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Diversity and Distribution of Microphytes and Macrophytes in Artificial Irrigation Ponds in a Semi-Arid Mediterranean Region (SE Spain)

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ABSTRACT: The seasonal diversity and distribution of microphytes and macrophytes in 40 artificial irrigation ponds constructed in a semi-arid region, and the most suitable conditions to maintain these enclaves as biodiversity spots were studied for the first time. A total of 104 species were detected. Bacillariophyta, cyanobacteria and chlorophyta dominated both pelagic and benthic microphytic communities, with dinophyta and euglenophyta also comprising a large part of the pelagic assemblages. Artificial ponds were built with low-density polyethylene (LDP) covered with stones and sand and were also constructed with other plastic materials, such as PVC or high-density polyethylene (HDP), with no natural cover. Regression tests were used to analyze the relationship between plant species diversity (Shannon index H') and physic-chemical pond water parameters. The test showed that the species diversity from the ponds was significantly correlated with pond's type. LDP ponds contained a significantly wider range of microphytes and macrophytes species, in summer than in winter, than HDP. These artificial irrigation ponds have led to the creation of new water habitats for plant diversity conservation within semi-arid areas.

Key words: Algae, Angiosperms, Cyanobacteria, Diversity, High-density plastic irrigation pools, Low-density Polyethylene irrigation pools

INTRODUCTION

In the semi-arid regions of Southern Europe, land use patterns have undergone considerable modifications in the last few decades (Delbaere, 2002, Donald *et al.* 2001, EEA 1998, Siebert *et al.* 2010). In south eastern (SE) Spain, the most relevant change, given its extension and socio-economic importance, has been the transformation of dry croplands and areas with native vegetation into new irrigated lands, particularly since the Tajo-Segura water transfer came into being in 1980 (Peiró *et al.* 1996). Increased intensive farming practices in SE areas of the Iberian Peninsula imply greater demand for water resources. Therefore, the use of farmed owned artificial ponds for agricultural requirements has become widespread (Bonachela *et al.* 2007). These changes have had a huge impact on the landscape and diversity in these areas. Research on European pond ecology and conservation has increased markedly over the last decade, demonstrating their relevance for biodiversity conservation at the landscape scale (Boavida 1999, Cereghino *et al.* 2008, Oertli *et al.* 2005). Artificial irrigation ponds vary greatly in design and their management is subject to considerable variation in terms of the crops with which they are associated (Wisser *et al.* 2010). These ponds were constructed since the early 1980s and they have been filled for the water transfer between Tajo and Segura Rivers from central to southeastern Spain, in order to keep water for drip irrigation of citrics (orange and lemon trees) and vegetables (mostly melon, artichoke and lettuce). The way these artificial ponds are managed may affect the distribution and abundance of the animals and plants that have colonized these habitats and have transformed them into an enclave with rich biodiversity, high value and of much ecological interest. Although these artificial ponds have become more common and widespread, their importance has been underestimated in macroecological studies (Downing *et al.* 2006). Traditionally, studies conducted on this type of aquatic environments have mainly focused on animal communities (Abellán *et al.* 2006, Armitage *et al.* 2012, Hazell *et al.* 2001, Kadoya *et al.* 2004, McKinstry & Anderson 2002, Sánchez-Zapata *et al.*, 2005, Tourenq *et al.* 2001, Wood *et al.* 2001), while algae and aquatic plants have received little attention.

There are not previous studies about algae and aquatic plants in artificial irrigation ponds constructed

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in the semi-arid regions of Southern Europe, despite its importance owing to the fact that these constructions have led to the creation of new water habitats for plant organisms. This research work focuses on investigating, for the first time, the seasonal diversity of microphytes and macrophytes in 40 artificial irrigation ponds constructed in a semi-arid region of Spain, and the most suitable conditions to maintain these enclaves as biodiversity spots. Furthermore, water quality was characterised from the physico-chemical perspective to propose sustainable management techniques for ponds to enable intensive farming practices to be compatible with biodiversity conservation, and which may be applied to other areas in the Mediterranean.

MATERIAL & METHODS

This study was carried out in the Vega Baja Valley in SE Spain where about 3,000 artificial irrigation ponds are distributed over an area of 95,840 ha in a landscape dominated by intensive farming (citrus fruits and vegetables).Climatological data reflect a Mediterranean climate with a marked aridity tendency with 2,800 solar hours per year. Two main peaks in precipitations are observed, in spring and at the beginning of autumn. Likewise, two minimum precipitations are noted: in summer, the main one, and towards the end of winter. In general terms, it is rare that annual rainfall exceeds 350 mm. The 300 mm value could be representative of the mean annual rainfall in this Mediterranean area. The mean summer temperature is around 25°C, while the mean winter temperature is approximately 13°C; Finally, mean annual temperatures arises 18ºC.

The landscape is dominated by palm trees (*Phoenix dactylifera*), towns and sparse houses. Small amounts of extensive crops such as almond (*Prunus amygdala*), olive (*Olea europea v. oleaster*) and cob trees (*Ceratonia siliqua*) still remain, as well as remnants of native vegetation such as Mediterranean shrubs (*Pistacea lentiscus*, *Rosmarinus officinalis*, *Rhamnus lycioides*, *Chamaerops humilis*, *Thymus* spp) and pine trees (*Pinus halepensis* and *P. pinea*). Relief is plain with small hills close to the sea (Sierra Escalona; 300 m.a.s.l.) and small rocky mountains in the vicinity of the Segura River (Sierra de Orihuela; 600 m.a.s.l.) and in the north of the study area (Sierra de Crevillente; 800 m.a.s.l.). But artificial ponds remain at the lowest altitude ranging from the sea level to 300 m.a.s.l. Except for the ponds, there are several natural or semi-natural wetlands as well as large artificial water reservoirs and traditional salines. Some of these places (El Hondo, Salinas de Santa Pola, Salinas de La Mata and Torrevieja, Salinas de San Pedro) enjoy regional environmental protection (as Natural Parks or Protected Places) as well as international status of Special Protection Areas (SPAs) and RAMSAR sites because of their importance for water-birds (http://ramsar.org/sitelist.doc).

Of the approximately 3,000 irrigation ponds in the study area, 40 were selected at random for my investigation to sample in winter and in summer. Ponds were classified into two categories in accordance with the construction materials used: (1) LDP ponds, those constructed with low-density polyethylene covered with sand and stones to prevent solar damage and characterised by both lower marginal slope and depth (n=29); (2) HDP ponds, those constructed with other plastic materials, such as PVC or high-density polyethylene, with no natural cover and characterised by both higher marginal slope and depth (n=11). The area (ha) occupied by the small and/or regular shaped ponds was measured in the field, while digitised aerial photographs (http://www.mapya.es/) and a geographic information system (GRASS) were used for large and/or irregular shaped ponds.

Copper-based herbicides and other chemicals are used extensively in artificial pool waters to control planktonic, filamentous algae and vascular macrophyte growth. Thus, I examined any influence of chemical control on the aquatic plants communities, assessing the presence or absence of chemical treatments from the copper (Cu) concentration in sediments. Microphytes and macrophytes were collected with a hand net from the top one meter of water and transported in a cold box to the laboratory. There, algal material was fixed with glutaraldehyde or isolated in liquid or solid Bold Basal Medium (Nichols 1973) and kept at 25.0ºC under 70.0 $\mu Em^{-2}s^{-1}$ light intensity with a 16h:8h light/dark photoperiod. Cultivation is usually necessary for detailed taxonomic studies. The morphology of the species was therefore studied both from field-collected material and from cultivated specimens. Microscopic examinations were made with a stereomicroscope Lan Optics and Olympus BX41 and Zeiss Axiovert 100 microscopes.

The following publications were used for the morphological identification of microphytes and macrophytes: Cirujano & Medina (2002), Ettl & Gärtner (1988), Geitler (1932), Komarek & Anagnostidis (1999), Komarek & Anagnostidis (2005), Komarek & Fott (1983), Round *et al.* (1990).

The basic water chemistry at each site was recorded using a portable water meter PCD 650 from the top one meter of water. The parameters measured included salinity, electrical conductivity, pH, dissolved oxygen and temperature. The top 2 cm of sediment were collected from the wall of ponds using a Perspex corer (5 cm in diameter), which remained and transported in a cold box to the laboratory where they were frozen for later analysis.

Water samples were taken in small bottles from the top one meter of water and transported in a cold box to the laboratory where they were frozen for later analysis using standard analytical techniques (Greenberg *et al.*, 1992). Ammonium, nitrates, phosphates, and DOC (Dissolved Organic Carbon) were determined in filtered samples (0.45 ?m membrane filter). Ammonium-N concentration was analyzed using a Continuous Flow Analysis system (Ammonia Analyzer mod. 255, European Analytical and Scientific Instruments, Technologies S.A.). Chloride, NO_3–N, NO_2–N, and PO_4–P were analyzed using the capillary electrophoresis technique [Waters, CIAQuanta 5000; Romano and Krol (1993)]. The DOC was analyzed using a Skalar 12SK TOC analyzer with UV/promoted persulfate oxidation. SUVA values (specific UV absorbance; 1 $mg^{-1}m^{-1}$) as a measure of the relative contents of aromatic structures in the overall DOM (Weishaar *et al.*, 2003) were calculated as (UV254/DOC) x100. Statistical analyses were performed using the SPSS software (Chicago, IL, USA). To compare groups of data, a t-test was used either when data in both groups were normally distributed. T-tests were also used to test differences in species diversity as a function of pond attributes for all microphytes and macrophytes and for individual taxonomic groups. The correlation between species was studied through Pearson coefficients. Finally, conductivity, nitrates, dissolved organic matter and pond's type were used as independent variables in multiple linear regression models to assess their contribution to species diversity (Shannon index H'). In addition, an analysis of collinearity was performed for all the variables included in the regression model and the autocorrelation residuals were studied, using a Durbin–Watson test.

RESULTS & DISCUSSION

A total of 104 species were found in the 40 selected irrigation ponds and the most frequent species are listed in Table 1. Among them, benthic and plankton species represented by several algal groups were found, as were some angiosperm species. Among the benthic species, bacillariophyta, cyanobacteria and chlorophyta predominated, whereas dinophyta, chlorophyta, bacillariophyta, cyanobacteria and euglenophyta featured mostly among the plankton species. Rhizobenthos was fundamentally made up of Characeae (*Chara canescens*, *C. contraria* and *C. vulgaris*) and Anthophyta (*Illecebrum verticilatum*, *Potamogeton pectinatus*). The following were found to intermingle with the former group: *Cladophora fracta*, *Rhizoclonium hieroglyphicum* and *Spirogyra* sp.

Benthic species grew and adhered to the stones spread out on LDP pond walls. The sediment accumulated on pond walls and pond bottoms meant that epilithic communities were mixed with those considered epipelic. In upper pond areas, which were between the top of the construction and the water level, taxonomically undetermined lichens were the dominant group. Moreover, a very obvious mat of cyanobacteria was found in temporarily submerged areas, whose stratified and yellowish sheaths afforded the group of cyanobacteria a blackish appearance. Sediments consolidated were arranged over the rest of the pond walls to make up firm crusts with a maximum thickness of 0.5 cm. These crusts contained a large number of mainly cyanobacteria species, of which the most outstanding were: *Gloeocapsa biformis*, *G. sanguinea*, *Microcoleus subtorulosus*, *M. vaginatus*, *Nostoc verrucosum*, *Oscillatoria brevis O. ornata*, *O. sancta*, *Phormidium retzii*, *P. splendidum*, *P. uncinatum*, *Pseudocapsa dubia*, *Schizothrix fasciculata*, *S. undulata. Gloeocapsa biformis* was very positively correlated with *Phormidium retzii* and *Pseudocapsa dubia* (r=1.000, p<0.001) and positively correlated with *Oscillatoria brevis* (r=0.332, p<0.05). *Gloeocapsa sanguinea* positively correlated with *Phormidium splendidum* (r=0.444, p<0.01) and *Schizothrix undulata* (r=0.327, p<0.05). *Microcoleus subtorulosus* very positively correlated with *Phormidium uncinatum* (r=0.630, p<0.001), negatively correlated with *Microcoleus vaginatus* (r=-0.327, p<0.05) and *Oscillatoria brevis* (r=-0.355, p<0.05). *Microcoleus vaginatus* very negatively correlated with *Schizothrix fasciculata* (r=-0.546, p<0.001). There were also some chlorophyta like *Choricystis chodatii* very positively correlated with *Nostoc verrucosum* (r=0.753, p<0.001) and *Stichococcus minor* positively correlated with *Oscillatoria sancta* (r=0.466, p<0.01) and *Phormidium uncinatum* (r=0.314, p<0.05), which contributed to the aggregate and to the particles consolidation that were deposited there.

The epilitic/epipelic algal community was distributed homogeneously from the water surface to the bottom of the ponds. The benthic assemblage was stable and not very variable throughout the year. Filaments of the chlorophyte *Cladophora fracta* formed a layer up to 15-20 cm thick on the underlying dense matrix of cyanobacteria and bacillariophyta. Such an assemblage also hosted taxa belonging to several genera, including *Spirogyra* and *Rhizoclonium*, positively correlated with *Cladophora fracta* (r=0.608 p<0.001, r=0.398 p<0.05 respectively). Older *C. fracta* filaments eventually detached, forming floating mats

Teble 1. Taxa composition present in LDP and HDP ponds. For each taxon the % of ponds is shown where present

	POND	**TYPE**
TAXA	**LDP**	**HDP**
Bacillariophyta		
Achnanthes brevipes Agardh	44.83	36.36
Amphora pediculus (Kützing) Grunow ex Schmidt	20.69	0
Amphora veneta Kützing	20.69	0
Asterionella formosa Hassall	31.03	0
Cocconeis pediculus Ehrenberg	86.20	81.82
Cyclotella ocellata Pantocsek	86.20	81.82
Cyclotella meneghiniana Kützing	31.03	0
Cymbella affinis Kützing	62.07	36.36
Cymbella aspera (Ehrenberg) Cleve	31.03	0
Denticula tenuis Kützing	86.20	81.82
Diatoma elongata (Lyngbye) Agardh	86.20	81.82
Diploneis elliptica (Kützing) Cleve	20.69	0
Diploneis ovalis (Hilse) Cleve	31.03	0
Fragilaria crotonensis Kitton	89.66	27.27
Gomphonema intricatum Kützing	37.93	27.27
Gomphonema minutum Agardh	31,03	0
Gyrosygma acuminatum (Kützing) Rabh	62.07	36.36
Melosira moniliformis (Müller) Agardh	37.93	0
Navicula radiosa Kützing	89.66	72.73
Nitzschia palea (Kützing) Smith	31.03	0
Nitzschia sigmoides (Ehr.) Sm.	31.03	0
Rhoicosphenia curvata (Kützing) Grunow	37.93	27.27
Surirella ovalis Brébisson	62.07	63.64
Synedra vaucheriae Kützing	20.69	0
Chlorophyta		
Aphanochaete repens Braun	62.07	63.64
Chara canescens Loiseleur-Deslongschamps	17.24	18.18
Chara contraria Braun ex Kützing	13.79	0
Chara vulgaris Linnaeus	44.83	45.45
Chlamydomonas sp	17.24	0
Choricystis chodatii (Jaag) Fott	10.34	0
Cladophora fracta (Müller ex Vahl) Kützing	86.20	81.82
Closterium lunula Ehrenberg & Hemprich ex Ralfs	31.03	0
Closterium pronum Brébisson	89.66	72.73
Coleastrum polychordum (Korshikov) Hindák	62.07	63.64
Cosmarium laeve Rabenhorst	62.07	63.64
Cosmarium ornatum Ralfs ex Ralfs	31.03	0
Desmodesmus communis Hegewald	17.24	18.18
Enteromorpha intestinalis (Linnaeus) Nees	31.03	0
Klebsormidium flaccidum (Kützing) Silva, Mattox & Blackwell	44.83	0
Monoraphidium irregulare (G.M.Smith) Komárková-Legnerová	13.79	18.18
Mougeotia sp	62.07	63.64
Oedogonium sp	89.66	27.27
Pediastrum boryanum (Turpin) Meneghini	31.03	0
Pediastrum duplex Meyen	13.79	0
Protoderma viride Kützing	13.79	0
Protosiphon botryoides (Kützing) Klebs	31.03	0
Rhizoclonium hieroglyphicum (Agardh) Kützing	62.07	63.64
Scenedesmus acuminatus (Lagerheim) Chodat	13.79	27.27
Scenedesmus linearis Komárek	27.59	0

Teble 1. Taxa composition present in LDP and HDP ponds. For each taxon the % of ponds is shown where present

Scenedesmus quadricauda (Turpin) Brébisson in Brébisson & Godey	44.83	0
Spyrogyra sp	89.66	72.73
Staurastrum sp	62.07	72.73
Stichococcus minor Nägeli	17.24	0
Stigeoclonium nanum (Dillwyn) Kützing	31.03	0
Tetraedron minimum (Braun) Hansgirg	13.79	18.18
Ulothrix tenerrima Kützing	31.03	0
Zygnema sp	31.03	18.18
Cyanobacteria		
Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault	62.07	63.64
Aphanothece saxicola Nägeli	6.90	0
Calothrix parietina (Nägeli) Thuret	89.66	27.27
Chamaesiphon cylindricus Boye-Petersen	31.03	18.18
Chamaesiphon incrustans Grunow	31.03	0
Chroococcidiopsis sp	27.58	0
Chroococcopsis gigantea Geitler	31.03	0
Chroococcus giganteus West	27.59	0
Dermocarpa parva (Conrad) Geitler	24.14	0
Gloeocapsa biformis Ercegovic	27.59	0
Gloeocapsa compacta Kützing	27.59	0
Gloeocapsa kützingiana Nägeli	13.79	0
Gloeocapsa sanguinea (Agardh) Kützing	20.69	0
Gloeothece violacea Rabenhorst	31.03	0
Leptolyngbya angustissima (West & West) Anagnostidis & Komárek	13.79	27.27
Leptolyngbya gracillima (Zopf ex Hansgirg) Anagnostidis & Komárek	20.69	18.18
Merismopedia glauca (Ehrenberg) Kützing	31.03	0
Microcoleus subtorulosus (Brébisson) Gomont ex Gomont	10.34	9.09
Microcoleus vaginatus (Vaucher) Gomont ex Gomont	89.66	72.73
Myxosarcina cocinna Printz	86.20	81.82
Nostoc sphaericum Vaucher	27.59	0
Nostoc verrucosum Vaucher	17.24	0
Oscillatoria brevis Kützing ex Gomont	89.66	27.27
Oscillatoria ornata Kützing ex Gomont	17.24	0
Oscillatoria sancta Kützing ex Gomont	10.34	0
Phormidium retzii (Agardh) Kützing ex Gomont	31.03	0
Phormidium splendidum (Greville ex Gomont) Anagnostidis & Komárek	17.24	27.27
Phormidium uncinatum (Agardh) Gomont	17.24	0
Pleurocapsa minor Hansgirg	13.19	27.27
Pseudanabaena catenata Lauterborn	93.10	0
Pseudocapsa dubia Ercegovic	31.03	0
Schizothrix fasciculata Nägeli ex Gomont	6.90	0
Schizothrix lateritia (Kützing) Gomont	13.79	18.18
Schizothrix undulata Virieux	13.79	0
Scytonema myochrous (Dillwyn) Agardh ex Bornet & Flahault	20.69	0
Staniera cyanosphaera (Komarek et Hindák) Komarek et Anagnostidis	86.20	81.82
Xenococcus kerneri Hansgirg	41.38	0
Dinophyta		
Ceratium hirundinella (Müller) Dujardin	89.66	81.82
Gymnodinium sp	17.24	18.18
Peridinium umbonatum Stein	31.03	0
Euglenophyta		
Euglena texta (Dujardin) Hübner	13.79	18.18
Lepocynclis ovum (Ehrenberg) Lemmermann	20.69	0
Phacus sp	17.24	27.27
Anthophyta		
Illecebrum verticilatum Linnaeus	65.52	72.73
Potamogeton pectinatus Linnaeus	89.66	27.27

on the water surface. The thick cellulose walls of *Cladophora fracta* acted as a suitable substrate for the colonization of a complex epiphytic community that comprised positively correlated bacillariophyta (*Cymbella affinis* $r=0.324$ $p<0.05$, *Diatoma elongata* $r=1.000$ $p<0.001$, and *Navicula radiosa* $r=0.608$ $p<0.001$), cyanobacteria (*Aphanothece saxicola* $r=0.546$ $p<0.001$, *Chamaesiphon incrustans* $r=0.356$ $p<0.05$ and *Dermocarpa parva* $r=0.359$ $p<0.05$) and chlorophyta (*Aphanochaete repens* $r=0.398$ $p<0.05$ and *Protoderma viride* $r=0.395$ $p<0.05$).

When volume of water was low, those areas with larger amounts of accumulated sediment were those colonised by *Illecebrum verticilatum* and *Potamogeton pectinatus*. However, charophyta remained in the marginal areas with a finer layer of sediments, and characterised the algal communities of the irrigation ponds in spring: *Chara canescens*, *Ch. contraria* and *Ch. vulgaris*. With regard to plankton communities, *Ceratium hirundinella* and *Peridinium umbonatum* were present all year round, along with some chlorophyta, especially chlorococcales, and desmidiaceae to a lesser extent, of which the following genera stand out: *Closterium*, *Cosmarium*, *Micractinium*, *Monoraphidium*, *Pediastrum*, *Scenedesmus*, and *Staurastrum*.

Closterium lunula very positively correlated with *Peridinium umbonatum* ($r=1.000$, $p<0.001$) and *Closterium pronum* positively correlated with *Ceratium hirundinella* ($r=0.608$, $p<0.001$). *Cosmarium ornatum* very positively correlated with *Peridinium umbonatum* ($r=1.000$, $p<0.001$) and *Cosmarium laeve* positively correlated with *Ceratium hirundinella* ($r=0.398$, $p<0.05$). *Pediastrum boryanum* very positively correlated with *Peridinium umbonatum* ($r=1.000$, $p<0.001$) and *Pediastrum duplex* positively correlated with *Ceratium hirundinella* ($r=0.793$, $p<0.001$). *Scenedesmus linearis* and *S. quadricauda* very positively correlated with *Peridinium umbonatum* ($r=1.000$ $p<0.001$, $r=0.777$ $p<0.001$ respectively). *Staurastrum* sp positively correlated with *Ceratium hirundinella* ($r=0.426$ $p<0.01$). Another important group that forms part of the plankton communities in all the studied ponds is the diatom group, particularly *Asterionella formosa* and *Nitzschia palea* very positively correlated with *Peridinium umbonatum* ($r=1.000$ $p<0.001$) and *Cyclotella ocellata* very positively correlated with *Ceratium hirundinella* ($r=1.000$ $p<0.001$). Chlorophyta and Euglenophyta predominated in the more eutrophicated ponds, especially when the water level dropped, which mainly included *Tetraedron minimum* and *Chlamydomonas* sp positively correlated with nitrates ($r=0.336$ $p<0.05$) and *Euglena texta* and *Phacus* sp positively correlated with conductivity ($r=0.365$ $p<0.05$). On the shores of the ponds, the following species grew on stones when water volume was maximum: *Pseudocapsa dubia* positively correlated with *Schizothrix lateritia* ($r=0.426$ $p<0.01$), *Scytonema myochrous* ($r=0.459$ $p<0.01$), *Stigeoclonium nanum* ($r=1.000$ $p<0.001$) and *Ulothrix tenerrima* ($r=1.000$ $p<0.001$).

The plant groups that presented greater species richness were chlorophyta, followed by bacillariophyta, cyanobacteria, euglenophyta, dinophyta and anthophyta (Table 2). Despite the lack of considerable differences in terms of pond sizes, species diversity was significantly greater in LPD ponds than in the HDP ones (Table 2). Likewise, greater species richness was noted in summer than in winter for both pond types (Fig. 1).

The water and sediment samples (Table 3) taken from the 40 randomly selected irrigation ponds revealed the presence of large amounts of Cu in the sediments, above all in the HDP ponds. This element formed part of the algicides and herbicides, which were frequently used in irrigation ponds to control plant growth. Furthermore, chemical treatment was found to be significantly higher in the HDP ponds (Table 2). The data for species diversity shown in Table 4 were evaluated by multiple regression resulting in a 73 % degree of explanation of the variation observed, by the following equation: $H' = 0.488+0.466 \log(C)-0.354 \log(N)-0.411 \log(DOM)-0.592T$ where H' was the Shannon index, C was the conductivity, N was the nitrates, DOM was the dissolved organic matter and T was pond's type (dummy variable that assumes a value equal to zero for HDP and one for LDP). The equation demonstrated the linear relation in species diversity and conductivity while the species diversity was negatively correlated with nitrates, DOM, and pond's type. Variations in the chemical management in the ponds might be expected to introduce variability into the regression model for maximum diversity because chemical management variations in cupper levels can strongly influence diversity rates. However, chemical management did not explain significant additional variance when included as an independent variable in the models. The cell wall of filamentous algae made an ideal substrate for a complex epiphytic community to colonise (Cambra & Aboal 1992). Epiphyte growth and the high degree of insolation probably caused the senescence of the apical, older *Cladophora fracta* filaments which, in turn, protected the younger, deeper filaments.

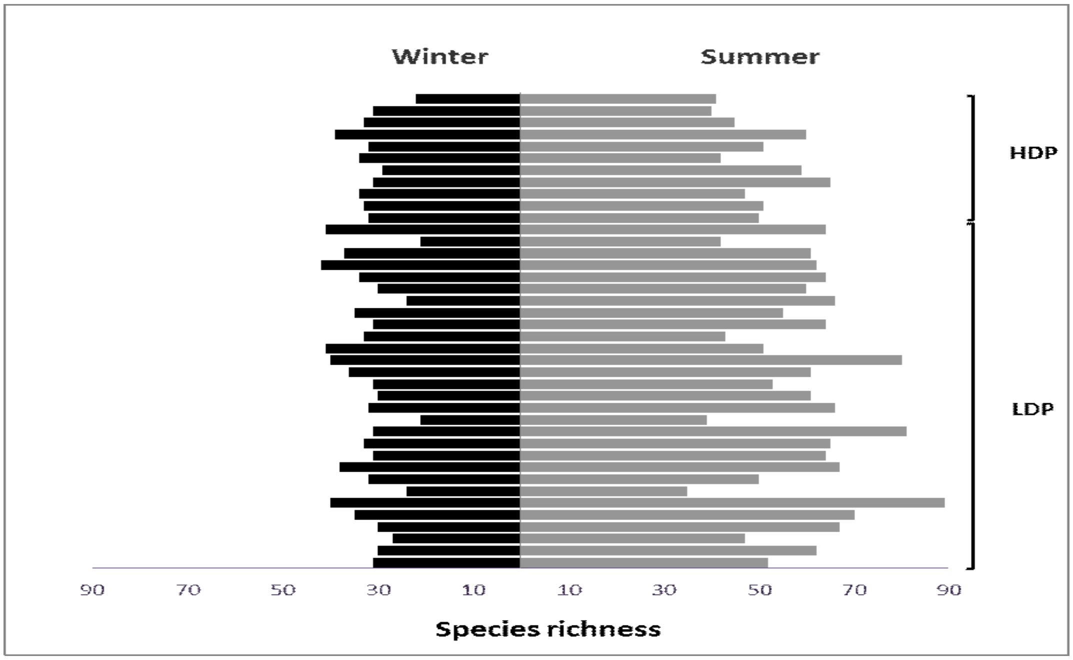

Fig. 1. Species richness in the 40 sampled irrigation pools in the winter and summer surveys

Table 2. Comparison of irrigation pool attributes and aquatic plants in high-density polyethylene (HDP) and low-density polyethylene (LDP) pools

Pool (n=40)	LDP (29)	HDP (11)	Statistic value (T-Test)	*p*
Irrigation pool attributes				
Area (ha)	(0.06-1.27) 0.37±0.32	(0.03-1.37) 0.65±0.53	1.90	0.076
Chemical management[a]	79.3	90.9	2.76	0.009**
Macrophytes and microphytes species				
Diversity (Shannon index)	1.11±0.16	0.88±0.13	4.45	0.000***
Taxa				
Bacillariophyta	27.03±4.29(36)	24.9±2.5(28)	1.54	0.133
Chlorophyta	45.65±4.18(55)	42.36±3.04(48)	2.37	0.023*
Cyanobacteria	9.79±4.27(21)	6.45±2.69(11)	2.40	0.021*
Dinophyta	2.93±1.03(5)	2.00±0.63(3)	2.78	0.008**
Euglenophyta	5.34±2.09(10)	3.63±1.5(6)	2.47	0.018*
Anthophyta	1.75±0.43(2)	1.18±0.4(2)	3.81	0.000***

Mean±S.D. are shown. Number of pools and absolute number of taxa comparable to species level are given in parentheses.

*p<0.05, **p<0.01, ***p<0.001

Minima and maxima of Area pools are presented in parentheses.

[a] Percentage of pools with presence of this biotic or abiotic characteristic.

Table 3. Values (average and standard deviation) of physical and chemical parameters measured in high-density polyethylene (HDP) and low-density polyethylene (LDP) pools

Parameter	**LDP (29)**	**HDP (11)**
Sediments		
Fe (mg/kg)	7798.67±4183.68	3487.91±2175.82
Cu (mg/kg)	1013.21±1764.0	1695.74±1574.81
Mn (mg/kg)	221.99±101.74	3214.27±6144.49
Zn (mg/kg)	46.87±25.89	82.24±35.62
Organic matter (%)	7.64±10.75	12.87±3.94
Water		
pH	7.99±0.18	7.72±0.17
Salinity (g/L)	0.69±0.31	0.57±0.29
Conductivity (mS/cm)	1874.12±637.84	1678.95±658.45
Dissolved oxygen (mg/L)	11.87±3.92	14.82±2.97
Oxygen saturation (%)	119.56±37.88	138.24±31.75
Na (mg/L)	181.12±97.71	148.39±103.85
K (mg/L)	14.38±10.86	4.95±1.97
Ca (mg/L)	137.29±49.64	106.21±19.82
Mg (mg/L)	78.27±28.61	59.41±10.34
HCO3 (mg/L)	152.12±55.26	159.82±27.14
NO3 (mg/L)	7.51±9.33	16.79±18.96
SO4 (mg/L)	377.15±181.27	280.11±86.88
PO_4(mg/L)	0.05±0.04	0.04±0.02
TON (mg/L)	16.24±28.17	46.77±79.46
COD (mg O2/L)	18.12±10.85	19.94±8.78
DOC (mg/L)	1.81±3.72	0.2±0.17

Table 4 . Summary of Multiple regression analysis applied to the macrophytes and microphytes species diversity (Shannon index H') in relation to physic-chemical pond water parameters

Multiple regression analysis of de Shannon index H' (dependent variable)

Variables	*Parameters*	*T-test*	*P*
Intercept	0.488	1.921	0.075 *
Conductivity	0.466	2.897	0.012 **
Nitrates	-0.354	-2.327	0.036 **
DOM	-0.411	-2.453	0.028 **
Chemical management	-0.120	-0.781	0.448 ^{ns}
Pond type	-0.592	-3.413	0.004 ***

^{ns} no significant;

Significant: **P*>0.1; ***P*>0.05; ****P*>0.01

Adjust model R^2 = 0.730

Despite the cloudy appearance of the waters, the radiation that penetrated was more than sufficient to allow algae and angiosperms to grow. The most outstanding feature of the flora colonising the ponds was the poor diversity of macroalgae and angiosperms, including *Cladophora fracta*, *Illecebrum verticilatum* and *Potamogeton pectinatus*. This accounts for the homogeneous appearance that the ponds present as opposed to rich microalgae diversity.

Homogeneously structured vegetation was noted when the ponds were full of water. *Cladophora fracta* grew quickly off the germinating spores in the sediments, and off other propagules in the water or the air, and formed a thick layer. This species needs much light intensity to grow, and its prolific growth contributed the most to the biomass production in stagnant waters. Den Hartog (1958) described a relationship between water turbidity and the diminished *C. fracta* belt extension. When the filament became partly fragmented, the basal part remained linked to the substrate. Therefore, it could regenerate or remain semi-dormant throughout the Winter (Whitton 1970), while the upper parts allowed other substratum to colonise (Dodds & Gudder 1992). *Potamogeton pectinatus* competes with the *Cladophora fracta* for light (Ozimek *et al*. 1991), but it better adapts to low light intensities (Blindow 1992) and, although *C. fracta* began to grow first, *P. pectinatus* quickly established mono-specific meadows in the ponds. *P. pectinatus* was able to overcome adverse conditions owing to tubers, and to a large number of seeds which could reach the ponds where it flowered all year round. Nevertheless, *P. pectinatus* colonised places where sediments considerably accumulated. *P. pectinatus* was an important species for the indication of habitats with higher amounts of ammonium and total phosphorus. It is able to tolerate high trophic levels and its domination indicates the most trophic habitats (Demars & Harper 1998). The LDP irrigation ponds were more susceptible to changes in water quality. When water volume was at a minimum, mineralisation increased and plant communities became impoverished, especially the benthic community as many of the cited species disappeared and different *Euglena* and *Phacus* species grew. Crusts contained a large number of species, fundamentally cyanobacteria, which contributed to the aggregate and to the compactation of the particles deposited there. Many filamentous cyanobacteria had mucopolymer-rich pods, whose compactation capacity is being used in some cases to fight erosion. It was easy to make out how many species were protected from the excessive insolation by migrating through the natural fissures of these crusts towards deeper and more protected layers to develop in a casmoendothilic manner, as described by Domínguez & Asencio (2011). Although their presence is usually associated with extreme conditions (Asencio & Aboal 2000) chasmoendolithic cyanobacteria colonise many types of environments. This situation was particularly evident when crusts had dried because when the fragments devoid of algae were separated, it was possible to see how the lower portion, directly in contact with gravel, was covered by a continuous green-bluish patina.

Applying multiple regression analysis to all the irrigation pools, we found that macrophytes and microphytes diversity was positively related to conductivity. The increased diversity observed in high-conductivity irrigation ponds may be a manifestation of a limitation in the lowest-conductivity irrigation ponds for this group of organisms according to Thomaz *et al*. (2004) in Brazilian aquatic ecosystems. However diversity was negatively related to the nitrates in agreement with Vădineanu *et al*. (1992) who studied the phytoplankton and submerged macrophytes in the aquatic ecosystems of the Danube Delta. An increase of the amount of nutrients in aquatic systems favors biological diversity to some extent. Nevertheless, a further increase of nutrients in water may lead to habitat degradation, to a decrease of overall biodiversity, the disappearance of some plant communities, and spreading of others (Heegaard *et al*., 2001). In the nutrient enriched conditions the submerged vegetation is replaced by free-floating communities because eutrophication promotes the growth of epiphytes and nonrooting macrophytes (Bini *et al*., 1999).

Multiple regression analysis also showed that diversity was negatively related to DOM. Flora of the lakes altered by the impact of DOM input did not have specific fea- tures. The primary process was the reduction in the number of species of all plant groups. As a result, DOM properties, including its concentration, are important drivers of aquatic communities (Williamson *et al*. 1999). At broad scales, watershed controls of DOM in aquatic systems have been demonstrated for lakes (Xenopoulos *et al*. 2003).

The pond's type influenced plant diversity in artificial irrigation pools. LDP ponds contained a significantly wider range of plant species, in summer than in winter, than HDP. Biodiversity losses may signify system simplification, loss of ecological integrity, and loss of resistance and resilience to disturbance. The analyses of the physico-chemical pond water parameters reveal that water was included among that apt for agricultural uses. However, owners were much more concerned about the irrigation filters and terminals becoming blocked by excessive algae and angiosperms growth. Owners overcame this problem using algicides or herbicides, which contained copper as the sediment analyses indicated. This measure may be substituted by using waterfowl populations which would control the growth of plant communities in the irrigation ponds located in South-eastern areas of the Iberian Peninsula, since this part of Spain is an important area for wintering and breeding waterbirds (Martí & Del Moral 2003). They are important stop-over places for migrating birds on their way from and to Africa because of their strategic location, and they are also important breeding sites for some endangered species.

CONCLUSIONS

Having determined the diversity of phytoplankton, macroalgae and macrophyta in irrigation ponds in SE Spain, and having characterised the irrigation water quality from the physico-chemical perspective, sustainable management techniques for ponds to enable intensive farming practices to be compatible with biodiversity conservation are proposed, which may be applied to other Mediterranean areas:

1. Construct only gravel ponds (LDP) in the future since they support greater plant growth and are more appropriate to maintain biodiversity.
2. Control the growth of plant communities in these ponds with using waterfowl populations since this part of Spain is an important area for wintering and breeding waterbirds to guarantee adequate sediments and water qualities for their use in agriculture.
3. Maintain networks of old and abandoned irrigation pools which can be refilled and not treated as a conservation strategy for pool biodiversity in agricultural landscapes.

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