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Biotic and abiotic parameters that distinguish types of temporary ponds in a Portuguese Mediterranean ecosystem

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ABSTRACT

Temporary ponds are seasonal wetland habitats subjected to extreme and unstable ecological conditions. Some are classified as priority habitats for conservation by the European Union Habitats Directive. Our study area was the coastal plain of southwest Portugal, which spans across 100 km north to south and hosts a large number of temporary ponds as a consequence of climatic and edaphic characteristics. Field sampling of floristic and edaphic data was carried out in 24 temporary ponds every spring between 2005 and 2008. We recorded a total of 174 plant species identified within visually homogeneous plots. We included the data in a geographic information system and classified ponds according to their floristic composition, using a biotic regionalization analysis based on species presence/absence, which is a practical and unambiguous criterion. We found three significantly different groups of ponds which corresponded to an eco-physiognomic pond typology: Mediterranean temporary ponds, marshlands, and disturbed ponds. For the first two pond types we defined characteristic or indicator plant species. We searched also for relationships between pond type and a series of large-scale climatic, geographic, and geological variables, as well as local-scale physical and chemical properties of the soil. Pond type was distinguished by a complex combination of some of these variables, including environmental energy, soil texture, nitrogen content of the soil and pH. A practical way of discriminating between different types of ponds is important so that management and conservation measures can be defined accordingly.

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1. Introduction

Wetlands can be found throughout the world and are very diverse in their nature, ranging from open water to forested ecosystems or from shallow permanent lakes to temporary ponds. Temporary ponds are rich and diverse seasonal freshwater wetlands that play a key role in safeguarding aquatic biodiversity (Biggs et al., 2005; Oertli et al., 2005; Williams et al., 2003). Species diversity in these ponds is usually higher than in other freshwater habitats such as rivers and lakes (Davies et al., 2008; Williams et al., 2003). Particularly in the Mediterranean region, temporary ponds host a large number of rare and endemic species and are classified among the most biologically interesting ecosystems (Grillas et al., 2004; Hammada et al., 2004), as they also have high beta diversity (Pinto-Cruz et al., 2009).

In temporary ponds, the fluctuation of ecological conditions is inherent to the seasonality in water availability. Pond basins are endorheic (i.e. closed, with no outflow) and usually have impermeable substrates. The water originates from rainfall and runoff from the surrounding catchment and is lost directly through evapotranspiration. The hydrological dynamics of these ponds and the consequent temporary availability of resources are crucial for these habitats' species specificity and diversity. Their plant communities are dominated by isoetid like, ephemeral aquatic and helophytic plants which are highly specialized, in order to tolerate the periodic cycle of flooding and drought (Jocque et al., 2010; Molina et al., 2009). *Isoetes* species, as an example, possess adaptations to survive submersed in saturated, anaerobic ecological conditions (Spierenburg et al., 2010). On the other hand, before drought, annual plant species are conditioned to a short life cycle and must produce seeds before the beginning of the dry season.

In terms of fauna, small crustaceans with very short life cycles are a typical component of these ecosystems, as well as some large branchiopod species, some of which live exclusively in temporary ponds (Cancela da Fonseca et al., 2008; Williams, 2006), favoured by

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the desiccation periods that prevent the presence of fish predators in these systems. Ponds are also crucial breeding habitats for several amphibian species, whose eggs and larvae live in the aquatic phase (e.g. Beja and Alcazar, 2003).

The importance of wetland conservation is recognized worldwide, as they are a source of freshwater supply and food (Mitsch and Gosselink, 2007; Moore, 2008). Nevertheless, this awareness is not so visible for temporary wetlands, as they are relatively small and may therefore seem less relevant. However, globally, ponds represent an exceptional freshwater resource, can help mitigate the impact of climate change and are an important asset for recreation and agriculture (EPCN, 2008). Moreover, their greatest value lies in the species diversity that inhabits them. Many temporary pond species are found in no other type of habitat, as they are highly specialized and adapted organisms. It is important to point out that the majority of species is only developed during the wet phase, making it sometimes extremely difficult to assess the ecological value of temporary ponds in comparison to what is known of other more permanent wetlands and organisms (Angeler and García, 2005; Angeler et al., 2010).

In terms of conservation, some temporary standing freshwater wetlands are considered important habitats for conservation and are recognized by the Ramsar Convention on Wetlands. Furthermore, some are classified as priority habitats by the European Union Habitats Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (European Commission, 2007). In particular, Mediterranean temporary ponds are considered one of the most remarkable and most threatened freshwater European habitats (EPCN, 2008).

To establish adequate management and conservation actions it is essential to know the species diversity and ecology of these ecosystems (Beja and Alcazar, 2003; Black and Zedler, 1996; Médail et al., 1998). It is also crucial to understand the spatial distribution of the different types of temporary ponds. A widely accepted typology classification system, clarifying differences and unique characteristics of each pond type, is also essential. Such classification is pertinent to allow comparative ecological assessments, the design of appropriate management procedures, and the application of conservation measures (Zacharias et al., 2007).

Due to the ephemerality of these ecosystems it is also important to identify indicators for both the dry and the wet phase, in order to assess the ecological conditions of temporary ponds. Robust tools are needed to predict the location of different pond types and help interpret the landscape. Modern approaches to natural resource management show an increasing focus on the collection and analysis of spatial information, and on the development of spatial indicators (Ostendorf, 2011).

The southwest of mainland Portugal, located within the Mediterranean region, encompasses a dense network of temporary ponds of natural origin (Beja and Alcazar, 2003; Pinto-Cruz et al., 2009). Yet being highly endangered by agricultural intensification, some well preserved temporary ponds still persist. On a global scale, the distribution of Mediterranean temporary ponds is well known, as it mirrors the Mediterranean climate zones (Barbour et al., 2005; Deil, 2005; Médail et al., 1998). Nevertheless, within their area of distribution, other types of temporary ponds coexist, and very little is known about the relative importance of environmental factors in determining their spatial variation. In this paper, we aimed to classify temporary ponds of southwestern mainland Portugal according to their floristic composition in order to achieve a pond typology, and to identify environmental factors that distinguish these pond types, as well as their bioindicator plant species. In particular, we tested the following hypotheses: (1) temporary ponds can be objectively classified into different types based on their plant species composition; (2) there are plant species exclusive of each pond type (indicator species); and (3) there are also environmental variables that distinguish pond types.

Table 1
Variables used to assess abiotic differences between temporary pond types.

Code	Variable	Source
Sand[a]	Proportion of sand	Own data
Silt[a]	Proportion of silt	Own data
Clay[a]	Proportion of clay	Own data
Conduct	Soil conductivity (μS/cm)	Own data
pH[a]	Soil pH	Own data
OrgMat[a]	Proportion of organic matter	Own data
Nitr[a]	Soil nitrogen content	Own data
Depth[a,c]	Maximum depth of pond (cm)	Own data
CUse[b]	Capability for land use	Agência Portuguesa do Ambiente (2007)
Lith[b]	Lithology	Agência Portuguesa do Ambiente (2007)
Io[b]	Ombrothermic index	Monteiro-Henriques (2010)
Itc[b]	Compensated thermicity index	Monteiro-Henriques (2010)
Prec[b]	Mean annual precipitation (mm)	Font (1983), digitised and interpolated by Barbosa et al. (2003)
PET[b]	Potential evapotranspiration	Font (1983), digitised and interpolated by Barbosa et al. (2003)
Geo[b]	Geology	Serviços Geológicos de Portugal (1992)
SoilOrd[b]	Soil order	SROA (1960–1961)
SoilT[b]	Soil type	Agência Portuguesa do Ambiente (2007)

[a] Local-scale variables measured in the field.
[b] Large-scale variables.
[c] Variables measured only in 17 of the 24 ponds.

2. Material and methods

2.1. Study area and variables

During 4 consecutive years (2005–2008) we analysed 24 ponds, with areas ranging between 0.1 and 5 ha, located along the southwestern coast of mainland Portugal, in a north–south extension of ca. 100 km. In each pond we performed floristic surveys in which we identified all plant species observed. The surveys were carried out in visually homogenous 4 m^2 quadrates where each species percent cover was recorded, sampling ponds' vegetation belts. It is important to note that data were obtained over different sampling times within each year, in early and late spring, thus covering the ponds' temporal dynamics and ensuring the representativeness of the data (Gómez-Rodríguez et al., 2009). Plant nomenclature follows Flora Iberica (Castroviejo et al., 1986–2010) and Nova Flora de Portugal (Franco, 1984; Franco and Rocha Afonso, 1994–2003).

In each pond we took also soil samples in the amphibic ecophase. We measured local-scale variables related to physical and chemical properties of the soil (Table 1). We analysed soil texture for each sample using the sedimentation method (Sedigraph 5100, Micrometrics Instrument Corporation, USA) with a further quantification of the relative percentages of sand, silt, and clay. Soil conductivity and pH were measured in distilled water solutions of soil, respectively 1:2.5 and 1:5 soil–water suspensions. Organic carbon was quantified by dry combustion (SC-144DR, LECO Instruments, USA). Nitrogen content was analysed according to the ISO14891: 2002 standard (ISO/IDF, 2002).

The location of the ponds was recorded in the field with the aid of a Global Positioning System device (Trimble 4700 RTK, USA). The coordinates were converted to a points map and included in a Geographic Information System with the *v.in.db* module of GRASS (Geographic Resources Analysis Support System; GRASS

Development Team, 2009) through the graphical interface provided by Quantum GIS (Quantum GIS Development Team, 2009). We then gathered georeferenced maps of nine large-scale variables related to geology, lithology, land use capability, and climate (Table 1). Within the climatic variables we included bioclimatic indexes meaningful to plant species distribution: the compensated thermicity index, which depends on the temperature range of the coldest month, and the ombrothermic index, which is a precipitation/temperature ratio. We overlaid the mapped ponds to the maps of these large-scale variables, to obtain a table with their values for each pond, using the *v.what.rast* and *v.what.vect* modules of GRASS.

2.2. Biotic differences and indicator species of pond types

We performed a biotic regionalization analysis (Márquez et al., 2001) to define groups of ponds significantly distinguished by their floristic composition. The analysis was based on a matrix of 24 ponds × 174 plant species, with the presences and absences of each species in each pond.

To assess the potential of different plant *taxa* as indicators of pond type, we carried out an Indicator Species Analysis (Dufrêne and Legendre, 1997) based on a matrix with the species percent cover in each pond (McCune and Mefford, 1999). We used PC-ORD 4.0 for Windows to calculate for each species an indicator value (IV) and the associated significance test (Monte Carlo technique).

2.3. Abiotic differences between pond types

We performed Partial Least Squares (PLS) regression of the variables listed in Table 1 on temporary pond type. PLS regression combines features from principal component analysis and multiple regression and is specifically designed to deal with multivariate analyses where the number of observations is limited, missing data are numerous, and the predictor variables are highly correlated. It extracts orthogonal linear combinations (latent variables, or components) of the predictor variables that maximize the explanation of the target variable, assuming that all measured variance is useful variance to be explained (Abdi, 2010; Carrascal et al., 2009). This analysis was carried out with SPSS 17.0.

Following Carrascal et al. (2009) we selected the ‘significant’ latent factors as those that explained more than 5% of the original variance in the response variable (i.e., pond type). Within these significant latent factors we chose the variables with VIP (Variable Importance in the Projection) higher than 1 and square weight (amount of variance explained) higher than 0.05 (Carrascal et al., 2009). We also repeated the analysis excluding depth, which turned out non significant and for which there were missing values (Table 1), this way increasing the analysed sample size.

3. Results

All the studied ponds are shallow temporary freshwater habitats, none of them deeper than 2 m. Soil conductivity, a surrogate for salinity, did not surpass 584.7 μS/cm. Organic matter (carbon) content varied from 0.71 to 8.37%, and nitrogen content ranged from 0.14 to 0.74. Soils were moderately or slightly acidic, with pH usually between 4.7 and 5.8. Soil texture varied from sandy to clay soils, with the percentage of sand in sediments ranging from 17 to 93%.

The amount of annual rainfall varied between 533.42 and 669.91 mm. According to the bioclimatic variables, namely energy-related ones (375.61 < compensated thermicity index < 399.76, 2.97 < ombrothermic index < 3.62), the study area has a Mediterranean macrobioclimate and a Pluviseasonal Oceanic bioclimate. The ombrotype horizon varies from lower to upper humid (Rivas-Martínez, 2007). Potential evapotranspiration values range from 790.63 to 816.63.

The biotic regionalization analysis yielded three groups of ponds with significantly distinctive plant species compositions. Two of these groups corresponded to pond typology: Mediterranean temporary ponds ($n = 9$) and marshlands ($n = 13$), while the third group corresponded to disturbed ponds ($n = 2$). The latter were excluded from subsequent analyses, as their sample size was too low and they represent ill-conserved temporary ponds degraded by agriculture and overgrazing (observed in the field).

Indicator species analysis identified 33 species as indicators of Mediterranean temporary ponds and 35 species as indicators of marshlands in our study area. We present only the indicator plant species with very high significance ($\rho < 0.001$; Table 2).

PLS regression of abiotic variables on pond type (Mediterranean temporary ponds vs. marshlands) resulted in three ‘significant’ latent factors that captured 50.4% of the variation in the independent variables and explained 81.4% of the variation in pond typology (Table 3). The first latent factor, which explained 61.5% of the variance in pond typology (Table 3), is composed mainly of variables related to environmental energy, such as the compensated thermicity index and potential evapotranspiration, and soil texture (Table 4). In the second latent factor, which explained 13.4% of the variance in pond type (Table 3), the three most important and significant variables represent soil type and order, soil nitrogen content and potential evapotranspiration (Table 4). The third latent factor added an extra 6.6% to the proportion of variance explained (Table 3) including, besides soil order, the soil pH (Table 4).

4. Discussion

4.1. Temporary pond types

Three different types of temporary ponds were distinguished based on their plant species composition. Two of these types, namely Mediterranean temporary ponds and marshlands, correspond to two freshwater habitats, subgroup of standing waters, according to the interpretation manual of European Union (EU) habitats (European Commission, 2007): Mediterranean temporary ponds correspond to the priority habitat 3170*, and marshlands correspond to habitat 3110 (oligotrophic waters containing very few minerals of sandy plains – *Littorelletalia uniflorae*). The third type, disturbed ponds, cannot be assigned to any EU habitat, as it results from habitat degradation (observed in the field).

The three pond types we identified are in accordance with the main results of a previous study based on plant community data principal component and discriminant analysis on the same study area (Pinto-Cruz et al., 2009). It is worth noting that the biotic regionalization analysis performed was based on pond flora, and that the presence/absence of plant species is a more practical and unambiguous criterion than the abundance of plant communities. Furthermore, the sampling of pond species is easier and less time-consuming compared to the traditional phytosociological surveys of plant communities.

The identification of species associated with or indicative of groups of samples (in this case, ponds) is a common aspect of ecological research, including studies on environmental management. Indicator Species Analysis (ISA) allows statistically rigorous assessments of these indicator species (Bakker, 2008). In order to enable a straightforward determination of whether or not a pond contains a habitat of European interest or priority, we performed an indicator species analysis. The results allowed identifying bioindicator plant species for any combination of habitat types (McGeoch and Chown, 1998). This identification is very useful in terms of habitat identification, monitoring, conservation, and management. The

Table 2
Indicator plant species of each temporary pond type with $\rho < 0.001$ (Monte Carlo permutation test of significance, based on 1000 randomizations; $n = 22$). IV: indicator value.

Mediterranean temporary ponds	IV	Marshlands	IV
Eryngium corniculatum	49.9	*Agrostis stolonifera*	54.4
Baldellia ranunculoides	33.6	*Holcus lanatus*	45.4
Myosotis debilis	33.0	*Anagallis tenella*	33.7
Illecebrum verticillatum	30.6	*Hydrocotyle vulgaris*	27.1
Eleocharis palustris	26.5	*Juncus bulbosus*	21.7
Phalaris coerulescens	25.8	*Eleocharis multicaulis*	19.6
Juncus emmanuelis	24.5	*Isolepis fluitans*	15.4
Carum verticillatum	23.4	*Panicum repens*	14.5
Isoetes setaceum	22.2	*Juncus effusus*	13.1
Chaetopogon fasciculatus	18.9	*Galium palustre*	12.6
Pulicaria paludosa	18.6	*Hypericum elodes*	11.6
Polypogon maritimus	17.5	*Lobelia urens*	11.2
Lythrum borysthenicum	15.5	*Potentilla erecta*	9.8
Ranunculus trilobus	12.8	*Lotus uliginosus*	9.6
Isoetes velatum	12.3	*Ranunculus flammula*	7.7
Agrostis pourretii	10.5	*Myosotis retusifolia*	7.0
Hyacinthoides v. subsp. *transtagana*	10.4	*Trifolium repens*	6.3
Gaudinia fragilis	8.2	*Lycopus europaeus*	5.6

Table 3
Results of PLS (partial least squares) regression of abiotic variables on pond type: proportion of variance of *X* (the abiotic variables) and *Y* (pond type) accounted for by each latent factor.

Latent factors	*X* variance	Cumulative *X* variance	*Y* variance	Cumulative *Y* variance (R^2)
1*	0.241	0.241	0.615	0.615
2*	0.173	0.414	0.134	0.749
3*	0.090	0.504	0.066	0.814
4	0.097	0.601	0.039	0.853
5	0.027	0.628	0.079	0.933

* 'Significant' latent factors (sensu Carrascal et al., 2009).

Table 4
Results of PLS (partial least squares) regression of abiotic variables on pond type: VIP (Variable Importance in the Projection) and the square weight of each variable (amount of variance explained) in the three significant latent factors. "Significant" variables (i.e., those with VIP larger than 1 and square weight larger than 0.05; Carrascal et al., 2009) are shown in bold type. Variable codes as in Table 1.

Variables	Latent factors					
	1		2		3	
	VIP	Weight^2	VIP	Weight^2	VIP	Weight^2
CUse = CU4	0.846	0.027	0.775	0.003	0.896	0.115
CUse = CU5	**1.311**	**0.064**	1.205	0.009	1.158	0.003
CUse = CU7	0.718	0.019	0.651	0.000	0.658	0.020
Lith = L17	0.787	0.023	0.857	0.047	0.938	0.094
Lith = L2	0.781	0.023	0.729	0.006	0.699	0.000
Lith = L282	0.718	0.019	0.807	0.047	0.781	0.005
Geo = G100	0.538	0.011	0.530	0.009	0.732	0.127
Geo = G166	0.383	0.005	0.541	0.036	0.566	0.023
Geo = G200	**1.311**	**0.064**	1.238	0.025	1.188	0.001
Geo = G234	0.718	0.019	0.807	0.047	0.781	0.005
Geo = G56	0.781	0.023	0.729	0.006	0.699	0.000
SoilOrd = argiluvian	0.718	0.019	0.807	0.047	0.781	0.005
SoilOrd = hydromorphic	0.546	0.011	0.712	0.054	0.714	0.020
SoilOrd = incipient	**1.523**	**0.086**	**1.524**	**0.087**	**1.520**	**0.080**
SoilT = S801	1.042	0.040	**1.112**	**0.072**	1.081	0.015
SoilT = S901	0.787	0.023	0.798	0.026	0.858	0.069
Sand	**1.313**	**0.064**	1.196	0.003	1.178	0.033
Silt	**1.396**	**0.072**	1.265	0.000	1.251	0.043
Clay	**1.391**	**0.072**	1.262	0.000	1.235	0.028
Condut	0.046	0.000	0.228	0.010	0.936	0.381
pH	1.058	0.041	1.013	0.022	**1.052**	**0.075**
OrgMat	0.121	0.001	0.874	0.156	0.868	0.023
Nitr	1.150	0.049	**1.522**	**0.255**	1.470	0.015
Io	1.101	0.045	1.024	0.011	0.982	0.000
Itc	**1.512**	**0.085**	1.370	0.000	1.323	0.011
Prec	0.114	0.000	0.708	0.102	0.753	0.049
PET	**1.617**	**0.097**	**1.571**	**0.067**	1.507	0.000

Notes: CU4: non-agricultural (forestal) with moderate limitations; CU5: non-agricultural (forestal) with severe limitations; CU7: complex; L17: loamy schists, greywackes, arenites; L2: dunes and eolic sands; L282: dolerites; G100: Mira formation, turbidites; G166: sand, arenites and littoral gravel of Baixo Alentejo; G200: consolidated dunes, terraces; G234: doloritic lode of Alentejo – basic rocks; G56: dunes; S801: orthic luvisols; S901: orthic podzols.

resulting list of species (Table 2) is exclusive for each habitat type in this study area, so on the whole these results provide a clear practical way to distinguish between some of the standing temporary freshwater EU habitat types. These plant species represent good indicator species, as they are not rare in the ponds, and their presence can also be related to the predominant environmental factors (Cousins and Lindborg, 2004). This list is also simple enough to be easily and routinely monitored in the field, allowing the establishment of standard protocols for ecological management (Dale and Beyeler, 2001).

Some of the identified indicator plant species are of conservation concern: *Juncus emmanuelis* is considered vulnerable and is endemic to the south-west of the Iberian Peninsula; *Hyacinthoides vicentina* subsp. *transtagana* and *Myosotis retusifolia* are vulnerable and in danger of extinction respectively, and are both endemic to Continental Portugal and listed in Annex II and IV of the European Directive (European Commission, 1992); *Isoetes setaceum* is recognized as near threatened (Rhazi, 2007); and *Eryngium corniculatum*, despite being in the "least concern" category (Rhazi et al., 2009), is almost exclusively associated to Mediterranean temporary ponds, which may render it more vulnerable.

4.2. Relationship between temporary pond types and environmental variables

As we stated before, the studied habitats have an inherent temporal dynamics, meaning cycles and sometimes unpredictable fluctuations of environmental conditions. Nevertheless, as the persistence and conservation of habitats depends upon the consistency of environmental conditions across time and space (Gómez-Rodríguez et al., 2009), the selected environmental variables reflect stable environmental parameters or are derived from averages of several years. The explanatory variables range from local (fine) to large (broad) scale, most of them being spatially structured, but also correlated (e.g. compensated thermicity index, ombrothermic index and potential evapotranspiration). The use of PLS regression allowed us to overcome the problems usually associated to such correlations between variables (Carrascal et al., 2009).

The PLS regression analysis confirmed the importance of a combination of several environmental variables in determining the type of temporary pond habitat. The retention of three latent factors and the large number of significant variables highlight the complexity of the system and the difficulty in disentangling the effects of particular environmental variables. Nevertheless, the variables with significant weights in the latent factors can be considered predictors of pond typology, safeguarding that the contribution of each environmental variable cannot be seen in an independent way.

In the discrimination between Mediterranean temporary ponds and marshlands we emphasize energy-related variables such as the compensated thermicity index and potential evapotranspiration, and fine-scale edaphic characteristics. Environmental energy influences the ponds' hydroperiod, that is, the equilibrium between incoming and outgoing water. We considered bioclimatic parameters, such as the compensated thermicity and the ombrothermic indices, rather than raw climatic parameters, as the former reveal the relationship between the numerical values of temperature and precipitation. These indexes take into account the territory's extreme temperatures, which are one of the limiting factors for the distribution of plant species. It is important to note that potential evapotranspiration was significant in two of the latent factors, as it reflects the ponds' potential water loss, summarizing water evaporation and plant transpiration (Sánchez Carrillo et al., 2004).

The three aspects of soil texture are also important determinants of temporary pond typology, as soil texture is determinant for water retention capacity (Saxton et al., 1986). Clay soils have a greater water holding capacity than sandy soils. Again, in our case study, Mediterranean temporary ponds were positively related with clay percentage in the soil (Pinto-Cruz et al., 2009), while marshlands were related to sandy soils. In terms of soil chemistry, pH was also a significant explanatory variable. Marshland ponds are more acidic and, in fact, most of the marshland indicator plant species are characteristic of acidic soils.

Contrary to expectations, bedrock geology, lithological substrate, soil order and soil type did not have a significant expression in our results. Only incipient soils appeared correlated with marshlands, in agreement with their sandy soil texture. We expected, for instance, that Mediterranean temporary ponds would be significantly associated to hydromorphic soils, as they represent areas of poor drainage. This may have an explanation in the small catchment area of these ponds and the coarser scale at which these variables were measured. Finer-scale data layers on geology and lithology would be needed to detect such relationships.

The realism of management models is increasing rapidly with the improvement of spatial data sources, models, and computational power (Ostendorf, 2011). However, important spatial information layers are often still unavailable at the ideal spatial resolution and extent, and some variables are difficult or even impossible to measure at the most relevant scale. This is one of the limitations of studies aiming at natural resource management (Ostendorf, 2011; Parrott, 2010).

The identification of management units (such as groups of ponds) may help to optimise locations for field data collection or monitoring. It also allows the development of indicators that allow spatial surrogates or proxies to be assessed regularly, at a high spatial resolution and a broad spatial extent. The most obvious choice is to apply classification methods using data that describe the heterogeneity of the region of interest (Ostendorf, 2011).

Our results support the existence of spatial patterns in pond type distribution in Mediterranean environments. These habitats do not occur at random in the landscape (Grant, 2005). In fact, this kind of clustering of pond typology is easily observable in the field.With respect to the amplitude in the environmental variables we can conclude that, although only small differences were observed, the interactions between these variables were significant in determining temporary pond flora and, consequently, habitat typology. Nevertheless, further studies are required to determine the threshold of environmental variability that produces a shift from Mediterranean temporary ponds to marshlands.

Zones, regions, or in our case pond types, describe spatial combinations of biotic and abiotic characteristics and are important for management and analysis; spatial modeling may improve the cost efficiency of management (Ostendorf, 2011). A practical way of distinguishing between different pond types is crucial to define and apply management and conservation actions accordingly.

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