

FORUM

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CLIMATE CHANGE AND BIRDS: HAVE THEIR ECOLOGICAL CONSEQUENCES ALREADY BEEN DETECTED IN THE MEDITERRANEAN REGION?

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SUMMARY.—*Climate change and birds: have their ecological consequences already been detected in the Mediterranean region?* Global climate has already warmed by 0.6 °C, mainly due to human activities, over the second half of the XXth century. Recent studies have shown that it is possible to detect the effects of a changing climate at individual and ecosystem levels. Among biologists, there is a growing concern about how global climate change may affect the phenology, physiology and distribution of plants and animals. Many phenological processes, such as the date of flowering, leaf unfolding, insect appearance, and bird reproduction and migration, have been affected by recent climate change. Although it is difficult to prove that climate change has been the cause of these effects, these findings emphasise the need to consider climate change for current and future conservation efforts. There is a particular interest in the study of how species have responded to climatic changes in the past in order to guess or predict how they may respond to future changes in different regions. Few bird studies and even fewer long-term bird data sets are currently available in the Mediterranean area. Therefore, it is essential for the scientific community, policy-makers and the general public to make them available. Amateur naturalist and ornithologists can provide essential records that, combined with climate data, can suggest predictions about the future impact of climate change in the Mediterranean basin.

Key words: birds, climate change, Mediterranean, migration, phenology.

RESUMEN.—*Cambio climático y aves: ¿Se han detectado ya sus consecuencias ecológicas en la región mediterránea?* Se ha demostrado que, a causa principalmente de las actividades del hombre, la temperatura media terrestre ha aumentado 0,6 °C durante la segunda parte del siglo xx. Este fenómeno se ha denominado cambio climático. Estudios recientes han mostrado que es posible detectar los efectos de este cambio climático a nivel del individuo (planta o animal) y del ecosistema. Entre los biólogos existe una creciente preocupación sobre cómo ha afectado el cambio climático a la fenología, fisiología y distribución de las plantas y animales actuales. Muchos procesos fenológicos, tales como la floración, desarrollo de las hojas, aparición de los insectos y la reproducción y migración de las aves, están siendo afectados por el cambio climático reciente. Aunque no es viable probar que el cambio climático es la causa de estos efectos, estos hechos resaltan la necesidad de considerar seriamente los posibles efectos del cambio climático en los esfuerzos actuales y futuros en biología de la conservación. Existen numerosos ejemplos en los que el cambio climático es la explicación más plausible para esclarecer los hechos observados. El estudio de cómo las especies han respondido al cambio climático en el pasado es particularmente interesante, ya que permitirá predecir futuras respuestas en di-

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ferentes regiones Sin embargo, pocos son los estudios o registros continuados disponibles para las poblaciones de aves en el ámbito Mediterráneo. Es esencial, tanto para la comunidad científica como para los políticos o el público en general, el hacer que estos datos salgan a la luz. En este sentido, un papel primordial lo puede jugar los naturalistas y ornitólogos aficionados que disponen de estos datos, pues al compararlos con datos climatológicos se pueden sugerir predicciones sobre cómo afectará el cambio climático a la fauna del Mediterráneo en general. Desde este trabajo se pretende animar a todo aquel que disponga de series temporales de datos sobre cualquier aspecto de la biología de las aves en el ámbito del Mediterráneo a que intente comprobar si se observan cambios temporales o espaciales, y si estos cambios se pueden explicar por variaciones climatológicas. Será la única forma de poder saber si existen efectos del cambio climático sobre la avifauna del Mediterráneo.

Palabras clave: aves, cambio climático, Mediterráneo, migración, fenología.

EVIDENCES OF CLIMATE CHANGE

Climate change has been defined as any change in climate over time, whether due to natural variability or as a result of human activities (IPCC, 2001). Average global surface temperature (the average of near surface air temperature over land and sea surface temperature) has increased since 1861 (IPCC, 2001). Over the XXth century this increase has been 0.6 °C (Huang *et al.*, 2000; IPCC, 2001), and it is now almost certain that human activities are contributing significantly to this global warming (Stott *et al.*, 2000; IPCC, 2001). Globally it is very likely that the 1990s were the warmest decade in the instrumental record since 1861 (Huang *et al.*, 2000). The greatest warming has been located over the land areas between 40° and 70° N (Wallace *et al.*, 1996). This increase in temperature in the continents of the Northern Hemisphere is unusual within the context of reconstructions of the past 1000 years from paleodata (Crowley, 2000). The rate of change of average global surface temperature predicted over the XXIst century is similar to that already encountered since 1970, reaching 3 °C by 2100 relative to 1880-1920 (Stott *et al.*, 2000). Based on recent global model simulations, it is very likely that most continents will warm more rapidly than average global surface temperature, particularly those at northern high latitudes during the cold season (Stott *et al.*, 2000).

On the other hand, average rainfall has increased by 0.5 to 1% per decade in the XXth century over most mid- and high latitudes of the Northern Hemisphere continents (IPCC, 2001). There has also been an increase in heavy and extreme daily precipitation events over the

land areas between 40° and 70° N (IPCC, 2001). In the mid- and high latitudes of the Northern Hemisphere there has been a 2 to 4% increase in the frequency of heavy rainfall events over the latter half of the XXth century (IPCC, 2001). Increases in heavy precipitation events can arise from a number of causes such as changes in atmospheric moisture, thunderstorm activity and large-scale storm activity. Based on global model simulations, average global water vapour concentration and precipitation are projected to increase during the XXIst century (IPCC, 2001). By the second half of this century, it is likely that rainfall will have increased with larger year-to-year variations over northern mid- to high latitudes of the Northern Hemisphere continents.

Climatic changes occur as a result of both internal variability within the climate system and external factors (both natural and anthropogenic). The influence of external factors on the atmospheric increases in carbon dioxide (CO₂) and other so-called «greenhouse gases» (methane, nitrous oxide, ozone and halocarbons) have been suggested as the basis of recent climate changes (IPCC, 2001). The atmospheric concentration of CO₂ has increased by 31% since 1750 (IPCC, 2001). The rate of increase of atmospheric CO₂ concentration has been about 1.5 ppm per year over the past two decades, with larger year-to-year variations due to the effect of several climate fluctuations, such as El Niño events, on CO₂ uptake and release by continents and oceans. About three-quarters of the anthropogenic emissions of CO₂ to the atmosphere during the past two decades have derived from burning fossil fuels. The rest have been due predominantly to land-use changes, especially deforestation.

CLIMATE CHANGE EFFECTS IN MEDITERRANEAN ECOSYSTEMS

The Mediterranean region is a transitional climatic region where it has been suggested that climate warming may have the strongest effects. As in other regions of Europe, an increase of ambient temperature since 1980 has been detected in the first decades of the last century, followed by a period of more than three decades when temperatures showed no long-term increase (Almarza, 2000). While predictions for average annual temperature change in this region suggest an increase of 2 to 3 °C over the first half of the XXIst century (Cubash *et al.*, 1996; Borén *et al.*, 2000), the direction and magnitude of change in rainfall is more unclear (Borén *et al.*, 2000). Based on regional climate model simulations, the total annual rainfall is projected to decrease in different regions of the Mediterranean basin during the present century (Cubash *et al.*, 1996). A recent climate model performed for the Iberian Peninsula has predicted an increase in winter rainfall, a slight decrease in spring and autumn rainfall and a dramatic decrease in summer rainfall during the XXIst century (Borén *et al.*, 2000). These theoretical predictions agree with data from the past decades. One significant effect of recent climate change is the increasing frequency of Saharan rains loaded with mineral dust over the Iberian Peninsula during the last decades (Avila & Peñuelas, 1999). This special rain can influence terrestrial biogeochemical cycles and affect plant productivity, with some clear ecological consequences (Avila & Peñuelas, 1999).

Biodiversity and endemism are very high in the Mediterranean region (Blondel, 1986). However, current patterns of species richness are extremely variable among taxonomic groups, as some taxa are highly diverse and rich in rare species (Blondel, 1990), while others are impoverished versions of their European counterparts (Blondel, 1984). The intensity of land-use changes produced by human activity in the Mediterranean countries has caused intense changes in the distribution and composition patterns of many Mediterranean groups (Blondel, 1986; Tellería, 1992). In the Mediterranean region, land-use alterations may be considered as one of the most important factors underlying the latest ecological changes detected in the region (Santos & Tellería,

1995). Thus, due to the characteristics of Mediterranean biodiversity, there is a particular interest in the study of how species have responded to climatic change in the past, in order to aid interpretation of how they may respond to future changes in this region (Fitter *et al.*, 1995; Sparks & Carey, 1995; Harrington *et al.*, 1999; Hughes, 2000).

ECOLOGICAL CONSEQUENCES OF CLIMATE CHANGE

Until recently it has often been believed that it would take decades before climate change impacts on ecological systems would become visible. However, in the past decade many scientific publications on observed ecological changes have shown that biological systems quickly respond in a visible way to climatic changes (reviewed in Harrington *et al.*, 1999; Hughes, 2000; McCarty, 2001; Peñuelas & Filella, 2001). Among biologists, there is a growing concern about how global climate change may affect the phenology, physiology and distribution of plants and animals (Hughes, 2000).

Recent climate warming is expected to change seasonal biological phenomena showed by plants and animals. These phenological changes, which would differ among species, may have a wide range of consequences for ecological processes, agriculture, forestry and human health. The study of the times of recurring natural phenomena, especially in relation to climate, is called phenology. Because of the complexity of the interactions between plants, animals and their environment, direct causal relationships are difficult to demonstrate and need long-term detailed studies of ecological processes. However, many such relationships have been already found and it is expected that future climate change will have many effects on phenological processes.

Recently, Peñuelas and collaborators (2002) have revealed that spring events, such as leaf unfolding, have advanced on average by 16 days in several Mediterranean plants, whereas autumn events, such as leaf falling, have been delayed on average by 13 days over the 1952-2000 period. Thus, the average annual growing season of deciduous plant species in the Mediterranean region has lengthened since the early 1950s (Peñuelas *et al.*, 2002). The pattern is

consistent with those found in different European regions (Myneni *et al.*, 1997; Ahas, 1999; Menzel & Fabian, 1999; Menzel, 2000). On the other hand, spring ambient temperature determines the life cycles of most animals. For example, the peak date of flight phenology of most common butterfly or aphid species has been advanced during the last decades in Europe (Ellis *et al.*, 1997). This fact has already been detected in the Mediterranean region (Peñuelas *et al.*, 2002). These observed changes in plant phenology and emergence of insects during the last century are likely to have had pronounced effects on food availability for breeding birds. These phenological changes are also important for the interactions between plants, insects and birds within the main food chain that can be studied in our woodlands (Buse *et al.*, 1999). Changes not only in average temperature but also in temperature patterns within seasons might be important in the synchronization between species (Stevenson & Bryant, 2000).

Although the correlational nature of most of these studies limits our ability to determine causal factors, the trends found are most parsimoniously explained by a correlation with recent climate warming in Europe (Hughes, 2000). Moreover, the current knowledge obtained from numerous experimental studies indicates that the observed phenological changes are mostly due to the recent warming of climate.

Changes in ambient temperature, atmospheric CO₂ concentration or rainfall may directly affect biological processes such as metabolic (photosynthesis) or growth rates in many plants and animals. There are many evidences that photosynthesis and plant growth have responded to recent temperature and atmospheric changes, although it is difficult to separate the relative contributions of both factors (Hughes, 2000). For example, some important changes, such as a decrease in stomatal density, have been reported in herbarium specimens collected during the last centuries in England (Woodward, 1987) and in northeast Spain (Peñuela & Matamala, 1990). Moreover, leaf contents seem to have changed over the last three centuries (Peñuelas & Matamala, 1990, 1993; Peñuelas & Azcón-Bieto, 1992). These changes have an important effect on water use efficiency of plants, implying important ecological consequences.

For insectivorous birds it has been suggested that the mismatch between the timing of food

supply and nestling demand caused by recent climate change might force parents to work harder to feed their young (Thomas *et al.*, 2001). They suggested this physiological prediction when the energy expenditure of Blue Tits *Parus caeruleus* breeding at different dates relative to the peak in prey abundance was measured in two Mediterranean populations (Thomas *et al.*, 2001). However, this result is based on a comparison of two different woodlands, which may have differed in many respects other than food availability. Several studies have shown a negative association between energy expenditure and food availability (or ambient temperature) in different insectivorous birds (Bryant & Tatner, 1988; Tinbergen & Dietz, 1994). Therefore, we have recently suggested (Sanz *et al.*, *submitted*) that when the mismatch between food abundance and nestling demand caused by recent climate change occurs, parents might be forced to invest less effort in feeding their young (see also Verhulst & Tinbergen, 2001). Under this climate change scenario, young might to some extent pay the cost of reproduction. At the present time, the impact of recent climate change on animal physiology remains as an open research field.

CONSEQUENCES ON BIRD BREEDING PERFORMANCE

During the last decade, evidence for ecological effects of climate change in bird populations has increased (Järvinen, 1994; Crick *et al.*, 1997; Winkel & Hudde, 1997; Forchhammer *et al.*, 1998; McCleery & Perrins, 1998; Visser *et al.*, 1998; Brown *et al.*, 1999; Crick & Sparks, 1999; Slater, 1999; Przybylo *et al.*, 2000; Sæther *et al.*, 2000; Sillet *et al.*, 2000; Both & Visser, 2001; Moss *et al.*, 2001). The impact of climate change on the breeding performance of individuals has been observed within local bird populations and at the continental scale (Dunn & Winkler, 1999; Sanz, 2002). A general increase in spring temperature would be expected to allow an earlier onset of breeding in most temperate resident bird species (Table 1). This advance in the timing of laying caused by climate change might affect egg production (Stevenson & Bryant, 2000) and population dynamics (Sæther *et al.*, 2000).

TABLE 1

Climate change effects on the timing of breeding observed in diverse bird species and study areas. The magnitude of changes for studies with multiple species include species showing no response or a response opposite to that predicted by climate warming. In most of these studies the trends were also tested against ambient temperature.

[Efectos del cambio climático sobre el inicio de la reproducción en varias especies y localidades. La magnitud de los cambios en algunos estudios con varias especies incluye datos de especies que no han respondido o lo han hecho en sentido contrario a las predicciones del posible efecto del cambio climático. En muchos de estos estudios también se ha analizado la tendencia con la temperatura ambiente.]

Species Observed [Especies observadas]	Change (days) [Cambio (días)]	Country [País]	Study period [Periodo de estudio]	Reference [Referencia]
19 of 36 bird species [19 de 36 especies de aves]	Earlier since 1980 [Adelanto desde 1980]	UK	1939-1995	Crick & Sparks, 1999
20 of 65 bird species [29 de 65 especies de aves]	Earlier since 1970 (8.8) [Adelanto desde 1970 (8,8)]	UK	1971-1995	Crick <i>et al.</i> , 1997
<i>Tachycineta bicolor</i>	Earlier since 1970 (5-9) [Adelanto desde 1970 (5-9)]	USA	1959-1991	Dunn & Winkler, 1999
<i>Aphelocoma ultramarina</i>	Earlier since 1971 (10.1) [Adelanto desde 1971 (10,1)]	USA	1971-1998	Brown <i>et al.</i> , 1999
<i>Ficedula hypoleuca</i>	Earlier since 1974 [Adelanto desde 1974]	UK	1957-1997	Slater, 1999
<i>Ficedula hypoleuca</i>	Earlier since 1978 [Adelanto desde 1978]	Finland	1966-1987	Järvinen, 1989
<i>Ficedula hypoleuca</i>	Earlier since 1980 [Adelanto desde 1980]	The Netherlands	1980-2000	Both & Visser, 2001
<i>Ficedula hypoleuca</i> , <i>Parus major</i> , <i>Parus caeruleus</i>	Earlier since 1970 [Adelanto desde 1970]	Germany	1970-1995	Winkel & Hudde, 1997
<i>Ficedula albicollis</i>	Earlier since 1980 [Adelanto desde 1980]	Sweden	1980-1995	Przybylo <i>et al.</i> , 2000
<i>Parus major</i>	Earlier since 1970 (11.9) [Adelanto desde 1970 (11,9)]	UK	1947-1997	McCleery & Perrins, 1998
<i>Parus major</i>	No change [Sin cambios]	The Netherlands	1973-1995	Visser <i>et al.</i> , 1998

For insectivorous birds, the abundance of arthropods at the time of maximum food requirement of their young is a crucial determinant of nesting success (Lack, 1968; Perrins, 1991). It is known that spring temperature determines the peak date of caterpillar biomass, the main food of growing nestlings (Visser *et al.*, 1998; Visser & Holleman, 2001). Synchrony between caterpillar biomass and the breeding phenology of birds is the main selection pressure on the timing of breeding in some passerine birds (Blondel *et al.*, 1993; Noordwijk *et al.*, 1995). Buse and collaborators (Buse & Good, 1996; Buse *et al.*, 1999) have experimentally demonstrated that at elevated temperature oaks open their buds earlier. An increase

in spring temperature does not appear to affect the synchronization between budburst of oaks and caterpillar emergence (Buse & Good, 1996; Buse *et al.*, 1999; but see Visser & Holleman, 2001), but the developmental period of caterpillars can be shortened (Buse *et al.*, 1999). These authors have predicted that climatic warming would change the synchronization between timing of breeding and food availability. Therefore, they suggested that insectivorous birds might also respond to climatic warming by reducing clutch size with the advantage of shortening the time between laying and hatching dates, and concentrating food resources on fewer offspring (Buse *et al.*, 1999).

For long-distance migrant bird species, climate change may advance the phenology in their breeding areas, but they may not detect this on their wintering grounds. Therefore, many migratory bird species may arrive at an increasingly inappropriate time to exploit the breeding habitat optimally, and thus face higher competition with resident species that may have responded to climate change by tracking the advancement in their food supplies. It should be known whether the phenology of spring arrival allows scope for advancing laying by females. Finally, although climate change apparently affects the breeding phenology of many European bird species (see references above), the wider implications for fitness measurements in different locations are unclear (but see Merilä *et al.*, 2001).

CONSEQUENCES ON BIRD DISTRIBUTION AND ABUNDANCE

Changes in bird distribution and abundance can be attributed to habitat alterations, mainly due to human activity. However, some reported cases have been more parsimoniously explained by recent climate warming (e.g., Parmesan *et al.*, 1999). Climate change is predicted to cause shifts in bird distributions along latitudinal or altitudinal gradients because species are expected to track climate as a function of their physiological tolerances (Root & Schneider, 1995). In mountains, climate changes more rapidly with elevation than it does with latitude, so rapid altitudinal shifts by bird species have been predicted (McCarty, 2001).

Climate is one of the main determinants of geographic range for many bird species (Root, 1988). Climate change has been shown to affect the distribution and/or abundance of bird species in different parts of Europe (Hughes, 2000). For example, the northern margins of many southerly British birds have moved north by an average of 18.9 km over the past decades (Thomas & Lennon, 1999). Such changes in distribution would occur at the population level from changes in the ratio of extinction to colonization at the southern and northern boundaries of the geographic range. Hence, it is important to document how climate change has affected the dynamics of bird populations near these southern and northern boundaries.

One observed effect of recent climate change is the increasing severity of some climatic events, such as El Niño (IPCC, 2001). Sillett and collaborators (2000) have reported some negative effects of El Niño on fecundity of the Black-throated Blue Warbler *Dendroica caerulescens*, a migratory bird of eastern North America, that had consequences for demography on following years. With these observed evidences, they predicted that variance in demographic rates of migratory bird populations will become amplified, leading to elevated extinction rates, especially for small populations (Sillett *et al.*, 2000).

In Scotland, the number of Capercaillie *Tetrao urogallus* has fallen greatly since the 1970s (Moss *et al.*, 2001). In northern Spain, Capercaillie populations have also declined during the past two decades (Purroy, 1999). The decline in Scotland has been due primarily to the low breeding success observed during the 1975-1999 period (Moss *et al.*, 2000). Several mechanisms, such as habitat fragmentation, predation or competition with ungulates, have been proposed to explain this fact. Recently, it has been suggested that the increase of spring temperature over the last decades seems to have been a major factor causing the decline of Scottish Capercaillie (Moss *et al.*, 2001). This type of findings has important implications for conservation biology (McCarty, 2001), and should be taken into account by decision-makers. Conservation scientists and policy-makers need to look at climate change as a current, not just a future, threat to species. Changes in climate need to be taken into account as one of the potential factors contributing to declines in different bird species (McCarty, 2001).

In birds, eggs and young are sensitive to microclimate in many taxa. Another effect of climate change on birds could be a change in nesting microhabitats that might influence their breeding success (Martin, 2001). This change in nest-site choice could be reflected in variations in the local distribution of bird species along a microhabitat gradient (i.e., elevation). Martin (2001) has recently shown that four ground-nesting bird species in central Arizona shifted the position of their nests on the microhabitat and nesting microclimate gradient in response to changing rainfall over the 1988-1997 period. Moreover, in the same study area,

annual bird abundance varied with precipitation over the 1985-1997 period (Martin, 2001).

CONSEQUENCES ON BIRD MIGRATION

Bird migration activity and arrival times at breeding sites are both closely linked to climate. Therefore, this behaviour would also be affected by recent environmental changes. The return of migrant birds in spring is always enthusiastically awaited across Europe, an event that has a long history of observations over the last two centuries (e.g., Sparks & Carey, 1995; Ahas, 1999).

In the past decade, several studies have been published to describe long-term changes in spring arrival times in several species over the European continent. In western Wielgopolska (Poland), during the period 1913-1996, there were evidences for 14 out of 16 bird species of a trend towards earliness in recent years (Tryjanowski *et al.*, 2002). However, only four species (Table 2) showed a significant trend over time towards earlier arrival (Tryjanowski *et al.*, 2002). In Leicestershire (UK), mean arrival date of four out of 23 species showed a significant trend over time towards earlier arrival (Table 2), while five of these species showed a significant trend over time towards later arrival during the period 1942-1991 (Mason, 1995; Table 2). In Catalonia (Spain), five out of six species showed a significant trend over time towards later arrival during the period 1952-2000 (Peñuelas *et al.*, 2002; Table 2). Non-significant trends towards earlier or later timing of spring migration had been suggested for a large number of bird species during the last century (see Mason, 1995; Both & Visser, 2001; Tryjanowski *et al.*, 2002). Contrary to the observed trends towards accelerated phenologies in plants and in insect appearance, a large number of migratory birds showed a temporal trend towards later arrival times in spring (Table 2). These changes in arrival times for migrants from tropical areas, which must rely on their internal clocks for arriving at an optimal time (most are insectivorous and arrive late), is much less variable than for those arriving earlier (Lundberg & Edholm, 1982; Mason, 1995). The trend towards earliness is less pronounced for long-distance (African) migrants than for short-distance (European) migrants (Tryjanowski *et al.*, 2002).

Climatic changes in Africa, where these migratory birds spend half of each year, must play an important role in the timing of migration, and this factor should also be taken into consideration. Long-distance migratory birds may be constrained by arrival time to the breeding grounds (Potti, 1998; Both & Visser, 2001). Climate change differs between temperate and tropical areas (IPCC, 2001), but the timing of spring migration relies on endogenous rhythms that are not directly affected by climate change. Therefore, a response to environmental cues, such as ambient temperature, for the onset of migration may not lead to an adequate arrival time to the breeding areas (Both & Visser, 2001). Arrival dates of migrant species is influenced by the temperature in southern Europe in the months previous to their arrival to central and northern Europe (Huin & Sparks, 2000). For example, arrival time of the Barn Swallow *Hirundo rustica* in Britain is related to the average March temperature in the Iberian Peninsula (Huin & Sparks, 1998). This fact suggests that climatic fluctuations in the Mediterranean region might have significant consequences on migrants across the European continent. Short-distance (European) migrants might be more flexible in their response, because the conditions on their wintering areas may be a better predictor for the optimal arrival time on their breeding areas (Berthold, 1990). Berthold (1990) had suggested that long-distance migrants would decline in a climate change scenario, due to an overall increase of competition for available resources during the breeding season with resident and short-distance migrants.

The Barn Swallow has been one of the better studied migrant bird in Europe in the last century. In Table 2 we can see that the Barn Swallow has been arriving earlier in recent years in some areas, while it has been arriving later in others (Sparks & Braslavská, 2001). This suggests that perhaps not all regions of Europe have been experiencing warming in the same way during the last decades. This also suggests that the complex changes in temperature patterns within seasons and localities might be important to interpret responses to climate change (Stevenson & Bryant, 2000). Therefore, more long-term data sets should be gathered and analysed to obtain a clear picture about the effect of climate change on the same species on a large continental scale.

TABLE 2

Temporal changes in the mean arrival date observed in diverse bird species and study areas. Only significant trends are reported.

[Cambios temporales de la fecha media de llegada en varias especies y localidades. Solamente se incluyen las tendencias estadísticamente significativas.]

Species observed [Especie observada]	Study period [Periodo de estudio]	Country [País]	Trend [Tendencia]	Reference [Referencia]
<i>Coturnix coturnix</i>	1952-2000	Spain	Later [Atraso]	Peñuelas <i>et al.</i> , 2002
<i>Columba palumbus</i>	1970-1996	Poland	Earlier [Adelanto]	Tryjanowski <i>et al.</i> , 2002
<i>Cuculus canorus</i>	1942-1991	UK	Later	Mason, 1995
	1952-2000	Spain	Later	Peñuelas <i>et al.</i> , 2002
<i>Upupa epops</i>	1952-2000	Spain	Later	Peñuelas <i>et al.</i> , 2002
<i>Alauda arvensis</i>	1865-1996	Estonia	Earlier	Ahas, 1999
<i>Riparia riparia</i>	1942-1991	UK	Earlier	Mason, 1995
<i>Hirundo rustica</i>	1970-1996	Poland	Earlier	Tryjanowski <i>et al.</i> , 2002
	1952-2000	Spain	Later	Peñuelas <i>et al.</i> , 2002
	1970-1996	UK	Earlier	Sparks <i>et al.</i> , 1999
	1969-1998	Scandinavia	Earlier	Sparks <i>et al.</i> , 1999
	1961-85, 1996-00	Slovak Republic	Later	Sparks & Braslavská, 2001
<i>Anthus trivialis</i>	1942-1991	UK	Later	Mason, 1995
<i>Motacilla alba</i>	1970-1996	Poland	Earlier	Tryjanowski <i>et al.</i> , 2002
	1865-1996	Estonia	Earlier	Ahas, 1999
<i>Luscinia megarhynchos</i>	1952-2000	Spain	Later	Peñuelas <i>et al.</i> , 2002
<i>Turdus migratorius</i>	1975-1999	USA	Earlier	Inouye <i>et al.</i> , 2000
<i>Phoenicurus ochruros</i>	1970-1996	Poland	Earlier	Tryjanowski <i>et al.</i> , 2002
<i>Saxicola rubetra</i>	1942-1991	UK	Later	Mason, 1995
<i>Acrocephalus schoenobaenus</i>	1942-1991	UK	Earlier	Mason, 1995
<i>Sylvia communis</i>	1942-1991	UK	Later	Mason, 1995
<i>Sylvia borin</i>	1942-1991	UK	Later	Mason, 1995
<i>Sylvia atricapilla</i>	1966-1995	UK	Earlier	Sparks & Crick, 1999
	1942-1991	UK	Earlier	Mason, 1995
<i>Phylloscopus collybita</i>	1942-1991	UK	Earlier	Mason, 1995

RESEARCH PRIORITIES FOR THE MEDITERRANEAN AVIFAUNA

There are two different approaches for the study of the impacts of climate change on plants and animals. One is to examine relationships between long-term or spatially extensive biological data sets and abiotic data, usually meteorological, available over a similar scale. One of the major requirements for the identification of changes in the phenology of different organisms is the availability of good long-term data sets. For instance, museum collections hold large

amounts of data, such as dates and localities of egg and bird collection and body mass of the birds collected, that would provide a potential source of data for phenological investigations (Scharlemann, 2001; Yom-Tov, 2001). These data sets are a useful source of information for the Mediterranean region. The second approach is based on the interpretation of experiments that include novel conditions expected for the future. An important drawback for the design of these experiments is the difficulty of predicting future conditions, a point that warrants more attention.

Consistent temporal changes in phenological variables at the population or individual level might, in principle, result from different mechanisms acting together or in isolation. The observed effects might have been caused by changes in gene frequency due to selection within populations or due to northward (or southward) migration of individuals adapted to different environmental cues. Therefore, the responses to large-scale climatic fluctuations could be due to microevolution. An alternative explanation is that these phenological changes are due to phenotypic plasticity, which occurs when the expression of genotypes is environmentally dependent. This last interpretation may seem more plausible (Przybylo *et al.*, 2000; Møller, 2002). However, it is far from clear, on the basis of current literature, whether correlations using long-term data sets reflect phenotypic responses, responses to selection, or both. More studies performed in different populations or bird species will reveal which mechanism is already acting.

It is important to emphasize the need for the creation or maintenance of national or regional long-term meteorological and biological data sets to validate model predictions. I hope that this article has shown the benefits of acquiring data from as many Mediterranean locations as possible and that it will encourage additional data to become available. Further analyses of existing long-term data sets will be essential to identify vulnerable species, communities or habitats. Since there are almost no such data sets available for the Mediterranean region, establishment of new baseline monitoring programs, such as the SACRE program of the Sociedad Española de Ornitología (SEO), will be essential. Organisations like SEO can provide the huge data sources that will enable a serious study of the effect of climate change on Mediterranean bird populations. Data sets gathered by amateurs are extremely important to ecologists interested in the timing of biological events, or phenology (Sparks & Carey, 1995; Whitfield, 2001). These naturalists can provide essential records that, combined with climate data, may suggest predictions about the impact of climate change in the future.

To determine the natural variability of terrestrial Mediterranean ecosystems, and to understand the effect of change on their biodiversity, it is essential to start monitoring

biodiversity at a large scale. However, funding and other constraints force scientists into 3-5 year projects (or even less), while major changes in biota tend to occur in cycles of more than 30 years. With a small-scale and short-term approach to ecological monitoring and research, attempts to predict ecological changes, both natural and man-induced, will probably risk to fall into irrelevance. Biodiversity, i.e., the number of species occurring in one site or ecosystem, has been found to be very high in the Mediterranean region (Blondel, 1986). The term biodiversity has been used as an indication of environment health by scientists, but also by mass media, policy makers and the general public. Present-day Mediterranean biological diversity is undergoing rapid alteration under the combined pressure of climate change and human impacts. Every species contributes to biodiversity but it is not possible to protect all of them individually. Policy laws have been designed to protect threatened and endangered species, but the experience has shown that species are effectively preserved if attention is paid to habitats or ecosystems (Franklin, 1993). Therefore, a new policy is necessary to approach the problems raised by the effect of climate change on biodiversity in the Mediterranean region. It should be remembered that the changes detected over the last century have occurred with warming levels of less than one half of those expected over the XXIst century (IPCC, 2001). Therefore, future climate changes could become one of the major forces shifting life histories of plants and animals, especially in our Mediterranean ecosystems.

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