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The ecology of the Iberian inland waters: Homage to Ramon Margalef

Aquatic macrophytes in Doñana protected area (SW Spain): An overview

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ABSTRACT

A big portion of the Doñana protected areas corresponds to wetlands; in them aquatic macrophytes are the main primary producers and play also other important ecological functions. Nevertheless, they are inconspicuous organisms and their importance in these ecosystems does not seem to be well reflected in the bibliography about this natural area. This paper reviews the most significant information gathered about this group of organisms in this protected area, provides an updated catalogue of this group of plants, and offers some considerations related with this topic.

Key words: Doñana, aquatic macrophytes, aquatic vegetation, SW Europe.

RESUMEN

Una gran parte de los espacios protegidos de Doñana corresponde a humedales, en ellos los macrófitos acuáticos son los principales productores primarios, realizando además otras importantes funciones ecológicas. Sin embargo, son organismos poco conspicuos y su importancia en estos ecosistemas no parece estar reflejada en las publicaciones existentes relativas a este espacio natural. Este artículo recopila la información más significativa sobre este grupo de organismos en este espacio protegido, proporciona el catálogo actualizado de este grupo de vegetales y ofrece algunas consideraciones relativas al tema.

Palabras clave: *Doñana, macrófitos acuáticos, vegetación acuática, SW Europa.*

INTRODUCTION

A large portion of the Doñana protected area (Fig. 1) is composed of wetlands. In these ecosystems, aquatic macrophytes are responsible for most primary production and also play an important role in increasing ecosystem structures or recycling nutrients and elements. Aquatic macrophytes are, therefore, key elements in this paradigmatic natural area. Moreover, flora is one of the best natural sources of information regarding current and potential conservation in any natural place. The scarce number of studies on this conspicuous group of organisms is thus surprising.

When the last Doñana Floristic Catalogue was published twenty-five years ago (Castroviejo *et al*., 1980), it was quite thorough at that time; however, the bulk of new floristic records since then have been aquatic plants (as shown in this

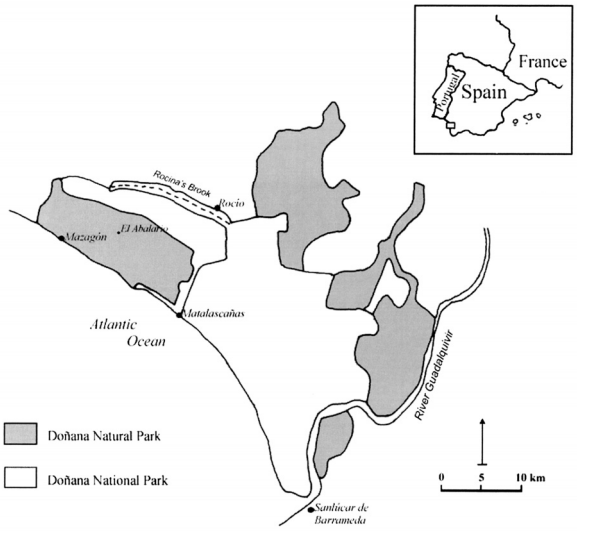

Figure 1. Location of Doñana protected areas. *Localización de los espacios protegidos de Doñana.*

paper). This indicates how little is known about aquatic plants in this area.

This is coupled with the fact that some significant environmental events have occurred in this same time period, an increase in intensive agriculture in the area, increased tourism in bordering areas, overexploitation of ground waters, invasions of exotic species, global warming, etc.

All of these issues point to the need to update the information related to the aquatic macrophytes in the Doñana protected area, which is the aim of this paper.

FIRST STEP: CATALOGUING

Unlike the cases of other places of great natural value in the southern Iberian Peninsula, such as the Sierra Nevada or Sierra de Grazalema, which were prospected by botanists during the nineteenth century or before, the first studies on Doñana´s flora appear much later in the mid-twentieth century. In 1945 C. Vicioso, an Aragonese botanist, published a list of taxa collected in the south part of the Huelva Province, but among these references there was no data on macrophytes. It was not until 1967, when references to aquatic macrophyte were found, that seven aquatic macrophytes were cited in an invertebrate catalogue (Mazaranov, 1967) for Guadalquivir Marshes (belonging to Doñana). Cabezudo later began the systematic study of flora in this preserved area, including 18 species of aquatic macrophytes in his studies (Cabezudo, 1974; 1975; 1978, and Galiano & Cabezudo, 1976). In 1981, some years later, the brilliant work of Castroviejo *et al*. (1980) completed the information compiled by Cabezudo, nearly completing the list of vascular plants in Doñana National Park. In subsequent years this Catalogue has changed very little, with the exception of aquatic plants that have contributed some important new records to the Doñana Catalogue: *Althenia orientalis* (García Murillo & Talavera, 1986), *Callitriche lusitanica* (Pizarro, 1990), *Zannichellia obtusifolia* (Talavera *et al.*, 1986, *Lemna trisulca*, and *Spirodella polyrhyza* (García Murillo *et al*., 1991), etc. (Table. 1).

In terms of the "other" plant groups included in aquatic macrophytes, i.e., Charophyta and Bryophyta, data on these are more scarce and inconsistent.

The first records of Charophyta were noted by Corillion (1961), who included two of Doñana's Charophyta species in his work on southern Spain and North Africa charophytes: *Chara connivens* and *Nitella flexilis*. Some years later, Comelles (1982) and Sánchez (1984) added two more taxa to the list: *Tolypella hispanica* and *Chara fragifera*, respectively. Almost one decade later García Murillo *et al*. (1993) added nine new records to Doñana's charophyte catalogue. Finally, the most recent records are on *Chara vulgaris* var. *oedophylla* and *Tolypella salina*, referenced by Espinar *et al*. (1997).

In the Bryophytes group, there are two papers on the *Riella* genus (Cirujano *et al*., 1988 and 1992); *Riccia fluitans* and *Ricciocarpos natans* were mentioned by Rivas Martínez *et al*. (1980) and *Sphagnum inundatum* by García Murillo *et al*. (1995).

Table 1 shows the complete and current catalogue of Doñana's submerged macrophytes. It includes 74 taxa (21 more than those related in 1993 by García Murillo *et al*.) of which 46 are Spermatophyta (62 %), 3 Pteridophyta (4 %), 6 Bryophyta (8 %) and 19 Chlorophyta (26 %). Besides, this table points to the first floristic record of each taxon.

Table 1. Catalogue of aquatic macrophytes of Doñana protected areas. *Catálogo de los macrófitos acuáticos de los espacios protegidos de Doñana.*

	TAXA*	FIRST RECORD
CHLOROPHYTA		
Characeae	*Chara aspera* Deth. ex Willd. var. aspera	García Murillo, Bernués & Montes, 1993
Characeae	*Chara canescens* Desv. & Lois.	García Murillo, Bernués & Montes, 1993
Characeae	*Chara connivens* Salmz. ex A. Braun	Corrillion, 1961

Table 1. Continued. *Continuación.*

CHLOROPHYTA		
Characeae	*Chara fragifera* Durieu	Sánchez, 1984
Characeae	*Chara fragilis* Desv.	Fernández Zamudio *et al*. (2006)
Characeae	*Chara galioides* DC.	García Murillo, Bernués & Montes, 1993
Characeae	*Chara hispida* L.	Van Vierssen *et al*., 1982
Characeae	*Chara vulgaris* L. var. *vulgaris*	García Murillo, Bernués & Montes, 1993
Characeae	*Chara vulgaris* L. var. *contraria* (A. Braun ex Kütz.) J. A. Moore	Fernández Zamudio *et al*. (2006)
Characeae	*Chara vulgaris* L. var. *oedophylla* (Feldman) R. D. Wood	Espinar *et al*., 1997
Characeae	*Chara vulgaris* L. var. *longibracteata* (Kütz.) J. Groves & Bullock-Webster	Fernández Zamudio *et al*. (2006)
Characeae	*Lamprothamnium papulosum* (Wallr.) J. Groves	García Murillo, Bernués & Montes, 1993
Characeae	*Nitella flexilis* (L.) C. Agardh	Corrillion, 1961
Characeae	*Nitella hyalina* (DC.) C. Agardh	García Murillo, Bernués & Montes, 1993
Characeae	*Nitella tenuisissima* (Desv.) Kütz.	García Murillo, Bernués & Montes, 1993
Characeae	*Nitella translucens* (Pers.) C. Agardh	García Murillo, Bernués & Montes, 1993
Characeae	*Tollypella glomerata* (Desv.) Leonh.	García Murillo, Bernués & Montes, 1993
Characeae	*Tollypella hispanica* Nordst. ex T.F. Allen	Comelles, 1982
Characeae	*Tollypella salina* Corillion	Espinar *et al*., 1997
BRYOPHYTA		
Ricciaceae	*Riccia fluitans* L.	Rivas-Martínez *et al*., 1980
Ricciaceae	*Ricciocarpos natans* L.	Rivas-Martínez *et al*., 1980
Riellaceae	*Riella cossoniana* Trabut	Cirujano *et al*., 1992a
Riellaceae	*Riella helicophylla* (Bory & Mont.) Mont.	Cirujano *et al*., 1988
Riellaceae	*Riella notarisii* (Mont.) Mont.	Cirujano *et al*., 1992a
Sphagnaceae	*Sphagnum inundatum*	García Murillo *et al*., 1995
PTERIDOPHYTA		
Azollaceae	*Azolla filiculides* Lam.	Cobo *et al*., 2003
Isoetaceae	*Isoetes velatum* A. Braun subsp. *velatum*	Galiano & Cabezudo, 1976
Marsileaceae	*Marsilea strigosa* Willd.	Fernández Zamudio *et al*. (2006)
SPERMATOPHYTA		
Apiaceae	*Apium inundatum* L.	Allier & Bresset, 1975
Apiaceae	*Oenanthe fistulosa* **L.	Cabezudo, 1975
Apiaceae	*Thorella verticillatinundata*** (Thore) Briq.	Cabezudo, 1974
Apiaceae	*Oenanthe globulosa*** L.	Cabezudo, 1975
	*Carum verticillatum*** (L.) Koch	Galiano & Cabezudo, 1976
Apiaceae	*Eryngium corniculatum*** L.	Cabezudo, 1974
Apiaceae	*Eryngium galiodes*** Lam	Cabezudo, 1978
Callitrichaceae	*Callitriche truncata* Guss. subsp. *occidentalis* (Rouy) Schotsman	Castroviejo *et al*., 1980
Callitrichaceae	*Callitriche lusitanica* Schotsman	Pizarro, 1990
Callitrichaceae	*Callitriche stagnalis* Scop.	García Murillo, Bernués & Montes, 1993
Callitrichaceae	*Callitriche brutia* Petagna	Castroviejo *et al*., 1980
Callitrichaceae	*Callitriche obtusangula* Le Gall	Fernández Zamudio *et al*. (2006)
Ceratophyllaceae	*Ceratophyllum demersum* L.	Mazaranov, 1967
Cyperaceae	*Scirpus fluitans* L.	Rivas-Martínez *et al*., 1980

Table 1. Continued. *Continuación.*

SPERMATOPHYTA		
Elatinaceae	*Elatine alsinastrum* L.	Mazaranov, 1967
Elatinaceae	*Elatine macropoda* Guss.	Mazaranov, 1967
Elatinaceae	*Elatine hexandra* (Lapierre) DC.	Cabezudo, 1975
Halogaraceae	*Myriophyllum alterniflorum* DC.	Mazaranov, 1967
Halogaraceae	*Myriophyllum spicatum* L.	Van Vierssen *et al*., 1982
Hydrocharitaceae	*Hydrocharis morsus-ranae* L.	Cabezudo, 1978
Juncaceae	*Juncus heterophyllus* Dufour	Galiano & Cabezudo, 1976
Lemnaceae	*Lemna gibba* L.	Galiano & Cabezudo, 1976
Lemnaceae	*Lemna trisulca* L.	García Murillo *et al*., 1991
Lemnaceae	*Lemna minor* L.	Mazaranov, 1967
Lemnaceae	*Spirodella polyrhiza* (L.) Schleiden	García Murillo *et al*., 1991
Lemnaceae	*Wolffia arrhiza* (L.) Horkel ex Wimmer	García Murillo, 2000
Lentibulariaceae	*Utricularia exoleta* R. Br.	Castroviejo *et al*., 1980
Lentibulariaceae	*Utricularia australis* R. Br.	Cabezudo, 1975
Nymphaeaceae	*Nuphar luteum* L.	Castroviejo *et al*., 1980
Nymphaeaceae	*Nymphaea alba* L.	Castroviejo *et al*., 1980
Polygonaceae	*Polygonum amphibium* L.	Castroviejo *et al*., 1980
Potamogetonaceae	*Potamogeton natans* L.	Galiano & Cabezudo, 1976
Potamogetonaceae	*Potamogeton polygonifolius* Pourret	Castroviejo *et al*., 1980
Potamogetonaceae	*Potamogeton lucens* L.	Mazaranov, 1967
Potamogetonaceae	*Potamogeton trichoides* Charm. & Schlecht.	Cabezudo, 1978
Potamogetonaceae	*Potamogeton crispus* L.	Mazaranov, 1967
Potamogetonaceae	*Potamogeton pectinatus* L.	Mazaranov, 1967
Ranunculaceae	*Ranunculus tripartitus* DC.	Cabezudo, 1978
Ranunculaceae	*Ranunculus peltatus* subsp *baudotii* (Godron) Meikle ex C. D. K. Cook	Allier & Bresset, 1975
Ranunculaceae	*Ranunculus peltatus* subsp *saniculifolius* (Viv.) C. D. K. Cook	Pizarro, 1993
Ranunculaceae	*Ranunculus peltatus* Schrank subsp *fucoides* (Freyn) Muñoz Garmendia	Cirujano *et al*., 1992b
Ruppiaceae	*Ruppia maritima* L. var. *maritima*	Cabezudo, 1978
Ruppiaceae	*Ruppia drepanensis* Tineo	Castroviejo *et al*., 1980
Zanichelliaceae	*Althenia orientalis* (Tzvelev) García Murillo & Talavera	García Murillo & Talavera, 1986
Zanichelliaceae	*Zannichelllia obtusifolia* Talavera, García & Smith	Talavera *et al*., 1986
Zosteraceae	*Zostera noltii* Hornem	Castroviejo *et al*., 1980

* Some taxa refereed to Doñana Protected Areas have been related with incorrect identifications (as *Callitriche palustris* L., *Hippuris vulgaris* L., *Zannichellia palustris* L. or *Zannichellia peltata* Bertol.) in other cases they correspond with synonyms (as *Ranunculus baudotii* Godron; *Ruppia maritima* subsp. *drepanensis* L.(Tin.) Maire & Weiller or *Utricularia gibba* L.).
** The juvenile form of these species show morphological, anatomical and physiological characters corresponding with aquatic macrophytes.

SECOND STEP: AQUATIC MACROPHYTES AND ENVIRONMENTAL FACTORS

At the end of the 1970s, González Bernáldez directed a series of studies on the relationship between the plants in Donaña and the environment (see García Novo, 1997). In this context, there was practically no mention of aquatic plants, with just one study found on the marsh's vegetation (Allier & Bresset, 1977). In 1980, Rivas Martínez *et al*. published an excellent work on the vegetation in the Doñana National Park, in which they carried out a detailed phytosociological analysis of the different communities of plants in this protected natural area. Nevertheless, despite the superior quality of the research done, the informa-

tion on aquatic plant communities was insufficient (as can be deduced from the chorological changes after 1980, included in Table 1).

In the 90s, in response to researches by Montes on Donaña's aquatic ecosystems, new data appeared on the ecology of aquatic plants in the area: data was published on their biomass (Duarte *et al*. 1990); the main factors (flooding time and salinity) controlling the distribution of these plants in Doñana's wetlands were identified (Bernués, 1990; Duarte *et al*., 1990); and a study was done on the marsh's seed bank (Grillas *et al*., 1993). Santamaría (Santamaría, 1995; Santamaría & Hootsmans, 1998; Santamaría *et al*., 1995; 1996), under the direction of Montes and with samples collected from Doñana, also carried out a series of studies on the autoecology of *Ruppia drepanensis* Tineo, one of the most abundant underwater macrophytes in the Doñana salt marsh. In this same period, Serrano & Toja (1995), working in sand lagoons of Doñana, related the presence of some aquatic macrophytes with other ecological parameters.

And finally, more recent works by Espinar (2004) and Espinar *et al*. (2002) have contributed valuable information on the salt marsh aquatic macrophytes in relation to their environment and to communities of helophytes.

Studies on Seed Dispersal

At the turn of the century, and as a result of the multidisciplinary approach taken by the Doñana Biological Station to environmental processes and with the involvement of Santamaría, a series of studies appeared on the role of birds in the passive transport of organisms. To be sure, a large number of these studies focused on the dispersal of aquatic macrophyte seeds by aquatic birds (Charalambidou *et al*., 2003; Green *et al*., 2002; Figuerola & Green, 2002 and 2004; Figuerola *et al*., 2002; 2003 and 2005). These researches have been consolidated as a line of work, which is currently being carried out in the Doñana Biological Station under the direction of Green, with outstanding results. Likewise, Espinar *et al*. (2004) have recently published studies in this area.

Aquatic Plants and Climate Change

As stated in the introduction to this paper, a site's flora is one of the best natural sources of information on that area. This fact is even more perceptible in aquatic plants since their reaction to environmental changes (due to their particular physiology) is much faster and precise. Based on this premise, recent studies carried out in the eastern part of Doñana National Park and in the park's lagoons have shown how useful diachronic studies on the presence and distribution of aquatic plants can be in detecting climatic changes within relatively recent timeframes. The work of Sousa (2004) and Sousa & García Murillo (1998; 1999; 2003 and 2005) illustrate this fact and find an explanation for the processes of aridization and desiccation of the coastal wetlands of Huelva Province by linking these processes to the end of the Little Ice Age, using –among other things– the presence of certain species of aquatic plans, the distribution of vegetation in the wetlands, and their changes over time.

THIRD STEP: REGARDING CONSERVATION

The uniqueness of the diverse species of aquatic macrophytes found in south-western Europe has been pointed out by some authors (Cook, 1983; García Murillo, 2003; Montes & Martino, 1987); the majority of these taxa are located in the Doñana area. The work of Cirujano *et al.* (1992b) is noteworthy here in its ranking of Spanish wetlands based on the presence of certain species of macrophytes; the Doñana salt marsh was ranked second among all wetlands considered.[1]

In addition, in the late 1990s, the Andalusian Regional Environmental Agency (later, the Environmental Council) started a line of research aimed at identifying the biology of the plant species most at risk from a conservation standpoint.

[1] In the work cited, the authors did not consider the Doñana lagoons or the changes in flora, which occurred after the work's publication, which clearly would have significantly increased the ranking of this area.

The most salient outcomes of these studies were the "Andalusian Plant Species Red List (Decreto 104/1994; Ley 8/2003)" and two volumes compiling the most significant information on the species selected (Blanca *et al*., 1999-2000). In contrast to previous Spanish "Red Lists" (ICONA, 1987), this one included a significant number of aquatic species, as well as *Althenia orientalis, Hydrocharis morsus-ranae, Utricularia exoleta, Wolffia arrhiza*, *Marsilea strigosa,* and *Thorella verticillatainundata* (García Murillo, 2000; Silvestre, 2000), found in the Doñana area.

This was followed, as proposed by the Ministry of Environment, by numerous studies intended to update the "Red List" (ICONA, 1987) nationally. These studies were compiled in the AFA Project (Bañares *et al*., 2003), including the red list and the most relevant data from the research done on the different species, although it was not possible to study some of the species listed. The AFA red list includes two aquatic macrophyte species found in Doñana (*Utricularia exoleta* and *Hydrocharis morsus-ranae*).

The surveys and research carried out for the Red Lists generated numerous articles which highlighted the state of some species of aquatic macrophytes. Included among such articles were those of Cirujano *et al*. (1998) and García Murillo *et al*. (2000) on species found in the Doñana protected area.

Exotic Organisms

The early 1980s brought the detection of the first exotic organisms in Doñana (García Murillo *et al*., 2004b). The first of such invaders was the American crawfish (*Procambarus clarckii*) and its spectacular proliferation. The ability of *P. clarckii* to physically transform its environment and alter the availability of resources for other species in the aquatic ecosystems in which it was introduced, deeply concerned environmentalists and scientists. Its effect upon macrophyte communities was tremendous, given that they are its principal food source. After the initial period of crawfish expansion, numerous Doñana macrophyte communities were simply dwindling, with some species wiped out due to the activity of this animal (Bravo *et al*., 1993; Duarte *et al.*, 1990; García Murillo *et al*., 1993). The numerous studies on *P. clarkii,* undertaken by the UAM (Universidad Autónoma of Madrid) research team headed by Montes, have emphasised the fact that it is now a key element in most of the aquatic ecosystems in Doñana and a significant control factor when it comes to aquatic macrophyte populations in this protected area (Bravo *et al*., 1993; Gutiérrez-Yurrita *et al*., 1998).

Likewise, the *Azolla filiculoides* species –a floating pteridophyte native to the New World– began to appear in the Doñana marsh in the early part of the 21st century (Cobo *et al*., 2003 and García Murillo *et al*., 2004a). In just a couple of years, its presence has extended over nearly the entire marsh, forming carpets sometimes reaching 10cm thick, which can be clearly seen from the RBD (Doñana's Biological Reserve) plane used for bird surveys. These carpets prevent the sun's rays from reaching the water below, thereby making it impossible for submerged macrophytes (nearly all present in this area) to develop. They also increase eutrophyzation since they can fix nitrogen, and their respiratory activity consumes the oxygen in the water below (García Murillo *et al*. 2004a). Just as with the American red crawfish, the changes in the aquatic ecosystems of Doñana attributable to *Azolla filiculoides* may be dramatic. The attempts to control it have, to date, been futile (García Murillo *et al*., 2004b).

Finally, in December of 2004, the tropical neophyte *Pistia stratiotes* was found in some irrigation canals located in the Doñana Park in the area of Sanlúcar de Barrameda covering 3Km of canals (García Murillo *et al.*, 2005a). Thanks to the quick intervention of the Andalusian Regional Council on the Environment –faced with the risk posed by this new invasion to the Doñana protected areas– and the low temperatures in January 2005, the *Pistia* carpets were eliminated (García Murillo *et al*., 2005b). Nevertheless, the risk continues to exist since some of the *Pistia* plants sampled had flowers and seeds, and it is well-known that the seeds of this species can remain functional for long periods of time buried under the water.

CONCLUSIONS

In the time span since the publication of the last floristic catalogue on the Doñana area, numerous references whose primary or secondary objective is the study of Doñana's aquatic macrophytes can be cited, although they are few in comparison to existing information on other in the same area.

With regard to the catalogue on aquatic macrophytes, we believe it is completed except for the addition of new exotic plants whose effects encompass this natural area (Cobo *et al*., 2003), and the withdrawal of others –cited by 20th-century researchers– which have disappeared due to the deterioration in water quality and the pressure of the environment surrounding this protected natural area.

The regional administration –and to a lesser extent the national one– has taken this situation into account, by including some of the aquatic macrophytes in its red list of species in danger of extinction. Nevertheless, the number of taxa which should be included in the list is greater (see Cobo *et al*., 2002).

Moreover, the importance of this area for the conservation of aquatic macrophytes is evident since it contains numerous species of aquatic macrophytes, many of which are limited-area species ("endemic species"), relatively uncommon in aquatic plants.

Along the same lines, a conflict has arisen in the area's flora conservation-management, fully affecting the group of aquatic plants: many of the aquatic macrophyte species found in Doñana cover wide areas of distribution (in theory); however (in reality) these areas are largely fragmented, with similarly fragmented populations. These species should be included in the red lists, since their vulnerability is quite high, a fact which has been ignored by environmentalists when it comes to the (theoretical) distribution areas of these species.

As studies are concerned on aquatic macrophytes and how they relate to environmental factors, while there are a number of quality studies on this subject, more work on the basic aspects of this relationship would be of value (e.g., how macrophytes relate to nutrients, factors determining macrophyte distribution, studies on succession, etc.). Finally, attention must be called to the deterioration of Doñana's waters, the effects of which operate on two levels:

1. By causing the disappearance of so-called "difficult environment" specialist plants that had taken refuge in this natural setting (such as plants from bogs or oligotrophic wetlands)
2. By facilitating the invasion of exotic species, some of which have great potential for habitat modification and its consequences.

A question remains: Is there still time for us to comprehend the full complexity of the native aquatic systems of Doñana or are the transformations detected in recent years the beginning of an irreversible process that will profoundly change this place?

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