3. IMPACTS ON INLAND AQUATIC ECOSYSTEMS

Miguel Álvarez Cobelas, Jordi Catalán and Diego García de Jalón

Contributing authors

M. Alons, V. Amores, J. Armengol, J. Artigas, J. Barquín, M. M. Bayo, D. Boix, A. Butturini, A. Camacho, P. Carrillo, J. Casas, S. Cirujano, F. A. Comín, L. Cruz Pizarro, A. Gaudes, J. Lucena, M. Menéndez, R. Morales, E. Moreno, I. Muñoz, C. Pérez Martínez, J. Pozo, X. Quintana, I. Reche, M. A. Rodrigo, A. Romaní, S. Sabater, P. Sánchez Castillo, J. Soria, M L. Suárez, S. Bernal, F. Sabater, J. Toja, J. C. Vega, I. de Vicente, M. R. Vidal Abarca

Reviewers

F. A. Comín, P. García Murillo, E. Montero, J. R. Picatoste,
J. C. Rodríguez Murillo, C. Rojo, A. Sousa, B. A. Valero Garcés

R. Psenner

ABSTRACT

Spanish inland aquatic ecosystems (SIAE) are very diverse, generally of a small size, are located in very large watershed, often depend on groundwaters and undergo intense hydrological fluctuations, related to the local water balance, which affect their ecological functioning. Their importance on an international level derives from the fact that 1) the climatic, geologic, physiographic, hydrological and landscape characteristics of the Iberian Peninsula provide Spain with the greatest diversity of inland aquatic ecosystems in Europe; 2) there are 49 wetlands included on the list of the Ramsar Convention; 3) these are mostly environments different from the cold temperate European ones, with a multitude of endorheic sites and temporary ecosystems, as well as unique and very specific flora and fauna, some of these dating from the Tertiary Period; 4) the alpine lakes of Sierra Nevada are the southernmost glacial lakes in Europe; 5) the new European Framework Directive on Water includes them in Iberian-Macaronesian Region, and also distinguishes the Pyrenees as a region of particular interest.

With a high degree of certainty, we can state that climatic change will make many of the SIAE lose their permanence and become seasonal instead – some will even disappear. The biodiversity of many of them will decline and their biogeochemical cycles will be altered. We cannot yet determine the magnitude of these changes. The ecosystems most affected will be: endorheic environments, alpine lakes, rivers and streams (1600-2500 metres), coastal wetlands and environments depending on groundwaters.

The possibilities of the SIAE to adapt to climatic change are limited. In order to attenuate the effects, water-saving policies are needed, along with an improvement in the quality and intensification of the conservation measures of the surrounding terrestrial habitats. If we take into account the foreseeable conflicts over water resulting from climatic change, it is reasonable to suggest that the SIAE will be given the lowest priority.

The changes the SIAE are likely to undergo will affect environmental conservation and the tourism sectors, population protection and resources management, water supply and inland fisheries. With regard to the relationship between climatic change and the SIAE, there is a series of information gaps resulting from 1) a lack of reliable series of long-term data; 2) the still very scant information on the ecological state and biology of the most important species; 3) lack of knowledge of the hysteresis processes and 4) ignorance of the possible effects on the SIAE of both the geology of the watersheds in which they are located and the abrupt or gradual changes in surrounding terrestrial plant communities. All the preceding factors therefore have implications for policies for the environment, tourism, sports fishing and science. There is a great need for research, as there has been practically no treatment of the relationship between the SIAE and climatic change.

3.1. INTRODUCTION

3.1.1. The Spanish Inland Aquatic Ecosystems

The approximate number of continental aquatic ecosystems rises to over 1,000 large reservoirs (Dirección General de Obras Hidráulicas – waterworks dept. - 1988), 2500 alpine lakes bigger than 0,2 ha in the large mountain ranges (Pyrenees, Sierra Nevada, Central System, Iberian System, Cordillera Cantábrica), 50 karstic lakes in Ciudad Real, Cuenca, Girona, Huesca and Lleida, 11 large watersheds with numerous temporary and permanent river courses, over 500 lakes generated by mining (Montes 1993) and around 800 wetlands of over 0,2 ha, including shallow lakes and coastal pools (INITEC 1991; www.mma.es/conserv_nat/planes/plan_humed/ plan_humed.htm).

3.1.2. The dependence on subterranean waters

Many continental aquatic environments (above all rivers, lakes and wetlands) depend on underground waters. The best example is the Las Tablas de Daimiel National Park, which became disconnected from the underground aquifer in 1986 due to overexploitation, and has since had to depend on water from another watershed to subsist. The regional and local flows of subterranean waters (Toth 1963) not only supply lakes and wetlands (Montero 2000), but also many river channels [see chapter on Hydrological Resources]. That is to say, many reaches of Spanish rivers are "winners" and that the flows and hydrochemistry upon which their ecological functioning depends are the result of the interaction between surface and underground waters (Montes 1995). In any case, the quantitative hydrological relationship between aquifers and surface waters has not been sufficiently studied in Spain to date (see Benavente and Rodríguez 1997; de Castro and Muñoz Reinoso 1997). Furthermore, the recharge of the aquifers depends on the relationship between the season of the year in which this takes place (or the number of times it occurs) and the amount of water available for the recharge (rainfall; Fetter 2001); these facts are particularly relevant in semiarid areas, found throughout much of Spain, in which the biggest recharge usually takes place following intense rainfall (Wood and Sandford 1994).

3.1.3. International importance of the Spanish continental aquatic ecosystems

This is based on the following aspects:

1) The climatic, geological, physiographic, hydrological and landscape characteristics of the Iberian Peninsula provide Spain with the greatest diversity of inland aquatic systems in Europe.

2) There are 49 wetlands included on the list of the Ramsar Convention (www.mma.es/conserv nat/acciones/humedales/html/comite/lista ramsar.htm; MIMAM 1999).

3) Most environments are different from the cold, temperate European ones, with numerous endorheic sites and fluctuating seasonal ecosystems, containing unique and very specific flora and fauna.

4) Although inland aquatic fauna are considered to be relatively recent, many wetlands contain relics from the Tertiary Period (Alonso 1998).

5) The alpine lakes in Sierra Nevada are Europe's southernmost glacial lakes.

6) The close dependence of our inland aquatic ecosystems on subterranean waters and on their watershed surface makes them very vulnerable, and a preferential objective of the new

European Framework Directive on Water (Directive 2000/60/CE), which includes them in the Iberian-Macaronesian Region (map A, appendix XI), although it distinguishes the Pyrenees as a region of particular interest.

3.1.4. Sensitivity of the Spanish aquatic ecosystems to climate

Spanish aquatic environments are extremely sensitive to climate because the vast majority of them has a very short water residence period and therefore depend on annual, or even seasonal, rainfall. The levels and flows of most rivers, lakes, reservoirs and wetlands are directly linked to short-term rainfall. Obviously, air temperature also conditions aquatic systems by means of its direct influence on water temperature which, in turn, affects the metabolic and biogeochemical processes taking place in aquatic ecosystems (Carpenter *et al*. 1992).

Furthermore, indirect climatic influences are very important in the continental aquatic environments of the Iberian Peninsula, as these environments depend on the characteristics of the watershed they are located in, and the effects of climatic change on the soils and vegetation of the watershed would therefore have additional effects on the aquatic environments (Catalan *et al*. 2002; Comín and Alonso 1988). In general terms, the watersheds are very big in comparison to the aquatic ecosystems found therein, which are therefore very sensitive to the influence of the landscape (Prat 1995). Changes in the evapotranspiration of the terrestrial vegetation, for instance, can have a great effect on the availability of water in the watersheds (Schindler 1997), as can be seen in the study by Beguería *et al*. (2003).

3.2. SENSITIVITY TO THE PRESENT CLIMATE

In relation to climatic change, temperature and rainfall will undergo a series of variations which have not yet been clearly established [see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century], and whose general effects on the inland aquatic ecosystems could be the following:

3.2.1. Effects of the changes in rainfall on water availability: averages and variability

There are two types of most likely rainfall tendencies for the future: a decrease in averages and increased variability, although there could well be relevant geographic variations [see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century]; section 1.3.6]. Both phenomena have important consequences on the availability of water for the inland aquatic ecosystems, because in the long term they could make many of the temporary systems disappear and turn some the currently permanent ones into temporary ones. The increase in the variability of the rainfall would determine a greater variability in flows (Arnell *et al*. 1996). The seasonal factor, however, still remains very uncertain. The foreseeable decrease in summer rainfall may not be very positive for the inland aquatic ecosystems, as their current values are low. To the contrary, the variations in winter and spring could be determinant for environments with a propensity for temporality, both lotic (for instance, streams and torrents) and lentic ones (for example, lakes and ponds in semiarid areas).

3.2.2. Effects of global warming

Mean air temperature will also increase, probably more in the cold months and at night than in the hot months and during the day. There will therefore be an increase in water temperature, which will perhaps prolong the autumnal period of biological activity. In any case, it would be reasonable to expect modifications in the rates of the biogeochemical and metabolic processes, which might eventually lead to changes in the structure of the biological communities. It is foreseeable that the stratification of the lakes will be prolonged throughout the year (Livingstone 2003). In mountain areas, the duration of the layer of snow and of the lacustrine ice cover will be shorter, advancing the spring phases in these systems, and these changes may affect the functioning of the lake for the rest of the hot period.

3.2.3. Effects of an increase in sea level

Although a big change is not forecasted (0.11-0.77 metres up to 2100; Church *et al*. 2001), there could be more important ones in the case of coastal wetlands, because they will either be flooded and destroyed (because they do not reach very far inland), or saline invasion will increase, thus changing the nature of the wetland. In any case, there will probably be very varied effects on the coastal areas, depending on the different zones of the Iberian Peninsula [see Chapter on Coastal Zones].

3.2.4. Effects of an increase in CO_2

No significant effects from CO_2 increase are expected on the inland aquatic ecosystems. In general, the variability caused by CO_2 is less relevant than that determined by seasonal variations in nutrients and climatic factors. To a certain extent, inputs of allochthonous carbon from watersheds that are very large in comparison to the limnetic ecosystems and the total or partial oxidation therein could mean that the Spanish aquatic ecosystems are sources rather than sinks of CO_2. A better solubility of calcite in rocks and soil by CO_2-enriched rain is expected, thus producing a higher input of calcium into lakes and streams (Roland Psenner, personal communication).

3.2.5. Effects of decreased cloudiness

A reduction in cloudiness during the hot part of the summer would lead to an increase in the amount of UV radiation reaching the aquatic ecosystem, with the subsequent possible effects of photo-inhibition of photosynthesis, of metabolic alterations in plants and animals and of an increase in the photo-oxidation of dissolved organic substances (Williamson and Zagarese 1994). But in any case, it does not seem that this effect of cloudiness will be significant throughout the whole territory, as the most exposed mountain areas already contain flora and fauna which are adapted to conditions of high radiation (Halac *et al*. 1997; Sommaruga *et al*. 1999). Whatever the case may be, these effects will likely be camouflaged by other more relevant consequences of climatic change.Some alpine waters may even become better protected from UV radiation, if the treeline moves upwards(Roland Psenner, personal communication), as it is expected (see Chapters on Terrestrial ecosystems and Forestry).

3.3. FORESEEABLE IMPACTS OF CLIMATIC CHANGE

The effects of climatic change may interact with other anthropic effects resulting, for instance, from changes in land use, removal of water or rubbish dumps. On occasions, it is difficult to differentiate between these factors, but in any case, we should take into account the possible interactions between them. For instance, extraordinary flooding is not provided for in the regulation of water flows, and it seems likely that this flooding will increase along with increases in extreme events. Although defining in detail the impacts of climatic change is a difficult task, given the available current forecasts, it is not at all unreasonable to think that there will probably be an increase in the socio-economic conflicts over water. In this sense, it is important to critically consider the arguments in favour of conserving the inland aquatic environments in a country that has traditionally turned its back on these if they produced no direct profit.

3.3.1. Analysis of the Holocene sedimentation in lakes and wetlands

Throughout the history of the Earth, there have been no conditions analogous to the current increase in atmospheric CO_2, as during the last 400,000 years, in which we have had a set of species and ecosystems similar to the current ones, there have never been concentrations of this compound as high as can be reached when the present increase has been stabilised, even in the best of possible scenarios. Nevertheless, it is very probable that we will experience transitory situations of greater or lesser duration which will be similar to certain situations in our recent past. In this sense, the records of the environmental conditions throughout the Holocene (the last 10,000 years) preserved in the sediment of lakes and wetlands may provide information on the situations and rates of change to be expected. The reconstructions of variable environments based on lacustrine sediments provide references at temporal scales higher than those derived from the use of instrumental measurements (maximum of two centuries) and from historic documents (Barriendos 1997) and enables us to observe the effects of sudden climatic changes in the past, which are impossible to evaluate experimentally in specific ecosystems at the present time (Kelts and Talbot 1989; Gierlowski-Kordesch and Kelts 1994; Last and Smol 2001; Cohen 2003). In any case, the interpretation of the processes observed is related to the local geology and geography, as the responses of lakes to global changes is always very dependent on its own geologic, geographic and climatic characteristics, and those of the local physical environment.

The climatic changes that took place on the Iberian Peninsula during the Holocene had a greater impact on water balance than on temperature, although neither of these is absolutely independent (Harrison *et al*. 1992, Cheddadi *et al*. 1997; Prentice *et al*. 1998). The environmental reconstructions based on stratigraphic data from the Holocene which are of most interest are therefore those related to water balance (Fig. 3.1). The reconstructions carried out show that, between the Mediterranean and Atlantic areas of Spain, there was a hydrological gradient during the Holocene similar to the present one, and that the ecosystems of the Mediterranean zones in which the water availability was always relatively lower, reacted faster to climatic fluctuations than those situated in the areas of Atlantic influence.

Reconstructions of lacustrine environments based on data from the Holocene are highly reliable at a scale of millennia (Pérez i Obiol and Juliá 1994; Luque and Juliá 2002). Since the Neolithic, the changes in the vegetation of the terrestrial ecosystems may have had an important anthropogenic component, whereas hydrological changes originated by human activity are limited to the last few centuries (Valero Garcés *et al*. 2000a-c). Although a change in vegetation can modify the water balance due to changes in the evapotranspiration in the basins brought about by variations in tree cover, the existing reconstructions are less reliable at more detailed temporal scales. The lack of studies in the right type of lakes, the poor vertical resolutuion of the sediment cores and the financial costs of a detailed study have all limited this type of studies up to the present time (Battarbee *et al*. 2002). In spite of this, different studies show the extreme sensitivity of lacustrine systems to fluctuations resulting from oscillations in the North Atlantic, such as, for example, the 1,500 year cycles found in Sanabria (Luque and Juliá 2002) and even with teleconnections much further away, like the records of the oscillations of El Niño in Gallocanta (Rodó *et al*. 1997). There are hardly any studies at seasonal scale to analyse the past or future impact of changes in the annual distribution of rainfall. There are indications, however, that changes in wintertime rainfall have been decisive in the water balance and in changes in plant communities (Valero Garcés *et al*. 2004).

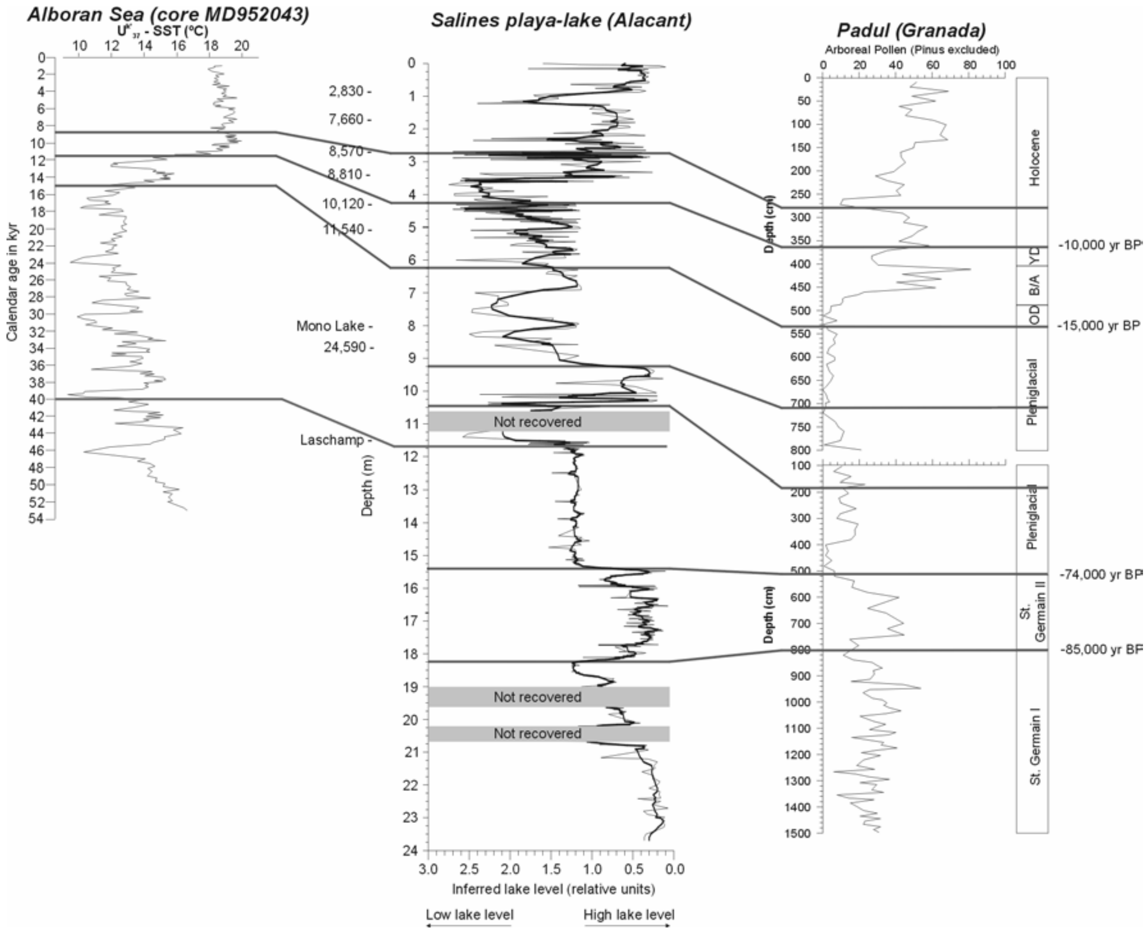


Fig. 3.1. *Reconstruction of the evolution of the Salines lake (Alicante) and its comparison with the pollen diagram of the sequence from the Padul bog in Granada (modified by Pons* and *Reille 1988) and with the reconstruction of the surface sea temperature (SST) carried out in palaeo-ecological survey MD952043 (Alborán Sea; modified from Cacho et al. 1999). The black lines show the visual correlation between the different sequences. The thick line on the Salines diagram shows the main evolution of the level of the lake (5 terms moving average). Source: Giralt* and *Juliá (2004).*

The climate on the Iberian Peninsula during the Holocene underwent noteworthy changes, particularly with regard to rainfall, which may have been related to latitudinal displacements and to changes in the intensity of the Azores anticyclone and of the polar front (Valero Garcés and Kelts 1997a). The spatial heterogeneity characterising the current ecosystems in Spain has existed for the last 10,000 years, as can be seen in the pollen data in lake sediments (Burjachs *et al*. 1997). In general, the lacustrine environments of Mediterranean influence have undergone oscillations with regard to water levels (Pons and Reille 1988; Giralt *et al*. 1999; Reed *et al*. 2001), probably related to seasonal water balance, which have been more notable than those of Atlantic influence (Peñalba *et al*. 1997; Allen *et al*. 1996; Sánchez Goñi and Hannon 1999; Luque and Juliá 2002).

The methodology used in the study of the reconstruction of climatic fluctuations during the Holocene, based on lacustrine sedimentary records, is now a multidisciplinary one (Bradley 1999; Last and Smol 2001). To date, most studies have considered the analysis of biological deposits independently from the stratigraphic and geochemical analysis, that is to say, that the lake’s past biology was not included within the geological framework (Cohen 2003). Our knowledge has been most advanced with the combination of Holocene studies of a biological nature (remains of Diatoms, Ostracods, Chironomids and pollen of higher plants; Battarbee *et* *al*. 2002; Reed 1998) with the geological ones (geochemistry, sedimentary facies, isotopic indicators, etc.; Valero Garcés and Kelts 1997b). In view of the study of the effects of climatic change on inland aquatic environments, the ideal solution would be to interrelate palaeo-studies of this nature with studies of the present-day aquatic ecology of the same ecosystem and its foreseeable future responses.

There are several studies of Holocene reconstruction in Spanish environments included in the Ramsar Convention. To our knowledge, studies have been published on Banyoles (Pérez i Obiol and Juliá 1994), Chiprana (Valero Garcés *et al*. 2000a-c), Gallocanta (Rodó *et al*. 2002), Tablas de Daimiel (Dorado *et al*. 2002) and Zóñar (Valero Garcés *et al*. 2004).

3.3.2. Effects on the number of ecosystems and their size

The number would obviously fall, if evapotranspiration increases in summer and rainfall does not, but we do not know to what extent [[see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century; section 1.C.6]. Specifically, many temporary environments could disappear, although the forecasted increases in rainfall in spring and greater summer evapotranspiration could counteract this effect.

In general, it seems that there will be bigger variations in fluctuations in size. If we keep in mind that: 1) the size of aquatic ecosystems depends on their water balance and 2) certain conditions therein (rainfall, evaporation) will probably be altered by climatic change (Ayala-Carcedo and Iglesias 2000; CEDEX 1997; MIMAM 1998), many environments will probably be subjected to a reduction in size. This is especially true for semiarid environments, like most Spanish systems, for which a good relationship can be established between the aridity of the area and the size of the lake (Mason *et al*. 1994). This is why some lakes can change from deep to shallow, and from being thermally stratified to undergo frequent mixing. This effect will not occur in most of the mountain lakes situated in basins with a positive water balance; in these sites, the thermal stratification will be reinforced and will be prolonged in autumn, as has been seen in Lake Redó in the Pyrenees (Catalan *et al*. 2002). Furthermore, many environments will change from permanent to temporary, this applies to rivers and of lakes or wetlands. The reservoirs destined to uses other than simple regulation (irrigation, supply, etc.) could spend years at very low levels, practically dry.

The small karstic lakes could be affected to a certain extent by climatic change, due to their extreme dependence on the underlying aquifers and on the recharge/discharge dynamics. With regard to endorheic lakes, any possible effects on their size will depend on the local rainfall regime, which will continue to be geographically very variable.

In the fluvial environments, it is very difficult for the time being to discern the effects of a possible increase in sudden heavy discharge from autumn to spring. Changes in the seasonality of rainfall will lead to changes in flows and hydroperiods, which can be expected to have significant effects on the seasonality of the transport of materials and on the seasonality of animal and plant populations (Carpenter *et al*. 1992).

3.3.3. Effects on water quality

Results unpublished (Alvarez Cobelas, personal communication) indicate that there is no relationship between water quality and rainfall for the ten stream sites of the *Confederación Hidrográfica del Guadiana* (Guadiana Water Board) en el Alto Guadiana (period 1973-2002), which suggests that the possible effects of climatic change on water quality are uncertain for the time being. The quality of the waters may worsen after springtime, the effects of dilution being reduced due to increases in evapotranspiration and, secondarily, because perhaps there will be less contributions of water. Increases in torrential rainfall, associated to climatic change, could also affect the quality of the water on specific occasions (Murdoch *et al*. 2000). Excessive rainfall (above the inter-annual average) following prolonged droughts increases the concentrations of substances in some wetlands, like the Tablas de Daimiel National Park (Sánchez Carrillo and Álvarez Cobelas 2001).

Evidently, water quality is an applied aspect of climatic change that requires research, which has been non-existent up to now in Spain. Nutrient retention and self-purification are inversely related with streamflow under natural conditions (Butturini and Sabater 1998), but `polluted streams do not follow this relationship (Martí *et al*. 2004); there are, however, many aspects to be distinguished between flow, temperature, nutrient load and land uses in order to establish a parameterisation permitting applications and predictions.

3.3.4. Effects on biogeochemical cycles

It has been suggested that an increase in temperature and a decrease in rainfall will lead to diminished export of organic carbon and nitrogen from terrestrial ecosystems to river courses (Clair and Ehrman 1996). However, certain observations exist which indicate that an increase in rainfall over areas rich in accumulations of organic material in the watershed, like some of the ones in the Northeast of Spain, has generated an increase, at lest a transitory one, in the export of dissolved organic carbon and metals to the rivers (Freeman *et al*. 2001).

3.3.5. Effects on the biota

Although the summertime drought in many fluvial streams has favoured the existence of a flora and fauna adapted to this extreme situation, and therefore the existence of endemic species of macroinvertebrates, fish and riparian vegetation, it is likely that we are witnessing – at least transitorily – a clear drop in biodiversity, if the area of extreme environments increases [see the Chapters on Plant Biodiversity and Animal Biodiversity]. In the vegetation of riverbanks, an increase in tamarisks (*Tamarix*) is expected, compared with salicaceae (*Salix*) and poplars (*Populus*; Stromberg *et al*. 1996). The oleander (*Nerium oleander)* will probably spread. In many areas, the *tamujo* (*Flueggea tinctoria*), typical of cold, acidic temporary rivers, could replace the alder (*Alnus*). In the vegetation emerging from the wetlands, clearly amphibious species may be favoured over the genuinely aquatic ones (for instance, *Phragmites* and *Scirpus* may end up dominating in most of the wetlands over *Typha* or *Cladium*); whatever the case may be, it seems certain that the competitive interactions will be substantially modified (Alvarez Cobelas *et al*. 2001).

Mass proliferation of phytoplankton may occur in eutrophic and hypertrophic environments, like many reservoirs and lakes, in which a higher temperature could favour sudden and excessive growth (Carpenter *et al*. 1992; McKee *et al*. 2003).

In fluvial systems not subjected to dessication, the rise in temperature will generate more primary production in the riparian zone, which –together with a higher concentration of particulate and dissolved organic carbon of an allochthonous nature– may favour higher primary and bacterial production in lakes, rivers and wetlands (Bazzaz 1990; Schindler 2001). It must be remembered, however, that temperature has a greater effect on respiration than on photosynthesis, and it is therefore foreseeable that the biogeochemical processes related to the decomposition of materials will accelerate. In the same way, secondary production will increase, because temperature is a key factor in animal metabolism (Benke 1993). The tendency towards warming of the water mass seems to lead to the destabilisation of the composition of communities of river macroinvertebrates and to a decrease in their global diversity due to the effect of the dominance of very few species, which may lead to a decrease in their faunistic richness (Gutiérrez Teira 2003).

The rivers maintaining a subsurface flow during the summer period can accommodate specialised limnephylic Trichopterans, which will live during the dry period as larvae in diapause or as pupae. If the drought is more intense, many adapted species of aquatic insects will spend this time as an egg; this capacity is noteworthy in endemic cryophilic species of Plecopterans such as *Thyrrenoleuctra* and *Guadalgenus*. The species with a long life cycle (several years) may have adaptation problems in mid-mountain rivers, due to the fact that these could become temporary reaches. These problems will probably be more serious in the Central and Iberian Systems, whose geological substrate is impermeable, which means that their baseline discharge during the low water period (which is already low) will tend to disappear.

The larger river fish (barbel and Iberian nases) are capable of developing different types of migratory strategies in order to tolerate the pronounced low water level, either swimming upriver until they find permanent waters, or downriver to the convergence with the main rivers. The most peculiar endemic fish are small-sized (*Squalius alburnoides, Chondrostoma lemmingii*, *Iberocypris*) and their basic adaptation consists in waiting during the summer in isolated pools in conditions of overpopulation (Carmona *et al*. 1999). Their isolation has led to the adoption of parthenogenetic reproductive mechanisms, as in the case of the chub (*Squalius alburnoides*; Fernández Delgado and Herrera 1994) with triploid specimens. The habitat of the Salmonids will be reduced (Eaton and Scheller 1996).

This can already be seen in the salmon captured in the rivers of Northern Spain (Fig. 3.2); in the North Atlantic, these reductions in the salmon catches have been linked to temperature increases in the sea water, resulting from climatic change (Friedland *et al*. 2003) [see also Chapter on Animal Biodiversity]. The fauna of the mid-level reaches can progressively invade the upper reaches of the rivers if the water temperature increases, thus substituting strictly cold-water fauna of the more mountainous zones (Rahel *et al*. 1996). As a consequence, the autochthonous trout populations will become fractionated due to the reduction of their habitat, which would favour processes of genetic drift, and eventually, speciation. In this process, the actions related to the reintroduction and management of species of fish-farming interest may be determinant in the future of local populations.

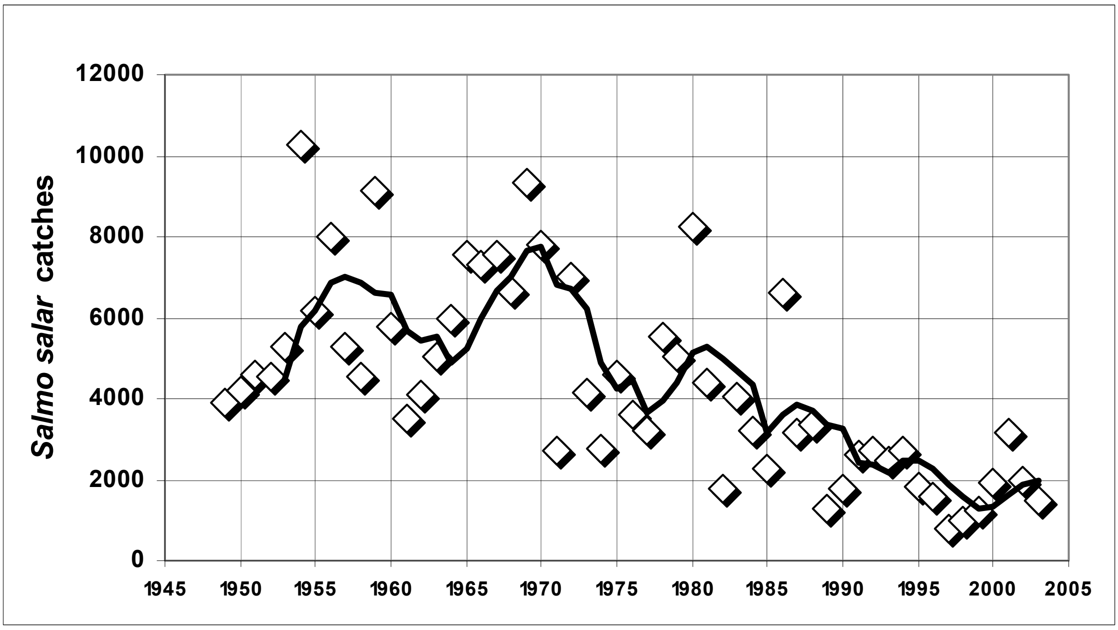


Fig. 3.2. *Long-term annual catches of salmons (Salmo salar) in northern Spanish rivers. The line is a five-terms moving average. Data source: Francisco Hervella, Galicia local government.*

In a general context, it is likely that the interactions between the benthic biota and the free-swimming ones will be modified (Lake *et al*. 2000).

3.3.6. Specific effects on the different types of ecosystems

3.3.6.1. Wetlands

Given their variety and intrinsic heterogeneity, the effects of climatic changes will depend on the particularities of each system, and it is therefore difficult to make a general evaluation. Given the irregular morphometry of many of them, the changes in volume will have unpredictable effects on their flooded area. However, there are certain predictable tendencies in some of the relevant processes in this type of environments; the specific behaviour of a determined wetland will depend on the local balance of these. Thus, temperature rises will increase the rate of microbial processes (Schindler 1997), the evaporation of the water surface and the transpiration of the emerging plants (Sánchez Carrillo *et al*. 2001). This increase in transpiration will probably generate more saline environments, synergistically favouring the dominance of species more tolerant to salinity (Lissner *et al*. 1999a) and to the lack of water, such as the reed (*Phragmites*), and lagged effects may also occur (Fig. 3.3). In the water balance, the anthropogenic changes in the uses of the water in the surroundings of the wetlands will also be very important. The decreased water supply involves a decrease in the hydroperiod which, in turn, will limit the recharge of the aquifer underlying the wetland (Sánchez Carrillo *et al*. 2005).

Changes in the types of vegetation will generate changes in the functions of the wetlands, particularly in the more complex ones (Doñana, for example, see Section 3.4.2), preferentially favouring one of the plant components of the landscape, and therefore, reducing diversity (Öquist *et al*. 1996).
In conditions of drought, erosion will be favoured. When there is abundant water, the rise in temperature will favour the faster decomposition of organic matter (Poff *et al*. 2002).

There will be changes in the amount and the timing of methane- and nitrous oxide emissions (Öquist *et al*. 1996). The permanent desiccation of many wetlands due to climatic change will obviously decrease the emissions of these greenhouse gasses.

Increases in CO_2 will increase the fertilisation and primary production of helophytic vegetation, but also the plant tolerance to stress (photoinhibition, drought, salinity; Lissner *et al*. 1999a-b).

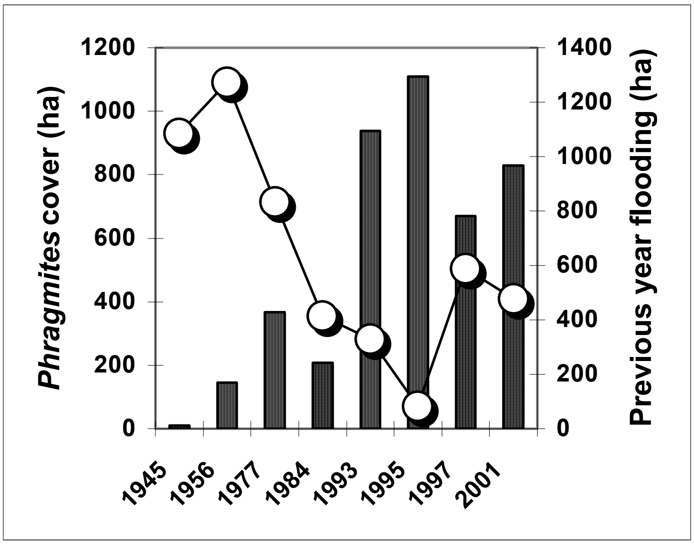
The foreseeable droughts will promote fires, which may be very big ones in the case of wetlands with big accumulations of carbon (peat; de Bustamante *et al*. 1995).

Changes in the vegetation and in the flooded surface, depending on alterations in hydrology, will probably bring about modifications in the biogeochemical cycles and in the populations of vertebrates and invertebrates that depend on the vegetation (above all, insects and birds; Roshier *et al*. 2001).

3.3.6.2. Rivers

In general, the baseline discharge will decrease, which will lead to an increase in the number of temporary rivers and reaches of rivers with flows that are only seasonal. Furthermore, the warming will raise the water temperature, which can lead to the displacement upstream of the zoning of the biocenoses. In this sense, it is interesting to take into consideration that the effect of the increase in air temperature on the increase in water temperature is not independent from rainfall. In this relationship, rainfall has a negative, quadratic influence (Jones and Thompson

2003). Decreased rainfall would therefore favour an increase in river temperature, which may be relevant in trout zones.



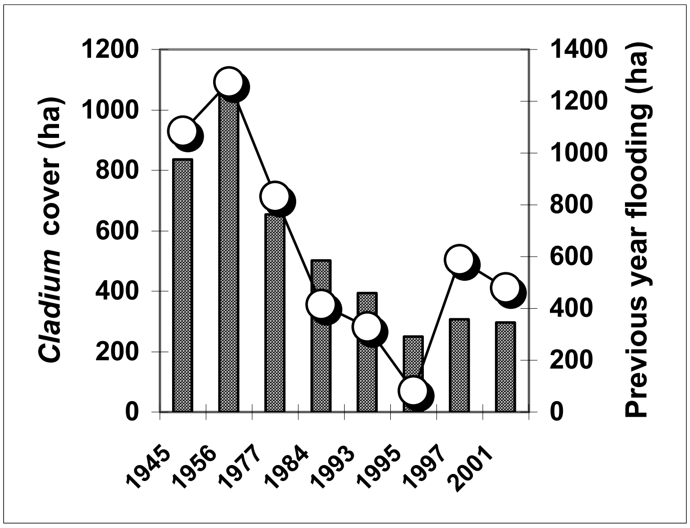


Fig. 3.3. *Annual cover (vertical bars, left-hand scale) of the two main species of vegetation emerging in Las Tablas de Daimiel National Park and flooding area in the previous year (open squares, right-hand scale) during the period 1945-2002. The representative covers are based on the aerial photography available for the period 1945-1997. Although it is not shown here, there is also a different relationship between flooding of the wetland in the preceding year and the cover of each species, which is a direct one in the case of cut-sedge (Cladium) and an inverse one in the case of the reed (Phragmites). In conditions of increasing aridity, resulting from climatic change, the spread of the reed would be favoured. Unpublished data by Cirujano* and *Alvarez Cobelas.*

A decrease in the flows would generate a drop in the concentration of dissolved oxygen, which is of particular importance if, besides, there is organic pollution and an increase in temperature (Jenkins *et al*. 1993).

Flooding, which causes an increase in suspended solids in the river channels, may be of greater importance in arid environments, where the soils are subjected to more erosion and the rainfall-runoff relationships are not linear (Arnell *et al*. 1996).

The increase in evapotranspiration in small watersheds will lead to a decrease in flows, and the effects will be more obvious in the reception reaches.

Changes in river hydrochemistry will be due to changes in the weathering of the rocky substrates of the watersheds in the zones with more humid, hotter climates (Ávila *et al*. 1996). Temperature increase will lead to a rise in the nitrification of the soils and, through runoff, increased nitrate in rivers (Jenkins *et al*. 1993). The same will occur with organic nitrogen in predominantly agricultural basins (Bernal *et al*. 2003). This effect will be more evident because of the intense flooding taking place after droughts.

In the rivers of the more arid areas (mainly in the Southwest of the Iberian Peninsula), ecological dynamics will be very susceptible to changes in the variability of the flows resulting from climatic change (Fisher *et al*. 1998), which can also affect seasonal rivers located in other parts of the Peninsula.

3.3.6.3. Lakes and reservoirs

Climatic change will have important effects on the ice-sheet in mountain lakes, as suggested by the simulation by Thompson *et al*. (2005), which shows that there are certain elevations that are more sensitive than others to these effects, and that they may undergo big changes in sensitivity (Fig. 3.4).

In the lakes with stable stratification (such as the Ruidera lagoons), the temperature of the epilimnion may increase by 1 to 4ºC with climatic change; however, if the stratification is greater, the hypolimnion will cool by several degrees. It seems clear that the stratification will last longer, and there will be a subsequent bigger consumption of oxygen in the deeper zones and the likelihood of anoxic conditions will increase. In the alpine lakes (above 1,500 m.a.s.l.), if the duration of the ice and snow cover is reduced, there will be less decreases in oxygen in the deeper layers and less liberation of phosphorus from the sediment. Springtime production will probably drop in favour of greater production in autumn.

In lakes the warming will increase primary production in the epilimnion if the stratification is more prolonged. The oxygen will also diminish in the deeper layers due to the increase in primary production and sedimentation, resulting from the increase in primary production, which will generate changes in the benthic fauna (Schindler 1997).

The drop in the level of the lake will affect the littoral area in those lakes that can vary their level significantly, this fringe is usually the most productive one and acts as a transition area between the terrestrial ecosystem and the aquatic one (Wetzel 1990). During the periods of ecological instability of the vegetation in the watershed, the overflowing of the smaller lakes located in deforested areas could accelerate with the reduction of the coastal buffer that limits the input of sediments of terrestrial origin.

The increased weathering of the rocks, resulting from simple thermal kinetics or from increases in the metabolism of the plant communities, due to increased air temperature, probably generates an increase in the alkalinity of the lakes.

With the thermal increase, the organic pollutants present in the water pass to the atmosphere more rapidly, and reach the higher altitudes more quickly, and these will become polluted more easily as a result of atmospheric deposition (Grimalt *et al*. 2001). The mobilisation of metals and metalloids (arsenic, lead) from the basin to the aquatic systems of cold areas will increase (Camarero *et al*. 2004), due to a greater mobilisation of these substances in the soils and to their atmospheric transport.

The possible effects of global warming on the trophic networks of the lakes are still to be debated (Jeppesen *et al*. 2003; Scheffer *et al*. 2003).

Lastly, we are still unaware of those factors which will affect the future redistribution of the lacustrine fauna because, in most cases, we know nothing of their dispersion in the past.

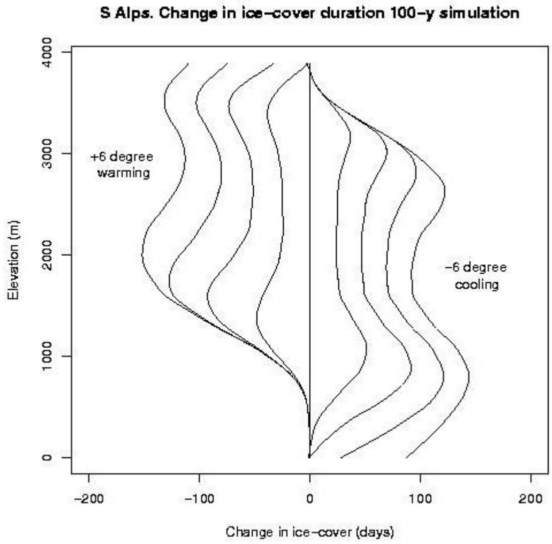


Fig. 3.4. *Simulation of the changes in the duration of the ice-cover of the lakes existing to the South of the Alps, between 0 and 4000 metres altitude. Nine different scenarios of climatic change were tested, using a simulation of one hundred years (cycles of one and a half years plus atmospheric time). Source: Thompson et al. (2005).*

In general, for the reservoirs we could apply the same assertions as for the lakes, but taking into account their higher water renewal rate, the extreme dependence of this rate on the water use of the reservoirs, and that they are usually subjected to greater eutrophication (Alvarez Cobelas *et al*. 1992), it would be very risky to make any type of prediction (Toja, personal communication).

3.4. MORE VULNERABLE AREAS

In accordance with the results presented in the Chapters Climate in Spain: past, present and climate scenarios for the XXI century and Hydrological Resources, the following areas will probably be the most vulnerable ones:

Endorheic environments

Many of these ecosystems are located in areas in which average rainfall will decrease and where its seasonal distribution will be very altered (La Mancha wetlands, for instance); these areas are therefore threatened with extinction.

High mountain lakes and ponds (1600-2100 m altitude) in the areas with deciduous forests and in those bordering on the forest.

High mountain rivers and streams (1800-2500 m altitude)

These ecosystems contain cryophilic endemic insects, whose distribution is already restricted. The dimension of their habitats will probably be reduced, as a result of climatic change, to a size that is critical for their survival.

Coastal wetlands

The coast will slowly reorganise itself in a natural manner if there are changes in sea level. However, given that there are numerous civil works on our coasts, perhaps there will be additional complications of the administrative kind which may limit this reorganisation.

Environments depending on groundwaters

The drop in groundwater levels, probably due to consumptive uses and to the decrease in recharge because of climatic change, will affect those environments considerably.

In the spatial sense, and taking into account the projections of the climate models (Section 1.3.6 of the Chapter on Climate in Spain: past, present and climate scenarios for the XXI century), it seems likely that there will be an increase in the rainfall in the NW of the Peninsula and a decrease in the southern zone and in the Mediterranean in wintertime, which is the most important time of year for the water recharge of the aquatic ecosystems.

3.4.1. Specific cases

Table 3.1 shows the information obtained on the incidence of the possible effects of climatic change on certain morphometric and biogeochemical aspects of determined inland aquatic environments in Spain, and was provided by the experts who have been working with these ecosystems for a long time. The information is still at the early stages and must be considered with care, as we still lack specific studies on these possible changes in all the ecosystems considered. There is a particular lack of direct information related to climatic change for most of the environments included in the Spanish list of Ramsar wetlands. A small section dedicated to Doñana is also provided, this being the most internationally known wetland of the Iberian Peninsula.

Table 3.1. *Likely effects on the most studied Spanish inland aquatic ecosystems, related to climatic change, based on the experience of the authors contributing to this chapter. These effects are characterised as non-existent (0), rare (1), considerable (2), important (3) or very important (4). The asterisk indicates environments included in the International Ramsar Convention for the Conservation of Wetlands.*

Name	Geographic location (central point)	Changes in permanence (temporary *vs* permanent)	Changes in size	Changes in the biogeochemical cycles	Changes in the biota
Doñana National and Natural Parks (Sevilla-Huelva) (*)	36º 34' N 6º 24' W	3	3	2	4

Tablas de Daimiel National Park (Ciudad Real) (*)	39º 08’ N 3º 43’ W	4	4	2	4
Albuferas de Adra (Almería) (*)	36º 45' N 2º 47' W	2	4	3	4
Main lake of the Albufera de Valencia (Valencia) (*)	39º 20’ N 0º 20’ W	0	1	4	4
Dune ponds of the Albufera nature Park in Valencia	39º 20’ N 0º 20’ W	4	3	3	2
Lakes of Alcázar de San Juan (Yeguas and Camino de Villafranca) (Ciudad Real) (*)	39º 24' N 3º 15' W	3	2	2	4
Arcas Lakes (Cuenca)	39º 59' N 2º 7' W	3	3	1	2
Banyoles Lake (Girona) (*)	42º 7' N 2º 45' E	0	0	2	2
Lakes of Cañada del Hoyo (Cuenca)	39º 59' N 1º 52' W	2	2	3	2
Lagoons of the Ebro Delta (Tarragona) (*)	40º 39' N 2º 32' E	2	2	2	2
Fuente de Piedra Lake (Málaga) (*)	37º 06’ N 4º 46’ W	1	0	1	1
El Hito Lake (Cuenca) (*)	39º 52' N 2º 41' W	3	2	2	4
Gallocanta Lake (Zaragoza-Teruel) (*)	40º 50' N 2º 11' W	4	4	4	4
Manjavacas Lake(Cuenca) (*)	39º 25' N 2º 50' W	3	2	2	4
La Nava Lake (Palencia) (*)	42º 04'N 4º 44' W	3	2	2	4
El Prado Lake (Ciudad Real) (*)	38º 55' N 3º 49' W	3	2	2	4
Puebla de Beleña ponds (Guadalajara) (*)	40º 53' N 3º 15' W	3	2	2	4

Redó Lake (Lleida)	42º 38' N 0º 46' E	0	0	2	2
Ruidera Lakes (Ciudad Real/Albacete)	38º 56' N 2º 37' W	3	3	2	4
Sanabria Lake (Zamora)	42º 07' N 6º 43' W	0	1	2	2
Sierra Nevada Lakes (Granada)	37º 05' N 3º 05' W	0	4	4	4
De la Vega Lake Ciudad Real) (*)	39º 49' N 2º 56' W	3	2	2	4
Villafáfila wetland (Zamora) (*)	41º 49' N 5º 36' W	0	0	0	1
Aiguamolls de l'Empordá (Girona)	42º 13' N 3º 6' E	1	1	0	0
Salburúa Wetland (Alava) (*)	42º 51' N 2º 39' W	3	2	2	4
Platja d'Espolla (Girona)	42º 9' N 2º 46' E	0	0	1	1
River Agüera (Vizcaya-Santander)	43º 18' N 3º 16' W	0	2	2	2
Chicamo River (Murcia)	38º 12' N 1º 03' W	3	4	3	3
Riera de Fuirosos (Barcelona)	41º 42' N 2º 34' E	1	0	2	1
Mouth of the River Guadalhorce (Málaga)	36º 40' N 4º 27' W	0	0	1	1
Riverine wells in the rivers Asón and Saja (Santander)	43º 10' N 4º 17' W	0	1	1	1
Riverine wells in the Parc Natural de la Albufera in Valencia	39º 20' N 0º 20' W	0	0	3	2
Aracena Reservoir (Huelva)	37º 55' N 6º 28' W	0	0	4	4
Arrocampo Reservoir (Cáceres)	39º 49' N 5º 43' W	0	0	0	0
Reservoir of El Hondo (Alicante) (*)	38º 10' N 0º 42' W	3	2	2	4

La Minilla Reservoir (Sevilla)	37º 43' N 6º 10' W	0	0	4	4
Sau Reservoir (Girona)	41º 58' N 2º 25' E	0	3	2	4
Torrejón Reservoir (Cáceres)	39º 47' N 5º 45' W	0	0	1	0
Arms of Ullibarri reservoir (Alava) (*)	42º 54' N 2º 32' W	3	2	2	4
Valdecañas Reservoir (Cáceres)	39º 49' N 5º 28' W	0	0	1	0

3.4.2. Doñana and climatic change

Its main aquatic systems comprise a marsh (of a seasonal nature and with variable salinity, supplied by rainwater and by surface runoff and with an area of around 40,000 ha), as well as a complex of coastal lakes located on the coastal aeolean area (supplied by phreatic water with low, very clean mineralisation covering 44,000 ha, including the National and Nature Parks). Furthermore, between the coast and the Arroyo de la Rocina stream, some peaty lagoons persist on siliceous sands, ranging from the Doñana Nature Park to the NW zone of Doñana National Park. These constitute the most vulnerable aquatic environment of Doñana. The area taken up by these ombrotrophic bogs has been considerably reduced since the beginning of the XVIII century (Sousa 2004), although this reduction has been particularly intense since the beginning of the XIX century (Sousa and García Murillo 2002, 2003).

Will the aquatic environments of Doñana undergo changes in their permanence? Yes. In the coastal lakes of the coastal aeolian area of Huelva, the volume of surface deposits and the piezometric levels will probably fall; the flooded surface will therefore probably decrease, although this is not yet very predictable, as it depends on the changes in the seasonality of the rainfall (Toja, personal communication). The water-rich peat heaths where *Erica ciliaris* dominates, currently a valuable relic (see Allier *et al*. 1974; Rivas Martínez 1979; and Rivas Martínez *et al*.; 1980; Cobo *et al*. 2002) will disappear and will be substituted by heaths of *Erica scoparia*, of lesser value for conservation. This will most probably affect the peat environments of Abalario and of Doñana National Park, which house much of Doñana's unique flora, such as carnivorous plants and sphagnum (García Murillo *et al*. 1995; García Murillo 2000, 2003). Therein there will also be an increase in eutrophication. With regard to the marsh, this change in conditions will result in an increase in helophytes and pastures, to the detriment of the submerged macrophytes, this, in turn, will increase the sediment accrual processes, which will create a positive feedback; in short, the sediment accrual speed of the marsh will accelerate.

Will the size of the aquatic ecosystems undergo changes? As we have said before, there will be changes, but these will depend on the successional stage of each environment in question. In general, the most plausible tendency will be towards the simplification of the natural habitats and of the biodiversity of the marsh and of the inland lagoons.

Will the climatic change affect its biogeochemical cycles? Probably. These changes will be particularly evident in the water-rich peat environments, characterised by a low concentration of nutrients and the accumulation of organic matter. The organic matter will cease to accumulate and the concentration of dissolved nutrients will increase, giving way to opportunistic species. In the marsh, as the submerged macrophytes diminish or disappear in a notable manner, the biogeochemical fluxes will follow other routes, as the different elements will fundamentally circulate through the helophytes and the pastures (Espinar *et al*. 2002).

Will the biota be affected by climatic change? There will be a decrease in biodiversity as a result of the decreased heterogeneity of the habitat. Likewise, there will be more change of invasion by exotic species (as is happening with the fern *Azolla*; García Murillo 2003).

Will the rise in sea level affect Doñana? Yes. Mush of the marshland is practically at sea level and is only separated from the sea by small dune walls, less than a metre high. If the sea level continues to rise at the present rates, a large part of Doñana will probably be taken over by the sea within a century.

Will there be marine intrusion? Currently, this does not exist (Lozano *et al*. 2002), but future changes cannot be ruled out if there are conflicts over the use of groundwaters in an area of intensive greenhouse agriculture and vast coastal tourist resorts.

3.5. MAIN ADAPTATION OPTIONS

The adaptations should be applied with regard to both the supply and the demand for water. In the first case, we must attempt to ensure the amount of water available for the aquatic ecosystems through water-saving policies, in the second case, by trying to reorient human demand towards low-consumption uses.

At the regional or local scale, there are no signs of any human adaptations aimed at mitigating or preventing serious effects (emissions of gases, carbon sequestration, etc.). At local scale, there may be some attempts to control flooding, improve biodiversity and reduce pollution (Arnell *et al*. 1996), both in lakes (Annadoter *et al*. 1999) and in wetlands (Zedler 2000; Angeler *et al*. 2003). In any case, it seems wise to point out that in a system of flows that has undergone as much intervention as in Spain, the water allocations to wetlands should be clearly defined in the watershed management, as recommended by the Ramsar Convention (ramsar.org/key_res viii_01_s.doc).

Having established that the adaptation of the inland aquatic ecosystems to climatic change is limited (Poff *et al*. 2002), we believe that the following measures should be taken:

3.5.1. Promotion of water-saving in agriculture

A generalised water-saving policy is urgently needed, and the technology already exists for increasing the efficiency of the irrigation systems. In this sense, we should consider a National Irrigation Plan that takes climatic change into consideration. Furthermore, the private management of the agricultural areas could be enhanced through agro-environmental measures in the vicinity of the aquatic ecosystems.

3.5.2. Promotion of aquifer recharge

This should be done in close consonance with the previous measure, and an attempt ought to be made to ensure that the recharge exceeds the discharge. The initiation of Specific Watershed Management Plans, within the National Hydrological Plan, should be used in this sense. An example of this would be the development of a Special Plan for the Upper Guadiana Basin to ensure the hydrological recovery and sustainability both of its aquifers and of the aquatic environments depending on them.

3.5.3. Promotion of recycling of waste waters

This needs to be further developed, and many important water uses (irrigation, for instance) do not require extreme cleansing. Much more attention must be paid to this point than has been done up to the present; the creation of artificial wetlands could be contemplated.

3.5.4. Improvement in the quality of surface waters

The discharge of pollutants must be reduced, and an attempt must be made to prevent clean or pristine ecosystems from being affected by pollutants in the future. The National Wastewater Treatment Plan and the transfer and application of the European Framework Directive on Water to Spanish law ought to facilitate this improvement, although the widespread problem of diffuse pollution has not yet been dealt with in Spain (Thornton *et al*. 1998).

3.5.5. Recovery of the floodable space within the River Channel Public Domain

Most rivers are very constrained by agricultural and housing development activities, but if the streams flow through public domain, they should be restored in cases of severe deterioration. This would favour the natural development of the riparian environments with the advantage of stimulating the development of this buffer zone to protect the inland aquatic environments from terrestrial effects.

3.5.6. Mass revegetation (forest or shrub) in watersheds, favouring the occupation of the space by autochthonous plants

Revegetation should be favoured to restore the riparian forest along those river banks where it has been eliminated or has become very deteriorated, whereby the natural function of each territory should be conserved.

3.5.7. Use of water transfers to provide minimum amounts to guarantee the survival of the inland aquatic ecosystems (ecological flows, minimum flooding levels, etc.)

This measure need only to be applied to areas of special interest for Nature Conservation (for example, environments included in the Ramsar Convention, habitats included in the Red Natura 2000, etc.) and only in exceptional cases, but always considering the needs of aquatic environments in national hydrological planning.

3.5.8. Promotion of the conservation of natural species and of the environmental connection between them within the framework of a restoration programme at national level

Special attention must be paid to the hydrological connection between ecosystems within the same watershed in order to promote the dispersion of endangered species.

3.5.9. Favouring accretion in coastal wetlands

Accretion should increase at a faster rate than the rise of the sea level, and transport of sediment by rivers in the case of deltas should be favoured. A clear case of anthropogenic interaction with the effects of climatic change is the Ebro Delta. Over the last 50 years, the construction of reservoirs on the middle- and lower reaches of the river has reduced the transport of sediments to the delta, thus reducing its size (Ibáñez *et al*. 1996); the forecasts for in sea level rises in certain parts of Spain (Section 3.2.3) indicate an exacerbation of this tendency in the near future.

3.6. REPERCUSSIONS IN OTHER SECTORS OR AREAS

3.6.1. Environmental conservation

If we do not mitigate the effects of climatic change, many ecosystems will disappear and we may have to invest more money in the conservation of the most appreciated ones. At the very least, it seems urgent to ensure the permanence of refuges and to prevent the fragmentation of habitats, in order to promote the persistence of certain species. In some cases there may be a need for active policies to generate new sites for habitats.

3.6.2. Tourism

The repercussions for tourism can be very serious, with more intense adaptation problems for hostelry and tourism businesses than for the tourists (Wall 1998). In the case of the Tablas de Daimiel marshlands, for example, there are around 200,000 visitors a year; in the years 1994-1995, at the height of the drought during that decade, the number of visitors was less than 10,000. Effects of this type can also be expected in other wetlands with a high influx of visitors, such as the Ebro Delta, Doñana and the Aiguamolls de l'Empordá.

Some effects of an occasional nature can also be particularly harmful for certain aquatic ecosystems. For instance, the *Romería del Rocío* fair, which usually attracts one million people every year, may end up affecting Doñana’s water supply if the water resources used to supply these visitors diminish, which is likely in a context of climatic change (García Murillo and Sousa, personal communication).

3.6.3. Public protection (prevention of flooding)

As most of the fluvial streams of the Iberian Peninsula have been channelled, there will be less natural reduction of the effects of floods, probably more frequent with climatic change. We can also expect synergic effects: with an increase in flooding, malfunctions in the fluvial network (biogeochemical changes, effects on flora and fauna, etc.) will become more obvious.

3.6.4. Water supply

This is important in the case of water supply reservoirs and of aquifers used for supply (around one third of the population uses water from wells in Spain; Custodio *et al*. 1998). Dammed water with a higher number of "blooms" of algae –which will be favoured by climatic change (see Section 3.3.7)– will have higher purification costs.

3.6.5. Inland fisheries

As we have already seen, the habitat of the salmonids will be reduced. It is not clear what will happen to the autochthonous cyprinid fishes (barbel, Iberian naces). They may be replaced by more thermophilic and, in general, alien ones ("black-bass", wels, etc.).

3.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

3.7.1. Lack of series of reliable long-term data for the study of the effects of climatic change

Apart from tendencies, the short, medium and long-term scales of variability should be identified, taking into consideration the close dependence of the changes in aquatic ecosystems on those that occur in the terrestrial environments of the watersheds. There is a lack of long-term observation and follow-up of the natural processes associated with inland aquatic ecosystems. The existing series of long-term data were not designed for this; the water quality records, for instance, deal more with the effects of pollution by urban waste waters. A series of environments ought to be chosen for long-term monitoring in order to establish the effects of climatic change, ruling out those sites subjected to pollution and flow regulation. The lack of coincidence between the flow gauging stations and those engaged in sample collection in many of our control networks limits our capacity to evaluate the relationship between quantity and quality, with regard to certain details related to climatic change.

3.7.2. Still very little information on the ecological and biological state of the most important species

Many valuable environments have hardly been studied at scientific level, but from the point of view of the avifauna. As can be seen in Table 3.1, most of the Spanish Ramsar wetlands have not been studied from the point of view of aquatic ecology; we only avail of data, sometimes very preliminary ones, on 17 of the 49 national ecosystems included on the list.

The biological sampling has not been standardised. However, in order to implement the European Framework Directive on Water in Spain, attempts are being made to fill this gap, with methodologies for biological study, levels of reference of aquatic environments and periodical reviews related to possible changes (among these, climatic ones) that might modify these reference conditions.

3.7.3. Lack of knowledge of hysteresis effects

No ecosystem, and in particular, the aquatic ones dealt with here, ever presents the same response to one same disturbance. There is always a certain degree of hysteresis in their behaviour which is difficult to assess, but the bigger the system, and the more closed the exchange of materials and species, the bigger the hysteresis effect will probably be. In this sense, lacustrine systems and wetlands may present a greater component of hysteresis (Comín *et al*. 1992). There are very few studies in this respect and, as an example, it is worth stating that in alpine lakes the production dynamics and populations of Chironomids seem to follow an adjustment to the climate at scales of tens of years (Catalan *et al*. 2002). Thus, it is likely that the incipient effects of the climatic change that is already occurring will manifest themselves in the next decade.

3.7.4. Lack of knowledge of the effects of abrupt or gradual changes in terrestrial plant communities and in the geology of drainage basins on aquatic ecosystems

Because drainage basins have so much influence on our aquatic ecosystems (Section 3.2), we have to consider the effects of climatic change on drainage basins. We are, however, still uncertain about the direction and magnitude of these basin effects.

3.8. DETECTING CHANGE

This is closely related to the previous section.

3.8.1. Long-term studies for the observation and follow-up of changes

Apart from tendencies, we should also identify short, medium and long-term scales of variability, taking into consideration the close dependence of the changes in aquatic ecosystems on those that occur in the terrestrial environments of the watersheds.

3.8.2. Use of models of inland aquatic ecosystems

In our case, and given the aforementioned dependence on the watersheds, the usefulness of the models will depend on the reliability of models for the terrestrial environment of the watershed. The better the basin models are, the better those of the aquatic environments will be.

No empirical models on the distribution of species in inland aquatic environments exist that explain species distribution on the basis of a limited number of environmental variables, among which could be those associated with climatic change (water temperature, flow, hydroperiod, etc.)

3.9. IMPLICATIONS FOR POLICIES

3.9.1. Scientific policy

The Ministry of Education and Science should promote research into the effects of climatic change on inland aquatic ecosystems and of the mitigation of these effects by means of ecological restoration. Most of the projects approved to date merely contemplate changes in the past. Hardly any projects have been approved dealing with the monitoring or detection of the effects of current climatic change. The Public Works and Agriculture Ministries should also become involved.

3.9.2. Inland fisheries policy

The Regional Governments (depts. of Agriculture and Fisheries or Environment) must be involved in fisheries policy. Given the foreseen changes in fauna (Section 3.3.5), the regulation and management of the fish populations must be adapted to the changes we can anticipate.

3.9.3. Environmental policy

This is the Responsibility of the Ministry of the Environment and of the Regional Autonomies (depts. of the Environment and Public Works), and they should become involved in the conservation of protected natural areas, many of which include inland aquatic ecosystems. This policy should be applied at the level of watersheds, including subterranean waters, if they are to be effective.

3.9.4. Regional and local tourism policy

To be implemented by the Regional Governments (Tourism Departments) and the Town Councils (Tourism departments) located in the vicinity of protected natural spaces.

3.10. MAIN RESEARCH NEEDS

3.10.1. Long-term studies of the environmental effects of climatic change in Spanish inland aquatic ecosystems in sensitive areas

Implementation of a series of long-term studies in standard ecosystems, located in uncontaminated and unregulated watersheds, such as the Pyrenean lakes (*e.g.* Lake Redó), Lake Sanabria, Sierra Nevada lakes, river environments of the Upper Duero and the Upper Tajo, ponds on *rañas* in northern Palencia, Ramsar wetlands, etc.

3.10.2. Studies of water quality in relation to climatic change

To date non-existent.

3.10.3. Design of a system of biological indicators of the impacts of climatic change

In collaboration with the work groups transferring and applying the European Framework Directive on Water for Spain, one ought to be designed for algae, macrophytes and aquatic macroinvertebrates.

3.10.4. Implementation of the existing models for the detection of effects of climatic change on inland aquatic ecosystems in Spain

To date non-existent.

3.10.5. Urgent finalisation of the inventory of the flora and fauna associated with aquatic environments, particularly of non-vascular plants and invertebrates, together with a description of their distribution on the Iberian Peninsula, Balearic Islands and Canary Islands

Many of these have not been started, but they are fundamental in order to know what exists at the present time and what might appear or disappear due to the effects of climatic change.

3.10.6. Study of the dispersion and ecology of invasive plants and animals (*Azolla caroliniana*, *Eirocheir sinensis*, *Dreissena polymorpha*, *Micropterus salmoides, Esox lucius*, etc.) in relation to climatic change

Invasion by certain species from other parts of the planet is to be expected to increase. Yet, little is known on the ecology involved in invasions of aquatic species on the Iberian Peninsula, apart from the mere detection of these processes.

3.10.7. Study of impacts and adaptations to climatic change at genetic, eco-physical, population and ecological levels

Crucial, given the existing lack of knowledge on the subject.

3.10.8. Studies of the changes in the biodiversity of macrophytes and vertebrates at local level associated with climatic change

To be carried out at the Ramsar sites; these are relatively simple evaluations, but must be done periodically over decades in order to assess what changes have occurred in biodiversity and how these changes can affect the functioning of the ecosystems.

3.10.9. Simulations *in situ* of the possible changes in determined ecosystems (small lakes, wetlands and watersheds), altering environmental conditions in an analogous way to the predicted changes

These simulations could be used to appreciate in a realistic manner changes in the ecosystems before they occur, and could generate very valuable information for the application of adaptation measures.

3.10.10. Study and inventory of biological communities georeferenced at regional scale

To be carried out primarily in the plant communities, this study aims at establishing their present environmental state in order to identify future transformations therein due to climatic change.

3.10.11. Study of the effects of the mitigation measures

Vital for evaluating their efficiency and necessary changes.

3.11. BIBLIOGRAPHY

Allen J.R., Huntley B. and Watts W.A. 1996. The vegetation and climate of northwest Iberia over the last 14000 yr. Journal of Quaternary Science 11: 125-147.

Allier C., González Bernáldez F. and Ramírez Díaz L. 1974. Mapa Ecológico de la Reserva Biológica de Doñana y memoria a E. 1:10.000. División del Consejo Superior de Investigaciones Científicas. Sevilla. 132 pgs.

Alonso M. 1998. Las lagunas de la España peninsular. Limnetica 15: 1-176.

Alvarez Cobelas M.., Muñoz P., Rubio A. and Prat N. 1992. Current state of eutrophication in Spanish inland waters. European Water Pollution Control 2(5): 27-32

Alvarez Cobelas M., Cirujano S. and Sánchez Carrillo S. 2001. Hydrological and botanical man-made changes in the Spanish wetland of Las Tablas de Daimiel. Biological Conservation 97: 89-97.

Angeler D.G., Chow-Fraser P., Hanson M.A., Sánchez Carrillo S. and Zimmer K.D. 2003. Biomanipulation: a useful tool for freshwter wetland mitigation? Freshwater Biology 48 : 2203-2213.

Annadoter H., Cronberg G., Aagren R., Lundstedt B., Nilson P.A. and Ströbeck S. 1999. Multiple techniques for lake restoration. Hydrobiologia 395/396: 77-85.

Arnell N. et al. 1996. Hydrology and freshwater ecology. In: Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A. and Maskell K. (eds.). Climate Change 1995. Cambridge University Press. Cambridge. Pgs. 325-363.

Avila A., Neal C. and Terradas J. 1996. Climate change implications for streamflow and stream water chemisty in a Mediterranean catchment. Journal of Hydrology 177: 99-116.

Ayala-Carcedo F.J. and Iglesias A. 2000. Impactos del posible Cambio Climático sobre los recursos hídricos, el diseño y la planificación hidrológica en la España Peninsular. El Campo 137: 201-222.

Barriendos M. 1997. Climatic variations in the Iberian Peninsula during the late Maunder Minimum (1675-1717): an analysis of data from rogation ceremonies. The Holocene 7: 105-111.

Battarbee R.W., Grytnes J.A., Thompson R., Appleby P.G., Catalán J., Korhola A., Birks H.J.B. and Lami A. 2002. Climate variability and ecosystem dynamics at remote alpine and arctic lakes: the last 200 years. Journal of Paleolimnology 28: 161-179.

Bazzaz F.A. 1990. The response of natural ecosystems to the rising global CO_2 levels. Annual Review of Ecology and Systematics 21: 167-196.

Beguería S., López Moreno J.I., Lorente A., Seeger M. and González Ruiz J.M. 2003. Assessing the effect of climate oscillations and land-use changes on streamflow in the central Spanish Pyrenees. Ambio 32: 283-286.

Benavente J. and Rodríguez M. 1997. Análisis cuantitativo de los flujos subterráneos en las lagunas de Campillos (Málaga). Limnetica 13:15-24.

Benke A.C. 1993. Concepts and patterns of invertebrate production in running waters. Verhandlungen der Internatale Vereinigüng für Limnologie 25: 15-38.

Bernal S., Butturini A., Nin E., Sabater F. and Sabater S. 2003. Leaf litter dynamics and N_2O emission in a Mediterranean riparian forest: implications for soil nitrogen dynamics. Journal of Environmental Quality 32: 191-197.

Bradley R.S. 1999. Paleoclimatology: Reconstructing climates of the Quaternary.. 2nd ed. Harcourt/Academic Press. New York.

Burjachs F., Giralt S., Roca J.R., Seret G. and Julia R., 1997. Palinología Holocénica y desertización en el Mediterráneo Occidental. In: Ibáñez J.J., Valero Garcés B.L. and Machado C. (eds.). El paisaje mediterráneo a través del espacio y del tiempo. Geoforma Ediciones, Logroño. Pgs. 379-394.

de Bustamante I., Dorado M., Rojas B., Temiño J., Segura M., García-Hidalgo J., Pérez del Campo P., Valdeolmillos A., Sicilia F., Fernández Reina I. and López Blanco M.J. 1995. Análisis del impacto ambiental de la explotación de los depósitos de turba asociados al río Guadiana en la Llanura Manchega e interés de su conservación. Informe Final. Proyecto para la Fundación Ramón Areces. Madrid.

Butturini A. and Sabater F.1998. Ammonium and phosphate ratention in a Mediterranean stream. Hydrological versus temperature control. Canadian Journal of Fisheries and Aquatic Sciences 55: 1938-1945.

Cacho I., Grimalt J.O., Pelejero C., Canals M., Sierro F.J., Flores J.A. and Shackleton N. 1999. Dansgaard-Oeschger and Heinrich event inprints in Alboran Sea paleotemperatures. Paleoceanography 14: 698-705.

Camarero L., Guilizzoni P., Muri G., Psenner R., Rose N., Stuchlik E. and Vidinova Y. 2004. Pan-European survey of heavy metals in alpine/arctic lake sediments: a record of diffuse atmospheric pollution at a continental scale. The Science of the Total Environment (submitted).

Carmona J.A., Doadrio I., Márquez A.L., Real R. and Vargas J.M. 1999. Distribution patterns of indigenous fishes in the Tagus River basin, Spain. Environmental Biology of Fishes 54: 371-387.

Carpenter S.R., Fisher S.G., Grimm N.B. and Kitchell J.F. 1992. Global change and freshwater ecosystems. Annual Review of Ecology and Systematics 23: 119-139.

de Castro F. and Muñoz Reinoso J.C. 1997. Model of long-term water-table dynamics at Doñana National Park. Water Research 31: 2586-2596.

Catalán J., Pla S., Rieradevall M., Felip M., Ventura M., Buchaca T., Camarero L., Brancelj A., Appleby P.G., Lami A., Grytnes J.A., Agustí-Panareda A. and Thompson R. 2002. Lake Redó ecosystem response to an increasing warming in the Pyrennees during the twentieth century. Journal of Paleolimnology 28: 129-145.

Cheddadi R., Yu G., Guiot J., Harrison S.P. and Prentice I.C. 1997. The Climate of Europe 6000 years ago. Climate Dynamics 13:1-19.

CEDEX 1997. Estudio sobre el impacto potencial del cambio climático en los recursos hídricos y las demandas de riego en determinadas regiones de España. Informe técnico para el Ministerio de Medio Ambiente de España. Madrid.

Church J.A., Gregory J.M., Huybrechts P., Kuhn M., Lambeck K., Nhuan M.T., Qin D. and Woodworth P.L. 2001. Changes in sea level. In: Climate Change 2001. Cambridge University Press. Cambridge. Pgs. 639-694.

Clair T.A. and Ehrman J.M. 1996. Variations in discharge and dissolved organic carbon and nitrogen export from terrestrial basins with changes in climate: a neural network approach. Limnology and Oceanography 41: 921-927.

Cobo M.D., Sánchez Gullón E. and García Murillo P. 2002. Flora y vegetación. In: Parque Nacional de Doñana. Canseco Editores. Talavera de la Reina. Pgs. 108-174.

Cohen A. 2003. Paleolimnology. The History and Evolution of Lake Systems. Oxford University Press. Oxford.

Comín F.A. and Alonso M. 1988. Spanish salt lakes: their chemistry and biota. Hydrobiologia 158: 237-246.

Comín F.A., Rodó X. and Comín P. 1992. Lake Gallocanta (Aragón, NE Spain): a paradigm of fluctuations at different scales of time. Limnetica 8: 79-96.

Custodio E., Llamas M.R. and Villarrroya F. 1998. The role of Spanish Committee of the International Association of Hydrogeologists in the management and protection of Spain's groundwater resources. Hydrogeology Journal 6: 15-23.

Dirección General de Obras Hidraúlicas 1988. Inventario de presas españolas, 1986. Ministerio de Obras Públicas and Urbanismo. Madrid.

Dorado M., Valdeolmillos A., Ruiz B., Gil M.J. and de Bustamante I. 2002. Climatic changes since the Late-glacial/Holocene transition in La Mancha Plain (South-central Iberian Peninsula, Spain) and their incidence on Las Tablas de Daimiel marshlands. Quaternary International 93/94: 73-84.

Eaton J.G. and Scheller R.M. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnology and Oceanography 41: 1109-1115.

Espinar J.L., García L.V., García Murillo P. and Toja J. 2002. Submerged macrophyte zonation in a Mediterranean salt marsh: a facilitation effect from estabilised helophytes?. Journal of Vegetation Science 13: 1-15.

Fernández Delgado C. and Herrera M. 1994. Population structure, growth and reproduction of *Tropidophoxinellus alburnoides* (Steindachter, 1866) in an intermittent stream of the Guadalquivir River basin (southern Spain). Archiv für Hydrobiologie 130: 359-369.

Fetter C.W. 2001. Applied Hydrogeology. Prentice-Hall. New York.

Fisher S.G., Grimm N.B., Martí E., Holmes R.M. and Jones jr, J.B. 1998. Material spiraling in stream corridors: a telescoping ecosystem model. Ecosystems 1: 19-34

Freeman C., Evans C.D., Monteith D.T., Reynolds B. and Fenner N. 2001. Export of organic carbon from peat soils. Nature 412: 785.

Friedland K.D., Reddin D.G. and Castonguay M. 2003. Ocean thermal conditions in the post-smolt nursery of North American Atlantic salmon. ICES-Journal-of-Marine-Science. 60: 343-355.

García Murillo P. 2000. *Utricularia exoleta* R. Br. In: Blanca G., Cabezudo B., Henández-Bermejo E., Herrera C.M., Muñoz J. and Valdés B. (eds.). Libro Rojo de la Flora Silvestre Amenazada de Andalucía, Tomo II, Especies Vulnerables. Consejería de Medio Ambiente, Junta de Andalucía. Sevilla. Pgs. 361-363.

García Murillo P. 2003. Plantas acuáticas and carnívoras en Doñana. Doñana 2005, 4: 8-11.

García Murillo P.; Sousa A. and Fuertes E. 1995. *Sphagnum inundatum* Russ., nuevo para Andalucía. Anales del Jardín Botánico de Madrid 53: 245.

Gierlowski-Kordesch E. and Kelts K. 1994. Introduction. In: Gierlowski-Kordesch E. and Kelts K.R. (eds.). Global Geological Record of Lake Basins. Volume 1. Cambridge University Press, Cambridge: xvii-xxxiii.

Giralt S. and Juliá R. 2004. Water level reconstruction in closed lakes based on the mineralogical composition of sediments. In: Valero Garcés B.L. (ed.). Limnogeology in Spain: a Tribute to Kerry R. Kelts. CSIC. Madrid. Pgs. 305-325.

Giralt S., Burjachs F., Roca J.R. and Juliá R. 1999. Late Glacial to Early Holocene environmental adjustment in the Mediterranean semi-arid zone of the Salines playa-lake (Alicante, Spain). Journal of Paleolimnology 21: 449-460.

Grimalt J.O., Fernández P., Berdie L., Vilanova R., Catalán J., Psenner R., Hofer R., Appleby P.G., Rosseland B.O., Lien L., Massabau J.C. and Battarbee R.W. 2001. Selectrive trapping of organochlorine compounds in mountain lakes of temperate areas. Environmental Science and Technology 35: 2690-2697.

Gutiérrez Teira B. 2003. Variaciones de las comunidades y poblaciones de macroinvertebrados del tramo alto del río Manzanares a causa de la temperatura. Posibles efectos del cambio climático. Tesis Doctoral. Escuela Técnica Superior de Ingenieros de Montes. Universidad Politécnica de Madrid. Madrid.

Halac S., Felip M., Camarero L., Sommaruga-Wögrath S., Psenner R., Catalán J. and Sommaruga R. 1997. An in situ enclosure experiment to test the solar UVB impact on plankton in a high-altitude mountain lake. I. Lack of effect on phytoplankton species composition and growth. Journal of Plankton Research 19: 1671-1686

Harrison S., Prentice I.C. and Bartlein P. 1992. Influence of insolation and glaciation on atmospheric circulation in the North Atlantic sector: implications of general circulation model experiments for the Late Quaternary Climatology of Europe. Quaternary Science Reviews 11: 283-299.

Ibañez C., Prat N. and Canicio A. 1996. Changes in the hydrology and sediment transport produced by large dams on the lower Ebro river and its estuary. Regulated Rivers 12: 51-62.

INITEC 1991. Estudio de las zonas húmedas de la España peninsular. Inventario y tipificación. 8 vols. Dirección General de Obras Hidráulicas. MOPU. Madrid.

Jenkins A., McCartney M.y Sefton C. 1993. Impacts of climate change on river quality in the United Kingdom. Report to Department of Environment. Institute of Hydrology. Wallingford. 39 pgs.

Jeppesen E., Søndergaard M. and Jensen J.P. 2003. Climate warming and regime shifts in lake food webs - some comments. Limnology and Oceanography 48: 1346-1349.

Jones P.D. and Thompson R. 2003. Instrumental records. In: Mackay A.W., Battarbee R.W., Birks H.J.B. and Oldfield F. (eds.). Global Change in the Holocene. Edward Arnold, London. Pgs. 140-158.

Kelts K.R. and Talbot M. 1989. Lacustrine Carbonates as Geochemical Archives of Environmental Change and Biotic/Abiotic Interactions. In: Tilzer M.M. and Serruya C. (eds.). Large Lakes, Ecological Structure and Function. Springer Verlag, New York. Pgs. 288-315.

Lake P.S., Palmer M.A., Biro P., Cole J.J., Covich A.P., Dahm C., Gibert J., Goedkoop W., Martens K. and Verhoeven J. 2000. Global change and the diversity of freshwater ecosystems: impacts and linkages between above-sediment and sediment biota. Bioscience 50: 1099-1107.

Last W. and Smol J.P. (eds.). 2001. Tracking environmental change using lake sediments. 4 vols. Kluwer Academic Publishers, Dordrecht.

Lissner J., Schierup H.H., Comín F.A. and Astorga V. 1999a. Effect of climate on the salt tolerance of two *Phragmites* australis populations. I. Growth, inorganic solutes, nitrogen relations and osmoregulation. Aquatic Botany 64: 317-333.

Lissner J., Schierup H.H., Comín F.A. and Astorga V. 1999b. Effect of climate on the salt tolerance of two *Phragmites* australis populations. II. Diurnal CO_2 exchange and transpiration Aquatic Botany 64: 335-350.

Livingstone D.M. 2003. Impact of secular climate change on the thermal structure of a large temperate Central European lake. Climatic Change 57: 205-225.

Lozano E., Coleto C., Manzano M. and Custodio E. 2002. Saline waters in the coastal area of the National Park of Doñana (SW of Spain) in absence of saline water intrusion. 17th Salt Water Intrusion Meeting: 239-249.

Luque J.A. and Juliá R. 2002. Lake sediment response to land-use and climate change during the last 1000 years in the oligotrophic Lake Sanabria (northwest of Iberian Peninsula). Sedimentary Geology 148: 343-355.

Martí E., Aumatell J., Godé L., Poch M. and Sabater F. 2004. Nutrient retention efficiency in streams receiving inputs from wastewater treatment plants. Journal of Environmental Quality 33: 285-293.

Mason I.M., Guzkowska M.A.J., Rapley C.G. and Street-Perrot F.A. 1994. The response of lake levels and areas to climatic change. Climatic Change 27: 161-197.

McKee D., Atkinson D., Collings S.E., Eaton J.W., Gill B., Harvey I., Hatton K., Heyes T., Wilson D. and Moss B. 2003. Response of freshwater microcosm communities to nutrients, fish, and elevated temperature during winter and summer. Limnology and Oceanography 48: 707-722.

MIMAM 1998. Libro Blanco del Agua. Madrid. 855 pgs.

MIMAM 1999. Plan estratégico español para la Conservación and Uso racional de los Humedales. Madrid. 88 pgs.

Montero E. 2000. Contribución al estudio de la geometría and los límites del acuífero del Campo de Montiel. Instituto de Estudios Albacetenses. Diputación Provincial de Albacete. Albacete.

Montes C. (Director) 1993. Estudio de los valores ambientales existentes en las láminas de agua generadas por actividades extractivas en la Comunidad de Madrid. Informe para la Agencia de Medio Ambiente de la Comunidad de Madrid. 4 vols. + apéndices. Universidad Autónoma de Madrid.

Montes C. 1995. La explotación y la gestión de las aguas subterráneas and la conservación de los humedales españoles: una perspectiva ecológica. In: Las aguas subterráneas en la Ley de Aguas Española: Un decenio de Experiencias. Univ. Murcia. Pgs. 305-327.

Murdoch P.S., Baron J.S. and Miller T.L. 2000. Potential effects of climate change on surface-water quality in North America. Journal of the American Water Research Association 36: 347-366.

Öquist M.G. et al. 1996. Non-tidal wetlands. In: Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A. and Maskell K. (eds.). Climate Change 1995. Cambridge University Press. Cambridge. Pgs. 215-239.

Peñalba M.C., Arnold M., Guiot J., Duplessy J.C. and Beaulieu J.L. 1997. Termination of the Last Glaciation in the Iberian Peninsula inferred from the pollen sequence of Quintanar de la Sierra. Quaternary Research 48: 205-214.

Pérez I., Obiol R. and Juliá R. 1994. Climatic change on the Iberian Peninsula recorded in a 30,000-yr pollen record from Lake Banyoles. Quaternary Research 41: 91-98.

Poff N.L., Brinson M. M. and Day jr. J.W. 2002. Aquatic ecosystems and global climate change. Pew Center on Global Climate Change. Arlington, Virginia. <www.pewclimate.org/global-warming-in-depth/all reports/aquatic ecosystems>

Pons A. and Reille M. 1988. The Holocene and upper Pleistocene pollen record from Padul (Granada, Spain). A new study. Palaeogeography, Palaeogeography and Palaeoecology 66: 243-263.

Prat N. 1995. El agua en los ecosistemas. El Campo 132: 29-48.

Prentice I.C., Harrison S., Jolly D. and Guiot J. 1998. The climate and biomes of Europe at 6000 yr BP: Comparison of model simulations and pollen-based reconstructions. Quaternary Science Reviews 17: 659-668.

Rahel F.J., Keleher C.J. and Anderson J.L. 1996. Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: response to climate warming. Limnology and Oceanography 41: 1116-1123.

Reed J.M., 1998. Diatom preservation in the recent sediment record of Spanish saline lakes: implications for palaeoclimate study. Journal of Paleolimnology 19: 129-137.

Reed J.M., Stevenson A.C. and Juggins S.J. 2001. A multi-proxy record of Holocene climate change in southwestern Spain: the Laguna de Medina, Cádiz. The Holocene 11: 705-717

Rivas Martínez S. 1979. Brezales and jarales de Europa occidental. Lazaroa 1: 5-127.

Rivas Martínez S., Costa M., Castroviejo S. and Valdés Bermejo E. 1980. La vegetación de Doñana (Huelva, España). Lazaroa 2: 5-189.

Rodó X., Baert E. and Comín F.A. 1997. Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation. Climate Dynamics 13: 275-284.

Rodó X., Giralt S., Burjachs F., Comín F.A., Tenorio R.G. and Juliá R. 2002. High-resolution saline sediments as enhanced tools for relating proxy paleolake records to recent climatic data series. Sedimentary Geology 148: 203-220.

Roshier D.A., Whetton P.H., Allan R.J. and Robertson A.I. 2001. Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. Austral Ecology 26: 371-384.

Sánchez Carrillo S. and Alvarez Cobelas M. 2001. Nutrient dynamics and eutrophication patterns in a semiarid wetland: the effects of fluctuating hydrology. Water, Air and Soil Pollution 131: 97-118.

Sánchez Carrillo S., Alvarez Cobelas M., Benítez M. and Angeler D.G. 2001. A simple method for estimating water loss by transpiration in wetlands. Hydrological Sciences Journal 46: 537-552.

Sánchez Carrillo S., Angeler D.G., Alvarez Cobelas M., Sánchez Andrés R. and Garatuza J. 2005. Evapotranspiration in semiarid wetlands: relationships between inundation and the macrophyte cover:open ratio. Advances in Water Research (en prensa).

Sánchez Goñi M.F. and Hannon, G.E 1999. High-altitude vegetational pattern on the Iberian Mountain Chain (north-central Spain) during the Holocene. The Holocene 9: 39-57.

Scheffer M., Straile D., van Nees E.H. and Hosper H. 2003. Climatic effects on regime shifts in lakes: a reply. Limnology and Oceanography 48: 1353-1356.

Schindler D.W. 1997. Widespread effects of climate warming on freshwater ecosystems in North America. Hydrological Processes 11: 1043-1057.

Schindler D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58, 18-29.

Sommaruga R., Sattler B., Oberleiter A., Wille A., Wögrath-Sommaruga S., Psenner R., Felip M., Pina S., Girones R. and Catalán J. 1999. An in situ enclosure experiment to test the solar UVB impact on plankton in a high-altitude mountain lake. II. Effects on the microbial food web. Journal of Plankton Research 21: 859-876.

Sousa A. 2004. Evolución de la vegetación higrofítica y de los humedales continentales en el litoral onubense oriental. Tesis Doctoral. Univ. Sevilla. Sevilla.

Sousa A. and García Murillo P. 2002. Méthodologie pour l'étude des effets du Petit Age Glaciaire dans le Parc Naturel de Doñana (Huelva, Espagne). Essai de reconstitution des formations palustres et du drainage superficiel. Publications de l'Association Internationale de Climatologie 14: 359-367.

Sousa A. and García Murillo P. 2003. Changes in the wetlands of Andalusia (Doñana Natural Park, SW Spain) at the end of the Little Ice Age. Climatic Change 58: 193-217.
Stromberg J.C., Tiller R. and Richter B. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6: 113-131.
Thompson R., Price D., Cameron N., Jones V., Bipler C., Rosén P., Hall R.I., Catalán J., García J., Weckstrom J. and Korhola A. 2005. Quantitative calibration of remote mountain lake sediments as climatic recorders of air temperature and ice-cover duration (submitted)
Thornton J.A., Rast W., Holland M.M., Jolankai G. and Ryding S.O. 1998. Assessment and control of nonpoint source pollution of aquatic ecosystems. MAB vol. 23. UNESCO. Paris.
Toth J. 1963. A theoretical analysis of ground water flow in small drainage basins. Journal of Geophysical Research 68: 4795-4812.
Valero Garcés B.L. and Kelts K.R. 1997a. Desertificación y cambio global en la Península Ibérica durante el último ciclo glacial a partir de restos lacustres. In: Ibáñez J.J., Valero Garcés B.L. and Machado C. (eds.). El paisaje mediterráneo a través del espacio y del tiempo. Geoforma ediciones. Logroño. Pgs. 419-437.
Valero Garcés B.L. and Kelts K.R. 1997b. Técnicas en limnogeología aplicadas al estudio del cambio climático y desertificación en la Península Ibérica. In: Ibáñez J.J., Valero Garcés B.L. and Machado C. (eds.). El paisaje mediterráneo a través del espacio y del tiempo. Geoforma ediciones. Logroño. Pgs. 395-4187.
Valero Garcés B.L., Delgado Huertas A., Navas A., Machín J., González Sampériz P. and Kelts K. 2000a. Quaternary palaeohydrological evolution of a playa lake: Salada Mediana, central Ebro Basin, Spain. Sedimentology 47: 1135-1156.
Valero Garcés B.L., González Sampériz P., Delgado Huertas A., Navas A., Machín J. and Kelts K. 2000b. Lateglacial and Late Holocene environmental and vegetational change in Salada Mediana, central Ebro Basin, Spain. Quaternary International 73/74: 29-46.
Valero Garcés B.L., Navas A., Machín J., Stevenson T. and Davis B. 2000c. Responses of a saline lake ecosystem in a semiarid region to irrigation and climate variability. The history of Salada Chiprana, Central Ebro Basin, Spain. Ambio 29: 344-350.
Valero Garcés B.L., Navas A., Mata P., Delgado Huertas A., Machín J., González Sampériz P., Schwalb A., Ariztegui D., Schnellmann M., Bao R. and González Barrios A. 2004. Sedimentary facies analyses in lacustrine cores: from initial core descriptions to detailed paleoenvironmental reconstructions. A case study from Zoñar Lake (Cordoba province, Spain). In: Valero Garcés B.L. (ed.). Limnogeology in Spain: a Tribute to Kerry R. Kelts, CSIC. Madrid. Pgs. 385-414.
Wall G. 1998. Implications of global climate change for tourism and recreation in wetland areas. Climatic Change 40: 371-389.
Wetzel R.G. 1990. Land-water interfaces: metabolic and limnological regulators. Verhandlungen der Internatale Vereinigüng für Limnologie 24: 6-24.
Williamson, C.E. and Zagarese H.E. (eds.) 1994. Impact of UV-B radiation on pelagic freshwater ecosystems. Archiv für Hydrobiologie, Beihefte Ergebnisse der Limnologie 43: 1-226.
Wood W.W. and Sanford W.E. 1994. Recharge of the Ogalalla: 60 years after C.V. Theis's analysis. Procedings of the Playa Basin Symposium: 23-33. Texas Technical University, Lubock.
Zedler J.B. 2000. Progress in wetland restoration ecology. Trends in Ecology and Evolution 15: 402-407.