The Catalan Breeding Bird Atlas (CBBA): methodological aspects and ecological implications

Lluís Brotons, Sergi Herrando, Joan Estrada, Vittorio Pedrocchi &
Jean Louis Martin

The first Catalan Breeding Bird Atlas (CBBA) published in the early eighties, covered, with a 10x10 km UTM grid, an area of 32,000 km^2 in north-east Spain and stands as a pioneer landmark in bird mapping in the Mediterranean region. Here, we present the context, novelties and main results of the new CBBA conducted 20 years later, between 1999 and 2002. This new atlas has included a series of methodological innovations amongst which we should emphasize the establishment of small scale timed censuses on a sample of 1x1 km UTM squares within each of the original squares of the 10x10 km UTM grid. These small-scale censuses (about 3,200) allowed a consistent sampling of the territory by covering uniformly about 10% of the total study area, and make possible the production of species distribution maps at local scales (e.g. 500 m resolution). These maps were generated using spatial logistic regressions in the framework of niche based modelling approaches. Such models included information from 45 environmental variables ranging from land use and relief to direct human influence and climate, as well as information on the spatial structure of the data collected for each sampled species data to account for spatial autocorrelation. Currently, the CBBA stands amongst the best current quantitative mapping of bird distribution in Europe.We also used data from the 1x1 km UTM squares to develop species-time curves and model the number of species found in each 10x10 km squares per unit of time. The application of these models to the first and the new CBBAs allowed an accurate estimation of changes in bird distribution between the two atlases by taking into account local differences in sampling effort (*e.g.* time spent on a given square) between the two periods. Overall, the new CBBA provides one of the best large-scale pictures of the changes that occurred during the last 20 years in southern Europe. The results obtained strongly support the hypothesis that strong changes in bird community patterns have occurred in large areas of the country, often associated with changes in land use patterns.

Key words: bird distribution mapping, habitat suitability modelling, distribution changes, monitoring programme.

Lluís Brotons*, Sergi Herrando, Joan Estrada & Vittorio Pedrocchi, *Catalan Ornithological Institute, Museu de Ciències Naturals de la Ciutadella, Passeig Picasso s/n, 08003 Barcelona, Catalonia, Spain.*
Lluís Brotons* & Jean Louis Martin, *Centre d'Ecologie Fonctionelle et Evolutive-CNRS, 1919 Route de Mende, 34293 Montpellier Cedex, France.*
Lluís Brotons* (present address), *Centre Tecnològic Forestal de Catalunya, Àrea de Biodiversitat, Ctra. Sant Llorenç, km. 2, 25280 Solsona, Catalonia, Spain.*
* Corresponding author: lluis.brotons@ctfc.cat

In 1984 the Atlas of Breeding Birds of Catalonia and Andorra was published (Muntaner *et al.* 1984). This publication was one of the first extensive atlases to be completed in Spain and Southern Europe. This atlas allowed, for the first time, the accurate mapping of the of the 214 breeding bird species observed in Catalonia on a 10x10 square grid in the *Universal Transversal Mercator* (UTM) geographic projection. The data used to map all the species were collected in the period 1975-1983, although most of the sampling effort was concentrated during the years 1981-1982. The development of the atlas project involved 129 people.

As species distribution is unlikely to remain constant for all species through time, the Catalan Ornithological Institute put forward a proposal to conduct a revision of the first breeding bird atlas in order to analyse temporal trends in bird distribution during the last 20 years and therefore update the knowledge on the country's bird fauna. The present number of Catalan ornithologists and their high identification skills and commitment, suggested that additional mapping of spatial variation in species abundance could be a possibility as it had been included in other recent atlases (Gibbons *et al.* 1993, Schmid *et al.* 1998). Indeed, the collection of objective data on the spatial patterns of bird species would advance knowledge of their ecology and therefore help in defining priorities for biodiversity conservation strategies.

The present Catalan Breeding Bird Atlas includes information on the distribution of species for which breeding evidence for the 1999-2002 period has been recorded in a spatial grid of 10x10 km UTM squares. The use of the same grid allows a direct spatial comparison with the previous breeding bird atlas of Catalonia and therefore allows the identification of new and extinct species as well as temporal trends in the spatial distribution of the rest. Maps of relative abundance for most species have been included in this atlas. These maps have been developed through information gathered in timed censuses conducted in a sampling of 1x1 km UTM squares throughout the study area. This information has been used together with geographic information on main environmental variables in different areas to allow the estimation of probability of occurrence maps for the species for the whole of Catalonia. This analysis has also allowed the gathering of preliminary but quantitative and comparable information about the main environmental variables that may be important in explaining the distribution of Catalan breeding species. This information may also become a useful tool in the design of conservation policies. In the forthcoming sections, we will briefly describe the information included in the new Catalan Breeding Bird Atlas and provide information on the methodology employed.

Bird atlas data provide the researcher with a powerful tool to broadly identify changes and state hypothesis more likely to be behind the detected changes in bird distribution (Donald & Fuller 1998). In this paper, we aim to summarise the main patterns of distributional change in bird species between the two Catalan breeding bird atlases, which are 20 years apart. We go on to discuss these changes in light of different hypothesis acting as drivers of change in bird populations. Although many factors act in conjunction to affect bird populations, land use changes are expected to be especially important at the temporal and spatial scales used by this atlas. Therefore, we concentrate our discussion on the main land use patterns and their changes as major drivers of species change (Tucker & Evans 1997).

Methodology

General organisation of the Atlas

In 1997, to coincide with the 20th anniversary of the Atlas of the Breeding Birds of Catalonia and Andorra 1975-1983, the ICO contacted a number of ornithologists and organisations to

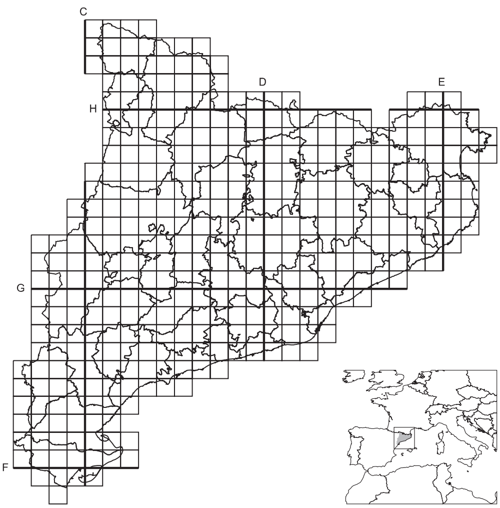

Figure 1. Study area and UTM grid used for plotting data gathered for this atlas. Square size is 10x10 km.
Àrea d'estudi i reticle UTM emprat per recopilar les dades d'aquest atles. Les dimensions del quadrat són 10x10 km.

produce a new, up-to-date atlas of the breeding birds of Catalonia. It was decided to use the same 10x10 UTM Universal Transverse Mercator grid as was employed in the previous atlas to allow for direct spatial comparisons between species (Figure 1). Catalonia corresponds to zone 31T. A total of 386 10x10 UTM squares were surveyed for this atlas. Unlike in the first atlas, which included Andorra and areas within Aragon and France in cross-border squares (Muntaner *et al.* 1984), in the present atlas the study area was strictly limited to the administrative territory of Catalonia. Hence, in those border squares the surveyed area was restricted to the Catalan portion of the square.

Criteria for species inclusion and taxonomy

Regardless of their origins (established or otherwise), species for which some breeding evidence was gathered during the sampling period (1999-2002) have been included in this atlas. Non-established (mostly exotic) species have also been included as their populations may stabilise in Catalonia and data regarding these colonisation processes may prove useful in the future.

In the main part of the atlas all breeding species and the exotic species for which there is evidence of breeding and continuous presence during the period 1999-2002 are considered. Exotic species showing occasional evidence of breeding, not regularly observed within the sampling period have been included in a Complementary Species section that also covers those species that only bred during the period between the two atlases (1984-1998) and the summer species that did not show any evidence of breeding within the period 1984-2002.

Sampling methods

The sampling methodology aimed to detect either by sight or by sound the maximum evidence of breeding for all the species found in each 10x10 UTM square. The assignment of the 10x10 UTM squares was aimed at guaranteeing that the territory was covered as thoroughly as possible. Volunteers were asked which areas they preferred to survey and were then given a series of 10x10 UTM squares still to be assigned to choose from. Those not showing a geographical preference were asked to survey one of the squares with a low density of ornithologists. If a volunteer could only survey a square that had already been assigned, then he/she was still accepted as a participant in the project. For this reason, some 10x10 UTM squares were surveyed by more than one person.

Evidence of breeding

The assignation of the different categories of evidence of breeding follows the recommendations of the European Ornithological Atlas Committee (EOAC) that has been working from 1992 as part of the European Bird Census Council (EBCC) (Hagemeijer & Blair 1997). Given that some observers tended to place in the 'possible breeding species' category some individuals surely not breeding in the area, it was decided to add two new categories in order to correctly classify these observations: 'non-breeding summer visitor' and 'migrant'. These additions allowed new data to be collected whilst avoiding confusing breeding species with those birds that would not breed in that particular square. Thus, the 'non-breeding summer visitor' category allows the real summer distribution of many species to be defined.

Timed censuses in UTM 1x1 squares

The use of timed censuses as a mean of producing abundance maps is one of the most significant features of the present atlas. Besides the generic sampling conducted for each UTM 10x10 square, a set of sample 1x1 km squares was established inside the former units: this approach is similar to that used, for example, in the British and Swiss ornithological atlases (Gibbons *et al.* 1993, Schmid *et al.* 1998). These 1x1 km units were established by dividing each of the UTM 10x10 squares into 100 UTM 1x1 squares. In order to reproduce as accurately as possible the environmental heterogeneity of each UTM 10x10 square, a number of 10 non-adjacent 1x1 squares had to be selected by the responsible observer in such a way that together they were proportionally representative of the habitats present inside the UTM 10x10 square. Those squares that were insufficiently covered and therefore had to be surveyed semi-professionally, the minimum coverage was lowered to five 1x1 squares.

For nocturnal species, a sub-sample of five out of the 10 previously selected UTM 1x1 squares were selected to be surveyed at night. This figure was lowered to two UTM 1x1 squares when surveyed semi-professionally. For both diurnal and nocturnal censuses, two 1-hour surveys were conducted for each one of the selected UTM 1x1 squares during which every square was entirely surveyed and every species recorded. The number of individuals was not noted.

Sampling period

As a general rule, the gathering of breeding evidence was restricted to the period March-July inclusive; for 'confirmed evidence of breeding', data obtained in dates previous or posterior to the prescribed period were accepted, especially for those species with very long reproductive seasons. The surveying period for nocturnal raptors was brought backward to February so that the territorial songs of species that principally call in winter could be detected (for example, Eagle Owl, Long-eared Owl and Tawny Owl).

If possible, surveys in the UTM 1x1 sample squares had to be conducted between sunrise and 11 am, and between 6 pm and sunset. Timetables and dates were approximate and could be adapted to local conditions provided they coincided with peak bird activity. The first survey was conducted in March-April to detect resident species and the second in May-June to detect summer visitors. For nocturnal species, the first survey was conducted in February for the reasons described above, and the second survey was conducted in May in order to detect the remaining nocturnal raptors and other nocturnal or crepuscular species such as the Common and Red-necked Nightjars and Stone Curlew. Nocturnal surveys were conducted at any time between sunset and sunrise, although the majority were carried out during the first hours of darkness.

Data Analysis

Distribution maps

Data collected during the field observations and surveys were marked on maps based on the UTM 10x10 km grid, showing the 'breeding evidence' distribution in the period 1999-2002. Breeding evidence on the maps is classed as 'possible', 'probable', 'confirmed' and 'summer non-breeding visitor'; migrants are not represented on the maps, although all relevant information has been stored in the atlas database.

In the background the previously known distribution of the species (Muntaner *et al.* 1984) is given allowing changes to be seen at a glance. Data from the previous atlas (including information on rare and/or sensitive species whose real distributions had been hidden in the original maps) were directly provided by its coordinator and then added to the database of the current atlas. Those data were also adapted into a single three categories breeding code ('possible', 'probable' and 'confirmed', so that only the best possible evidence of breeding per species and per sheet was considered.

Changes in species' distribution: variations in the occupation of UTM 10x10 squares between atlases

Animal populations are not always stable and changes may affect their spatial distribution. Since one of the main goals of an atlas is to accurately identify these hypothetical changes, it was essential to differentiate between real changes in distribution and simple variations in the sampling effort between atlases. This is particularly relevant for bird atlases because these large-scale projects usually incorporate data from different sources, with subsequent temporal and spatial variations in the data-collection effort. For this reason, several bird atlases have tried to increase the reliability of their estimates of spatial (and temporal) variations in distribution by placing a great deal of emphasis on the standardisation of applied field methods (i.e. Schmid *et al.* 1998). Despite possible biases, such as an heterogeneous spatial effort within atlas data affecting the reliability of the comparison with future atlases, the usefulness of these analyses (Donald & Fuller 1998) makes it necessary to use methodologies that overcome limitations in data collection.

For a particular species, the quantification of changes in its distribution can be estimated by way of an analysis of the changes in occupied UTM 10x10 squares. However, a temporal variation in sampling effort may create a significant bias in the estimates of distribution changes. While only 129 observers took part in data collection during the first atlas (Muntaner *et al.* 1984), the number climbed up to 497 during the second period. Unfortunately, both the data collected for the first atlas and, to some degree, the data from the present atlas were not (completely) standardised in relation to the sampling effort applied to each UTM 10x10 square. Despite the timed censuses conducted in the UTM 10x10 squares, a large portion of the data obtained for the new atlas comes from observations gathered in a non-standardised way from a time effort point of view. Thus, changes in a single species distribution may be a consequence of the differences in sampling effort between the two data sets or more realistically due to the general higher sampling effort in the second atlas. In these circumstances, the perceived expansion of a particular species may be related both to biological causes and/or to more thorough fieldwork during the second atlas.

Changes in a species' distribution from one atlas to the other have been analysed using estimates of the change in the total number of UTM 10x10 squares occupied by the species, corrected for using information gathered from species accumulation curves. This approach used timed censuses conducted on the sample of UTM 1x1 squares located within each of the UTM 10x10 squares. Species' accumulation

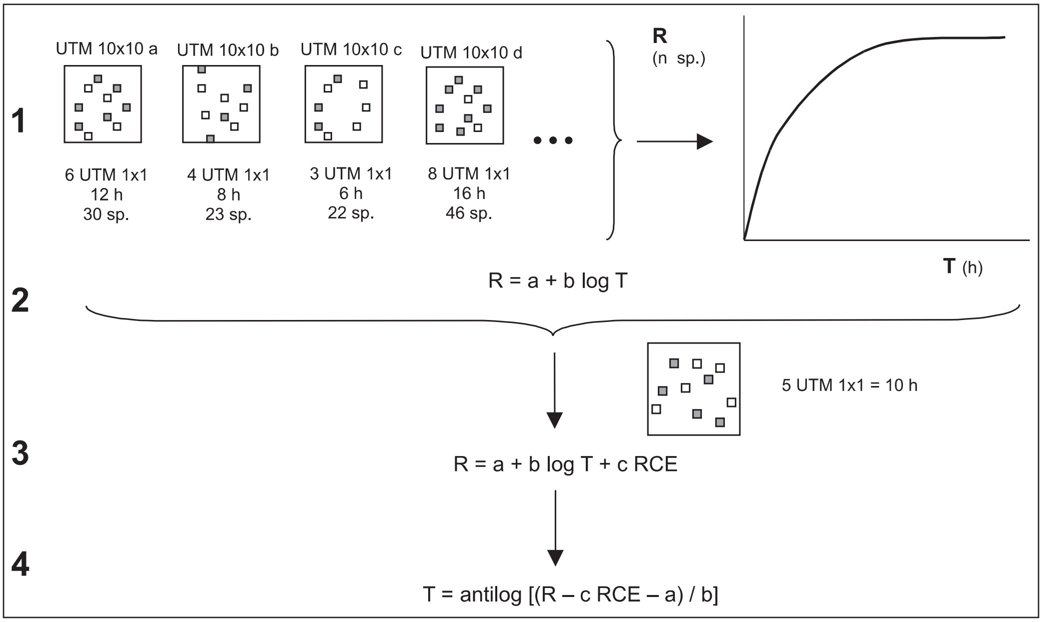

Figure 2. Diagram of the process for obtaining the effective sampling time for each UTM 10x10 square from curves of richness-effort controlling the effect of environmental heterogeneity. 1) Production of the basal curve richness-sampling effort (hours) from the information gathered in the timed censuses conducted in UTM 1x1 squares. 2) The first step allows us to obtain a preliminary relationship between effective sampling time and the number of detected species. 3) Generation of a second regression equation that allows us to control the effect of environmental heterogeneity in the UTM 10x10 squares by means of the number of species detected in five UTM 1x1 squares. 4) Application of the generated equation of richness values per UTM 10x10 square in order to obtain the effective sampling time (in hours)
Diagrama del procés utilitzat per a l'obtenció del temps de mostratge efectiu realitzat en cada quadrat UTM 10x10 a partir de corbes riquesa-esforç, controlant l'efecte de l'heterogeneïtat ambiental. 1) Producció de la corba base entre riquesa i esforç de mostratge (en hores) a partir de la informació recollida en els censos de temps controlat portats a terme en quadrats UTM 1x1. 2) Aquest primer pas ens permet obtenir una associació preliminar entre el temps efectiu de mostratge i el nombre d'espècies detectades. 3) Generació d'un segon model de regressió que permeti controlar l'efecte de l'heterogeneïtat ambiental a cada UTM 10x10 a través del nombre d'espècies detectades en 5 quadrats UTM 1x1. 4) Aplicació d'aquesta darrera equació als valors de riquesa obtinguts en els quadrats UTM 10x10 per tal d'obtenir el temps de mostratge efectiu (en hores).

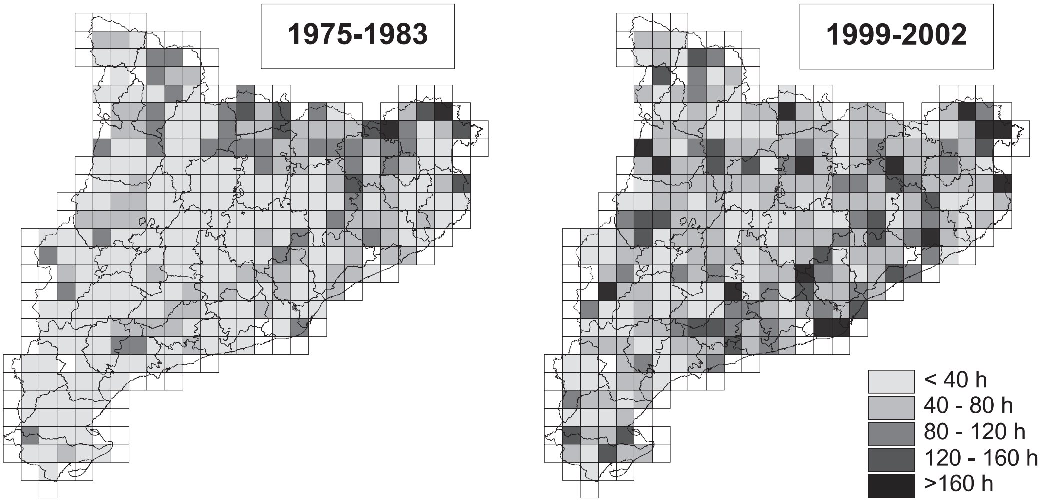

Figure 3. Spatial representation of the sampling effort invested in each UTM 10x10 square in Catalonia for both breeding bird atlases. The unit employed is the estimated effective number of hours invested in bird surveying, not necessarily the total time spent by observers in every square.
Representació espacial de l'esforç de mostratge invertit en cada quadrat UTM 10x10 de Catalunya en els dos atles dels ocells nidificants. La unitat emprada és el nombre estimat d'hores invertides cercant ocells, les quals no corresponen necessàriament al temps total que els observadors han passat en el quadrat.

curves were created from these data and by reversing the process the effective surveying time for particular species richness was estimated (Figure 2). The independent evaluation of the effects derived from the sampling effort (effective census time) and from the period (first vs. second atlas) on the presence of each species was carried out by means of a logistic regression for repeated measures (Genmod SAS software module). The number of UTM 10x10 squares in which every species was detected, either in the first atlas (1 vs. 0), in the present one (0 vs. 1) or in both (1 vs. 1), was used.

Once survey effort was estimated, these statistics allowed us to determine the significance of the change in the number of squares occupied by every species in the period between atlases. It also enabled us to obtain corrected estimates of change, expressed in the results as the percentage increase or decrease in the number of UTM 10x10 squares occupied during the period between atlases. Importantly, this analysis only indicates changes in the number of squares, which means a quantitative variation in the size of the distribution area of the species. If this variation is not significant it does not necessarily imply that the species' distribution has remained the same, since the number of occupied squares may be unchanged even if their location may have varied. Thus, not infrequently the disappearance from one area and appearance at a similar scale in another area implies an overall stability in the number of squares but also important qualitative changes in distribution.

On average, the effective sampling time (estimated form species accumulation curves) per UTM 10x10 square was 66 hours (standard deviation = 44 hours) for the present atlas and 43 hours (standard deviation = 43 hours) for the previous atlas. Thus, from a general point of view, any UTM 10x10 square was surveyed for 23 more hours during work on this atlas than work on the previous one. The spatial pattern of change in the sampling effort from one atlas to another is far from homogeneous (Figure 3).

Patterns of temporal change across species groups

The main objective of an atlas is to provide information on the distribution of the bird species present in a given region as well as the ecological factors determining such distributions (Gibbons *et al.* 1993, Schmid *et al.* 1998). However, given that a historic atlas exists in Catalonia conducted 20 years ago, an equally important objective has been to quantify the temporal changes in bird distribution occurred between the two atlases (*e.g.* changes in the number of 10x10 UTM squares occupied by a particular species) and try to provide information on the likely causes behind such changes.

In order to identify hypotheses behind distribution changes in a Mediterranean context, we conducted analyses on the spatial patterns of distribution changes in Catalonia in different bird groups according to their broad habitat selection patterns and discuss their associations with land use variables generated from satellite imagery. We then (1), analyse the overall trends in species changes according to their habitat preferences, and (2) map the overall patterns in spatial trends of such changes among some of the species groups showing significant variations in distribution. Due to the pioneering initiative of the first Catalan atlas, the results of this new Atlas stand amongst the first large-scale temporal comparison of main tendencies in bird distribution within the Mediterranean region.

To analyse the patterns of distribution changes in the Catalan breeding bird fauna, we first classified the species considered in the present atlas according to their main habitat used during the breeding season and their migratory status. According to their main habitat selection as derived from the literature (Muntaner *et al.* 1983, Cramp & Perrins 1994), species were divided in seven categories: forests, shrublands, wetlands and rivers (including coastal and inland wetlands), farmland, steppes (as particular extensive dry farmland habitats), alpine habitats located in the Pyrenees (including both subalpine forests and alpine non-forested areas above the tree line), and a final group of other species, which selects habitats at larger spatial scales, including most raptors and aerial species weakly associated to terrestrial habitats.

Migratory status was assigned according to whether the species winters south of the Sahara (long distance migrant), makes short to medium distance movements during winter (short distance migrant) or always remains in or around the area where it breeds (resident).

Changes in species distributions between the two atlases were calculated after taking into account the sampling effort per 10 km square and comparing the number of squares occupied in the two different periods (see section *Changes in species distribution: variations in occupation of UTM 10x10 squares between atlases*). For analyses involving several species, we used a distribution change index = (range2nd atlas – range1statlas)/((range2nd atlas+ range1st atlas)/2). This index allowed us to measure distributional increases and declines symmetrically around 0, with maximum decline in the case of extinction as -2, and maximum increase in case of colonisation as +2 (BohningGaese & Bauer 1996). Changes in distribution were also weighted because extinctions and colonisations are not equally reliable in rare and abundant species. Weights were calculated as the logarithm of the mean number of squares occupied in the two atlas (BohningGaese & Bauer 1996). Species consistently using two different habitats were included in the two habitat categories and we assigned to each category half of the corresponding weight in statistical analyses.

It is important to underline the fact that given a low sample size, it was not possible to calculate the distribution change index for some species. Therefore, species lists from the present chapter may appear shorter than in other sections of this Atlas.

Abundance index maps: modelling habitat quality

Mapping spatial bird distribution accurately and consistently is not a straightforward task. Firstly, detecting a species requires considerable effort, which raises logistical limitations when a large area (as usually happens in bird atlases) is under study. Therefore, a trade-off is likely to appear between the spatial coverage of the atlas and the effort put in to cover it. In general, this compromise has led to bird atlases giving complete coverage of the study region but describing occurrence (verified presence vs. inferred absence) at a relatively coarse resolution of 10x10 km (*e.g.* Martí & del Moral 2003) or 50x50 km (*e.g.* Hagemeijer & Blair 1997).

Niche-based models are a simple way of obtaining directly a species-presence probability value for each point in space from available environmental information. Niche-based models make no use of additional species data other than those that collected during the species sampling; the process is based on the fact that species use a restricted combination of environmental parameters that allow us to model their ecological niches (Guisan & Zimmermann 2000). These niche-based models are based on modelling species' response to a set of environmental variables and on the subsequent prediction of their presence in unsampled areas using values for environmental variables (Figure 4). This approach has been widely applied to small spatial scales, however until now, niche-based models have only had limited applications in the mapping of species' distribution at large scales (Osborne & Tigar 1992, Parker 1999, Suarez-Seoane *et al.* 2002).

The modelling approach used in the Catalan Breeding Birds Atlas

For this atlas, we estimated the probability of occurrence of a species by applying niche-based models to the data collected during 1x1 UTM square censuses (3,077 squares in the case of diurnal birds and 1,204 for nocturnal birds). The models developed allowed us to estimate each species' response to the selected environmental variables and thereby obtain the predicted probability of occurrence for each species for a particular combination of those environmental variables.

In addition to species-presence data, the availability of good quality environmental data is essential for implementing niche-based models. Fortunately, over recent years a great deal of work has been done by different institutions such as the Catalan Government, Centre for Ecological Research and Forestry Applications (CREAF: *Centre de Recerca Ecològica i Aplicacions Forestals*) and the Catalan Cartographic Institute (ICC: *Institut Cartogràfic de Catalunya*) on building up high-quality digital databases of environmental information. We used these databases in order to generate pertinent environmental variables that were used as predictors of species' occurrence. These variables were selected to incorporate those factors known *a priori* to determine bird distribution at different spatial scales (Wiens 1989). The different groups of variables (a total number of 45) included in the analysis included habitat/land use variables, climate and relief variables and human influence (see Brotons *et al.* 2004a for more information on the variables included).

A way to account for the unknown variables that may be relevant to species distribution is to use measures of spatial autocorrelation. Spatial autocorrelation depends on the fact that the presence of a species in a given area is not usually independent of whether the species occurs or not in surrounding areas (Vaughan & Ormerod 2003). In these cases, the information on the degree of spatial contagion in species occurrence may be used as a surrogate for environmental information missing from the model. Examples of such missing environmental variables are historical factors. For instance, recently lost areas of a species' distribution that are still suitable for the species may be difficult to identify if they are environmentally similar to others where the species occurs (Brotons *et al.* 2004a). In this case, given that the species would be completely absent from such areas, the use of contagion information may help us include information about the species' current absence in the model. In the Catalan atlas, we used three different contagion variables that are autocovariables as defined in Augustin *et al.* (1996). These contagion variables were calculated for all species and represented an estimate of the mean occurrence of the species around each 1x1 UTM square (Figure 4) including a different number of neighbours in the calculation.

Statistical modelling approach

Different methods based on the estimation of species' ecological niches exist for generating species habitat-suitability maps. A major difference between all these methods is the quality of data needed. Preliminary studies with different methodologies suggested that in our data set the additional information provided by absence data tended to increase the predictive accuracy of niche-based models (Brotons *et al.* 2004a). Therefore, we selected a method that uses both data indicating the presence of species in 1x1 UTM squares and data indicating their absence. We used generalised linear models (GLM) to estimate the probability of a species occurring at a given locality and thus obtain estimates of its relative abundance. GLMs have proven to be robust in a multitude of previous modelling exercises and their predictive

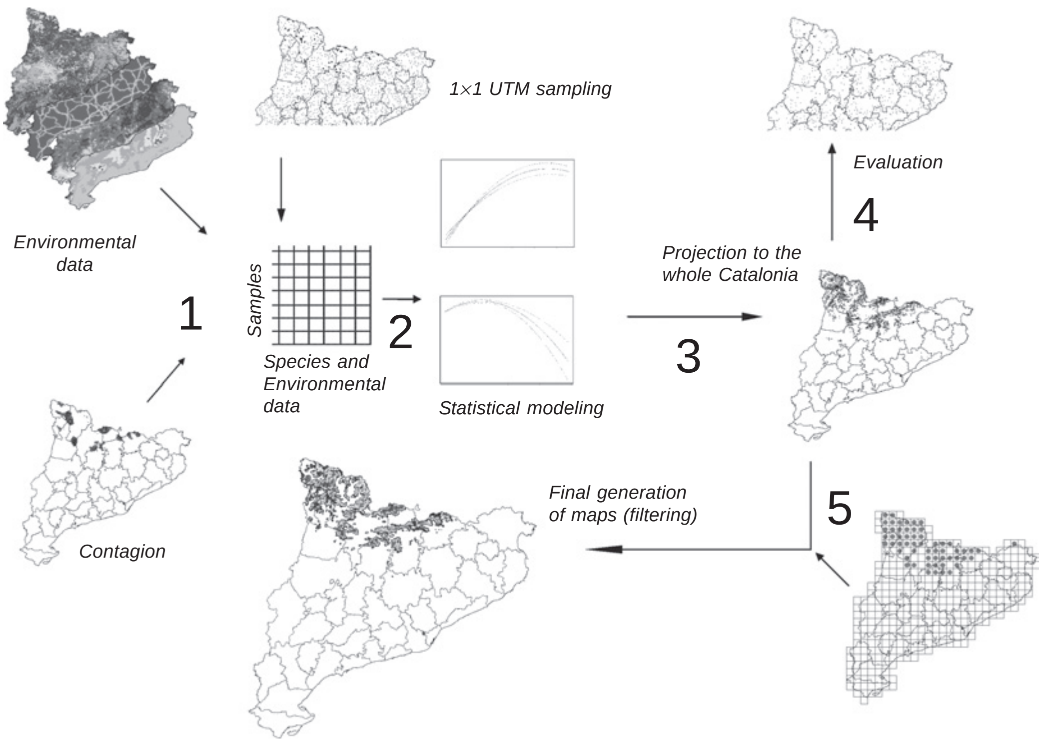

Figure 4. Schematic representation of the methodology used in this atlas to generate abundance index maps (see text for further explanation).
Representació esquemàtica de la metodologia utilitzada en aquest atles per generar els mapes d'índex d'abundància (vegeu text per a més explicacions).

accuracy is generally comparable to that of the much more complex methods mentioned above (Osborne & Tigar 1992, Fielding & Haworth 1995).

In this atlas, GLM were used as predictive rather than explanatory tools; hence the accuracy of model projections is more important than the significance of a particular ecological term (Legendre & Legendre 1998). The main consequence of this approach is that the best environmental models did not always lead to easily interpretable ecological hypotheses. Niche-based models need a minimum set of data to correctly estimate response curves. The selection of minimum sample sizes for developing these models is not easy since the number of observations may interact with sample size to determine model accuracy. In this analysis, we have included niche-based models for species detected at least in 10 1x1 UTM atlas squares.

Evaluation of niche-based models

We used a cross-validation procedure to evaluate the accuracy of model predictions (Guisan & Zimmermann 2000). This procedure consisted of dividing the data (1x1 UTM square surveys) into two different sets by randomly assigning 70% of occurrence values for each species to a calibration data-set and the remaining 30% of occurrences to an evaluation data-set. The calibration dataset was used to develop the niche-based model. The evaluation process consisted of measuring quantitatively to what degree predictions from the models fitted the independent observations that were not used for the development of the model.

A powerful approach is to assess model success across a range of dichotomies from different cut-off points using the receiver operating characteristic (ROC) plots. The ROC plot is based on a series of misclassification matrices computed for a range of cut-offs from 0 to 1. It then plots on the y-axis the true positive fraction against the false positive fraction from the same misclassification matrix (Fielding & Bell 1997). The area under the ROC curve (AUC) is a convenient measure of overall accuracy, and commonly varies between 0.5 (for chance performance) and 1 (perfect discrimination). We obtained the AUC and its standard error with a customised function in the S-Plus software.

Good models are those that reliably predict species presence in unknown sites. The AUC can be interpreted here as a measure that indicates the percentage of classification errors that the model is likely to make once the predictions are compared to the observed occurrences of the evaluation data set. According to previously defined ratings we classified model performance as poor (0.5-0.7), fair (0.7-0-8), good (0.8-0.9) and excellent (0.9-1). The AUC was used as the main indicator of model performance and only models with an AUC higher than 0.7 were included in this atlas.

Final generation of abundance index maps

Once they had been calibrated and evaluated, we proceeded to extrapolate our niche-based models to the unsampled 1x1 UTM squares for which environmental information was available. We projected species-specific niche-based models (logistic formulas) on the whole of Catalonia by means of a Geographical Information System (G.I.S., Arc-View 3.2). The grid maps generated initially had a cell size of 1x1 km (the same resolution as the sampling grid). A new version of the map was then created by reclassifying each pixel grid map to a resolution of 500 m and by applying smoothing that reclassified each value by assigning the mean value of their adjacent neighbours. This smoothing step assumes that the probability of occurrence of a species varies linearly between two points, a seemingly valid assumption given the spatial scale involved.

Many authors consider maps generated by niche-based models to be equivalent to potential distribution maps and not to real distribution maps (Guisan & Zimmermann 2000). As previously commented, due to unrecorded environmental variables, historical factors or habitat fragmentation (among other factors), niche-based models may predict species presence where a given species is certainly known to be absent. Although our models predicted very accurately the occurrence of most species, we decided to include an additional step in the final map production to ensure that the final relative abundance maps corresponded as accurately as possible to real rather than potential distribution maps. This additional step consisted of the application of a filter that would delete zones where the model predicted a species as present outside its known 10x10 UTM distribution range (i.e. taking into consideration the squares were the species was known to be present and all neighbouring squares in direct contact). This step was taken in order to allow for the inclusion in the abundance maps of areas of low relative abundance at the edges of species' distributions where the non-recording of the species in the 10x10 UTM sampling may have occurred for stochastic reasons. All relative abundance maps were filtered and we made sure that the hypothetical occurrence of a species did not appear outside its known distribution range.

The final maps at a resolution of 500 m correspond to the final abundance index maps and measure the estimated probability of occurrence (from 0 to 1) in each 500x500 m unit of the territory within the known distribution of the species in question. Such a probability of occurrence is assumed a surrogate for species abundance and as such is interpreted in the present atlas as a reliable estimator of a species' relative abundance in each square. This assumption seems justified since abundance patterns at small spatial scales are often strongly related to the probability of the occurrence of the species during sampling.

Ecological requirements: graphs and tables

The main objective of any bird atlas is to unravel the distribution of birds in the area under study. Species' ecological requirements, which vary in strictness from one species to another, are described in terms of ranges in temperature, altitude, slope gradients, forest cover, salinity and so forth. In the texts for each species various experts discuss some of the species' main ecological requirements; also included in this section (when available) is information regarding the selection of altitudinal ranges (graph of

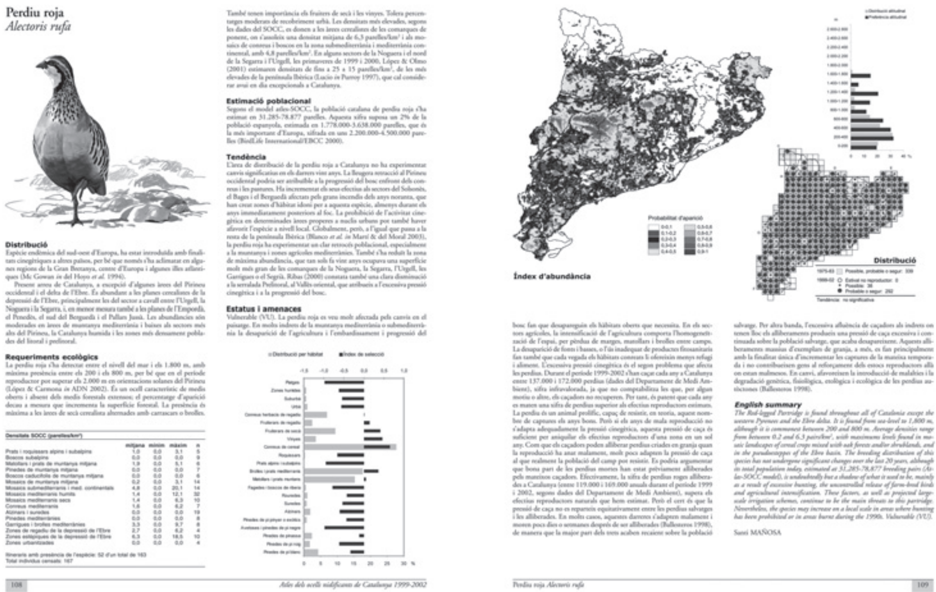

Figure 5. Examples of species accounts, the Red-legged Partridge *Alectoris rufa.* Main text in Catalan with English summary.
Exemple de fitxa d'espècie, la perdiu roja Alectoris rufa. El text principal està en català i el resum en anglès.

altitude) and the use and selection of different landscape types measured at 1x1 km scale (graph of landscape types).

In a mountainous country such as Catalonia, height above sea level is an essential factor in a species' distribution, since it strongly influences climate, vegetation and human activity. The other significant group of environmental characteristics is related to habitats and how they combine to form landscape types. Therefore, both the species' main habitats and the selections they make, as well as abundances in the principal landscape types, are shown whenever possible.

One of the most frequently used parameters in the study of a species' ecological requisites is its abundance or density in different environmental conditions. The launching of the Common Bird Survey in Catalonia (SOCC) in 2002 provided useful data for estimating bird densities in the main landscape types of the country. Data from transects were converted into density estimates and are shown in a table as the mean, maximum and minimum densities for 16 pre-defined landscape types: alpine and subalpine pastures and rocky outcrops, subalpine forests, montane thickets and meadows, montane pine forests, montane deciduous forests, montane mosaics, sub-Mediterranean and continental Mediterranean landscape mosaics, humid Mediterranean landscape mosaics, dry Mediterranean landscape mosaics, Mediterranean farmlands, Holm and Cork Oak forests, Mediterranean pine forests, Mediterranean shrublands, irrigated farmlands in the Ebro depression, steppes in the Ebro depression, and built-up areas.

Population estimates

One of the main objectives of the present atlas was to generate reliable population estimates for the different bird species breeding in Catalonia and thus take an important step towards knowing the conservation status of these species. Generally, due to their scarcity some species have been the target of greater conservation efforts and research institutes, governments and individuals have devoted an important amount of time to try to estimate their populations. This is the case of a number of raptors, wetland and steppe birds, all of which are birds of special conservation concern in our country. The total populations of these species are often known very accurately and are re-evaluated regularly, often on a yearly basis. This atlas is an attempt to unify all the work carried out in these specific monitoring schemes by different research groups.

In spite of this, specific procedures to evaluate population size only exist for a few Catalan breeding species. Thus, new methodologies have had to be designed to address this issue and either consists of data collected by atlas contributors or the combining of data from other monitoring projects such as the Common Bird Survey in Catalonia (SOCC). One of this new methodologies used was the the Atlas-SOCC model. The initial hypothesis under this methodological procedure is that the probability or frequency of occurrence of a species in an area is related to its absolute abundance (see Herrando *et al.* 2008, this proceedings). In cases in which the Atlas-SOCC could not be estimated and accurate population estimates based on direct species censuses were not available, population estimates came from atlas contributors' field data.

Atlas contributors were also asked to estimate the population of each bird species in each 10x10 UTM surveyed. This methodology tries to capture quantitatively contributors' impressions of bird numbers, since, despite not having to count bird numbers, all spent many hours covering the 10x10 square in search of birds. It should be remembered that this method is very subjective and different observers may give distinct values for the same species and square, and it is not necessarily true that overestimates and underestimates compensate one another.

On average, Catalan 10x10 km squares have estimates for 81% of bird species, and 313 squares have more than 75% of their species with at least one population estimate. In squares without estimates for a particular species, we assessed values using the mean of the number of pairs of that species in all Catalan squares. Then, the Catalan population was assessed following the methodology used in the European atlas (Hagemeijer & Blair 1997) based on geometric means as the most reliable estimator of each square's population.

General considerations on population estimates

Population estimates shown in the atlas come from three different sources depending on the species: from specific estimates from particular monitoring projects, from the Atlas-SOCC model or from estimates made on a basis of atlas contributors' field data. We believe that a hierarchy in the accuracy of the estimates exists, with estimates being generally better from the Atlas-SOCC model and poorer from the atlas field estimates. In the species texts the accuracy of each estimate is only given for the Atlas-SOCC model estimates (acceptable, good, very good), whereas every atlas field estimate is taken to be acceptable. In the group of specific estimates by experts, accuracy varies according to the level of current knowledge of the species; this will be much greater in the case of intensively monitored species such as the Bonelli's Eagle than in many poorly monitored passerine species. Nevertheless, in many cases expert specific estimates have the substantial advantage of being focussed on scarce and localised species, whose total populations can often be estimated very accurately.

Another aspect to bear in mind is the different interpretation of the accuracy of estimates (closeness to the real value) and their precision (estimate range); this largely depends on methodology. The atlas field estimates are usually much more precise than the other two estimates, although they are much less accurate.

Species conservation status

Until recently the conservation status of a given species was often decided by using partial criteria based on particular aspects of a species' biology or its population status, rather than a combination of all this information. On some occasions, the conservation status of a species may have been determined by purely non-scientific or social criteria that have more to do with the attractive distinctiveness of the species than its scarcity. Thus, there has been a marked tendency to protect species belonging to bird groups such as the larger raptors or wetland birds, leaving other groups such as small passerines unprotected even in cases where clear and urgent conservation action is required to ensure short-term survival. This bias in the assignment of conservation status is widespread and is not unique to Catalonia, where the Catalan government's Law 3/1988 on wildlife protection and its revision Law 22/2003 tend to give greater conservation priority to spectacular species such as Grey Heron, White Stork, Lammergeier, Griffon Vulture, Golden Eagle, Peregrine and Eagle Owl. However, all of these species except for the Lammergeier have at present relatively secure populations in Catalonia and thus should be of low conservation concern. On the other hand, declining species of critical conservation concern such as Dupont's Lark, Bearded Tit, Lesser Grey Shrike and Reed Bunting have very small populations and hence should have a higher conservation status.

The data in the atlas provide a standardised and objective assessment of the conservation status of the bird species that breed in Catalonia. We decided to follow the IUCN (International Union for Conservation of Nature) criteria applied worldwide (UICN 2001), as well as the regional correctors proposed by Gardenfors *et al.* (2001) and other correctors for species such as raptors whose Catalan densities and population are very small (for the whole procedure, see Estrada *et al.* 2004). The status of each bird species were further discussed with 43 Catalan ornithologists, all experts in different groups of birds and with historical visions of the changes in bird populations that are occurring in Catalonia, and their conclusions were also compared with data provided by the authors of each text.

The categories and main criteria considered for Catalonia are:

- Extinct (EX): A species is considered to be Extinct in Catalonia when there is no doubt that it once bred regularly in Catalonia and that it has now disappeared. Likewise, exhaustive surveys in known or prospective habitats at appropriate times (diurnal, seasonal, annual) throughout its historic range have failed to record any individual.
- Critically Endangered (CR): A species is considered to be Critically Endangered in Catalonia when it is thought to be facing an extremely high risk of extinction, either because of an extremely low population (less than 25 breeding pairs), a population of 25-125 breeding pairs in serious decline, or a larger population in drastic decline with no possibility of spontaneous immigration from nearby populations reversing the trend.
- Endangered (EN): A species is considered to be Endangered in Catalonia when it is thought to be facing a very high risk of extinction, either because of very low population levels (less than 125 breeding pairs), a population of 125-500 breeding pairs in decline, or a larger population in drastic decline with no possibility of spontaneous immigration from nearby populations reversing the trend. Those species that could be considered as Critically Endangered but whose populations could be reinforced by the spontaneous immigration from nearby populations are also classified as Endangered.
- Vulnerable (VU): A species is considered to be Endangered in Catalonia when it is thought to be facing a high risk of extinction, either as a result of low population levels (less than 500 breeding pairs), or by having a higher population but a large decline, or by having a very small distribution, with no possibility of spontaneous immigration from nearby populations reversing the trend. Those species that could be considered as Endangered but whose populations could definitely be reinforced by the spontaneous immigration from nearby populations are also classified as Vulnerable.
- Near Threatened (NT): A species is considered to be Near Threatened in Catalonia when it does not qualify at present for the Critically Endangered, Endangered or Vulnerable categories, but is close to doing so at present or will be in the near future, either because of its small population, a marked decline or a distribution over-concentrated in one area. Those species that would be considered as Vulnerable but whose populations could certainly be reinforced by the spontaneous immigration from nearby populations are classified as Near Threatened. Finally, raptors whose Catalan populations presently have low numbers as a result of their position in trophic chains and their great spatial requirements have been considered only as Near Threatened if no other threatening factors also occur.
- Least Concern (LC): A species is considered to be of Least Concern in Catalonia when it does not qualify for the Critically Endangered, Endangered or Vulnerable categories or, in

case of being initially classified as Near Threatened, if it has numerically important populations in Catalonia and it is thought certain to be reinforced by spontaneous immigration from nearby populations.
- Data Deficient (DD): A species is considered to be Data Deficient when available information does not allow for a direct or indirect assessment of its conservation status and/or risk of extinction.
- Not Evaluated (NE): None of the species that have been artificially introduced into Catalonia since 1900, nor those species that have never bred regularly in Catalonia have been evaluated.

Results and discussion

Patterns of bird distribution and land use changes

In order to generate consistent hypothesis about the main processes affecting changes in bird distribution, consistent patterns across species should be used (BohningGaese & Bauer 1996). Determining the causes of changes in distribution of bird populations is not a trivial task due to the number of not mutually exclusive mechanisms likely to be involved. Different factors may affect bird populations and eventually lead to changes in their spatial distribution. These factors can be of natural origin such as genetic or ecological factors, but also strong climatic events such as cold winters or mild summers may have a strong impact on species demography. Major causes behind changes in bird species distributions have often a direct or indirect human related origin. Human activities may a) directly affect individuals through hunting or contamination, b) transform habitats via exploitation or species translocations or c) indirectly contribute to large scale climatic patterns, all of which may have different impact on bird populations (Thomas & Lennon 1999, Gaston *et al.* 2003). Recent reviews have identified global warming, biological invasions and changes in land use patterns as major threats to biodi-

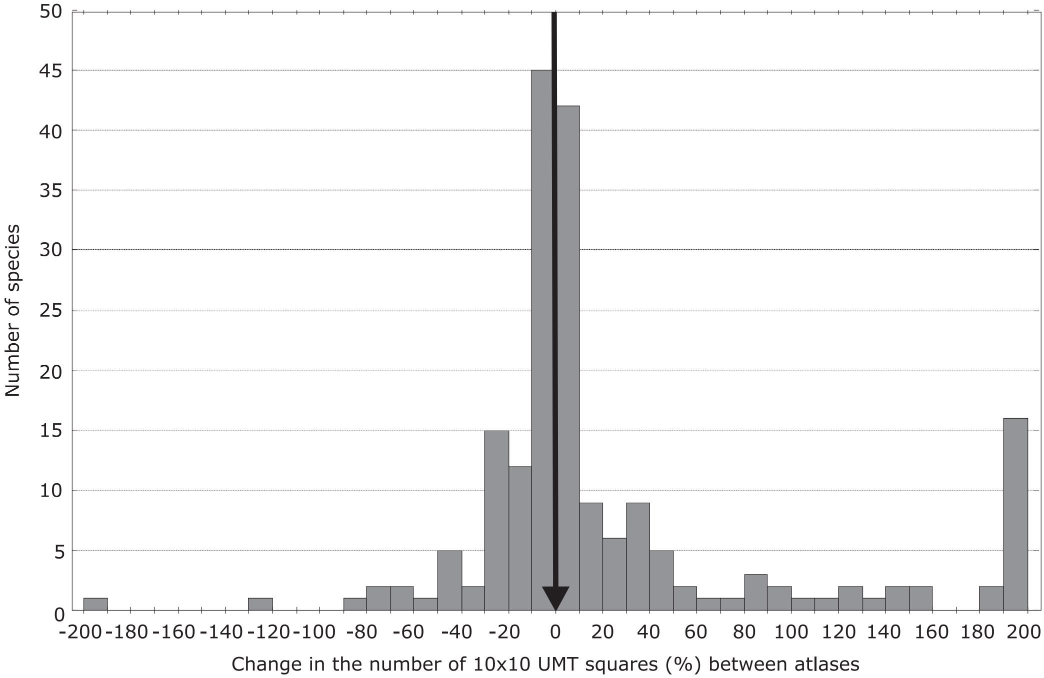

Figure 6. Frequency distributions of changes in the number of 10x10 UTM squares occupied by each species between the two atlases.
Distribucions de freqüència dels canvis en el nombre de quadrats UTM 10x10 ocupats per cada espècie entre els dos atles.

versity at a global scale during the coming years. These studies point out also that Mediterranean systems may be especially sensitive to these changes because future projections point towards an especially strong and simultaneous impact of many of these factors (Tucker & Evans 1997, Sala *et al.* 2000).

Patterns of change in breeding birds

A remarkable result of the present atlas is the number of introduced species detected in Catalonia. Up to 10 species were detected, although only three of them were present in more than 10 UTM squares.

Amongst indigenous species from which changes in distribution could be estimated using changes in the number of occupied 10x10 UTM, we suggest that Catalan bird fauna has suffered remarkable changes during the last 20 years (Figure 6). Changes in distribution did not show a homogeneous pattern of change, and rather were dependent on the different habitat selection of the considered groups ($F_{5,176}$=4.04, $p<0.01$). While species of shrublands, steppe-like extensive agricultural areas, forests and specially wetland habitats showed a clear tendency to expand their distributions, farmland and alpine species showed a marginal tendency to shrink their distributional range (Figure 7). Other species (mainly raptors) showed a consistent tendency to increase in distribution area (Figure 7). We did not detect a significant effect of the migratory behaviour in the overall species distribution change ($F_{2,176}$=1.08, n.s.), nor within each habitat category ($F_{10,188}$=0.88, n.s.).

Spatial patterns of bird distribution changes according to habitat use

Analysis of the distributional changes of different bird groups in Catalonia between the two atlases supports the hypothesis that changes have not been homogeneous throughout the territory and some areas have suffered more marked variations than others.

We describe the spatial pattern of distribution change for some example groups including species that either have increased their overall distribution (expanding species group, having significantly $p<0.05$ increased the number of occupied 10x10 UTM squares, or by at least

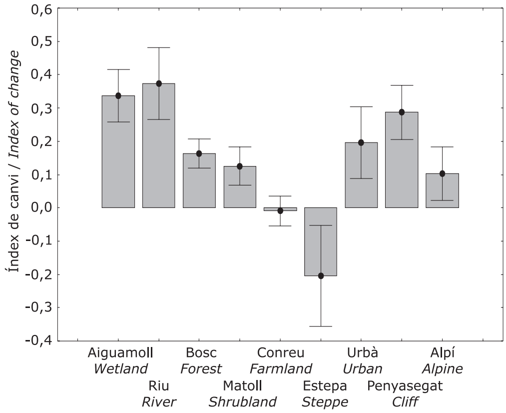

Figure 7. Mean index of distribution change according to the habitat categories of the species. Change index = (range2nd atlas – range1statlas)/((range2nd atlas+ range1st atlas)/2). This index measures distributional increase or decline symmetrically around 0, with maximum decline in the case of extinction as -2, and maximum increase in case of colonisation as +2.
Índex de la mitjana de canvi en la distribució d'acord amb la categoria d'hàbitat de les espècies. Índex de canvi: (distribució2n atles – distribució1er atles)/((distribució2n atles+ distribució1er atles)/2). Aquest índex permet mesurar els increments i decrements en la distribució de forma simètrica al voltant de 0: -2 significaria un valor de regressió màxim (extinció) i +2 un valor d'increment màxim (colonització).

having a 20% increase) or that have decreased their overall distribution (contracting species group, having significantly $p<0.05$ decreased the number of occupied 10x10 UTM squares, or by at least having a 20% decrease). Alternative hypotheses behind the observed patterns of change are discussed. We have restricted the analyses described above to forest and farmland species groups.

Forest species

• Increasing forests species

Forest species that experienced significant increases in range in Catalonia according to the comparison between atlases (Table 2) have expanded most in central and eastern parts of the territory. These species have only shown minor changes in the western half of Catalonia (Figure 8). Abandonment of traditional farming activities leads to forest colonisation, but at the same time, creates a lower rate of exploitation of forest resources due to low economic benefits. Therefore regions have more forest, but more important is the increase in maturity and

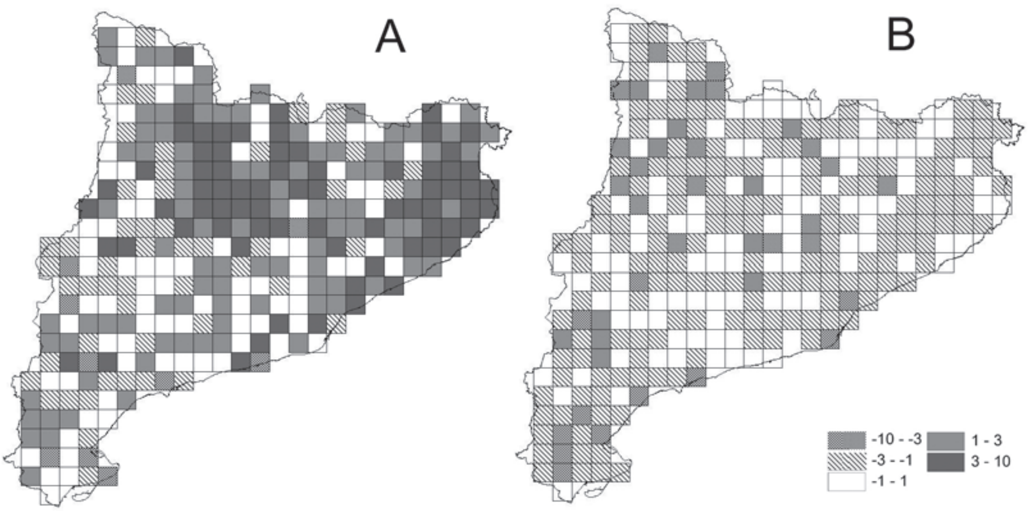

Figure 8. Spatial representation of changes in species distribution of (A) increasing and (B) decreasing forest species between the two breeding bird atlases (periods 1975-1983 and 1999-2002).
Representació espacial dels canvis en la distribució entre els dos atles d'ocells nidificants (períodes 1975-1983 i 1999-2002): (A) espècies forestals en augment i (B) espècies forestals en disminució.

complexity of vegetation structure. This maturation may have allowed strict forest species such as the nuthatch or some woodpecker species to colonise new forest areas that might have been not used due to lack of appropriate vegetation structure (Camprodon 2003). Increases in bird populations inhabiting core forest habitats may in turn result in a surplus of individuals that disperse to other areas not necessarily of recent origin but just happen to be near population source areas (Donald & Fuller 1998). Overall the results suggest further investigation and careful examination of forest species expansion patterns in Catalonia in the light of current and predicted expansion and maturation of forested habitats in the area (Preiss *et al.* 1997).

• Decreasing forests species

Forest species contracting in range showed a rather homogeneous spatial pattern with the decreases being in large areas of the coast, and western pre-Pyrenees. Only some areas located in central Catalonia, north-east coast and inland south, escape the general decreasing tendency (Figure 8).

Decreasing forest species (*e.g.* Stock Dove, Turtle Dove, Green Woodpecker) seem to be species that to some extent depend on the availability of nearby open habitats to gather some essential resources, especially food (Brotons *et al.* 2004). Given the importance of open habitats for forest species, distributional changes may be related to changes occurring in those open habitats (either agricultural, shrubs or both) surrounding the forests where the species breed, or to variation in landscape heterogeneity and the relative composition of different habitat type in the landscape (Dunning *et al.* 1992).

Farmland species

• Increasing farmland species

Farmland species with expanding distributions concentrated increases in agriculture areas in western and inland Catalonia and in two coastal areas nearer the central and northern coastline (Figure 9). Minor decreases of otherwise increasing farmland species seemed apparent in southern areas and in more local areas in the north. Positive changes for this group seemed to have concentrated in areas with lower proportions of wooded farmland in the 80's indicating that expansions have mostly occurred in mosaic farmland areas due to changes occurring within these habitats (Estrada *et al.* 2004). To some degree, these changes may be associated with changes in agricultural activities leading to intensification in the area as suggested by the positive relationship between farmland bird expan-

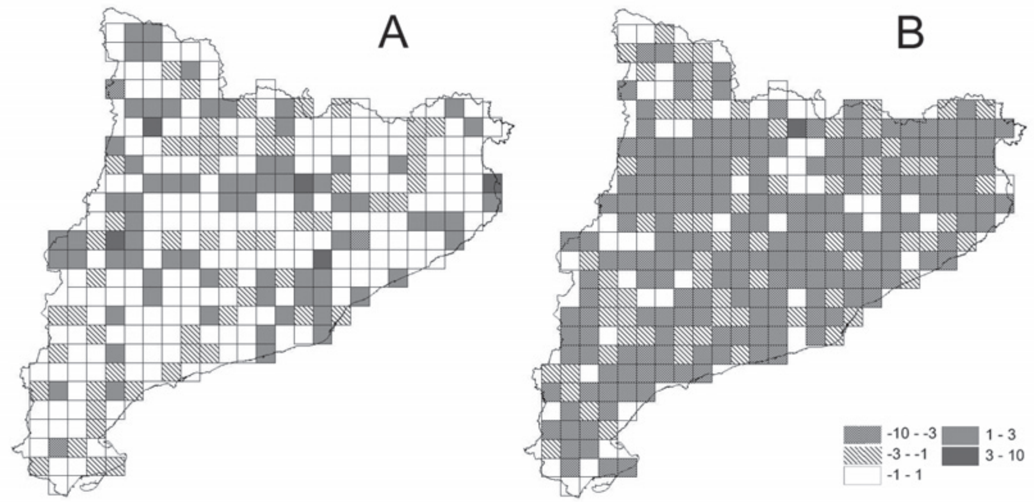

Figure 9. Spatial representation of changes in species distribution of (A) increasing and (B) decreasing farmland species between the two breeding bird atlases (periods 1975-1983 and 1999-2002).
Representació espacial dels canvis en la distribució entre els dos atles d'ocells nidificants (períodes 1975-1983 i 1999-2002): (A) espècies de medis agrícoles en augment i (B) espècies de medis agrícoles en disminució.

sion and the amount of urban and suburban habitats in 1987. Expanding farmland species tended to increase more in areas with relatively high proportion of forests in the 80's indicating that generalist species already using diverse landscapes with a high proportion of forests seemed to suffer less from the changes occurred and rather may have partially benefited from them.

• Decreasing farmland species

Farmland species with significant range contractions showed a very consistent pattern in distributional change, with apparent higher loss of species in the Mediterranean coastal and precoastal area. Inland, losses appeared to be high in western regions (Figure 9). Decreases in farmland species were larger in open herbaceous farmland with relatively higher amounts of forest habitat in the landscape (Estrada *et al*. 2004). This suggests that decreases in habitat quality of the already marginal farmland habitats may have been important here or alternatively, that decreases in the permeability of the landscape to farmland birds due to forestation may play an important role. An additional predictor of farmland species loss in Catalonia appears to be the amount of tree crop cover in 1987. These results suggest that agricultural areas containing tree crops may prove to be important habitats for decreasing farmland species. In fact, recent changes in agriculture have meant large changes in the tree species cropped in Mediterranean areas (loss of almond trees, increase in olive trees). The results suggest that socioeconomic processes occurring within these farmland habitats may be critical to a number of farmland species which certainly merits further investigation (Calvet *et al.* 2004).

The results of the present atlas on distribution changes of farmland birds in Catalonia are in line with the results found elsewhere in central Europe on the negative effects of agricultural intensification on farmland bird community (Fuller *et al.* 1995, Gates & Donald 2000, Donald *et al.* 2001). However, particularities of Mediterranean agricultural mosaics should be considered here. The pattern of change seems to be less intense than the one found in the previous studies, stressing the fact that agricultural practices in the Mediterranean may be less harmful for birds due to its less intensive character. Future research should identify the proximate reasons affecting populations at different stages of life cycle for different focal species in these habitats, with a special focus on the role of habitat heterogeneity on species occurrence, which has been recently identified as a key factor behind biodiversity loss in farmland systems (Benton *et al.* 2003).

Conclusions

The distribution of Catalan avifauna has been far from stable during the last 20 years and significant changes have occurred in a large number of species. Changes were often concentrated in particular areas, which greatly differed according to the habitat selection of the different groups and their general distribution trends. This result stresses the importance of taking into account variation in sampling effort to analyse temporal variations in distributions.

Differences in sampling effort were by far the most significant single predictor of the detected differences between the two atlases (Estrada *et al.* 2004). However, and in spite of the broad character of the categorisation employed, the results also provide strong evidence that the observed changes in distribution patterns between the two atlases are to some degree linked to parallel changes in landscape composition during this period or to changes in the quality of specific habitats. In particular, wetland management, forest maturation, fire regime and changes in agricultural practices appear amongst the most powerful driving factors of bird distribution changes in Catalonia during the 20-year interval.

The methodology used in this atlas is a powerful tool for mapping complete species distribution from a detailed standardised grid. Furthermore, it will allow for a simple visual interpretation of changes in species' distribution at a local scale in future atlases. Since changes in land-use and climatic patterns will be captured by future GIS layers, new niche-based models generated from new data and future distribution maps depicting new conditions will be able to be produced.

Although not entirely new, the modelling approach used by this atlas represents one of the first applications of niche-based models to the generation of high-resolution species distribution maps. The accuracy of the model's predictions and the possibility of objective model evaluation make this methodology a robust tool that will undoubtedly be incorporated into faunal cartography.

In spite of the promising results obtained, our analysis is clearly a tentative first step towards the identification of causal hypotheses behind distribution changes in Catalan bird populations. In addition to land use patterns and their temporal changes, other factors are surely critical to explain the changes in the distribution of a particular species group. Amongst these factors, climate change and the impact of invasive species should be considered further. Other unforeseen factors are likely to affect particular species and therefore should be treated on a species per species basis. The identification and quantification of causes behind population and distribution changes in birds is essential to help in their understanding and conservation. We hope that the data included in the atlas and this preliminary analysis help to guide future approaches.

These future studies should be conducted on focal species or groups to further explore main patterns and the mechanisms causing them. Combination of different data from different bird monitoring programs may help fill gaps in our knowledge. The availability of other monitoring programmes lead by ICO such as SOCC (Common Bird Survey), SYLVIA (Constant Effort Ringing Sites), PERNIS (Raptor Migration) and available environmental information including satellite data will crucially contribute to this objective.

Acknowledgements

The results described in this manuscript depend on the work of more than five hundred volunteers. We would like to thank their invaluable effort. We would also thank for the support given by the Government of Catalonia by means of *Departament de Medi Ambient i Habitatge* and by *Obra Social Caixa Catalunya*. This research is a contribution to the Montpellier-Barcelona LEA "Mediterranean Ecosystems in a Changing World" and has been supported by the Marie Curie programme within the 6th European Community Framework.

Resum

Atles dels ocells nidificants de Catalunya: aspectes metodològics i implicacions ecològiques

El primer atles dels ocells nidificants de Catalunya, publicat a principis dels vuitanta del segle passat, va cobrir en una quadrícula UTM de 10x10 km una àrea de 32.000 km^2 situada al nordest d'Espanya, constituint una experiència pionera en relació a la

cartografia d'ocells en la conca Mediterrània. Ara es presenten les novetats i els principals resultats del nou atles dels ocells nidificants de Catalunya, portat a terme 20 anys després, en el període 1999-2002. Aquest nou atles va incorporar una sèrie d'innovacions metodològiques entre les quals cal ressaltar els censos de temps controlat en una mostra de quadrats UTM 1x1 km dintre de cadascun dels quadrats UTM 10x10 km. Aquests censos a petita escala (al voltant de 3.200) van permetre un mostreig uniforme del voltant del 10% de l'àrea d'estudi, i van possibilitar així la producció de mapes de distribució d'espècies a escala local (a 500x500 m de resolució). Aquests mapes van ser generats a través de regressions logístiques en el marc dels models de nínxol ecològic. En el nostre cas aquests models van incloure informació de 45 variables ambientals que van des dels usos del sòl i el relleu a la influència humana i el clima; d'altra banda es va incorporar informació sobre l'estructura espacial de les dades per tal d'incorporar l'efecte de l'autocorrelació espacial. Actualment, aquest atles està entre els millors treballs de mapatge quantitatiu de les distribucions d'ocells a Europa. D'altra banda, es van utilitzar les dades dels censos en quadrats UTM 1x1 km per a produir corbes d'acumulació d'espècies en el temps i estimar així el nombre d'espècies que es poden trobar en cada quadrat UTM 10x10 km per unitat de temps. L'aplicació d'aquests models per al primer i el nou atles va permetre una estimació dels canvis en la distribució dels ocells tenint en compte les diferències en l'esforç de mostreig (temps emprat en el cens d'un determinat quadrat) entre els dos períodes. En general, el nou atles proporciona una de les millors imatges dels canvis a gran escala ocorreguts en l'avifauna del sud d'Europa durant els últims 20 anys. Els resultats obtinguts donen suport fermament a la hipòtesi que en aquest període hi ha hagut canvis de distribució molt destacats, sovint associats a modificacions en els usos del sòl.

Resumen

Atlas de las aves reproductoras de Catalunya: aspectos metodológicos e implicaciones ecológicas

El primer atlas de las aves reproductoras de Cataluña, publicado a principios de los años ochenta del siglo pasado, cubrió en una cuadrícula UTM de 10x10 km un área de 32.000 km^2 situada en el nordeste de España, constituyendo una experiencia pionera en relación a la cartografía de aves en la cuenca Mediterránea. Ahora presentamos las novedades y los principales resultados del nuevo atlas de aves reproductoras de Cataluña, llevado a cabo 20 años después, en el período 1999-2002. Este nuevo atlas incorporó una serie de innovaciones metodológicas entre las que hay que resaltar los censos de tiempo controlado en una muestra de cuadrículas UTM 1x1 km dentro de cada una de las cuadrículas UTM 10x10 km. Estos censos a pequeña escala (alrededor de 3.200) permitieron un muestreo uniforme de alrededor del 10% del área de estudio, posibilitando así la producción de mapas de distribución de especies a escala local (a 500x500 m de resolución). Estos mapas fueron generados a través de regresiones logísticas en el marco de los modelos de nicho ecológico. En nuestro caso estos modelos incluyeron información de 45 variables ambientales que van desde los usos del suelo y el relieve a la influencia humana y el clima; por otro lado se incorporó información sobre la estructura espacial de los datos para incorporar el efecto de la autocorrelación espacial. Actualmente, este atlas está entre los mejores trabajos de mapeo cuantitativo de las distribuciones de aves en Europa.

Asimismo, se utilizaron los datos de los censos en cuadrículas UTM 1x1 km para producir curvas de acumulación de especies en el tiempo y estimar así el número de especies que se pueden encontrar en cada cuadrícula UTM 10x10 km por unidad de tiempo. La aplicación de estos modelos para el primer y el nuevo atlas permitió una estimación de los cambios en la distribución de aves teniendo en cuenta las diferencias en esfuerzo de muestreo (tiempo empleado en el censo de una determinada cuadrícula) entre los dos períodos. En general, el nuevo atlas proporciona una de las mejores imágenes de los cambios a gran escala ocurridos en la avifauna del sur de Europa durante los últimos 20 años. Los resultados obtenidos apoyan firmemente la hipótesis de que en este período ha habido cambios de distribución muy destacados, a menudo asociados a modificaciones en los usos del suelo.

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