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Saline lakes: integrating ecology into their management future

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Abstract

Defining the key temporal scales of variability in ecological processes is fundamental to saline lake management because the physical, chemical and biological characteristics of saline lakes undergo fluctuations at different time scales, compared to those of freshwater lakes. A long-term study of Lake Gallocanta (25 km^2 area inland saline lake in NE Spain) provides the ecological basis for its management. The coupling of the administrative framework with its ecological processes is examined. Limnological and climatological parameters were measured using standard methods during 1977–1995. Complete desiccation of the lake occurred in 1983–86 and in 1994–95. Water level fluctuations were strongly correlated with meteorological events, particularly rainfall for seasonal and decadal time scales. The relationship between salinity and water volume follows the typical model described for playa lakes. However, the intensity and frequency of the salinity and water volume fluctuations in Lake Gallocanta also change over time. Most species show pulsing population dynamics at the larger time scales (annual, decadal). However, many of these show a continuous population development at shorter time scales. Examples are provided for several phytoplankton and zooplankton species. Fluctuations in water level also influence phyto and zooplankton community structure. The combination of the number of species, S, and the number of individuals, N, as $K=\log S/\log N$ indicates that the community structure also fluctuates at different time scales. Most of the present laws established for the management of saline lakes are centered on the conservation of waterfowl. Although some generic laws attempt to preserve the overall natural ecosystem, only those dealing with the protection of wild flora and fauna, and threatened species, are implemented. However, ecological knowledge now suggests that the major objective for the conservation of saline lakes should be to preserve the fluctuation of the hydrological balance, avoiding groundwater extraction in the catchment area and surface water. Generic laws regulate water use in Spain and in many other countries. These laws are not useful for saline lake management because they do not offer solutions to the frequent conflicts arising between the water demand for intensive agriculture and nature conservation, which are common in the semi-arid zones where saline lakes are located. Integrated management of the land and water resources in the catchment area is required to preserve saline lake characteistics. Recent legislation aims to promote such management. A model of conservation and development of the overall ecosystem is presented.

Introduction

Saline lake ecosystems are suffering an accelerating process of degradation all around the world (Williams, 1992). The lack of management plans for saline lakes and their catchment area contrasts with the considerable efforts put into preserving and managing freshwater lakes. Furthermore, experience in managing freshwater lakes is much more extensive (De Bernardi et al., 1996), perhaps because human settlements have developed with more frequency and intensity in the vicinity of freshwater lakes than of saline ones. This difference bears no relation to the quantity of water in either type of lake which is quite similar (Vallentyne, 1972), nor to their respective value (economic, social, recreative, aesthetic) which is very high for saline lakes (Williams, 1981a). There is, then, no significant reason for the existing difference between management and legislative regulations affecting freshwater lakes and those affecting saline lakes. However, for the last 20 years, knowledge about saline lakes has increased in concert with their use, environmental impact and management problems (Williams, 1981b; Hammer, 1983; Melack, 1988; Comín & Northcote, 1990; Hurlbert, 1993).

Many physical, chemical and biological characteristics, apart from the salt content, distinguish saline from freshwater lakes and constitute an essential part of their natural resources (Comín et al., 1992). These differential characteristics should be taken into account when drawing up their management and legislative plans. For example, most saline lakes are very shallow and their waters do not stratify vertically. In deep saline lakes, stratification of the water occurs through differences in salt content between the upper and lower layers. Moreover, the physical processes controlling the dynamics of the water column are not stimulated by the exchange of heat or other type of energy between the lake and atmosphere, but are due to wind-induced currents in shallow saline lakes and to changes in the density of the water mass because of changes in salt content in deep saline lakes. Currently, major water inflows take place in most saline lakes *via* groundwater discharges. This is the reason why environmental impact on the groundwater of the catchment area is greater in saline lakes than in freshwater lakes, where major inflows are, in general, surface runoff.

However, the most striking and common characteristic of saline lakes is the high number of different time-scale fluctuations followed by all their characteristics, due to the fact that saline lakes are located in regions subjected to stronger climatic fluctuations than the zones where freshwater lakes are located. This is the most important feature in understanding the functional ecology of saline lakes (Comín et al., 1991). It is also a key feature of all biological systems and in certainly freshwater lakes, but with considerable fewer temporal scales or, at least, scales which appear to have less resolution than in saline lakes. However, these fluctuations have not yet been incorporated into the framework for the conservation and management of lakes; nor can they be easily incorporated into management plans for lakes. Yet it is essential to do so, as the success of any lake management will only be achieved if both spatial and temporal lake heterogeneity is preserved.

This paper presents the ecological fluctuations occurring in Lake Gallocanta (NE Spain), the largest saline lake in Spain, and its present management and legislative framework as a model for other saline lakes in S. Europe. Because of the wide range of ecological fluctuations occurring in Lake Gallocanta, this model can be useful to develop future strategies of management and legislative planning, which are also discussed here.

General background

Lake Gallocanta is the hydrological terminus of the surface waters from a closed catchment (area 520 km^2) in the Iberian Range (40° 50′ N, 2° 11′ W) (Figure 1). Most of the catchment is used for agricultural purposes, a small part of it is naturally forested. There are no industrial activities in the area. The human population (about 2000 inhabitants) is distributed in 12 villages, the largest one with 500 inhabitants. The

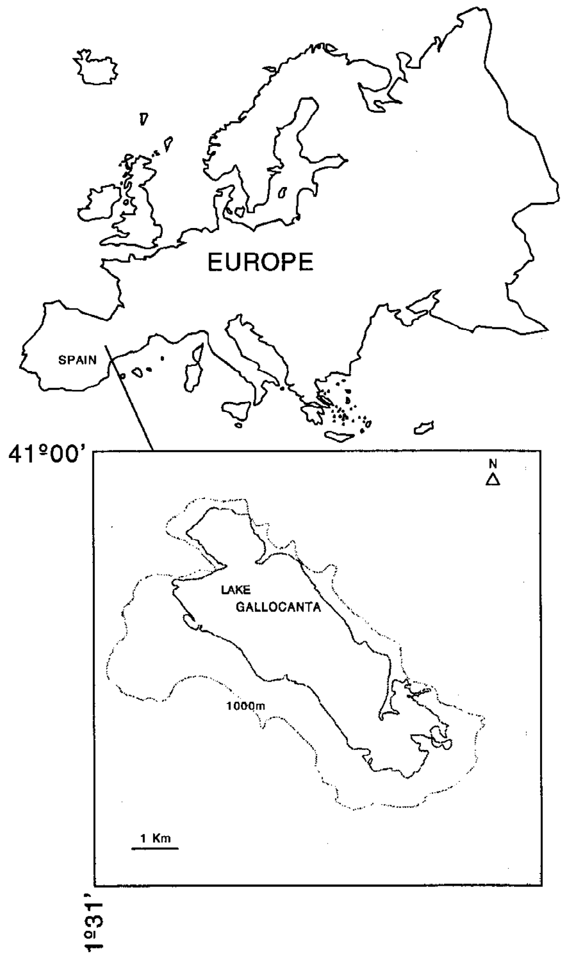


Figure 1. Geographical setting of Lake Gallocanta in Europe.

socio-economic status of the zone is typical of mountain areas in inland Spain. A high percentage of the population migrated during the sixties and seventies, and nowadays most people are elderly (50% over 60 years old).

The lake is the largest saline lake in Spain and, very probably, in Europe (see Williams, 1981a). It was recognized by the Ramsar Convention as a valuable wetland because of the high number of bird species and individuals staying in the zone at some periods of the year. However, no management plans relating to the natural resources or the development of the socio-economical structure of the site have been prepared or implemented. Specific public investments for some activities (agriculture) have been made in some parts of the catchment. General laws regulating uses of land affect this zone too. However, these do not include impacts on, or relationship with, the natural environment.

Limnological data were collected using the following methods. Water level was recorded every five days between 1974 and 1994 by visual observations of graduated stick by rangers of the regional Nature Consevancy Department. Water samples were collected from the same location in the central basin of the lake at different intervals: monthly during 1981–1990 and weekly during 1990–94. Total dissolved solids were determined from filtered (Whatman GF/C filters) samples by drying 110 °C and weighing the remaining solids. Water subsamples were stored frozen for analysis. Analyses were performed using standard methods (Grasshoff, 1975). Phytoplankton samples were preserved with Lugol's and counted (at 840× magnification) using an inverted microscope (Utermohl, 1958). Zooplankton samples were collected with a Neeskens bottle, filtered through a 55 μm mesh, preserved in formalin (4%) and counted at 140× magnification with an inverted microscope.

Hydro-ecological features

Fluctuations of the water level occur on different time scales (Figure 2). A typical annual fluctuation was observed every year from 1975 to 1984 and from 1989 to 1994, characterised by an increasing water level during the rainy periods of the year (most frequently autumn and spring) and a decreasing water level during the dry periods of the year (always in summer, but also in winter in some years). This pattern was not clearly observed during extremely dry years (1984–86), nor during some years of irregular distribution of the annual rainfall (1987–89, 1991–92).

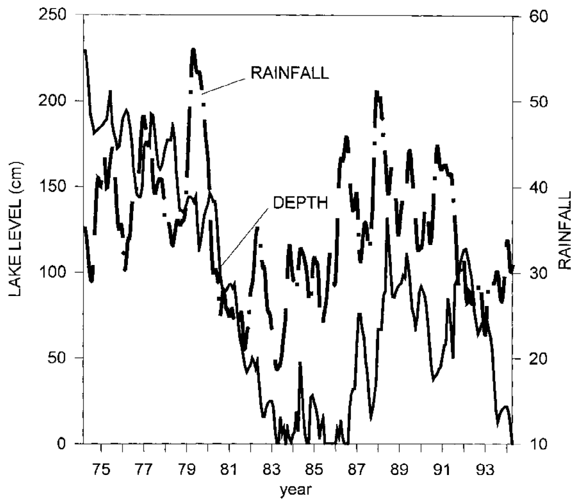


Figure 2. Temporal changes of water level and rainfall in Lake Gallocanta.

Superimposed to the annual fluctuation, there have been rising trends for some years and falling trends in others. Although there are no data before 1975, many old people living in the villages surrounding Lake Gallocanta remember that the lake dried up completely (no water at all above the sediment of the Lake basin for at least four months) six times during the present century. Recently, evidence supporting this information was obtained by paleolimnological studies of the lake sediment (Rodó et al., submitted). This means that water level also fluctuates at an interannual scale (with an approximate frequency of 14 years).

Water level also fluctuates in Lake Gallocanta on other time scales. Longer time-scale fluctuations than those mentioned above occurred in the past as a consequence of climatic changes (Comín et al., 1991; Gracia, 1995). Fluctuations at time scales of less than one year occur with a frequency of several months. There may also be fluctuations at time scales of less than one month, even one week. However, the frequency of data recording (every 5 days) and the precision of the records (0.5 cm) does not permit interpretation at this scale.

The lake level fluctuations are strongly related to rainfall (Figure 2). A response lag of water level with respect to rainfall of between 0.3–2.4 months was calculated using data corresponding to the period 1975–1983 following Langbein's approach (Langbein, 1961) to the hydrology of closed lakes (Comín et al., 1991). A time lag of 0 to 1 month has been estimated using data for the period 1975–1995 after time series analysis (Rodó & Comín, unpublished data).

The water level fluctuations correspond to those of the water table in the Quaternary aquifer which is made up of detritic materials, connected to the lake and occupies half of the catchment area, mostly that surrounding the lake. Its average depth is 110 m, and the discharges from this aquifer occur through the hydrographic network of temporary streams and several springs round the lake's shores. A carbonated aquifer, made up of Jurassic (50 m thickness) and Cretaceous materials (450 m thickness), separated by Mesozoic sand deposits (30–180 m thickness) also contributes to the lake. It flows through springs and surface run-off in the upper parts (1050 m a.s.l.) of the catchment and through its discharge into the Quaternary aquifer on the western side of the lake. The Mesozoic materials occupy 40% of the Gallocanta catchment area, which is an important zone for groundwater recharge. The two aquifers are underlain by Triassic (Keuper) clay and gypsum. Several smaller aquifers exist but are quantitatively unimportant. The whole hydrogeological system maintains more than 100 small (less than 5 ha), mostly temporary, water bodies distributed around the Gallocanta catchment. Direct runoff through aboveground streams is important during rainy periods. The porosity of the soil in the catchment area is very high and the surface run-off then reaches the lake through 5 temporary streams.

It has been estimated through a simulation programme, that groundwater abstraction for agricultural irrigation and water supply to the villages, can decrease the lake water level about 15 cm (Serrano, 1993). Surface water flow control in the catchment area also takes place by means of an artificial dam on one of the streams, during alternate years. The amount of water stored in this way could increase the level of the northernmost basin of Lake Gallocanta (Lagunazo de Gallocanta) up to 20 cm.

Although the hydrogeological studies performed have been inconclusive, several theoretical budgets have been proposed for the groundwater system of Lake Gallocanta. All of them attribute major importance to the recharge occuring in the Mesozoic area of the watershed, and some importance to the inputs occurring through the Quaternary materials. The major outputs are attributed to evapotranspiration from the lake and its shores. Water extraction for agricultural and urban purposes was calculated to be 1–2 Hm^3 ann^{-1} during 1987–89 and 0.37–0.77 Hm^3 ann^{-1} during 1978–83, which accounted for up to 20% of the total outputs from the lake's catchment area (Serrano, 1993). Differences between dry and rainy years are about 45% for the water inputs and 20% for the outputs.

Salinity in Lake Gallocanta also fluctuates at different time scales (Figure 3a), which means that salinity changes with different intensity and frequency, within the recorded range 11–350 g TDS l^{-1}. On the interannual time scale, these changes were, in general, inverse to those of water level, i..e. salinity increases as water level decreases, and vice versa, during the period 1975–1995. The same is true for annual periods of time. However, the salinity vs. water level (or water volume) changes follow a typical closed lake model (Figure 3b) (Langbein, 1961) during the drying up and refilling periods.

The other chemical characteristics of the water in Lake Gallocanta do not follow as clear a relationship with the water level as does salinity. An increase in micronutrient concentrations (nitrogen and phosphorus) was observed during periods of increasing water level, and vice versa, at shorter time scales (from weeks to a year) (Comín et al., 1983; Comín & Rodó, 1992). However, the ranges of variation of some chemical characteristics in the open waters of Lake Gallocanta (pH 7–10.5, alkalinity 2–8 meq l^{-1}, dissolved inorganic nitrogen 4–50 μM, soluble reactive phosphorus 0–10 μM) indicate that there are not great changes of these variables, nor are the waters affected by the impact of intensive industrial, agricultural or urban activities. However, the waters in the Quaternary aquifer do contain nitrate (connected with the presence of potassium), at concentrations higher than 50 mg l^{-1} over most of its area, which indicates a non-point source pollution by fertilizers, and nitrites above the concentration permitted by law in the vicinity of two villages located in the South plains of the Lake, which indicate point source pollution by wastewater.

The biological patterns differ between species. Temporal changes in abundance reflect the physical and chemical characteristics of the water and are also affected by interspecific relationships. Figure 4 shows a range of different temporal scales of variability for a group of the most abundant planktonic species. During 1990–94, the population of *Arctodiaptomus salinus* fluctuated at a longer temporal scale (interannual) than *Brachionus plicatilis*, reflecting their respective adaptations to the chemical changes associated with the water level fluctuations. They both also fluctuated over

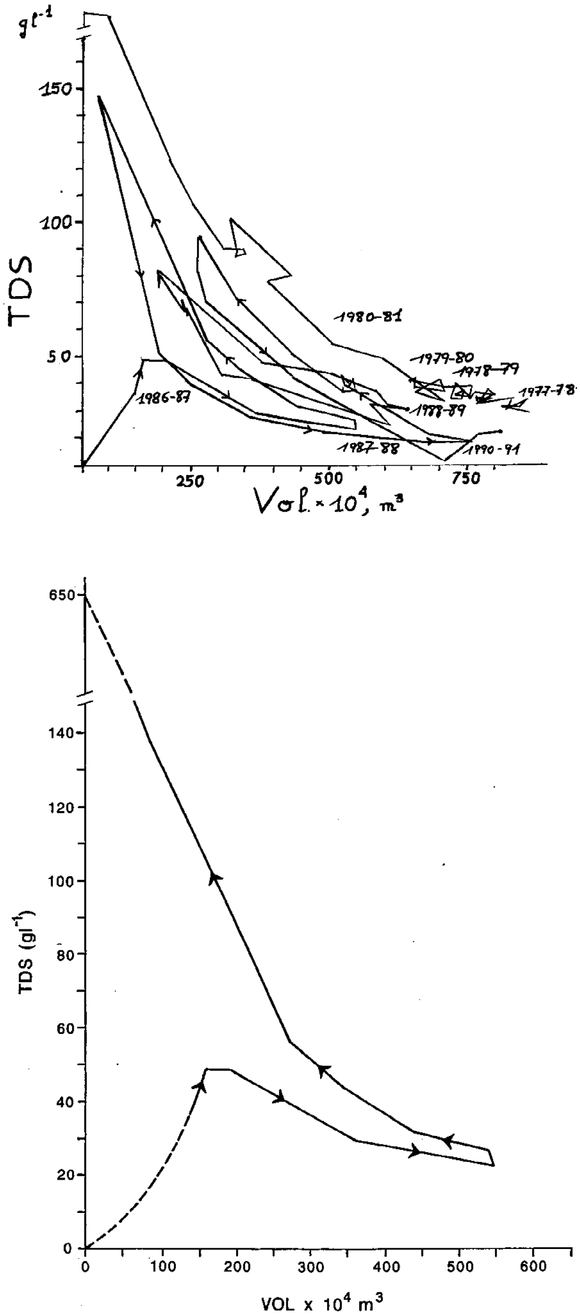


Figure 3. Total dissolved solids vs. water volume fluctuations in Lake Gallocanta during 1977–1991, above. Langbein's model for salinity vs. water volume fluctuations in closed lakes, below.

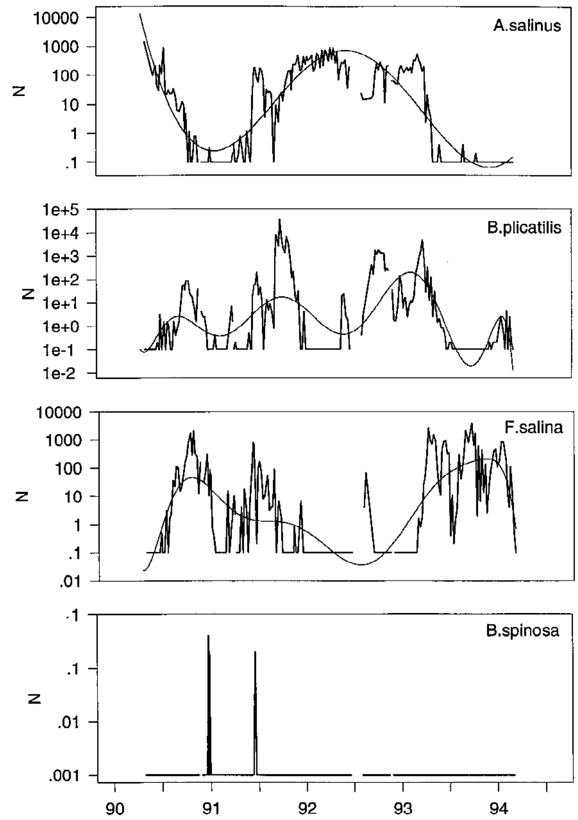


Figure 4. Temporal changes of the abundances of the several populations of zooplankton (*Arctodiaptomus salinus, Brachionus plicatilis, Fabrea salina, Branchinella spinosa*) in Lake Gallocanta during 1990–1994. Cyclic changes of these abundances are indicated in the figures by a simple 10-term moving average.

annual and shorter time scales. The range of temporal scales is completed by *Branchinella spinosa*, which only develops a population in the water column over several years after a total dryness. Similar examples have been observed for phytoplanktonic species. Macrophytes (*Ruppia drepanensis* and *Lamprothamnion papulosum*) develop seasonally during periods of relatively deep water column (>20 cm) and low salinity concentrations (<45 g l^{-1}).

Other biological populations fluctuate in Lake Gallocanta on different time scales. It is known as a migrating station for the largest European populations of common crane (*Grus grus*) however, numbers are not strongly related to water level fluctuations because cranesonly use flooded areas as night stopping-places. On the other hand, the total number of waterfowl individuals shows a strong correlation with the water level and with other characteristics (Comín et al., 1992), as they depend mostly both for nesting and feeding on the other aquatic species. Huge numbers of waterfowl (200 000 waterfowl, mostly overwintering birds) were observed in Lake Gallocanta during the seventies, whereas only between a few hundred and a few thousand were observed during the nineties, and none at all during completely dry years (1983–86, 1994–95).

Thus all the characteristics of the Lake display temporal fluctuations with different time scales strongly related to climatic fluctuations; and the overall ensemble of ecological features is only shown if the complete range of fluctuations is permitted to occur naturally. It is likely (and desirable) that fluctuations in the lake's characteristics occur in the future and this may be conceptually modelled by a loop (Figure 5, compared with Figure 3). The shorter the trajectory of the loop, the higher the constancy of the community structure and lake stability. During years of high increase or decrease in the water level, a long loop is shown, which indicates a large change in the lake's characteristics, including the biological community.

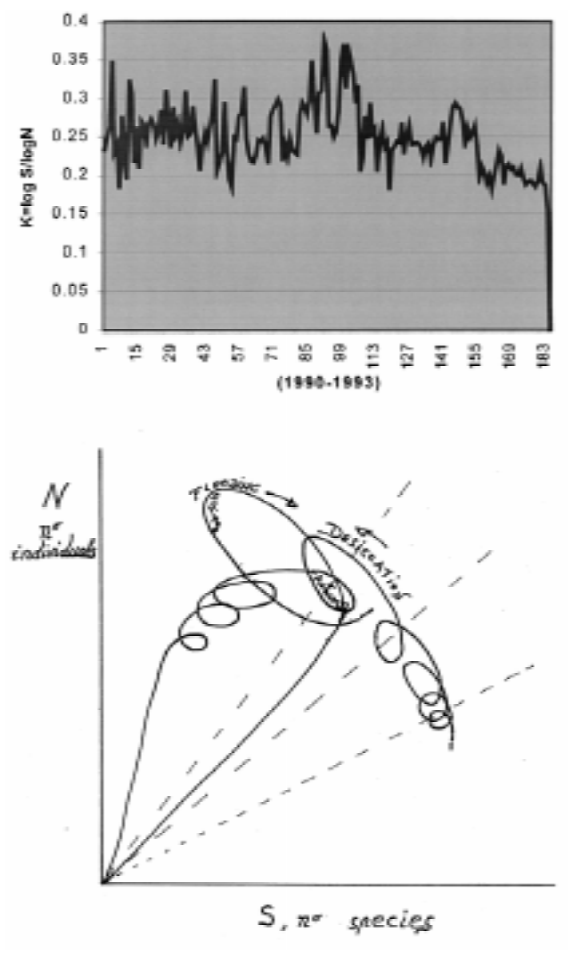


Figure 5. Temporal changes of the diversity (K=log$S$/log$N$) of phytoplankton during 1990–94, above, and a schematic diagram of the K changes during a longer period of time (every loop corresponds to an annual period), below.

It is easy to recognize the different dynamics shown during drying and refilling periods. This approach emphasises that the lake's overall richness is shown where the different time-scale of biological fluctuations occur at the rhythm imposed by the climatic fluctuations.

Present legislative and management framework

A large legislative arsenal exists at international, national and regional levels to regulate the conservation of this type of environment (Figure 6). However, most of these regulations deal with particular aspects of the territory and with species protection and do not consider the overall ecosystem and the physical and biogeochemical processes linking its different components.

The basic Spanish law for water management, which regulates all activities related to the use of water, is the Law of Water of 1995 (LA/95). In addition, the Regulation of the Hydraulic Public Domain, regulates the uses of water and defines the zones which are state property because of their importance. These laws also regulate groundwater extraction and establish conditions for the disposal of wastewaters. However, in practice there are several non-regulated activities or undefined areas with very negative effects on the management of saline lakes. For example, groundwater extraction is not, in reality, regulated because abstraction of up to 7000 m^3 per annum per rural property is permitted without any administrative authorization. Because of this, there are now more than 200 wells used for agricultural irrigation in the Gallocanta catchment area where the amount of water extracted, and its impact on the aquifer and lake is out of the control of the water and environment authorities. Moreover, regulations established an upper limit to the shores of Lake Gallocanta based on the average depth of the water for a limited number of years, without taking into account the fluctuating water level as a dynamic, essential, part of the lake's ecology. If adopted, these regulations would eliminate all the natural resources and ecological functions associated with much of the lake's shores. It would be better to define the upper limit of the hydraulic public domain in saline lakes as the highest elevation reached by the lake waters during the present climatic-ecological- conditions. Incorporating this definition would mean establishing a clear conservation objective for this type of habitat.

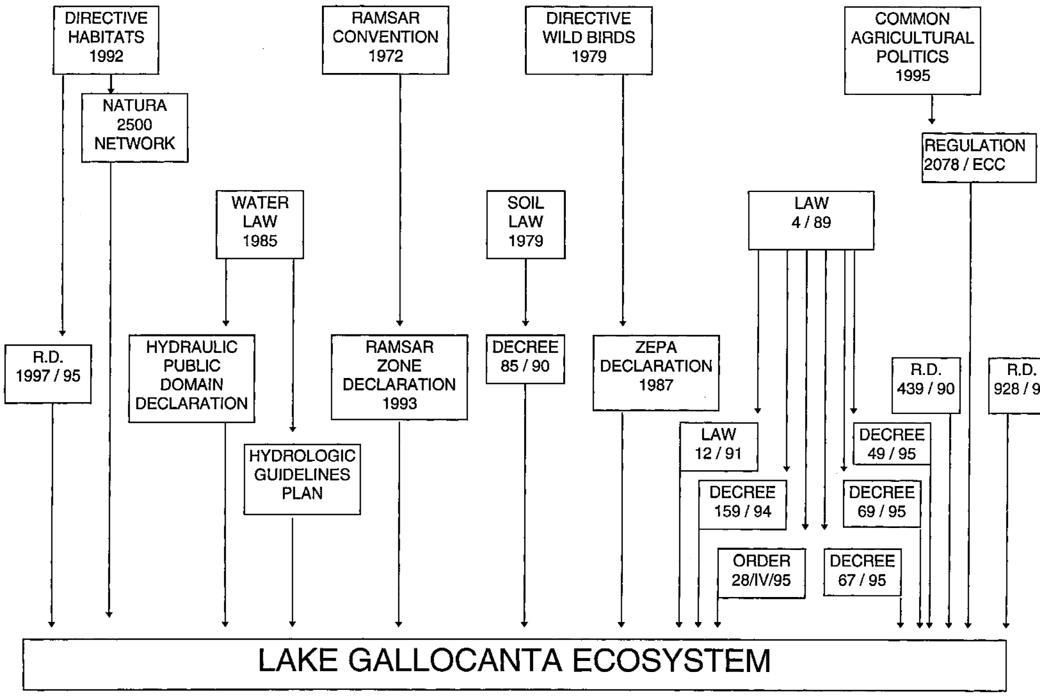


Figure 6. Diagram showing the present legislative framework affecting Lake Gallocanta ecosystem. The laws are distributed in three levels: the upper one contains international laws, the intermediate contains national laws and the lower one regional laws.

Regional Decree 85/1990, based on the Law of Land (Ley del Suelo), protects zones of high environmental value against the effects of urban developments by defining boundaries fot these zones. This decree also establishes that the authorities in charge of nature conservation must report offficially to the Provincial Urban Commissions, which take the final decision on all urban development projects, about the effects of these projects. In fact, these reports should be binding when they impose restrictions on urban development.

Birds are one of the most important natural resources of saline lakes: Lake Gallocanta was included in the Ramsar Convention in 1993 because of the high richness and abundance of bird species living at or visiting the lake. Furthermore it was declared an special zone for the Protection of Birds (ZEPA) based on EC Directive 79/409/ECC, after which the Spanish Government declared the zone a Wild Fauna Refuge (Decree 69/1995). However, these regulations focused only on the protection of animals and against hunting. They did not include the definitions of protection and conservation declared by IUCN-WWF (1980) and EC Directive 92/43/ECC, which are concerned with the conservation of natural habitats, and of wild flora and fauna. A new law passed in 1989, Law 4/89 on the Conservation of Natural Areas and Wild Flora and Fauna, was a significant advance in the protection of species and their habitats and in planning natural resources. This law was in line with the principles of the Spanish Constitution. A National and Regional Registry of Threatened Species was opened, which gave those species which required special protection a separate category. In the case of Gallocanta, *Puccinellia pungens* and *Botaurus stellaris* are endangered species by law. The common crane was given a special interest category. However, these regulations, in practice, mostly concerned the preservation of species rather than habitats. There was no consistent conservation of the ecosystem.

This was the objective of another initiative, called Rea Natura 2000, stemming from the same EC Directive 92/43/CEE and Spanish Royal Decree 1997/1995, which tries to develop the missing points of Law 4/89 for the protection and preservation of special areas. The aim is to declare, as Special Zones of Conservation, areas of ecological value and interesting habitats. Inexplicably, inland saline lakes and their associated habitats, which are one of the most representative and valuable ecosystems in Europe, are not included in the list of this Royal Decree. However, Lake Gallocanta will be able to take advantage of the Royal Decree 1997/95, because it was declared a special protected zone for birds (ZEPA).

During the 1980s and 1990s, a long conflict arose between farmers and conservationists because of the feeding habits of the common crane population, which ate cereal seeds on the arable land surrounding Lake Gallocanta and other zones. This arose because of the slow reaction of the regional administration, which compensated the farmers for the loss of productivity caused by cranes, but with lack of consistent assessment criteria for a few years. Management practice was also very inefficient because the costs of calculating the loss of productivity (calculated by insurance company valuers) were much higher than the loss of productivity itself. This situation was improved recently by an agreement between the administration and farmers to pay compensation for the year of lost productivity on a satisfactory basis for the farmers. Because of this and other experiences, different regional and national regulations have been established during the last decade in order to promote nature conservancy by farmers by avoiding extensive uses of natural areas and intensive uses of agricultural land which may have negative effects on natural areas. The National Law 4/89, and the regional Law 12/1992 regulating hunting activities in Aragón, included rules to compensate for damage to farming activities by wild or protected fauna. More recently three laws (Decree 159/1994 and Order 28 April 1995, both approved by the Regional Administration, and the Royal Decree 928/1995) have been passed to favour sustainable activities (e.g. cultivation of plants consuming low amounts of water, no groundwater extraction, over planting of seeds, preservation of wetland pastures) compatible with the preservation of natural areas of interest. Many of these measures are co-funded by the European Commission, which in this way makes practical its clear interest in the preservation of natural habitats, by the Spanish State and the Regional Government. 40 applications (pieces of land) were made under one of these measures during its first year in force and 400 during the second year, which is an indicator both of the possibility of integrating nature conservancy and socio-economic development, and of the potential interest of local people in participating actively in the management of land and water uses, which include natural processes in development plans aimed at preserving the overall ecological system.

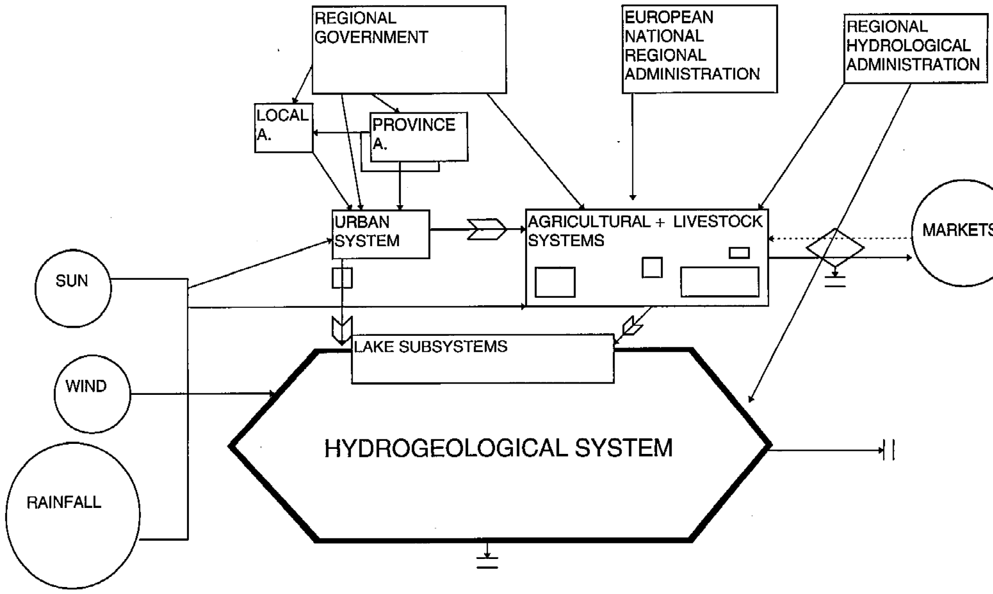
A new law, the regional Decree 67/1995 to begin to establish a Plan of Regulation of the Natural Resources (PORN) in the ZEPA area of Lake Gallocanta, has been recently added to the legislative framework for the Lake Gallocanta ecosystem. This decrees that all activities requiring administrative authorization should also have a positive report from the authority in charge of the preservation of the natural environment. In practice, this law is the consequence of the social and political situation after the conflicts between some farmers and conservation groups. This fact shows the considerable social and political pressure on the administration and the lack of knowledge of the lake's ecosystem, including the basis for a sustainable long-term socio-economic development, and also the lack of clear policies for nature conservation.

The present legislative framework (represented in Figure 6) is in practice very inefficient as no clear statment about the conservation of the lake's ecosystem has been achieved. It is quite chaotic with different Governments (local, regional, national) involved on the management of different parts of the territory. Figure 7 (above) shows schematically this situation and the lack of consideration of ecological information in the management.

Future management framework

The history of the management steps followed in Lake Gallocanta, as in many other saline lake ecosystems, is characterized by two outstanding features – the lack of a planned objective and the imposition of initiatives by outside agencies. The objectives of the different management activities performed during the last 23 years were to protect some physical components of the ecosystem (e.g. birds, some particular plant species, promotion of a type of agricultural activity) and were based on such a general legislative framework that it was very difficult to apply them efficiently. Nevertheless, specific laws designed to provide economic stimulation of local activities, mostly farming, were very succesful. However, this is not an efficient way of pemanently managing an ecosystem because people's activities are not integrated in a general management strategy, but are just compensated not to do one thing for a certain time, which they can start again at any time.

However, opinion is growing, both among the catchment's inhabitants and external groups, in favour of integrating the conservation of the lake ecosystem into the socio-economic development of the catchment area, and also of the preservation of the natural re-



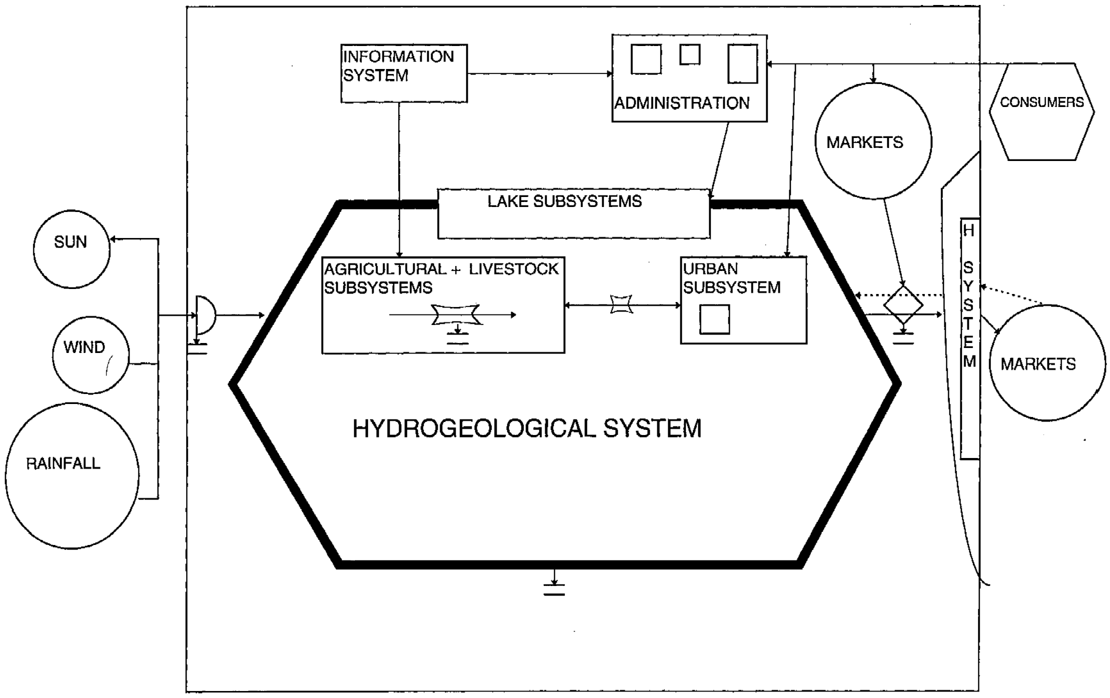


Figure 7. Flow diagram showing the present relationships between different compartments of Lake Gallocanta ecosystem and the management structure, above. Flow diagram of Lake Gallocanta ecosystem showing an idealized view which incorporates the ecological knowledge in its management structure, below.

sources by the inhabitants themselves. This is based on two facts: – no significant collective improvement in the relative (compared to other culturally close territories) standard of living has taken place in the catchment area for the last 23 years and a number of initiatives carried out by some people living in the catchment area and its vicinity have revealed the efficiency of adopting new practices as alternatives to the traditional socio-economic activities developed in the zone.

Undoubtedly, the conservation of the Lake Gallocanta ecosystem, and similar areas in S. Europe is a major objective to be achieved as soon as possible, and one which has been assumed by different general documents from the European Commision (Europe Environment, 1996) Participation of local people is vital in defining the objectives and, also, to make them aware of the importance of the natural resources of the area and the role they must play. However, the arsenal of legislation on water and natural areas is not based on the ecological knowledge of this type of ecosystem which could contribute to its preservation and management. In the case of Lake Gallocanta, it is clear that a protected natural area should be established, including the entire catchment area with zoning, providing different levels of protection. Two basic requirements must be accomplished to improve the management of the Lake Gallocanta ecosystem (and other saline lake ecosystems):

1. Planning the objectives should include local participation. Because the lake ecosystem's functioning is mostly dependent on groundwater flows, this planning should include inhabitants of the whole hydraulic catchment area. Their participation in the hydrogeological system should also be stimulated. The cultural heritage of local people is of inestimable value because it has evolved under and adapted to the same fluctuations as the lake and because they are also part of the lake ecosystem. Figure 7 shows schematically the ideas of integrating the overall ecosystem and incorporating the ecological knowledge in the management structure of this type of environments.

2. Inclusion of the lake ecosystem's fluctuations in the future management and legislative framework should be uncontroversial, since the overall values of the ecosystem are only of value if the fluctuations occur in relation with the climatic fluctuations and are not negatively affected by human disturbance. The lake and the ground waters should be permitted to fluctuate in line with natural climatic fluctuations and activities negatively affecting these fluctuations should be restricted. For example, an increased groundwater extraction of 3.5 and 4.5 Hm^3 ann^{-1} for agricultural irrigation would cause a lake water fall of 4, 12 and 15 cm, respectively, (Serrano, 1993), which is enough to produce a complete change in the structure of the biological community and the ecological functioning of the lake, during the periods of time when the lake water level is lower than 1 m. Moreover, the present groundwater abstraction for intensive irrigation in the catchment area can take the overall lake ecosystem to more frequent and persistent desiccation periods with a clear loss of natural resources (Figure 8). Alternative activities for the socio-economic development of the zone, which integrate the conservation of the lake's ecosystem and its natural resources, should be promoted and stimulated both from within the catchment and from outside.

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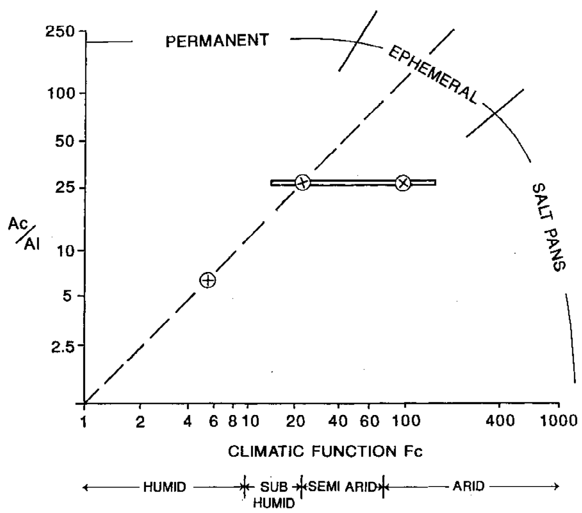

Figure 8. Idealized changes of Lake Gallocanta morphological function (A_c/A_l, catchment area/lake area) as a function of climatic changes (F_c=((E-P)/P_f)+1), where E is evaporation, P rainfall, both as L m^{-2} and P_f the water volume entering the lake per square meter of catchment area) and man made water abstraction.

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