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Artificial ponds in a Mediterranean region (Andalusia, southern Spain): agricultural and environmental issues

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abundance and distribution; Andalusia; artificial ponds; construction typology; naturalisation stage; water quality.

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Abstract

A total of 16 543 artificial ponds were inventoried. Ninety-one per cent of the ponds were classified as for farming use. Generally, the fraction of farm land converted to pond structures was close to that predicted from the average annual precipitation in the region. However, in several areas, this fraction was remarkably higher than the value predicted, probably due to excessive groundwater extraction. Overall, the naturalisation stage of ponds was poor. However, ponds sited on natural substrate basins had more structured-marginal vegetation, compared with ponds of artificial substrate basins. Furthermore, other factors related to pond management might seriously limit their naturalisation stage. Despite the high abundance of ponds in Andalusia, our results suggest that, in order to improve the potential for biodiversity conservation in these environments, substantial structural and management changes are required.

Introduction

Ponds, particularly artificial ones, are a growing uninventoried resource that has been underestimated in macroecological studies (Downing *et al*. 2006). Research into European pond ecology and conservation has increased markedly over the last two decades, demonstrating their relevance for biodiversity conservation at the landscape scale (e.g. Boavida 1999; Oertli *et al*. 2005; Cereghino *et al*. 2008).

There is satisfactory knowledge of natural ponds on the Iberian Peninsula, which has occasionally helped to promote their protection (e.g. Alonso 1998; Fernández-Aláez *et al*. 2006; Quintana *et al*. 2006; Serrano *et al*. 2006). However, severe wetland loss – in excess of 50% – and degradation has been reported over the last century for the Iberian Peninsula and other European regions (Commission of the European Community 1995). In Mediterranean regions, wetland loss and impairment have occurred mainly due to the expansion of irrigated agriculture, giving rise to the construction of thousands of artificial ponds (Bonachela *et al*. 2007). However, studies on the potential for biodiversity conservation of these ponds are scarce (e.g. Sánchez-Zapata *et al*. 2005).

During the second half of the last century, the irrigated area in Spain doubled due to higher crop productivity and the strong financial support by successive governments (MAPA 2007). This expansion has been particularly marked in regions primarily devoted to agriculture, like Andalusia (Consejería de Agricultura y Pesca 1999). In this paper, we present an inventory and characterisation of artificial ponds in Andalusia. We discuss the agricultural factors determining the abundance, distribution and other traits of ponds that might limit the potential environmental functions of these water bodies, by determining the naturalisation stage as biophysically diverse aquatic ecosystems (Rhoads *et al*. 1999).

Study area

Andalusia (Spain) is a region of 87 597 km^2, located in the southernmost part of continental Europe (between parallels 36°N and 38°44′N) (Fig. 1a). The region is geologically diverse and can be roughly divided into two main areas separated by the Guadalquivir River axis: the north-western part dominated by acidic rocks, of the Sierra Morena mountain ranges, and the south-eastern part by calcareous-dolomitic rocks of the Betic ranges. In this second area, several high mountain zones – of over 2000 m a.s.l. – are dominated by schist, and valleys settled on recent marine deposits rich in highly soluble salts

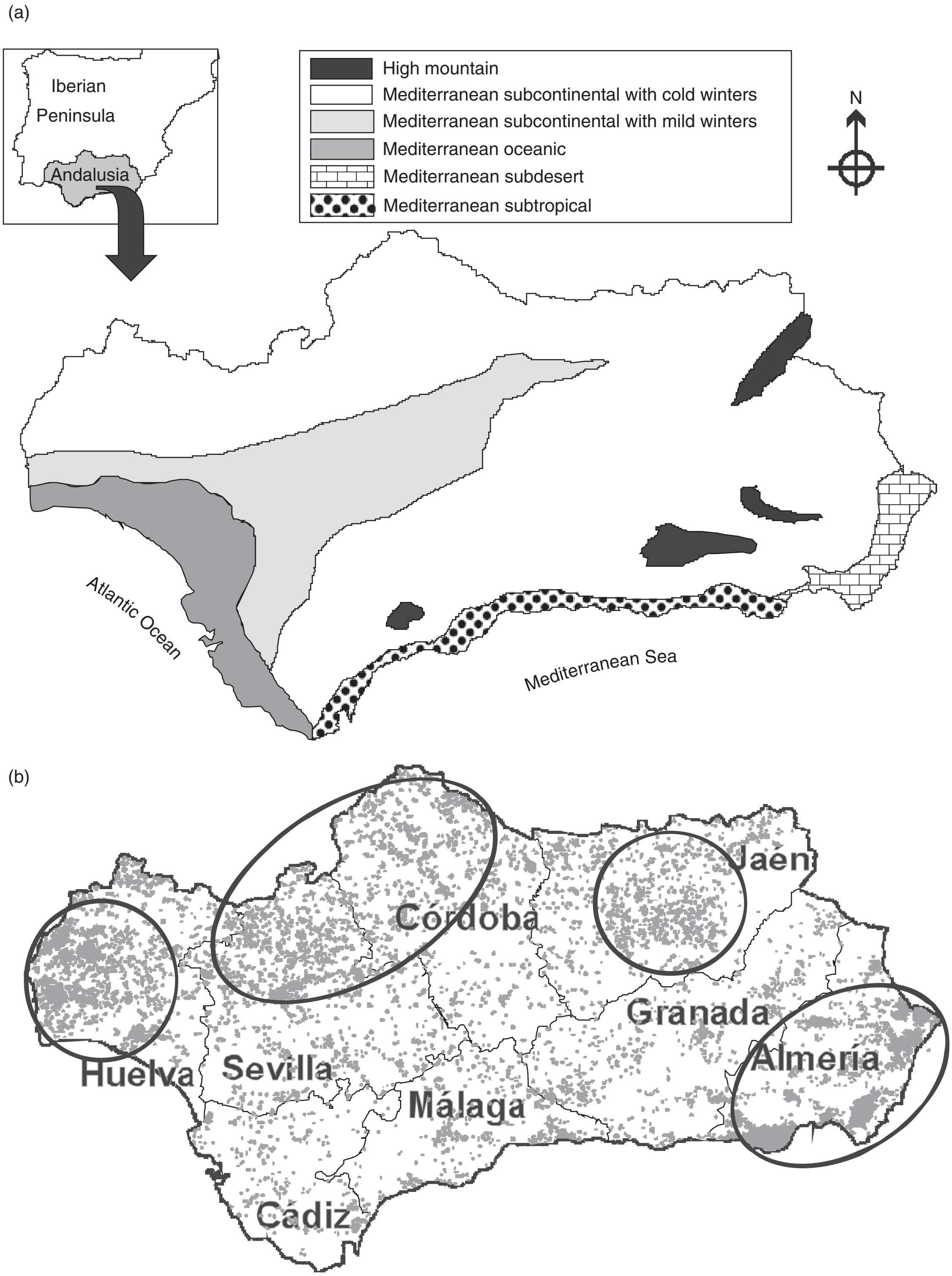

Fig. 1. (a) Geographical location and the main climatic areas of Andalusia. (b) Geographical distribution of the inventoried ponds (grey points). The boundaries and the name of the administrative provinces are shown. Four areas with a high pond concentration are highlighted.

(marls) are frequent. The climate is Mediterranean, with an average rainfall ranging from 600 mm in the western part to 200 mm in the south-eastern part. However, the geographical location and the high relief heterogeneity of this region account for an outstanding climatic diversity (Fig. 1a).

Methods

Multispectral images (Landsat^{TM}:2003, USGS, Sioux Falls, SD, USA) were used to detect artificial water bodies, excluding large dams. After this initial screening, ponds were characterised using ortho-image interpretation (B/W 1 : 20 000; years 2001–2002). This study focused on ponds of over 700 m^2, with the exception of the greenhouse areas, where ponds of over 150 m^2 were also characterised, due to their extraordinary abundance. The characteristics studied using ortho-images were as follows: pond surface area, construction type – artificial if ponds had a regular shape or natural-looking if they appeared irregular and connected to the surrounding drainage network, presence of marginal vegetation (MV) and pond use as deduced from the surrounding main land use. Thereafter, field trips were carried out to inspect pond appearance and accessibility, to select a final group to monitor the physical, chemical and biological characteristics. Several criteria were used to select representative ponds for this survey: geographical location, lithological and climatic conditions, pond surface area, construction type, naturalisation stage and pond use. These criteria were used during spring 2007 to select and sample 157 ponds for structural evaluation, 90 of which were also for water characterisation.

Water samples were taken integrating a depth profile of two central and two littoral locations, using a 3-m-long tube sampler (Knoechel & Campbell 1992). Electric conductivity and pH were measured using field probes. Subsamples were filtered (Whatman GF/C, GE Whatman, Maidstone, Kent, UK) to measure planktonic chlorophyll *a* and suspended solids, using spectrophotometric and gravimetric methods, respectively. A 1 L subsample of water was analysed in the laboratory within 36 h for total dissolved solids, total organic carbon (TOC), alkalinity, sulphate, chloride, calcium, magnesium, sodium, potassium, nitrate, nitrite, ammonia, total phosphorus and phosphate (American Public Health Association 1992). Results were analysed using principal component analysis (PCA), an ordination technique that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. All variables, except pH, were log (x+0.001) transformed to meet normalisation criteria. The software PRIMER.5 was used to perform PCA.

Structural characterisation and naturalisation stage included construction type and the following morphological and vegetation measurements. Maximum depth was measured using a string marked in centimetres, in the central point in bowl-shaped and cube-shaped ponds, and near the dam in embankment ponds. The average marginal slope was measured in six randomly selected points using a clinometer. The average belt width and % of pond perimeter covered by woody species and emergent macrophytes of the MV were measured using optical distance metres. Percentage cover of submerged aquatic vegetation (SAV) was determined along two randomly selected transects – three transects in pond over 1000 m^2 – from the shore to the centre. Taxa composition of MV was determined by careful inspection of the whole pond perimeter, and that of SAV was determined by four randomly selected samples in ponds of area $<1000\ m^2$, and six for ponds $>1000\ m^2$. The Mann–Whitney *U*-test, for an unequal sample size, was used to determine the statistical significance of differences for these variables among pond groups defined by construction type. Pond use, management and water source were determined by landowner interviewing and/or by inspecting the surroundings.

Results

Inventory and characterisation of ponds based on satellite and aerial imagery

A total of 16 543 artificial ponds over 150 m^2 in size were inventoried (Fig. 1b; Table 1). Generally, most ponds were classified as for irrigation use (60%), livestock farming (25%) or both (6%). Industry (6%) and mining (3%) represented minor uses (Table 2). Pond use and density showed notable geographical variability. Four main areas (Fig. 1b) can be pointed out for their high concentration of ponds: (1) the semiarid littoral area of Almería, dedicated to greenhouse horticultural crops – over 250 km^2 – harbours about half of the ponds inventoried, showing an extraordinary concentration of small artificial ponds (Table 2). (2) The western and southern parts of Huelva, dominated by strawberry and citric crops, are growing irrigated areas expected to reach 700 km^2 of irrigated crops in the near future. (3) In the north of Huelva, Cordoba and Seville, in the Sierra Morena mountains, many natural-looking embankment ponds are dedicated to livestock farming in dehesas, traditional agro-sylvo-pastoral systems. The central and southern parts of Cordoba and Seville are dominated by irrigated herbaceous, citrus and olive crops, where ponds tend to be less naturalised (Table 2). The largest mean surface area per pond was found in these two provinces. (4) The core activity of the province of Jaen is olive production, mostly irrigated from artificial ponds (Table 2). The relatively

Table 1 Geographical distribution (provinces) and area of the ponds inventoried using aerial imagery

Province	Number of ponds $> 150\,m^2$	$> 700\,m^2$	Total pond area (km^2)	Average pond area ($\times 10^{-2}\,km^2$)	Actual pond area as % of total farm land	Predicted pond area as % of total farm land
Almería	8730	1714	6.17	0.07	0.21	0.04
Cadiz	587	325	3.98	0.68	0.09	0.15
Cordoba	1057	1057	8.05	0.76	0.09	0.13
Granada	930	930	2.54	0.27	0.03	0.07
Huelva	1952	1952	10.54	0.54	0.34	0.11
Jaen	1256	1256	7.83	0.62	0.09	0.13
Malaga	640	413	2.01	0.31	0.06	0.13
Seville	1391	1391	16.32	1.17	0.16	0.13
Total	16 543	9038	57.44	0.35	0.12	0.10

The actual proportion of farmland converted to ponds and the prediction based on annual average precipitation are shown. The regression equation used for predictions is in Downing *et al*. (2006).

Table 2 Percentages, per province, of pond types deduced from orthoimages

	Type of use						Type of basin		Presence
Province	IR	IR+LS	LS	IN	MI	OT	ART	NAT	of MV
Almería	100	<1	<1	<1	<1	<1	100	<1	<1
Cadiz	68	9	9	3	3	8	69	31	16
Cordoba	22	11	51	13	3	<1	29	71	13
Granada	90	2	2	5	1	<1	97	3	5
Huelva	25	9	64	<1	2	<1	21	79	9
Jaen	57	4	19	18	2	<1	74	26	4
Malaga	76	2	1	11	1	9	91	9	6
Seville	61	12	20	3	4	<1	46	54	8
Total	60	6	25	6	3	<1	62	38	8

IR, irrigation; IR+LS, irrigation plus livestock; LS, livestock; IN, industry; MI, mining; OT, other uses or unrecognizable use; ART, artificial; NAT, natural; MV, marginal vegetation.

Table 3 Distribution, per province, of the 157 ponds studied in situ, grouped by construction type and water source

	Number of ponds	Type of construction				Source of water			
Province	studied	EMB	EXC	PET	CON	NDW	CSW	CGW	RWW
Almería	72	0	0	33	39	0	15	47	10
Cadiz	10	5	5	0	0	7	0	3	0
Cordoba	14	10	4	0	0	11	1	2	0
Granada	14	0	4	2	8	2	6	5	1
Huelva	12	8	1	3	0	8	1	3	0
Jaen	9	3	0	6	0	3	6	0	0
Malaga	9	2	2	4	1	3	2	4	0
Seville	17	13	3	0	1	15	2	0	0
Total	157	41	19	48	49	49	33	64	11

EMB, embankment; EXC, excavated; PET, polyethylene-lined; CON, concrete ponds; NDW, natural drainage; CSW, channelled surface water; CGW, channelled groundwater; RWW, recycled wastewaters.

high percentage of ponds of industrial use in Jaen and Cordoba (Table 2) might be related to the olive oil industry wastewater treatment plants.

Overall, 38% of ponds were classified as sited in a natural basin – embankments in streams or excavated ponds in natural depressions – however, MV was only detected in 8% of the inventoried ponds (Table 2).

Characterisation based on a field survey

Sources and quality of water

The water sources for ponds were diverse: surface, groundwater, a combination of both and recycled wastewater (Table 3). The first three axes extracted by PCA explained <65% of the total variance of the data matrix (Table 4). The unexplained variance (37%) might be attributed to the diversity and combinations of water sources and to factors related to pond management that may add noise to the correlations between the variables included in the PCA.

The main pattern of variability was water mineralisation (PC1, Table 4 and Fig. 2), showing a wide range of salinity and ionic composition. Most ponds located in mountain areas received naturally drained water (NDW) of relatively low mineralisation, ranging between 0.07 and 1.5 g/L, and with a predominance of CO_3^{2+}. In lowland areas, water was more mineralised, particularly in valleys draining recent marine sediments (up to 4.5 g/L), with ionic composition dominated by SO_4^{2+} or Cl^-. Here, a combination of different water sources occurs. Apart from NDW, ponds may receive channelled waters from nearby rivers [channelled surface water (CSW)] and/or groundwater [channelled groundwater (CGW)] (Table 3). In the greenhouse areas of Almería, groundwater is the main source – with salinity values of up to 3 g/L – due to the scarcity of superficial water (Table 3). The high water demand in this area determines increasing recycled wastewater reclamation (RWW) (Table 3) and rainwater run-off collection from greenhouse covers. In fact, 32% of the studied ponds collected rainwater.

The second principal component of variability was associated with phytoplankton biomass, which owed its significant positive correlation to chlorophyll *a* and TOC (Table 4, Fig. 2). The most oligotrophic ponds (lower part of the biplot, Fig. 2) were located in Sierra Morena. The most eutrophic ponds (upper part of the biplot, Fig. 2) were those fed by RWW or CSW from organically polluted rivers. Phosphate and total phosphorous were not significantly associated with this second PC, but were associated with the third one (Table 4).

Table 4 Percentage of variance explained by the main three components extracted using PCA of the water characteristics of 90 ponds

	PC1	PC2	PC3
% variance explained	36.4	15.4	11.7
Variable			
pH	0.005	0.265	0.044
Alkalinity	0.118	0.040	0.034
Chloride	**0.364**	0.093	– 0.008
Sulphate	**0.341**	– 0.159	0.008
Calcium	**0.358**	– 0.131	0.103
Magnesium	**0.353**	– 0.124	0.103
Sodium	**0.353**	0.114	0.017
Potassium	0.277	**0.365**	– 0.075
Conductivity	**0.379**	0.030	0.007
Total dissolved solids	**0.306**	– 0.028	0.092
Ammonia	0.074	0.227	– 0.291
Nitrate	0.145	– 0.293	0.027
Nitrite	– 0.015	0.074	**0.420**
Phosphate	– 0.075	0.120	**0.569**
Total phosphorus	– 0.078	0.080	**0.605**
Total organic carbon	0.063	**0.543**	– 0.047
Chlorophyll *a*	– 0.062	**0.505**	0.011

Correlations of variables with each component are given. Significant ($P<0.05$) correlations are in bold.
PCA, principal component analysis.

Construction type, management and naturalisation stage

Ponds can be roughly classified into four main construction types (Table 3): embankment ponds (EMB) – dams in streams – and excavated ponds in natural depressions (EXC). Both types contain natural substrate and NDW (Table 3), although occasionally, they may receive CSW or CGW (Table 3). Two types of completely artificial ponds were differentiated: polyethylene-lined (PET) and concrete (CON) ponds (Table 3). These types generally exhibited poor substrate naturalisation. However, 33% of the PET ponds had a gravel layer, added to protect the low-density polyethylene.

The marginal slope angle of the four types was significantly different ($P<0.001$). EMB ponds had the lowest and CON ponds had the highest slope angle (Fig. 3). Maximum pond depth was not significantly different (all P values >0.1) among EMB, EXC and PET types, but CON ponds were by far the shallowest (all P values <0.001) (Fig. 3). Overall, less than 2% of ponds exceeded 10 m in depth and 83% were less than 7 m deep.

Both natural substrate and lower slope angle in EMB and EXC, as opposed to PET and CON ponds, probably determined the significantly ($P<0.001$) higher

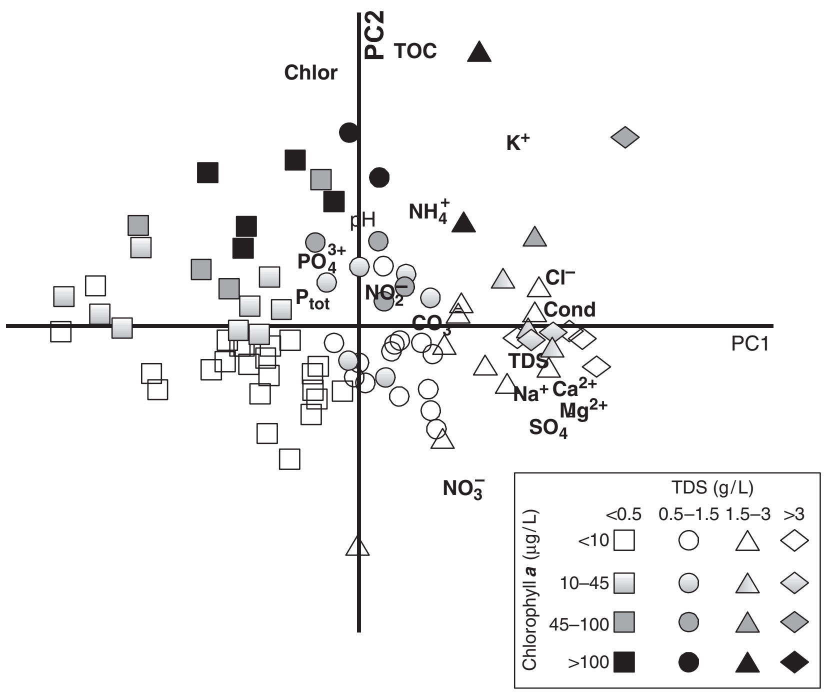

Fig. 2. PC1 and PC2 biplot, samples and water variables, of the 90 ponds analyses using PCA. Ponds are classified into four salinity (TDS) (symbols) and four chlorophyll *a* ranges (grey scale).

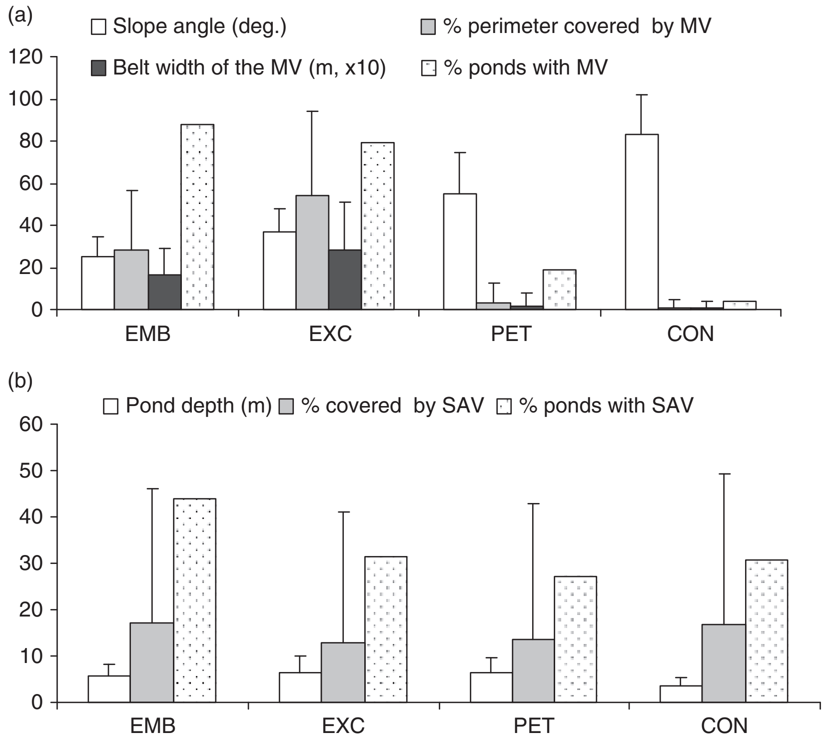

Fig. 3. Mean ± 1 SD marginal physical characteristic and vegetation (MV) (upper plot), maximum depth and % cover of submerged aquatic vegetation (SAV) (lower plot), for each construction type: EMB, embankment; EXC, excavated; PET, polyethylene lined; CON, concrete ponds. The percentage of ponds with MV and SAV in each type is also shown.

development of MV in the two former types (Fig. 3). Furthermore, average taxa richness per pond of MV was significantly higher ($P<0.01$) in the less artificial pond types, EMB and EXC, compared with PET and CON ponds, where just a few taxa were able to colonise the margins of a low number of ponds (Table 5). EMB and EXC ponds showed a more structured MV, frequently made up of emergent macrophytes, shrubs and phreatophyte tree species (Table 5). In EMB and EXC ponds, the native *Tamarix* spp. and *Typha* spp. were the most frequent taxa, but the exotic *Arundo donax* and *Eucaliptus* spp. were also relatively frequent. Those PET ponds with MV were colonised by *Phragmites australis* and/or *Tamarix* spp., and had the plastic material covered with gravel. There was a virtual absence of MV in PET ponds without added gravel and CON ponds (Table 5).

SAV developed in < 30% of ponds (43% in EMB) and average cover was less than 20% in the four groups (all P values <0.1), although the intragroup variability was high (Fig. 3). As for MV, differences between the most and the least natural-looking pond groups were clear-cut, because EMB and EXC types showed significantly higher ($P<0.01$) average species richness per pond compared with the PET and CON types (Table 5). Overall, the most frequent SAV species were *Potamogeton pectinatus* and *Chara vulgaris* (Table 5).

Pond owners mentioned two main techniques for pond management, mainly to control unwanted or excessive SAV growth: chemical treatment and mechanical removal of plants and/or sediments. Neither EMB nor EXC ponds were treated with biocides, and were seldom mechanically devoid of submerged plants. However, 65% of PET and CON ponds were treated with copper sulphate (50%) or other biocides (15%). The average dose of copper added to these ponds was approximately 5 ppm, with the average frequency varying between eight times per year in CON and five times per year in PET ponds. Eighty percent of CON, as opposed to 30% of PET ponds, were subjected to mechanical removal of plants and sediments, usually by desiccation. The frequency of this mechanical control varied widely, but on average, was around every 4 years for both pond types.

Discussion

Factors determining pond abundance, distribution and size

Most ponds were related to irrigation and/or livestock farming as these activities account for 80% of human water use and nearly 10 000 km^2 are dedicated to irrigated agriculture in Andalusia (Sánchez-Picón 2002).

The irrigated area increased in this region by a factor of 2.3, over 3000 km^2, from 1956 to 2003 (http://www.juntadeandalucia.es/medioambiente). This expansion undoubtedly determined a huge increase of ponds over

Table 5 Taxa composition, taxa richness and average number of taxa per pond of marginal vegetation (MV) and submerged aquatic vegetation (SAV) in the four pond types differentiated with regard to construction characteristics

	Pond type			
	EMB	EXC	PET	CON
Taxa of MV				
Arundo donax	9.76	21.05	0.00	0.00
Ceratonia siliqua	0.00	5.26	0.00	0.00
Cistus ladanifer	12.20	0.00	0.00	0.00
Cyperus sp.	2.44	0.00	0.00	0.00
Erica sp.	2.44	0.00	0.00	0.00
Eucaliptus spp.	24.39	15.53	0.00	0.00
Genista sp.	2.44	0.00	0.00	0.00
Juncus spp.	39.02	5.26	0.00	0.00
Mentha sp.	2.44	0.00	0.00	0.00
Nerium oleander	26.83	0.00	0.00	0.00
Olea europaea var. *sylvestris*	4.88	0.00	0.00	0.00
Phragmites australis	7.32	31.58	10.42	0.00
Pinus spp.	4.88	0.00	0.00	0.00
Pistacia lentiscus	4.88	5.26	0.00	0.00
Populus alba	4.88	15.79	0.00	0.00
Quercus ilex	9.76	5.26	0.00	0.00
Retama sphaerocarpa	2.44	0.00	0.00	0.00
Rhamnus alaternus	0.00	5.26	0.00	0.00
Rosmarinus officinalis	2.44	0.00	0.00	0.00
Rubus spp.	7.32	5.26	0.00	0.00
Salix sp1	2.44	5.26	0.00	0.00
Salix sp2	0.00	5.26	0.00	0.00
Scirpus holoschaenus	19.51	0.00	0.00	0.00
Scirpus sp1	17.07	0.00	0.00	0.00
Scirpus sp2	2.07	0.00	0.00	0.00
Tamarix spp.	39.02	57.89	2.08	0.00
Typha spp.	24.39	36.84	4.17	2.04
Ulex sp.	2.44	0.00	0.00	0.00
Total number of taxa	25	17	3	1
Margalef's richness index	6.46	5.43	0.52	0.00
Average number of taxa per pond	1.88	1.84	0.19	0.02
Taxa of SAV				
Callitriche sp.	9.76	0.00	0.00	0.00
Ceratophyllum demersum	4.88	0.00	0.00	0.00
Chara connivens	9.76	5.26	0.00	0.00
Chara fragifera	0.00	0.00	2.08	0.00
Chara fragilis	0.00	5.26	4.17	6.12
Chara hispida	0.00	0.00	4.17	2.04
Chara vulgaris	7.32	5.26	8.33	8.16
Myriophyllum alterniflorum	12.20	0.00	0.00	0.00
Myriophyllum spicatum	2.44	5.26	0.00	0.00
Najas marina	2.44	10.53	4.17	4.08
Potamogeton pectinatus	12.20	5.26	20.83	16.33
Potamogeton pusillus	2.44	5.26	2.08	0.00
Potamogeton trichoides	7.32	5.26	0.00	0.00
Ranunculus trichophyllus	9.76	0.00	0.00	0.00
Ranunculus tripartitus	2.44	0.00	0.00	0.00
Ruppia sp.	0.00	5.26	0.00	2.04
Zannichellia obtusifolia	2.44	0.00	0.00	0.00
Zannichellia pedunculata	2.44	0.00	0.00	0.00
Zannichellia peltata	0.00	5.26	0.00	0.00
Total number of taxa	14.00	10.00	7.00	6.00
Margalef's richness index	3.50	3.06	1.55	1.28
Average number of taxa per pond	0.95	0.58	0.48	0.39

For each taxon the % of ponds is shown where present. Pond types as in Table 3.

the last decades, because the new drip irrigation systems require more precision for water balancing and distribution as compared with the traditional ones. In fact, the provinces at present with the highest pond concentrations, or the highest total pond area, are those that have undergone the most notable transformation of land from different uses to irrigated crops (Consejería de Agricultura y Pesca 1999).

On the regional scale, the proportion of farmland dedicated to pond structures is close to that predicted from the average annual precipitation in the area (Table 1), using the regression model for several political units in diverse world regions obtained by Downing *et al.* (2006). This highlights the principal role of precipitation in determining farm pond abundance. However, the area of water impounded by ponds in the provinces of Almería and Huelva – 82 and 66%, respectively – is clearly above the value predicted from rainfall by the mentioned model (Table 1), which might be related to excessive ground-water extraction in these areas. In fact, the overexploitation of two important aquifers on the Huelva littoral has led to a decline in the piezometric level of around 6 m during the period 1978–1995 (http://www.igme.es/INTERNET/sistemas_infor/). In Almería, there are further examples of overexploited aquifers, associated with the high water demand for greenhouse horticulture. Intensive pumping has caused a drawdown of the water table by nearly 40 m over the last 30 years within the carbonate aquifer of Campo de Dalias. Sea-water intrusion, together with brine mobilisation caused by excessive pumping, has been detected in this and other aquifers in Almería (Sánchez-Martos *et al.* 1999; Martín-Rosales *et al.* 2008). According to Puigdefábregas & Mendizábal (1998), this situation is contributing to a widespread desertification syndrome in northern Mediterranean coastal areas, also common to other irrigated regions around the world (Pimentel *et al.* 2004): nonsustainability of the use of water resources due to overdraft and lack of internal mechanisms to limit its own growth.

The largest average area per pond was recorded in the farming productive systems of the Guadalquivir valley, possibly due to the relatively large size of the properties and/or pond pooling. Extensive irrigated herbaceous crops are predominant here, together with an ever larger surface area of irrigated olive groves. In fact, over the last two decades, the most conspicuous changes to agriculture in the Guadalquivir valley, and other Andalusian areas, are related to the increase (23%) in irrigated olive groves (Consejería de Agricultura y Pesca 2002). Nearly 50% of the total area occupied by olive groves in Andalusia is composed of properties ranging from 5 to 50 ha, and 25% are over 50 ha (Consejería de Agricultura y Pesca 2002). On the other hand, the highest concentration of small ponds is to be found in the greenhouse areas of Almería. This system is characterised by high profitability of up to 30 000 €/ha smallholdings, on average 1.5 ha, with a private pond.

Sources and quality of water

The chemical composition and levels of nutrients in ponds are decisive for structuring their aquatic communities (Alonso 1998). Pond hydrochemistry is highly dependent on the type of water source (e.g. Fernández-Aláez *et al*. 2006). The dominant source of water impounded by ponds was of surface origin – natural drainage or impounded rivers. This coincides with the dominant use of surface water for irrigation in this region – 70% – whereas groundwater supplied around 28% (MAPA 2007). The most arid province, Almería, represents a conspicuous exception, because groundwater covers most irrigation needs. Nevertheless, due to the high water demand and the consequent aquifer overexploitation and salinisation (Pulido-Bosch *et al*. 2005), the use of alternative water sources, recycled urban wastewaters and rainwater harvested from greenhouse covers, is on the rise in this province. These miscellaneous water sources undoubtedly determine the wide range of water mineralisation and nutrient status observed in the studied ponds.

Phytoplankton biomass and phosphorus showed independent patterns of variation. This seems to be typical of shallow as opposed to deep aquatic systems, where a positive relationship between these variables is more clear-cut. As pointed out by Scheffer (1998), besides nutrients, the phytoplankton biomass of shallow waters depends strongly on other factors, namely, intense zooplankton grazing, competition with SAV, turbidity or flushing with water devoid of algae. Regarding the last two factors, we must bear in mind that many ponds are fed by surface waters draining highly erodible agricultural soils or with water from rivers with a high load of suspended solids. Furthermore, a noteworthy characteristic of our systems is the low residence time of the water and use of biocides, two factors that may add noise to the expected algal–nutrients relationship.

Construction type, management and naturalisation stage

A major goal of environmental conservation agencies might be to promote the construction of naturalised ponds or the naturalisation of the existing ones, taking into account the high potential value of ponds for biodiversity conservation at a landscape scale (Oertli *et al*. 2005). Diverse and well-structured pond vegetation, MV and SAV, are major ecosystem components improving both invertebrate and vertebrate pond biodiversity (Biggs *et al*. 2005; Markwell & Fellows 2008). Overall, MV showed a deficient naturalisation stage in our ponds. This is not surprising owing to the high abundance of highly artificial ponds, particularly PET and CON with unsuitable substrate and slope gradient for vegetation. These results highlight the importance of pond design in promoting pond ecosystem integrity. In fact, all PET ponds showing any development of MV were those with added gravel. However, although 38% of ponds were classified as sited on a natural basin – embankment and excavated ponds – MV was only detected using aerial imagery for 8% of the ponds. Therefore, apart from marginal substrate and slope angle, management factors must be taken into account to explain the poor development of MV. For instance, water-level fluctuations due to the irregular precipitation regime and intense water extraction during summer seems to be a singular trait of these environments that may constrain MV development (e.g. McHorney & Neill 2007). Additionally, or alternatively, free access of livestock to EMB ponds may hinder the development of MV. In fact, all ponds inspected located in extensive livestock farms showed free access to animals around the entire perimeter, without any device to prevent trampling or browsing of MV. It is symptomatic that in EMB ponds, species with adaptations to prevent browsing, such as *Nerium oleander* and *Tamarix* spp, were frequent. On the other hand, EXC ponds were featured by minor use for livestock farming, and were more frequently colonised by reed. This species is highly sensitive to vertebrate herbivores and develops dense stands in the absence of livestock browsing (e.g. Vulink *et al*. 2000). The high frequency of giant cane and *Eucaliptus* spp. in EXC and EMB ponds is also noteworthy. These two exotic taxa are normally associated with considerable anthropic pressure, which highlights a somewhat deficient naturalisation of these pond types.

Most studied ponds are shallow and therefore prone to domination by SAV (Scheffer 1998), particularly considering the high irradiance levels in Andalusia. However, on average, SAV development was scarce in our ponds, with no significant differences among construction types. Several factors may hinder SAV development. Eutrophication due to high nutrient availability may enhance phytoplankton and epiphyte biomass, therefore increasing competition for light with SAV (Scheffer *et al*. 1992; Weisner *et al*. 1997). Periodic treatments with biocides and SAV harvesting or pond desiccation are common management methods in PET and CON ponds. Furthermore, exotic carps and the American red swamp crayfish, which are major deleterious agents for submerged vegetation (Harper *et al*. 1990; Scheffer 1998; Rodríguez *et al*. 2003), were frequent in ponds (unpublished data). In fact, the most frequent submerged plant in our ponds, fennel pondweed, is a cosmopolitan species with ample environmental tolerance (Pilon *et al*. 2002).

Conclusions

(1) There is a relatively high abundance of ponds in Andalusia, most of them being used for irrigation and/or livestock farming, as is to be expected in a Mediterranean region primarily devoted to agriculture.
(2) High pond concentrations were detected in growing irrigated areas sustained by groundwater, in some cases extracted from extremely overexploited aquifers.
(3) Water mineralisation and nutrient status was diverse, as expected from the heterogeneous lithological composition and water sources.
(4) Phytoplankton biomass and phosphorus showed independent patterns of variation, as frequently found in shallow aquatic systems.
(5) More structured and diverse MV was present in embankment and excavated ponds, as well as higher species richness of submerged vegetation, compared with polyethylene-lined and concrete ponds, which could be related to the natural substrate, lower marginal slope and absence of periodic dredging and biocide treatment in the first two types.
(6) The promotion of changes or adaptations of certain construction characteristics, mainly related to substrate, slope gradient of the margins and mechanisms to prevent excessive flocks trampling and browsing, together with the suppression or reduction of aggressive biocide treatment and prevention of exotic species introduction or invasion, might therefore significantly improve the quality of pond habitat for biodiversity conservation.

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