this, we must:

- (1) build a forest-model of the study area in numeric form;
- (2) define a local measurement of forest fragmentation;
- (3) check that the species under study react better to this measurement than to other parameters.

In the case where (1) to (3) are accepted, it becomes possible to:

- (4) modelise the local abundance of the species according to the fragmentation measurement;
- (5) spatialise the model by extending the results to the whole study area;
- (6) map the results.

2. Study area

2.1. Location

The study area was located in the North-West of the city of Toulouse (France). It was rectangular in shape, measuring 53.5 Km by 43.5 Km, giving a total area of 2327 Km². The location was chosen for three main reasons:

1. its proximity to Toulouse;
2. the availability of a large body of ornithological data;
3. the diversity of forest types and their suitability to the aims of the study.

The forest coverage of this area is only 4%. There are three distinct features (Fig. 1a):

1. large forests (area larger than 1000 Ha), mainly located in the north and the south of the map. The principal trees are oaks (*Quercus pedunculata*), in association with the hornbeam (*Carpinus betulus*) and the ash tree (*Fraxinus excelsior*). Several conifers, introduced for commercial forestry grow alongside the oaks.
2. the riparian forest along the Garonne river. This linear tract belongs, in its natural state, to the

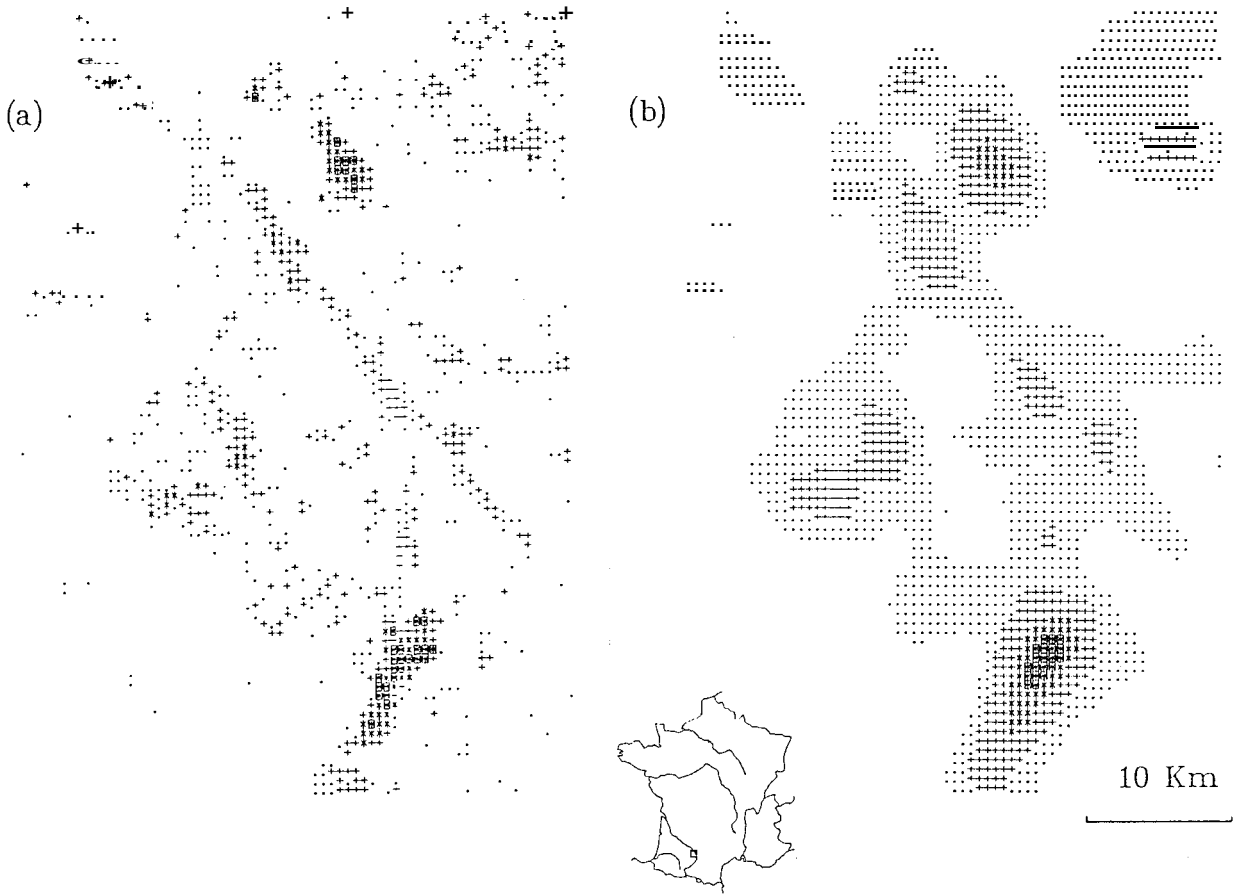


Fig. 1. (a) Forest cover of the study area (2327 km²). The data are expressed as percent of forest cover on a 85 x 69 grid (QFC in the text). Each grid element is 650 m wide. The characters used to print the map correspond to the classes: 0–5%, 5–15%, 15–50%, 50–75%, 75–100%. (b) NFC characteristics on the same area. Values range from 0 to 1000. The characters used to print the map correspond to the classes: 0–50, 50–150, 150–500, 500–750, 750–1000.

Alnus series. The native forest is often replaced by planted poplars.

3. a mosaic of woodlots of largely differing areas, scattered over the whole region. In some places, the mosaic becomes denser. As in the larger forests, the oak *Quercus pedunculata* dominates.

The two dominant features of the study area are thus the poor forest cover and its fragmentation.

2.2. Quantitative analysis of the forest cover

The quantitative data were get after processing a Landsat MSS scene of the area (# 214–029), dated

July 30th 1981. The study area was first extracted from the whole scene. The resulting size was 509,080 pixels. The subsequent analysis was aimed at extracting the forest component alone. The classic method of crossing Channel 5 (radiometric interval: 29 to 36) with Channel 7 (radiometric interval: 28 to 110) was used (Gonzales 1988, Barrett and Curtis 1976).

As soon as the features of a given pixel are located inside these two intervals, it is classified in the 'forest' class. Thus the final pictures, after completing the processing, is binary-coded. It differentiates between forest cover and all the other types of ground cover (water, arable land, orchards, urban areas etc.).

The Landsat MSS pixel is too small an element

for locating the sampling design of the avifauna. Thus the pixels were aggregated, giving a final grid of 85 x 65 square quadrats, 650 m wide.

For each quadrat the Quadrat Forest Cover (QFC), expressed in percent, has been computed

$$\text{QFC} = \frac{\text{Number of 'forest' pixels in the quadrats}}{\text{Total number of pixels in the quadrat}} \times 100$$

The resulting values ranged between 0% and 94.32%. The study area encompassed 5865 quadrats. (Fig. 1a).

A 650 m grid-size now allows the sampling points to be located with a negligible error.

2.3. Sampling the avifauna

The forest-breeding avifauna were sampled during the spring of 1985 and of 1987 by the EEP method (Blonde1 1975). Briefly it consists of recording, on a presence/absence scale, all the species, both seen or heard, from a point, during a 20 mn session.

Only the forests and the copses of the study area were sampled. Open fields were discarded.

The sampling scheme was stratified according to area classes, and the distribution of point-counts is given in the following table

Area (Ha)	0.3-1.5	1.6-4.9	5-12	25-35	50-75	120-450	1000	2000
Number of point counts	50	50	70	70	60	76	60	120

A total of 556 point-counts allowed us to record 72 species. Only six of them are considered in this paper, namely those most dependent on woodland:

1. the robin (*Erithacus rubecula*),
2. the song thrush (*Turdus philomelos*),
3. the firecrest (*Regulus ignicapillus*),
4. the chaffinch (*Fringilla coelebs*).

Together with these four species, we also considered:

5. the tree pipit (*Anthus trivialis*) and
6. the nightingale (*Luscinia megarhynchos*)

as they are only marginally linked to forests, thus giving examples of non-woodland species. We ex-

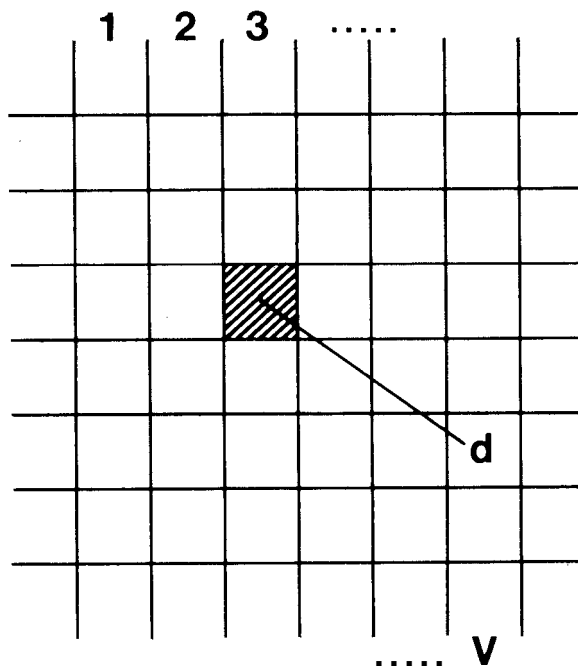


Fig. 2. The NFC is computed over a domain V on the grid. Each quadrat, situated at a distance d has a QFC value (in %) P_i .

pect these two species to react differently to forest fragmentation from the first four.

3. An index of forest fragmentation

The QFC of a given quadrat says nothing about forest fragmentation, it gives only a local measurement of cover. Thus each quadrat had to be completed by an index not related to its own characteristics but with those of the neighbouring quadrats.

Several alternative measurements were considered (Taylor 1975). We will use here a formula based on the exponential relationship (Fig. 2).

The number given using this formula on a quadrat will be called the Neighbourhood Forest Cover (NFC).

The NFC, measured over a neighbourhood V , is given by:

$$\text{NFC} = \sum_{i=1}^v P_i e^{-ad_i}$$

where P_i stands for the QFC of a quadrat situated at a distance d_i .

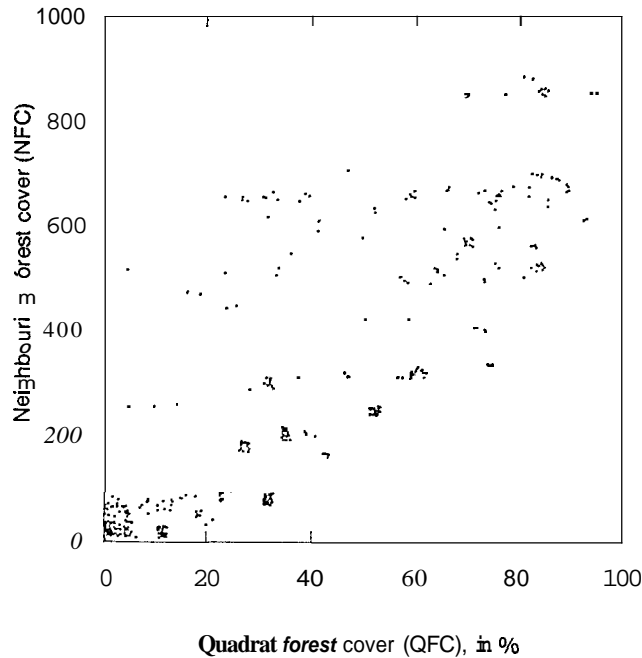


Fig. 3. QFC and NFC values of the 556 sample points. The correlation $r = 0.797$ is near $r = 0.759$ for the whole study area.

The parameter a measures the decreasing influence of the forest cover with distance. Several values of a were tried; they gave essentially the same information since the results were always strongly correlated ($r > 0.98$). The value of $a = 0.563$ is used throughout this paper. It gives a weight of 0.5 to a point situated 800 m away. The size of V , the domain of computation, was chosen such that the contributing effects of the quadrats situated on the border became negligible (see also appendix).

The extreme values of NFC on the study area were respectively 2.7 and 891 (Fig. 1b).

The concept of forest fragmentation becomes evident when the NFC and QFC maps are superimposed. The correlation between the two measurements is $r = 0.759$ ($N = 5865$), indicating that they share only $r^2 \times 100 = 57.6\%$ of common variance.

Forest fragmentation, in fact, tends to lower the value of r because it increases the situation where NFC and QFC tend to take opposite values. This will be the case for isolated woodlots (high value of NFC, low value of QFC) and large clearings (low value of QFC and high value of NFC).

Table 1. Species repartition in 556 sampled quadrats. The Kruskal-Wallis test assesses the difference in QFC and NFC values between the quadrats where the species are present or not. The critical value of the test, for 1 D.F. and $p = 0.05$ is 3.84. For the QFC values the difference is not significant in two cases out of six. Differences are always more conspicuous on NFC values.

Species	Number of quadrats		Kruskal-Wallis χ^2 (1DF)	
	Present	Not recorded	QFC	NFC
Song thrush	306	250	88.28	99.28
Chaffinch	343	213	72.58	108.23
Firecrest	68	488	2.89 (NS)	11.35
Robin	241	315	13.42	29.45
Nightingale	308	248	34.41	50.50
Tree pipit	23	533	0.088 (NS)	4.71

As far as possible, the sampling scheme was stratified so as to reflect the correlation between QFC and NFC. The observed value for r (0.797, $N = 556$) is very near that for the whole study area ($r = 0.759$, $N = 5865$) (Fig. 3).

4. Forest dependency of the species

The dependency of the species on the quadrat characteristics (QFC and NFC) was assessed by a non parametric ANOVA. For each of the six species under study, the Kruskal-Wallis test was used to compare the QFC and the NFC values between the quadrats in which the species was present with those where it was not recorded. (Table 1).

In all cases the NFC gives the most conspicuous contrasts. Even if the species are mainly to be found in the quadrats with a high QFC value (with the exception of the tree pipit, a bird mostly found in clearings), they are more regularly and more clearly found in quadrats with a high NFC value.

The Firecrest and the Tree pipit are special cases. As can be seen in Table 1, the QFC values do not significantly differ between the quadrats where the species was found and those where they were not recorded. However the difference is clearly marked on the NFC values.

For the firecrest, this result appears to be caused by a slight difference in the mean value of QFC be-

Table 2. The tree pipit is found in clearings. In the quadrats where it is recorded, the mean value of QFC tends to lower and the NFC tends to rise.

Tree pipit	Mean values of	
	QFC	NFC
Present	37.60	395.41
Not recorded	39.08	288.09

tween the two categories of quadrats (not recorded: 38.2%, recorded: 44.7%). The relative difference is only $(144.7 - 38.2)/38.2 \times 100 = 17\%$. The NFC values, at the same time, increase by 41%, a highly significant value.

For the tree pipit, this is due to biological factors. This bird is to be found in clearings, *i.e.* in areas with low QFC values but with high NFC values, due to the proximity of surrounding forests. The available data confirm this fact (Table 2). Out of the six species under study, the tree pipit is the only one where the QFC values tend to lower in the quadrats where it is recorded.

5. Incidence surfaces

As shown in Table 1 the presence of the species studied is closely linked to the QFC and NFC values of the quadrats. As stated in the previous paragraph the correlation between these two values is $r = 0.797$. Their common variance is only $r^2 \times 100 = 63.5\%$. Thus both characteristics of the quadrat, QFC and NFC contribute specific information and both have to be taken into account to compute species incidence.

The incidence function (Diamond 1975) formalizes this kind of relationship. For a given characteristic of the biotope, this function gives the probability of finding the species. In our case, this probability has to be linked not to a single characteristic of the habitat but rather to two: the QFC and the NFC. This function of two variables then becomes a surface: the Incidence Surface.

More precisely, denoting:

- I the incidence, *i.e.* the probability of finding the species in the quadrat (under the hypothesis of the same sampling effort),

- p the NFC value of the quadrat,
 - q the QFC value of the quadrat,
- the incidence surface is a function $I(p,q)$, where $0 \leq I(p,q) \leq 1$.

The data are divided between two categories only:

- $I(p,q) = 0$ when the species is not recorded,
- $I(p,q) = 1$ when the species is recorded.

Adjusting a continuous function to this kind of data can be achieved in several ways. We will use the logistic function for its simplicity, usefulness and ease of implementation (Berkson 1953; Grizzle et al. 1969; Tardiff 1976).

So $I(p,q)$ in logistic form can be written:

$$I(p,q) = \frac{e^{aq+bp+c}}{1 + e^{aq+bp+c}} \quad (1)$$

The coefficients a , b and c are estimated by a maximum likelihood method. Moreover their significance can be assessed.

Discarding the constant term c , it will prove useful to test the null hypothesis of 'no effect' for both the QFC ($a=0$) and the NFC ($b=0$). This test can be achieved by computing a maximum likelihood ratio (Tardiff 1976).

The results are shown in Table 3 for the six species. The predominant influence of NFC, already noticed in Table 1 is confirmed.

The b coefficients, related to NFC in eq. (1), were always significantly different from 0 ($p < 0.001$). The a coefficients, related to QFC in eq. (1), do not differ significantly from 0 for three species: the chaffinch, the firecrest, the nightingale. So the incidence can be written:

$$I(p) = \frac{e^{bp+c}}{1 + e^{bp+c}}$$

(We will nevertheless take the QFC parameter into account in computing incidence maps for the chaffinch, even if its contribution is weak. See later).

Knowing the a , b and c coefficients for a given species, the incidence surface is easily computed. Moreover the graph of this surface allows the differential influence of QFC and NFC to be per-

Table 3. Coefficients of the logistic regression on the data for six species. The significance of each value is tested against 0. Three values out of six do not differ significantly from zero for QFC values. For NFC values all coefficients are highly different from zero.

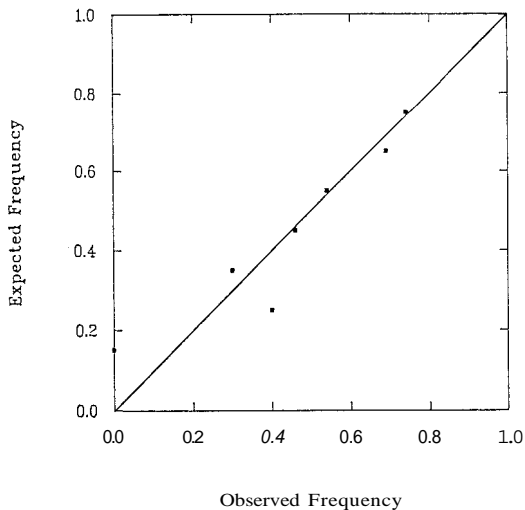
Species	QFC		NFC	
	a coef.	prob(a=0)	b coef.	Prob(b=0)
Song thrush	.0141	.007	.0025	.0001
Chaffinch	.0026	.64 (NS)	.0045	.0000
Firecrest	-.0110	.13 (NS)	.0025	.0010
Robin	-.0124	.02	.0034	.0000
Nightingale	-.0063	.20 (NS)	-.0019	.0008
Tree pipit	-.0340	.005	.0044	.0005

ceived on the probability of finding the species in a given quadrat, given the two values.

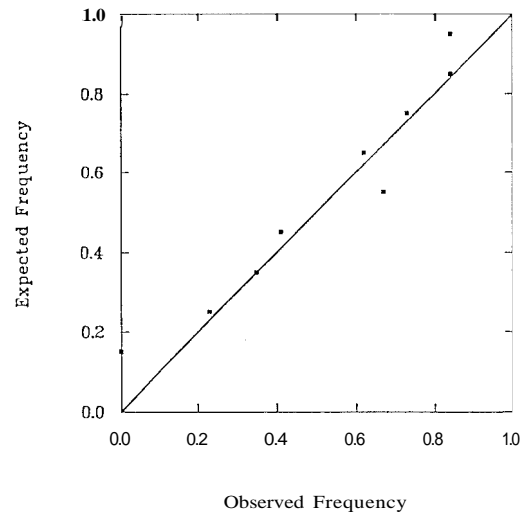
The fit of the incidence surface to the data has to be verified before continuing. In only three cases out of six the fit appears to be fairly good (Fig. 4): the song thrush, the chaffinch and the robin. Thus Fig. 5 depicts the incidence surface for those species only. The extreme values used in the computations are:

- QFC : 0% to 100%.
- NFC: 0 to 1000.

(c) Robin



(a) Song Thrush



(b) Chaffinch

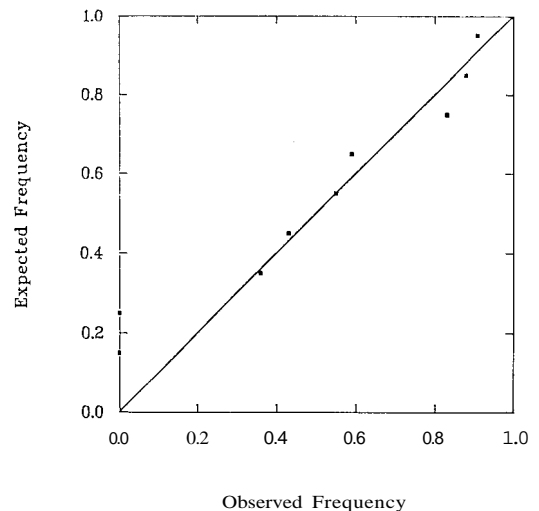


Fig. 4. Fitting the logistic incidence surface $l(p,q)$ to the data for three species: (a) song thrush, (b) chaffinch, (c) robin. The diagonal line would represent a perfect fit.

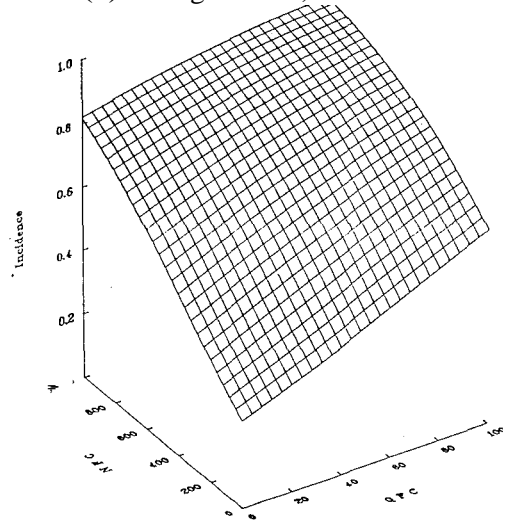
The maximum height of these surfaces, for our data and on the study area, correspond to NFC and QFC values of quadrats where the best probability of finding the birds occurs.

6. Incidence maps of species

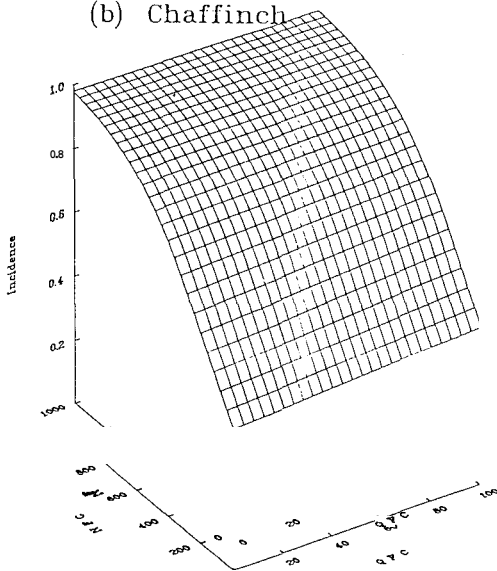
The incidence surface of a species (or the incidence function for a single variable) formalizes the relationship between the probability of finding the species given the forest characteristics of the quadrat: NFC and QFC.

As we know the two characteristics for each quadrat, calculating the probabilities over the whole study area is an easy task. The result can be expressed as a map: the Incidence Map. The isovalue lines in these maps define regions where –

(a) Song Thrush,



(b) Chaffinch



(c) Robin

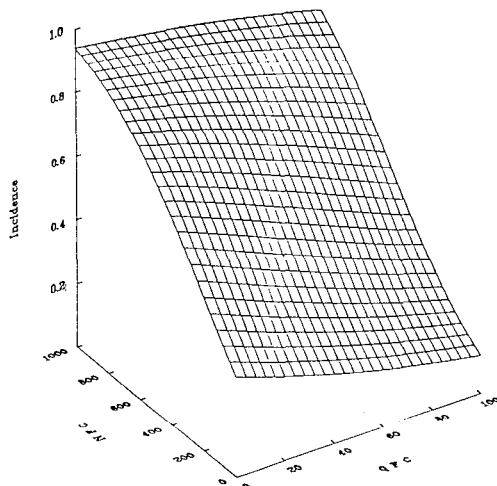


Fig. 5. Incidence surface for three species (a) song thrush, (b) chaffinch, (c) robin, given the two characteristics of a quadrat: QFC and NFC.

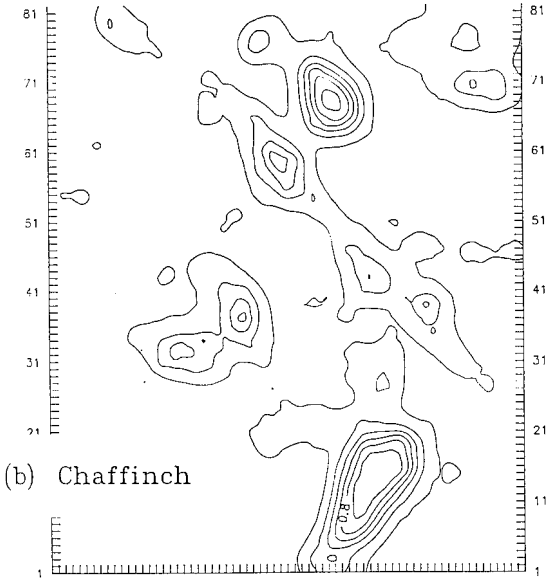
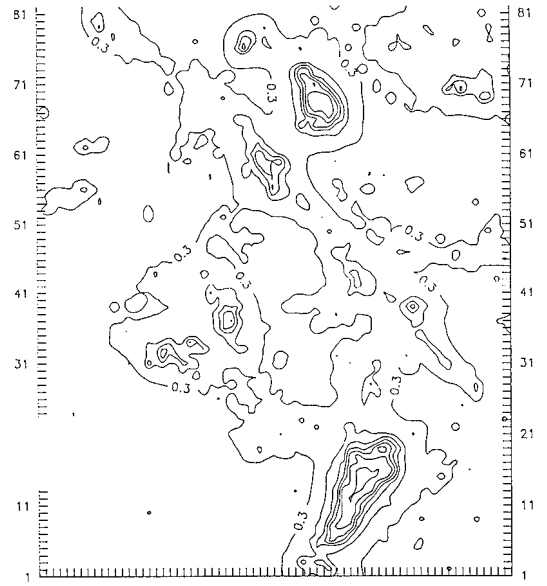
at least theoretically – there is an equal probability of finding the species.

Three maps are shown in Fig. 6, for the song thrush, the robin and the chaffinch. As previously seen, since the logistic model fits the data quite well and the sampling scheme appears to be correctly stratified, the resulting maps can be considered as being relatively accurate. The contours of equal probability values in Fig. 6 span the interval 0.3 to 1 in steps of 0.1.

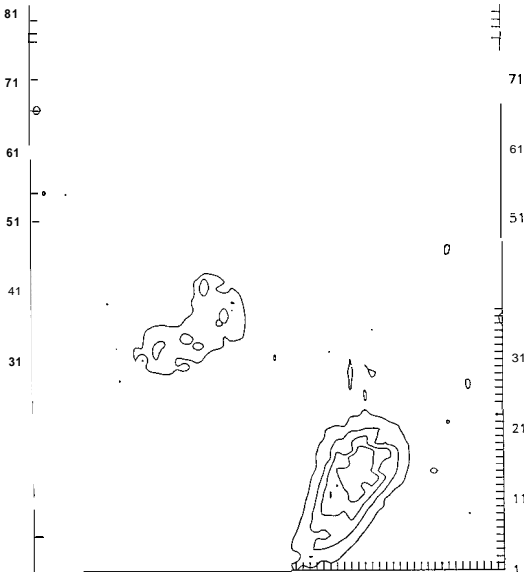
For the song thrush, between the two large forests, located in the north and the south of the map, lie a pair of branches in which the species can easily be found. The eastern part of the branch follows the Garonne river and consists largely of the riparian forest, on the other side the western branch coincides with a mosaic of forest patches with high NFC values. The incidence map correlates well with the NFC map (Fig. 1b).

For the chaffinch, three zones are conspicuous. On the western side of the map, an isolated region corresponding to high NFC values, which consists of a mosaic of forest patches. In the north and the south, two areas corresponding to the large forests. The importance of the riparian forest, along the river, can also be seen.

For the robin, the areas with high incidence



(b) Chaffinch



1) If the results are correct in three cases, this is probably because among numerous factors acting on the local abundance of birds, the QFC and the NFC are the main ones. A good fit to the data can be achieved if the sampling scheme is correctly stratified. It seems to be the case in this study since about the same value on the sampling points and on

The incidence maps give a good indication of the status of the species, over an extended area, for a

points would be necessary to improve their useful-

2) Failing to model the incidence for three species out of the six has numerous causes. We can consider three of them.

■ The map on which all the resulting computations are made is divided into two classes: forest and 'non-forest'. The latter category is only negatively defined and thus built up from several classes: urban areas, open water, arable land, orchards etc. Therefore non forest species are excluded from our methodology. A possible way to improve the results could be to take more categories of land use into account.

■ Fitting the logistic equation was made on first-order terms only. Interaction terms do not belong to the model. At least theoretically, taking second-order terms and/or interactions into account would be possible, but we did not use this means of analysis. The reason is that by artificially extending the complexity of the model we would also artificially increase the fit to the data but still neglect the lack of other elements of importance for the birds which do not figure in the forest maps.

■ The temporal dimension and the evolution of bird populations appear nowhere in our study. They are as yet too poorly known to be quantified. But we do know that they exist. The 556 quadrats were sampled over two years but the results gathered in a single body of data. Thus a given species could be recorded in a quadrat a given year but may be absent the next year. Therefore the incidence maps only sketch a 'mean' situation. For species in which population levels are subject to rapid changes, this approach may be too coarse and thus open to errors.

There is today an increasing concern in modelling wildlife/habitat relationships (Verner *et al.* 1986). Such models are of operational value only when they are able to express their results on maps, whatever the scale, and when they offer the opportunity to simulate the effects of different management practices on wildlife. The results we present here for forested zones only, suggest that building spatial models is possible. Furthermore, the models obtained could easily be used in simulation studies. We expect that the use of remotely-sensed data and Geographical Information Systems (GIS) will extend the opportunities where such an approach would prove useful.

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Appendix

Some comments on the formula used to compute NFC.

1. The reason to use an exponential factor of the distance to neighbouring grid-cells is to avoid problems when $d=0$, *i.e.*, when the cell itself is taken into account.

In this case $\exp(-ad) - \exp(0) - 1$.

2. The determination of $a=0.563$ for a Half Influence distance of 800 m is achieved in the following way.

Since the width of a cell is 650 m, $800 \text{ m} = 1.231 \text{ cell width}$. Thus a is such that $\exp(-1.231 a) = 0.5$.

Taking logs on both sides leads to $-1.231 a = -0.6931$, thus $a = 0.563$.

3. The domain V , expressed in cell widths is easily determined, knowing a . For a grid cell with 100% QFC, the contribution C to the NFC along varying distances d is simply:

$$C = \exp(-0.563 d) \times 100.$$

$$\text{Thus for } d=5 \quad C=6,$$

$$d=8 \quad C=1,$$

$$d=10 \quad C=0.36.$$

When reaching the borders of the area, the computations become less and less precise. This is because the domain V is only partially defined and thus partially used. The better compensation for this side effect is not to compute artificial corrections, but to define the area in such a way that the most interesting forests lie well within it and not on the borders.