6. IMPACTS ON ANIMAL BIODIVERSITY

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ABSTRACT

Spain, possibly the EU's richest country with regard to animal species, has the highest number of endemisms. The number of new species described every year indicates that a high percentage of the fauna remains unknown. Greater effort is required in our country with regard to taxonomic research. There exists much evidence of climatic effects on the biology, abundance and distribution of vertebrates and of certain groups of insects of our fauna, and there are very little data on most of the invertebrates.

There are two future scenarios of the effects of climate change on the biodiversity of vertebrates: 1) Ecosystems will be displaced jointly in accordance with climate, and 2) ºEcosystems will adapt and change. The first scenario is unrealistic, due to the tremendous and growing fragmentation of habitats in Europe and the complexity of the responses by the different species and of the interactions between them. A possibility of displacement of the biocenoses only appears to exist in rivers. The second point does not allow for accurate predictions in most cases in view of the current level of knowledge.

There is evidence of the direct effects of climate change to date, in spite of the scarcity of good temporal series. Thus, large phenological changes have been detected in populations of vertebrates and invertebrates, with advances (and in certain cases delays) in processes of initiation of activity, the arrival of migratory species or reproduction.

The maladjustment between predators and their prey resulting from differential responses to climate is another detected consequence of recent changes.

The distribution of certain species is being displaced towards the North or towards higher altitudes, which for certain mountain species is involving a clear reduction of their areas of distribution. Likewise, in rivers the displacement has been observed of thermophilous species upstream (particularly of molluscs), whereas the proportion of cold water species is diminishing (especially of insects). In lagoons and lakes it has been seen that altitude, latitude and depth have similar effects upon communities, which appears to be related to temperature.

There is some evidence of greater virulence of parasites or of an increase in populations of invasive species, in general more adaptable to environmental change that may be dependent on climate change.

The deterioration of fragile habitats such as small bodies of water, springs, small streams and isolated forests due to desiccation or fire or the disappearance of food plants of limited distribution could seriously affect animal populations and even lead to species disappearance, above all of invertebrates.

Neither the displacement of distribution areas (hypothesis I) nor the rapid adaptation to new ecological conditions (hypothesis II) appear to be viable solutions for most of the species studied.

Among the areas most vulnerable to the effects of climate change, we could include coastal areas, wetlands, permanent water courses that would become seasonal, seasonal ones that would have a more irregular flow or would even disappear, high mountain areas and humid pasturelands.

The main adaptational solutions should include the design of reserves and nature parks to allow for the possibility of migration and changes in distribution by means of interconnecting biological corridors. The network of protected areas should incorporate latitudinal and altitudinal gradients

to enable the protection of populations with geographic distributions undergoing processes of geographic displacement resulting from climate change.

It would be interesting to promote the classification or creation of “zones or areas especially sensitive to climatic change”, for those areas with unique, original ecosystems or threatened or endemic species that cannot opt to change their habitat and that may become extinct. Examples of these zones are high-mountain areas or springs, streams or other water- courses containing endangered or vulnerable species.

The conservation of biodiversity ought to pay attention not only to the protected areas, but also very particularly to the generalised promotion of land uses that are compatible with conservation and capable of counteracting the effects of climatic change.

The increase in the demand for water for human use, due to temperature increase and in a possible context of prolonged droughts, might possibly determine an increase in technological solutions that do not take into consideration the impacts on the biodiversity of animals that depend on the maintenance of aquifers and of permanent water courses.

Reforestation could have positive or adverse effects on faunistic diversity depending on how it is implemented. In any case, it will affect the taxonomic composition of the edaphic fauna.

It is necessary to promote research into taxonomy and in relation to long temporal series, both at specific and community level, and to prevent the deterioration or progressive disappearance of sources of information such as the phenological database of plants and animals (birds and insects) initiated in 1940 by the Agricultural Meteorology Service, belonging to the National Meteorology Institute (INM).

6.1. INTRODUCTION

6.1.1. Vertebrate fauna in Spain

The number of vertebrate species existing in Spain has been calculated with a reasonable degree of accuracy (see recently published Atlas and *Libros Rojos* - red books). Around 51,000 species or 4,1% of species described worldwide are vertebrates (Ramos and Templado 2002 and Table 6.1). On the Iberian Peninsula, approximately 1,180 species have been estimated, including continental and marine fish and among the birds taking into account only the residents and reproducers (Ramos *et al*. 2002), which would constitute less than 2% of all the animal species existing in our country. There are around 118 species of mammals, 368 species of birds, 61 species of reptiles and 29 species of amphibians. In amphibians, reptiles and mammals, this figure can vary slightly, according to the taxonomic criterion used, but the greatest discrepancy occurs with the least known and most diverse taxonomic group, marine and continental fish, of which there could be around 750 species (Doadrio and Ramos, pers. com.). With reference to the known number of different kinds of vertebrates in Europe, Spain is the country with the highest number of described species and the highest proportion of endemisms (8%, compared to the next ranking country, Italy, with 4%) (Ramos *et al*. 2002). Unfortunately, it is also the country with the highest number of species in danger of extinction, 7% (Ramos *et al*. 2002). Spain is therefore a key country in the preservation of the biodiversity of vertebrates in Europe. We must highlight the high rate of endemism of the vertebrate fauna of the Canary Isles. All the 14 species of reptiles in the Canaries, except for one introduced species, are endemic. With regard to birds, the number of endemic species is higher than in the rest of the country, ranging from 4 to 6 species, depending on authors.

6.1.2. Invertebrate fauna in Spain

The extraordinary environmental variety in Spain, in which four of the six biogeographic regions of the European Union are represented (Mediterranean, Atlantic, Alpine and Macaronesian), as well as 60% of the habitats of community interest included in the Red Natura 2000 (Hidalgo 2002 and Chapters 2, 3, 4 in this book), endows our country with a high diversity of animal species. The combination of causal factors of this biodiversity, in terms of geographic position, orography, climatology, lithology and palaeobiogeographic and sociological factors, were revised by Ramos *et al*. (2001) and are summarised in Chapter 5. The huge diversity of ecosystems and unique habitats, both in the Peninsula and the archipelagos of the Balearic and Canary Isles is not only seen in the high number of species (approximately 50% of those inventoried by the projects *Fauna Europaea* 130,000 species, and *European Register of Marine Species* (ERMS) 25,000 species), but also in a high percentage of endemisms (over 50% of Europe's endemic species), especially considering that our territory represents less than 6% of European territory.

Although complete inventories of the species described in Spain (http://www.fauna-iberica.mncn.csic.es/), are not yet available, it is estimated that in our country there are around 68,000 animal species (Ramos and Templado 2002 and Table 6.1). The invertebrates undoubtedly constitute the greatest contribution to animal diversity in the terrestrial environment and in the freshwater, brackish and marine ones of the Peninsula and the Archipelagos. Around 98% of the species of our fauna are invertebrates and of these, around 76% are insects (around 50,000 species). Although the figures for non-insect invertebrates are relatively low compared to those for insects, they make a noteworthy contribution to the biodiversity and to the life processes of the planet. With regard to life forms, whereas all the insects belong to one same group of arthropods, with the category of Class in the Animal Kingdom, the remaining invertebrates with representatives in Spain belong to 32 of the 33 groups with the category of *Phylum* described on the planet, which indicates a large number of independent evolutionary lines, corresponding to different structural plans within the Animal Kingdom.

We have very little knowledge of our invertebrate fauna. In the last few years, certain studies have been published that compile and analyse the new taxa described on the Peninsula and the Archipelago in the Macaronesian region (Templado, *et al*. 1995; Fernández 1996 1998 2000 2001 2002 and 2003; Esteban and Sanchíz 1997). These studies record, in the 1994-2000 period, a total of 2,152 new species described in Spain (1,737 peninsular ones and 415 in the Canary Isles) of which 609 (465 on the Peninsula and 144 in the Canaries) correspond to non-insect invertebrates. This is equivalent to a description rate of 250-300 new species per year, of which 72% are insects and the rest correspond to other types of invertebrates. The data from the project *Fauna Europaea* (unpublished) corroborate the fact that the countries in the Mediterranean Basin are the ones with the highest number of species in Europe. Spain, followed by Greece and Italy, are notable for their high number of new species described yearly. The asymptote in the rate of new descriptions is still far from being reached.

Fourteen out of the 32 *Phyla* are exclusively marine, the representatives of the remaining 17 *Phyla* live both in marine and continental environments in our country (Table 6.1). Of these, nine are represented in all the terrestrial and freshwater environments, whereas another seven only live in marine and freshwater ecosystems. The *Phyla* with the greatest evolutionary success are the Molluscs, the Nematodes (a group that is still poorly known) and specially the Arthropods (which include the insects -Hexapoda- and therefore take up three quarters of the planet's biodiversity and, of our fauna).

Table 6.1. *List of the* Phyla *of living animals with an indication of their relative presence in marine, freshwater or terrestrial environments in the first column, number of described species at worldwide level in the second, estimated number of species in Spain (Peninsula and Archipelagos) in the third. This number of species is then split according to the main environments: marine fourth column, freshwater fifth and terrestrial, sixth. A question mark after a figure means that the group has been insufficiently studied and the number of species is just an estimate. An isolated question mark means that no data are available to make an estimate. (Taken from Ramos* and *Templado 2002).*

	Environ ment	**Nº described species global**	**Nº estimated species Spain**	**Nº species M**	**Nº species F**	**Nº species T**
PLACOZOA	M	2	1?	1?	—	—
PORIFERA	Mf	10,000	606	600	6	—
CNIDARIA	Mf	10,500	650	647	3	—
CTENOPHORA	M	90	20	20	—	—
MESOZOA	M-P	90	25?	25?	—	—
PLATYHELMINTHE	MFT	19,000	800?	500?	200?	100?
GNATHOSTOMULID	M	80	15?	15?	—	—
GASTROTRICHA	Mf	500	100?	75?	25?	—
ROTIFERA	mF	2,000	350	20	330	—
ACANTHOCEPHAL	MFT-P	1,200 P	50?	50?	?	?
CYCLIOPHORA	M-P	1	1?	1? P	—	—
ENTOPROCTA	Mf	100	20?	20?	—	—
NEMERTINA	Mft	900	146?	145	1	—
SIPUNCULA	M	150	35	35	—	—
ECHIURA	M	120	15	15	—	—
ANNELIDA	MFT	13,100	1,328	1,000	25	300
MOLLUSCA	MFT	125,000	2,700	2,250	120	330

NEMATODA	MFT	20,000	1,000?	300?	100?	600?
NEMATOMORPHA	mF	250	?	?	?	—
KINORHYNCHA	M	80	15?	15?	—	—
LORICIFERA	M	20	1?	1?	—	—
PRIAPULA	M	17	3	3	—	—
ONYCHOPHORA	FT	110	—	—	—	—
TARDIGRADA	MFT	800	30?	30?	?	?
ARTHROPODA	MFT					
Hexapoda	T	800,000	50,000	?	?	50,000
Myriapoda	T	15,000	500	?	?	500
Chelicerata	mfT	70,000	3,400	270	630	2,500
Crustacea	Mft	100,000	3,550	2,500	700	350
CHAETOGNATA	M	60	30	30	—	—
PHORONIDA	M	10	8	8	—	—
BRACHIOPODA	M	350	31	31	—	—
BRYOZOA	Mf	4,500	300	300	?	—
ECHINODERMATA	M	7,000	300	300	—	—
HEMICHORDATA	M	80	5	5	—	—
CHORDATA	MFT					
Urochordata	M	1,400	350	350	—	—
Cephalochordat	M	25	2	2	—	—
Vertebrata	MFT	51,000	1,792	1,180	108	504
TOTAL		1,238,535	68,179	10,747	2,248	55,184

Abbreviations
M= marine, F= freshwater, T= terrestrial, P= parasite
M= exclusively marine group
Mf= mostly marine, with some species in fresh water.
Mft= mostly marine, with some species in freshwater and in the terrestrial environment.
MFT= well represented in all marine, freshwater and terrestrial environments.
mF= mostly freshwater, but also marine.
mfT= mostly terrestrial, with some aquatic species.
T= exclusively terrestrial.
FT= exclusively terrestrial and freshwater.
P= exclusively parasites +

Molluscs constitute the most diversified *Phylum* of the Animal Kingdom after the Arthropods. Only the classes Gastropods and Bivalves are found in continental environments. They are being studied intensively in Spain where there are a high number of endemisms (above all among the terrestrial and freshwater gastropods). This number is particularly high among the land snails Helicoidea (both in Canaries and in the Mediterranean region) and among the freshwater Hydrobiids (with 90% of endemic species on the Iberian Peninsula and Balears). The freshwater bivalves include, apart from the small Sphaeriids, present in practically all the environments, the large-sized and threatened naiad species. All molluscs seem to be very sensitive to climatic factors.

If there is a group of animals that has had unprecedented success and which has an important role to play in all the ecosystems, it is the Arthropods. In addition to insects, the arthropods include spiders, mites and scorpions (Chelicerata), most of which are terrestrial, and the centipedes, millipedes, and their relatives (Myiriapoda) with around 500 terrestrial species described in Spain and a high percentage of endemisms. Crustaceans make up the other large group of arthropods which, unlike the previous ones, dominates the aquatic environment. It includes many different groups like crabs (Malacostraceans), water fleas (Amphipods), sow bugs, pill bugs (Isopods), and many plankton forms, such as many Copepods. The latter are so abundant in plankton that they constitute the animal group with the highest number of individuals on the planet. The Isopods are the dominating crustaceans in the terrestrial environment and have numerous endemisms in Spain. It should be noted that a high number of endemisms and new crustacean species (Bathynellids, Copepods and Ostracods) have been described from subterranean waters and caves, both in peninsular fresh water and in the anchihaline environment (karstic cavities and volcanic tubes flooded with stagnant seawater) in the Balearic and Canary Isles. There are also numerous endemisms among freshwater Amphipods. Most of these groups are excellent indicators of water quality and environmental changes produced directly by the climate and indirectly by anthopogenetic influence.

The insects are a particularly successful group. There is over one million currently known species of Insects, which is around 75% of all known living species, and they are involved in practically all ecological processes in continental habitats (Galante and Marcos García 1997, Samways 1994, Tepedino and Griwold 1990).

The Mediterranean Basin, one of the areas of highest diversity in the world (Myers *et al*. 2000), hosts approximately 150,000 insects (Balletto and Casale 1991), and the Iberobalearic region in Spain is the European geographic area with the highest level of diversity, it being estimated that there are around 50,000 species of arthropods, which is around 81% of all animal species in Europe (Ramos *et al*. 2001, and 2002, Martín-Piera and Lobo 2000). To this extraordinary biodiversity in this part of Spain, we must add the great entomological richness of the Canary Isles, with over 6,000 species of arthropods and an endemicity rate at around 45% (Machado 2002).

Iberian mountain ranges generally present a high number of endemisms in animal groups associated with vegetation and altitude (Martín *et al*. 2000). Furthermore, there is a high level of endemicity among other groups of species living in areas with more extreme climate or with higher rates of aridity, like the coastal areas in the Southeast of the Iberian Peninsula (Verdú and Galante 2002). This means that the Iberobalearic region has one of Europe's highest endemicity rates for insects (Galante 2002), and although the percentage varies greatly according to groups (Ganwere *et al*. 1985, Guerrea and Sanz Benito 2000, Vives 2000, Mico and Galante 2002), it could be said that almost 25% of the species associated with terrestrial ecosystems in Spain are endemic. This percentage is surpassed by far in certain groups like the Coleopteran *Tenebrionidae* in which 60.2% of the 522 species and 129 subspecies in Spain are endemic (Cartagena 2001).

With regard to the freshwater entomological fauna of the Iberobalearic region, over 25% of the species of aquatic insects known in Europe live here, with the exception of Diptera (Pujante Mora 1997). One third of the species of Trichoptera, Plecoptera and Efemeroptera found in Spanish water courses and lacustrian ecosystems are endemics with a very restricted distribution (Alba-Tercedor 2002, Alba-Tercedor and Jáimez-Cuéllar 2003, Tierno de Figueroa *et al*. 2003).

6.2. SENSITIVITY TO THE PRESENT CLIMATE

6.2.1. Role of the present climate in the distribution and biology of Vertebrate fauna

There is evidence about the impact of climate on the biology, abundance and distribution of vertebrates in Spain:

- Inventories made over 15 years in 4 sites of a small river in Asturias reveal a clear relationship between water flow in March (when the trout smolt of *Salmo trutta* emerge from the spawning grounds) and the number of the year's young trout in July (P. Rincón, com. pers.). The relationship is non-linear, showing a maximum for intermediate flow values and minimums for years of drought or heavy rainfall. These relationships have also been established in other studies (Moore and Gregory 1988a, b). In turn, the amount of trout in July accounts for over 70% of the variation in the number of adult trout 16 months later (breeding season). The areas protected from currents, associated with the shore and necessary for smolt, are more extended with intermediate currents. An increase in the proportion of dry years would reduce population size by reducing the habitat available for the smolt.

- The captures of salmon *Salmo salar* in Spanish rivers has decreased from figures of around 10,000 specimens in the 60s of last century to 20% of that figure at present. This could be related to increase in sea temperatures, although these effects could be confused with those of the overexploitation and deterioration or destruction of the freshwater habitat. Specifically, there is evidence of seriously negative effects on the capture of other species. If the temperature changes in the freshwater and marine environments are not synchronised, the death rate in post-smolt could increase (Hansen 2003). A critical period for salmon species is embryonic development. In some phases of this, particularly during hatching, there is a very high oxygen demand, and a tendency towards temperature increase in rivers could have very severe consequences for survival. More information and research is needed in relation to the genetic architecture of the characters involved (metabolic rate), the genetic differentiation of populations associated with different thermal environments, and the plasticity of the early development stages in response to changes in incubation temperature and embryonic development.

- The reproduction dynamics of the Natterjack Toad *Bufo calamita* ("a species of special interest", as indicated by the Catálogo Nacional de Especies Amenazadas) follows certain natural cycles conditioned by spring rainfall which has a clear effect on the success of metamorphosis (Tejedo 2003). These cycles can last for one decade, which suggests the need to establish temporal series of longer duration in order to understand the reality of demographic decline.

- In Spanish populations of Chameleon *Chamaeleo chamaeleon* ("a species of special interest"), the dry years give rise to a high death rate among females and a lower fertility level (Díaz-Paniagua *et al*. 2002). Long series of dry years could reduce the populations of this species. This problem is exacerbated by the reduced longevity of the species, which in many cases only reproduces once in its lifetime, rarely twice or more. This species, like many other reptiles, lays eggs covered by a flexible shell, very permeable to water. Increased soil aridity during incubation (summer) is a direct risk for these animals, because it causes a higher death rate of the eggs and less viability of offspring (apart from a higher death rate among females and lower fertility levels). One prediction of climate change is precisely an increase in the aridity of the soil, which could be particularly aggressive in the soft soils in which the chameleon lays its eggs (sand). This environmental change could affect the embryonic development and reproduction of reptiles with flexible shells in arid areas (ophidians and saurians, excluding salamanders). Field data show an extremely high death rate among eggs laid naturally, which in some cases surpasses 80% of all eggs laid, and experiments corroborate this sensitivity (Díaz-Paniagua and Marco in prep.).

- Rainfall is the best environmental predictor of the presence of several reptiles such as Schreiber's green lizard *Lacerta schreiberi* ("a species of special interest"), a saurian associated with mountain streams (Marco and Pollo 1993).

- Species like Carbonell's wall lizard *Podarcis carbonelli* present a distribution, which is very much conditioned by distance from the coast (related to humidity) in the Doñana area (J. Román, in prep.). These southern edge populations of certain distributions could be forced to withdraw by a temperature increase and/or a reduction in humidity.

- There is a high risk of extinction for certain populations of large-sized endemic reptiles in restricted areas of some of the islands of the Canary Isles, as is the case of the La Gomera Giant Lizard (*Gallotia gomerana*), whose only remaining population survives in the crags of Mérica (La Gomera) (Nogales *et al*. 2001), the El Hierro Giant Lizard (*Gallotia simonyi*, "an endangered species") in the crags of El Risco de Tibataje (Jurado and Mateo 1997) and the Tenerife speckled lizard (*Gallotia intermedia*, "an endangered species") in the Acantilado de Los Gigantes, in Tenerife (Hernández *et al*. 2000). Any alteration of environmental conditions could force them into extinction.

- Rainfall has a clear effect on the abundance of forest passerines in Iberian forests (Santos and Tellería 1995). The northern and palearctic species (many of these "of special interest") become scarcer with less rainfall. At the level of all Spanish avifauna, climate accounts for 7% of species diversity, which increases with rainfall and decreases with insolation (Carrascal and Lobo 2003).

- On the Canary Isles, especially on the more arid eastern islands, several species of birds appear to react to rainy years by advancing reproduction. In dry years, certain species (quail, corn bunting) may even stop breeding. The laurel forest pigeons, especially Bolle's laurel pigeon (*Columba bollii*, "a species sensitive to habitat alteration"), practically stop breeding in some years, which might be due to a low level of fruit production. A series of years with low rainfall could affect population size. Displacement outside the forest in search of food could lead to more damage to crops and greater vulnerability to poachers and poison. In the case of the Houbara bustard (*Chlamydotis undulata,* "an endangered species"), the different levels of rainfall among islands (Lanzarote, Fuerteventura, La Graciosa) can force movement from one island to another, with the consequent displacement costs.

- The abundance of waterfowl in the Tablas de Daimiel National Park during springtime is closely correlated to the flooded area, which in turn depends on water level and therefore, indirectly, on rainfall. This is not so for the wintering waterfowl (Álvarez Cobelas, personal communication).

- There is a correlation between the distribution of the Lesser kestrel *Falco naumanni* ("species of special interest") and rainfall in Andalucia, this species showing a preference for areas with more rainfall within this region (Bustamante 1997). There is an optimum rainfall level for the distribution of this species in Spain, close to medium-high rainfall levels (Seoane *et al.* 2003).

- In populations of common vole *Microtus arvalis* and Mediterranean pine vole *M. duodecimcostatus,* strong positive correlations have been established between abundance and spring and autumn rainfall levels in Central Spain (Veiga 1986).

- Autumn rainfall initiates the production of the rabbit *Oryctolagus cuniculus*, a keystone species in the ecosystems of Iberian *maquis* (Villafuerte 2002). Furthermore, torrential rains can be disastrous for rabbit populations (Palomares 2003). A rainfall regime marked by a higher frequency of extreme phenomena could condition the abundance of rabbits and of their predators.

- In populations of mountain goat *Capra pyrenaica* in southern Spain there is a close positive correlation between the production of offspring and rainfall in spring. Long series of dry springs could negatively affect the productivity of these populations (Escós and Alados 1991).

- In populations in Andalucia of wild boar *Sus scrofa*, reproduction in years of drought is minimal, with only 17% of females giving birth and an average litter size of only 3 offspring (Fernández-Llario and Carranza 2000).

6.2.2. Role of the present climate in the distribution and biology of Invertebrate fauna

Most of the studies of the effects of climate change on invertebrates have referred to insects. The data published on the effects of climate on non-insect invertebrates and the distribution and population dynamics of these are practically non-existent or occasional. Furthermore, with such a great diversity of animal groups, our knowledge of the geographic and biological distribution of the species is very deficient. Most of the few available data refer to experimental work, occasional observations in faunistic studies and unpublished extrapolations and observations. Molluscs are probably the best known.

It can generally be said that the vagility of the heterogeneous group of organisms that we call non-insect invertebrates is low. Their dispersal capacity is often limited to passive transport. We will therefore jointly review the few available data referring to the fauna associated with edaphic and aquatic ecosystems (lagoons, wetlands, springs, streams and rivers), as these concentrate the representatives of all the animal Phyla on the continent, and we will analyse the effects of changes on the fauna itself or the influence of this upon the ecosystems.

- The nine animal *Phyla* with terrestrial species have representatives or spend some of their life on the ground, although little is known of the genetic and taxonomic diversity of the organisms, due to the abundance and complexity of these. Ground-dwelling fauna, together with microflora, in turn, play a fundamental role in the functioning of the ecosystem: in the decomposition of organic matter, the transformation of nutrients and (together with the roots of plants) in the maintenance of soil structure and in the production of greenhouse gasses (Ingram and Wall 1998). Soil is a dynamic and highly structured substrate, the result of stable interactions among its own structure and the biota (Erhlich and Erhlich 1992). The effects of global change, through alterations in temperature, rainfall or changes in land use, can destabilise the system. Some of the alterations caused by brusque climate changes (diminished stability, increased erosion, decreases in carbon levels and microbial activity) are often masked by the effects of the chemical pollutants used in agriculture, these having a more direct and drastic influence on the biota.

- The edaphic fauna is often more conditioned by the indirect effects of climate changes on vegetation (in herbivorous species), nutrient availability and effects upon the soil itself, than by the direct effects of climate change. All the direct and indirect effects of climate change, however, cannot be disassociated from changes in land uses, which often mask or act synergically with those caused by global change. Edaphic organisms are universally present in all terrestrial ecosystems, and given the great variety of these organisms, their interactions are tremendously complex. That is, although we can learn of the individual role played by each one of their components in the ecosystem, or how they are affected by climate change, it is difficult to predict the impact of a change upon the communities they form. There are very few studies of edaphic biodiversity, although sufficient evidence exists to identify the key groups in the functioning of ecosystems, which, consequently, can be used as indicators of environmental change (Ingram and Wall 1998, Porazinska and Wall 2002). In relation to fauna, these refer above all to earthworms in moist habitats, termites in dry habitats and nematodes which, although existing in all types of soils, show a preference for certain degrees of moisture. Nematode populations appear to be very sensitive to alterations in soils and show rapid response to environmental variations over short time series, which suggests that they could also be affected by long-term climate changes (Porazinska and Wall 2002). Stability in the structure of the earthworm community (proportion of sizes among species, etc.) is essential for the maintenance of the physical properties of the soils. (Young *et al*. 1998). Ants constitute a potentially important group, although there are so few studies that the only thing that can be said is that the role they play is less relevant than that of termites (Lobry de Bruyn and Conacher 1990).

- It has been established that alterations in cycles of humidity/drought or frost/thaw, which can occur with an alteration in the intensity of the rainfall regime, have a direct influence, increasing the risk of erosion, which is undoubtedly the main source of degradation among the series of alterations that can be caused by climatic variables. The fauna most affected is the one living in soils subjected to higher risk levels, which are found in the temperate areas of the planet which includes the Mediterranean Basin (Young *et al*. 1998).

- Experimental study has been made of the effect of two climate scenarios on a community of terrestrial molluscs and their interaction with the meadow vegetation on calcareous land in the United Kingdom (Sternberg 2000). The two scenarios consisted of: 1) warm winters with increased summer rainfall and 2) warm winters and summer drought. The climatic manipulations had a significant effect upon the relative abundance of molluscs, but no changes were observed in species composition. The distribution and densities of snails and slugs were affected by changes in the physical environment and the vegetation in the grassland. The responses of the different species to the climate manipulations were strongly influenced by their phenological traits and food preferences.

- Experimental study was also made on the isolated and combined effect of an increase in CO_2 and in temperature on the behaviour and population dynamics of a generalist herbivorous mollusc, *Helix aspersa.* The number of juveniles recruited when CO_2 is high does not differ from the control population, whereas less offspring were obtained with a temperature increase. In the combined experiment (high CO_2 and temperature), however, the number of juveniles was higher than the control. The emergence of juvenile was not affected within each experiment, but these emerged 70 days earlier in the combined experiment than in the one involving temperature. In no case was any relationship observed with the quality of the foliage (C:N proportion), or with the abundance of the preferred food plant *Cardamine hirsuta.* The abundance of the species was altered in the three experiments (Bezemer and Knight 2001).

- Seven animal *Phyla* are represented in the freshwater environments (rivers, streams, lakes, lagoons, reservoirs, wetlands, springs). Invertebrates and the communities they comprise, are the most sensitive to alteration of aquatic ecosystems, due to environmental stress (warming of the water body) and human induced stress (pollution, overexploitation of aquifers, etc.), and above all, to a combination of both. The composition of the invertebrate community is consequently the best indicator of the health of the ecosystem. Increased summer drought and a decrease in rainfall will reduce the area of wetlands and biogeochemcial processes, the consequence of which for the fauna will depend on the characteristics of each system. The great diversity of the wetlands in the Mediterranean area makes it difficult to predict general patterns. We can, however, expect the more primitive, and therefore the least specialised, animal groups and species to be favoured, as they have greater plasticity and are more tolerant to stress. The consequent dominance of these species does not necessarily involve a decrease in faunistic richness, although we could expect an impoverishment of specific diversity. Some species or animal groups would respond to drought by producing durable eggs or resistant forms (e.g. Turbellarians, Branchiopoda and Rotiferans, among other), and others would do so by prolonging the pupa phase (some insects, such as the Trichoptera).

- In the case of rivers, the only study known in Europe, involving long time series was made by Daufresne *et al*. (2003). In the upper Ródano the fish (37 species) and invertebrate (92 taxa) communities were compared and inventoried from 1979 to 1999. It was observed that variability in the abundance of fish was correlated with flow and temperature in the reproduction period: low flow and high temperatures coincided with a greater abundance of fish (April-June). It was also seen that the fish species and taxa of thermophilous invertebrates gradually replaced the cold water fish and invertebrate taxa. In general, the taxa of non-insect invertebrates, molluscs in particular, which prefer medium flows with slow currents (*Potamopyrgus, Corbicula, Theodoxus fluviatilis, Physella, Valvata, Pisidium, Radix, Ancylus fluviatilis,* etc., in this order*)* were favoured*,* showing an increase in individuals and a spread upstream, compared with most of the taxa of insects studied, which show a preference for fast-flowing currents (in particular, and in this order, *Chloroperla, Protonemoura, Nemoura, Rhyacophila*, Stratiomyidae were the most negatively affected). These patterns were the most directly correlated with temperature variables, implying the causal effect of climatic warming. These *in situ* results support the predicted effects of climate change on the upstream displacement of freshwater communities.

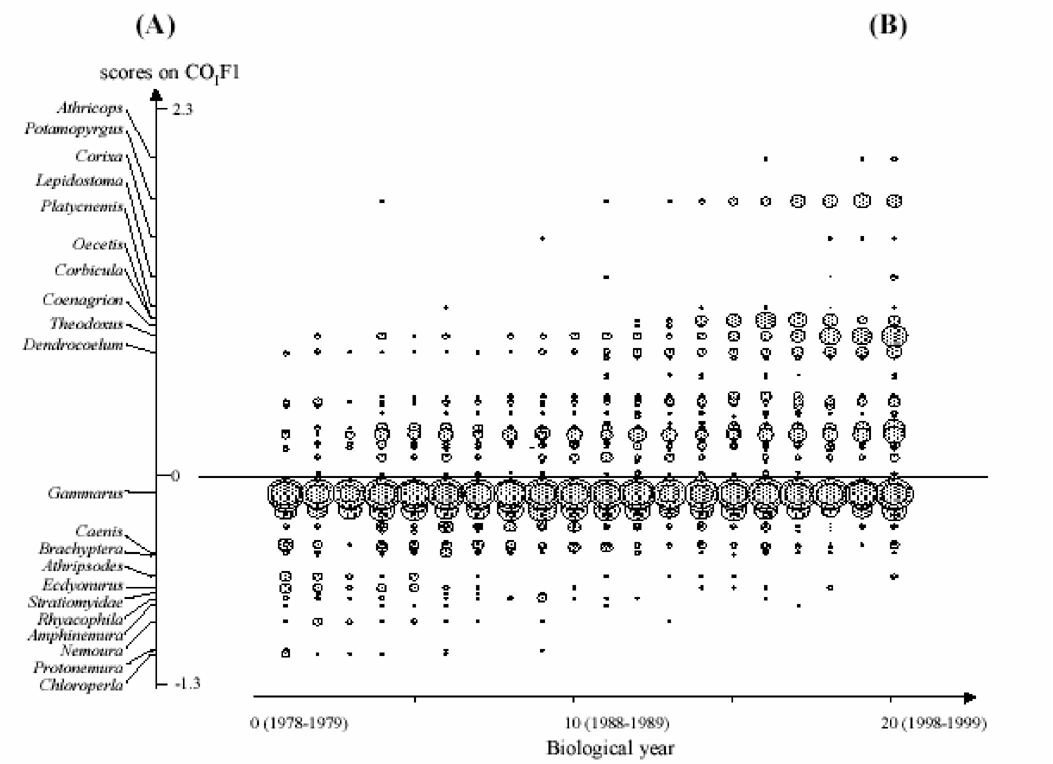

Fig. 6.1*. Evolution of the faunistic composition of invertebrate taxa of the Upper Rhone River from 1979 to 1999. Mean annual abundance per sample of invertebrate taxa (circle area and abundance are proportional) classified according to the first axis of a correspondance analysis of invertebrate data (CO1F1). Only the 10 taxa with the highest factorial scores and the 10 taxa with lowest factorial scores are given. (Figure from Daufresne et al. 2004 and kindly provided by the first author)*

- In salmon and trout's rivers, an evident decrease in fish populations can now be noted, a consequence of habitat fragmentation (Chapter 3). Among the most noteworthy effects upon invertebrates, we can highlight the negative effect of this on populations of large freshwater bivalves, which require a host fish to terminate their life cycle, with the metamorphosis of their larvae on the body of the host fish. Some of these species, such as *Margaritifera margaritifera* and *M. auricularia,* show a high degree of specificity with the host fish. In the case of *M. margaritifera* these are trout and salmon, and we can therefore expect a serious decline in their populations, which only live in the rivers in the North and in the Northwest of the Peninsula (Ramos 1998). *M. margaritifera* is protected by the Berne Convention (Annex III), the Habitats Directive (Annexes II and V), UICN (endangered). There is still uncertainty with regard to the host fish of the larvae of *M. auricularia* in nature -River Ebro and adjacent channels- (if it has not already become extinct), although it has been demonstrated that the river blenny (*Salaria fluviatilis*), could be a potential host (Araujo, *et al*. 2001). It is, however, a threatened species of fish, with fragmented populations, and the survival of both species is therefore compromised. *M. auricularia* is protected by the Berne Convention (Annex II), the Habitats Directive (Annex IV), UICN (endangered), National Catalogue of Threatened Species ("endangered"). The species *Unio elongatulus* uses several fish species as hosts, and is therefore not threatened to such a degree. This species is protected by the Berne Convention (Annex II) and the Habitat Directive (Annex V).

- The annual growth rings on the shells of *Margaritifera margaritifera* in Sweden were studied along a North-South gradient and provided a record of the growth variation over 217 years (1777 – 1993) (Schöne *et al*. 2004). The pattern observed indicates that annual growth is very much controlled by summer temperatures. The months of June-August are crucial in the more northern populations, those of autumn for the southern ones. Growth is generally greater at higher temperatures. This study highlights the fact that the shells of bivalve molluscs, generally long-lived (around 70 years) constitute excellent tools for recording climatic events, in particular, temperature variations.

Freshwater ecosystems are very sensitive to environmental stress and that caused by man, and they therefore respond more rapidly than terrestrial ecosystems to alterations. The following figure 6.2 illustrates this phenomenon.

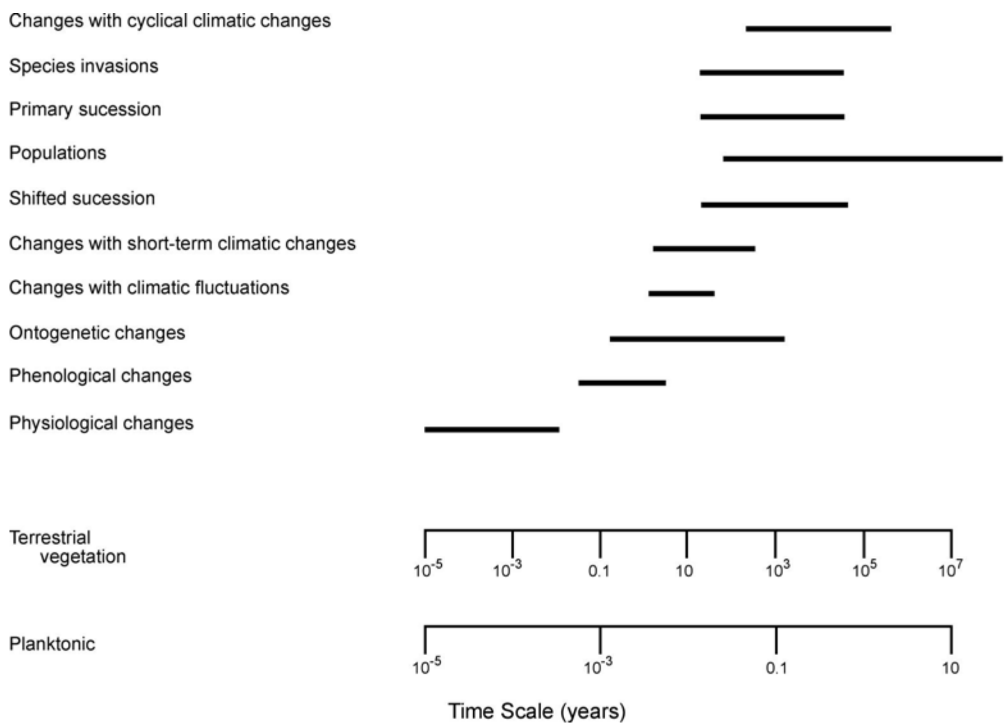

***Fig. 6.2**. Differences in the temporal scale of processes in terrestrial and plankton communities. The scale is logarithmic and the cellular processes in organisms of both environments coincides at approximately 10-5 years (i.e., 5 min). Molecular Ecology of Aquatic Microbes, Successional change in the planktonic vegetation: species, structures, scales, Reunolds, C.S., pp 115-132. 1995, (Springer Verlag, Berlin).*

Certain data exist in Spain on the effects of climate on species of arthropods and on models predicting changes in distribution or population dynamics resulting from climatic changes.

- There is evidence that the number of butterfly species in the Northeast of the Iberian Peninsula is basically conditioned by two climatic variables, temperature and rainfall. Species richness is negatively correlated to temperatures and positively to the rainfall index (Stefanescu *et al*. 2004). These data indicate that in the context of climate change, a temperature increase would lead to a clear loss of species diversity.

- The butterfly *Parnassius apollo* (Lepidoptera Papilionidae) is a species protected by the Berne Convention (Annex II), UICN 2000 (Vulnerable), CITES (Annex II) and the Directive on Habitat (annex IV). This species is widely distributed throughout Eurasia, although in a fragmented and isolated way in small populations. Numerous subspecies have been described (up to 160 throughout the whole distribution area and up to 24 in Spain). It has a discontinuous boreal-alpine distribution throughout Europe, and spreads through Siberia to Central Asia. On the Iberian Peninsula, it is found in the main mountain ranges between altitudes of 800 and 3,000 m. The main population nuclei are on the Cantabrian coast (from the Montes de Leon and Asturias to the mountains of Álava), the Pyrenees of Huesca and Catalonia, Sistema Ibérico (from the northernmost provinces to Teruel and the Valencia Regional Autonomy), Sistema Central (Guadarrama mountains) and the Betic ranges (from Sierra María in Almería to Sierra Nevada). According to the only existing study on the movement of adults, displacements are short, between 260 m and 1,840 m (Brommer and Fred 1999). Anthropic activities (especially ski resorts and high-mountain infrastructures), along with climatic change, have been identified as the main factors accounting for the regression of populations in the southernmost mountains of Spain (Baixeras 2002). It is a species generally restricted to small habitats, and any factor directly affecting the species at its lower distribution elevations would trap it within limits that are unsuitable for its survival in many places. It has been estimated that in some southern, isolated populations, like those in Penyagolosa (Castellón), an annual increase of 0.1º C could bring about the disappearance of these populations in around 30 years (Baixeras 2002).

- *Culicoides imicola* is a dipteran of the Ceratopogonidae family, a cattle arbovirus vector which causes, among other diseases, bluetongue fever in ruminants and horse fever in Africa (Wittmann *et al*. 2001), diseases included in the international lists of epizooties. It is presently known to exist in the south western half of the Iberian Peninsula (Rawling *et al*. 1997). The distribution of *Culicoides imicola* is conditioned by mean annual temperature and rainfall (Baylis and Rawling 1998). In accordance with the prediction model developed by Wittman *et al*. (2001), this species has been seen to rapidly spread its distribution area northwards. An increase of around 2º C in global mean temperature in this century could lead to a 200 km extension of the northern limit of its distribution in Europe, which would undoubtedly lead to the appearance of epizooties in Spain, which could reach northern France and Switzerland (Wittman *et al*. 2001). The predictive data on the northward dispersion of this species have recently been confirmed, with the capture of specimens in the Balearic Isles, Catalonia, and the Valencia Regional Autonomy (Sarto i Montenys and Saiz Ardanaz 2003).

- *Linepithema humile* is the so-called Argentine ant, an invasive species in many parts of the world. This species originated in Argentina and has managed to penetrate numerous urban and natural habitats of Mediterranean and tropical ecosystems. It causes serious damage in ecosystems and damage to human resources, leading to large financial losses. This species exists in Spain, and according to the existing predictive models, it will spread effectively to Northern Europe in the next 50 years, which implies its generalised presence in Spain (Roura *et al*. 2003). This would have serious consequences for the biodiversity of many habitats, through competition in some cases and predation in others.

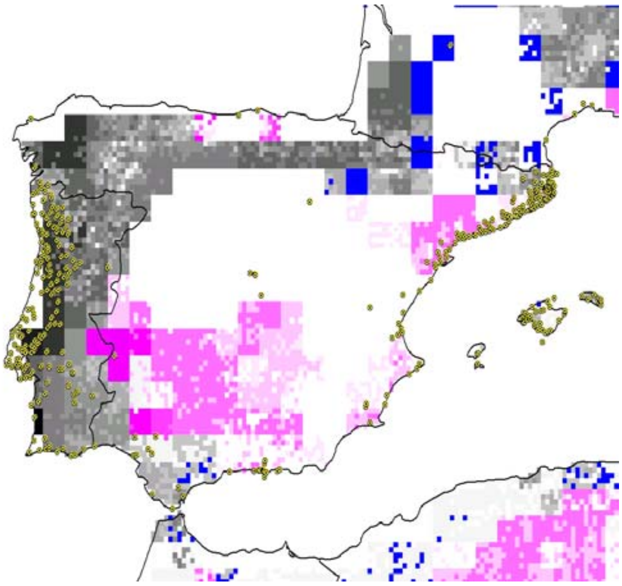

Fig. 6.3. *Modelling of the effects of climate change on the potential distribution of the Argentine Ant (Linepithema humile), an invasive species. The black-grey tones indicate the areas with the suitable conditions for the existence of the species at the present time, whereas the blue and pink tones indicate the areas to be reduced and enlarged, respectively, in the future. The dots show the places where the species exists at the present time (Extracte from Roura et al. 2003).*

- Existing data indicate that in Mediterranean ecosystems, the spatial distribution and daily periods of activity of species of Scarabaeid and Geotrupid beetles depend on temperature (Mena *et al* 1989, Galante *et al*. 1991, Galante 1992), and a thermal increase will therefore have serious consequences for the species of these groups.

- It has been observed in some species of Lepidoptera and Coleoptera in the Iberian Mediterranean environment that a survival strategy during the most unfavourable times is to retard ovarian maturation, thus avoiding immature phases at a time when food is scarce and environmental conditions do not allow for development (García-Barros 1988, Lumbreras *et al*. 1990 1991). For instance, in studies by Galante and his group it was seen how in the scarabaeid beetle *Bubas bubalus*, females appearing at the beginning of autumn copulate and store the spermatozoids in their spermatheca, without the eggs being fertilised. The ovaries reabsorb the ovules and mobilise fat reserves, which enables them to optimise their energy resources during the winter phase, and they develop eggs anew the following spring, which will probably be fertilised through further copulation (Lumbreras *et al* 1991).

- It has been demonstrated that temperature has a large impact on populations of aphids (Hemiptera Aphidinea), causing an alteration in flight periods. At present the European network EXAMINE (Exploitation of Aphid Monitoring in Europe) has made a follow-up in 19 countries over 3 years of the migratory period of aphids, using suction traps (Harrington *et al*. 2001, Hulé *et al*. 2003). Reliable data have been established which indicate a clear relationship between the population dynamics of aphids and environmental variables. Climatic variables are a sound means of accounting for at least 50% of the variation in the flight periods and range in aphids, although other factors operate at local scale, like changes in land use and habitat fragmentation.

- The EXAMINE project has shown that there is a clear relationship between increased winter temperatures and less rainfall, with an advance in the annual flight periods of aphids.

However, the main factor at work in this advance of annual flight periods appears to be temperature increase (Harrington *et al*. 2003, Seco-Fernández *et al*. 2003).

6.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

There are insufficient good temporal series with which to duly illustrate what has happened in recent times. There is historic evidence of what has happened in the last 10,000 years, such as the northward withdrawal of humid forests and the enlargement of the Mediterranean drought areas (and the Sahara, which has spread 7 degrees of latitude northwards in the last 15,000 years). From this temporal perspective, what we are now observing may only be the continuation, perhaps aggravated by human intervention, of a process that could have very grave consequences to our country in terms of biodiversity. If the predictions of the models of global circulation for the XXI century are correct, increased drought will lead to increases in hydric stress in trees and shrubs that are currently at the limit of their possibilities due to the preceding prolonged change processes. As Spain is situated in a peripheral and peninsular region of the continent (Ramírez and Tellería 2003), this could lead to the regression of many species of Atlantic origin (which would be the majority in the case of vertebrates), an increase in insularity of relict boreal-alpine species and the extinction of many populations of these “northern” organisms which currently present a noteworthy fragmentation towards the south. On the other hand, the Gibraltar straight might constitute a barrier preventing northernwards expansion of African species, which would lead to a considerable faunistic impoverishment.

Recently, the risk of extinction of 1,103 species of animals and plants in regions covering 20% of terrestrial areas was modelled with the use of predictions of climate change up to 2050 (Thomas *et al*. 2004). In a conservative scenario with global temperature increases of 0.8-1.7 º C these models indicate that 18% of the species would be extinguished, whereas in a dramatic scenario of global temperature increases higher than 2º C, up to 35% of the species would become extinct. According to this study, climate change may become the main factor of species extinction in the XXI century.

6.3.1. Future scenarios and uncertainties according to different hypotheses

There are two future scenarios of the effects of climate change on the biodiversity of vertebrates:

6.3.1.1. Hypothesis I: Ecosystems will be jointly displaced

It is based on the idea that whole ecosystems will be displaced northwards or in altitude, depending on changes in temperature and rainfall. This scenario is unrealistic due to the tremendous and growing fragmentation of habitats in Europe and to the complexity of the responses by different species and of their interactions. The impacts of global climate change have been considered on occasions as mere displacements of distribution areas, but there is evidence to indicate that displacements of distributions might increase the derived costs of biotic interactions when species occupying habitats for which they are not adapted, or in which new ecological interactions take place, are forced to live together (Martin 2001).

6.3.1.2. Hypothesis II: Ecosystems adapt and change

It contemplates the modification of present ecosystems with regard to their composition and the relationships between species, due to differential response of these to the change. The disappearance of certain species or the immigration of new species could lead to cascade reactions in relation to other components of the ecosystems. With our current level of knowledge, this scenario does not allow for accurate predictions in most cases.

6.3.2. Detected changes that might affect the survival of populations

6.3.2.1. Phenological changes

6.3.2.1.1. Phenological changes in vertebrates

Advances or delays in natural processes caused by rapid climatic changes could give rise to responses in the phenology of vertebrate populations. Many vertebrates' prey organisms can respond more rapidly than them to the change, bringing about a loss of synchronisation between consumers and resources. Many vertebrate species respond to seasonal variation in circadian rhythms in order to initiate processes of reproduction, migration or hibernation, and this variation is not affected by climate change. However, the resources upon which they depend may respond to climate conditions, which would cause a loss of synchronisation. One of the most likely consequences of a loss of synchronisation between species at different trophic levels is the maladjustment between food requirements and availability thereof for the species at higher levels, and this could lead to reproductive failure or reduced survival (hypothesis II).

Species with shorter cycles can respond to selection by means of very rapid micro-evolutionary changes. For species with long generation time, response to rapid changes in the availability of resources can only be by means of phenotypic plasticity. The degree of plasticity is modulated by variability in the environmental conditions experienced by species in evolutionary time. Genetic variability can also make adaptation to change by short lived species possible.

- One of the most notable changes detected in amphibians is the advance in reproduction of many species in Europe and North America (Beebee 1995, Gibbs and Breisch 2001). However, there has been no long-term study in Spain capable of detecting these advances. Data have been collected for the last five years for populations of the common frog (*Rana temporaria*, "species of special interest") in low zones (< 600 masl) and high zones (>1600 masl) in the Cordillera Cantábrica mountains (A. G. Nicieza, pers. com.) During this time, reproduction starts in high areas when the snow withdraws from the pools, but this had never happened (even if there is no snow in the area) before the second or third week in March. It would be interesting to obtain information on the genetic and environmental components of the process determining the start of migration towards breeding grounds.

- With regard to phenological changes in birds, we can highlight those observed in reproduction and migration. Research has been done into whether there are advances in the initiation of reproduction attributable to recent climate change on the Peninsula. In the three species studied (Great tit *Parus major*, blue tit *Parus caeruleus* and pied flycatcher *Ficedula hypoleuca*, all "of special interest") no change was noted in the laying date or size of the clutch in the last three decades (Sanz 2002 2003, Sanz *et al*. 2003). This contrasts with what has been observed for the rest of the western palearctic, where these changes have been detected and attributed to recent climate change (Sanz 2002, Sanz 2003). This can be explained by the fact that in the populations studied on the Peninsula, the temperature increase detected in the last few decades occurred in the months following the start of reproduction and not earlier, so effects on reproductive success could therefore be expected (Peñuelas *et al*. 2002, Sanz *et al*. 2003). In the Canary Isles, sporadic cases of reproduction in October and November have been detected in the blue tit.

- There is evidence that the reproductive phenology of several species of Iberian birds is affected by temperature or rainfall before reproduction is initiated. Thus Fargallo and Johnston (1997) have shown that the start of reproduction in a blue tit population in the centre of the peninsula is affected by temperature one month beforehand. With temperature increases at the beginning of spring, these birds advance the laying date. In the Lesser kestrel a relationship has been found between temperature and rainfall in spring and laying date (J. Bustamante, pers. com.). We still have to learn, with the use of long series of data, which are still unavailable, whether the temperature increase detected in the last few decades has affected the reproductive phenology of these birds.

- During the last 18 years, a decrease in reproductive success together with a loss of fledgling condition and lower recruitment levels has been observed in populations of the pied flycatcher in the Sistema Central (Sanz *et al*. 2003). This study was carried out at the southern margin of the distribution of the species in Europe. Given that the Iberian peninsula constitutes the southernmost part of the distribution of many bird species (Martí and del Moral 2003), and that, as a response to climate change, many species may change their distribution towards northern Europe, it is important to study this precisely in these areas. The process may involve the colonisation of new breeding grounds or the extinction of populations in the southern zone. There is evidence to indicate that the reproductive success of many species breeding on the Iberian Peninsula is negatively affected by less rainfall during spring (Carrascal *et al*. 1993, Zuberogoitia 2000, García and Arroyo 2001) or by an increase in temperature (Lucio 1990). However, no study has attempted to see whether these effects, which are to be expected in a scenario of climate change, have occurred in these species in the last few decades.

- With regard to migration, changes have been detected, showing an average delay of 15 days in the arrival of 6 trans-saharan migrating birds during the last 50 years (Hoopoe *Upupa epos*, Common swallow *Hirundo rustica*, Cuckoo *Cuculus canorus*, Common nightingale *Luscinia megarrhynchos*, Quail *Coturnix coturnix* and Common swift *Apus apus*, all of these, except for the quail, “of special interest”). In this study, carried out in a site in Barcelona province (Peñuelas and Filella 2002), it was seen that 5 of the 6 species showed a statistically detectable delay, and in 4 species there was a relationship with temporal changes in temperature, and in one species, there was a relationship with temporal changes in rainfall. This delay in arrival at the breeding grounds on the Peninsula is in contrast with the generalised advance observed in the same period in the phenology of plants and insects (Peñuelas and Filella 2002). This suggests that these species must have a lower reproductive success rate with the passing of time, as a result of the maladjustment between their arrival and the availability of food (hypothesis II). Predators specialised in hunting migratory birds, like Eleonora’s falcaon (*Falco eleonorae*, “of special interest”), could suffer maladjustment between their reproductive cycle and migratory transit.

- It is known that arrival date of the Common swallow in England is related to the mean temperature in March on the Iberian Peninsula (Huin and Sparks 1998). The greater the temperature increases along the migration route, the lager the advance in the date of arrival at the breeding grounds. The Iberian Peninsula being an important area of migratory transit on a continental level, any changes that take place therein can be seen in phenological changes in different species of migratory birds that breed in other regions of the continent. Furthermore, certain species of birds, like the Common stork or the Common swallow, have changed their migratory behaviour. Many individuals of these species spend the winters in the south of the Peninsula, thus avoiding migrating across the Sahara (Ardeola ornithological news). It is not clearly known whether this established fact is due to the increase in mean winter temperatures on the Peninsula or to other causes. The constant presence of food in rubbish dumps probably has a greater effect than temperature.

- Drought conditions delay reproduction in the Deer *Cervus elaphus*, reduce fertility in females and increase the death rate in offspring, especially in males (Clutton-Brock *et al* 1982, Carranza 1999).

6.3.2.1.2. Phenological changes in invertebrates

- Using climatic manipulation in herbaceous habitats, in a community of molluscs in the United Kingdom (Sternberg 2000) it has been shown that the different species of the snail and slug community present different responses, which are mainly seen in their phenology and in their feeding preferences. In conditions of summer drought, the increased litter cover on the soil favoured the species that feed on this (e.g. *Monacha cantiana*) which showed an increase in activity and population, whereas the species that feed on green leaves and tender shoots (e.g. *Candidula intersecta, Deroceras reticulatum*) increased their populations with supplements of rainwater in summer. It can be predicted that the species with an annual life cycle (most Helicidae) will be more sensitive to changes during their growth period. It was also experimentally observed that in *Helix aspersa* a simultaneous increase in CO_2 and temperature leads to an increase in recruitment of juveniles and an acceleration in their emergence (Bezemer and Knight 2001).

- In the Northeast of Spain, it has been observed that, since 1988, the flight period of a large number of butterfly species is starting increasingly earlier, which for some species constitutes a significant advance of between one and seven weeks, with an average of 0.1 weeks/year (Stefanescu *et al* 2003). This process is logical if we consider that the development periods of the immature phases of insects very much depend on temperature (Ratte 1985), and that in most butterflies the end of the diapause and the end of their development coincides with the arrival of spring (a period in which greater temperature increases have also been detected).

- There is evidence that some species of Satyrid and Lycaenid butterflies show very marked responses to climate change, varying greatly in their annual peaks of flight activity (Stefanescu *et al*. 2003).

- In some species of Satyridae a clear advance in the flight period has been demonstrated, like in the case of *Melanargia lachesis*, *Pyronia tithonus*, *Pyronia cecilia*, *Coenonympha pamphilus* and *Lasiommata megera*, all of these with a larval regime associated with grasses (Stefanescu *et al*. 2003).

- The temperature increase is expected to cause an advance in the start of the annual migration of aphids. Many of these species cause plagues in crops, and the factor related to their early arrival in many areas should be taken into account. An advance in the colonisation of crops is expected, occurring at earlier development stages of these plants, which are therefore more sensitive to attack by pests, which could cause either direct damage, or indirect damage through viruses. This could cause an increase in the use of chemical insecticides.

6.3.2.2. Changes in morphology, physiology and behaviour

6.3.2.2.1. Changes in the morphology, physiology and behaviour of vertebrates

One of the possible consequences of temperature increases might be a directional selection in favour of smaller body sizes. According to Bergmann's rule, in homeothermic vertebrates, warmer climates would favour a smaller body size, due to its greater capacity to eliminate heat. In certain birds in Israel, significant decreases in body size have been detected throughout the last century (Yom-Tov 2001). There is no study of this nature in Spain, although there are collections of specimens from different periods that could be used to this end.

Certain negative effects have been suggested regarding the effects of temperature increases on the embryonic stage of vertebrates. In many species of reptiles, sex is determined by the temperature of the nest. An increase therein could lead to an exaggerated bias of sexes, negatively affecting the capacity of individuals to reproduce (Dawson 1992). In mammals, temperature increases could cause hyperthermia in pregnant females, and the consequent thermal stress on the embryos, which in some species would determine a high death rate of embryos (McLean 1991). These effects of temperature on the viability of embryos have been proposed as a reason for the disappearance of many large mammals after the last glaciation (McLean 1978).

In bats, a bioenergetic model predicts a closely related combination of temperatures in the hibernacle and winter durations in order to allow for successful hibernation. This suggests that the thermal dependence of the hibernation energetics constrains the biogeography of these species (Humphries *et al*. 2002). The model predicts a pronounced spread northwards of hibernnating bats in the next century. No study of hibernation bioenergetics has been made in Spain. Furthermore, the capacity to regulate body temperature and to prevent hyperthermia in their daytime refuges may become limited and lead to direct mortality (M. Delibes, pers. com.).

A general proposal that has been put forward is that ectothermic vertebrates would be more sensitive to abrupt climate changes, given their lower level of autonomy in relation to the thermal environment. In general, adaptation to climate change could derive from micro-evolutionary changes based on underlying genetic variation or on phenotypic plasticity (Dawson 1992). At present, there are no studies in Spain to explore the viability of both routes to adaptation in vertebrates.

- The age structures of several populations of Iberian cyprinid fish species show a greater abundance of old age classes in relation to young ones (Rincón and Lobón-Cerviá 1989, Velasco *et al*. 1990). This indicates that there are frequent inter-annual differences in reproductive success and recruitment. No rigorous study has been made in Spain of the correlations between climatic variables and the reproductive success of cyprinid species, but studies in other countries of a widespread cyprinid which is also characterised by these fluctuations in recruitment suggest that these variations are modulated by temperature, and to a lesser degree, by rainfall, during the first stages of development (Lobón-Cerviá *et al*. 1996).

- In the Pied flycatcher negative tendencies have been detected in energy expenditure (reproductive effort) or in provisioning rate during the last few decades in populations studied in the *Sistema Central* (Sanz *et al*. 2003). These insect-eating birds suffer maladjustment with their main prey (caterpillars), due to recent climate change, and they have varied the prey that they take back to the nest for their young (hypothesis II). Changes in the physical condition of males and females were observed (Sanz *et al*. 2003). The daily energy expenditure, an integrated measurement of the reproductive effort of these birds, has dropped in recent years, mainly due to its negative relationship to environmental temperature (Sanz *et al*. 2003). These changes in synchronisation with their prey (caterpillars) due to recent climate change probably accounts for the changes observed in adult metabolism, reproductive effort and reproductive success (see above).

- There is also evidence that rainfall in spring affects the condition and growth of the chicks of nesting birds (Carbonell *et al*. 2003). With less rainfall, the condition and growth of the chicks of Blackcaps (*Sylvia atricapilla*, “of special interest”), measured by means of fluctuating asymmetry and feather growth, are impaired (Carbonell *et al*. 2003). This indicates that we can predict effects on the growth of these birds in a scenario of climate change.

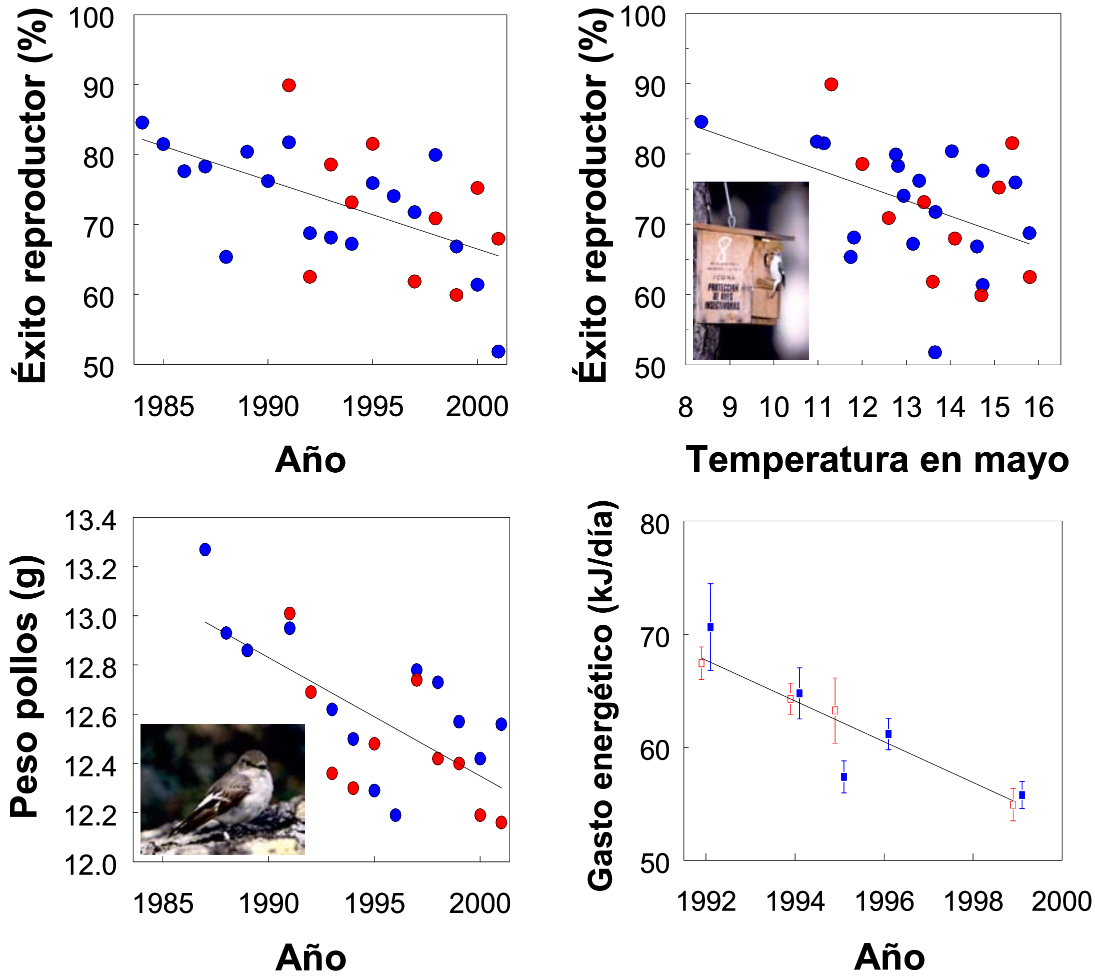

Fig. 6.4. *Temporal changes over more than one decade in the reproductive success of two populations of pied flycatcher in the Sistema Central (blue dots: La Hiruela, Madrid; red dots: Valsaín, Segovia) and in the daily energy expenditure of adults during the end of the nestling stage(blue symbols: females, red symbols: males) fom Sanz et al. 2003).*

- In the Lesser kestrel, a bioclimatic model indicates that reproductive success is positively affected by rainfall. However, despite the fact that rainfall has decreased significantly since 1966 in the study area, a retrospective analysis of the evolution of the size of several colonies in Andalucia indicates that the effect of climate change on reproductive success cannot be responsible for the historic population decline (Rodríguez and Bustamante 2003).

6.3.2.2.2. Changes in the morphology, physiology and behaviour of invertebrates

- A similar effect to the Bergmann's rule, previously mentioned for vertebrates, has also been observed in molluscs. In the gastropod *Capaea nemoralis* a direct correlation has been described between the diameter of the shell (standard size measurement) and altitude in three valleys in the Spanish Pyrenees (Ramos 1981). That is, size increases in populations at greater altitudes where temperature is lower.

- On some occasions, experimental results in relation to terrestrial gastropods are contradictory. Thus, the consumption of food in the juveniles of *Helix pomatia* increased in environments with high levels of CO_2 (Ledergeber *et al.* 1998), whereas in another experiment with *Helix aspersa* consumption was not affected by CO_2 concentration (Diaz *et al*. 1998). The different response of the two species could be due to intrinsic physiological differences. In any case, these results suggest that predictions cannot be based on the variation of one single factor (temperature, humidity or CO_2 concentration), and that there is a need for the combined study of the different environmental factors that can vary synergically as a consequence of climate change in natural conditions, and we should also keep in mind microclimatic factors, the evolutionary history of the animal group and the physiological characteristics of the species.

- Both in natural (Potts 1995; Chevalier 1980 1992) and experimental conditions (Iglesias *et al*. 1996), a latitudinal gradient has been observed in the life cycle of *Helix aspersa.* The length of the hibernation period decreases with latitude, from seven months in Scotland to four months in the Northwest of Spain. In Atlantic areas of Galicia, the species has a long hibernation period without aestivation and reproduces during summer, whereas in the other part of Galicia, with a Mediterranean climate, there is both hibernation and estivation and reproduction takes place in spring and autumn (Iglesias *et al*. 1996). Reproduction in autumn is typical in all Helicidae gastropods in the Mediterranean area, although the survival rate of the autumn offspring is much lower due to wintertime cold than in those reproducing in springtime. Furthermore, both in *H. aspersa*, and in *H. pomatia* and *H. texta* rainfall appears to be the determinant factor in species activity in Mediterranean areas (the exit from hibernation is related to rainy periods and entry into aestivation to the start of the dry periods), whereas photoperiod might be more important at high latitudes. In any case, this latitudinal cline is conditioned by the microclimatic factors affecting the population, which can make it deviate from the general pattern.

- The longevity of the individuals of the species *Margaritifera margaritifera* varies with latitude. Thus, whereas the average life span of specimens in Spain is around 70 years, this can reach up to 200 years in Scandinavia and on the Kola Peninsula (Araujo, personal communication). In this case, water temperature may be an important factor.

- The population dynamics of species of terrestrial arthropods is conditioned to a great extent by the environmental conditions of temperature and humidity. The movement observed towards the northern limit of the distribution area of insect species should be interpreted as a response to an increase in mean annual temperature. Temperature increases also cause greater variability in rainfall periods, in the intensity of these and in evapotranspiration rates (Piñol *et al*. 1998). The significant changes taking place in the amount and seasonal distribution of rainfall may have negative effects on population viability, with a higher risk of extinction (McLaughlin *et al*. 2002). In order to demonstrate this hypothesis, research would be needed that took into consideration several orders of insects in which species with well-known distribution and biology are selected.

- Furthermore, we are aware of the existence of groups of insects, capable of regulating their internal flight temperature, and which present activity during the cooler times of day, like dusk or the early hours of the night (Heinrich 1993). These groups have well-developed muscle masses, a high wing loading and their capacity for flight depends on the balance they establish between the generation of body heat and its loss by means of external diffusion into the surrounding atmosphere. These insects behave like endothermic ones during flight, and have the capacity for thermoregulation, but when they are not flying, they are poikilothermic. . An increase in temperature could seriously affect these species among which we find lepidoptera like the Sphingidae, and pollinating insects like many hymenopteran Apoidea and coleopteran Scarabaeidae. Many of these species have a very restricted distribution in Western Europe, or are Iberian endemisms, and also have a low reproductive rate (Verdú *et al* 2004a).

- The changes observed in some lepidoptera in relation to the advance in their flight period, could indicate that some insects have a type of response that enables them to adapt to the new climatic conditions of global warming. This response is not a generalised one, however, and our available data are very scarce and geographically local. There is a need for long annual series showing the abundance of the populations affected; the historic fauna records are scant and poor, due to a great extent to the lack of support for this type of studies from Spanish scientific policymakers.

- The changes that may occur in the phenology of the appearance of adults in insects and larval development periods could have serious consequences in the near future with regard to changes in population abundance resulting from the possible desynchronisation in the phenology of nutrient plants and insects. In the Mediterranean basin, many species of rhopalocera butterflies lay their eggs at the end of spring or the beginning of summer, and enter into a state of calm or aestivation that may last the whole winter, thus avoiding the more environmentally unfavourable periods. An advance in the period of emergence of adults causes an advance in the clutch period and birth of the larvae, which could represent a critical lengthening of the aestivation period with fatal consequences for the survival of the first larval stages (Stefanescu *et al*. 2003).

6.3.2.3. Changes in geographic distribution:

6.3.2.3.1. Changes in latitudinal or altitudinal geographic distribution in vertebrates:

The prediction of displacements towards the north or in altitude of species affected by climate change (hypothesis I) is based on the capacity for migration of the individuals towards more favourable habitats (Root and Schneider 2002). It must be pointed out that this capacity differs among groups of vertebrates. Whereas birds can fly over different types of barriers, amphibians and reptiles have much less capacity for migration, and mammals are in an intermediate situation. Besides, several human factors restrict this capacity, especially in Europe. The main factor in this sense is surely the increasing fragmentation of habitats. Terrestrial environments are interrupted by increasingly larger areas of infrastructures and urban environments, while river environments are fenced in more and more by reservoirs. Spain has become modernised in its transport infrastructures and has adopted the town planning model of large suburban areas far from the city centres. Habitat fragmentation is one of the prices of economic development and of the adoption of the new town planning models. Furthermore, Spain is one of the countries in the world with most reservoirs per inhabitant, which does not seem to imply any decline in the construction of new ones. As a result of all this, the tremendous and growing fragmentation of natural habitats does not only impede the geographic displacement of distributions according to climate (hypothesis I), but probably even any genetic exchange needed to guarantee the viability of many fragmented populations in a scenario of no climate change (a paradigmatic example is the Iberian Lynx *Lynx pardina*). In island ecosystems on the Canary Isles, the species cannot respond in the same way as those on the continent, which move northwards, and their potential capacity for response would be restricted to changes in altitude, and only on islands with high elevations (for instance, the central and western islands of the Canaries: Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro). This type of movement would be much more limited on the eastern islands, Lanzarote and Fuerteventura.

Certain species have a reduced possibility to react by means of changes in distribution. These are the ones living in high mountain areas and the island populations. They have literally nowhere to go. In Spain, the barriers constituted by several mountain ranges running from west to east prevent northward displacements of some species. Those species highly specialised with regard to certain climatic conditions would also be more sensitive.

The simplistic model that predicts that plants will respond to climate and that animals will follow the plants (hypothesis I) does not take into consideration that animals may respond directly to climate in order to avoid physiological limitations (Dawson 1992) and may change habitats regardless of vegetation. This could involve changes in biotic interactions, with effects on survival and reproduction.

- With the exception of northern Portugal, the rivers in Cantabria constitute the southern limit of the distribution area of the Atlantic Salmon in Europe. Survival during the embryonic and post-embryonic stages (previous to exit from the gravel pits) is closely related to temperature. An increase of 3-4 º C above optimum for survival leads to a drastic increase in death rate and the proportion of deformed unviable individuals (A. G. Nicieza, pers. com.). The same can be applied to the lamprey or the trout (Ojanguren 2000, Rodríguez-Muñoz 2000). A continuous or maintained increase in water temperature during the winter and spring months could contribute to population decline and to the displacement towards the north of distribution limits.

- In general terms, and despite the lack of studies aimed at determining the effect of climate change on populations of amphibians, the biogeographic islands represented by the mountains (and certain areas with higher rainfall) in the centre and south of the Peninsula are ceasing to serve as efficient refuges for the fauna of more northern distribution, and the endemisms of these areas, like the Iberian midwife toad (*Alytes cisternasii*, "of special interest") and the southern subspecies of Common midwife toad (*Alytes obstetricans,* "of special interest") and Salamander *Salamandra salamandra* are seriously threatened (R. Márquez, pers. com.). Thus, local populations of salamander have disappeared in Sierra de la Demanda and Neila (Burgos, although here, the introduction of salmonids may be an alternative or additional factor), Colomerá and El Padul (Sierra Nevada, Granada) and Puerto y Llanos de Zafarralla (Granada) and of the Alpine newt (*Triturus alpestris*, "of special interest") in Carrales and Pantano del Ebro (Burgos) (Pleguezuelos *et al*. 2002). Reductions of salamander populations have been detected in Sierra de las Nieves (Málaga), Sierra Bermeja and Serranía de Ronda (Málaga) and in the Sierra de Córdoba, of the Alpine newt in Northern Castilla-León, Cantabria and Álava and of the Iberian frog (*Rana iberica*, "of special interest") in Peñalara (Sierra de Guadarrama, Madrid) and in Las Villuercas, Guadalupe and Valencia de Álcantara (Extremadura) (Pleguezuelos *et al*. 2002).

- There have been recent observations of low-altitude species in high-mountain habitats in the centre of the Peninsula, which were previously the exclusive refuge of species of more northern distribution (hypothesis I). Thus, in the Laguna Grande de Gredos (Ávila) the Common Frog *Rana perezi* has only been sighted in recent decades, and the Common tree frog (*Hyla arborea*, "of special interest") can currently be found in some of the alpine lakes of the Somiedo Nature Park (Asturias) (R. Márquez, pers. com.).

- From the 50s to the 80s of last century, a change in the distribution of the Algerian sand lizard (*Psammodromus algirus*, "of special interest") was detected in a valley of the Pyrenees (hypothesis I), and its presence was recorded 30 km upriver from where it had initially been seen (Bauwens *et al*. 1986).

- In this context we must mention reptiles typical of mountain habitats with a distribution very much associated with climate. Climate change would cause their rise in altitude and their disappearance at low elevations (hypothesis I). One example is Schreiber's green lizard, an Iberian endemic species which, in the Mediterranean area is associated with mountains and in the Southern half is now found in more humid and cooler available habitats (Marco and Pollo 1993, Brito *et al*. 1996). Climate change is threatening populations in the Montes de Toledo, Sierra de Guadalupe, Sierra de Monchique, etc., because these cannot rise any higher and are losing ideal low-altitude habitats, and it is very likely that this species has become extinct in the last few decades in Sierra Morena. There are very old references to the Lizard in the Sierra de Andújar and some sightings in the 1980s, but in the last intensive sampling sessions, it was not seen again in these places. In Andalucia, it is classified as threatened, precisely due to these references from the 80s (Marco 2002). In a similar situation appears to be the Spanish Algyroides (*Algyroides marchii*, "of special interest"), the Viviparous lizard (*Lacerta vivipara*, "of special interest"), the Pyrenean rock lizard (*Lacerta bonnali*, "vulnerable"), the European smooth snake (*Coronella austriaca*, "of special interest") and the Iberian rock lizard *Lacerta monticola*.

- GIS distribution models extrapolated to increases of 2-3 º C up to 2080 predict a reduction of the distribution area of the Long-tailed salamander (*Chioglossa lusitanica*, "of special interest") by 20% (Teixeira and Arntzen 2002);

- On the Iberian Peninsula, changes may occur in the distributions of birds, given that current distribution and abundance patterns can be accounted for, along with other factors, by climatic variables (Carrascal and Lobo 2003). Potential changes in temperature and rainfall regimes must affect the distribution of these species, but no temporal study has been carried out on the Peninsula aimed at contrasting this hypothesis.

- In the case of the Great bustard (*Otis tarda*, "of special interest"), the ecological niche was modelled using 23 points of occurrence in Europe and twelve climatic and topographic covers (Papes personal communication). The prediction of the present distribution was subsequently intersected with the land use GIS covers, in order to only retain those areas most convenient for the Great bustard. Likewise, the ecological niche model was projected in the two scenarios of climate change and the average of the two was intersected with the current distribution, assuming zero capacity of the species to disperse. Figure 6.5 shows that the southern part of the current potential distribution of the Great bustard will disappear with the future climatic conditions.

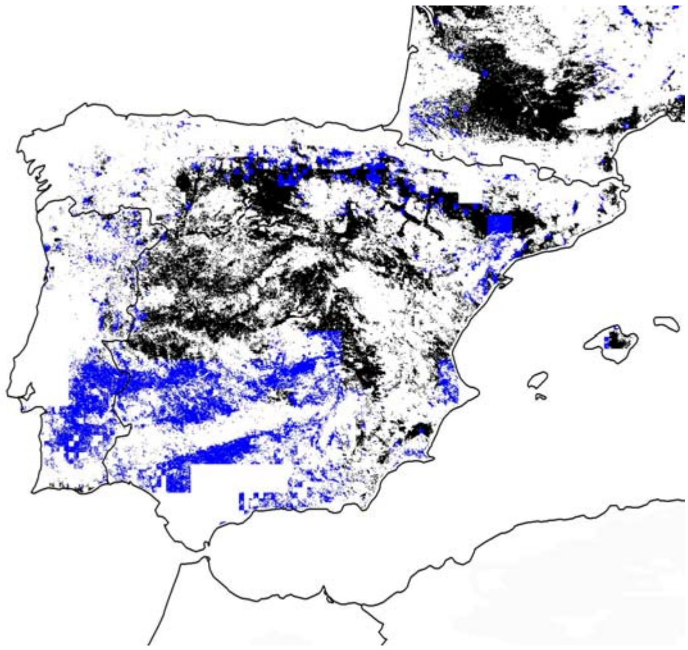

***Fig. 6.5.** Modelling of the effects of climatic change on the potential distribution of the Great bustard (*Otis tarda*), a threatened species. The black-grey tones show the areas with the right conditions for the species at present, whereas the blue tones indicate the areas that will be reduced in the future*

- In the case of the Capercaillie (*Tetrao urogallus cantabricus*, "vulnerable") in the Cordillera Cantábrica, the display sites or leks abandoned recently are at lower altitudes than those still occupied by capercaillies (Obeso and Bañuelos 2004).

6.3.2.3.2. Changes in latitudinal or altitudinal geographic distribution or zoning in Invertebrates:

- As was mentioned in section 2.2, we cannot expect the communities of terrestrial molluscs, or the majority of unspecialised edaphic invertebrates (i.e. mites, nematodes, etc.), to be seriously affected by the direct effects of climate changes. The most limiting factor is humidity (Subías personal communication), whereas temperature changes could have a long-term effect due to the buffering effect of the soils, provided plant cover is maintained. Only a drastic alteration of the ecosystem, such as erosion, could have serious consequences. An irreversible latitudinal and/or altitudinal displacement of plant communities could cause modifications in the species composition of the malacofauna, and other edaphic communities, although this will differ depending on whether we are dealing with herbaceous, xerophilous habitats, or different types of forests.

- In the case of rivers, reduced flow and warming of the waters could cause the intrusion of the fauna from mid-mountain to high mountain areas, as well as habitat fragmentation. In the first case, there would be a displacement of the biocenosis upstream (Hypothesis I) (see Chapter 3), provided that other factors, such as substrate type of current speed do not limit the survival of thermophilous species, and at the same time, the populations of cold water species could be reduced and, in some cases, totally disappear. Fragmentation appears to be the case of trout and salmon rivers, in which the decrease, already evident, of these fish species would be accentuated. This would have very negative consequences for the highly threatened species of large bivalves.

- Altitude, latitude and depth seem to play the same role on the distribution and diversity of the malacocenosis (gastropods and bivalves) in 43 European lakes (Mouthon 1990). The stations with the greatest species richness correspond to the littoral zones of medium to low altitude lakes, and is greater towards the South. The littoral areas of mountain lakes and the deep parts of all lakes are the places poorest in species. This distribution suggests that temperature (and the associated climatic conditions) is the main factor associated with species distribution and abundance. That is, unless a temperature rise, increased drought, eutrophication by pollutants or desiccation of aquifers cause the disappearance of permanent lakes and lagoons, or irreversibly alter them, the predicted change may not affect, or even have a positive effect on the freshwater malacofaunas therein. This may even have a positive influence upon the following links in the trophic chain. The mollusc species inhabiting these environments, however, belong to more generalist and tolerant groups, in which endemisms are rare.

The available data on insects indicate that alterations may occur in the ecosystems and show the extent of damage caused by invasive species of medical-veterinarian importance and with regard to crop plagues.

- Analysis of the whole distribution area in Europe of 35 species of butterflies, showed that 63% of them had spread to latitudes further north of their distribution area, whereas 6% had spread southwards and 3% had done so in both directions (Parmesan *et al*. 1999).

- In the 70s of last century, of a total of 38 species of non-migratory butterflies living in Great Britain, it was found that 47% of the species had spread their distribution area northwards, whereas only 8% had done so towards the south (Parmesan *et al*. 1999). The magnitude of movement of the distribution area towards Northern Europe of some butterflies is, depending on species, between 35 and 240 km, which cannot simply be attributed to the mere spread of the species, as it significantly surpasses the distances of natural colonisation processes of any of the species considered in this study (Parmesan *et al*. 1999).

- On analysing the distribution of 40 species of butterflies (France, Spain, Morocco, Tunisia and Algeria), a northward displacement was observed in the southern limit of distribution in 22% of the species and a southward spread in distribution in 5%, the rest remaining invariable (Parmesan *et al*. 1999).

- It has been observed that the southern distribution limit either remains stable in most of the species studied (approximately 65%) or a small displacement towards the north of this southern limit is observed (in approximately 35%).

- *Heodes tityrus* (Lepidoptera Lycaenidae), a species whose southern distribution limit was in Catalonia, has changed its range of distribution. It was an abundant species in Montseny (Barcelona) throughout the last century, but it disappeared at the end of of the 1990s due to causes that cannot be attributed to habitat alteration. At the same time it has been seen that in Estonia, where sightings were sporadic throughout the last century, it has established permanent breeding grounds (Parmesan *et al*. 1999).

- In order to evaluate the possible consequences of climate change on many endemic species of the Iberian Peninsula, we must remember that we are in an interglacial period which began around 10,000 years ago, and during which the strips of vegetation and the associated insects were gradually displaced northwards. It is important to keep in mind that in many insect species, the populations isolated on mountain tops, and therefore without any genetic exchange, are the result of a previous colonisation process during cold periods, when population continuity existed, and that they are real glacial relicts of past times. In these cases, although they have not given rise to new species during recent history, they have generated numerous subspecies differentiations, as has happened, for example, with *Parnassius apollo* (Lepidoptera Papilionidae), whose populations are found at the highest elevations on the different Spanish mountain ranges. Species like the aforementioned one do not have any possibility to make south-north migrations due to the transversal (latitudinal) arrangement of the mountain ranges, and are restricted to small areas with the sole possibility of emigrating towards higher elevations, if this possibility were, in fact, to exist.

- In other cases, the consequence of the glacial period was a drastic reduction of geographic distribution areas, so that many species were confined to authentic Iberian Pleistocene refuges, as no subsequent recovery of their primitive distribution area has taken place. In this way, species that had long been considered endemic of a certain area, are the remaining legacy of an abundant and widely distributed population from before the last glaciation, the geographic distribution area they currently occupy constituting their last refuge (Elias 1994). Thus, in Spain we found insect species that are real evidence of past times and which are currently confined to enclaves in Mediterranean Europe, like A*phodius bonvouloiri* (Coleoptera Aphodiidae), a coprophagous species very abundant in the pastures of the mountains of the Sistema Central and the Cordillera Cantábrica and which we know lived in Great Britain during the warm periods half-way through the last glaciation, where it was associated with other species of insects typical of more temperate climates (Coope and Angus 1975). Likewise, during the last interglacial period, many species of coprophagous scarabaeid coleoptera (dung beetles) now considered as typical of the Mediterranean regions in southern Europe, like *Onthophagus furcatus* or *Euoniticellus fulvus* existed in Great Britain in the preglacial period (Coope 1990). Many other examples have been found among the coleoptera because of the greater ease with which they leave subfossil deposits, which is why we know that some species of carabids whose present distribution area covers part of the Iberian Peninsula and the South of France must have existed in much of Europe before the last glacial period (Coope 1990). All these groups of insects can be expected to be seriously affected by global warming.

- Although the species of migrating insects may be able to respond to a great extent to climate change by means of variation and adjustment of their annual displacement periods in accordance with new environmental conditions, most arthropods are sedentary, and displacements are within a radius of, at the most, a few hundred metres. For sedentary species, response to climate change will involve changes in the northern and southern limits of their distribution areas. This will inevitably lead to changes in their population levels, causing variations in the relationship between extinction and colonisation to the north and south of the species' distribution range.

6.3.2.4.Changes in ecological interactions

6.3.2.4.1. Changes in ecological interactions in Vertebrates

There are two possible effects of climate change on vertebrate populations that are of increasing concern to specialists. One is the possibility that more benign climatic conditions will favour displacements towards our latitudes of parasite vectors or of the parasites themselves (Rogers and Randolph 2000, Patz *et al*. 2000). The interaction between the effects of changes in temperature and rainfall is crucial in this sense. The conditions of temperature increases accompanied by reduced rainfall do not necessarily favour parasitosis. Thus, for example, the incidence of the viral haemorrhagic epidemic in rabbits appears to be less virulent, at both local and regional scale on the Iberian Peninsula, in the dry areas than in the wetlands, perhaps because there are more vectors in more humid conditions (M. Delibes, pers. com.). In relation to this problem, it is possible that the virulence of existing parasites may be favoured by the immunodepression of the hosts caused by environmental change. The spectacular global decline of amphibians detected in the last few decades seems to be associated, among other factors, with infections in eggs, larvae or adults by parasites, especially fungi (Blaustein and Kiesecker 2002). In some cases, this could be related to immunodepression in the hosts. To what extent climatic conditions favour the spread of parasites (hypothesis II) still remains to be seen.

The other problem associated with climate change could involve the spread of introduced species due to more favourable climatic conditions. For example, the introduction of foreign species of fish in our rivers for sports fishing is a problem for the conservation of our autochthonous fish, regardless of climate change (Doadrio 2001, Elvira and Almodóvar 2001). If this increase were also to be favoured by the aforementioned climate change, the problem would get worse (Elvira 2001). Many examples can be given of the dramatic effects on biodiversity of species introductions (turtles, parrots, etc.). However, other introduced species could be negatively affected by the foreseeable climate changes (for example, the American mink). The introduction of exotic species or varieties favoured by climatic change could lead to crossbreeding and the loss of endemic genetic diversity on the Peninsula. In the Canary Isles, this type of species, especially parrots, are spreading rapidly, favoured by their commercial value and by irresponsible practice of zoological nuclei ("escapes") for tourism, which are subjected to no control by the public authorities. This has led to a marked transformation of the urban fauna in the last 20 years. However, we must consider that in the Canaries there are forest of great scientific interest, the subtropical laurel forests that occupied the Mediterranean basin in the Tertiary. This subtropical feature might be optimum for certain species of parrot which are being introduced, while these relictic forests harbour two species of endemic pigeons, Bolle's Laurel pigeon (*Columba bollii*) and the Laurel pigeon (*Columba junoniae*, "sensitive to habitat alteration") (Martín *et al*. 2000), which could be negatively affected.

- A collapse has been detected in populations of Common midwife toad due to infection by fungi, through the possible involvement of climate change (Bosch *et al*. 2001).

- We know that, with an increase in temperature during springtime in the Sierra de Ayllón (Madrid), the number of nests of pied flycatchers attacked by ectoparasites has increased (Merino and Potti 1996). In a scenario of temperature increase and/or reduced rainfall, some nesting birds in our latitudes may be expected to show a drastic reduction in reproductive success due to infestation of their nests by ectoparasites.

6.3.2.4.2. Changes in ecological interactions in Invertebrates:

- Fluctuations in temperature and humidity and changes in land uses directly affect edpahic fauna in the long term. This is often more conditioned by the effects of indirect climate changes and CO_2 increases on the vegetation (in herbivorous species), nutrient availability and effects on the soil itself. It seems that these direct and indirect effects could have a cascade effect on herbivorous and decomposing organisms. The lack of good taxonomies hinders research into these processes, which tends to be based on experimental models. One hypothesis suggests that there is considerable species redundancy within each functional group, although changes in the diversity of functional groups could have serious consequences for the processes of ecosystems. Given the great diversity and adaptability of soil organisms, these ecological concepts suggest that redundancy and/or substitution are frequent in edaphic systems. One possible consequence is that the impact of environmental changes might be less than what was expected from the extrapolation of the results of studies to isolated organisms. To the contrary, bigger impacts that modify the bidiversity threshold, with gains or losses in a given functional group, such as earthworms or termites, could have a significant effect upon edaphic processes. While these alterations are more likely due to changes in land uses and pollution, which lead to displacements of the vegetation, the differential capacity of soil organisms to migrate could lead to changes in the functional composition of edaphic communities (Ingram and Wall 1998, Swift *et al*. 1998).

- Climate scenarios like the one expected for Spain include hotter and drier summers followed by warm winters and more rainfall, which would create the ideal environment for a reduction of the carbon available in the shallower layers of the soil. Given the direct relationship between organic carbon and the structural stability of the soil, the likelihood of erosion increases with a decrease in organic carbon, with the consequent impact and impoverishment of the fauna. This effect would be greater in Mediterranean ecosystems.

- Alterations in the annual period of activity do not affect all groups and species of insects in the same way, which could therefore lead to a serious maladjustment in the necessary synchronisation of the periods of activity of host and parasitoid insects (Hassell *et al*. 1993).

- Likewise, global warming allows for the spread in altitude of species of phytophagous insects that cause plagues, possibly affecting new plant species and relictic forest formations in the south of the Iberian Peninsula. We found an example of this in the altitudinal penetration in Sierra Nevada of *Traumatocampa pityocampa*, a lepidopteran that can cause serious damage to the pines *Pinus nigra*, *P. halepensis* and that seriously affects *P. sylvestris* in the populations situated at lower altitudes. In Sierra Nevada and Sierra de Baza the southernmost populations of Scots pine considered as the subspecies *P. sylvestris nevadensis* are found. Global climate change could very seriously affect this Iberian endemism as a consequence of the altitudinal rise of *T. pityocampa*, given that an increase in the population levels of caterpillars of this species causes a high level of defoliation that reduces the growth rate of *P. sylvestris* by up to 50%, with the consequent reduction of seed production and renovation rate (Hódar *et al*. 2003)

- Furthermore, in groups like the aphids, an increase in mean annual temperature can cause an advance in emigration periods and the early appearance of pests at a time when the crops are most vulnerable (EXAMINE, Victoria Seco pers. com.).

6.3.2.5. Changes in area and quality of potential habitats (degradation, loss, fragmentation, colonisation by invasive species)

6.3.2.5.1. Changes in area and quality of potential habitats for vertebrates

Climate change can determine changes in the availability of favourable habitats for many species of vertebrates. For instance, droughts and longer periods of intense heat can be expected to determine faster desiccation of ponds, wetlands and temporary water courses in spring. For amphibians and fish, this could lead to the extinction of populations of greater genetic isolation (Márquez and Lizana 2002). Some mammals that are widely distributed throughout the Iberian Peninsula, like water shrews of the *Neomys* genus, the water rat *Arvicola sapidus* or the Cabrera Vole *Microtus cabrerae*, could be seriously affected by this problem. The Cabrera vole, endemic of the Peninsula, depends on small masses or bodies of water where it does not compete so much with the water rat, and its populations are therefore very fragmented and vulnerable to prolonged drought (M. Delibes, pers. com.).

Forest fires also cause the loss of forest habitats, as well as the desiccation and sediment accrual in ponds and water points. The forest vertebrate fauna may suffer even greater fragmentation of their habitats and amphibian and fish populations may be reduced even more by a higher incidence of forest fires (see chapter ¿?) due to climate change.

The high temperatures may lead to a proliferation of aquatic plants like, for example, the tropical fern of the genus *Azolla* recently detected in Doñana (García Murillo, pers. com.), which imply anoxia in lagoons and water-courses, with negative effects for freshwater fish. The impacts of these changes (hypothesis II) are still to be studied in Spain. In aquatic ecosystems, the high temperatures would also lead to an increase in the concentration of nutrients with a greater risk of eutrophication (hypoxia, proliferation of algae and toxic bacteria) and also to an increase in the concentration of many types of low-volatility pollutants (the very volatile ones might be less soluble at higher temperatures) (see chapter ?).

The predictable increase in sea level could seriously affect coastal habitats. In important areas for vertebrate species like the Doñana National Park, the increased salinity could have a very grave impact on many species.

- A loss of viability has been detected in the eggs of three species of amphibians (Common toad *Bufo bufo*, Iberian spadefoot *Pelobates cultripes* and Common frog *Rana perezi*, these two “of special interest”) in central Spain, due to natural levels of UVB radiation (Lizana and Pedraza 1998, Marco and Lizana 2002, Marco *et al*. 2002). The incidence of these radiation levels may be related to climate if decreased springtime rainfall reduces the level of water in ponds and water courses, because the eggs of amphibians would probably be exposed to dangerous levels of UVB radiation due to a lower protective volume of water. This effect would be less serious for amphibians that lay their eggs on the surface. Thus the Common frog usually lays its eggs on the shores, perhaps to make use of thermal radiation in order to speed up development, so that, even if there is a large layer of water, they lay their eggs in shallow waters. They apparently avoid deep ponds or the deeper parts of these, and the greatest concentration of clutches is always found in the shallow areas, with large masses of eggs “flowering” on the surface. The Common frog, when it breeds in reservoirs, mountain lakes or lagoons, normally lays eggs on the shores or in the water, but in this case, the eggs usually remain on the shallower layers (A. G. Nicieza, pers. com.).

- In the Canaries, there is a serious problem with the population of Blue chaffinch living on Gran Canaria (*Fringilla teydea polatzeki*, "in danger of extinction"), as it is only present in the *montes* of Pajonales, Ojeda and Inagua, and its population has been estimated at around 200 individuals (Rodríguez and Moreno 1996). These pine forests are a geographic unit of *Pinus canariensis*, of around 3.700 Ha, in the West of the island. A big fire would not totally destroy this forest, as the Canary pine is quite resistant to fire, probably as a result of its evolution in volcanic terrain, but the habitat would undoubtedly be seriously impoverished, which would negatively affect the survival of this endemic subspecies.

6.3.2.5.2. Changes in area and quality of potential habitats for Invertebrates:

Alteration of habitat will be one of the determining factors either of the disappearance of species or of their displacement. Many species of insects with aquatic larval phases, such as Odonata, Trichoptera, Plecoptera, Ephemeroptera, Coleoptera, Hemiptera among others, would be affected by the disappearance of pools, humid areas and water courses caused by an increase in drought periods and in mean annual temperatures.

Likewise, given the interaction between many insect species and vegetation, the disappearance of plant species or a change in their area of distribution would seriously affect many species of invertebrates.

- In the upper Tajo region, a bioclimatic area has been described which is differentiated from the neighbouring ones, with elements of flora and invertebrate fauna (molluscs, carabid beetles, isopods) of a central European nature (Ramos 1985, Serrano 1984). This is an area with conditions of marginality and the associated evolutionary phenomena, in several species of molluscs (e.g. *Cepaea nemoralis*, *C. hortensis*) (Ramos and Aparicio 1984). This area could disappear as a result of the loss of the associated deciduous forest, or might be displaced northwards. The latter hypothesis seems unlikely because of the influence of microclimatic factors, which would disappear towards the desertified area of the Ebro basin.

One of the effects of climate change, particularly in the Mediterranean area, is the risk of fire (see chapter 11). The effects of fire have been studied in mollusc communities in the Mediterranean region. The results show that the communities appear to be highly resistant to fire, and to other types of anthropic alterations, provided that the alteration is not maintained for several years and that there is sufficient time between two alterations to recover (see review in Kiss *et al*. 2004). The response patterns to fire appear to be multifactorial. The composition of the present communities of terrestrial molluscs is not only the result of a long history of recurring fires since the Neolithic, but also of other anthropic alterations, of changes in the landscape over centuries, of the structure of the habitat previous to the fire and of the influence of a biogeographic gradient (Kiss *et al*. 2004). It should be mentioned that the Helicidae family (the most numerous with regard to species) has undergone a particular diversification in the Mediterranean Basin. The response pattern obtained may be due to the existence of cryptic refuges in the burnt areas, which would allow for the survival and conservation of the malacofauna following successive fire episodes. This hypothesis is reinforced by the fact that, after fire episodes, the malacofaunas recover and even maintain the proportion of their central European elements in the populations most distant from the Mediterranean sea. This pattern is similar to what has been observed in other components of edaphic fauna, such as in the case of Oribatid mites (Subías, personal communication). 15-20 years after the fire, an almost total recovery of the oribatids community was observed, probably due to the existence of microclimates of refuge areas that have conserved their faunistic elements, thus allowing for re-colonisation.

A unique ecosystem is constituted by springs and small streams. These are habitats with cold and well-oxygenated waters and with a continuous current throughout the year which is not too intense. Due to the mountainous nature of the Peninsula, these habitats are numerous and diverse. They are rich in invertebrates and endemisms, as they are frequently isolated, or only communicatethrough the phreatic waters by which they are fed. These habitats are therefore very fragile, fragmented and sensitive, both to natural desiccation processes and to direct and indirect human activity. The accumulation of wastes, the spillage of pollutant elements and alteration (resulting from activities that cause desiccation or reductions of the phreatic level) are the most common cause of the extinction of the invertebrate populations inhabiting therein. Water scarcity resulting from long periods of summer drought and rises in mean annual temperature, predicted for Spain's Mediterranean area, will exacerbate the problem, either through actions affecting aquifers or greater human intervention, with the consequent irreversible disappearance of these habitats.

- The fauna of these ecosystems remains quite unexplored. Data on the freshwater mollusc family Hydrobiidae indicate that most European species occur in the circum-Mediterranean, area, with the highest species number around three centres of differentiation: the Balkans, Italian and Iberian peninsulas. Numerous genera and new species are being described on the Peninsula (Ramos and col. 2000, Arconada and Ramos 2001 2002 2003). Approximately 90% of the species are endemic, probably due to ancient processes of geographic isolation and to their poor dispersal capacity. The systematic study of hidrobiids molluscs, over the last ten years has indicated the disappearance of some populations and species due to the desiccation of their habitats, even previous to their being described (Arconada and Ramos 2003, in press).

Invasive species constitute an important element of global change and a serious threat to biodiversity. Three species of invasive freshwater molluscs are known in Spain: the gastropod *Potamopyrgus antipodarum* (a native of Australia), and the bivalves *Corbicula fluminea* and *Dreissena polymorpha* from Asia and the Caspian Sea, respectively. The latter two have a huge potential for invasion (based on reproduction strategies and high environmental tolerance), both in Europe and in America, with a tremendously negative impact, not only upon native fauna, but also on the river ecosystems they colonise, and are of serious consequence for different economic sectors (construction, water inlets of hydroelectricity, thermal and nuclear plants, etc.). These invasive bivalves cause rapid changes in the benthic community. They displace the native mollusc species, causing an increase in organic substrate cover *(macrofouling*) and favour the presence of oligochaetes and leeches (Darrigran 2002) *Corbicula fluminea* has already invaded the rivers of the Atlantic side of the Peninsula (Araujo *et al*. 1993 and Jiménez *et al*. pers. comm.) and has recently been found in the Ebro (López and Altaba 1997). In this river, too, the first invasion of *Dreissena polymorpha* has recently been recorded in Spain. The consequences of this invasion will be even more serious as this is a bivalve with byssus, which produces large agglomerations of individuals, with planktonic larvae, which facilitates dispersal and makes it extremely aggressive. The transfer of water from the Ebro to the rivers of the Levant will undoubtedly cause invasion. According to the results of Daufresne, *et al* (2004 and pers. comm.), these three species will be favoured by the increased water temperature in the rivers resulting from global warming. Indeed, among molluscs, which is the group that will benefit the most, the two species that most increased their densities in the 1979-1999 period were *Potamopyrgus* and *Corbicula.*

6.3.2.6. Interaction between climate change, vegetation, herbivores, human management and biodiversity in continental ecosystems.

The maintenance of biodiversity necessarily involves the maintenance of habitats. Changes in habitats deriving from human activity are recognised as being the main cause of species extinction. Climate change can directly affect habitats by affecting vegetation, but it is important to point out how activity by herbivores, exacerbated by human management, can accelerate certain processes.

- *Dehesas* and Mediterranean forests. The main use of these areas has been for extensive livestock farming, for which there has been a tendency to eliminate the shrub cover. *Dehesas* without shrubland are unsustainable in the long term due to the lack of natural regeneration of the trees. The main causes of the death rate of the seedlings are summertime drought and the impact of herbivores (Pulido 1999). The temperature increase and/or reduced rainfall lead to early withering of the herbaceous vegetation, which is associated with a greater impact by herbivores on woody plants (Rodríguez-Berrocal 1993). If forest and shrubland areas do not increase in comparison to *dehesas*, climate change could provoke less regeneration of the trees and greater impact by herbivores on the areas occupied by woody vegetation. If there is no intervention, the process could reinforce itself, leading to desertification. The change in use from domestic livestock farming to wild ungulates for hunting may favour management involving an increase in the areas with woody plants, with positive effects for biodiversity (Carranza 1999 2001).

Changes in traditional uses in wetlands, caused by a progressive loss of surface water, have led and lead to a decrease in the phreatic level of the waters by which they are fed, with their consequent salinisation. To this alteration we must add the desiccation and pollution of many of Spain's marshlands. Enrichment in nutrients and organic matter from nearby croplands, extensive farming, and industrial dumping lead to an increase in the degree of eutrophy of the wetland, a reduction of diversity, and the homogenisation of the flora and fauna. In addition to these threats, we must also consider others that have appeared in recent times, such as the use of coastal wetlands to harvest species of economic interest, or the introduction of exotic species like the American crayfish *Procambarus clarki*. This extremely voracious and aggressive species has thrived to the extent that it is now a real pest and a serious threat to many macrophytes. Furthermore, together with the aphanomycosis carried by the introduced individuals, it has destroyed and/or displaced the only autochthonous species of river crab, *Austrapotamobius pallipes,* which has been banished to pools or close to the source of the rivers. Even though it appears that *A. pallipes* populations are recovering, an increase in water temperature could favour the invasive species, allowing it to expand its distribution range upstream. This would put the native species at a clear competitive disadvantage. This species is protected by the Berne Convention (Annex II), Habitats directive (Annex V), UICN (vulnerable). The river crab has not been included in the National Catalogue of Threatened Species, although it is protected in several catalogues of certain regional autonomies.

6.3.2.7. Conclusions based on detected changes

Both hypotheses of future scenarios are confirmed in some cases, whereas they are unrealistic in others. The displacement of distributions would mainly affect species with a good capacity for dispersal (birds, certain insects), whereas it does not seem viable in others (amphibians, fish and most invertebrates). The new ecological challenges for the former in their new distribution areas could prevent colonisation. The alteration of ecological interactions might already be affecting many desynchronised populations with regard to their trophic resources, due to phenological changes, but this has only been confirmed in some cases. Neither the displacement of distribution areas (hypothesis I) nor the rapid adaptation to new ecological conditions (hypothesis II) appears to be viable solutions for most of the species studied.

With regard to future projections, no serious study has been done on this theme in Spain. It is not easy to base distribution models of animals on climatic data only, given the complexity of their ecological interactions with vegetation and with other animal species and of their patterns of habitat use for protection and reproduction. Studies done to date outside Spain present a worrisome panorama with regard to possible impacts. With the current knowledge of Spanish populations, we can state that if certain patterns detected up to the present continue, much of our animal diversity will disappear during this century.

6.4. MOST VULNERABLE AREAS

Among the areas most vulnerable to climate change, we could include coastal areas, wetlands, permanent water courses, which would become seasonal and seasonal ones that would have a more irregular flow or might even disappear, high mountain areas and humid pastures. The vulnerability is maximum for specific habitats (especially mountain ones) that are totally isolated and contain endemic fauna that have no capacity to migrate or where there is no possibility of creating natural corridors or where there is nowhere to migrate to. With climate change, large populations could disappear in the short term, and all of their available habitats in the medium term. There are several examples of this on the Peninsula, particularly in mountain areas in the South and Centre. With regard to vulnerable reptiles and amphibians, we must mention *Algyroides marchii, Lacerta monticola cyreni*, *Podarcis carbonelli*, *Lacerta schreiberi* and *Salamandra salamandra longirostris* (subspecies endemic to the mountains in southern Andalucia). Among the invertebrates, hydrobiid molluscs, which live in springs and small streams are a clear example of the disappearance, now a reality, of some populations and even species, previous to their being described (pers. obs.).

6.5. MAIN ADAPTATIONAL OPTIONS

There are several types of adaptational measures that can be taken in the event of climate change, in order to dilute or mitigate its effects on the biodiversity of terrestrial vertebrates and continental invertebrates.

6.5.1. Design of reserves and nature parks and habitat connection:

The design of reserves and nature parks should incorporate the possibility of migration and changes in distribution by means of interconnecting biological corridors.

6.5.2. Latitudinal and altitudinal gradients in the network of protected areas:

The network of protected areas should incorporate latitudinal and altitudinal gradients in order to allow for the protection of populations with geographic distributions in the process of geographic displacement due to climatic change. We should consider the areas of greatest altitude in the distribution limits of the species to be conserved (endemics, rare species, threatened and endangered ones).

Biodiversity conservation should pay attention not only to the protected areas, but also very especially to the generalised promotion of land uses that are compatible with conservation and capable of counteracting the effects of climate change.

6.5.3. Genetic diversity and conservation

Another consideration is that the genetic diversity of affected populations should be given top priority, because only this can ensure adaptation to climate change. It is important to support research in this field. Crossbreeding with foreign species favoured by climatic change may eliminate endemic genetic varieties in our country.

6.5.4. Genetic diversity and use of species for sports and similar uses

Other possible measures of adaptation to climate change applied without conservation in mind may exacerbate even more the situation of vertebrates and arthropods. Loss of certain species necessary for the control of other populations or for sport uses may lead to the introduction of foreign species, which could have pernicious collateral effects derived from competition with, or depredation on threatened species of vertebrates. The introduction of biological control agents for plagues of arthropods should be well controlled. The prevention of new or more virulent plagues resulting from climate change may determine the use of more pesticides with the consequent impact on the accompanying fauna and an increase of toxic compounds in the environment.

Fragmentation and certain types of management of deer populations provoke a decrease in allelic diversity and increases the degree of homozygosis (Martínez *et al*. 2002). For these cases, recommendations are available for mitigating effects (Carranza and Martínez 2002).

6.5.5. Hydric demands, persistence of species and conflicts over the resource

The increase in demand for water for human uses due to temperature increases and in a possible context of prolonged droughts, will possibly determine an increase in technological solutions that do not take into account the impacts on the biodiversity of species of vertebrates and invertebrates depending on permanent water courses (dams, canals, aqueducts, etc). Communication between water-courses and diverse faunas by canals, has dramatically affected populations of autochthonous species of river fish (Torralba and Oliva 1997, Elvira 2001, Elvira and Almódovar 2001,) and has definitely affected populations of aquatic invertebrates. The alteration of the structure of river courses (construction of dams and reservoirs) causes an alteration of thermal and hydrographic regimes which itself causes changes in entire communities (Power *et al* 1996). These effects can be exacerbated or counteracted (for instance, when a warm and temperate aquatic community changes to a cold water one as a consequence of the construction of a dam upriver) by tendencies to global warming.

Overexploitation of aquifers as a result of water scarcity will cause the permanent desiccation of springs with the consequent loss of species and communities inhabiting therein. Wetlands, in particular the inland marsh ecosystems of the Mediterranean region, mainly occupying sedimentary basins, may suffer a serious impact. The supply could be considered of a wetland with water from different basins, or with different physicochemical characteristics, in order to maintain levels more or less stable for use by the bird community, or for use as a water resource. These interventions could cause alterations to the ecosystem, in many cases irreversible ones. Artificial water supply can cause changes in the environment that impede the normal development of the biota characteristic of the wetland affected and even introduce species that displace the autochthonous ones, with the consequent changes in the original biocenosis. A clear example of this is the Las Tablas de Daimiel National Park, which, following desiccation, receives water from another basin (see Chapter XX). Following this episode, several sampling sessions have shown that the mollusc species described therein have disappeared (Araujo and Ramos, personal communication), and only empty shells can be found. The same thing might have occurred with other animal groups whose disappearance has left no visible signs.

The clear decrease in the flow of Mediterranean coastline rivers in the last century, fundamentally due to increased demand for water, may be responsible for the scarcity or lack of the Otter *Lutra lutra* in these rivers (Jiménez and Delibes 1990, Jiménez and Lacomba 1991).

6.5.6. Advantages and disadvantages of measures for the mitigation of climate change in relation to reforestation

One of the main mitigation measures contemplated in the context of climate change and in relation to the Kyoto Protocol is the creation of new forest masses that could serve as carbon sinks. This could have positive effects on the fauna depending on forest ecosystems. However, it could also cause serious problems for the conservation of terrestrial biodiversitiy. One of the main ones involves reforestation with fast-growing foreign species or the establishment of plantations with few species. The importance should be highlighted of conserving the existing masses of mature, slow-growing forests, compared with the alternative of reforestation with fast-growing species (if the priority objective really is carbon sequestration). Reforestation with fast-growing species will sequestrate carbon faster, but this will also be released faster (Körner 2001). It really seems quite frivolous to argue about which species is the most efficient for capturing CO_2 from the atmosphere when, on the other hand, CO_2 is being released by the massive deforestation of mature forests that constitute an important carbon store. Replacement of mature forests by plantations would be of no advantage to our autochthonous fauna, but would rather serve as an excuse to destroy whole masses of autochthonous forests and to eliminate habitats of conservationist interest, like agricultural steppes, mountain pastures or Mediterranean shrublands. Furthermore, substitution of mature forests with foreign species could lead to the impoverishment of the soils, and of the associated biodiversity, due to acidification and loss of plant organic matter that is vital for the balance of the ecosystem. Grants for reforestation are having pernicious effects in tropical countries, where native forests are being destroyed to justify the reforestation of barren land, funding agencies not being informed that this land was previously covered with forest. The simplification of habitats caused by plantations or single cropping with one or few species can only be bad for biodiverity. The plantation of species that demand water in order to grow rapidly can only worsen the drop in phreatic levels and the destruction of habitats of vertebrates or invertebrates depending on aquatic habitats. In a scenario of climate change, it is important to conserve the Mediterranean maquis given its low capacity for evapotranspiration compared to other forest habitats that lose more water than they retain (see terrestrial ecosystems).

In Mediterranean ecosystems it is necessary to promote the natural regeneration of forests (especially *Quercus* spp), by allowing for the ecological succession of the Mediterranean shrubland in large areas inserted into the *dehesa* areas (Pulido 1999, Carranza 2001). However, in relation to reforestation policies, we must point out that the Mediterranean environment has been shaped and transformed by incessant human activity for thousands of years, which has led to a landscape mosaic comprising fields of crops, pastures bordering with herbaceous vegetation or shrubland, cohabiting with original plant formations which have been managed by man for thousands of years (Díaz-Pineda *et al*. 1998). This historic process of transformation of the environment has surely conditioned, to a great extent, the composition of the fauna and vegetation currently found in the Mediterranean basin (Blondel and Vigne 1984, Erhardt and Thomas 1991, Galante 1994, Mönkkönen and Welsh 1994, Samways 1994). Thus, the highest levels of entomological diversity and the highest percentages of endemisms are found in open spaces (Galante 2002, Verdú and Galante 2002, Martín *et al*. 2000). Thus, a generalised reforestation policy, along with the promotion of changes in land use, encouraging the abandonment of traditional agricultural and livestock farming activities, may become a very negative factor for the conservation of Iberobalearic biodiversity, which will lead to the rapid disappearance of numerous species of insects and other invertebrates.

6.5.7. Interactions between the use of different types of renewable energy and fauna

Other possible mitigation measures considered involve opting for hydraulic or aeolic energy. The former would be based on new dams and the fragmentation of our rivers, the latter on the construction of windcraft parks, with annexed infrastructures which could contribute both to the possible death of birds during migration and to serious alterations or damage in the surrounding environment resulting from construction. The main migration routes of birds from Europe to Africa cross Spanish territory (Bernis 1966)

The few data available in this respect for rivers (Daufresne *et al*. 2003) suggest that artificial warming foci, such as thermal and even nuclear power plants, can on occasions affect the surrounding communities, although they do not appear to have a significant effect on the tendency towards upstream displacement in the present zonal distribution of fish and invertebrates in rivers.

6.6. IMPACTS ON OTHER SECTORS OR AREAS

Agricultural and cattle-raising activities can be seriously affected by climate change. Measures taken against prolonged droughts (dams, containments, over-exploitation of aquifers) will have adverse effects on animal biodiversity (see other sections). A greater incidence of pests could imply an increase in pesticide emission into the medium. This, in turn, could favour the selection of pests that are increasingly more virulent. Increased incidences of parasitosis in domestic animals will require an increase in antiparasitic treatments, which could favour selection for greater resistance in parasites and increase their virulence.

Sport hunting and fishing currently constitute economic activities involving many people and which generate large amounts of capital, as well as affecting increasingly larger areas fundamentally managed for the practice of these activities. The target species of hunting and fishing will be affected in the same way as other species by the aforementioned potential changes. The introduction of varieties or breeds which are poorly adapted to the Mediterranean climate could cause further problems.

Supplementary food is given to the game to mitigate the effects of summer drought in the southern half of Spain. The effects of this supplementary feeding system are usually undesirable (Carranza *et al* 1995, Sanchez-Prieto *et al*., in press) and could be exacerbated with climate change. An increase in the areas of forest and shrublands, along with the suitable insertion of these in mosaics, might contribute to attenuating the need for supplementary food in summer (Carranza 1999; 2001).

Management practices that are incompatible with the conservation of game species and freshwater fish and their habitats ought to be controlled (Carranza and Martínez 2002), but the use of the territory for hunting may be more compatible with conservation of certain species than traditional uses like extensive agriculture and livestock farming (Carranza 2001), and it can also be more easily used to prevent the effects of climate change than agriculture and livestock farming.

6.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

None of the studies reviewed here can irrefutably demonstrate that climate change alone is responsible for the tendencies detected in species and communities (Hughes 2000, McCarty 2001). The destruction, degradation, fragmentation and contamination of habitats caused by changes in the models of economic development are occurring simultaneously with climate change, and to separate the signs of these synergic processes would require much more detailed and costly studies than those that the Spanish scientific community has been able to implement to date. This does not mean that we cannot propose possible effects of climate change, provided that the estimates upon which the climate model is based, as well as the predictions of effects on populations are clearly established.

With regard to invertebrates, there are also numerous factors that should be studied in order to evaluate the possible effects of climate change on their populations. One of the key questions to be researched is the relationship between the changes in the distribution area of the species and climate change, and in this process the influence of the present changes in land use and in hydric resources and habitat fragmentation should be analysed. To this we must add the changes in phenology that climate change is causing and which should be analysed together with changes in distribution. Changes in inter-species ecological interactions and the interaction between these species and the environment should be subjected to more in-depth study.

6.8. DETECTION OF CHANGE

Change can be detected by means of any long-term study of animal populations capable of eliminating sources of variation resulting from other human impacts on habitats (changes in policy, infrastructures, housing development, pollution, introduction of exotic species, etc,.). This is obviously easier in populations in areas little affected by humans, like protected areas. But there are also groups of species, which have proven to be extremely vulnerable to environmental change, and population collapses have been detected in remote or protected regions. Among the vertebrates, we can highlight amphibians in this sense, due to their morphology and physiology. There is also a global observation network for the observation of changes in amphibian populations, which facilitates the transfer of information at international level. Migratory birds, due to the discrete nature of the phases of their annual cycle, offer good possibilities for the detection of changes in phenology and in behaviour. The animals living in high-mountain areas can also be good indicators of changes, as these areas are real ecological islands the area of which would gradually be reduced by climate change.

6.9. IMPLICATIONS FOR POLICIES

6.9.1. Scientific policy

The Science and Education Ministry should promote research into the effects of climate change on the processes affecting the biodiversity of terrestrial organisms. Most of the projects approved up to now only contemplate changes in the past. Hardly any prospective projects or ones related to detection of the effects of climate change have been approved to date. These projects ought to appraise the effects of climate change and its relationship with profound changes in land uses and with habitat fragmentation. International scientific cooperation, especially within the EU, is the only way to advance research on such complex subjects that are not limited to the strict geographic boundaries of our country. This cooperation should be encouraged through programs like “Global Change”, within the program framework of the EU.

6.9.2. Environmental policy

The Environment Ministry (DGB, OA national Parks) and the Regional Governments should take a stance on the conservation of the network of protected areas. This policy should be applied at the level of regional autonomies, given the geographic scale of the problems.

Areas containing species particularly affected by climate change could be subjected to special protection in order to reduce to a minimum the effects of climate change (protection of hydrological and forest resources, control of all types of land uses, like excessive livestock farming, tourism or housing development). It would be interesting to appraise the classification or creation of “zones or areas particularly sensitive to climate change” for areas with unique original ecosystems or with endangered or endemic species that have no alternatives for the displacement of their habitats and that can become extinct. Examples of these areas are high-mountain territories, water courses containing vulnerable species and wetlands and other aquatic ecosystems such as springs and small strems, which are not subjected to any legal protection.

6.9.3. Regional and local tourism policy

To be implemented by the Regional Autonomies (Tourism Depts.) and by the City Councils (Municipal Tourism Depts.) located in the surroundings of protected natural areas. Alteration by tourism of vulnerable high-mountain areas or of lacustrian-river areas should be strictly limited.

6.9.4. Hunting and freshwater fishing policy

The Regional Autonomy would be involved (Agriculture and Fisheries or Environmental Depts.). The introduction of foreign species of fish for sports fishing should be controlled or prevented if the intention is to conserve the rich diversity of endemisms of freshwater fish that still exist in our country. The introduction of varieties or species for hunting typical of other regions should also be controlled in order to avoid negative effects through crossbreeding on the autochthonous varieties which are better adapted to the Mediterranean climate.

Sport fishing activities, and even the use of boats on lakes and lagoons to this end, can cause the accidental translocation of invasive species as e.g. of the larvae of *Dreissena polymorpha*. Upstream movement of sport fishing boats on the river Miño has spread upstream the species *Corbicula fluminea*. Appropriate measures need to be established to control carriers of invasive species (renovation of fishing tackle, cleaning boats on changing basins, etc.), and there is also a drastic need for follow-up in this respect. Awareness of the population is essential in order for these measures to be effective.

6.10. MAIN RESEARCH NEEDS

6.10.1. Creation and maintenance of long temporal series

As can be deduced from the incorporated information, there are very few long temporal series in Spain that can be used to explore the possibilities of changes in the phenology or dynamics of populations. Long-term studies should be established and funded dealing with animal populations located in habitat that do not suffer (or hardly) from human effects different from climate change. Short temporal series prevent us from separating the effects of possible climate changes from natural demographic variations. Long temporal series permit us to explore the effects of extreme climatic events (such as that of the summer of 2003), and variation of climatic conditions in relation to mean temperature increases.

At present, there exists a phenological database of plants and animals (birds and insects) initiated in 1940 by the Agricultural Meteorology Service, belonging to the National Meteorology Institute (NMI). From the start, different phenological phases were recorded (for example, flowering and leaf unfolding in plants, or the arrival and departure of migrating birds) in between 100 and 200 stations throughout the Peninsula, the Balearic Isles and the Canary Isles. The data were collected by observers who, under specific instructions, forwarded the information on a monthly basis. These data are being computerised by J.J. Sanz within the framework of a collaboration agreement between the NMI and the MNCN - CSIC- (National Museum of Natural Sciences - Higher Council for Scientific Research). The number of observations has been gradually decreasing since 1940, and if this database is not revitalised, its future is quite uncertain. For example, in the 1950s, there were around 300 observations of arrivals of swallows to different locations; this number has dropped to 150 in the 1980s and in the last 5 years it has dropped below 100 locations per year. The main problem with this phenological database is the low entry of data from new observers. This type of phenological database should be promoted with the use of Internet as a means of communication between observers. It would be a good idea to use park rangers as phenological observers, given their suitable biological training for this activity. Internet could be used to reduce costs as much as possible, and the observers would be encouraged to contrast their data with the existing ones. The database should have someone in charge of validating the observations in order to provide the information to the Administration. The objective of this information would be to provide bioindicators of possible climate changes in the present or nearby future. Furthermore, this activity could be promoted among conservationist NGOs specialised in certain organisms, like SEO/BirdLife for birds. This NGO has a great potential with regard to observers, who are well distributed throughout the Peninsula and the islands, and who could provide valuable data. Indeed, there are already programmes underway (SACRE), the future results of which can be used as bioindicators of global change.

6.10.2. The Establishment of research programs on latitudinal and altitudinal gradients and distribution limits

Given its geographic location and complex orography compared to other European countries, Spain offers many unique possibilities for research along latitudinal and altitudinal gradients. Research on animal population dynamics and adaptations along these gradients would provide important information to assess animal species adaptation to rapid climate changes. The life histories of some populations could exhibit altitudinal microevolutionary diversification as a result of having adapted to altitudinal gradients. This altitudinal diversification could be more important than latitudinal diversification and deserves to be studied and preserved. Altitudinal biodiversity could be seriously affected by climatic changes. At the same time, our country's geographic position offers a unique opportunity to study the ecological factors that determine distribution limits of animal species, and how these limits may change. This type of research must be supported if we wish to have some predictive ability over the future of our animal populations.

6.10.3. Basic studies of the ecology or ecophysiology of wild species in order to allow for minimally reliable predictions of bioenergetic models

There is also the need for further study of the ecology or ecophysiology of wild species in order to predict bioenergetic models that are reliable. It is very important to evaluate the interaction between climate change and other environmental stress factors, by magnifying the effects on wild species of single factors in isolation.

6.10.4. Surveillance systems for possible population collapses

There is an important need for surveillance systems inside and outside reserves in order to detect population collapses and local climate changes. Thus, the near-extinction of the Iberian lynx almost caught the Administration and the conservation NGOs by surprise. Many species, endemic but less charismatic than the lynx, like the Pyrenean desman, are disappearing from large areas of our country, without any apparent reaction by the professionals or people responsible for managing the fauna.

6.10.5. Evaluation of the efficiency of the possible mitigation measures

There is also a need for evaluations of the impact of the possible measures proposed for adaptation and mitigation.

6.10.6. Taxonomic studies in invertebrates

Predictive models of possible changes in the functioning of ecosystems resulting from climate change (species substitution, interaction among the elements of communities, etc.), are seriously hindered by the lack of taxonomic knowledge of the species that integrate them, and of what role they play in the ecosystem.

A priority is therefore: 1) to increase taxonomic studies, in particular of the less known animal groups, and of those that serve as bioindicators, and 2) to develop tools to bring within the reach of ecology scientists, environment managers and society as a whole, easier access to available information.

6.10.7. Conservation Biology for the future

Research into conservation biology and the development of long-term projects ought to be a priority of the Administration in order for future reports to provide more data and less speculation than at present. The study of animal population dynamics should be central to conservation biology studies related to climate change. The length of the reproductive season can affect interactions with predators and parasites, as well as population size and density.

There is a need to promote the study of life cycles, reproduction strategies and population dynamics in relation to altitude and latitude, etc., and of species that are a key to the functioning of ecosystems as well as on invasive species in order to be able to apply the best practises for the protection of native fauna and the control of alien species.

With regard to arthropods in general, research programmes should be developed dealing with the effects of climate change on:

- Groups of endemic insects associated with Iberian transversal mountain ranges, the distribution of which is previous to the Pleistocene glaciations, like the case of *Parnassius apollo*. We could say that they are trapped within their limits, with no possibility to emigrate northwards, and the only response their populations can therefore have involves a vertical displacement towards higher elevations.

- Groups of endemic arthropods, in many cases non-flying wingless ones, or those with little chance of displacement, associated with arid ecosystems with extreme conditions of humidity and temperature, due to the fact that global warming may make the survival of their populations unfeasible.

- Groups of predatory insects and parasitoids, in relation to their biology and that of their prey and their hosts. The lack of synchronisation in their cycles may have serious consequences with regard to increased plagues in crops.

- Groups of migrating insects, in relation to the advance periods of their displacement phases. There could be different consequences: their arrival to ecosystems may not be synchronised with the phenology of food plants, they may not be able to implement their pollinating processes, which are so important for the maintenance of Mediterranean endemic plants

(Pérez Bañón *et al*. 2003), the early appearance of plagues (EXAMINE, project V, Seco pers. com.), etc.

- Insect dispersal related to potential changes in distribution of food plants.

6.11. BIBLIOGRAPHY

Alba-Tercedor J. 2002. Ephemeroptera. In: El Reino animal en la Península Ibérica e islas Baleares (- The animal Kingdom of the Iberian Peninsula and Balearic Islands-).Página web del Proyecto Fauna Ibérica. CSIC: Madrid. http://www.fauna-iberica.mncn.csic.es/htmlfauna/faunibe/zoolist/ insecta/ephemeroptera/epheme.html.

Alba-Tercedor J. and Jáimez-Cuéllar P. 2003. Checklist and historical evolution of the knowledge of Ephemeroptera in the Iberian Peninsula Balearic and Canary Islands. In: Gaino E ed., Research Uodate on Ephemeroptera y Plecoptera. Perugia Servicio Stampa di Ateneo dell,Università degli Studi di Perugia: 91-97.

Araujo R., Bragado D. and Ramos M.A. 2001. Identification of the River Blenny, *Salaria fluviatilis* as a host to the glochidia of *Margaritifera auricularia*. Journal of Molluscan Studies 67: 128-129

Araujo R., Moreno D. and Ramos M.A. 1993. The Asiatic clam Corbicula fluminea (Müller 1774) (Bivalvia Corbiculidae) in Europe. American Malacological Bulletin 10: 39-49.

Arconada B. and Ramos M.A. 2001. New data on Hydrobiidae systematics: two new genera from the Iberian Peninsula. Journal of Natural History 35: 949-984.

Arconada B. and Ramos M.A. 2002. Spathogyna, a new genus for *Valvata* (? *Tropidina*) *fezi* Altimira 1960 from eastern Spain: a second case of natural pseudohermaphroditism in a Hydrobiidae species (Mollusca Prosobranchia). Journal of Molluscan Studies 68: 319-327.

Arconada B. and M.A. Ramos 2003 The Ibero-Balearic region: one of the areas of highest Hydrobiidae (Gastropoda Prosobranchia Rissooidea) diversity in Europe. Graellsia 59(2-3): 91-104.

Arconada B. and Ramos M.A. The genus *Islamia* (Gastropoda Hydrobiidae) revised in the Iberian peninsula and description of two new genera Malacologia (in press).

Baixeras J. 2002. Investigación aplicada a la conservación de las mariposas de Penyagolosa. Informe inédito elaborado para la Consejería de Medio Ambiente de la Generalitat Valenciana. Valencia.

Balleto E. and Casale A. 1991. Mediterranean Insect Conservation. In: Collins N.M. and Thomas J.A. (eds.). The Conservation of Insects and their Habitats. Academic Press London.

Bauwens D., Hordies F., Van Damme R. and Van Hecke A. 1986. Notes on distribution and expansion of the range of the lizard *Psammodromus algirus* in Northern Spain. Amphibia-Reptilia 7: 389-392.

Baylis M. and Rawling P. 1998. Modelling the distribution and abundance of *Culicoides imicola* in Morocco and Iberia uinf climatic data and satellite imagery. Archives of Virology Suppl. 14: 127-136.

Beebee T.J.C. 1995. Amphibian breeding and climate. Nature 374: 219-220.

Bernis F. 1966. Migración en Aves: Tratado teórico y práctico. Publicaciones de la Sociedad Española de Ornitología.

Bezemer T.M. and Knight K.J. 2001. Unpredictable responses of garden snail (*Helix aspersa*) populations to climate change. Acta Oecologica 22: 201-208.

Bisdom E.B.A., Dekker L.W. and Schoute J.F.Th. 1993. Water repellency of sieve fractions from sandy soils and relationships with organic material and soils structure. Geoderma 56: 105-118.

Blaustein A.R. and Kiesecker J.M. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. Ecology Letters 5: 597-608.

Blondel J. and Vigne J.D. 1984. Space time and man as determinants of diversity of birds and mammals in the Mediterranean Region. In: Ricklefs R.E and Schluter D. (eds.). Species diversity in ecological communities. The University of Chicago Press.
Bosch J., Martínez-Solano I. and García-París M. 2001. Evidence of a chytrid fungus infection involved in the decline of the common midwife toad (*Alytes obstetricans*) in protected areas of central Spain. Biological Conservation 97: 331-337.
Brito J.C., Abreu F., Paulo O.S., Da Rosa H.D. and Crespo E.G. 1996. Distribution of Schreiber's green lizard (*Lacerta schreiberi*) in Portugal: a predictive model. Herpetological Journal 6: 43-47.
Brommer J.E. and Fred M.S. 1999. Movement of the Apollo butterfly related to host plant and nectar plant patches. Ecological Entomology 24(2): 125-132.
Bustamante J. 1997. Predictive models for lesser kestrel *Falco naumanni* distribution, abundance and extinction in southern Spain. Biological Conservation 80: 153-160.
Carbonell R., Pérez-Tris E. and Tellería J.L. 2003. Effects of habitat heterogeneity and local adaptation on the body condition of a forest passerine at the edge of its distributional range. Biological Journal of the Linnean Society 78:479-488.
Carranza J. 1999. Aplicaciones de la Etología al manejo de las poblaciones de ciervo en el suroeste de la Península Ibérica: producción y conservación. Etología 7: 5-18.
Carranza J. 2001. INFORME PROYECTO FEDER I+D, MCYT, Ref: 1FD1997-1504
Carranza J. and Martínez J.G. 2002. Consideraciones evolutivas en la gestión de especies cinegéticas. In: Soler M. (ed.). Evolución, la base de la Biología Proyecto Sur Ediciones Granada. pgs. 373-387.
Carrascal L.M. and Lobo J.M. 2003. Respuestas a viejas preguntas con nuevos datos: estudio de los patrones de distribución de la avifauna española y consecuencias para su conservación. In: Martí R. and del Moral J.C. (eds.) Atlas de las Aves Reproductoras de España. Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología. Madrid. Pgs. 651-668
Carrascal L.M., Bautista L.M. and Lázaro E. 1993. Geographical variation in the density of the White Stork *Ciconia ciconia* in Spain: influence of habitat structure and climate. Biological Conservation 65: 83-87.
Cartagena M.A. 2001. Biología y Ecología de los Tenebriónios (Coleoptera Tenebrionidae) en ecosistemas iberolevantinos. Tesis doctoral, Universidad de Alicante.
Cartagena M.A.,. Viñolas A y. Galante E. 2002. Biodiversidad de Tenebriónidos (Coleoptera Tenebrionidae) en saladares ibéricos. Butlletí Insitutció Catalana Historia Natural 70: 91-104.
Chevallier H. 1980. Les escargots de genre *Helix* commercialisée en France. Haliotis 10. 11-23.
Chevallier H. 1992. L'Élevage des Escargots. Editions du Point Vétérinaire Maisons-Alfort, France.
Clutton-Brock T.H., Guinness F.E. and Albon S.D. 1982. Red deer. Behaviour and Ecology of two sexes. Edinburg: Edinburg Univ. Press.
Coope G.R. and Angus R.B. 1975. An ecological study of a temperate interlude in the middle of the last glaciation, based on fossil Coleoptera from Isleworht, Middlesex. Journal Animal. Ecology 44: 365-391.
Coope G.R. 1990. The invasion of Northern Europe during the Plesitocene by Mediterranean speccies of Coleoptera. In: Di Castri F., Hansen A.J. and Debussche M. (eds.). Biological invasions in Europe and Mediterranean Basin. Kluwer Academic Publishers London. Pgs. 203-215.
Darrigran G. 2002. Potential impact of filter-feeding invaders on temperate inland freshwater environments. Biological Invasions 4: 145-156.
Daufresne M., Roger M.C., Capra H. and Lamouroux N. 2003. Long-term changes within the invertebrate and fish communities of the Upper Rhône River: effects of climatic factors. Global Change Biology 10: 124-140.
Díaz S., Fraser L.H., Grime J.P. and Falczuk V. 1998. The impact of elevated CO_2 on plant-herbivore interactions: experimental evidence of moderating effects at the community

level. Oecologia 117: 177-186.
Dawson W.R. 1992. Physiological responses of animals to higher temperatures. In: Peters R.L. and Lovejoy T.E. (eds.) Global Warming and Biological Diversity. Yale University Press. Yale CT. Pgs. 158-170
Díaz-Paniagua C., Cuadrado M., Blázquez M.C. and Mateo J.A. 2002. Reproduction of *Chamaleo chamaleon* under contrasting environmental conditions. Herpetological Journal 12: 99-104.
Díaz-Pineda F., de Miguel J.M. and Casado M.A. (coordinadores). 1998. Diversidad biológica y cultura rural en la gestión ambiental del desarrollo. Mundi-Prensa Madrid.
Doadrio I. 2001. Atlas y Libro Rojo de los Peces Continentales de España. Consejo Superior de Investigaciones Científicas-Ministerio de Medio Ambiente. Madrid.
Elias S.A. 1994. Quaternary insects and their environments. Smithsonian Institution Press Washington
Elvira B. 2001. El Plan Hidrológico Nacional, los ecosistemas fluviales y los peces de río. In: El Plan Hidrológico Nacional a debate P. Arrojo (ed.), Colección Nueva Cultura del Agua Bakeaz Bilbao pp. 139-146.
Elvira B. and Almodóvar A. 2001. Freshwater fish introductions in Spain: facts and figures at the beginning of the 21st century. Journal of Fish Biology 59 (suppl. A): 323-331.
Erahrdt A and Thomas J.A. 1991. Lepidoptera as indicators of change in the seminatural grasslands of lowland an upland Europe. In: Collins N.M. and Thomas J.A. (eds.). The conservation of insects and their habitats. Academic Press London. Pgs. 231-236.
Erhlich P.R. and Erhlich A.H. 1992. The value of biodiversity. Ambio 21: 219-226.
Escós J. and Alados C.L. 1991. Influence of weather and population characteristics of free-ranging Spanish ibex in the Sierra de Cazorla y Segura and in the eastern Sierra Nevada. Mammalia 55: 67-78.
Esteban M. and Sanchíz B. 1997. Descripción de nuevas especies animales de la península Ibérica e islas Baleares (1978-1994): Tendencias taxonómicas y listado sistemático. Graellsia 53: 111-175.
Fargallo J.A. and Johnston R.D. 1997. Breeding biology of the Blue Tit *Parus caeruleus* in a montane mediterranean forest: the interaction of latitude and altitude. Journal Fur Ornitologie 138, 83-92.
Fernández J. 1996. Nuevos táxones animales descritos en la península Ibérica y Macaronesia entre 1994 y 1997. Graellsia 52: 163-215.
Fernández J. 1998. Nuevos táxones animales descritos en la península Ibérica y Macaronesia desde 1994 (3ª parte). Graellsia 54: 143-168.
Fernández J. 2000. Nuevos táxones animales descritos en la península Ibérica y Macaronesia desde 1994 (4ª parte). Graellsia 56: 119-150.
Fernández J. 2001. Nuevos táxones animales descritos en la península Ibérica y Macaronesia desde 1994 (5ª parte). Graellsia 57: 153-163.
Fernández J. 2002. Nuevos táxones animales descritos en la península Ibérica y Macaronesia desde 1994 (6ª parte). Graellsia 58: 97-124.
Fernández J. 2003. Nuevos táxones animales descritos en la península Ibérica y Macaronesia desde 1994 (7ª parte). Graellsia 59: 101-130.
Fernández-Llario P. and Carranza J. 2000. Reproductive performance of the wild boar in a Mediterranean ecosystem under drought conditions. Ethology, Ecology and Evolution 12: 335-343.
Galante E. 1992. Escarabeidos coprófagos. In: Gómez Gutierrez J.M. (ed.). Las Dehesas Salmantinas. Consejería de Medio Ambiente. Junta de Castilla y León. Pgs. 905-927.
Galante E. and Verdú J.R. 2000. Los Artrópodos de la “Directiva Hábitat” en España. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente. Madrid.
Galante E. 2002. Insectos. In: Reyero J.M. (ed.) La Naturaleza de España. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente. Madrid. Pgs. 208-215.
Galante E., García-Román M., Barrera I. and Galindo P. 1991. Comparison of spatial distribution patterns of dung-feeding Scarabs (Coleoptera: Scarabaeidae Geotrupidae) in

wooded and open pastureland in the Mediterranean Dehesa area of the Iberian Peninsula. Environmental Entomology 20(1): 90-97.

Galante E. and Marcos-García M.A. 1997. Detritívoros Coprófagos y Necrófagos. In: Melic A. (ed.). Los Artrópodos y el Hombre. Sociedad Aragonesa de Entomología. Zaragoza.

Galante E. 1994. Los Artrópodos los grandes desconocidos en los programas de protección ambiental. In: Jiménez-Peydró R. and Marcos-García M.A. (eds.). Environmental Management and Arthropod Conservation. Asociación española de Entomología. Valencia. Pgs. 75-87.

García J.T. and Arroyo B. 2001. Effect of abiotic factors on reproduction in the centre and periphery ranges: a comparative analysis in sympatric harriers. Ecography 24:393-402

García-Barros E. 1988. Delayed ovarian maturation in the butterfly *Hiparchia semele* as a possible response to summer drought. Ecological Entomology 13: 391-398.

Gibbs J.P. and Breisch A.R. 2001. Climate warning and calling phenology of frogs near Ithaca New York 1900-1999. Conservation Biology 15: 1175-1178.

Gurrea Sanz P. and San Benito M.J. 2000. Endemismos de Curculionoidea (Coleoptera) de la Peínsula Ibérica Islas Baleares y Canarias. Publicaciones de la Universidad Autónoma de Madrid. 384 pgs.

Harrington R., Barbagallo S., Basky Z., Bell N., Coceano P.G., Cocu N., Denholm C., Derron J., Hullé M., Katis N., Knight, J., Lukášová H., Marrkula I., Maurice D., Mohar J., Pickup J., Rolot J.L., Rounsevell M., Ruszkowska M., Schliephake E., Seco-Fernandez M.V., Sigvald R., Tsitsipis J., Ulber B. and Verrier P. 2001. EXAMINE (EXploitation of Aphid Monitoring IN Europe): an EU Thematic Network for the study of global change impacts on aphids. Detecting Environmental Change: Science and Society. London, UK 17-20 July 2001, pgs 93-94.

Harrington R., Denholm C., Verrier P., Clark S., Welham S., Hullé M., Maurice D., Rounsevell M., Cocu N., Knight J., Bell N., Barbagallo S., Basky Z., Coceano P.G., Derron J., Katis N., Lukášová H., Marrkula I., Mohar J., Pickup J., Rolot J.-L., Ruszkowska M., Schliephake E., Seco-Fernández M.-V., Sigvald R., Tsitsipis J. and Ulber B. 2003. Impacts of environmental change on aphids throughout Europe. Integrated Biological Systems Conference San Antonio Texas USA 14-16 April 2003

Hassell M.P., Godfray H.C.J. and Comins H.N. 1993. Effects of insecf global change on the dynamics of insect host-parasitoid interactions. In: Kareiva P.M., Kingsolver J.G. and Huey R.B. (eds.). Biotic Interactions and Global Chang. Sinauer, Surderland, MA. Pgs. 402-423.

Heinrich B. 1993. The Hot-Blooded Insects. Strategies and Mechanisms of Thermoregulation. Springer-Verlag. 601 pgs.

Hidalgo R. 2002. Red Natura 2000. In: Reyero J.M. (ed.) La Naturaleza de España. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente. Madrid. Pgs. 272- 283.

Hódar J.A., Castro J. and Zamora R. 2003. Pine processionary caterpillar *Thaumetopoea pityocampa* as a new threat for relict Mediterranean Scots pine forest under climatic warming. Biological Conservation 11: 123-129.

Houghton *et al.* (eds.) 1996. Climate Change 1995. Report of Working Group I. Intergovernmental Panel on Climate Change. Cambridge Univ. Press.

Hughes L. 2000. Biological consequences of global warming: is the signal already apparent? Trends Ecological Evolution 15: 56-61.

Huin N. and Sparks T.H. 1998. Arrival and progression of the Swallow *Hirundo rustica* through Britain. Bird Study 45: 361-170.

Hullé M., Harrington R., Cocu N., Denholm C., Verrier P., Maurice D., Rounsevell M., Knight J., Bell N., Barbagallo S., Basky Z., Coceano P.G., Derron J., Katis N., Lukášová H., Marrkula I., Mohar J., Pickup J., Rolot J.-L., Ruszkowska M., Schliephake E., Seco-Fernández M.-V., Sigvald R., Tsitsipis J. and Ulber B. 2003. EXAMINE: an EU thematic network to evaluate impacts of environmental changes on aphids at a regional scale. Proceedings IOBC/WPRS meeting `Landscape Management for Functional Biodiversity', Bologna Italy, May 2003. IOBC/WPRS Bulletin (Bulletin OILB SROP) 26(4). 71-75.

Humphries M.M., Thomas D.W. and Speakman J.R. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature 418: 313-316.

Iglesias J., Santos M. and Castillejo J. 1996. Annual activity cycles of the land snail *Helix aspersa* Müller in natural populations of North-Western Spain. Journal of Molluscan studies 62: 495-505.

Jimenez J. and Delibes M.1990. Causas de la rarificación. In: M. Delibes (ed.). La nutria (*Lutra lutra*) en España. ICONA Serie Técnica Madrid. Pgs. 169-177

Jimenez J. and Lacomba J.I. 1991. The influence of water demands on otter distribution in Mediterranean Spain. Habitat 6: 249-254 (Proceedings V International Otter Colloquium, C. Reuther and R. Rochert, eds.).

Jones J.G. 2001. Fraeshwater ecosystems. Structure and responses. Ecotoxicology and Environmental Safety 50: 107-113.

Kiss L., Magnin F. and Torre F. 2004. The role of landscape history and persistent biogeographical patterns in shaping the responses of Mediterranean land snail communities to recent fire disturbances. Journal of Biogeography 31: 145-157.

Körner C. 2001. Experimental plant ecology: some lessons from global change research. In: Press Huntly and Levin 8eds.). Ecology: Achievement and challenge: Blackwell, Oxford.

Ledergeber S., Leadley P.W., Stöcklin J. and Baur B. 1998. Feeding behaviour of juvenile snails (*Helix pomatia*) to four plant species grown at elevated CO_2. Acta Oecologica 19: 89-95

Lizana M. and Pedraza E.M. 1998. Different mortality of toad embryos (*Bufo bufo* and *Bufo calamita*) caused by UV-B radiation in high mountain areas of the Spanish Central System. Conservation Biology 12: 703-707.

Lobón-Cerviá J., Dgebuadze Y., Utrilla C.G., Rincón P.A. and Granado-Lorencio C. 1996. The reproductive tactics of dace in central Siberia: evidence for temperature regulation of the spatio-temporal variability of its life history. Journal of Fish Biology 48: 1074-1087.

López M.A. and Altaba C.R. 1997. Présencia de *Corbicula fluminea* (Müller 1774) (Bivalvia Corbiculidae) al Delta de L'Ebre. Bulletí del Parc Natural Delta l'Ebre10: 20-22.

Lucio A.J. 1990. Influencia de las condiciones climáticas en la producción de la Perdiz Roja (*Alectoris rufa*). Ardeola 37:207-218.

Lumbreras C., Galante E. and Mena J. 1990. Seguimiento de una población de *Bubas bubalus* (Olivier 1811) a través del estudio combinado de diversos caracteres indicativos de edad (Col. Scarabaeidae). Boletín Asociación española de Entomología 14: 243-249.

Lumbreras C., Galante E. and Mena J. 1991. Ovarian Condition as an Indicator of the phenology of *Bubas bubalus* (Coleoptera: Scarabaeidae). Annnals of the Entomological Society of America 84(2): 190-194

Machado A. 2002. La biodiversidad de las Islas Canarias. In: Pineda F.D., de Miguel J.M., Casado M.A. and Montalvo J. (eds) La Diversidad Biológica de España. Prentice Hall, Madrid. pgs. 89-99.

Marco A. 2002. *Lacerta schreiberi*. In: Pleguezuelos J.M., Márquez R. and Lizana M. (eds.). Atlas y Libro Rojo de los Anfibios y Reptiles de España. Dirección General de Conservación de la Naturaleza Madrid. Pgs. 232-234.

Marco A. and Pollo C. 1993. Análisis biogeográfico de la distribución del lagarto verdinegro (*Lacerta schreiberi* Bedriaga 1878). Ecologia 7: 457-466.

Marco A. and Lizana M. 2002. Efectos de la radiación ultravioleta sobre los anfibios en áreas de montaña. Actas de las III Jornadas Científicas del Parque Natural de Peñalara y del Valle del Paular. Biodiversidad: investigación conservación y seguimiento. Comunidad de Madrid. Pgs. 73-80.

Marco A., Lizana M., Suárez C. and Nascimento F. 2002. Radiación ultravioleta y declive de anfibios. Quercus 192: 30-37.

Márquez R. and Lizana M. 2002. Conservación de los Anfibios y Reptiles de España. In: Pleguezuelos J.M., Márquez R. and Lizana M. Atlas y Libro Rojo de los Anfibios y Reptiles de España. Dirección General de Conservación de la Naturaleza-Asociación Herpetológica Española. Madrid. Pgs. 417-453

Martí R. and del Moral J.C. (Eds.) Atlas de las Aves Reproductoras de España. Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología. Madrid.

Martín J., García-Barros E., Gurrea P., Luciañez M.J., Munguira M.L., Sanz M.J and Simón J.C. 2000. High endemism areas in the Iberian Peninsula. Belgian Journal Entomologie 2: 47-57.

Martín Piera F. and Lobo J.M. 2000. Diagnóstico sobre el conocimiento sistemático y biogeográfico de tres órdenes de insectos hiperdiversos en España: Coleoptera Hymenoptera y Lepidoptera. En. Martin Piera F, Morrone J.J. and Melic A. (eds.). Hacia un proyecto CYTED para el Inventario y Estimación de la Diversidad Entomológica en Iberoamérica. Pribes 2000. Monografías Tercer Milenio 1, Sociedad Entomológica Aragonesa. Zaragoza.

Martin T.E. 2001. Abiotic vs. biotic influences on habitat selection of coexisting species: climate change impacts? Ecology 82: 175-188.

Martínez J.G., Carranza J., Fernández J.L. and Sánchez-Prieto C.B. 2002. Genetic variation of red deer populations under hunting exploitation in South-Western Spain. Journal of Wildland Management 66(4): 1273-1282.

McCarty J.P. 2001. Ecological consequences of recent climate change. Conservation Biology 15: 320-331.

McLaughlin J.F., Hellmann J.J., Boggs C.L. and Ehrlich P.R. 2002. Climate change hastens population extinctions. Proceeding National Academy Sciences USA 99: 6070-6074

McLean D.M. 1991. A climate change mammalian population collapse mechanism. In: Kainlauri E., Johansson A., Kurki-Suonio I. and Geshwiler, M. (eds.) Energy and Environment. ASHRAE. Atlanta Georgia. Pgs. 93-100

McLean D.M.1978. A terminal Mesozoic “greenhouse”: lessons from the past. Science 201 401-406.

Mena J., Galante E. and Lumbreras C.J. 1989. Daily flight activity of Scarabaeidae and Geotrupidae (Col.) and analysis of the factors determining this activity. Ecologia Mediterranea 15(1-2): 69-80.

Merino S. and Potti J. 1996. Weather dependent effects of nest ectoparasites on their bird hosts. Ecography 19:107-113.

Mico E. and Galante E. 2002. Atlas fotográfico de los escarabeidos florícolas ibero-baleares. Arganda Editions Barcelona.

Mönkkönen M. and Welsh D.A. 1994. A biogeographical hypothesis on the effects of human caused landscape changes on the forest bird communities of Europe and North America. Annales Zoologici Fennici 31: 61-70.

Moore K.M.S. and Gregory S.V. 1988a. Response of young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. Transactions of the American Fisheries Society 117: 162-170.

Moore K.M.S. and Gregory S.V. 1988b. Summer habitat utilization and ecology of cutthroat trout fry (*Salmo clarki*) in Cascade Mountain streams. Canadian Journal of Fisheries and Aquatic Sciences 45: 1921-1930.

Mouthon J. 1990. Importance des conditions climatiques dans la différentiation des peuplements malacologiques de lacs européens. Archiv für Hydrobiologie 118: 353-370.

Myers N., Mittermeler R.A., Mittermeler C.G., Da Fonseca G.A.B and Kent J. 2000. Biodiversity hotspots for conservation priorities. Nature 103: 853-858.

Obeso J.R. and Bañuelos M.J. 2004 El urogallo (*Tetrao urogallus cantabricus*) en la Cordillera Cantábrica. Serie Técnica. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente

Ojanguren A.F. 2000. Efectos de factores ambientales y del tamaño de huevo sobre eficacia biologica en trucha común (*Salmo trutta* L.). Universidad de Oviedo. 146 pgs.

Palomares F. 2003. The negative impact of heavy rains on the abundance of a Mediterranean population of European rabbits. Mammalian Biology 68: 224-234.

Parmesan C., Ryrholm N., Stefanescu C., Hill J.K., Thomas C.D., Descimon H., Huntley B., Kaila L., Kullberg J., Tammaru T., Tennent W.J., Thomas J.A and Warren M. 1999.

Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399: 579-583.

Patz J.A., Graczyk T.K., Geller N. and Vittor A.Y. 2000. Effects of environmental change on emerging parasitic diseases. International Journal of Parasitology 30: 1395-1405.

Peñuelas J., Filella I. and Comas P. 2002. Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. Global Change Biology 8: 531-544.

Perez Bañón C., Juán A., Petanidou T., Marcos-García M-A. and Crespo M.B. 2003. The reproductive ecology of *Mendicago citrina* (Font Quer) Greuter (Leguminosae): a bee-pollinated plant in Mediterranean island where bees are absent. Plant Systematics and Evolution 241: 29-46.

Peters H.A., Baur B., Bazzaz F. and Körner, C. 2000. Consumption rates and food preferences of slugs in a calcareous grassland under current and future CO_2 conditions. Oecologia 125: 72-81.

Piñol J., Teradas J. and Lloret F. 1998. Climate warming, wildfire hazard, and wildfire occurrence on coastal eastern Spain. Climatic Change 38: 345-357.

Porazinska D.L. and Wall D.H. 2002. Population age structure of nematodes in the Antarctic dry valleys: perspectives on time space and habitat suitability. Arctic, Antarctic and Alpine Research 34: 159-168.

Potts D.C. 1975. Persistence and extinction of local populations of the garden snail *Helis aspersa* in unfavourable environments. Oecologia 21: 313-334.

Power M.E., Parker M.S. and Wootton J.T. 1996. Disturbance and food chain length in rivers. In: Polis G.A. and Winemiller K.O. (eds.). Food webs: integration of patterns and dynamics. Chapman and Hall, London. Pgs. 286-297.

Pujante Mora A.M. 1997. Los Artrópodos como bioindicadores de la calidad de la aguas. In: Melic A. (ed.). Los Artrópodos y el Hombre. Bol. S.E.A. 20: 277-284. Sociedad Aragonesa de Entomología.

Pulido F.J. 1999. Herbivorismo y regeneración de la encina (*Quercus ilex* L.) en bosques y dehesas. Tesis Doctoral. Universidad de Extremadura.

Ramírez Á. 2003. Efectos geográficos y ambientales sobre la distribución de las aves forestales ibéricas. Graellsia 59: 219-231.

Ramos M.A. 1980. Estudio del tamaño de la concha de *Cepaea nemoralis* (L.) en tres valles del Pirineo español. Comunicaciones del I Congreso Nacional de Malacología SEM, Madrid: Pgs. 47-49.

Ramos M.A. 1985. Shell polymorphism in a southern peripheral population of *Cepaea nemoralis* (L.) in Spain. Biological Journal of the Linnean Society of London 25: 197-208.

Ramos M.A. 1998. Implementing the Hábitat Directive for mollusc species in Spain. Journal of Conchology, special publication 2: 125-132.

Ramos M.A. and Aparicio 1984. La variabilidad de *Cepaea nemoralis* (L.) y *Cepaea hortensis* (Müll.) en poblaciones mixtas de la Región Central de España. Iberus 4: 105-123.

Ramos M.A., Lobo J.M. and Esteban M. 2001. Ten years inventoring the Iberian fauna: results and perspectives. Biodiversity and Conservation 10: 19-28.

Ramos M.A., Lobo J.M. and Esteban M. 2002. Riqueza faunística de la península Ibérica e islas Baleares. El proyecto 'Fauna ibérica'. In: Pineda F.D., de Miguel J.M., Casado M.A. y Montalvo J. (eds). La Diversidad Biológica de España. Prentice Hall, Madrid. Pgs. 197-207.

Ramos M.A. and Templado J. 2002. Invertebrados no insectos. In: Reyero J.M. (ed.). La Naturaleza de España. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente. Madrid. Pgs. 190-207

Ratte H.T. 1985. Temperature and insect development. In: Hoffman K.H. (ed.). Environmental Physiology and Biochemistry of Insects. Springer-Verlag, Berlín: 33-66.

Rawling P., Pro M.J., Pena I., Ortega M.D. and Capela R. 1997. Spatial and seasonal distribution of *Culicoides imicola* in Iberia in relation to the transmission of African horse sickness virus. Medical and Veterinary Entomology 11(1): 49-57.

Rincón P.A. and Lobón-Cerviá J. 1989. Reproductive and growth strategies of the red roach, *Rutilus arcasii* (Steindachner 1866), in two contrasting tributaries of the River Duero Spain. Journal of Fish Biology 34: 687-705.
Rodríguez Muñoz R. 2000. Reproduccion y desarrollo larvario en una población anadroma de lamprea marina (*Petromyzon marinus* L.). Universidad de Oviedo. 155 pgs
Rodríguez C. and Bustamante J. 2003. The effect of weather on lesser kestrel breeding success: can climate change explain historical population declines? Journal of Animal Ecology 72: 793-810.
Rodríguez-Berrocal J. 1993. Utilización de los recursos alimenticios naturales. Nutrición y alimentación de rumiantes silvestres. Córdoba: Publ. Fac. Veterinaria UCO.
Rogers D.J. and Randolph S.E. 2000. The global spread of malaria in a future warmer world. Science 289: 1763-1766.
Root T.L. and Schneider S.H. 2002. Climate Change: Overview and Implications for Wildlife. In: Schneider S.H. and Root T.L. (eds.). Wildlife Responses to Climate Change. Island Press Washington. Pgs. 1-56
Roura N., Suarez A.V., Gómez C., Touyama Y. and Peterson T. 2003. Predicting Argentine ant (*Linepithema humile* Mayr) invasive potential in the face of global climate change. (comunicación en Congreso). Land Open Sciences .Conference: Integrated Research on Coupled Human Environmental Systems. Morelia. México.
Samways M. J. 1994. Insect Conservation Biology. Chapman and Hall, London
Santos T. and Tellería J. 1995. Global environmental change to and the future of Mediterranean forest avifauna. In: Moreno J.M. and Oechel W.C. (eds.). Global change and Mediterranean type ecosystems. Springer-Verlag, New York. pgs.457-470
Sanz J.J. 2002. Climate change and breeding parameters of great and blue tits throughout the western Palearctic. Global Change Biology 8: 409-422.
Sanz J.J. 2003. Large scale effect of climate change on breeding parameters of pied flyactchers in Western Europe. Ecography 26: 45-50.
Sanz J.J., Potti J., Moreno J., Merino S. and Frías O. 2003. Climate change and fitness components of a migratory bird breeding in the Mediterranean region. Global Change Biology 9: 461-472.
Sarto I., Monteys V. and Saiz Ardanaz M. 2003. Culicoides midges in Catalonia (Spain) with special reference to likely bluetongue virus vectors. Medical and Veterinary Entomology 17: 288-293.
Schöne B.R., Dunca E., Mutvei H. and Norlund, U. 2004. A 217-year record of summer air temperature reconstructed from Freshwater pearl mussels (M. Margaritifera Sweden). Quaternary Science Reviews 23: 1803-1816.
Seco-Fernández M.V., Fereres Castiel A., Denholm C., Barbagallo S., Basky Z., Bell N., Clark S., Coceano P.-G., Cocu N., Colucci R., Derron J., Ferrara V., Gotlin Euljak T., Harrington R., Hatala Zseller I., Hullé M., Katis N., Knight J., Limonta L., Lukášová H., Marrkula I., Maurice D., Mohar J., Pickup J., Rolot J.L., Rounsevell M., Ruszkowska M., Schliephake E., Sigvald R., Stolte T., Tsitsipis J., Ulber B., Verrier P. and Welham, S. 2003. Aprovechamiento de los sistemas de control de áfidos en Europa -EXAMINE (EXploitation of Aphid Monitoring systems IN Europe). XX Jornadas de la Asociación Española de Entomología – AeE.
Seoane J., Viñuela J., Díaz-Delgado R. and Bustamante J. 2003. The effects of land use and climate on red kite distribution in the Iberian peninsula. Biological Conservation 111: 401-414.
Serrano J. 1984. Estudio Faunístico de los Caraboidea del Alto Tajo (Coleoptera Adephaga). Graellsia. 39: 3-30.
Smith B. R. and Tibbles J.J. 1980. Sea lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan and Superior: history of invasion and control 1936-78. Canadian Journal of Fisheries and Aquatic Sciences 37(11): 1780-1801.
Stefanescu C., Peñuelas J. and Filella 2003. Effects of climatic change on the phenology of butterflies in the northwest Mediteranean Basin. Global Change Biology 9: 1494-1506.

Stefanescu C., Herrando S. and Páramo F. 2002. Butterfly species richness in the north-west Mediterranean Basin: the role of natural and human-induced factors. Journal of Biogeography 31: 905-915.

Sternberg M. 2000. Terrestrial gastropods and experimental climate change: A field study in acalcareous grassland. Ecological Research 15: 73-81.

Swift M.J., Andrén O., Brussaard L., Briones M., Couteaux M.-M., Ekschmitt K., Kjoller A., Loiseau P. and Smith P. 1998. Global change soil biodiversity, and nitrogen cycling in terrestrial ecosystems: three case studies. Global Change Biology 4(7): 729-743.

Teixeira J. and Arntzen J.W. 2002. Potential impact of climate warming on the distribution of the Golden-striped salamander, *Chioglossa lusitanica* on the Iberian Peninsula. Biodiversity and Conservation 11: 2167-2176.

Tejedo M. 2003. El declive de los anfibios. La dificultad de separar las variaciones naturales del cambio global. In: Rubio X. (ed.). La conservación de los anfibios en Europa. Munibe Suplemento16: 20- 43.

Tellería J. and Santos T. 1994. Factors involved in the distribution of forest birds in the Iberian Peninsula. Bird Study 41:161-169.

Tepedino V.J. and Grsiwold T.L. 1990. Protecting endangered plants. Agricultura Research 38: 16-18.

Templado J., Villena M. and Fernández J. 1995. New invertebrate taxa (insect excluded) described in the Iberian Peninsula and Macaronesia between 1994 and 1996. Graellsia 51: 171-189.

Thomas C.D., Cameron A., Green R.E. and otros 16 autores. 2004. Extinction risk from climate change. Nature 427: 145-148.

Tierno de Figueroa J.M., Sánchez Ortega A., Membiela Iglesias P. and Luzón Ortega J.M. 2003. Plecoptera. In: Ramos M.A. *et al.* (eds.) Fauna Ibérica vol 22.. Museo Nacional de Ciencias Naturales CSIC., Madrid.

Torralba M.M. and Oliva F.V. 1997. Primera cita de *Chondrostoma polylepis* Steindachter 1865 (Ostariophysi Cyprinidae) en la cuenca del río Segura. Limnetica 13: 1-3.

Veiga J.P. 1986. Interannual fluctuations of three microtine populations in Mediterranean environments: the effect of the rainfall. Mammalia 50: 114-116.

Velasco J.C., Rincón P.A. and Lobón-Cerviá J. 1990. Age growth and reproduction of the cyprinid *Rutilus lemmingii* (Steindachner 1866) in the River Huebra central Spain. Journal of Fish Biology 36: 469-480.

Verdú J.R. and Galante E. 2002. Climatic stress food availability and human activity as determinants of endemicity patterns in the Mediterranean Region: the case of dung beetles (Coleoptera: Scarabaeoidea) in the Iberian Peninsula. Diversity and Distributions 8: 259-274.

Verdú J.R. and Galante E. 2004a. Thermoregulatory strategies in two closely-related sympatric *Scarabaeus* species (Coleoptera Sacarabaeinae), Physiological Entomology 29: 32-38.

Verdú J.R. and Galante E. 2004b. Behavioural and morphological adaptations for a low quality resource in semi-arid environments: dung beetles (Coleoptera Scarabaeoidea) associated with the European rabbit (*Oryctolagus cuniculus* L Journal of Natural History 38: 708-715

Villafuerte R. 2002. *Oryctolagus cuniculus* Linnaeus 1758.. In: Palomo L.J. and Gisbert J. (eds). Atlas de los mamíferos terrestres de España. Dirección General de Conservación de la Naturaleza-SECEM- SECEMU, Madrid. Pgs. 464-467

Vives E. 2000. Insecta Coleoptera Cerambycidae. In: Ramos M.A. *et al.* (eds.). Fauna Ibérica vol 12. Museo Nacional de Ciencias Naturales CSIC., Madrid.

Wittmann E.J., Melor P.S. and Baylis M. 2001. Using climate data to map the potential distribution of Culicoides imicola (Diptera: Ceratopogonidae) in Europe. Revue Scientifique et Technique de l'Office International des Épizooties 20 (3): 731-740.

Yom-Tov Y. 2001. Global warming and body mass decline in Israeli passerine birds. Proceedings of the Royal Society London Series B 268: 947-952.

Young I.M., Blanchart E., Chenu C., Dangerfield M., Fragoso C., Grimaldi M., Ingram J. and Jocteur Monrozier L. 1998. The interaction of soil biota and soil structure under global change. Global Change Biology 4(7): 703-712.

Zuberogoitia I. 2000. La influencia de los factores meteorológicos sobre el éxito reproductor de la Lechuza Común. Ardeola 47:49-56.