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1 IMPACT OF CLIMATIC VARIATIONS ON BIRD SPECIES

2 OCCUPANCY RATE IN A SOUTHERN EUROPEAN FOREST

3

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5

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1 Abstract

2 Species that are affected by climatic variations can undergo modification in range and/or
3 abundance. Knowing how individuals or species occupy their habitat is essential to
4 understand how species use their environment, and detecting variations that might affect this
5 use can be determinant in species management.

6 Hierarchical modeling is regularly used to assess for occupancy rate (i.e. proportion of
7 patches occupied in a region), particularly when it is required to consider detectability-related
8 issues. The present study is the first application of the conditional model presented in Dupuis
9 *et al.* (2010), and which is applied in the case of a heterogeneous area that might be divided
10 into homogeneous sub-areas. Their approach is used to study the impact of three consecutive
11 particularly cold winters on a selected set of bird species in a forest of southern France in the
12 context of available prior information on birds detectability.

13 We examined a limited range of factors that might influence the response of some bird
14 species to climatic. We considered the case of sedentary, partially migrating and migrating
15 species. We also assessed if the biogeographical origins of the different species affect their
16 occupancy rates. Globally, changes in occupancy rates between 1985 and 1987 indicates for
17 the first time a continentalization of the regional forest fauna, reflected by the expansion of
18 Palearctic and Turkestanian-European faunistic type species, with depletion or extinction of
19 European, Turkestanian-Mediterranean and Mediterranean sedentary species. We have also
20 shown the importance of prior information.

21

22 **Keywords:** Climatic changes, detectability, hierarchical modeling, occupancy rate, prior
23 information.

24

25

1 Introduction

2 Two of direct effects of climate change that species will likely have to face are an increase
3 in mean temperature) (e.g. Malcom *et al.*, 2006) and an increased in the frequency of extreme
4 temperatures (e.g. Colombo *et al.*, 1999). Species' responses to these climatic changes may
5 include evolution or adaptation, modification in range and abundance, or extinction (Ackerly,
6 2003 ; Parmesan, 2006).

7 Most of the examples of rapid adaptation to climate change lie in evolution toward higher
8 frequencies of already existing heat-tolerant genotypes in the interiors of species' ranges
9 (Parmesan, 2006). While adaptation can occur after a significant amount of time, for punctual
10 variation of the climate, migration and extinction are more likely (Huntley, 1991 ; Davis &
11 Zabinski, 1992 ; Coope, 1994). Extinction or increased risk of extinction due to climatic
12 changes have been documented in a wide range of taxa such as amphibians (Pounds *et al.*,
13 1999, 2005), tropical corals (Hoegh-Guldberg 1999; Wilkinson 2000), mammals (e.g. Arctic
14 polar bears, Derocher ; 2005, Stirling *et al.* 1999) and birds (e.g. Antarctic Adélie Penguins,
15 Ainley *et al.*, 2003 ; Croxall *et al.*, 2002). In fact, if an unusual variation in temperature
16 occurs, such as a significantly colder winter, species that are not adapted to cold temperature
17 and that have not migrated might have to undergo extreme conditions and potentially go
18 locally extinct. Range shifts are expected to occur poleward and upward. Several species of
19 Lepidoptera (butterflies and moths) have undergone an expansion of northern boundaries
20 situated in Finland (Mikkola, 1997), Great Britain (Hill *et al.*, 2002), and across Europe
21 (Parmesan *et al.*, 1999). Some bird species have been shown to have a northern shift of their
22 range boundaries (Thomas & Lennon, 1999). Some species have even shown elevational
23 shifts in response to climate changes (e.g. lowland birds, Pounds *et al.*, 1999, 2005 ; alpine
24 flora, Grabherr *et al.*, 1994, Pauli *et al.*, 1996).

1 In this context, understanding how individuals or species occupy their habitat and use their
2 environment (Krebs, 1978) will be essential to predict population response to extreme
3 climatic conditions and take suitable management dispositions (Kendall, 2001; Williams *et al.*,
4 2002 ; Nichols, 2004 ; MacKenzie *et al.*, 2006). Site occupancy modeling has been
5 thoroughly developed during the last decade, leading to powerful methods to estimate site
6 occupancy, which in turn allows estimation of population parameters such as colonization and
7 extinction probabilities. These models have proven to be reliable for common ecological data
8 (i.e. detection-non detection), and when the area of interest is large (such as a country) or
9 relatively small (e.g. a forest), or when the considered area is divided in an important number
10 of quadrat (i.e. sub-unit of the global area that might be sampled) or not.

11 Site occupancy rate is one of the key variables for determining how species use their
12 environment. While density and abundance carry information on the population state,
13 occupancy rate describes how species use the spatial environment they live in. It is defined as
14 the proportion of patches occupied and is a state variable in various metapopulations models
15 (e.g., Levins, 1969, 1970 ; Lande, 1988 ; Hanski, 1997). Site occupancy rate by definition has
16 to be considered in a 'closed environment', i.e. with a finite number of locations (termed sites
17 or quadrats). While this has been well studied when there is a large number of sites,
18 improvements are still needed when the number of sites is small (MacKenzie *et al.*, 2006).

19 Estimating occupancy rate using hierarchical modeling allows accommodation of issues
20 related to detectability. We now can account for the fact that when a species is not detected it
21 could correspond to an effective absence or just a failure in detection. Modifications of the
22 original approach of MacKenzie *et al.* (2002) allowed for a more accurate estimation of
23 occupancy rate in the specific case of a small homogeneous area with a small total number of
24 quadrats (e.g. MacKenzie *et al.*, 2006) or when species are particularly hard to detect (Dupuis
25 *et al.*, 2010). This difficulty in detection can emerge from individual's characteristics (e.g.

1 cryptic abilities) or simply because a species has a low presence probability, which is typical
2 of endangered species.

3 Here, we apply the conditional model presented in Dupuis *et al.* (2010) to the case of a
4 heterogeneous area that can be divided into homogeneous sub-areas (e.g. edge and inner part
5 of a forest). One of the main characteristics of this model is that it uses a conditional approach
6 for estimating the quantity of interest (here, occupancy rate); conditioning bearing on the
7 presence of target species in the region of study. The unconditional approach (MacKenzie *et*
8 *al.*, 2006) does not presuppose that the target species is present in the whole region of interest.
9 Conditional approach has been proven to be a necessary approach in the case of undetected
10 species which are known to be present in the area from another source of information (such as
11 net capture) (Dupuis *et al.*, 2010). Moreover, we shall take advantage of that some prior
12 information on detectability is available, since it is expected that this significantly improves
13 the precision of estimates when the target species has been very few or not detected, and is
14 known to be easily detectable (Dupuis *et al.*, 2010). The data used in this study present
15 several such examples. Furthermore, in each instance where a species is not detected in our
16 dataset it is known from external sources that it was in fact present in the study area.

17 We focus on several factors that might influence the response of bird species to climatic
18 changes (here the succession of three significantly colder winters). First, occupancy rate in the
19 inner forest might be less affected by the decrease in temperature than in the edge of the forest
20 because more protection is available for individuals. Evolution of occupancy rates might be
21 crucially different between the external and the inner parts of a forest. For example, species
22 can have preferences into one or the other part, and if no distinction is made between these
23 regions, one could not see a modification of occupancy. Second, we compare sedentary,
24 partially migrating and migrating species. We expect migratory species occupancy rate to be
25 less impacted by cold winters than that of sedentary species, because they are not directly

1 affected by local low temperatures at reproduction sites. Specifically, we predict sedentary
2 species' occupancy rate to decrease. Third, we compare species with different bioclimatic
3 affiliations which illustrate tolerance of a species to cold. We predict that species with a more
4 continental bioclimatic affiliation will not experience a dramatic decrease in occupancy rate
5 compared to other species. Finally; in the discussion, each of the conclusions resulting from
6 this local application will be examined in the light of what happened at the continental scale.

7

8

9 Material & Methods

10 *Location* – We focus on data collected in May 1985 and May 1987 in order to estimate
11 occupancy rates of nesting bird species present in the Montech forest (located near Toulouse,
12 France), and the impact of 3 successive particularly cold winters. Montech forest has an area
13 of 900ha and is part of the French National Forest System (*Office National des Forêts*). While
14 this forest has a mixed management regime of mature and coppiced forest, it is now only
15 managed as a mature forest. The forest is dominated by oak species (*Quercus robur*, *Quercus*
16 *sessiliflora* and *Quercus pubescens*). The undergrowth is composed of hawthorns (*Crataegus*),
17 blackthorns (*Prunus spinosa*), brooms (*Fabaceae*), and heaths (*Erica*). Some Coast Douglas-
18 firs (*Pseudotsuga menziesii*) and Maritime Pines (*Pinus pinaster*) plots are present in the
19 south part of this forest. The study area is proximate to continental, Mediterranean, alpine and
20 Atlantic ecoprovince (fig.1).

21

22 Data are a part of a broad study of bird populations in the Midi-Pyrénées region of
23 southwest France. Data collection began in 1985 (Joachim *et al.*, 1997). Montech forest
24 underwent 3 colder-than-usual winters in 1985, 1986 and 1987. During these winters, mean
25 monthly temperatures dropped up to 5°C below the average monthly temperature of 14

1 previous years, and 3°C below the coldest temperatures during this reference period (Fig. 2).
2 These three winters correspond to a hinge period. In contrast, from 1965 to 1985, winters
3 were fairly mild. Empirical observations suggest that these mild temperatures led to a
4 colonization of Mediterranean and a retreat of continental bird species. The exceptional 1985-
5 1987 period contrasted strongly and that likely impacted the fauna potentially leading to a
6 strong re-continentalization. While species might easily overcome one colder than usual
7 winter, the succession of 3 cold winters on end can be expected to have consequences for bird
8 species.

9
10 *Data and species list* – We focus on to the estimation of occupancy rate and detection
11 probabilities of 10 bird species of the overall 47 detected species. The list of the species of
12 interest is denoted by \mathcal{L} . Here, the list of chosen bird species, liable to be present in the
13 forest of Montech, in spring 1985 and 1987 includes 10 species: whitethroat, chiffchaff,
14 nightingale (which are migratory species), Eurasian nuthatch, green wood pecker, short-toed
15 treecreeper (which are sedentary species), and finally song thrush, common blackbird,
16 European robin, mistle thrush (which are partial migrants). Partial migrant species are species
17 with overlapping reproductive and wintering areas. Migratory status and biogeographical
18 origins are presented in table 2. Moreover, for each species, prior information on detection
19 probability is available (tab. 3).

20
21 Montech forest, with a surface area of 900 hectares has been divided into A homogeneous
22 subregions of biological interest, here $A=2$ with the two sub-regions being the inner forest
23 ($a=1$) and the edge forest ($a=2$). A sampling is performed in each sub-region R_a . The sub-
24 region R_a is divided into J_a spatial units, here termed quadrats. They are also called sites in
25 the literature. A subset of T_a quadrats is sampled. Draw is usually performed at random so as

1 to have a sample representative of the whole region R_a . We assume that these quadrats are of
 2 equal area. Twenty-two quadrats are located in the inner forest ($J_1=22$), while 18 quadrats
 3 correspond to forest's edges ($J_2=18$). In 1985, all quadrats were sampled ($T_1=J_1=22$;
 4 $T_2=J_2=18$), while in 1987 only 14 quadrats were sampled in inner forest ($T_1=14$) and 6 in edge
 5 forest ($T_2=6$).

6 Information about the presence of nesting species was provided by acoustic recognition of
 7 singing males according to the following procedure. Listener spent a twenty minutes at each
 8 station, listening for birds. This time spent on each quadrat was divided into K equal sessions,
 9 here $K=4$, during which detection are recorded. The number of quadrats in region R_a in which
 10 species s has been detected is denoted by $V_s(a)$. Total number of sessions in region R_a during
 11 which species s has been detected is denoted by $W_s(a)$. These data are given in table 1. All
 12 records were made following the listening point method (EPS, Spitz 1974, EFP, Blondel,
 13 1975) over a 500-meters sided grid. Length of the side of a quadrat (that is 500 meters) has
 14 been chosen so that the listening range (a disk of 150-meter radius) is strictly included within
 15 the quadrat. Consequently, from a station performed in a given quadrat, the observer cannot
 16 hear songs of (males) conspecifics that would nest in adjacent quadrats; consequently, if the
 17 song of a male of a given species s is detected in the quadrat j , thus the species s is present in
 18 this quadrat. Further details of the protocol can be found in Decamps *et al.* (1987).

19 The dataset of observations is afterwards denoted by y ; therefore
 20 $y = \{y_s(a); s \in \mathcal{L}, a = 1, \dots, A\}$, where $y_s(a)$ denotes the observation related to species s in region
 21 R_a . A possible record of $y_s(a)$ for a region R_a could be $y_s(a)=4021003$. Here, $V_s(a)=4$,
 22 $W_s(a)=10$. Finally, the number of detection of species in the sampled quadrat j is denoted by
 23 y_{sj} .

24

25 Modeling

1 *Underlying processes and missing data structure* – To specify the missing data structure
 2 inherent in quadrat sampling data, we view the record y_s as the result of two processes: one is
 3 related to the presence-absence process (in quadrats), and the other is related to the detection
 4 process. Such a formalism also allows us to formulate rigorously the biological assumptions
 5 made and to introduce, in a natural way, the parameters of biological interest.

6 We denote by Z_{sj} the indicator of presence of species s in quadrat j ; therefore, $Z_{sj} = 1$ if
 7 species s is present in quadrat j , and 0 otherwise.

8 Conditioning on $Z_{sj}=1$, X_{sj} is the number of times that species s has been detected in
 9 quadrat j during the K sessions. It is clear that $X_{sj}=0$ and $Y_{sj}=0$ do not have the same
 10 meaning. The event $X_{sj} = 0$ means that the species s (present in quadrat j) has not been
 11 detect in it; while the event $Y_{sj} = 0$ resorts two distinct situations. Missing can occur in
 12 different circumstances. First, when a species s has not been detected in quadrat j (that is
 13 when $Y_{sj} = 0$), it is clear that Z_{sj} is missing; the event $Y_{sj} = 0$ covers in fact two exclusive
 14 situations: either species s is present in quadrat j but has not been detected, or it is not
 15 present in quadrat j (and cannot have been detected). Formally, one has the equivalence
 16 $(Y_{sj} = 0) \Leftrightarrow (Z_{sj} = 1 \text{ and } X_{sj} = 0) \text{ or } (Z_{sj} = 0)$. Conversely, when $1 \leq k \leq K$, one has
 17 $(Y_{sj} = k) \Leftrightarrow (Z_{sj} = 1 \text{ and } X_{sj} = k)$. Second, Z_{sj} is also missing, when quadrat j is not a part of
 18 the sampled quadrats.

19

20 *Notation* – Throughout the paper $p(\cdot)$ denotes a probability mass function. The local
 21 occupancy rate of species s in region R_a is denoted by γ_{sa} ; therefore, one has:

22
$$\gamma_{sa} = \frac{1}{J_a} \sum_{j \in R_a} Z_{sj}$$

Occupancy rate modeling for bird species undergoing climatic changes

1 We apply the conditional model of Dupuis *et al.* (2010) to each sub-region R_a for estimating
 2 γ_{sa} . Biological assumptions related to the occurrence of species in the J_a quadrats are
 3 supported by the values of Z_{sj} , and those related to detection in the T_a sampled quadrats by
 4 the values of X_{sj} .

5
 6 *Modeling detectability* – We assume that the probability of detecting species s in quadrat j
 7 does not depend on its detection in the other quadrats. Considering the experimental protocol,
 8 size and distance between sampled quadrats, this is a realistic assumption.

9 For any quadrat j of R_a , we assume that conditionally on $Z_{sj}=1$, X_{sj} follows a
 10 Binomial (K, q_{sa}) . Here q_{sa} represents the probability of detecting species s in quadrat j
 11 (located in region R_a) during any session (given that it is present in quadrat j). Detection
 12 probability can vary strongly among species, and can also differ depending on the subarea
 13 considered. We also can define the parameter $\mu_{sa} = \Pr(X_{sj} \geq 1 | Z_{sj} = 1) = 1 - (1 - q_{sa})^K$ which
 14 represents the probability of detecting species s in quadrat j (conditionally on its presence)
 15 over the K sessions of a visit. This parameter is commonly the parameter on which prior
 16 information is available.

17
 18 *Modeling occupancy* – Let s be a species present in the study area R_a , we set
 19 $Z_s(a) = \{Z_{sj}; j \in R_a\}$. Since we adopt a conditional approach, $Z_s(a)$ is distinct from the null
 20 vector. The p.m.f. (probability mass function) of $Z_s(a)$ is:

$$21 \quad p(Z_s(a) | \varphi_{sa}) = \frac{\varphi_{sa}^{N_s(a)} (1 - \varphi_{sa})^{J_a - N_s(a)}}{1 - (1 - \varphi_{sa})^{J_a}} \quad (3.3)$$

22 where $N_s(a)$ is the number of quadrats (of R_a) where species s is present. φ_{sa} is the probability
 23 that species s is present in quadrat j of R_a , given that it is present in at least one other quadrat

1 of R_a . Note that φ_{sa} is a conditional occurrence parameter (contrary to what appear in
2 MacKenzie *et al.*, 2006). Also γ_{sa} is not a parameter of the model, in contrast to φ_{sa} ; but they
3 are linked, since $E[\gamma_{sa} | \varphi_{sa}] = \varphi_{sa} / [1 - (1 - \varphi_{sa})^{J_a}]$. Due to the conditioning, the random
4 variables Z_{sj} are not independent. However, a certain form of conditional independence
5 between the Z_{sj} 's holds. Let i, j be any two quadrats of R_a , Z_{si} and Z_{sj} are independent, if
6 species s is present in at least one other quadrat of R_a (distinct from i and j).

7 Therefore, from a biological point of view, we assume that the presence of species s in
8 quadrat i is not affected by the presence of that species in quadrat j (given that it is present
9 elsewhere in R_a); this assumption is standard (disregarding the conditioning).

10

11 *Prior information on species detectability* – These data are part of a large study in the Midi-
12 Pyrénées (i.e. South-West of France), therefore we have access to prior information on the
13 probability of detecting species during the entire visit. Information on this detectability is also
14 available from the literature. It should be noted that, astonishingly, in the literature Bayesian
15 studies using informative priors are not as common as it could be expected. Here, since this
16 information is available and can bring substantial improvements to estimates, we have
17 logically used it in the process of occupancy rate assessing.

18 Typically, literature provides information on species detectability and these species can
19 be define for example as highly detectable or hardly detectable (Blotzheim & Bauer, 1985,
20 1988, 1993, 1997). Dupuis & Joachim (2006) have defined categories of detectability in order
21 to classify bird species depending on this information for 1985. Using information provided
22 by external data, they have found the Beta prior distribution for detection probability μ_{sa}
23 corresponding to each of these categories.

Occupancy rate modeling for bird species undergoing climatic changes

1 Here we use 4 categories: low, intermediate low, intermediate high and high detectability.
 2 The mean and 95%CI of the prior distributions for each category, respectively, are 0.2 [0 –
 3 0.4], 0.4 [0 – 0.65], 0.6 [0.3 – 0.8] and 0.8 [0.65 – 1]. These specific priors for each species
 4 are presented in Table 3. We have used the prior means and CI_{95%} intervals on μ_{sa} to
 5 determine coefficients of the corresponding Beta distribution by the use of a binary search
 6 algorithm (see MatLab code in appendix 1). Then, these coefficients are used to estimate
 7 coefficients of the prior Beta distribution on q_{sa} (the probability that a species is detected
 8 during each session of a visit) through the use of classical Monte Carlo methods (see MatLab
 9 code in appendix 2). Finally, the prior information on q_{sa} is used to estimate γ_{sa} .

10 Prior information on detectability for some species varies between 1985 and 1987 and/or
 11 between areas (see Table 3). Modification of detectability classification for some species in
 12 1987 is due to regional specificities or changes in the abundance of individuals. For example,
 13 the song thrush is less inclined to sing as the number of conspecifics in the neighborhood
 14 decreases. In the case of the whitethroat in the forest interior, no estimation has been done
 15 because it is known that this species does not live in this type of environment (therefore, no
 16 prior has been specified in table 3).

17

18 *Likelihood* – The parameter of the model is $\theta = \{\varphi_{sa}, q_{sa}; \mathbf{s} \in \mathcal{L}, a = 1, \dots, A\}$. The likelihood of
 19 θ based on $y = \{y_s(a); \mathbf{s} \in \mathcal{L}, a = 1, \dots, A\}$ is:

$$20 \quad L(\theta; y) = \prod_{\mathbf{s} \in \mathcal{L}, a=1, \dots, A} p(y_s(a) | \varphi_{sa}, q_{sa})$$

21 Note that we implicitly assume that species behave independently with respect to occupancy.

22 For any species \mathbf{s} such that $y_s(a)$ is different from the null vector:

$$23 \quad p(y_s(a) | \varphi_{sa}, q_{sa}) = \frac{\rho_{sa} \varphi_{sa}^{V_s(a)} q_{sa}^{W_s(a)} [1 - q_{sa}]^{U_s(a)} [(1 - q_{sa})^K \varphi_{sa} + 1 - \varphi_{sa}]^{T_a - V_s(a)}}{1 - (1 - \varphi_{sa})^{J_a}} \quad (1.1)$$

1 where $U_s(\mathbf{a}) = KV_s(\mathbf{a}) - W_s(\mathbf{a})$, and $\rho_{sa} = \prod_{j \in R_a} \binom{K}{y_{sj}}$; moreover, if $y_s(\mathbf{a})$ is a null vector, we
 2 have:

$$3 \quad p(y_s(\mathbf{a}) | \varphi_{sa}, q_{sa}) = \frac{((1 - q_{sa})^K \varphi_{sa} + 1 - \varphi_{sa})^{T_a} - (1 - \varphi_{sa})^{J_a}}{1 - (1 - \varphi_{sa})^{J_a}}. \quad (1.2)$$

4 Computational details are available from the authors on request. The formulae (1.1) and
 5 (1.2) allow computation of the probability (in function of J_a , T_a , K , φ_{sa} and q_{sa}) that a
 6 species s present in R_a has not been detected (or rarely detected). This occurs with relatively
 7 high probability when species s is spatially rare and/or hard to detect (Dupuis *et al.*, 2010).

8

9 *Estimating the occupancy rate* – We use Monte Carlo Markov Chain methods (MCMC) in
 10 order to obtain the bayesian estimations of γ_{sa} . Here, we are especially interested is the
 11 estimation of the occupancy rate but in some cases it could be required to also estimate the
 12 parameters q_{sa} and φ_{sa} . The MCMC algorithm, taking advantage of the missing data structure,
 13 is implemented on (θ, Z_m) where $Z_m = \{Z_s^{mis}(\mathbf{a}); s \in \mathcal{L}, \mathbf{a} = 1, \dots, A\}$ and $Z_s^{mis}(\mathbf{a})$ is the set of the
 14 missing Z_{sj} 's related to s (where j is in R_a). The bayesian estimate of γ_{sa} is easily obtained by
 15 applying the ergodic theorem (details are omitted). For further details, refer to Dupuis *et al.*
 16 (2010). The MatLab code for estimating γ_{sa} , φ_{sa} and q_{sa} is provided in Appendix 3.

17 We also compare differences between estimates obtained under both MacKenzie *et al.*,
 18 (2006) unconditional and Dupuis *et al.* (2010) conditional approaches in the case of not
 19 detected species that are known to be present and easily detectable. This comparison is done
 20 with non informative and informative priors on the detection probability.

21

22 Results

Occupancy rate modeling for bird species undergoing climatic changes

1 Globally, occupancy rates variations between 1985 and 1987 do not seem to be mainly
2 directed by the migratory status (Tab. 4). For example, while some sedentary species'
3 occupancy rates decreases (e.g. the short-toed treecreeper), others have increased (e.g. the
4 Eurasian nuthatch). The same result exists for migrating species and partial migrants (e.g.
5 mistle thrush occupancy rates increased contrary to the song thrush).

6
7 Overall, occupancy rates in interior and edge forests presented the same type of changes
8 (i.e. increase or decrease), but the extent of these variations can differ between these two sub-
9 areas. For example, while the song thrush and the nightingale greatly retreat between 1985
10 and 1987 in the edge forest, this variation is less important in the inner forest. On the other
11 side, increase in mistle thrush population was more important in the inner forest than in the
12 edge forest, apparently revealing a protecting role of the inner forest.

13
14 In the end, variations of occupancy rates seem to be mainly driven by biogeographical
15 origins with an occupancy rate increase of European and continental species (e.g. mistle
16 thrush, Eurasian nuthatch, European robin) and a decrease of Mediterranean and Atlantic
17 species (e.g. nightingale, song thrush).

18
19 We observe that the bayesian non informative estimates of the occupancy rates are precise
20 when the number of detections is high. Moreover, in 1987 and in edge, most of species have
21 been few detected (except the common blackbird, the chiffchaff, and the mistle thrush), and,
22 not surprisingly, we observe that most of non informative estimates are imprecise.

23 We also observe that taking into account the prior information available on detectability
24 significantly improves the precision of estimates when the target species has been very few
25 detected ($W_s(a)=1$) or has not been detected ($W_s(a)=0$): the green woodpecker, the nightingale

1 and the whitethroat are concerned by this remark (tab. 4 and 5). In Dupuis *et al* (2010), this
2 observation has already been mentioned, and indicated that this improvement is particularly
3 significant when the target is highly detectable.

4 Finally, we observe that taking into account the prior can make decrease the precision of
5 the bayesian estimate. For the mistle thrush (in 1987 and in inner forest), the range of the 95 %
6 posterior credible interval is 0.37 in non informative situation, and 0.46 in informative
7 situation. This unusual phenomenon typically occurs when the two following conditions are
8 fulfilled: the weights of the data and the prior are similar, and the (informative) prior mean of
9 the parameter of interest and its (non informative) posterior mean are very different, which
10 indicates a 'conflict' between the prior and the data. In our case, the prior variance of q_{sa} in
11 informative situation (namely 0.075^2) is effectively relatively close to the posterior variance
12 of q_{sa} in non informative situation (namely 0.084^2), while the (informative) prior mean of q_{sa}
13 (namely 0.21) is effectively very far from the non informative posterior mean of q_{sa} (namely
14 0.66).

15 Use of priors here can be essential to obtain a better estimation of occupancy rates. For
16 example, raw data in edge forest are identical for the whitethroat (1985) and for the green
17 woodpecker (1987). With $V_s(a)=2$ and $W_s(a)=2$ for these 4 species, we would have failed to
18 detect variation in occupancy rate without prior information (e.g. for the whitethroat), or we
19 could have underestimated the extent of the species occupancy rate variation (e.g. for the
20 green woodpecker). We can highlight the importance of including prior information on
21 detectability when available in the case of low detection data and easily detectable species.

22 For a species not detected by the quadrat sampling, but for which it is known that it was in
23 fact present in the region of study R_a (e.g. the Green Woodpecker in 1985 or the Nightingale
24 in 1987 in edge forest), tables 6a and 6b show that ignoring such an additional information
25 (by using the unconditional MacKenzie *et al.*, 2006, approach) will underestimate γ_{sa} . In non

1 informative situation, distances between both estimates are very important when the region of
2 study has been entirely sampled ($J=T=18$) (tab. 6a), and less important (though not negligible)
3 in the opposite case ($J=18, T=6$) (tab. 6b). In informative situation, distances in absolute
4 values are definitely less important (though not negligible), regardless the region of study is
5 totally or partially sampled. Nevertheless, we note that when $J=T=18$ the ratio between both
6 estimates is particularly high (namely >3.5). To be complete, let us add that when the target
7 species has been well detected estimates obtained under conditional and unconditional
8 approaches are quite similar.

9

10

11 Discussion

12 Globally, occupancy rates variations between 1985 and 1987 do not seem to be mainly
13 directed by the migratory status and no important differences between interior forest and edge
14 forest has been shown. The main factor responsible for species' response to climate changes
15 appeared to be their biogeographical region of origin.

16

17 *Migratory status* - Contrary to what we expected, the species migratory status did not seem to
18 be an important cause of differences in changes of occupancy rates under climate changes.
19 Evolution of occupancy rates as a response to climate changes could have been affected
20 because of direct effects on bird species of these changes, or secondary consequences. For
21 example, decrease may be due to the direct impact of rigorous winters on populations
22 (especially for sedentary species) or indirect impacts such as a decrease in available resources
23 (particularly for migratory species that should not be affected by the direct consequences of
24 cold in the region). An increase of occupancy rates or a less important impact of the specific
25 regional climatic events might be expected because other species might be negatively

1 impacted by cold winters and therefore leave unused resources and part of ecological niche.
2 Variation in population is the result of trades-offs between these negative and indirect positive
3 consequences and the influence of other external factors (e.g. a population already in a
4 decrease phase).

5 The impact of climatic extremes on bird densities is well-known (Wiens, 1981,
6 Grzybowski 1983, Balda *et al.*, 1983 ; Hejl & Beedy, 1986). According to these authors,
7 rigorous winters affect sedentary but not migratory bird species. In our study area,
8 Palearctic and Turkeстано-european faunistic type species expanded, while European,
9 Turkeстано-mediterranean and Mediterranean sedentary species experience population
10 reductions or extinction. This signifies a continentalization of the local avifauna. However,
11 not all of the sedentary birds were negatively affected by cold winters. Woodpeckers,
12 Eurasian Nuthatch and tits population increased. Fauna continentalization can also be seen
13 with migrants. Whitethroat, Tree Pipit, Spotted Flycatcher, but also Yellow Wagtail, Red-
14 backed Shrike and Garden Warbler have increasing occurrence frequencies.

15 The absence of clear impact of the migratory status can be due to the specific
16 characteristics of some of the species' local populations. For example, the Chiffchaff, which
17 has an important over-wintering population in Midi-Pyrenees, is found in winter near to
18 stagnant and running waters in the plain, where birds are sedentary. It is therefore strongly
19 affected by rigorous winters, leading to a drop in numbers in riparian forest, observed
20 between 1985 and 1987 (Lauga & Joachim, 1992). However, local populations, which are
21 mainly migratory outside of riparian forests, are not greatly affected (Affre, 1975*b* ; Joachim
22 *et al.*, 1997). Another example implies the European Robin. It was a common bird in this
23 region before the cold January of 1985. Rarer in 1985 spring, it almost disappeared from the
24 study area by spring 1987. It was only present in the largest terrace forest where its frequency
25 was greatly reduced ($F = 30\%$ instead of 80% in 1985). This local extinction happened in

1 plains and hills of the piemont Garonne. However, in mountainous areas such as Haute-
2 Garonne Pyrenees and Ariège, no significant frequency variation occurred between 1985 and
3 1987: F=100% for Cagire beech groves (Haute-Garonne, 1000 m) and beech and birch groves
4 in the Beille plateau (Ariège, 800-1400m) for both years (Joachim *et al.*, 1997). Therefore, it
5 can be hypothesized that the European Robin from the Garonne plains was sedentary and did
6 not survive the rigorous winters while the one from Central Pyrenees are migratory and
7 avoided these winters. Génard & Lescourtet (1985) found insular type adaptative characters in
8 European Robin of the Pyrenees. However, this species general range skirts Mediterranean
9 areas and shows no interruption between Pyrenees and the rest of France. Therefore, the
10 authors could not explain this phenomenon. Recent events suggest a distinction between East
11 and Central Pyrenees populations and more northern populations. First, during cold winters,
12 the Garonne population disappears and there is a real separation between areas. Second,
13 during mild winters, a sedentary Garonne population of European Robin develops but because
14 it is sedentary, it stays isolated from migratory Pyrenees' European Robins which have then
15 developed specific insular peninsular characteristics.

16

17 *Interior vs. edge forest* - We have not detected significant differences between interior and
18 edge forest, and globally species occupancy rates seemed to vary the same way in these two
19 sub-area. No changes of habitat preferences has been detected, but response to climate
20 changes might be less important in some cases in the interior forest than in the edge forest
21 indicating that actually, the interior forest might have provided a better protection. The extent
22 of this phenomenon may even be more important that what we could see here. In fact, because
23 of the poor sampling rate in the edge forest, the credible intervals of estimates are large
24 leading to a possible underestimation of the protection role played by the inner forest. It is

1 interesting to note that without the use of prior information, the detection of this effect would
2 have been compromised.

3 On a larger scale, detected variations in frequency are generally associated to colonization
4 or retreat from areas that do not correspond to preferred habitat (defined by sampling from
5 1985; Joachim, 1986). Largely wide-spread in woods located in this area, the Chiffchaff has
6 partially retreated from riparian forests while wren populations decreased in terraces. Birds
7 that are mainly forest birds have colonized small groves (e.g. Mistle Thrush, Lesser Spotted
8 Woodpecker), and open-field birds have penetrated into forest edges (e.g. Tree Pipit,
9 Whitethroat). These clues suggest that bird species with continental affinities, even if
10 progressing for various reasons, have difficulties in finding their optimal habitat. The local
11 frequency increase with occupation of unusual environments might reflect healthy
12 neighboring continental populations (e.g. in northern France, the Massif Central, or the
13 Pyrenees) with individuals that would settle in environments marginal to our region. Such
14 phenomena have been demonstrated by Askins & Philbrick (1987), and Askins *et al.* (1987)
15 for forest fauna in Connecticut (USA), by Van Dorp & Opdam (1987) in Dutch groves, and
16 by Helle & Järvinen (1986) in northern Finland.

17 In open-fields of near the study area, ornithologists have pointed out the disappearance of
18 some species (*Cisticola juncidis*, Indo-african faunistic type, *Sylvia undata*, Mediterranean
19 faunistic type), but no disappearance has been noticed in woody areas. *Cettia cetti* has
20 undergone a drastic regression in riparian forests without disappearing, and so has *Erithacus*
21 *rubecula* in all forests. Globally, species from forest areas seems to cope better with climatic
22 variations (even if affected) than sedentary open-field species. Some forest species have even
23 profited of new climatic conditions.

24

1 *Role of the species' biogeographical origins* - Continentalization of the regional forest fauna
2 has not been yet reflected by loss or gain of species, but instead by population reduction or
3 expansion by locally common species. However, some species have been more affected and
4 show a general reduction (or even extinction) or global colonization in the studied area. Some
5 extant monitoring programs such as the European Bird Census Council
6 (<http://www.ebcc.info/>) are interested in the expansion or regression of occupied areas of
7 several species, but no particular attention is drawn to the biogeographical origins of species,
8 which, as shown here, can be crucial.

9 In a broader context, during the 1970's, a different situation occurred with the settlement
10 or expansion of Mediterranean species (e.g. Dartford Warbler, Subalpine Warbler, Woodchat
11 Shrike), Turkestano-Mediterranean species (e.g. : Cetti's Warbler, Bee-eater) or Indo-African
12 species (Zitting Cisticola) in our study area during a succession of mild winters (Affre 1975 *a*
13 and *b*, Yeatman 1974). This expansion often extended to the French Atlantic coast which
14 provided a mild winter climate (Yeatman, 1976). Highly contrasting seasons from 1985, 1986
15 and 1987 have been correlated with regression and even local extinction of sedentary
16 populations to the benefit of these colonizing species, leaving small populations on the
17 Atlantic coast (e.g. Warblers). Depending on annual climatic variations, the Val de Garonne
18 area is alternatively colonized by Mediterranean thermophilic species using early stages of
19 plant successions, or continental species (especially forest species) uncomfortable in isolated
20 wood patches present in the agricultural plains (Blondel, 1984). These temporary
21 colonizations still permit the exchange of individuals between populations that are
22 intermittently isolated from each other (e.g. populations from the Pyrenees' continental fauna
23 and mid-Europe reservoir, and Mediterranean populations from the Atlantic coast and
24 Mediterranean reservoir). European partial migratory species with a sedentary edge area that
25 encompass the South-West of France hardly succeed to sustaining populations.

Occupancy rate modeling for bird species undergoing climatic changes

1 Various biogeographical influences acting on this region, usually thought to be an
2 enriching factor to natural environment, here, are paradoxically related to a noticeable
3 faunistic deficit (Balent *et al.*, 1988). Climatic variations and advanced deforestation only
4 allow commonly wide-spread species and pioneer species. Riparian Garonne forest seems to
5 be important, because regardless of climatic conditions, it contains a fauna of diverse
6 biogeographical regions, such as the Turkeстано-Mediterranean Cetti's Warbler, the European
7 Garden Warbler (Affre, 1980) and the palearctic Marsh Tit (Joachim, 1987). Avifauna
8 responses to climatic variations are slower here than in the open-fields of neighboring
9 agricultural plains. While the Garonne riparian forest, with a small area, can not be a local
10 fauna local reservoir and populations therein are not as unchanging as in large forest areas
11 (Glowacinski, 1981). It constitutes a moderating element in Garonne landscape because of its
12 slow response to climatic variations,. It also provides a more or less hospitable link between
13 remote patches of biogeographically different faunas and their source areas.

14

15

16 Taking into account some prior on the detectability of the target species can significantly
17 improve the estimation of its occupancy rates when it has been very few detected (or not
18 detected) and is known to be easily detectable (as already pointed out by Dupuis *et al.*, 2010).
19 As a matter of fact, ignoring such an available prior may have led to different conclusions
20 such as detection of a variation in occupancy rate while not true (e.g. Green Woodpecker or
21 Whitethroat in edge forest), a wrong estimation of the impact of rigorous winters (e.g.
22 Nightingale or European Robin in edge forest), or worse, it would have failed to detect a
23 diminution of the occupancy (e.g. Nightingale in the inner forest). Moreover, in our dataset,
24 we have undetected species which were known to be present in the study area; we have thus
25 adopted the conditional approach of Dupuis *et al.* (2010) for estimating their occupancy rates.

Occupancy rate modeling for bird species undergoing climatic changes

1 As shown in the comparison between unconditional and conditional approaches, not
2 accounting for the known presence of an undetected species can lead to significant
3 underestimation of its occupancy rate.

4

1 Appendices

2

3 **Appendix 1.** MatLab code for the binary search algorithm to determine the coefficients of
 4 the Beta distribution placed on detection probability over the whole visit μ_{sa} from a prior
 5 mean and 95% credible interval. *Output: Beta distribution parameters a and b.*

6

```

7 function [ParamBetaMu] = BinarySearchAlgorithm()
8
9 mu=input('Prior mean of Mu(sa): ')
10 CIinf=input('Lower bound of prior CI95%: ')
11 CIsup=input('Upper bound of prior CI95%:')
12 prec=input('Required interval precision: ')
13
14 CI=[CIinf CIsup] ;
15
16
17 % Initialization
18 margin=prec+1 ;
19 lambda1=0 ;
20 lambda2=10000 ;
21
22 % Binary search algorithm
23
24 while (margin>prec)
25     lambda=(lambda1+lambda2)/2 ;
26     a=lambda*mu ;
27     b=lambda*(1-mu) ;
28     prob=betainc(CIinf,a,b)-betainc(CIsup,a,b) ;
29     margin=abs(prob-0.95) ;
30
31     if (prob<0.95)
32         lambda1=lambda ;
33     end
34
35     if (prob>0.95)
36         lambda2=lambda ;
37     end
38 end
39
40 a=lambda*mu ;
41 b=lambda*(1-mu) ;
42 ParamBetaMu=[a b] ;

```

43

Occupancy rate modeling for bird species undergoing climatic changes

1 **Appendix 2.** MatLab code to obtain the Beta distribution parameters on q_{sa} (detection
2 probability during each session of a visit) from the Beta distribution on μ_{sa} . *Input: Beta*
3 *distribution parameters on μ_{sa} provided by function BinarySearchAlgorithm(). Output: Beta*
4 *distribution parameters for q_{sa} .*
5

```
6 function [ParamBetaQ]=MuGlobal_QLocal(ParamBetaMu)
7
8 a= ParamBetaMu (1);
9 b= ParamBetaMu (2);
10
11 K=input('enter the number of sessions K during a visit:');
12 L=input('enter the number of iterations for the MCMC algorithm:');
13
14 %Initialization
15 sumq=0;
16 sum2q=0;
17
18 %Beginning of MCMC algorithm
19
20 for l=1:L
21     X=betarnd(a,b);
22     k=1/K;
23     q=1-(1-X)^k;
24     Y(l)=q;
25     sumq=sumq+q;
26     sum2q=sum2q+q*q;
27     espq(l)=sumq/l;
28 end;
29
30 %End of MCMC algorithm
31
32 meanq=sumq/L;
33 varq=sqrt(sum2q/L-meanq^2);
34 lambq=((meanq*(1-meanq))/varq^2)-1;
35
36 alpha=lambq*meanq;
37 beta=lambq*(1-meanq);
38
39 Force=alpha+beta;
40 APrioriMean=alpha/(alpha+beta) ;
41
42 ParamBetaQ =[APrioriMean Force];
```

43
44

```

1 Appendix 3. MatLab code for estimating  $\gamma_{sa}$  (and  $\phi_{sa}$  and  $q_{sa}$  if required) using the Data
2 Augmentation scheme:  $\phi_{sa}$  is updated via a Hasting-Metropolis step,  $q_{sa}$  and missing data via
3 a Gibbs step. Input: Total number Vobs of quadrats where the species of interest has been
4 detected, total number W of detection of targeted species, total number J of quadrats in
5 region  $R_a$ , number T of sampled quadrats, number K of sessions per visit, number L of
6 iterations for the MCMC algorithm. Output: Estimates of posterior mean and 95% credible
7 interval for occupancy rate  $\gamma_{sa}$ .


---


8 function
9 [estimgamma, ICgamma1, ICgamma2, ICgamma3]=DBJDataAugV1V2 (Vobs,W,J,T,K,L)
10
11 delta=input('enter value of tuning parameter on phi (by default, take 0.3)
12 for Hasting-Metropolis algorithm:');
13
14 % Computation of Beta distribution parameter of a priori on Qsa
15 [parammu]= BinarySearchAlgorithm ();
16 [paramq]= MuGlobal_QLocal(parammu) ;
17 priorq=paramq(1);
18 lambdaq =paramq(2);
19
20 %DATA
21 dataVW=[Vobs,W];
22 dataVW;
23
24 %Non-informative a priori on phi
25 priorphi=0.5;
26 lambdaphi=2;
27
28 %Initialization
29 phi=0.1;
30 phi_init=phi;
31 phi_init;
32
33 q=0.3;
34 q_init=q;
35 q_init;
36
37 accept=0;
38 sumq=0;
39 sum2q=0;
40 sumphi=0;
41 sum2phi=0;
42 sumgamma=0;
43
44
45
46
47
48
49 %Beginning of MCMC algorithm
50
51 for l=1:L
52
53
54 % 1) DATA AUGMENTATION
55 omega=(phi*(1-q)^K)/(phi*(1-q)^K+(1-phi));
56
57 if (Vobs==0);
58     Vsim=0;
59     while (Vsim==0)
60         Vsim1=binornd(T,omega);

```

Occupancy rate modeling for bird species undergoing climatic changes

```

1      if (J>T)
2          Vsim2=binornd(J-T,phi);
3      else
4          Vsim2=0;
5      end;
6      Vsim=Vsim1+Vsim2;
7      end;
8  else
9      if (T>Vobs)
10         Vsim1=binornd(T-Vobs,omega);
11     else
12         Vsim1=0;
13     end;
14     if (J>T)
15         Vsim2=binornd(J-T,phi);
16     else
17         Vsim2=0;
18     end;
19     Vsim=Vsim1+Vsim2;
20 end;
21 V=Vobs+Vsim;
22
23 gamma=V/J;
24 grafgamma(1)=gamma;
25
26 % 2) UPDATE $q$ via Gibbs
27 q=betarnd(lambdaq*priorq+W,lambdaq*(1-priorq)+(K*Vobs-W)+K*Vsim1);
28
29 % 3) UPDATE $phi$ via Hast. Metro.
30 e=max(0,phi-delta);
31 f=min(1,phi+delta);
32 phihm=(f-e)*rand(1)+e;
33 ehm=max(0,phihm-delta);
34 fhm=min(1,phihm+delta);
35 logratiog=log(fhm-ehm)-log(f-e);
36
37 piphih=betapdf(phihm,priorphi*lambda phi,(1-priorphi)*lambda phi);
38 piphi=betapdf(phi,priorphi*lambda phi,(1-priorphi)*lambda phi);
39 logratioprior=log(piphih)-log(piphi);
40
41 logPrc=V*(log(phihm)-log(phi));
42 logPrd=(J-V)*(log(1-phihm)-log(1-phi));
43 logPre=log(1-(1-phi)^J)-log(1-(1-phihm)^J);
44 logratiolike=logPrc+logPrd+logPre;
45
46 logrho=logratiolike+logratioprior-logratiog;
47 rho=exp(logrho);
48
49
50 if (rho>=1)
51     phi=phihm;
52     accept=accept+1;
53 else
54     U=binornd(1,rho);
55     if(U==1)
56         phi=phihm;
57         accept=accept+1;
58     end;
59 end;
60
61 sumgamma=sumgamma+gamma;

```

Occupancy rate modeling for bird species undergoing climatic changes

```
1  sumphi=sumphi+phi;
2  sum2phi=sum2phi+phi*phi;
3  sumq=sumq+q;
4  sum2q=sum2q+q*q;
5
6  espgamma(1)=sumgamma/l ;
7
8  end;
9  %End of MCMC algorithm
10
11 rate=accept/L;
12 rate;
13
14 estimgamma=sumgamma/L;
15
16 estimq=sumq/L;
17 errorq=sqrt(sum2q/L-estimq^2);
18
19 estimphi=sumphi/L;
20 errorphi=sqrt(sum2phi/L-estimphi^2);
21
22 estimationqphi=[estimq,errorq,estimphi,errorphi];
23
24 cigamma=sort(grafgamma);
25
26 CIgamma1=[cigamma(0.025*L),cigamma(0.975*L)];
27 CIgamma1;
28
29 CIgamma2=[cigamma(0.05*L),cigamma(L)];
30 CIgamma2;
31
32 CIgamma3=[cigamma(1),cigamma(0.95*L)];
33 CIgamma3;
34
35 % Take the shortest CI
36
37 estimgamma ;
38 plot(1:L,espgamma)
```

39
40

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4

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1 Tables and Figures

2

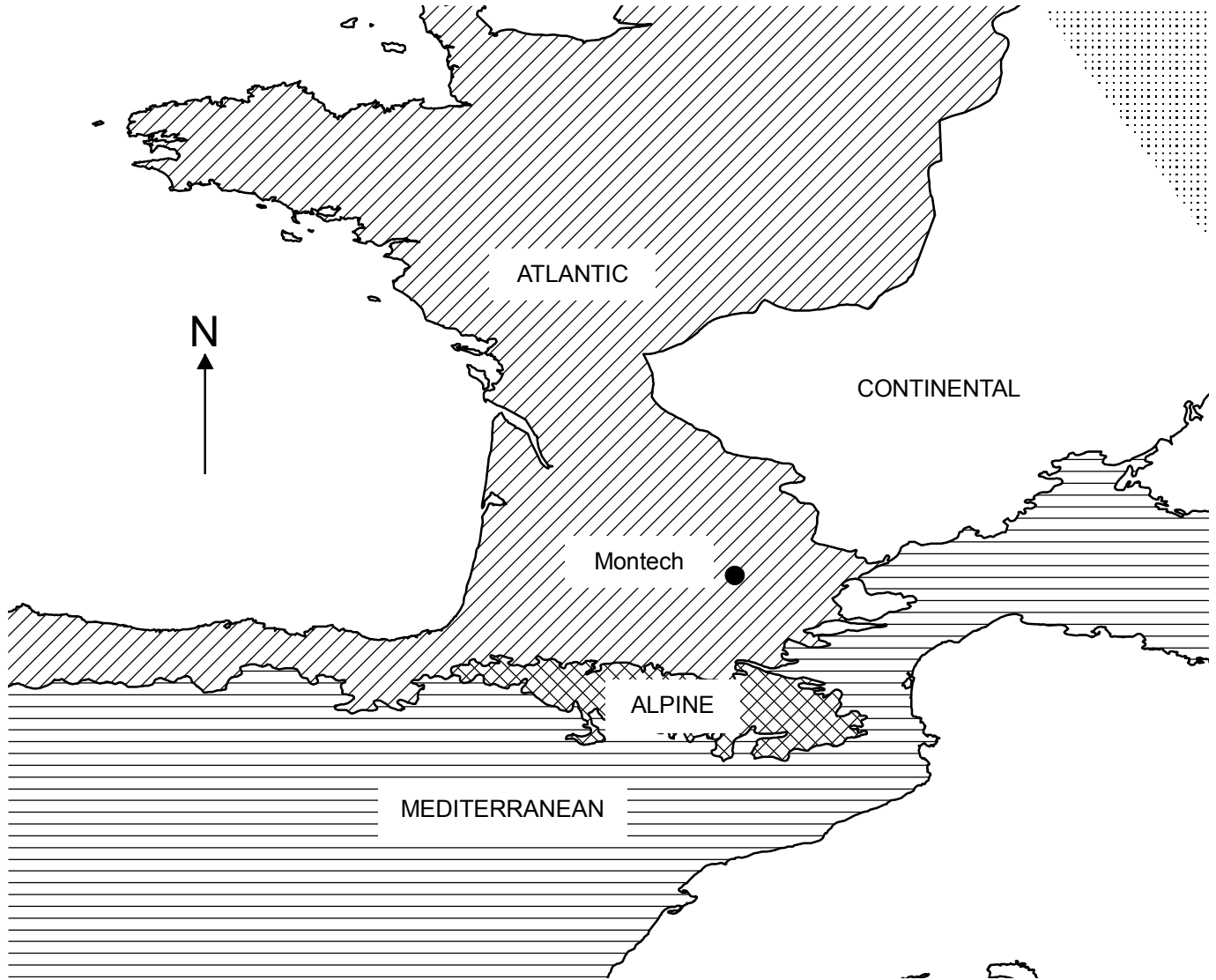
3 Figure 1. European map of biogeographical region and location of Montech Forest. (using
4 data provided by the European Environmental Agency: www.eea.eu.int). (*Black point:*
5 *Montech Forest, Cross hatch: Alpine, Diagonal simple hatch: Atlantic, Ordered stipple:*
6 *Continental, Horizontal simple hatch: Mediterranean*).

7

8 Figure 2. Mean monthly temperatures in 1985, 1986 and 1987 (*Spotted line: 1985, Hatched*
9 *line: 1986, solid line: 1987*) compared to 1970-1984 period (maximum and minimum
10 values from this 14 year period bounded in gray).. (from Joachim & Lauga, 1992)

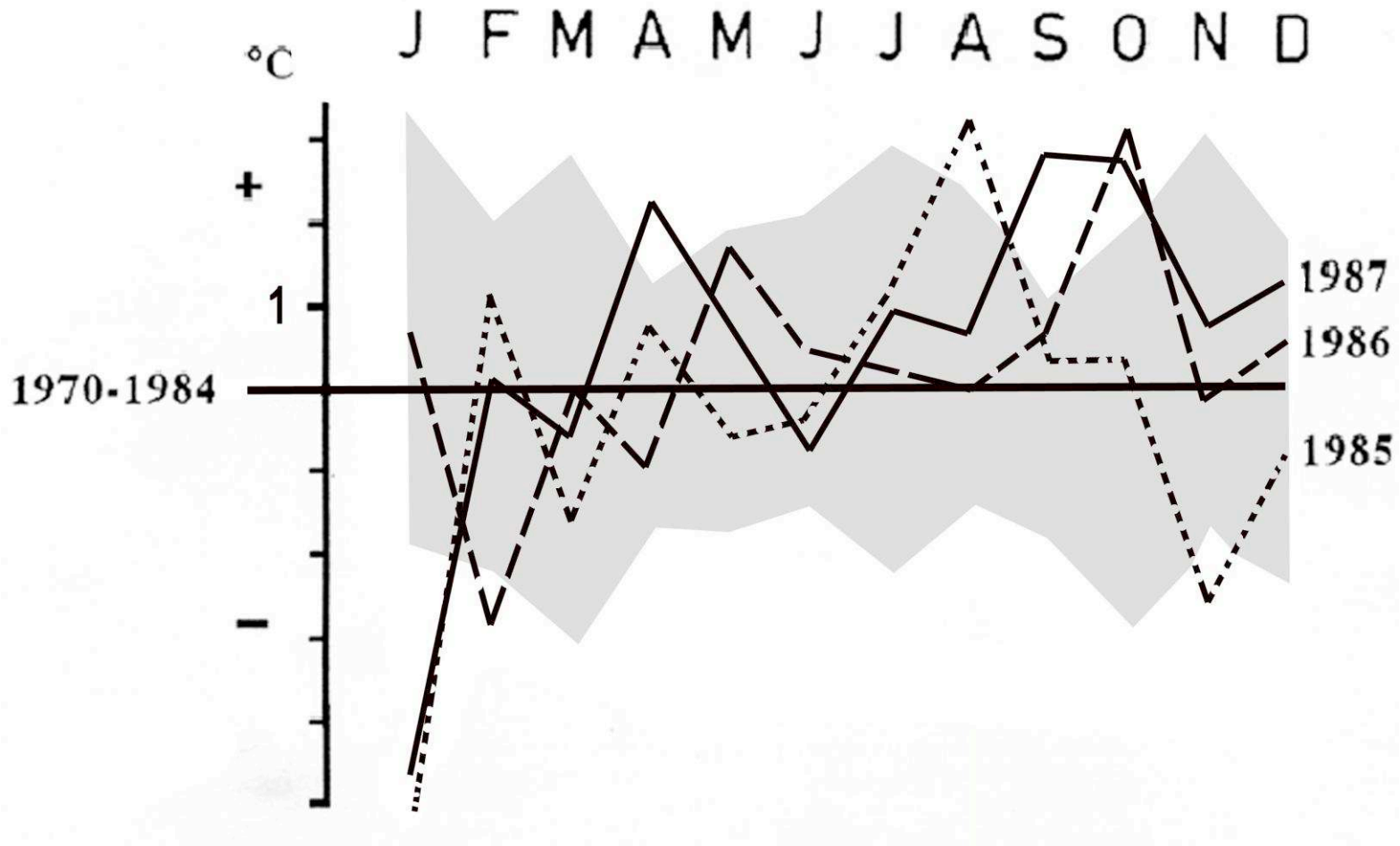
Figure 1.

1



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Figure 2.



Occupancy rate modeling for bird species undergoing climatic changes

Table 1.

Table 1. Data ($V_s(a)$, $W_s(a)$) for 1985 and 1987 in Montech forest.

Species		Inner forest		Edge forest	
		1985	1987	1985	1987
Song Thrush	<i>Turdus philomelos</i>	(20 ; 53)	(10 ; 20)	(16 ; 43)	(1 ; 2)
Common Blackbird	<i>Turdus merula</i>	(17 ; 32)	(12 ; 25)	(14 ; 35)	(4 ; 6)
Whitethroat	<i>Sylvia communis</i>	-	-	(2 ; 2)	(1 ; 1)
Chiffchaff	<i>Phylloscopus collybita</i>	(15 ; 30)	(5 ; 13)	(10 ; 24)	(4 ; 8)
Eurasian Nuthatch	<i>Sitta europea</i>	(7 ; 17)	(9 ; 26)	(4 ; 8)	(2 ; 2)
Green Woodpecker	<i>Picus viridis</i>	(1 ; 1)	(3 ; 3)	(0 ; 0)	(2;2)
Short-toed Treecreeper	<i>Certhia brachydactyla</i>	(15 ; 22)	(10 ; 17)	(11 ; 28)	(2 ; 2)
European Robin	<i>Erithacus rubecula</i>	(9 ; 17)	(5 ; 8)	(7 ; 12)	(2 ; 6)
Nightingale	<i>Luscinia megarhynchos</i>	(4 ; 9)	(1 ; 1)	(5 ; 7)	(0 ; 0)
Mistle Thrush	<i>Turdus viscivorus</i>	(6 ; 13)	(8 ; 22)	(4 ; 5)	(3 ; 4)

Occupancy rate modeling for bird species undergoing climatic changes

Table 2.

Table 2. Migratory status and biogeographical origins of the selected species. *Migratory status: Sedentary (S), Migrant (M) or Partial migrant (P).*

Species	Migratory status	Global faunistic class	European biogeographical origin
Song Thrush	P	European	Atlantico-continental
Common Blackbird	P	Palaearctic	European
Whitethroat	M	Turkestano-european	Atlantico-mediterranean
Chiffchaff	M	Palaearctic	Atlantico-continental
Eurasian Nuthatch	S	Palaearctic	European
Green Woodpecker	S	European	European
Short-toed Treecreeper	S	European	European
European Robin	P	European	Atlantico-continental
Nightingale	M	European	Atlantico-mediterranean
Mistle Thrush	P	European	Continental

Occupancy rate modeling for bird species undergoing climatic changes

Table 3.

Table 3. Prior mean and CI_{95%} of detection probability μ_{sa} during 1985 and 1987 in Montech forest.

Species	Inner forest		Edge forest	
	1985	1987	1985	1987
Song Thrush	0.8 [0.65 – 1]	0.6 [0.3 – 0.8]	0.8 [0.65 – 1]	0.4 [0 – 0.65]
Common Blackbird	0.8 [0.65 – 1]	0.6 [0.3 – 0.8]	0.8 [0.65 – 1]	0.8 [0.65 – 1]
Whitethroat	-	-	0.8 [0.65 – 1]	0.8 [0.65 – 1]
Chiffchaff	0.8 [0.65 – 1]	0.8 [0.65 – 1]	0.8 [0.65 – 1]	0.8 [0.65 – 1]
Eurasian Nuthatch	0.8 [0.65 – 1]	0.8 [0.65 – 1]	0.6 [0.3 – 0.8]	0.6 [0.3 – 0.8]
Green Woodpecker	0.6 [0.3 – 0.8]	0.6 [0.3 – 0.8]	0.8 [0.65 – 1]	0.8 [0.65 – 1]
Short-toed Treecreeper	0.8 [0.65 – 1]	0.8 [0.65 – 1]	0.6 [0.3 – 0.8]	0.6 [0.3 – 0.8]
European Robin	0.8 [0.65 – 1]	0.6 [0.3 – 0.8]	0.8 [0.65 – 1]	0.2 [0 – 0.4]
Nightingale	0.6 [0.3 – 0.8]	0.6 [0.3 – 0.8]	0.8 [0.65 – 1]	0.8 [0.65 – 1]
Mistle Thrush	0.6 [0.3 – 0.8]	0.6 [0.3 – 0.8]	0.4 [0 – 0.65]	0.4 [0 – 0.65]

Occupancy rate modeling for bird species undergoing climatic changes

Table 4.

Table 4. Posterior mean and CI_{95%} of γ_{sa} for inner and edge regions of Montech forest in 1985 and 1987. Estimates were computed using informative prior on q_{sa} .

Species	Inner forest		Edge forest	
	1985	1987	1985	1987
Song Thrush	0.95 [0.91 ; 1]	0.85 [0.68 ; 1]	0.93 [0.89 ; 1]	0.47 [0.06 ; 0.94]
Common Blackbird	0.89 [0.77 ; 1]	0.93 [0.77 ; 1]	0.84 [0.78 ; 0.94]	0.76 [0.44 ; 1]
Whitethroat	-	-	0.16 [0.11 ; 0.28]	0.08 [0.06 ; 0.17]
Chiffchaff	0.79 [0.68 ; 0.96]	0.42 [0.23 ; 0.59]	0.63 [0.56 ; 0.78]	0.74 [0.44 ; 1]
Eurasian Nuthatch	0.37 [0.32 ; 0.45]	0.68 [0.50 ; 0.86]	0.36 [0.22 ; 0.61]	0.59 [0.22 ; 1]
Green Woodpecker	0.11 [0.05 ; 0.32]	0.46 [0.14 ; 0.86]	0.07 [0.05 ; 0.14]	0.49 [0.11 ; 0.83]
Short-toed Treecreeper	0.87 [0.73 ; 1]	0.84 [0.64 ; 1]	0.72 [0.61 ; 0.89]	0.59 [0.11 ; 0.94]
European Robin	0.51 [0.41 ; 0.68]	0.60 [0.32 ; 0.96]	0.50 [0.39 ; 0.72]	0.57 [0.11 ; 0.94]
Nightingale	0.28 [0.18 ; 0.45]	0.19 [0.05 ; 0.50]	0.39 [0.28 ; 0.61]	0.15 [0.06 ; 0.39]
Mistle Thrush	0.39 [0.27 ; 0.59]	0.67 [0.45 ; 0.91]	0.59 [0.28 ; 1]	0.75 [0.39 ; 1]

Occupancy rate modeling for bird species undergoing climatic changes

Table 5.

Table 5. Posterior mean of γ_{sa} and CI_{95%} for inner and edge regions of Montech forest in 1985 and 1987. Estimates were computed using a non informative prior on q_{sa} . *Only results differing from the informative approach are presented here.*

Species	Inner forest		Edge forest	
	1985	1987	1985	1987
Song Thrush	-	-	-	0.29 [0.06 ; 0.72]
Common Blackbird	-	-	-	-
Whitethroat	-	-	0.41 [0.11 ; 0.94]	0.42 [0.06 ; 0.94]
Chiffchaff	-	-	-	-
Eurasian Nuthatch	-	-	-	-
Green Woodpecker	0.24 [0.05 ; 0.82]	0.56 [0.23 ; 1]	0.25 [0.05 ; 0.82]	0.59 [0.22 ; 1]
Short-toed Treecreeper	-	-	-	-
European Robin	-	0.52 [0.23 ; 0.86]	-	0.37 [0.11 ; 0.61]
Nightingale	-	0.42 [0.06 ; 0.94]	-	0.24 [0.05 ; 0.78]
Mistle Thrush	-	0.58 [0.36 ; 0.73]	-	0.67 [0.33 ; 1]

Occupancy rate modeling for bird species undergoing climatic changes

Table 6a. Comparison between γ_{sa} estimates under unconditional (MacKenzie *et al.*, 2006) and conditional (Dupuis *et al.*, 2010) approaches when a species is not detected, for a non informative and an informative prior on q_{sa} : case of the Green Woodpecker in edge region of Montech forest in 1985. $J=T=18$.

	Unconditional approach	Conditional approach
Non informative prior	0.13 [0 ; 0.68]	0.25 [0.05 ; 0.82]
Informative prior	0.02 [0 ; 0.11]	0.07 [0.05 ; 0.14]

Table 6b. Comparison between γ_{sa} estimates under unconditional (MacKenzie *et al.*, 2006) and conditional (Dupuis *et al.*, 2010) approaches when a species is not detected, for a non informative and an informative prior on q_{sa} : case of the Nightingale in edge region of Montech forest in 1987. $J=18, T=6$.

	Unconditional approach	Conditional approach
Non informative prior	0.20 [0 ; 0.78]	0.24 [0.05 ; 0.78]
Informative prior	0.12 [0 ; 0.39]	0.15 [0.05 ; 0.39]