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Functional analysis and restoration of Mediterranean lagunas in the Mancha Húmeda Biosphere Reserve (Central Spain)

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ABSTRACT

1. The Mancha Húmeda Biosphere Reserve includes approximately 50 lakes, most of them shallow and temporary (lagunas).
2. Despite their international importance, numerous impacts affect them, including pollution in lagunas located near villages and the partial or total desiccation of most sites due to river channelization and groundwater over-exploitation.
3. Restoration attempts over a period of years failed because they aimed to improve living conditions for only unrepresentative indicator taxa and neglected the temporal dynamics of aquatic systems.
4. Key recommendations are discussed for restoration, based on functional analysis: i) Restoring and/or preserving the original hydroperiod (including drought) and the diversity of water input; ii) protecting the structure and function of sediments, considering nutrient availability to assess water quality; iii) categorizing the environments in terms of the dominant primary producers; iv) complementing estimates of production by considering its fate and form of consumption; and v) identifying key events triggering the main patterns of ecosystem organization (either episodical or periodical, abiotic or biotic).

KEY WORDS: lake restoration; lagunas; wetlands; conservation value

INTRODUCTION

The most important threat to Spanish lentic systems is a lack of water. When they are not deliberately drained, channelization or groundwater exploitation deprive them of their surface or subsurface water inputs. Spanish lentic systems also suffer from many other impacts that eventually become important at a regional or local scale. In recent years, the oddest impact was caused by waterfowl farming activities or 'zootechnical' projects, which are pretentiously considered as wetland restoration by their authors (Casado *et al*., 1992). These projects seek to transform aquatic ecosystems to create favourable conditions for the breeding, nesting, feeding or resting of the highest possible numbers of waterfowl. Moreover, they disregard the difference in environmental features between the natural and the 'restored' situation (Molina, 1990). Many experts, however, demand that restoration projects have an ecosystem-based

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approach, i.e. operating within a framework which attempts to restore the various functions and general values of aquatic ecosystems and not simply to create habitats for particular species (Montes *et al*., 1995). Identifying these functions is the object of the latest generation of wetland evaluation techniques (Brinson *et al*., 1994; Maltby *et al*., 1996).

Essentially, the procedure for the functional assessment of wetlands aims to identify abiotic and biotic features of wetlands that are either easily measurable or available from the literature and serve to predict the probability that a wetland site performs certain functions. Wetland functions are deduced from the analysis of hydrogeomorphic features of wetlands and their correspondences with functional profiles of the main wetland classes as defined by previous scientific studies. These procedures have been applied to river marginal wetlands in Europe and a diversity of North American wetlands, but none of them is representative of the Mediterranean regions.

The essential characteristic of Mediterranean wetlands is the particular temperature and rainfall rhythm resulting from their opposition in seasonal timing, so that the minimum water availability coincides with the period of maximum evaporation and demand. This general trend varies greatly, both among and within the Mediterranean-type regions of the world (di Castri, 1991; Gonzalez Bernaldez, 1992). Moreover, all climates of the Mediterranean type are characterized by the irregular distribution and scarcity of rainfall through time. As a result, the principal feature of Mediterranean inland aquatic ecosystems is the annual and inter-annual variation in water level, with a sharp and unpredictable alternation of wet and dry periods.

Spain is the driest country in western Europe, and its climate is Mediterranean in most regions. Most natural lentic systems in Spain are lagunas, i.e. small, shallow lakes where the length of the annual dry period often experiences marked deviations from the average dry period of 3–4 months, particularly in the summer (Florín *et al*., 1993). These diverse Spanish lagunas are probably the most valuable in Europe, partly because of their spatial and temporal variability, but also for two additional reasons: 1) the rate of loss of natural lentic habitats has been slower in Spain than in the rest of Europe due to a lower population density and a slower rate of economic development until recent times; and 2) the privileged location of Spain at a biogeographical crossroads for many different groups of organisms.

This paper proposes a set of guidelines for the restoration of Mediterranean wetlands based on recently developed procedures of functional assessment. It also uses case studies to compare this approach with that of recent waterfowl farming activities, referring to key indicators for the functioning of selected lagunas that have a high conservation value and that suffer impacts of different types and intensities.

STUDY AREA

UNESCO's Mancha Húmeda Biosphere Reserve includes a selection of about half of the 100 lagunas and other wetlands of the most important wetland district in Spain. These valuable systems are located in the natural region known as La Mancha, that covers an area of 8000 km^2 in the northern part of the Upper Guadiana river basin (Central Spain) (Figure 1). The climate is typically Mediterranean, with the lowest average monthly rainfall occurring in summer, but with a high inter-annual variability.

There are many types of standing waters in Mancha Húmeda (Florín *et al*., 1993), from lakes to floodplains, episodically flooded to permanent, subsaline to hypersaline and natural to artificial. Sulphate is often the dominant anion in these waters (Florín *et al*., 1989), and this allows sulphide accumulation in sediments under conditions of long-term waterlogging. A number of lagunas receive wastewater inputs, resulting in the artificial attraction of large populations of waterfowl for two reasons: i) the increase in the magnitude (intensity and duration) of flooding periods with respect to the natural hydroperiod; and ii) an excessive increase in the provision of food resources.

The conservation status and human impacts on the lagunas and wetlands of La Mancha were described in detail by Florín *et al.* (1993), ASHUMAN (1994) and Oliver and Florín (1995) (Figure 1). According to these sources, only 12 sites are currently threatened with disappearance (Figure 1), but they account for about half of the remaining wetland surface area (3138 ha). The eight relatively well-conserved sites (Figure 1) account for only 295 ha, while both impacted and strongly impacted sites account for a similar wet surface area (2051 and 1586 ha, respectively). Sites that have now disappeared account for 3419 ha. Water-table reduction is the main threat to the Mancha Húmeda lagunas, affecting both the quantity and the quality of their water budgets. Causes of water-table lowering include river channelization, direct drainage of the site or its surroundings, and overall groundwater abstraction. Over-exploitation of aquifers has become the major environmental problem for La Mancha; groundwater is the main source for domestic water supply, but also the basis of economic development (through irrigation for agriculture). However, recent restoration activities have not focused on the problem of water shortage, but on the few eutrophic systems because of their importance for waterfowl.

Conservation value

The designation of the Mancha Húmeda as a UNESCO Biosphere Reserve in 1980 is only one among the many international acknowledgements of the conservation value of its wetlands. Five of them are included

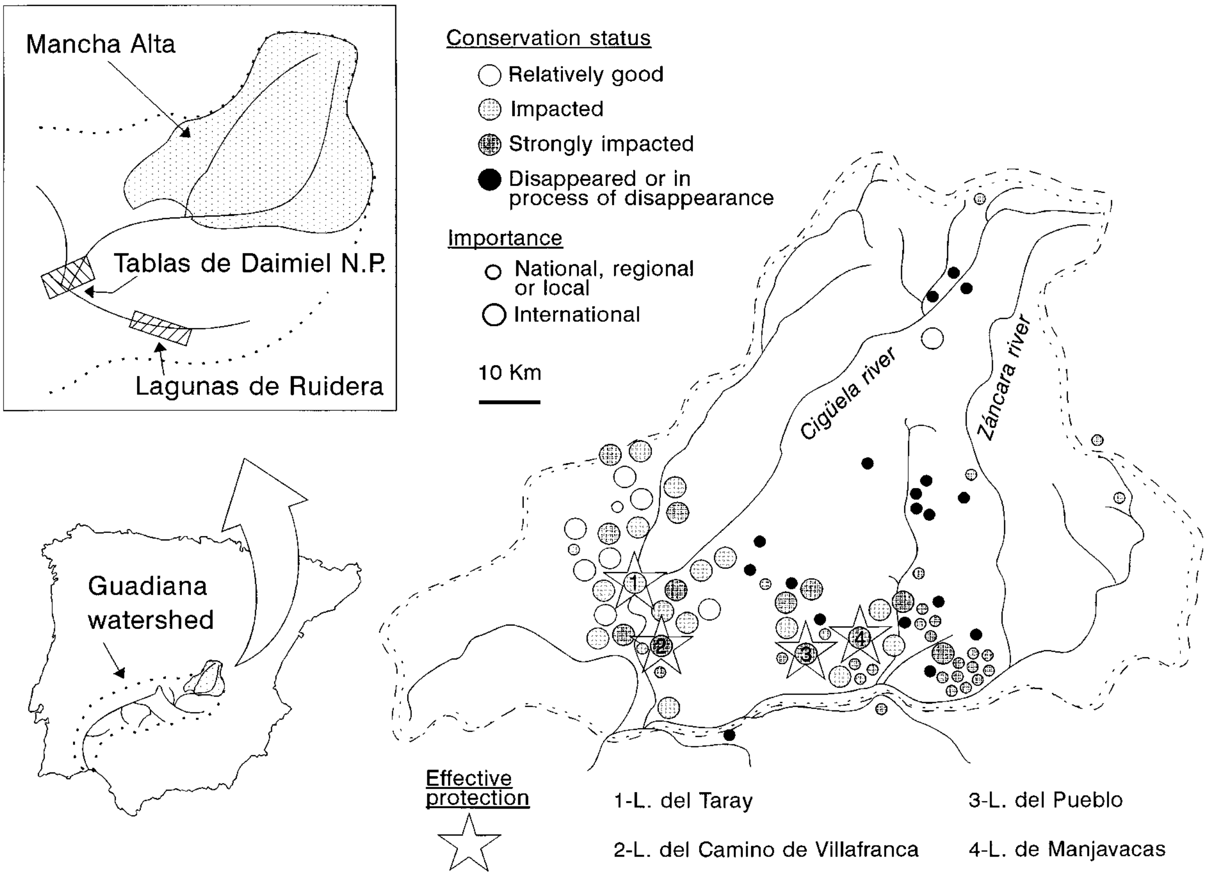

Figure 1. Location and conservation status of lagunas and wetlands in La Mancha. Modified from ASHUMAN (1994).

in the Ramsar List of Wetlands of International Importance. One of them, Las Tablas de Daimiel, also represents the only Spanish National Park located in an inland wetland (Figure 1).

The high conservation value of the Mancha Húmeda lagunas in international terms is due to many reasons. Their landscape and associated socio-economic features are unique in Western Europe (Jessen, 1946), as are their geochemical processes (de la Peña *et al*., 1982). The contribution of the Mancha Húmeda wetlands to global and European biodiversity is also very important, according to standard criteria (Table 1). However, red lists and international conventions disregard other conservation values. This is the case for the rare aquatic herb *Althenia orientalis* (Zannichelliaceae), a species with a very restricted geographical distribution that the present authors collected there in 1986, as well as for the riparian beetle fauna, which includes the Iberian endemic *Orthomus expansus* (Pterostichidae) and two species with a North African–Iberian distribution, namely *Cicindela maroccana* (Cicindelidae) and *Harpalus microthorax* (Harpalidae) (Rueda, 1990).

The lagunas studied are also important for conservation at a habitat or community level. Six types of habitats that are extensively represented in the Mancha Húmeda are considered to be of interest within the European Union (Directive 92/43/EEC, adapted 97/62/EC): inland salt meadows, Mediterranean halophilous bush formations (*Sarcocornetea fruticosi*), Mediterranean salt steppes (*Limonietalia*), oligotrophic calcium-carbonate waters with a benthic vegetation of *Chara* spp., Mediterranean temporary lagunas, and calcium-carbonate wetlands of *Cladium mariscus*. However, other valuable communities not officially acknowledged were described by Margalef (1947) as being unique in western Europe, and comparable to only a few other wetland districts elsewhere in the world (notably in North Africa and Central Asia). This also applies to the microbial mats dominated by the cyanobacteria *Microcoleus chtonoplastes*, the communities of submerged macrophytes dominated by *Ruppia drepanensis* (Potamogetonaceae), the crustacean community *Arctodiaptometum salini* (Alonso, 1996), and the communities of riparian carabids (Rueda, 1990).

METHODS

Guidelines for restoration were developed using the assessment process described by Brinson *et al*. (1994), with particular reference to three steps in their approach: 1) hydrogeomorphological classification of wetlands; 2) definition of relationships between hydrogeomorphological features and wetland functions; and 3) description of the functional profiles for each wetland class. These assessment procedures have a clear scientific rationale, as proposed by Maltby *et al*. (1996). However, there were also differences between this approach and those of Brinson *et al*. (1994) and Maltby *et al*. (1996).

The first difference refers to the classification of lagunas that differ greatly from the North American wetlands and European floodplains where the most recent procedures for functional assessment were developed. Although in these cases the definition of hydrogeomorphological units is fundamental, it would be ineffective in Spain where sites are smaller and discontinuous. As a result, the hydrogeomorphological classification of La Mancha lagunas used was that developed by Florín *et al*. (1993), that treats sites as the lowest-order units. The most important predictors in this classification are: 1) the ratio of surface area to maximum water level, which provides information about the water retention capacity of lake basins; and 2) the proximity of main watercourses, which is related to the existence of natural, large sources of water by association with either the fluvial water table or the areas of regional groundwater discharge. This descriptive classification was then integrated with the functional analysis of hydroperiod dynamics and sediment features made by Florín *et al*. (1994).

Second, the functional assessment of lagunas was complemented by a comparative analysis between relatively well-conserved and artificially enriched lagunas. This was carried out using the following series of descriptors: maximum water level, hydroperiod, sediment features, salinity, concentration of or-

Table 1. Some biota of international importance in the Mancha Húmeda wetlands

Group, species and (Family)	Assessment source and conservation status or measurements			
	IUCN Red Lists	Bern Convention	Birds Directive	Habitats Directive
Plants				
Puccinelia fasciculata (Gramineae)	Vulnerable			
Microcnemum coralloides (Chenopodiaceae)	Vulnerable	Strict protection		
Dorycnium pentaphyllum (Leguminosae)	Rare			Control activities
Linum muelleri (Linaceae)				Strict protection
Lythrum flexuosum (Lythraceae)	Vulnerable	Strict protection		Priority interest
Birds				
Marmaronetta angustirostris (Anatidae)	Vulnerable	Strict protection	Habitat conservation	
Netta rufina (Anatidae)		Protection		
Ardea purpurea (Ardeidae)		Strict protection	Habitat conservation	
Botaurus stellaris (Ardeidae)		Strict protection	Habitat conservation	
Nycticorax nyoticorax (Ardeidae)		Strict protection	Habitat conservation	
Recurvirostra avosetta (Recurvirostridae)		Strict protection	Habitat conservation	
Himantopus himantopus (Recurvirostridae)		Strict protection	Habitat conservation	
Gelochelidon nilotica (Laridae)		Strict protection	Habitat conservation	
Chlidonias hybrida (Laridae)		Strict protection	Habitat conservation	
Podiceps nigricolis (Podicipedidae)		Strict protection		
Otis tarda (Otididae)	Vulnerable	Protection	Habitat conservation	
Tetrax tetrax (Otididae)	Near-threatened	Protection	Habitat conservation	
Other vertebrates				
Emys orbicularis (Emydidae)	Near-threatened	Strict protection		Strict protection
Triturus marmoratus (Salamandridae)		Protection		Strict protection
Lutra lutra (Mustelidae)	Not evaluated	Strict protection		Strict protection

Assessment sources: 1996 and 1997 IUCN Lists of Threatened Animals and Plants, the Bern Convention on the Conservation of European Wildlife and Natural Habitats, and the Directives 79/409/EEC and 92/43/EEC (adapted 97/62/EC) of the European Communities. Species citations: Cirujano (1980), Oliver and Florín (1995) and unpublished data.

thophosphate, nitrate, nitrite, planktonic chlorophyll-a and dominant primary producers. These features were selected because they were identified as being salient predictors of the functioning of the Mancha Húmeda laguna ecosystems (Florín, 1994). Information on these and other descriptors was collected in the Mancha Húmeda lagunas during three extensive limnological surveys (in the winter and spring of 1984–1985 and 1985–1986, and in 1989). Fortnightly to monthly monitoring was undertaken between

1991 and 1993 in a few sites of different functional types. Hydrochemical sampling and analysis were performed using standard techniques (American Public Health Association *et al*., 1985). The collection of hydrochemical data and information on biota was not possible when lagunas were dry at times of inter-annual fluctuations and hydrological impacts.

RESULTS

Classification of lagunas

Four classes of lagunas were identified (Table 2). Three of them include natural lagunas that show good relationships between hydrological regime and the dominant type of primary producers; the fourth consists of lagunas receiving wastewater inputs.

The ratio of surface area to maximum water level ($S{:}Z_{max}$) serves to distinguish between lagunas receiving wastewater inputs together with those characterized by microbial mats, (average $S{:}Z_{max} = 1.02$), and lagunas characterized by submerged macrophytes and phytoplankton (average $S{:}Z_{max} = 1.38$ and 2.35, respectively). The only well-conserved laguna with microbial mats is also much shallower than eutrophic systems (Table 2).

The distance to the nearest stream (L_{NS}) is even shorter for phytoplankton lagunas (average $L_{NS} = 3.80$ km) than for eutrophic lagunas (average $L_{NS} = 4.26$ km), but the former are the most temporary systems, while the latter are the most permanent ones. Lagunas characterized by microbial mats and submerged macrophytes are farther from watercourses (average $L_{NS} = 4.67$ and 5.36 km, respectively). An exception is the Masegar laguna, representative of the numerous floodplain wetlands and shallow lakes associated with rivers in Mancha Húmeda.

Relationships between hydrogeomorphological features and key functions of lagunas

Submerged macrophytes are favoured in the lagunas that have alternating large floods and dry periods. In these lagunas, sediment anoxia and subsequent accumulation of organic matter and sulphide (toxic to macrophytes) are limited by the occurrence of dry periods. However, flooding events that are long enough still occur to enable macrophytes to complete their life cycles (Figure 2a). On the other hand, a succession of frequent short flood and dry periods leads to phytoplankton- or microbenthic-dominated communities of primary producers (Figure 2b and c). This is also the case when ephemeral flooding occurs during a long, dry period in a macrophyte-dominated laguna.

Box-and-whisker plots of sediment features (Figure 2d) show that differences between sediment moisture in flood and dry periods of some lagunas (Figure 2a and b) are highly significant; however, this is not the case in the laguna shown in Figure 2c. The stability of sediment waterlogging in this laguna allows a well structured microphytobenthic community to resist the superficial desiccation of the laguna.

Description of the functional profiles for four classes of lagunas

Although the previous descriptions do not include all types of the Mancha Húmeda lagunas, they provide the basis for classifying a few functional profiles in terms of the descriptors previously selected (Table 2). Four main groups of lagunas may be distinguished, three of them being relatively well-conserved. The fourth type consists of eutrophic systems that receive wastewater inputs; all of these, with the exception of the Laguna Larga, are Ramsar sites and targets for restoration. It is noteworthy that eutrophic lagunas have a higher NO_2^- concentration, together with a higher water level and lower salinity. Nitrate concentrations are not markedly different between eutrophic and unenriched lagunas, but the highest concentrations of PO_4^{3-} and consistently high concentrations of chlorophyll-a were recorded in the

Table 2. Range of key descriptors of different functional types of the Mancha Húmeda lagunas

Laguna	L_{NS} (km)	S:Z_{max}	Z_{max} (cm)	Salinity (g L^{-1})	PO_4^{3-} (mg L^{-1})	NO_3^- (mg L^{-1})	NO_2^- (mg L^{-1})	Chlorophyll-a (mg L^{-1})	Hydroperiod, sediment type and dominant primary producers
Masegar	—	—	59	3–15	0.01–0.04	0.18–1.4	0.01	0.84–2.7	Inter-annual, high-magnitude flood and dry periods (Masegar is dammed). Sandy sediments. *Ruppia drepanensis*, except in Masegar and Dehesilla, with *Chara* spp. and *Lamprothamnium papulosum*, respectively. Masegar also with *Cladium mariscus* and *Phragmites australis*, Altillo I also with *Althenia orientalis*. Eventually, macrophytes are replaced by phytoplankton during short flooding periods.
Altillo II	4.5	1.2	15	4	0.00	4.7	0.06	2.29	
Albardiosa	2.9	3.2	80	5–147	0.00–1.2	0.00–0.39	0.00–0.09	0.56–57	
Pajares	7.7	1.0	7	11–39	0.24–0.89	0.28–1.2	0.11–0.13	1.2–4.5	
Dehesilla	4.2	0.7	40	27–45	2.4	0.31–3.4	0.21	4.2–10	
Salobral	3.7	0.3	30	30–314	0.02–0.41	0.05–0.43	—	1.8–80	
Sánchez-Gómez	4.5	1.6	40	35–95	3	1.7	0.34	9.4	
Altillo 1	5.1	1.4	4	45	0.24	0.24	0.13	9.7	
Salicor	10	1.7	63	66–440	0.00–5.0	0.00–4.6	0.00–0.69	0.46–131	
Alcahozo	4.7	1.0	18	68–460	0.04–1.8	0.01–8.7	0.00–0.21	0.92–19	Irregular alternation of short periods of flooding and desiccation. Sandy sediments rich in organic matter. Microbial mats characterized by *Microcoleus chtonoplastes*.
Mermejuela	5.1	0.2	14	39–427	0.00–2.1	6.7–9.0	0.00–0.37	7.2–18	Irregular alternation of short periods of flooding and desiccation. Clay sediments. Only phytoplankton is present, typically *Dunaliella* spp.
Tirez	4.0	2.4	20	163–231	4.4–19	0.62–1.4	0.08–0.49	11	
Grande de Quero	4.0	1.9	8	217	7.9	—	0.53	3.7	
Peña Hueca	2.1	5.0	20	86–460	0.00–8.4	0.00–1.3	0.00–0.41	2.5–228	
El Pueblo	6.9	0.8	50	6–14	0.02	0.36	0.21	1.7–14	Main water inputs are relatively constant flows of wastewater throughout the year. Organic sediments up to 40 cm deep, accumulated during years. Hardly any macrophytes, phytoplankton typical of wastewater.
Manjavacas	5.2	3.6	60	11–12	0.02–31	0.00–0.14	0.26–0.61	58–21	
Camino Villafranca	4.6	4.6	40	18–29	—	—	—	72	
Larga Villacañas	2.4	2.1	80	46	5.2	—	—	99	
Yeguas	2.2	3.2	11	41–119	35.7	1.3	0.77	85	

L_{NS}, distance to the nearest stream; S:Z_{max}, ratio between the surface area divided by the maximum water level; Z_{max}, maximum water level.

eutrophic lagunas. There does not appear to be any particular difference between the Laguna Larga and the other eutrophic but restored lagunas in terms of PO_4^{3-} and chlorophyll-a concentrations.

The functional groups of non-eutrophic lagunas are characterized by the complex interaction of several factors, adding to the other differences in hydrology, sediment features, and dominant primary producers (Table 2). Alcahozo, the unique laguna dominated by the microphytobenthos, is very shallow and has relatively low concentrations both of nutrients and chlorophyll-a, and intermediate to high salinity. Lagunas dominated by macrophytes experience wide fluctuations in the concentration of phytoplanktonic chlorophyll-a and salinity, and have relatively high water levels. Finally, phytoplankton-dominated habitats have low water levels, high to very high salinities, and wide fluctuations in the concentration of chlorophyll-a.

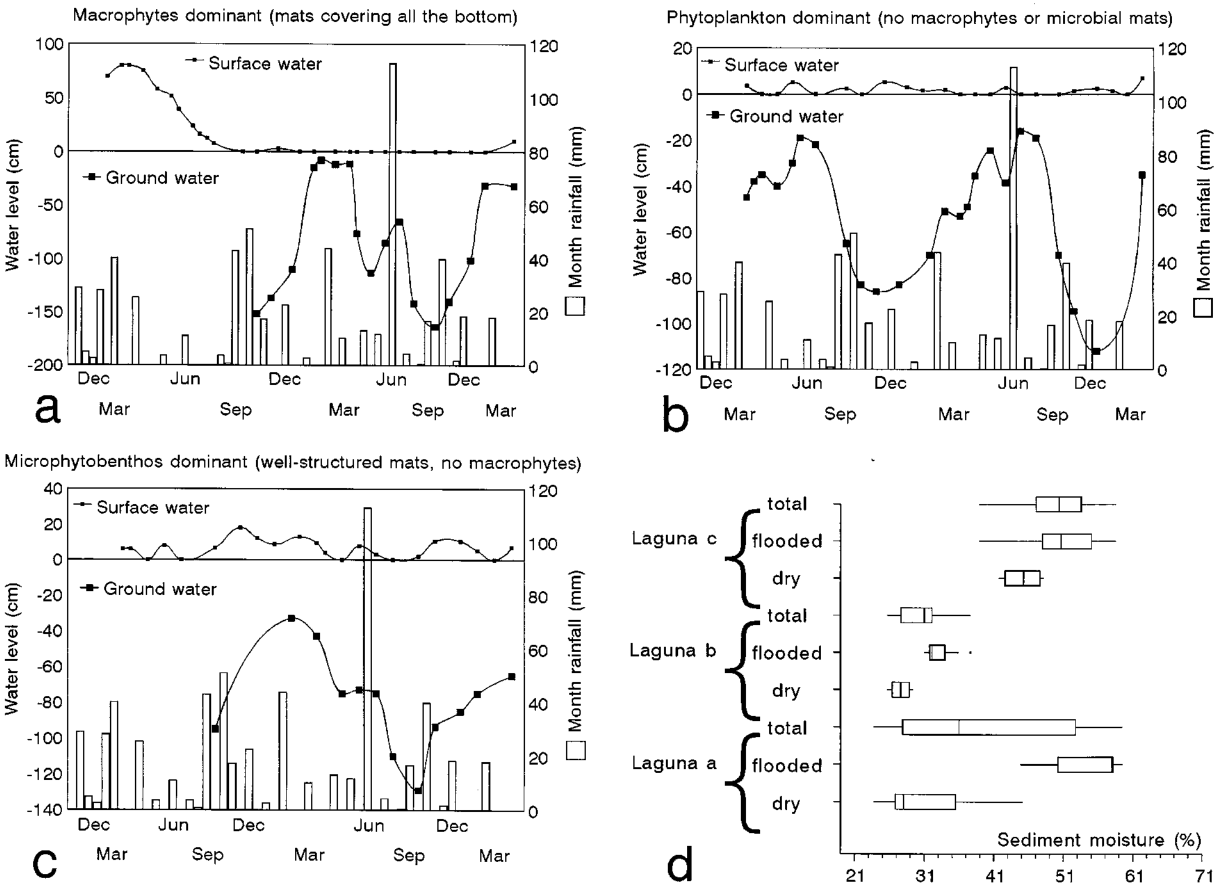

Figure 2. Variation of hydrological descriptors between December 1990 and March 1993 in three lagunas with different dominant types of primary producer: a) Albardiosa, characterized by submerged macrophytes; b) Peña Hueca, characterized by phytoplankton; and c) Alcahozo, characterized by microbenthos; d) shows their sediment features both in dry and flooded periods (number of sampling visits, 22; three replicates per site and per sampling visit). These lagunas represent three of the functional profiles described in Table 2 (i.e. the non-eutrophic lagunas).

DISCUSSION

Implications of functional analysis for restoration

The Mancha Húmeda lagunas are small, shallow systems with a strongly fluctuating water level (Figure 1). This explains the wide variability in the concentration of chlorophyll-a and (in some cases) nutrients (Table 2). In effect, the alternation of flooding and desiccation exposes ecological communities to an intense recycling of nutrients and organic matter.

Within the overall definition of Mediterranean lagunas, there is an important variability that results in the existence of quite different trophic patterns, but also high conservation values (Table 1). Waterfowl and other vertebrates—indeed animals in general and even higher plants—are absent from some of the most unusual functional profiles that were found among the Mancha Húmeda lagunas. Therefore, site restoration should be planned more on the basis of constant features throughout the different functional types. The dominant group of primary producer is the most appropriate for this purpose, since each one builds specific trophic patterns that should be assessed at the same level of priority.

These general principles can best be applied to restoration by using well-defined protocols, particularly with reference to the controlling variables that define key relationships between hydrogeomorphological classes and functions of lagunas, e.g. the water retention capacity of lakes and the occurrence and quality of water inputs. These were assessed in Mancha Húmeda using lake descriptors such as the ratio of surface area divided by the maximum water level, the proximity of main watercourses and the sediment water content. Their integrated analysis seems to serve well to distinguish between the functional profiles of natural lagunas described in Table 2, but also between natural and eutrophic systems. Therefore, these variables may be used as predictors of the functional integrity of lagunas. Florín *et al.* (1993) consistently found abnormal relationships between the values of the two former descriptors and the expected hydrological regime for impacted sites, both when the sites were drier and wetter than predicted.

Once laguna types and restoration priorities are fixed, functional profiles, such as those described in Table 2, may serve to identify ecological targets for restoration. These profiles show the specific correspondences between ecological functions and ranges of the predictors mentioned above, and also show links with the timing, frequency, duration, intensity and long-term pattern of hydrological fluctuations (Figure 2). These profiles should not be taken as being definitive for two reasons: i) many episodically flooded and strongly impacted lagunas on which information is still lacking are not likely to be represented; and ii) the functional predictors proposed should first be calibrated against independent sets of representative reference sites for each profile (Brinson *et al.*, 1994). Filling these gaps in knowledge is a question of time, rather than an unsuitability of the approach proposed.

The application of the above guidelines may be extended beyond the scope of the Mancha Húmeda district. The broad validity of the approach is supported by the theoretical formulations of Margalef (1987) concerning the connections between hydrogeomorphological features and the functions of primary producers in systems characterized by a fluctuating water-level. These are typical of Mediterranean and semi-arid regions, where water shortage is common (Williams and Aladin, 1991; Williams, 1993a). Frequently, these wetlands or lakes are also threatened by hydrological impacts, but they still maintain their high conservation value (Williams, 1993b).

Review of the Mancha Húmeda restoration projects in the light of functional analysis criteria

'Restoration' projects developed thus far in the study area have not been based on a reliable classification and the subsequent setting of priorities for action. The most outstanding result of this is the absolute neglect, for restoration purposes, of the most threatened lagunas of Mancha Húmeda, i.e. those of its northern part (Figure 1) (Florín *et al.*, 1993). Any criteria of international importance (Table 1) are also disregarded. Four of the most conspicuous projects described by Molina (1990) involve Ramsar sites which receive wastewater inputs. However, there is no evidence of action aimed at protecting or enhancing Ramsar values. Special attention will be paid here to these projects, because they are a responsibility of the regional environmental authority of Mancha Húmeda.

In all cases, the projects developed tend to increase water levels and to smooth the hydrological fluctuations that are natural in Mediterranean wetlands. Molina (1990) absurdly describes the maintenance of water during summer as proof of success of a 12-hm^3 trans-catchment import of water to the National Park of Daimiel in 1988. This sort of attitude is sometimes even more harmful, for example when the local authorities decided to restore the Salobral laguna. In 1992, solid urban waste discharges were accumulated in its margins to deepen the natural basin, and an encircling channel was excavated to direct subsurface run-off towards the laguna. Two other lagunas have been artificially filled with water from wells for bathing purposes.

In some cases, restoration action had a regional impact. Hydrological restoration of the Daimiel National Park (Sánchez, 1995) included the 'cleaning' (channelization) of the Cigüela river upstream of the Daimiel wetland, just where the river crosses one of the western wetland sectors (Figure 1). This included ditching, deepening and straightening 25–80 km of the river course. It meant breaking the hydrological exchange between the river and its marginal wetlands, and also between the river and the regional water cycle. The action was aimed at ensuring that all river discharge reached the Daimiel wetland, instead of being partially lost in the Cigüela floodplains. Channelization as a restoration measure? Not even for the Daimiel wetland, because after deepening the river channel, its bed coincided with a layer of more porous substrata, resulting in a higher infiltration of water along its course.

In general, restoration activities include the excavation of lagunas and the transport of sediments from one to another side of their basins in order to construct islands, ponds and beaches that favour the presence of waterfowl (Molina, 1990). This may be acceptable in artificial ecosystems, such as the abundant gravel pits of the neighbouring Tagus catchment (Escribano *et al.*, 1995). Nevertheless, it is the converse of true restoration if carried out in natural lakes, especially if they have conservation values such as those shown in Table 1. Sediment functions are seriously threatened by its removal, dramatically affecting the water retention capacity of laguna basins. Biogeochemical processes are disturbed, sediment organic matter is remobilized and eutrophication may be enhanced. Microbial mat communities depend upon the steadying influence of sediments against hydrological fluctuations (Figure 2c and d). Sediments shelter spores, seeds, eggs or drought-resistant forms of a number of species and communities of high conservation value (e.g. Characeae algae, the aquatic herbs *Althenia* and *Ruppia*, and zooplanktonic forms of the *Arctodiaptometum* community). Damaging the sediment structure has impacts at different time scales: i) in the short-term on the food webs involving the above processes and biota; and ii) in the longer-term on related succession paths and on the function of sediments as biodiversity reservoirs against hydrological fluctuations.

The restoration projects described by Molina (1990) also failed to take into account water quality. The fact that the restored sites are polluted seems to be incidental, because no action was taken to stop wastewater inflows. In the Daimiel National Park, the dilution of indirect wastewater inputs with supplementary water inputs has been mentioned as a proof of success of the plan for its hydrological regeneration because 'undetectable pollution indexes' were reached (Molina, 1990). It is not even true that these projects serve to favour waterfowl populations. Recycling of organic matter is lower in lagunas that are managed to maintain a constant water level. Thus, organic matter tends to accumulate and, what is more, these systems tend towards dystrophy if they also receive wastewater inputs. This is probably an abundant source of food for numerous waterfowl, mainly *Anas platyrhyncos* and *Fulica atra*. Under these conditions, pathogenic bacteria are also likely to be favoured, according to the frequent summer epidemics (mainly botulism) that affect waterfowl in the restored sites (Molina, 1990).

Finally, consideration of living organisms other than waterfowl are generally absent from the restoration projects developed in Mancha Húmeda. When vegetation is considered, it is because 'flora may satisfy the ecological needs of aquatic fauna' (Molina, 1990, p. 335). This author states that waterfowl habitat may be improved by delaying ecological succession by: i) the partial clearing of dense vegetation; and ii) controlled burning of vegetation in the wetland bed and its margins. These practices are traditionally used in the wetland hunting sites of the region.

CONCLUDING REMARKS

Recent approaches to the functional assessment of wetlands have been successfully applied here to provide guidelines for restoring Mediterranean lagunas. It is proposed that different models be used to assess the functions of sites dominated by different groups of primary producers (microbenthos, plankton and macrophytes). Functional profiles are defined using predictors that can be extensively measured in a regional context. Major controlling variables for all functional profiles are the water retention capacity of lake basins, the occurrence and quality of large water sources, the temporal features of hydroperiod and the steadying influence of sediments. In the same way that natural profiles may be used to define restoration targets, their predictors can serve as a restoration tool.

The assessment was carried out using information that is easy to measure or available from the literature. The only requisite was to focus the analysis on the functioning of laguna ecosystems, rather than on isolated species or communities. This was the failure of previous restoration experiences in Mancha Húmeda, resulting in lessening or threatening various functions of the affected sites (e.g. biodiversity maintenance, food-web and habitat support, both hydrological and biogeochemical).

If special care is taken with the inclusion in the classification of the relevant types at the relevant scale, and in defining the relationships between the hydrogeomorphological features that defined these types and the functions of lagunas, then the setting of restoration targets will become much more objective than the zootechnical-based activities carried out until now. No controversy between aquatic ecologists and wildfowl biologists is intended. If the natural functions of a diversity of lagunas are restored, birds will certainly be conserved at the proper sites, but so also will remaining conservation values that justify the international acknowledgement of the Mancha Húmeda wetlands.

Information gaps should be identified and filled in the short- or long-term. Meanwhile, using available information from functional assessment procedures is an open approach that has the potential to be improved with time, and it avoids the disadvantage of taking decisions based on subjective criteria. Further research is needed on the functioning of the less-saline wetlands and lagunas, perhaps less interesting from the scientific point of view, but much more threatened. This includes the investigation of the relationships between hydrogeomorphological features of lagunas and new functions not identified before, and also the definition of the corresponding functional profiles. Clarifying the trophic and geographical relationships between waterfowl and primary producers will surely provide a number of additional guidelines for restoring Mediterranean wetlands. Last, but not least, it is desirable that zootechnical engineering creates wetlands in areas where they have been lost completely, rather than interfering with the functioning of systems which can be restored to their former states (P. Evans, Durham University, personal communication).

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