Doñana Wetlands, Spain

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Introduction

The Doñana Wetlands (37ºN, 6º25'W) are located in southwest Spain including parts of the provinces of Huelva, Sevilla and Cadiz (Fig 1). Doñana contains one of the largest wetland complexes in Western Europe, lying within the delta of the Guadalquivir River. It consists of an intricate matrix of marshlands and aquifer-fed dune ponds. It is surrounded by Mediterranean scrubland, pine forests, a 30 km-long mobile dune ecosystem along the shoreline of the Atlantic Ocean, and cultivated areas (Fig 2). Two main habitat types characterize Doñana's natural wetlands: extensive seasonal marshes and adjacent eolian sands with natural depressions which can hold over 3,000 temporary ponds in rainy years (Díaz-Paniagua et al. 2010). Examples of wetland systems and fauna characteristic of the Doñana Wetlands are illustrated in Figures 3 to 7.

Figure 1: Protected area limits of Doñana Natural Space at national, European and International Scales (Figure by LAST-EBD/CSIC 2014).

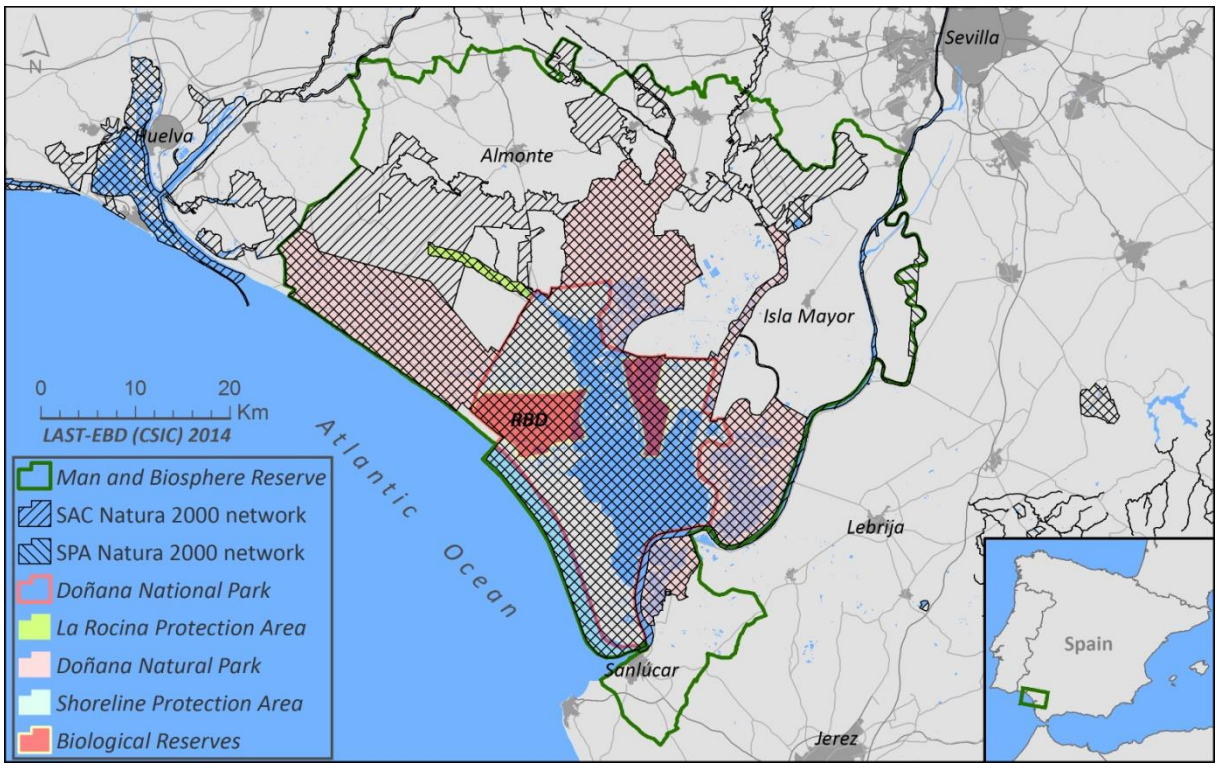
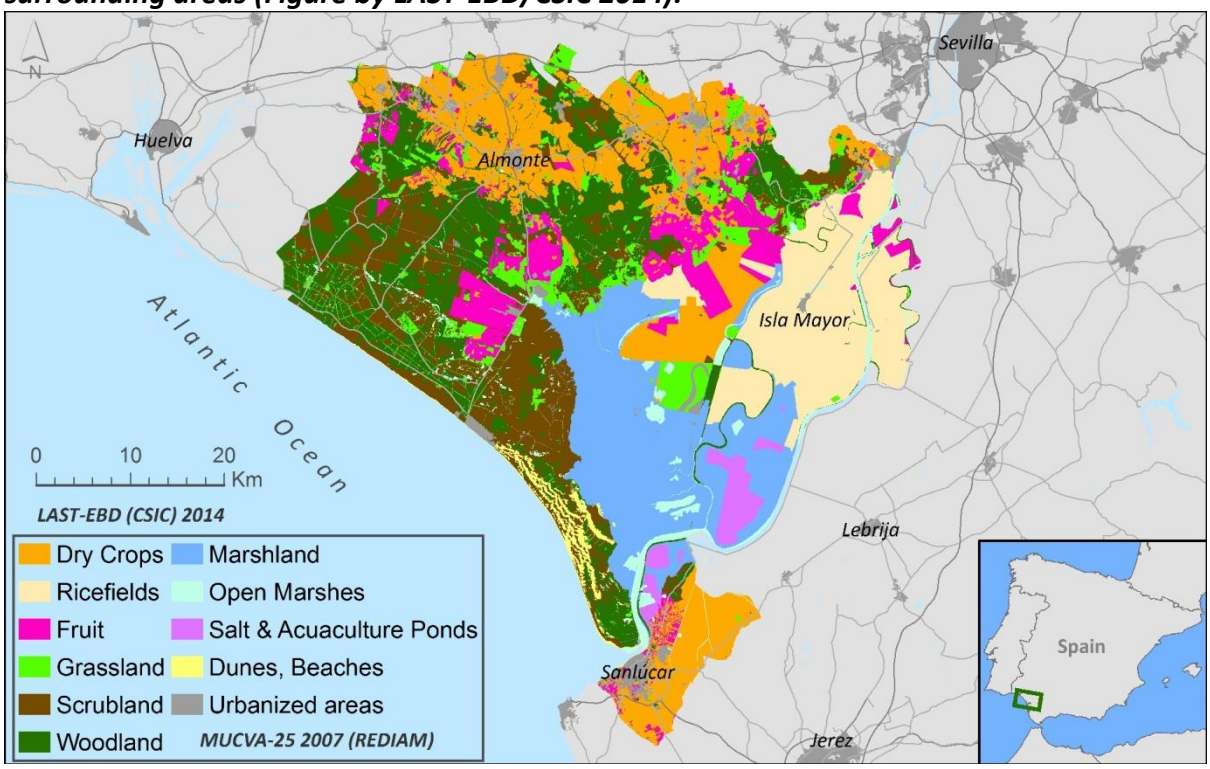


Figure 2: Distribution of main land uses and land covers in the Doñana Natural Space and surrounding areas (Figure by LAST-EBD/CSIC 2014).



The first written references to the territories of Doñana date from the fourteenth century, in a book dedicated to game hunting by King Alfonso XI. The area is named after Doña Ana de Silva y Mendoza, wife of the seventh Duke of Medina-Sidonia. In the nineteenth century, kings and nobles who used this area for hunting and leisure were joined by naturalists such as Abel Chapman and Walter J. Buck, attracted by the great diversity of fauna and the ease of obtaining new specimens for scientific collections in Northern Europe. In the middle of the twentieth century, Doñana was studied by pioneering Spanish ornithologists such as Francisco Bernis and José Antonio Valverde, who caught the interest of conservationists from abroad, such as the founders of the World Wildlife Fund. Their support led to the purchase in 1963 of what became the first protected area of Doñana, which was then managed by the largest scientific entity in Spain (the Spanish National Research Council-CSIC).

Hydrology and history

Doñana is located in the Mediterranean climatic region, with a sub-humid climate with rainy autumns and winters, hot and dry summers and mild winters. Average annual rainfall is 549 mm, and the average daily temperature ranges from 4.6 ^{o}C in January to 32.6 ^{o}C in July. Of deltaic origin, Doñana is located between the Guadalquivir River Estuary, and the Atlantic Ocean. The size and depth of the wetlands varies remarkably between years, driven principally by variable rainfall. Wetland inundation starts from September onwards, although the first rainfall is highly unpredictable. On average, the highest monthly rainfall occurs in November and maximum inundation levels are reached during February. In late spring, evaporation becomes the most important factor influencing water levels, and both the marshes and ponds dry up slowly until most of the surface area is completely dry by the end of July.

Most dune ponds in Doñana are temporary, classified within a wide gradient of hydroperiod. Ponds are mainly filled by the rise of water table after heavy rains, and the high inter-annual variation in

rainfall increases the variation in hydroperiod of the ponds, which in some years may be filled in autumn, during other years in winter, and still others in spring. This unpredictable hydrological cycle generates a high level of inter-annual variation in the aquatic communities present in each pond (Gómez-Rodriguez et al. 2010; Florencio et al. 2014). Only a small number of dune ponds retain water throughout the year, these being at the interface between mobile and stable dunes where the local and regional aquifers discharge. There is a high heterogeneity of size, depth and water chemistry in the dune ponds, as well as in their flora and fauna, which is mainly related to variations in geomorphology (Díaz-Paniagua et al. 2010; Florencio et al. 2014). Some natural ponds have been deepened to supply water for domestic and wild animals, converting them into permanent water bodies. These ponds play an important role in the conservation of aquatic flora and fauna, as in the case of some hydrophytes that presently only persist in these permanent water bodies.

The marshes were formed by sediment deposition in the estuary of one of Spain's largest rivers, the Guadalquivir, but currently receive most of their water from a network of streams (some of which are fed by aquifer discharge) and direct rainfall. Until the XVIIIth century, the Doñana marshes were largely tidal, but gradually this marine influence has reduced; and most of the wetlands currently have a continental character. Sediments from the rivers have formed an elevated platform of about 3.6 m above mean sea level. Sea water only enters a small part of the marshes with high tides. The natural marsh is largely a flat bed of clay, but slight changes in topography translate into a wide diversity of hydroperiods and vegetation types, ranging from channels "caños" and seasonal lakes "lucios" to low-lying islands or "vetas". A few flooded areas are artificially maintained around the edge of the National Park at Visitor Centres, notably at the José Antonio Valverde Centre where a major heronry has been established (Ramo et al. 2013).

From historical data, the original extent of the natural marshland has been estimated at around 180,000 ha, which has been gradually reduced to the remaining 32,000 ha and confined to the western side of the Guadalquivir river bed. The remaining 150,000 ha have mainly since 1960 been completely drained or turned into cultivated marshlands, such as ricefields (up to 37,000 ha), fish farms (3,200 ha) and salt ponds (1,000 ha). Drier parts are cultivated with cotton, wheat, sunflower and other crops, or turned into urban areas and roads. The rivers and its meanders that formed Doñana's marshes have been greatly modified, and two of the three arms of the Guadalquivir River were closed off, while the central channel has been repeatedly dredged to allow progressively bigger ships to reach the port of Seville. Remaining rivers and streams were channelized, with dykes to prevent the flooding of fields. In the 1980s a large dyke was built along the boundary between the marshes in the Doñana National Park and the Guadalquivir River with the aim of recovering part of the natural marshland. The presence of this dyke means that water levels become artificially high in wet winters, and the excess water is slowly drained into the river through sluice gates. The Aznalcóllar mine spill disaster in 1998 contaminated part of the area adjacent to the National Park with sludge rich in heavy metals (Taggart et al. 2006). The response by the central government was an ambitious "Doñana 2005" restoration project. The aim was to partially recover the natural dynamics of the Doñana marshland, and has included the restoration of over 5,000 ha of agricultural land back to marshland by eliminating the drainage system (García-Novo and Marín-Cabrera 2006). Measures to improve water quality using water purification and treatment systems were also included, as was the development of an extensive experimental system of 96 temporary ponds (Frisch et al. 2012). Plans to restore exchange between the Guadalquivir and the marsh inside the National Park within the framework of this restoration project were not completed before 2014.

Biodiversity

Doñana has a biodiversity that is unique in Europe. The area features a great variety of ecosystems and holds a highly diverse combination of European and Africa flora and fauna, including many

globally threatened species such as the Marbled duck (*Marmaronetta angustirostris*), Spanish Imperial Eagle (*Aquila adalberti*) and Iberian Lynx (*Lynx pardinus*) as well as localized and Iberian endemics. Temporary ponds form a robust network of aquatic habitats of specialized aquatic flora and fauna, with different strategies to resist summer desiccation, whereas the Doñana marshes have many similarities with the Camargue in the Rhône river delta in France (*Parc Naturel Régional de Camargue*). At least 33 Natura 2000 habitats have been identified in Doñana, of which 8 are European priority habitats (Mediterranean temporary ponds, several dune communities, wet heath *Erica* sp, and Mediterranean salt steppes and pseudo-steppe habitats).

Including all habitats, over 1,300 vascular plants have been identified in the Doñana region, 170 of which are endemic species and 60 are threatened (applying IUCN criteria). Nearly 400 species are typical of Doñana wetlands (marsh and dune ponds), with almost 23 species exclusive to the Iberian Peninsula (e.g. *Juncus emmanuelis; Rorippa valdes-bermejoi*). At least 24 species are threatened at national and 6 at international level (e.g. *Avellara fistulosa, Hydrocharis morsus-ranae, Micropyropsis tuberosa, Caropsis verticillato-inundata*). Three main groups of hydrophytes can be differentiated for the vegetation of temporary ponds: (1) non strict aquatic plants (*Agrostis stolonifera, Paspalum paspalodes, Cynodon dactylon, Mentha pulegium, Baldellia ranunculoides*); (2) wetland species occupying the borders of ponds (*Juncus maritimus, Eleocharis palustris, Eleocharis multicaulis*); and (3) submerged and floating macrophytes in the deep zones (*Juncus heterophyllus, Ranunculus peltatus, Isolepis fluitans, Myriophyllum alterniflorum, Callitriche obtusangula*) (Diaz-Paniagua et al. 2010). In the marshes, two main vegetation groups are found: the lower marsh is dominated by the emergent bulrushes *Bolboschoenus* (*Scirpus*) *maritimus* and *Schoenoplectus* (*Scirpus) litoralis;* whereas the higher marsh is a salt-marsh dominated by the glasswort *Arthrocnemum macrostachyum* and common woodrush *Juncus subulatus (*Espinar et al. 2002). The microflora is not well studied, but includes diatom species not recorded elsewhere (Blanco et al. 2013).

Regarding vertebrates, exceptional numbers have been recorded for birds. Due to its strategic location between the continents of Europe and Africa and its proximity to the Strait of Gibraltar, Doñana's large expanse of seasonal freshwater marshes is a breeding ground as well as a transit point for hundreds of thousands of European and African birds (aquatic and terrestrial), and hosts many species of migratory waterbirds during the winter. Over 300 different species of birds may be sighted there annually, of which about half are local breeding species, and over 60 are localized or in decline at a European level (such as the Crested Coot *Fulica cristata*). Many are waterbirds (e.g. *Ardeola ralloides, Plegadis falcinellus, Platalea leucorodia, Phoenicopterus ruber*), Doñana being one of the most important sites in Europe and the Mediterranean region for breeding waterbirds (Martí and del Moral 2003), with major increases in the number of colonial waterbirds in recent decades (Ramo et al. 2013). Eight of the regularly occurring bird species are nationally threatened and five are globally threatened (IUCN criteria), such as marbled duck and white-headed duck (*Oxyura leucocephala*). Doñana meets the Ramsar Convention's 1% criterion for international importance for at least 25 species of wintering waterbirds. Many of these species are highly dependent on the ricefields and fish-farms, and this is likely to explain why these species have tended to increase their population size (Rendón et al. 2008). Although originally protected because of its spectacular wetlands and waterbird concentrations, Doñana is also famous for its birds of prey, which are highly dependent upon the aquatic systems as well (Sergio et al. 2011). The Doñana coast is also of considerable importance for wintering and roosting seabirds (e.g. Audouin's gull *Ichthyaetus audouinii*). In the last century, species like *Turnix sylvaticus* and *Otis tarda* became extinct.

In Doñana, 27 continental fish species have been identified (e.g. *Mugil cephalus, Atherina boyeri*). Seven species are exotic, these being highly dominant (e.g. *Gambusia holbrooki*, *Cyprinus carpio*). Nearly all native species are classified as Vulnerable or Endangered using IUCN criteria (e.g. *Anguilla*

anguilla), one species is endemic (*Aphanius baeticus*), and *Acipenser sturio* is now extinct. Amphibians reach high abundance and diversity in this area: six out of a total of twelve species are Iberian endemics. A characteristic dwarfism has been reported for the populations of some amphibians of Doñana (*Triturus pygmaeus*, *Lissotriton boscai* and *Pelobates cultripes*). Among the aquatic reptiles, there is a high abundance of the aquatic turtles *Mauremys leprosa* and *Emys orbicularis* that mainly inhabit the more permanent ponds, both considered threatened at a national level (IUCN criteria). Also *Natrix maura* and *Natrix natrix* are also present in the area. Mammals include both wild and domestic animals. The Iberian lynx (*Lynx pardinus*) is the most emblematic predator in the area, and the Eurasian otter (*Lutra lutra)*, genet cat (*Genetta genetta*) and other carnivores are also present. The Eurasian water vole *Arvicola sapidus* is characteristic of the temporary ponds. Ancient breeds of cattle (Mostrenca cow) and horses (Retuertas' horse) feed in the marshlands. All mammals depend heavily on the water bodies during summer for drinking.

There is a high diversity of aquatic macroinvertebrates, with more than 110 species of aquatic Coleoptera (including ibero-african endemics such as *Hygrotus lagari*, *Hydroporus lucasi* and *Cybister tripunctatus africanus,* as well as rare species such as *Rhantus hispanicus* and *Haliplus andalusicus*), 19 heteropterans, and seven large branchiopods (Millán et al. 2003; Florencio et al. 2014). Doñana is considered a hotspot for Odonata, with 42 species recorded, including eleven threatened species, among which the vulnerable *Lestes macrostigma* find optimal habitats in temporary ponds and marshes (Florencio and Díaz-Paniagua 2012). The zooplankton are relatively well studied, including 48 cladocerans, 20 cyclopoids, 13 diaptomids, 8 harpacticoids (Fahd et al. 2009), 20 ostracods (Alcorlo et al. 2014) and 74 rotifers (García-Novo and Marín-Cabrera 2006). There are species of Rhabdocoela flatworms that have not been recorded elsewhere (Van Steenkiste et al. 2011).

Conservation status

In 1969, the Doñana Biological Reserve and several surrounding estates were declared a National Park, enclosing nearly 38,000 ha. In 1974, park management was handed over from the Doñana Biological Station (EBD-CSIC) to the authorities with responsibility for environment and nature conservation (Institute of Nature Conservation, Ministry of Agriculture). EBD-CSIC has remained in charge of research coordination since that time. In 1978, the National Park was extended to over 50,000 ha and buffer zones of over 25,000 ha were delimited. In 1989, these buffer zones were declared a “Natural Park” by the regional government (Andalucía). An important extension of the Natural Park followed in 1997, and the latest extension of the National Park occurred in 2004. Doñana is the third biggest National Park in Spain, and the largest wetland protected as a National Park. The National and Natural Park together now cover over 110,000 ha (Fig. 2). The Doñana Natural Space (‘Espacio Natural de Doñana’ END) is the official name used to refer collectively to these two protected areas since 2006.

Doñana is covered by four international protection designations. The Doñana Biosphere Reserve was declared in 1980 and then occupied both the National Park and buffer zones (about 77,000 ha). It was extended in 2013 to nearly 270,000 ha, including nearly all municipalities of the region (Fig. 2). Doñana was included in the Natura 2000 Network as a Special Protection Area for Birds (Birds Directive) in 1987 and as Site of Community Importance (Habitats Directive) in 1997, being extended with adjacent areas in 2006. Today nearly 145,000 ha of the area are included in the Natura 2000 Network (Fig. 2), covering the whole Doñana protected area and nearby water bodies as well as pine forests. The area was designated as a Ramsar wetland in 1982, first covering the National Park and being extended subsequently to include the Natural Park in 2005. In 1994, Doñana National Park was designated as a World Heritage Site.

Ecosystem Services

There have been several studies on the ecosystem services provided by the Doñana wetlands, their monetary estimation and criteria for their valuation (Martín-López et al. 2007a, 2007b, 2009), and their spatial distribution (Palomo et al. 2012, 2014). Also, there has been a preliminary review of the ecosystem services provided by waterbirds (Green and Elmberg 2014). In terms of the cultural values provided by birds, Doñana is clearly critical for the maintenance of many populations across the Western Palearctic. The seed dispersal service provided by birds dependent on Doñana is also of great importance.

The greater Doñana ecosystem is used to produce strawberries that are exported all over Europe, as well as large quantities of rice. The deliberate introduction of the Louisiana red swamp crayfish (*Procambarus clarkii*) starting in 1974 aimed to promote commercial exploitation of this species (Habsburgo-Lorena 1978), although this has probably had serious negative consequences for the rest of the fauna. Crayfish are extracted and mainly exported to other parts of the Iberian Peninsula, Europe and the United States. Hunting is still permitted in limited areas outside the National Park, including small game (rabbits, partridge, thrushes, etc.) and waterfowl. Limited grazing of livestock is permitted across the National Park. Other natural resources exploited in the area are pine kernels, honey and charcoal. The marine areas off the shores of Doñana are hugely productive and traditional shellfish exploitation on the beaches of the National Park is permitted under authorization.

Doñana attracts birdwatchers and other ecotourists from all over Europe and beyond. The beaches are used mainly by national tourists and day trippers from Seville during weekends and summer holidays. The El Rocío pilgrimage is of huge cultural importance and is strongly linked with the natural values of Doñana. The major pilgrimage, with participation of nearly one million people, takes place in the week before Pentecost, while during the rest of the year small groups of pilgrims visit the shrine of El Rocío each weekend.

Threats and challenges

The most important threats to Doñana are related to human activities in the surrounding areas (Fernández-Delgado 1997). The ecosystem has been under constant threat from the drainage of the marshes, the gradual intensification of agricultural production (including groundwater extraction from thousands of wells, and use of fertilizers and other chemicals), and the expansion of tourist facilities along the coast. These activities affect both the amount and quality of the water available for the marsh and dune pond ecosystems. Groundwater extraction has led to the shortening of hydroperiods, loss of some of the most important seasonal ponds and has reduced the flow into the Rocina, a major stream feeding the marshes (Guardiola-Albert and Jackson 2011; Manzano et al. 2013; WWF 2009, 2013). Agricultural and urban pollution has led to a major increase in Phosphorus loading of the marsh since 1990, causing eutrophication (WWF 2012). In the absence of better management of the catchment area and aquifer, climate change will exacerbate these problems (Guardiola-Albert and Jackson 2011). Owing to the low altitude of the area, sea level rise poses a long-term threat to the freshwater marsh and temporary ponds. Finally, the planned dredging in the Guadalquivir River to allow even bigger ships to reach Sevilla port is likely to cause a major change in the hydrology of the area, including salinization of the lower part of the river, and an increase in the risk of invasive species entering the Doñana wetlands.

Invasive species represent a major problem, such as the crayfish *Procambarus clarkii*, the aquatic fern *Azolla filiculoides*, exotic fish species (*Ameiurus melas*, *Gambusia holbrooki*), and pathogens like *Phytophthora cinnamomi* (affecting the roots of cork oaks). The eutrophication of the marsh (Espinar et al. in press) and the rainfall pattern along the hydrological cycle (Fernández-Zamudio 2011) have played a major role in the invasion by *Azolla*. Some exotic species like the raccoon dog *Nyctereutes procyonoides*, American Sliders *Trachemys scripta* and the North American ruddy duck *Oxyura*

jamaicensis have been eradicated locally but are still present in other areas of Spain or Europe. The presence of emergent infectious diseases whose vectors are associated with wetlands (migrating birds and mosquitos: West-Nile, plasmodium) is being monitored although not yet of concern (Vázquez et al. 2011).

Herbivory may influence the population dynamics of endangered plant species, but little research has been dedicated to this phenomenon. Ungulates (e.g. *Sus scrofa* and cattle) affect ground breeding bird species, reducing breeding success significantly. Human-induced wildlife mortalities (power lines, road kills, illegal hunting, poisoning) and impacts related with tourists and pilgrimages are managed, reducing their impacts. The isolated position of Doñana, surrounded by intensive agricultural areas (greenhouses, orange groves, etc.), a highway connecting the main cities of the area (Huelva and Seville) and the Guadalquivir River, creates dispersal problems for many terrestrial vertebrates. A corridor connecting Doñana with more northern areas has been partially created along the Guadiamar River, but needs to be extended in order to become efficient.

Cross-references

The Axios, Aliakmon and Gallikos Delta Complex, Greece

Prespa Lakes Trilateral Ramsar Park, Greece

The Philippi Peatland, Greece

Anatolia's Heart: Sultan Marshes, Turkey

Burdur Lake, Turkey

Goksu Delta, Turkey

Ebro Delta, Spain

The Hula Wetland, Israel

The Nile Delta, Egypt

The Nile River Basin, Egypt.

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FIGURE LEGEND

Figure 3. Flamingos, Phoenicopterus ruber, in the Doñana marshes (municipality of Hinojos) (Author: Héctor Garrido).

Figure 4. Feral horses in the Doñana marshes (Sotogrande River mouth) (Author: Héctor Garrido).

Figura 5. White storks, Ciconia ciconia, in the Doñana Natural Park (Veta la Palma real estate) (Author: Héctor Garrido).

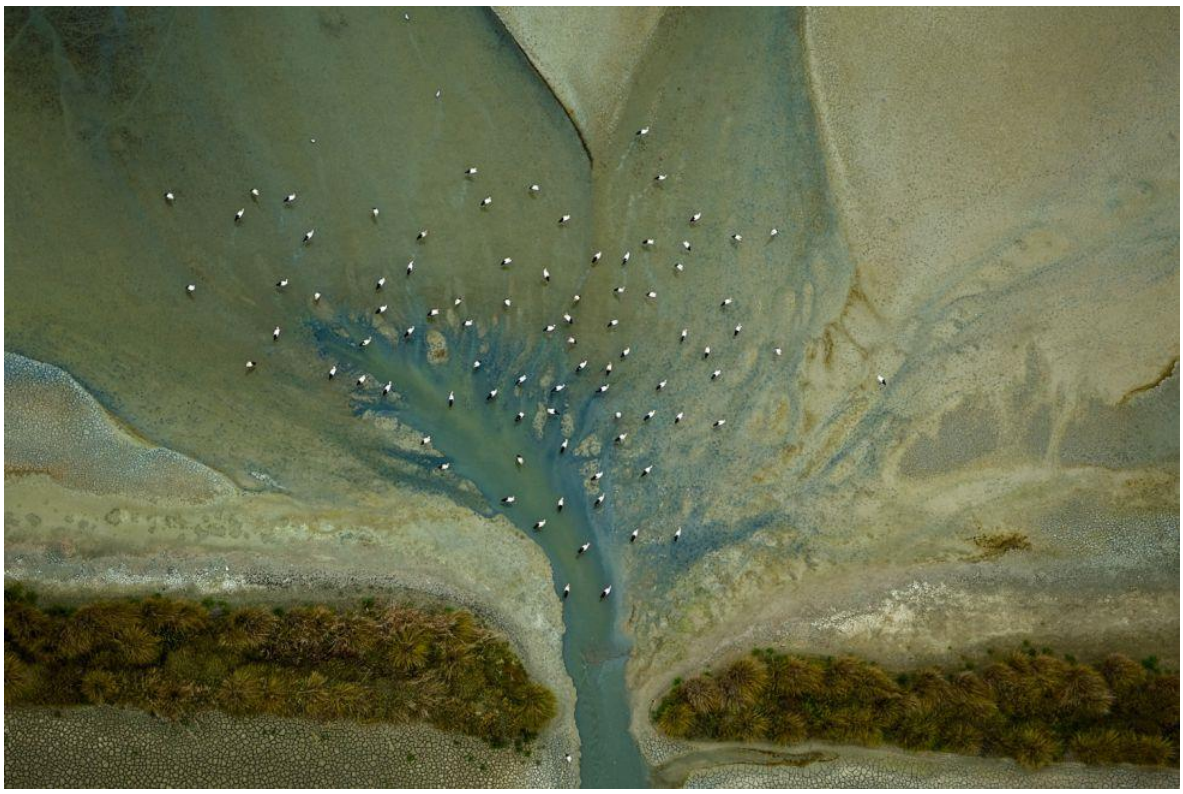

Figure 6. Dark Spradwings, Lestes macrostigma, are abundant in Doñana marshes and in temporary ponds, where they lay the eggs in the stems of reeds (Author: Carmen Díaz-Paniagua).

Figure 7. The natterjack toad, Bufo calamita, is one of the most abundant amphibian of Doñana, laying long strings of eggs in shallow temporary ponds, where tadpoles may complete metamorphosis in 1-2 months (Author: Héctor Garrido).

Figure 8. A typical temporary pond in Doñana, usually drying out during summer (Author: Carmen Díaz-Paniagua).

Figure 9. In Spring, Doñana ponds exhibit a dense cover of macrophytes, such as Ranunculus peltatus in the laguna del Sopetón (Author: Carmen Díaz-Paniagua).