



UNIVERSITAT DE BARCELONA



Departament de Biologia Animal
Facultat de Biologia
Universitat de Barcelona



Departamento de Ecología Evolutiva
Museo Nacional de Ciencias Naturales
Consejo Superior de Investigaciones Científicas

Spatial and temporal migratory patterns of trans-Saharan birds in the Iberian Peninsula

Memòria presentada per Oscar Gordo Villoslada
per optar al títol de Doctor

Programa de doctorat: Zoologia
Bienni 2002-2004

El doctorand

Oscar Gordo Villoslada

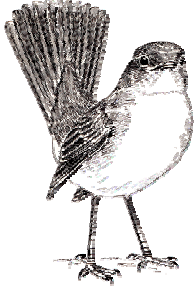
Vist i plau dels Directors

Dr. Xavier Ferrer Parareda

Dr. Juan José Sanz Cid

Dr. Lluís Brotons i Alabau

Barcelona, Juliol 2006



Chapter 4

Climate change and bird phenology: a long-term study in the Iberian Peninsula

Oscar Gordo^{1,2}, Juan José Sanz²

¹ Departament de Biologia Animal (Vertebrats), Universitat de Barcelona.

² Departamento de Ecología Evolutiva, Museo Nacional de Ciencias Naturales (CSIC).

ABSTRACT

Many studies in recent years have demonstrated long-term temporal trends in biological parameters that can only be explained by climate change. Bird phenology has received great attention, as it studies one of the most conspicuous, popular, and easily observable phenomena in nature. There are many studies of long-term changes in spring arrival dates, most of which concur with earlier records from the last few decades. However, few data are available for autumn departures or length of stays. Furthermore, existing data offer an equivocal picture. In this study, we analysed a huge database of about 44,000 records for five trans-Saharan bird species (*Ciconia ciconia*, *Cuculus canorus*, *Apus apus*, *Hirundo rustica*, and *Luscinia megarhynchos*). Data were collected from over 1300 sites around Spain during the period 1944-2004. Common spring arrival patterns were found in all species. Spring arrival dates have tended to advance since the mid-1970s. Current dates are similar to those from the 1940s (except for *C. ciconia*). Thus, the advance of spring migration over the last three decades could be seen as a return to the initial timing of arrival dates, after abnormally delayed arrivals during the 1970s. A strong negative relationship with temperature in Spain at arrival time was observed in all species. A negative relationship with the Sahel Index (a measurement of precipitation in the African Sahel area during the rainy season) for the previous year was also found in *C. canorus*, *A. apus* and *H. rustica*. Regarding autumn departures, all species showed common interdecadal fluctuations, but only *H. rustica* is leaving earlier Spain at present. All species departed earlier in years that had higher temperatures during their reproductive period. However, only for *H. rustica* the relation between Spanish temperatures at departure time and the last sightings of individuals was significant. A heterogeneous temporal response for the length of stay was also found: *C. ciconia* increased, *A. apus* did not change and *H. rustica* decreased its stay. This is the first study, based on an extensive bird phenology observational network covering a large region, that shows the most complete and thorough analysis available for the Mediterranean region.

INTRODUCTION

Long-term phenological changes have been used as irrefutable evidence that most plant and animal species are currently reacting to climate change (Parmesan & Yohe, 2003; Root *et al.*, 2003). In most cases, these responses are correlated with changes in ambient temperature (IPCC, 2001; Root *et al.*, 2005).

Many biological features of birds, such as: migratory behaviour (Sparks, 1999); breeding performance (Crick *et al.*, 1997); fitness components (Sanz *et al.*, 2003); population dynamics (Sæther *et al.*, 2000); or geographical distribution (Thomas & Lennon, 1999) have been significantly linked to climate change. Most published studies look at migratory behaviour. They examine temporal changes in the arrival of migrants to their breeding grounds. Such studies indicate that the arrival time is advancing (Sanz, 2002; Crick, 2004; Lehikoinen *et al.*, 2004). This supports the hypothesis that an earlier arrival is advantageous for individuals, as spring begins earlier in their breeding grounds (e.g. Menzel *et al.*, 2001). However, few studies have analysed temporal changes in the autumn departure of migrants and no clear patterns have been found. This suggests that there is probably a highly specific component in species' responses, due to the different selective pressures acting on them (Gatter, 1992; Jenni & Kéry, 2003).

Most bird phenological studies have relied on records from local field stations or from historical data sets collected systematically (Whitfield, 2001). Therefore, most have used data from only one site. The observed results could not be extrapolated for a whole region. Most of the results reported to date come from central and northern Europe (Sanz, 2002; Crick, 2004). Only long term time-series have been analysed from two Mediterranean localities (Peñuelas *et al.*, 2002; Gordo *et al.* 2005; Gordo & Sanz, 2005). Most western European migrants arrive at breeding grounds throughout the Iberian Peninsula. Huin and Sparks (1998, 2000) showed that barn swallows (*Hirundo rustica*), nightingales (*Luscinia megarhynchos*) and spotted flycatchers (*Muscicapa striata*) arrive in Britain early after warmer Marches and Aprils in the Iberian Peninsula. Therefore, it is important to obtain conclusive results about the

impact of climate on bird migration in this region. This study presents some data to fill this gap. We analysed a huge database of bird migratory behaviour, covering hundreds of Spanish sites over the last 60 years. This study examined whether some migratory birds show long-term changes in their migratory behaviour in the Spanish part of the Iberian Peninsula, and whether these changes can be attributed to climate change.

MATERIAL AND METHODS

Bird phenological database

In 1942, the *Instituto Nacional de Meteorología* (INM) created a monitoring network to study phenology in Spain. The aim was to better understand the timing of the seasons and to improve agricultural practices, like in other European countries (Germany, Menzel *et al.*, 2001; UK, Huin & Sparks, 1998). This phenological network is still in operation. It is probably one of the most successful long-term volunteer monitoring programs in Europe. Since 1943, hundreds of volunteer observers have been recording phenological plant and animal events, using standard observation rules and a list of common, popular and easily identifiable species (Anon., 1943). These individual observers simply pay attention to plants and animals in streets, parks, gardens, fields or forests in or around their home cities and towns. They record all observable phenological events throughout the year, with no special emphasis on a particular season or species. Such observations are simple and easy, as INM proposed species which have favourable characteristics for a volunteer phenological monitoring programme: *i*) species are widespread throughout Spain (everyone in the country is a potential observer); *ii*) they are abundant (observation of phenological events is not constrained by the number of individuals and no special effort is required to observe them), *iii*) they have an unmistakable morphology and/or behaviour (everybody knows them, which makes data highly reliable). Therefore, this methodology ensures that data are highly homogeneous, enabling all collected records from different observers to be compared.

The migratory behaviour of five trans-Saharan bird species (white stork *Ciconia ciconia*; cuckoo *Cuculus canorus*; common swift *Apus apus*; barn swallow and nightingale) was selected and proposed by the INM as a potential bioindicator of the timing of seasons. The species monitored are some of the most common and abundant migrants in the Iberian Peninsula (Martí & Del Moral, 2003). These species' spring phenology was measured by the date the first individuals were detected in the study sites each year. For the white stork, common swift and barn swallow, detection was defined as the first sighting of an individual member of the local population. For less conspicuous species (cuckoo and nightingale) it was defined as the first singing male heard. The autumn phenology of the white stork, common swift and barn swallow was monitored by means of the last individual sighted in the study sites. A third phenological variable could also be defined for these three species: the length of the stay. This new variable was calculated as the number of days between the first and the last sighting of individuals, when both records were available for the same site and the same phenological year.

We collected and computerized all available records of these five species' spring and autumn phenology. Data were checked to eliminate incorrectly recorded single values, which could have resulted from human error in recording dates or in the computerization process. A database of about 44000 records remained after this data quality check. Data came from sites all around Spain (1384 sites) and was collected from 1944 to 2004. Each date was transformed into a Julian day (1 = 1 January), taking into account leap-years. In leap years, one day was added after February 28.

Information about UTM coordinates (longitude and latitude) and altitude (m a.s.l.) from each observer's site was also available. We used them to account for the observed variability in arrival dates, caused by the broad geographical range of used sites and thus to prevent spatial gradients (Legendre *et al.*, 1993). For this purpose, we constructed a multiple regression model with these variables as predictors and recorded dates for each species and phenophase as dependent variable. Quadratic terms were also included to identify non-linear patterns only in those cases in which they were significant.

The interaction between latitude and longitude was also included. Hence, arrival dates were corrected for their spatial position, giving fully comparable values of a species' early or late arrivals from different sites since within year variability were removed. For each species and phenophase, the residuals were averaged by year to obtain a unique annual phenological value for Spain. Years with less than 20 observations were not included. These time-series were used hereinafter for statistical analyses.

Climate data

To evaluate the impact of climate on spring arrivals, we took into account climate data from both breeding and wintering grounds. Spain's climate in the spring was measured as the average of the mean monthly temperature for the best adjusted two months to the arrival date of each species. Therefore, the average of temperatures for January and February was used for the white stork and the average of March and April temperatures was used for the other species.

The effect of the African wintering grounds' climate was evaluated by means of rainfall in the Sahel. Previous studies have pointed out the importance of wintering conditions for trans-Saharan species. Such conditions affect subsequent life cycle traits (e.g. spring arrivals, Gordo *et al.*, 2005; reproductive success, Saino *et al.*, 2004; or sexual selection, Møller, 2004). Interannual variability in Western African rainfall was seen to be the main driver of changes in spring phenology for some species analysed in a previous study of one Spanish site (Gordo *et al.*, 2005). We wanted to test whether these results could be generalized to most Iberian populations of these species. Therefore we used the Sahel Index, a synthetic measure of precipitation anomalies in the Sahel. Such anomalies have already been quantified by some authors (Nicholson, 1979; Tarhule & Lamb, 2003; Dai *et al.*, 2004) and are available at http://tao.atmos.washington.edu/data_sets/sahel/ for the years 1898 to 2004. This index is derived from the average deviation from monthly rainfall at 14 meteorological stations located in the western part of this region (10°N-17°N and 18°W-6°E). The average of monthly Sahel Index values was calculated for the rainy season (i.e. June to October; Dai *et al.*, 2004).

The influence of climate on autumn departures was evaluated by examining monthly temperatures during two phases of the bird's stay in Spain. The hypothetical delaying effect of climate on departures was tested using the mean temperature for Spain during breeding months (April to June). Better climatic conditions during hatching and/or when raising juveniles may accelerate this phase, which in turn could advance subsequent stages of the vital cycle (e.g. second clutches) until departure time (Lack, 1958; Ellegren, 1990). In addition, we controlled for the potential prompt and direct effect of climate on departures, including temperatures during the month birds leave Iberia. The best-adjusted month, according to the mean value for the whole departure of each species, was selected to examine the direct effect of climate on departure. Therefore, August was selected for the white stork and the common swift, and September for the barn swallow.

Statistical analyses

The analyses can be divided into two parts. Firstly, the existence of temporal trends were tested in all three phenological phases (arrivals, departures and stays) by means of a multiple regression model for each species including only year and its quadratic term (when it was significant) as predictors. Secondly, we examined the effect of climatic variables on temporal trends in arrival and departure dates by means of another multiple regression model for each species including only those selected climatic variables (see above). All analyses were conducted with STATISTICA (StatSoft, 2001).

RESULTS

Temporal trends

With exception of the nightingale, spring arrival dates for all species showed significant temporal trends during the last six decades (Table 4.1). The white stork had the best model. Its arrival dates showed the most pronounced changes with advancement about 40 days over the study period. This advance occurred over the last twenty years in particular (Fig. 4.1). In the rest of species, arrival dates at present are similar to those ones reported during the 1940s-50s (Fig. 4.1). However, for the common swift and the barn swallow a notable delay

in their arrivals was noticed during the early 1970s, with a clear trend towards the advance since that time (approximately 6 days for the common swift and 13 days for the barn swallow). Singing dates for the cuckoo and nightingale were always fitted to a narrow band in the first and second weeks respectively of April. The maximum interannual difference recorded in the last six decades has been about 12 days (Fig. 4.1).

Species	Annual records	Mean	year	<i>P</i>	Squared year	<i>P</i>	r^2	<i>F</i>	df	<i>P</i>
<i>Arrivals</i>										
White Stork	88	29.4	57.85	<0.001	-0.015	<0.001	0.754	86.04	2,56	<0.001
Cuckoo	104	95.6	11.66	0.039	-0.003	0.040	0.132	3.94	2,52	0.025
Common Swift	94	109.6	16.41	0.013	-0.004	0.014	0.140	4.55	2,56	0.015
Barn Swallow	182	82.1	38.14	<0.001	-0.010	<0.001	0.387	17.96	2,57	<0.001
Nightingale	53	107.1	0.020	0.353			0.016	0.88	1,55	0.353
<i>Departures</i>										
White Stork	45	226.4	0.04	0.187			0.030	1.78	1,57	0.187
Common Swift	69	239.2	-0.05	0.080			0.052	3.17	1,58	0.080
Barn Swallow	110	264.4	-0.06	<0.001			0.201	14.33	1,57	<0.001
<i>Stays</i>										
White Stork	41	197.7	-47.80	<0.001	0.012	<0.001	0.838	131.67	2,51	<0.001
Common Swift	57	127.5	-0.05	0.291			0.020	1.14	1,56	0.291
Barn Swallow	93	181.3	-22.11	0.012	0.006	0.012	0.318	13.31	2,57	<0.001

Table 4.1 Results of the multiple regression models for temporal trends in phenological data. The mean number of records per year employed, the mean (arrivals and departures in Julian day, stays number of days), the values of the slope and its significance in the linear and quadratic term of the year, and the final model explanatory capacity (r^2), F-test (*F*), degrees of freedom (df) and its significance are indicated in each case.

Only departure dates of the barn swallow showed a significant temporal trend (Table 4.1) in spite of the clear interannual fluctuations observed in all three species (Fig. 4.2). In all species, an advancement of departures was recorded until mid-1960s. During the next twenty years a certain trend to leave later the breeding grounds was observed (Fig. 4.2). Since mid-1980s individuals are departing earlier, being this especially patent in the common swift and barn swallow (Fig. 4.2).

The picture offered by the length of the stay was quite different for the white stork, the common swift and the barn swallow (Fig. 4.3) due to the peculiar interannual fluctuations in each species' arrivals and departures. The length of the stay in the white stork showed really the best explicative temporal model (Table 4.1). Since the 1970s it has increased more than 1 month. In the

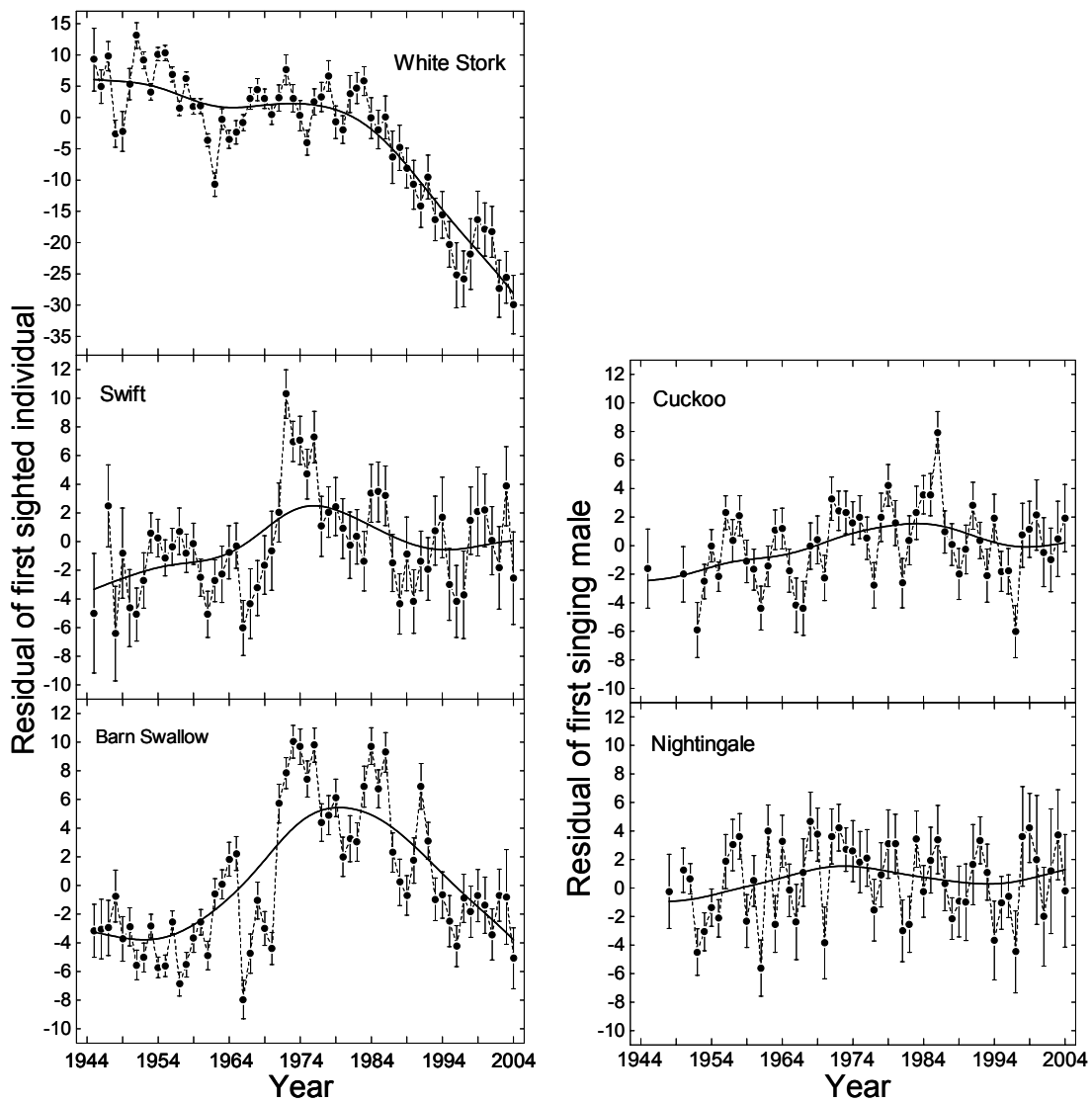


Figure 4.1 Temporal trends for the residuals once the geographical variability was removed of the first individuals of the white stork, cuckoo, common swift, barn swallow and nightingale to be detected. Black dots are the mean residual for each year and bars are standard error. A distance-weighted smoothed line (least squares method; Statsoft, 2001) has been superimposed to emphasize the underlying trend (solid line). X-axis units = days.

case of the barn swallow, despite of the same sign in the parameters of the model, a clear break point appears in the early 1970s which reduced about 15 days the length of the stay. Since then, a slight trend toward the increase of this period has been recorded. The common swift did not show significant temporal trends.

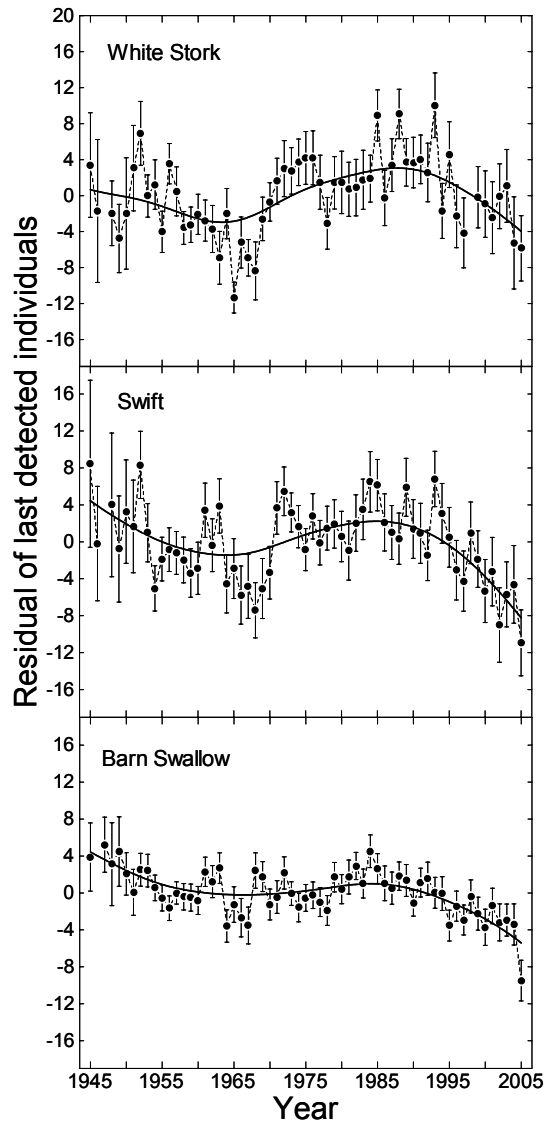


Figure 4.2 Temporal trends for the residuals once the geographical variability was removed of the last detected individuals of the white stork, common swift and barn swallow. Black dots are the mean residual for each year and bars are standard error. A distance-weighted smoothed line (least squares method; Statsoft, 2001) has been superimposed to emphasize the underlying trend (solid line). X-axis units = days.

Relationships with climate

Spring arrival dates of all species showed highly significant models with climatic variables accounting up to 56% of variability. In all cases, temperatures in Spain during arrival month were included. The negative sign of the relationships means that individuals arrived earlier in warmer years. The effect of climate in wintering ground was also significant in the cuckoo, the common swift and the barn swallow. In these three cases, the effect was also negative.

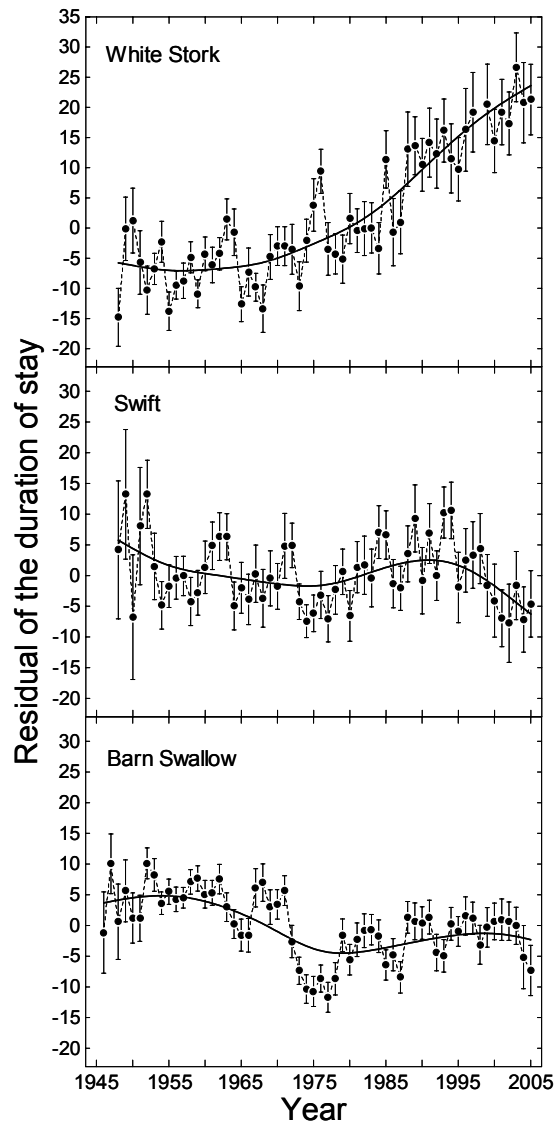


Figure 4.3 Temporal trends for the residuals once the geographical variability was removed of the length of the stay of the white stork, common swift and barn swallow. Black dots are the mean residual for each year and bars are standard error. A distance-weighted smoothed line (least squares method; Statsoft, 2001) has been superimposed to emphasize the underlying trend (solid line). X-axis units = number of days.

Therefore, wet years in the Sahel region were linked to earlier detections of individuals.

Climatic effects on departures were much less strong than climatic effects on arrivals. A trend towards earlier departures after warmer springs was found in all three species studied (Table 4.2), although in the case of common swift this relationship was non-significant. The prompt and direct effect of temperatures during the month of departures was only significant in the case of

Species	Arrival temperature		Sahel Index		Multiple regression model			
	b	P	b	P	r ²	F	df	P
<i>Arrivals</i>								
White Stork	-3.453	0.015	0.035	0.136	0.150	4.93	2,56	0.011
Cuckoo	-1.758	<0.001	-0.014	0.005	0.511	27.17	2,52	<0.001
Common Swift	-1.671	<0.001	-0.016	0.023	0.308	12.48	2,56	<0.001
Barn Swallow	-2.041	<0.001	-0.052	<0.001	0.564	36.85	2,57	<0.001
Nightingale	-1.505	<0.001	-0.006	0.301	0.272	10.07	2,54	<0.001
	Reproduction temperature		Departure temperature		Multiple regression model			
	b	P	b	P	r ²	F	df	P
<i>Departures</i>								
White Stork	-1.837	0.005	0.299	0.599	0.131	4.21	2,56	0.020
Common Swift	-1.165	0.074	-0.411	0.476	0.075	2.32	2,57	0.108
Barn Swallow	-0.675	0.047	0.487	0.016	0.155	5.13	2,56	0.009

Table 4.2 Results of the multiple regression models for climatic effects in phenological data. The values of the slope (b) and its significance (P) for climatic variables and the final model explanatory capacity (r²), F-test (F), degrees of freedom (df) and its significance are indicated in each case.

barn swallow. This species trends to depart later in years with warmer Septembers.

DISCUSSION

General remarks

This is the first study assessing the impacts of climate change on temporal trends in the migratory behaviour of a large number of populations in the Mediterranean region. Furthermore, no study on bird migration has used such an extensive number of records and sites (but see: Sparks & Braslavská, 2001; Forchhammer *et al.*, 2002; Ptaszky *et al.*, 2003). Recently, some authors have attempted to compare data covering part of Europe (Sparks *et al.*, 2005). This study used high quality records, but too few sites were considered for such a wide range of geographical, environmental and climatic conditions. Despite the coherent patterns of advances in spring migration reported in most of the studies and for most species (Sokolov *et al.*, 1998; Sparks, 1999; Tryjanowski *et al.*, 2002; Hüppop & Hüppop, 2003; Lehikoinen *et al.*, 2004; Zalakevicius *et al.*, 2006), more caution is required when extrapolating conclusions. Only

studies that involve a large number of time-series and represent a wide range of conditions would be conclusive (Forchhammer *et al.*, 2002).

Two aspects of our database could be criticised: 1) records belong to a broad range of geographical (from 9.05°E to 3.22°W, from 36.02°S to 43.68°N, from 3 to 1730 m a.s.l) and environmental conditions (from the most arid Mediterranean to wet Eurosiberian); 2) data were provided by hundreds of amateur observers. However, results indicate that these facts do not seem to be problematic. In spite of the enormous heterogeneity of the data, changes in the year to year timing of migration of the species studied are large enough to be detected. This heterogeneity could include opposite responses in different regions (Gordo *et al.*, 2005; Gordo & Sanz, 2005), which can make it difficult to detect global effects. Additionally, the first arrival date (or last departure date) may in itself be another source of bias, as indicated in many studies (Sparks *et al.*, 2001; Tryjanowski & Sparks, 2001; Lehikoinen *et al.*, 2004). However, the drift effect that may be induced by recording the first individual in a single site does not occur in our study. Our study is not subject to the aberrant or anomalous, non-representative migratory behaviour of one individual as we worked with many records per year (in some cases over 400). Therefore, interannual changes in the first arrival date for the whole of Spain are not subject to the bias effect of data on the first individual. They reflect a real trend of earlier or later arrivals of these first individuals in many Spanish populations in a certain year. Thus, results offer a real picture of the timing of migration each year. The errors or vagueness in some records (an unavoidable problem when working with large databases) are absorbed by the vast sample size employed.

Most of the previous studies assessing temporal trends in migratory behaviour and the relation of such trends to climatic changes have the advantage of analysing a large number of species. This is due to the great monitoring effort undertaken by specialists at a single site (e.g. 81 species in Vähätalo *et al.*, 2004; 65 in Jenni & Kéry, 2003; 60 in Loxton *et al.*, 1998; 46 in Gatter, 1992; 40 in Zalakevicius *et al.*, 2006; 39 in Sparks & Mason, 2001). Our study showed trends in only five species. These species are common, popular and widespread enough throughout Spain to be recorded by anybody, with no

search effort and no specific abilities. However, in our opinion, these species are heterogeneous enough (in size, timing of migration, food supplies, habitat preferences, or reproductive performance) to indicate a common temporal signal in the majority of trans-Saharan migrants.

Spring arrivals

Spring migration did not advance steadily; there were decadal fluctuations (i.e., polynomial patterns). Current arrival dates are similar or even seem to be a bit later (see the cuckoo, common swift and nightingale in Fig. 4.1) to those occurring at the beginning of the study period (except for the white stork). Therefore, caution is required when interpreting results, to avoid drawing erroneous conclusions about changes in the migratory behaviour of bird species. In this study, the advance in arrival date recorded over the last few decades should be better interpreted as a trend toward re-establishing the timing of migration after an anomalous period of delayed arrivals during the 1970s-80s.

Despite of our purely correlational analyses, spring temperatures in Spain (Fig. 4.4) seem to be an important driver of the observed interannual fluctuations in arrivals for all species. This result is in agreement with most of the previous studies (Loxton *et al.*, 1998; Sokolov *et al.*, 1998; Sparks, 1999; Sparks & Mason, 2001; Tryjanowski *et al.*, 2002; Zalakevicius *et al.*, 2006). The earlier arrivals related to higher temperatures should be due to the advancement of the spring course in the Iberian Peninsula and consequently the presence of ecological suitable conditions for an early colonization of first breeders. In basis to the found relationship, we thus may hypothesize that predicted future warming (IPCC, 2001; de Castro *et al.*, 2005) will favour earlier arrival dates. African climate was also significantly related to some species' arrivals. The negative relation indicates that dry years in the Sahel were associated with later arrivals of Spanish populations. In arid environments such as the Sahel, water availability is a restrictive factor (Winstanley *et al.*, 1974; Svensson, 1985; Mullié *et al.*, 1995; Shine, 2003; Gordo *et al.*, 2005). Wet years enhance ecological conditions in the region, due to higher plant productivity

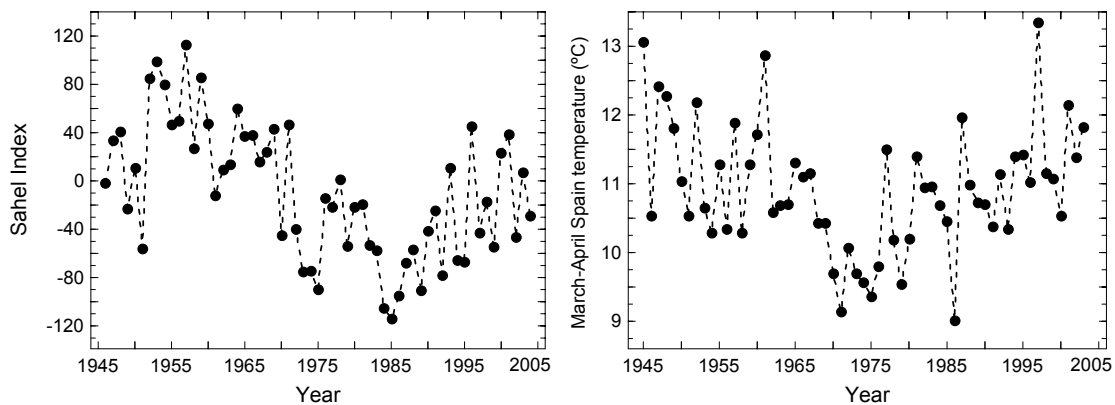


Figure 4.4 Annual values of the Sahel Index during the rainy season (June to October) and the average temperature of Spain for March and April.

(Nicholson *et al.*, 1990; Herrmann *et al.*, 2005). This leads to a greater abundance of insects, which are food resources for insectivorous birds (such as our studied species; Winstanley *et al.*, 1974). In the case of the white stork, the amount of rainfall also directly affects the availability and extension of wetlands. Wetlands are a key ecosystem for the stork's survival (Mullié *et al.*, 1995; Brouwer *et al.*, 2003; Shine, 2003). Increased food supplies can benefit species in two ways: *i*) they increase winter survival rates; *ii*) they enhance the winter moult and the chances of obtaining the necessary fat reserves prior to the beginning of the spring migration and/or during the journey. Both of these factors, either individually or together, would result in advanced arrival dates. If winter survival rates increased, there would be more individuals, which would increase the chance of early observations. In the second case, birds would complete their journey in less time, as they would have improved feathers and body condition and/or enhanced environmental conditions en route, which in turn may reduce stopover times. Furthermore, the northern limit reached by the monsoons in dry years is at lower latitudes, moving transitional regions between desert and savannah some hundreds of kilometres southward. This notably increases spring migration distances over the Sahara (Winstanley *et al.*, 1974; Svensson, 1985). Therefore, recent earlier arrivals for some species are induced by a combination of climate warming in Spain and improved ecological conditions in the Sahel region of Africa, as a result of the end of a drought period.

One of the most notable results in our data was the great delay in arrival dates of the common swift and barn swallow during the years 1970-72 (see Fig. 4.1). An examination of the climatic variables shows that the Sahel Index was very low between 1969 and 1971 (see Fig. 4.4). In parallel, the subsequent springs in Spain for those years (i.e. 1970-72) were three consecutive and extremely cold seasons (see Fig. 4.4). The mean temperature for March and April (the mean arrival months of these species) of these three years was only 9.1°C. The mean temperature at this time in the rest of study years was 10.5°C ($t_{57} = 2.59$; $P = 0.012$). We suggest that the pronounced delay in arrivals from 1970-72 was due to the synergistic effect of extremely unfavourable conditions both in wintering and breeding areas. In the case of the barn swallow, the effect of these three successive bad years seems to have been especially long-lasting, as it has only arrived on similar dates to those previous to 1970 in recent years.

Autumn departures

The last sighting of a migratory species is more difficult to interpret than the first sighting. It is probably affected by the same sources of bias as the first arrival date (it is the tail of a population size-dependent distribution). Hence, it could be argued that it is not representative of the real autumn migratory behaviour of the whole population. Furthermore, intrinsically, it is a less precise measure than first arrival date. The behaviour of individuals prior to departure is generally more cryptic than during spring arrivals (e.g. there is an absence of singing activity; although barn swallows make large roosts prior to migrating in flocks) and it therefore requires more attention. Despite these difficulties, there were strong interdecadal oscillations in all species (see Fig. 4.2) although only in the barn swallow these had a significant temporal trend.

There is a lack of data for the last sighting of individuals, as indicated in previous studies. Bird departures attract less attention than arrivals, as they are a less conspicuous phenomenon. Few time-series to date have analysed the phenology of autumn migration (Harmata, 1980; Gatter, 1992; Bezzel & Jetz, 1995; Sokolov *et al.*, 1999; Bairlein & Winkel, 2001; Sparks & Braslavská, 2001; Sparks & Mason, 2001; Gilyazov & Sparks, 2002; Cotton, 2003; Jenni & Kéry,

2003; Witt, 2004; Gordo & Sanz, 2005), and evidence of delays or advances are equivocal. Although our broad study was only carried out with three species, similar temporal patterns were found for all of them during certain decades (see Fig. 4.3). Since the beginning of the eighties, the common trend has been towards an advance in departure dates (which agrees with long-distance migrant results of Jenni & Kéry, 2003). This advance in autumn departures is probably indirectly affected by phenological changes in arrivals (but see: Kosicki *et al.*, 2004) through intermediate phases of the life cycle. Individuals arrive earlier, reproduce earlier (Crick *et al.*, 1997; Sokolov & Payevsky, 1998; Both & Visser, 2001), and due to the nexus between reproduction and autumn departure (Lack, 1958; Ellegren, 1990; Sokolov 2000; Bojarinova *et al.* 2002) then depart earlier, to take advantage of the benign environmental conditions in the Sahel at the end of the rainy season in October (Morel, 1973; Gatter, 1992; Jenni & Kéry, 2003). This hypothesis may explain the negative relations found between reproductive period temperatures and departure dates (see Table 4.2). But it is difficult to understand how climate change can be related to temporal trends in autumn phenology, if weak direct (temperature at departure time) and indirect (temperature affecting the timing of reproduction) relations exists.

Length of stay

The consequences of long-term changes in the time between arrivals and departures has been assessed in very few studies (Bairlein & Winkel, 2001; Sparks & Braslavská, 2001; Sparks & Mason, 2001; Gilyazov & Sparks, 2002; Cotton, 2003; Gordo & Sanz, 2005), despite the biological implications that fluctuations in this measure should have on the species' life cycle. An increase in length of stay should be advantageous to reproduction, as it increases fledgling survival and chances of second or third broods. A reduction should be disadvantageous for the opposite reasons (unfortunately, no data about reproductive success of the species studied are available to test this hypothesis). However, species can also maintain this part of their life cycle constant, regardless of changes in migratory behaviour. We studied few species, but the variation in their responses seems to disagree with the general trend towards increased stays reported previously (Bairlein & Winkel, 2001;

Sparks & Mason, 2001; Gilyazov & Sparks, 2002). If we look at the results for the common swift and barn swallow in such studies, variation between sites is also observed. It is therefore quite difficult to draw conclusions, as each species showed a different pattern over the last 60 years. Thus, there is an interesting, but complex, picture of possible heterogeneous responses of stay length to climate change.

The special case of the white stork

This species showed the greatest rates of advance in their spring arrivals, inducing the greatest changes in the length of stay. These results concur with a study of this species in Poland (Ptaszyk *et al.*, 2003; but see Czyżowicz & Konieczny, 2001; Zalakevicius *et al.*, 2006), even though this was clearly a different population with different migratory pathways and wintering areas (Bernis, 1959; Fiedler, 2001).

The presence of wintering individuals in Iberia has been repeatedly reported since many decades ago (Duclós, 1956; Cruz-Valero, 1964). The occurrence of wintering individuals in other places in the Mediterranean basin is also well-known (Van den Bosche, 2002). Therefore, there have always been some individuals both in western and eastern European populations that do not overwinter in Africa. This non-migratory behaviour seems to be spreading. Over the last decade, increasing numbers of individuals have been recorded in Iberia during the winter (Tortosa, 1992; Máñez *et al.*, 1994; Tortosa *et al.*, 1995; Anon., 1997; Tortosa *et al.*, 1997). Wintering has also been reported in other western Mediterranean areas (Archaux *et al.*, 2004, in France; Samraoui & Houhamdi, 2001, in Algeria). Human-induced environmental changes (e.g., increases in the numbers of rubbish dumps) have been proposed as the origin of this apparent trend toward settlement of the white stork (Máñez *et al.*, 1994; Tortosa *et al.*, 1995; Tortosa *et al.*, 2002; Peris, 2003; Archaux *et al.* 2004). However, recent climate change may also favour this settlement, due to milder winters (Mata *et al.*, 2001). The notable advance in spring arrivals, recorded since the 1980s, could be due to individuals that remained in the Iberian Peninsula or North Africa during the winter (Máñez *et al.*, 1994; Tortosa *et al.*, 1995), thus reducing strongly their migratory journeys (Fiedler, 2001). This

hypothesis has been proposed as an explanation for earlier spring arrivals in migratory birds (Coppack & Both, 2003; Coppack *et al.*, 2003). Therefore, we suggest that the major changes in spring phenology reported in the populations studied since the 1980s reflect changes in migratory behaviour. Changes in migratory behaviour may be due to selective pressures acting on the white stork. Individuals that migrate to Afrotropics are faced with many hazards, which have a negative effect on their survival and probably on their reproductive success. Bad ecological conditions in the Sahel, resulting from hard droughts until the mid-1980s (see Fig. 4.4; Dai *et al.*, 2004; Herrmann *et al.*, 2005), improved human hunting activity in sub-Saharan countries (Thauront & Duquet, 1991); the degradation of wetlands used for resting and thermoregulation (Mulli e *et al.*, 1995; Brouwer *et al.*, 2003; Shine 2003); and expenditure of time and energy on a longer journey, due to the southward expansion of the Sahara desert (Tucker *et al.*, 1991; Mulli e *et al.*, 1995; Nicholson, 2001), are some examples of the migration costs for this species. Individuals that remained in Iberia or North Africa, benefit from: mild winters; guaranteed food supplies from rubbish dumps; an increase in populations of the invasive red swamp crayfish *Procambarus clarkii* (M a ez *et al.*, 1994; Tortosa *et al.*, 1995; Tortosa *et al.*, 2002; Peris, 2003); and better opportunities to adjust their spring arrivals to the spring course in the breeding grounds. Thus non-migrant white storks benefit from many factors. It is therefore likely that the absence of migratory behaviour is increasing in Spanish populations. Consequently, earlier arrivals are detected.

REFERENCES

- Anonymous (1943) *Atlas de plantas para las observaciones fenol gicas*. Servicio Meteorol gico Nacional – Secci n de Climatolog a, Madrid.
- Anonymous (1996) I censo invernal de Cig e a Blanca en Espa a. *La Garcilla*, **96**, 42-43.
- Archaux F, Balan a G, Henry PY, Zapata G (2004) Wintering of White Storks in Mediterranean France. *Waterbirds*, **27**, 441-445.
- Bairlein F, Winkel W (2001) Birds and climate change. In: *Climate of the 21st Century: Changes and Risks* (eds Lozan JL, Gra l H, Hupfer P), pp. 278-282. Scientific Facts, GEO, Hamburg.
- Bernis F (1959) La migracion de la cig e as espa olas y de las otras cig e as 'occidentales'. *Ardeola*, **5**, 9-80.

- Bezzel E, Jetz W (1995) Verschiebung der Wegzugperiode bei der Monchsgrasmucke (*Sylvia atricapilla*) 1966-1993 – Reaktion auf die Klimaerwärmung. *Journal für Ornithologie*, **136**, 83-87.
- Bojarinova JG, Rymkevich TA, Smirnov OP (2002) Timing of autumn migration of early and late-hatched Great Tits *Parus major* in NW Russia. *Ardea*, **90**, 401-409.
- Both C, Visser ME (2001) Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature*, **411**, 296-298.
- Brouwer J, Mullié WC, and Scholte P (2003) White Storks *Ciconia ciconia* wintering in Chad, northern Cameroon and Niger: a comment on Berthold *et al.* (2001). *Ibis*, **145**, 499-501.
- Coppack T, Both C (2003) Predicting life-cycle adaptation of migratory birds to global climate change. *Ardea*, **90**, 369-377.
- Coppack T, Pulido F, Czisch M, Auer DP, and Berthold P (2003) Photoperiodic response may facilitate adaptation to climate change in long-distance migratory birds. *Proceedings of the Royal Society of London-Series B*, **270**, 43-45.
- Cotton PA (2003) Avian migration phenology and global climate change. *Proceedings of the National Academy of Sciences USA*, **100**, 12219-12222.
- Crick HQP (2004) The impact of climate change on birds. *Ibis*, **146**, 48-56.
- Crick HQP, Dudley C, Glue DE, Thomson DL (1997) UK birds are laying eggs earlier. *Nature*, **388**, 527-527.
- Cruz-Valero, A (1964) Primeras observaciones de Cigüeñas en 1962 y 1963 en Badajoz. *Ardeola*, **9**, 137.
- Czyżowicz W, Konieczny K (2001) Terminy przylotów i odlotów wybranych gatunków ptaków w okolicach wsi Brzózka (powiat Wolów) w latach 1947-1985. *Ptaki Śląska*, **13**, 126-129.
- Dai A, Lamb PJ, Trenberth KE, Hulme M, Jones PD, Xie PP (2004) The recent Sahel drought is real. *International Journal of Climatology*, **24**, 1323-1331.
- de Castro M, Martín-Vide J, Alonso S (2005) El clima de España: pasado, presente y escenarios de clima para el siglo XXI. In: *Evaluación preliminar de los impactos en España por efecto del cambio climático* (ed Moreno Rodríguez JM), pp 1-65. Ministerio de Medio Ambiente, Madrid.
- Duclós, C (1956) Permanencia de *Ciconia ciconia* en nuestra península. *Ardeola*, **3**, 304.
- Ellegren H (1990) Timing of autumn migration in bluethroats *Luscinia svecica svecica* depends on timing of breeding. *Ornis Fennica*, **67**, 13-17.
- Fiedler W (2001) Large-scale ringing recovery analysis of European White Storks (*Ciconia ciconia*). *Ring*, **23**, 73-79.
- Forchhammer MC, Post E, and Stenseth NC (2002) North Atlantic Oscillation timing of long- and short-distance migration. *Journal of Animal Ecology*. **71**, 1002-1014.
- Gatter W (1992) Zugzeiten und Zugmuster im Herbst: Einfluß des Tribhauseffekts auf den Vogelzug? *Journal für Ornithologie*, **133**, 427-436.
- Gilyazov A, Sparks TH (2002) Change in the timing of migration of common birds at the Lapland Nature Reserve (Kola Peninsula, Russia) during 1931-1999. *Avian Ecology and Behaviour*, **8**, 35-47.
- Gordo O, Brotons L, Ferrer X, Comas P (2005) Do changes in climate patterns in wintering areas affect the timing of the spring arrival of trans-Saharan migrant birds? *Global Change Biology*, **11**, 12-21.
- Gordo O, Sanz JJ (2005) Phenology and climate change: a long-term study in a Mediterranean locality. *Oecologia*, **146**, 484-495.

- Grishchenko V, Serebryakow V, Galinska I (1995) Phanologie des Weissstorchzuges (*Ciconia ciconia*) in der Ukraine. *Vogelwarte*, **38**, 24-34.
- Harmata W (1980) Phenological dynamics of arrivals and departures on migratory birds in Cracov, Poland, and the environments in the 19th and 20th century. *International Journal of Biometeorology*, **24**, 137-140.
- Herrmann SM, Anyamba A, Tucker CJ (2005) Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, **15**, 394-404.
- Huin N, Sparks TH (1998) Arrival and progression of the swallow *Hirundo rustica* through Britain. *Bird Study*, **45**, 361-370.
- Huin N, Sparks TH (2000) Spring arrival patterns of the Cuckoo *Cuculus canorus*, Nightingale *Luscinia megarhynchos* and Spotted Flycatcher *Muscicapa striata* in Britain. *Bird Study*, **47**, 22-31.
- Hüppop O, Hüppop K (2003) North Atlantic Oscillation and timing of spring migration in birds. *Proceedings of the Royal Society of London-Series B*, **270**: 233-240.
- IPCC (2001) Climate change 2001: impacts, adaptation, and vulnerability. In: *Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (eds McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS), Cambridge University Press, Cambridge.
- Jenni L, Kéry M (2003) Timing of autumn bird migration under climate change: advances in long-distance migrants, delays in short-distance migrants. *Proceedings of the Royal Society of London-Series B*, **270**, 1467-1471.
- Kosicki J, Sparks TH, Tryjanowski P (2004) Does arrival date influence autumn departure of the White Stork *Ciconia ciconia*? *Ornis Fennica*, **81**, 91-95.
- Lack D (1958) The return and departure of swifts *Apus apus* at Oxford. *Ibis*, **100**, 477-502.
- Legendre P (1993) Spatial autocorrelation: trouble or new paradigm? *Ecology*, **74**, 1659-1673.
- Lehikoinen A, Sparks TH, Zalakevicius M (2004) Arrival and departure dates. *Advances in Ecological Research*, **35**, 1-31.
- Loxton RG, Sparks TH, Newnham JA (1998) Spring arrivals dates of migrants in Sussex and Leicestershire (1966-1996). *The Sussex Bird Report*, **50**, 181-196.
- Máñez M, Tortosa FS, Barcell M, Garrido H (1994) La invernada de la cigüeña blanca en el suroeste de España. *Quercus*, **105**, 10-12.
- Martí R, Del Moral JC (2003) *Atlas de las aves reproductoras de España*. Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología, Madrid.
- Mata AJ, Caloin M, Michard-Picamelot D, Ancel A, Le Maho Y (2001) Are non-migrant white storks (*Ciconia ciconia*) able to survive a cold-induced fast? *Comparative Biochemistry and Physiology A – Molecular and Integrative Physiology*, **130**, 93-104.
- Menzel A, Estrella N, Fabian P (2001) Spatial and temporal variability of the phenological seasons in Germany from 1951 to 1996. *Global Change Biology*, **7**, 657-666.
- Møller AP (2004) Protandry, sexual selection and climate change. *Global Change Biology*, **10**, 2028-2035.
- Morel GJ (1973) The Sahel zone as an environment for Palaearctic migrants. *Ibis*, **115** 413-417.
- Mullié WC, Brouwer J, Scholte P (1995) Numbers, distribution and habitat of wintering White Storks in the eastcentral Sahel in relation to rainfall, food and anthropogenic influences. In: *Proceedings of the International Symposium on the White Stork (Western Population), Basel Switzerland, 7-10 April 1994* (eds Biber O, Enggist P, Marti C, Salathé T), pp 219-240. Schweizerische Vogelwarte Sempach, Switzerland.

- Nicholson SE (1979) Revised rainfall series for the West African subtropics. *Monthly Weather Review*, **107**, 620-623.
- Nicholson SE (2001) Climatic and environmental change in Africa during the last two centuries. *Climate Research*, **17**, 123-144.
- Nicholson SE, Davenport ML, Malo AR (1990) A comparison of the vegetation response to rainfall in the Sahel and east Africa, using normalized difference vegetation index from NOAA AVHRR. *Climatic Change*, **17**, 209-241.
- Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421**, 37-42.
- Peñuelas J, Filella I, Comas P (2002) Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biology*, **8**, 531-544.
- Peris S (2003) Feeding in urban refuse dumps: Ingestion of plastic objects by the White Stork (*Ciconia ciconia*). *Ardeola*, **50**, 81-84.
- Ptaszyk J, Kosicki J, Sparks TH, Tryjanowski P (2003) Changes in the timing and pattern of arrival of the white stork (*Ciconia ciconia*) in western Poland. *Journal für Ornithologie*, **144**, 323-329.
- Root TL, MacMynowski DP, Mastrandrea MD, Schneider SH (2005) Human-modified temperatures induce species changes: Joint attribution. *Proceedings of the National Academy of Sciences USA*, **102**, 7465-7469.
- Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA (2003) Fingerprints of global warming on wild animals and plants. *Nature*, **421**, 57-60.
- Sæther BE, Tufto J, Engen S, Jerstad K, Rostad OW, Skåtan JE (2000) Population dynamical consequences of climate change for a small temperate songbird. *Science*, **287**, 855-856.
- Saino N, Szép T, Ambrosini R, Romano M, Møller AP (2004) Ecological conditions during winter affect sexual selection and breeding in a migratory bird. *Proceedings of the Royal Society of London-Series B*, **271**, 681-686.
- Samraoui B, Houhamdi M (2002) L'hivernage de la cigogne blanche *Ciconia ciconia* en Algérie. *Alauda*, **70**, 221-223.
- Sanz JJ (2002) Climate change and birds: have their ecological consequences already been detected in the Mediterranean region? *Ardeola*, **49**, 109-120.
- Sanz JJ, Potti J, Moreno J, Merino S, Frías O (2003) Climate change and fitness components of a migratory bird breeding in the Mediterranean region. *Global Change Biology*, **9**, 461-472.
- Shine T (2003) The conservation status of eastern Mauritania's ephemeral wetlands and their role in the migration and wintering of black storks (*Ciconia nigra*). *Aves*, **40**, 228-240.
- Sokolov LV (2000) Spring ambient temperature as an important factor controlling timing of arrival, breeding, post-fledging dispersal and breeding success of Pied Flycatchers *Ficedula hypoleuca* in Eastern Baltic. *Avian Ecology and Behaviour*, **5**, 79-104.
- Sokolov LV, Markovets MY, Morozov YG (1999) Long-term dynamics of the mean date of autumn migration in passerines on the Courish Spit of the Baltic Sea. *Avian Ecology and Behaviour*, **2**, 1-18.
- Sokolov LV, Markovets MY, Shapoval AP, Morozov YG (1998) Long-term trends in the timing of spring migration of passerines on the Courish Spit of the Baltic Sea. *Avian Ecology and Behaviour*, **1**, 1-21.
- Sokolov LV, Payevsky VA (1998) Spring temperatures influence year-to-year variations in the breeding phenology of passerines on the Courish Spit, eastern Baltic. *Avian Ecology and Behaviour*, **1**, 22-36.

- Sparks TH (1999) Phenology and the changing pattern of bird migration in Britain. *International Journal of Biometeorology*, **42**, 134-138.
- Sparks TH, Bairlein F, Bojarinova JG, Hüppop O, Lehikoinen E, Rainio K, Sokolov LV, Walker D (2005) Examining the total arrival distribution of migratory birds. *Global Change Biology*, **11**, 22-30.
- Sparks TH, Braslavská O (2001) The effects of temperature, altitude and latitude on the arrival and departure of the swallow *Hirundo rustica* in the Slovak Republic. *International Journal of Biometeorology*, **45**, 212-216.
- Sparks TH, Mason CF (2001) Dates of arrivals and departures of spring migrants taken from Essex Bird Reports 1950-1998. *Essex Bird Report*, **1999**, 154-164.
- Sparks TH, Roberts DR, Crick HQP (2001) What is the value of first arrival dates of spring migrants in phenology? *Avian Ecology and Behaviour*, **7**, 75-85.
- StatSoft Inc. (2001) STATISTICA (data analysis software system), version 6. www.statsoft.com.
- Svensson SE (1985) Effects of changes in tropical environments on the north European avifauna. *Ornis Fennica*, **62**, 56-63.
- Tarhule A, Lamb PJ (2003) Climate research and seasonal forecasting for West Africans: perceptions, dissemination, and use? *Bulletin of the American Meteorological Society*, **84**, 1741-1759.
- Thauront M, Duquet M (1991) Distribution et conditions d'hivernage de la cigogne blanche *Ciconia ciconia* au Mali. *Alauda*, **59**, 101-110.
- Thomas CD, Lennon JJ (1999) Birds extend their ranges northwards. *Nature*, **399**, 213-213.
- Tortosa FS (1992) Censo invernal de cigüeña blanca *Ciconia ciconia* en la provincia de Córdoba durante 1989 y 1990. *Oxyura*, **6**, 95-96.
- Tortosa FS, Caballero JM, Reyes-López J (2002) Effect of rubbish dumps on breeding success in the White Stork in southern Spain. *Waterbirds*, **25**, 39-43.
- Tortosa FS, Máñez M, Barcell M (1995) Wintering white storks (*Ciconia ciconia*) in South West Spain in the years 1991 and 1992. *Vogelwarte*, **38**, 41-45.
- Tryjanowski P, Kuźniak S, Sparks TH (2002) Earlier arrival of some farmland migrants in western Poland. *Ibis*, **144**, 62-68.
- Tryjanowski P, Sparks TH (2001) Is the detection of the first arrival date of migrating birds influenced by population size? A case study of the red-backed shrike *Lanius collurio*. *International Journal of Biometeorology*, **45**, 217-219.
- Tucker CJ, Dregne HE, Newcome WW (1991) Expansion and contraction of the Sahara desert from 1980 to 1990. *Science*, **253**, 299-301.
- Vähätalo AV, Rainio K, Lehikoinen A, Lehikoinen E (2004) Spring arrival of birds depends on the North Atlantic Oscillation. *Journal of Avian Biology*, **35**, 210-216.
- Van den Bosche W (2002) *Eastern European White Stork populations: migration studies and elaboration of conservation measures*. Bundesamt für Naturschutz (BfN)/German Federal Agency for Nature Conservation, Bonn.
- Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guidberg O, Bairlein F (2002) Ecological response to recent climate change. *Nature*, **416**, 389-395.
- Whitfield J (2001) The budding amateurs. *Nature*, **414**, 578-579.
- Winstanley D, Spencer R, Williamson K (1974) Where have all the Whitethroats gone? *Bird Study*, **21**, 1-14.
- Witt K (2004) Erst- und Letztbeobachtungen des Mauerseglers (*Apus apus*) in Berlin. *Berliner Ornithologischer Bericht*, **14**, 186-192.

Zalakevicius M, Bartkeviciene G, Raudonikis L, Junalaitis J (2006) Spring arrival response to climate change in birds: a case study from eastern Europe. *Journal of Ornithology*, **147**, 326-343.

RESUM

El canvi climàtic i la fenologia de les aus: un estudi a llarg termini a la Península Ibèrica

Molts estudis recents han demostrat l'existència de tendències temporals a llarg termini en tota mena de paràmetres biològics que només es poden explicar a través del canvi climàtic. La fenologia de les aus ha rebut molta atenció gràcies a que estudia un dels fenòmens més conspicus, populars y fàcilment observables de la natura. Hi ha molts estudis de canvis a llarg termini en les dates d'arribada primaveral, la majoria dels quals han constatat dates més primerenques a les últimes dècades. En canvi, hi ha poques dades disponibles per a l'emigració de tardor o la durada total de l'estada als territoris de nidificació, oferint a més resultats contradictoris. En aquest estudi s'han analitzat uns 44,000 registres per a cinc espècies d'aus trans-saharianes (*Ciconia ciconia*, *Cuculus canorus*, *Apus apus*, *Hirundo rustica*, y *Luscinia megarhynchos*). Les observacions es van dur a terme en més de 1300 localitats distribuïdes per tota Espanya durant el període 1944-2004. Es van trobar patrons comuns per a les dates d'arribada primaveral a totes les espècies. Hi ha hagut una tendència a avançar-se des de mitjans dels 70. Les dates actuals són similar a aquelles dels anys 40 (amb excepció de *C. ciconia*). Per tant, l'avançament de la fenologia migratòria primaveral durant les últimes tres dècades hauria d'interpretar-se com una tornada a les dates originals després d'un període d'arribades anormalment tardanes que va ocórrer durant els 70. A totes les espècies es va trobar una relació negativa amb les temperatures a Espanya al moment de l'arribada. En el cas de *C. canorus*, *A. apus* e *H. rustica*, també es va trobar una relació negativa amb l'índex del Sahel (una mesura de les precipitacions a la regió africana del Sahel durant l'estació plujosa) de l'any anterior. Respecte a l'emigració de tardor, totes les espècies van mostrar fluctuacions interdecadals similars, tot i que només *H. rustica* té una tendència significativa, deixant abans Espanya actualment. Totes

les espècies emigren abans els anys amb temperatures més elevades durant el període reproductor. En canvi, la relació entre les temperatures d'Espanya en el moment d'emigrar i les dates quan es van veure els últims individus va ser significativa només en el cas de *H. rustica*. Es van observar tendències temporal heterogènies a la durada de l'estada: *C. ciconia* l'ha incrementada, *A. apus* no l'ha canviat, i *H. rustica* l'ha reduïda. Aquest és el primer estudi que cobreix un àrea extensa, que està basat en una xarxa de nombrosos observadors i que ofereix l'anàlisi més complert disponible per a la regió mediterrània.