



# SCIENCE TO SAVE DOÑANA

EVIDENCE OF ITS ECOLOGICAL DEGRADATION IN 2024

**Science to save Doñana.  
Evidences of its ecological degradation in 2024.**

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Little Egret flying over the Doñana marshes.

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# INTRODUCTION

This report reflects the extensive scientific knowledge on some of the key issues —water, biodiversity and climate change— for the conservation of Doñana's natural heritage, including its evolution since the 1960s. Since 2016, when a similar WWF Spain report on water in Doñana was released, more than 70 relevant scientific papers have been published. This report stems from the enormous concern of WWF Spain and many people linked to scientific research about the state of the ecosystems, biodiversity and natural assets of this natural site, based on current knowledge. Moreover, very worrying deterioration trends have been observed, owing to the unsustainable management of the region. Some of its consequences are being exacerbated by the effects of climate change that are already manifesting.

Likewise, for WWF Spain there is an urgent need to commit a joint political strategy to effectively resolve the environmental problems affecting Doñana in an integrated manner, and to transfer global commitments for biodiversity conservation to the local level. Scientific studies indicate that Doñana is much worse off than official plans and documents acknowledge.

Equally worrying is the scarce use of existing knowledge for the sustainable management of this unique area for the conservation of biodiversity and its environment. As a result, many of the decisions that are made about its management are not based on existing scientific evidence, and result in further deterioration and unhelpful investments.

In WWF Spain's view, the fact that this is happening in a significant area for policy and media attention as Doñana raises a great number of doubts about the management of many other wetlands in Spain and the Mediterranean area, for which there is less research and knowledge, and which in general do not have such extensive monitoring systems in place.

WWF Spain would like to warmly thank all the co-authors and other participants in this initiative for their individual and collective effort in gathering and analysing the information reflected in this document, and discussing ways to transfer this knowledge to management and further the knowledge of Doñana and its environment in a way that will result in the improvement of its conservation status.

# THE PRESENT AND FUTURE OF FLOWS IN THE DOÑANA RIVERS, STREAMS AND MARSHES

## THE PROBLEM

**Doñana's main environmental assets are a result of its character as a freshwater wetland**, reflecting its dependence on rainfall, flows from rivers, streams, canals and springs from the aquifer at different points (discussed in another section).

The marshland was substantially transformed in the 1950s-60s when the water flows were diverted to reach the sea more quickly; this favoured the drying of the wetlands to make cultivation possible. The transformation of Doñana's environment continues, leading to reduced discharge from the aquifers into the surface watercourses that feed the marshlands, as well as the deterioration of their banks.

In this scenario, **the impact of climate change is aggravating the situation of the wetland**: more frequent heat waves, lower and more irregular rainfall, heavier runoff, less water retention in the soil and, in the aquifer itself, greater consumption in towns and for irrigation, and higher levels of evapotranspiration linked to the increased average temperatures, saline intrusion due to the rise in sea level. All this is leading to a Doñana with less available fresh water.

To date, **the water requirements for the different habitats and species have either not been estimated** (e.g., for the Guadalquivir estuary) or their calculation has not been rigorous. At the same time, **the demand for more water resources has been promoted**, especially in terms of industrial irrigated agriculture and to support the summer tourist demand, involving new water infrastructures and ineffective control of groundwater abstraction in the area. Nor have effective actions been implemented to mitigate the combined impact of water plundering and climate change on the rivers, streams and marshes on which the natural area depends, even though these are reflected in planning instruments.

## THE STATUS OF RIVERS, STREAMS AND MARSHES IN KEEPING WITH OFFICIAL PLANS

According to the Guadalquivir Water Management Plan (Plan Hidrológico del Guadalquivir; PHG) 2022-2027 (CHG, 2022) the ecological status of the surface water bodies located within the area of "*Outstanding Universal Value*" according to United Nations Educational, Scientific and Cultural Organisation (UNESCO) criteria has been assessed as "*good*"; "*worse than good*" in the majority of the water bodies located elsewhere, although in the lake-type bodies "*Abalario*" and "*Ribatehilos*" no significant human activity has been detected to justify this.

The Guadalquivir River Basin Authority (Confederación Hidrográfica del Guadalquivir; CHG) considers that this poor state may be related to the shallow depth of these two lagoons and their seasonal nature, which, together with the activity of both wildlife and livestock, may favour eutrophic water conditions. However, the reference conditions and the limits of the different classes of ecological status established in Royal Decree 817/2015 do actually refer to those that would occur in lagoons with these characteristics.

The 2022-2027 Guadalquivir Water Management Plan also indicates that the river network, with the exception of the upper Guadiamar basin, is in a poor ecological state. The Guadalquivir River Basin Authority considers that there are indications that this is caused by high levels of nutrients (nitrates, phosphorus, ammonium and nitrites) associated with insufficient urban water treatment in the catchment areas of the El Partido and La Cigüeña streams and agricultural activity near the La Rocina and Majalberraque streams, which do not receive inputs from large wastewater treatment plants (WWTPs).

According to the assessment of the 2022-2027 Guadalquivir Water Management Plan, high levels of copper and zinc have been detected in the Crispinejo River upstream of the Agrío reservoir, where there are no active mines, but there are acid leachate inputs from the old abandoned mines of Castillo de las Guardas. In addition, the sections of the "*Crispinejo River downstream of the Agrío reservoir*", the "*middle section of the Guadiamar River*" and the "*lower section of the Guadiamar River*" are in a poor state chemically, very probably due to mining activity throughout the area, not only in recent times but also over the past two thousand years. However, there is ample evidence that pollution in the Aznalcóllar area is due to modern mining, not attributed to Roman prospecting (Olías et al., 2021).

The Guadalquivir River Basin Authority indicates that the final stretch of the Guadalquivir Estuary is bordered by the area of "*Outstanding Universal Value*" and the Doñana Natural Area, and that it has a tidal connection, giving rise to terrestrial habitats related to it. According to the assessment carried out for the third planning cycle, its water bodies have a "*worse than good*" status in terms of physico-chemical and biological indicators. The Guadalquivir River Basin Authority considers that this situation is related to that of the Guadalquivir basin as a whole, as it is the receptor medium for all its pollutant load, as well as for a significant sediment load generated by erosion upstream. Deterioration has also been detected in two coastal bodies due to excess nutrients, with the nitrogen and phosphorus thresholds being slightly exceeded in the "*Pluma de Guadalquivir*" body and phosphorus in "*Doñana- Matalascañas*" water mass.

There has been no hydromorphological status assessment of any of the surface water bodies in Doñana, so the pressures related to the structure of the rivers and streams, and their repercussions on the functioning of the aquatic and fluvial habitats related to the river banks, have not been evaluated in this status assessment (Treviño et al., 2023).

Similarly, the fish indicator has not been included in either the assessment of surface water bodies in Doñana, or in the rest of the district.

## WATER NEEDS OF DOÑANA

Although the revision of the Guadalquivir Water Management Plan for the period 2022-27 defines minimum environmental flows for the river Guadiamar, the proposed regime is inconsistent with respect to hydrological and biological criteria, for example, it ignores the distributions in wet and dry months, which are very pronounced in monitoring stations in close proximity to one another. If the reproductive biology of a species such as the Andalusian barbel (*Luciobarbus sclateri*) is considered as one of the criteria used to help adjust the environmental flow of the Guadiamar River, the fact that the month of May appears in the Guadalquivir River Basin Authority proposal as "*dry*" is illogical (Sánchez Navarro, 2021), given that the spawning season is variable and depends on the conditions each year, and can range from the end of February to May (Rodríguez and Granado, 1992).

According to the Guadalquivir Water Management Plan, the water needs of the "*lake*" type bodies of water in the district have not yet been determined. Given the scarcity of information on these areas after 20 years of implementing the Water Framework Directive, it is still difficult to define water requirements and data collection is a priority.

However, an effort has been made to better define the actual role of groundwater bodies in the conservation of aquatic ecosystems. To this end, the River Basin Management Plan 2022-27 (Plan Hidrológico de Demarcación; PHD) has considered the groundwater component of the environmental flows, this being equivalent to the minimum flow at the mouth of the basin (378 hm<sup>3</sup> per year) and the input flow proportional to the recharge volume of each Groundwater Body (GWB). Furthermore, the environmental requirements of all the inputs to the large springs in the basin were also added, also ensuring that the environmental requirements of the groundwater discharge component were not less than the discharges that were considered in the water management plan for the second planning cycle corresponding to the period 2015-2021. However, these approximations do not guarantee *per se* that the water needs of the wetlands will be met, as these needs have not been defined by the Guadalquivir River Basin Authority (Sánchez-Navarro, 2021).

Finally, according to the monitoring reports of the Guadalquivir River Basin Management Plan 2015-21, during the 2018/2019 hydrological year, the average daily flows recorded in the Guadiamar were lower than the minimum flows in the regulations on 279 days, representing a 76% degree of non-compliance with the minimum flows set out in the Guadalquivir Water Management Plan Regulations 2015-2021 (Sánchez Navarro, 2021).

## THE EVOLUTION OF PRECIPITATION

With respect to precipitation, a comparison of average rainfall values in Doñana indicates a slight reduction of 10% from 675 mm/year (1994-2004) and 552 mm/year (2005-2015) (Rodríguez- Rodríguez et al., 2021); although precipitation in the decade 1994-2004 was above average (Olías Álvarez, pers. comm. 2023).

According to water management planning (CHG, 2021b), in the *Representative Concentration Pathway/RCP 4.5* scenario (RCP emission stabilisation scenario), the average precipitation decreases between 1980-2018 and 2039 will be 4.0%, ranging between 3.0% and 4.6%. In the RCP 8.5 scenario (increased RCP emission), the decrease is almost threefold at 11.3% and ranges from 10.6% to 13.0%. They coincide with data from the EUROCORDEX project (Rodríguez y Gutiérrez, 2018; Montes-Vega et al., 2023)

for the RCP 4.5 and RCP 8.5 climate scenarios of the Intergovernmental Panel on Climate Change (IPCC), according to which average precipitation in the Doñana area will decrease by 14% during the period 2030-2059 with respect to the historical period.

## THE EVOLUTION OF TEMPERATURES

In the past, the interannual evolution of temperature and wind speed exhibited positive trends of 0.11°C and 0.05 m/s per decade (1994-2014), respectively (Casana-Barrera & Olivares, 2020).

Climate models predict an increase in temperatures. According to the IPCC climate scenarios RCP 4.5 and RCP 8.5, the temperature in the Doñana area will increase by 1 to 1.5 °C during the period 2030-2059 with respect to the historical period. The average minimum temperature will increase by 11-15% and the average maximum temperature by 5-6% (Rodríguez & Gutiérrez, 2018). For the period 2071-2100, mean temperatures in the Doñana area are projected to increase by between 1.2°C and 7.4°C (Kohfahl et al., 2019; Guardiola-Albert & Jackson, 2011).

# THE EVOLUTION OF WATER FLOWS

The evolution of the marsh flooding between 1974 and 2014 has been studied by the Spanish National Research Council's (Consejo Superior de Investigaciones Científicas; CSIC) Doñana Biological Station (Estación Biológica de Doñana; EBD) using remote sensing techniques (Díaz-Delgado et al., 2016), revealing that the average flooded area of the marsh as a whole has remained stable since at least the 1970s, with no significant trends (CHG, 2021b).

The monitoring of the flow evolution in the La Rocina stream is also noteworthy. The data from monitoring station 5150 "La Rocina stream", although fragmentary and incomplete, allows us to compare similar pluviometric data before and after 2004, and we can see a clear decrease in circulating flows of more than 60% (from 775 l/s to 292 l/s). The effects of these changes are reflected in bank alterations with a decline of hygrophilous species (Rodríguez-González et al., 2017). However, the northwestern area of the marsh, where the La Rocina stream flows into the marsh, has experienced an increase in the hydroperiod, due to the creation of a delta at its entry to the marsh resulting from the high level of anthropic erosion that occurs in its basin (Olías Álvarez, pers. comm. 2023).

According to Juárez et al (2012), "... the area is affected by the increased deep groundwater abstraction, which has led to a decrease in the water present in the streams and channels in some areas, from the drainage of the phreatic aquifer, with the result that the inputs to the La Rocina and Marismas streams have decreased. In areas close to the irrigation area, stream flows have been temporarily replaced by drainage water from irrigation surpluses." Where the decline is greatest (groundwater irrigation of the rice fields in the Hatos area and in the agricultural fields around El Rocío) the streams remain dry and part of the cork oak population has been left without a groundwater supply and is progressively dying off." (Custodio et al., 2008).



Aerial image of the Doñana marshes. © Héctor Garrido / EBD-CSIC



# EFFECTS ON ECOSYSTEMS AND SPECIES

The Mediterranean region is warming faster than the rest of the planet, and precipitation is decreasing as temperature increases (Cramer et al., 2018). Higher temperatures and lower precipitation will cause an area of >15% of all Ramsar sites in Andalusia to be lost (Xi et al., 2021).

For example, waterbird communities —of such outstanding value in Doñana— are changing in response to global warming, and species are redistributing according to their thermal niche. The transformation of natural wetlands is accelerating the loss of thermally niche-limited species (Gaget et al., 2020). Thermophilic species may experience evapotranspiration increases approaching their dehydration tolerance limits, so an increase in temperatures could induce changes in the microhabitat use patterns or even distribution of these species (O'Connor et al., 2018). These changes could impact predator-prey interactions, triggering cascading effects on other species in the community (Camacho et al., 2017; Coccia et al., 2024), or affecting individuals in local populations. In the case of the red kite (*Milvus milvus*) in Doñana, individuals born during a drought were found to be at a disadvantage throughout their lives, leading to a 40% decline in the predicted population size and a 21% shortening of the time to extinction. These results imply that climate change may erode populations more rapidly and severely than is currently appreciated (Sergio et al., 2022).

In terms of the red-necked Nightjar (*Caprimulgus ruficollis*), an insectivorous and locally abundant bird species in the Doñana Natural Area, differences in spatial behaviour have been documented between relatively rainy (~700 mm) and dry (~300 mm) years. The size of breeding areas can increase by more than 50% in dry years (Camacho et al., 2014) due to movements to relatively distant feeding areas, more than 10 km from their nests (C. Camacho & P. Sáez-Gómez, unpublished data from GPS tagging in 2016-2020, pers. comm.). As a result, nightjar abundance at feeding sites closest to the nesting areas can be reduced by around 40% in dry years (Camacho et al., 2017). Taken together, these two indicators of behavioural changes suggest a greater need to explore areas somewhat further away from nesting sites to find food in less rainy years, with potentially negative consequences for the reproduction of this and possibly other nesting species in the Doñana Natural Area (Sáez-Gómez et al., 2018).

Minimum winter temperatures in Doñana have increased since the 1950s, giving floating plants a competitive advantage. Together with an increase in phosphorus (P) the warmer winters have facilitated the spread of the invasive water fern (*Azolla filiculoides*) since 2001 (Espinero et al. 2015), which also causes a deterioration of food chains (Pintero et al., 2021).

Changes in temperature can affect the populations of some mosquito species, such as *Ochlerotatus caspius*, a highly anthropophilic species. For other species, no significant populational changes are expected due to the opposing effects of higher temperatures but lower rainfall (Roiz et al., 2014). Studies on horses in the Doñana Biological Reserve and the Guadamar Biological Reserve, since 2005, indicate that the rise in minimum winter temperatures may lead to an increase in the incidence of West Nile virus, a zoonotic disease transmitted by mosquitoes (Magallanes et al., in review).

Despite the existence of officially approved state-level methods for assessing the conservation status of Habitats of Community Interest (HCI) and, in particular, wetland ecosystems (Camacho et al., 2019; MITECO 2019), the status of most of these HCIs has still not yet been assessed in Doñana. As water-dependent ecosystems and in particular those included in the Natura 2000 Network, they are, although not declared as water bodies, among the protected areas established under the Water Framework Directive. This lack of knowledge, together with the failure to determine the water needs necessary for them to achieve a good conservation status, makes it difficult to include the water needs of these wetlands in water management planning.

## THE ACTIONS ENVISAGED

The Guadalquivir River Basin Management Plan for the period 2022-2027 (CHG, 2022) includes the following 14 measures to improve the flow situation and water needs of rivers, streams and the Doñana marsh:

- Measure to increase surface resources to meet the water demands of “Upstream infrastructures for the transfer of resources from the Tinto, Odiel and Piedras River Basin District to the Guadalquivir River Basin District (Doñana crown) in accordance with the law on the transfer of 20 hm<sup>3</sup>” (Code ES050\_3\_Guadalquivir5496), with a budget of 15 million euros.
- Measure to increase surface resources to replace pumping in the Los Hatos area through the “Expansion of the Agrío reservoir” (Code ES050\_12\_Guadalquivir0299) with a budget of 30 million euros.
- Measure to “Determine the water needs of lake-type water bodies” (Code ES050\_3\_Guadalquivir5547) with a budget of 400,000 euros.
- Measure to “Review the pending actions of the Doñana 2005 project and derived actions” (Code ES050\_3\_Guadalquivir5549) with a budget of more than 15 million euros.
- Measure for the “Study of climate change in the estuary” (Code ES050\_3\_Guadalquivir5567) with a budget of 100,000 euros.
- Measure to “Improve longitudinal permeability in the Lower Guadalquivir area” (code ES050\_1\_Guadalquivir0321) with a budget of 3.5 million euros.
- Measure for the “Rehabilitation of the main collector of the Seville conurbation in the Doñana area” (Code ES050\_3\_Guadalquivir5451) with a budget of 95 million euros.
- Measure for the “Drainage and water treatment in the Doñana area (Condado de Huelva II)” (code ES050\_3\_Guadalquivir5449) with a budget of 1.1 million euros.
- Measure for the “Drainage network in the Doñana area (various municipalities in Aljarafe)” (Code ES050\_1\_Guadalquivir0277) with a budget of 1.1 million euros.
- Measure for “Improving governance in the Doñana environment” (ES050\_3\_Guadalquivir5469) with a budget of 2.8 million euros.
- Measure for “Improving knowledge of the lake-type water bodies in Doñana” (Code ES050\_2\_Guadalquivir0827) with a budget of 379,000 euros.
- Measure for the “Study of the characterisation and improvement of the definition of thresholds for surface water bodies discharging into the Doñana Natural Area (Madre de las Marismas stream, La Rocina stream, Guadiamar channel)” (Code ES050\_2\_Guadalquivir0774) with a budget of 70,000 euros.
- Measure for the “Development of an ecological and hydrological model of the Doñana area” (Code ES050\_3\_Guadalquivir5499) with a budget of EUR 2 million.
- Measure to “Control of the state of the Guadalquivir marshes (Doñana Natural Area)” (Code ES050\_3\_Guadalquivir5507) with a budget of 500,000 euros.

There is no reference to specific actions in the National Park’s Master Plan for Use and Management, which only includes general objectives and criteria for use and management. In addition to incorporating most of the measures contained in the Guadalquivir River Basin Management Plan, the Framework of Actions for Doñana (MITECO, 2022) includes the following actions:

- 1.1. The closing of illegal wells and improvement of governance, with strict control of pumping, including remote sensing and remote monitoring of meters, and increased security work (3.8 million euros).
- 1.2. Groundwater user communities to be set up for aquifers at risk of not reaching good quantitative or chemical status. Drafting of an action programme. (4 million euros).
- 2.1. Acquisition of land with rights for the restoration of water bodies in the Doñana area (100 million euros).
- 2.4. Reduction of the impact caused by water abstractions to supply Matalascañas. First phase. (1.2 million euros).
- 2.5. Reduction of the impact caused by water abstractions to supply Matalascañas. Second phase. Transfer to Matalascañas from the Tinto drinking water treatment plant in the Tinto in the Tinto, Odiel and Piedras River Basin District (10 million euros).
- 3.1. Recovery of the natural fluvial dynamics of the marshes (16 million euros).
- 3.2. Hydrological-forestry restoration of the Los Mimbrales estate (0.3 million euros).

- 3.3.1. Vegetation improvements and geomorphological restoration of the El Partido stream. Hydrogeomorphological restoration and naturalisation of the final section of the El Partido stream to favour the natural recharge of the Almonte-Marismas aquifer. (1.6 million euros).
- 3.3.2. Vegetation improvements and geomorphological restoration of the El Partido stream. Reforestation and vegetation improvements in the Pinar Pinto, Moralejo and Las Monjas mountains, in the Doñana natural area, to prevent flooding of the El Partido stream (2.9 million euros).

## ASSESSMENT AND PROPOSALS

The revision of the Guadalquivir River Basin Management Plan for the 2022-2027 cycle was approved in January 2023, meaning that most of the aforementioned measures have not been initiated. Likewise, the Action Plan for Doñana was presented at the end of November 2022, meaning that the actions provided for therein will foreseeably be developed in parallel with those of the River Basin Management Plan. As the planning cycle progresses, it is expected that many of these actions will be completed.

The detail provided by the Programme of Measures is scant and does not allow us to know exactly what each of the measures will consist of, nor does it provide information on the development schedule envisaged by the various competent authorities. As a result, confidence in the development of these actions is low, especially considering the delays experienced in the two previous planning cycles (for example, with regard to the fulfilment of the sanitation and purification obligations in the Doñana area). The competent administrations should:

- Ensure control and metering of the water actually used to meet irrigation demands. Despite the existence of regulations since 2009<sup>1</sup>, the actual abstractions are unknown. This prevents adequate calculations of exploitation rates, the state of the aquifer and the calibration of the hydrogeological model for the aquifer.
- Encourage the restoration of deteriorated areas of the marshland. The restoration of the Caracoles estate due to action number 6 of the Doñana 2005 project has been a success in terms of the recovery of terrestrial vegetation (Velez-Martin et al., 2020), aquatic invertebrates (Coccia et al., 2020) and waterbirds (Almeida et al., 2020). This is largely due to the exclusion of cattle from the estate. In temporary ponds, livestock favour the dominance of mosquito larvae and cyanobacteria (McBurnie et al., 2015).
- In coordination with the authorities responsible for managing and conserving protected natural areas (including the Natura 2000 Network), establish the water requirements of the habitats (e.g., MEDWET, 2020) and water-dependent species (ponds, streams, riparian forests, etc.) to integrate these into the water requirement, ecological flow and groundwater abstraction regime restrictions to be established by the Guadalquivir River Basin Authority.
- Review the water needs of wetlands and the current minimum environmental flows for all surface water bodies feeding Doñana, in order to incorporate all the components of an adequate input regime to help improve the status of water bodies and protected areas (in flowing waters: minimum flows, maximum flows, rates of change, generative flows and solid flows).
- Restore and recover the fluvial space (including riparian habitats) associated with all rivers and streams that feed the Doñana marsh.
- Restore the hydrological regime and the area connecting the Guadiamar basin (north of the marsh —Guadiamar channel) and the Guadalquivir estuary through the Brazo de la Torre (north-east of the marsh). This means restoring the connection and hydrological dynamics of the Almonte-Marismas aquifer with the surface watercourses (mainly the Guadiamar and Guadalquivir rivers) in the area where they discharge into the marshes.

<sup>1</sup> Order ARM/1312/2009, of 20 May, regulating the systems for effectively controlling the volumes of water used by water abstractions in the public water domain, of the returns to the aforementioned public water domain, and of the discharges to it. <https://www.boe.es/eli/es/o/2009/05/20/arm1312>

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# WATER POLLUTION IN DOÑANA

## THE PROBLEM

In Doñana there are two main causes of surface and groundwater pollution: on the one hand, **urban-industrial discharges**, and on the other, **fertilisers and other pollutants used in agriculture (intensive and industrial)**.

Both problems should have been addressed decades ago, since wastewater **treatment plants** were built in 2002 (Serrano et al., 2006), and the declaration of the nitrate vulnerable zone (NVZ) dates from 2008<sup>2</sup>. However, the treatment plants have not been properly maintained and upgraded, nor have ambitious programmes against diffuse agricultural pollution been implemented, despite these actions being programmed with a budget of approximately 1 billion euros since 2010 for the entire basin (CHG, 2010 and 2015).

The new Guadalquivir Water Management Plan (2022-2027) once again includes measures to tackle pollution problems, but given the **failure to implement the previous plan**, there are serious doubts about its effectiveness. Moreover, according to existing scientific data, the level of pollution has worsened in recent years, in some areas significantly affecting ecosystems and species.

## WATER POLLUTION ACCORDING TO THE OFFICIAL PLANS

According to the 2022-2027 Guadalquivir River Basin Management Plan (*Annex 7 Assessment of water body status*), there are 12 water bodies<sup>3</sup> in Doñana with a good chemical status and 14 with a "poor" status<sup>4</sup>. For its part, the Guadalquivir River Basin Authority considers that, according to the current administrative division, four of the five groundwater bodies in the Almonte-Marismas aquifer have a good chemical status (ES50MSBT000055104, ES50MSBT000055103, ES50MSBT000055102, ES50MSBT000055105), one (ES50MSBT000055101) has a poor status, while the "Condado" groundwater body corresponding to the Tinto, Odiel and Piedras district has a poor chemical status.

The Natural Resources Management Plan (Plan de Ordenación de los recursos Naturales; PORN, 2016) highlights the fact that the inclusion of a large area of marshes and wetlands in the area sensitive to urban wastewater pollution known as Doñana National Park and its surroundings is a fundamental aspect in terms of establishing measures to prevent pollution from wastewater discharges. The Doñana Natural Area is also affected by the zone vulnerable to nitrate pollution in the Guadalquivir Valley to nitrate pollution in the Guadalquivir Valley (Contreras et al., 2023). The Guadalquivir River basin is characterized by a high potential for diffuse pollution, especially throughout the central river valley, where land uses dedicated to intensive agriculture are concentrated, followed by drainage basins to the left bank. An example of diffuse contamination is the high concentration of nitrates measured in these areas of greater vulnerability, which generally tends to be greater in humid years.

2 Decree 36/2008 of 5 February, 2008, designating vulnerable zones. Latest modification: Order of 23 November, 2020, approving the modification of the vulnerable zones defined in Decree 36/2008, of 5 February, designating vulnerable zones and establishing measures against nitrate pollution.

3 ES050MSPF012000004\*\*\*, ES050MSPF012000028\*\*\*, ES050MSPF012100003\*\*\*, ES050MSPF012000027\*\*\*, ES050MSPF012000025\*\*\*, ES050MSPF011002041, ES050MSPF011002042, ES050MSPF011002001, ES050MSPF011002040, ES050MSPF013213005\*, ES050MSPF013213013\*, ES050MSPF014116001\*\*

4 ES050MSPF011002004, ES050MSPF013213014\*, ES050MSPF011002039, ES050MSPF013213014\*, ES050MSPF012100004\*, ES050MSPF013213004\*, ES050MSPF013213007\*, ES050MSPF013213008\*, ES050MSPF013213009\*, ES050MSPF013213010\*, ES050MSPF013213011\*, ES050MSPF013213015\*, ES050MSPF014114002\*\*, ES050MSPF014116000\*\*

It also explains that there may also be occasional problems related to local pollution episodes or to the quality of the water in some of its tributaries, especially during the dry season. Eutrophication processes and the proliferation of cyanobacteria associated with nutrient inputs can lead to wildlife die-offs that significantly increase the risk of epizootic diseases. This problem mainly affects duck communities, but is especially critical for those with smaller populations or very specific habitat requirements, such as the coot (*Fulica cristata*), the ferruginous duck (*Aythya nyroca*) and the marbled duck (*Marmaronetta angustirostris*). These three species are listed in Annex I of the Birds Directive.

## NUTRIENT CONTAMINATION OF THE STREAMS AND MARSHES

The eutrophication of Doñana's tributaries and marshes near the inlets of rivers and streams has accelerated in recent decades, often reaching levels incompatible with the conservation of biodiversity. In addition, the effects of climate change are highly synergistic with water eutrophication, which significantly reduces the scope for a "safe operating system" for biodiversity conservation in Doñana and its tributary basin (Green et al., 2017).

Nutrient concentrations are significantly higher in the streams than in the marshes, particularly in the El Partido and La Rocina streams, which often reach values corresponding to a poor chemical status. The El Partido stream is the tributary most polluted by nutrients, particularly ammonium (NH<sub>4</sub>) and nitrites (NO<sub>2</sub><sup>-</sup>). There are wide stretches of the La Rocina and El Partido streams where levels of some parameters are considered toxic for fish (Paredes et al., 2021).

The very high nitrogen (N) concentrations in the arroyo del Partido are probably due to the continuous discharges from the urban wastewater treatment plants of Condado de Huelva, Bollulos, Chucena-Escacena-Paterna-Manzanilla, Isla Mayor and Planta Carrión in addition to their non-compliance with European regulations. This also causes the presence of a high genetic diversity of the bacteria *Escherichia coli* in the northwestern area of the Doñana marshes (Cabal et al., 2017) and which may be the cause of waterfowl mortality. Ammonium concentrations (> 1 mg NH<sub>4</sub><sup>+</sup>/L) in the El Partido stream frequently exceed established thresholds for good physico-chemical and ecological status (Paredes et al., 2019).

In the other tributary catchments, which have less environmental protection, nutrient pollution is mainly due to increased intensive agriculture under plastic. This is reflected by inorganic nitrogen (N) from fertilisers (Paredes et al., 2019; Paredes et al., 2020).



Greenhouses and crops under plastic that affect surface runoff flow. © Jorge Sierra / WWF Spain

In addition, the abandonment of 42% of the traditional vineyard area in the catchment area of the El Partido stream and the land's conversion to other crops is causing further erosion and consequent sediment deposition in the marshes. Between 1995 and 2006, the area with a high erosion rate has increased by 36% (from 1037 to 1410 ha) and the area with a very high erosion rate by 252% (from 370 to 931 ha). All land use changes result in increased erosion and, in the worst-case scenario, the sediment load resulting from the abandonment of 1,676 hectares of vineyard between 1995 and 2007 may have reached 1,173 tonnes/year, of which approximately one third (391 tonnes/year) may also have been washed downstream into the marshes (Gaitán-Cremaschi et al., 2017; Borja et al., 2009).

The sea clubrush (*Bolboschoenus maritimus*) holds some of these nutrients in the marshes (Paredes et al., 2019), but pollution is causing the loss of biological diversity (aquatic plants, invertebrates) in the zone. It also increases the likelihood of cyanobacteria blooms (e.g., *Microcystis*, *Pseudanabaena*, and *Anabaena*) that can result in fish and waterfowl deaths. This process is further accelerated by increased surface and groundwater abstractions, projected climate change effects (i.e., reduced water inputs and increased temperatures, Green et al., 2017; Paredes et al., 2019) and excessive livestock numbers on the marshes, as this impedes vegetation growth.

While many waterbirds have high plasticity and are relatively insensitive to eutrophication, those wintering waterbirds with negative population trends in Doñana —such as herbivorous ducks —are likely to suffer the greatest impacts from the eutrophication of the marshes. (Rendón et al., 2008; Paredes et al., 2021).

## NUTRIENT POLLUTION OF THE ESTUARY

The Guadalquivir estuary is characterised by an environment with a high nutrient load, that could facilitate its biomass production capacity. However, this is reduced due to the high concentration of suspended sediments from the erosion in the Guadalquivir basin, which attenuate the passage of light (Diez-Minguito & de Swart, 2020). These sediments subsequently move towards the Gulf of Cádiz from the mouth of the Guadalquivir, and even reach the Alborán Sea (Gomiz Pascual et al., 2021).

During the period 1981-2009, the nitrate concentration in the estuary was above the threshold defined in the Guadalquivir River Basin Management Plan in 40-50% of cases in the lower (La Señuela) and upper (Alcalá del



Río dam) reaches. In the case of ammonium and total phosphorus, the threshold is exceeded more frequently in the middle section (Puente del Patrocinio), due to wastewater inputs from urban centres in the Aljarafe area (Contreras et al., 2013).

As a result of the exchange between fresh and sea water, and the temperatures recorded, the Guadalquivir estuary offers good conditions as a breeding ground for different commercial species, such as anchovies, sardines, prawns and shrimps, all of which have a high abundance of eggs, larvae and post-larvae in spring and summer. This contributes to the abundance of these species in fisheries in the Gulf of Cadiz (Llope, 2017).

In the specific case of the estuary, while an increase in temperatures driven by climate change may result in an increase in the abundance of juvenile anchovy (*Engraulis encrasicolus*), there is evidence of its negative effect on shrimp body size and fertility (Mysida; de Carvalho-Souza et al., 2018).

## OTHER POLLUTANTS

In addition to nutrients, other pollutants have been detected in Doñana. There are significant concentrations of anti-inflammatory drugs, antibiotics and other pharmaceuticals in the waters and sediments of the La Rocina and El Partido streams, and the Guadiamar and Guadalquivir rivers, which often exceed the limits that generate toxic effects in animals and plants (Camacho Muñoz et al., 2010a, 2010b, 2013; Martín et al., 2011).

The greatest presence of non-persistent agrochemicals is found in red swamp crayfish (*Procambarus clarkii*) in the rice-growing area between the Guadalquivir and Guadiamar rivers, as well as in the upper section of the La Rocina stream. A moderate presence of these substances is found in the El Partido stream (Vioque Fernández et al., 2009). Pueyo et al. (2011) found the following compounds in the La Rocina stream: PCB138, Bromacil and Dimethoate; and in the El Partido stream: 4,4 DDD, Dichlofluamid, Folpet, Molinate; and in the Matochal-Guadiamar stretch: Malathion, Bromacyl, Dimethoate, Acrinathrin, Chlorpyrifos, Trifluralin, Penconazole and Methidathion. In the estuary, a high percentage (60-80%) of cases exceeding the defined threshold for the herbicides terbuthylazine and simazine were found in the period 1981-2009 (Contreras et al., 2013).

A recent study detected 26 pesticides in bird eggs collected over a period of more than 20 years (1999-2021) in the Doñana National Park, with 4.4 DDE being both the most frequently detected and in the highest concentrations. In general, a downward trend in organophosphates was observed. In contrast, an apparent increase in pyrethroids was detected from 2013 onwards, especially fenvalerate, whose median concentration was 3 to 5 orders of magnitude higher in the most recent samples. In addition, other pesticides such as oxadiazon, oxyfluorfen and fenitrothion were detected for the first time in samples in 2021. Finally, two variables estimating the cumulative impact of pesticides significantly decreased the reproductive performance of the booted eagle, a top predator in the area (Peris et al., 2023).

A study in the Santa Olalla lagoon and its surroundings (Fernández et al., 2022) showed higher concentrations of heavy metals after prolonged drought that were not associated with concentration effects due to water evaporation but instead to reductive mobilisation. Likewise, Alcorlo & Baltanás (2013) identified five heavy metals (As, Cd, Zn, Cu, Pb) in samples of crayfish (*Procambarus clarkii*) from the Brazo del Este, in the Guadiamar river and in the Charco de la Boca (Doñana Marshes) taken in 2000-2001. García Sevillano et al. (2014) detected an elevated presence of several heavy metals (Mn, Cu, Zn, and Cd) in mice (*Mus spretus*) in samples taken in 2011 from El Matochal (rice fields near the Guadiamar river) and close to the El Partido stream. Natural arsenic in groundwater near Palacio de Marismillas is mobilised to high concentrations in the artificial pools by phytoplankton activity leading to elevated pH and alkalinity, thereby passing into food chains (Kohfahl et al., 2015). In the estuary, a decrease in the number of times the defined threshold for zinc was exceeded was observed in the period 1981-2009 (Contreras et al., 2013).

Atmospheric deposition of pollutants from the industrial area of Huelva into the environment of the Doñana National Park was demonstrated by Castillo et al. (2013) with data from 2008 to 2011. The study reflects the presence of antimony, molybdenum, bismuth, arsenic, lead, tin and cadmium near Matalascañas, as well as the

dissolution of copper, zinc, manganese and nickel as potentially toxic elements in the coastal waters of Doñana. Fernández et al. (2022) also identified significant atmospheric deposition of the elements Cu, Zn, Ni, Sb and Tl in the aquatic environment of the Santa Olalla lagoon system.

After the El Rocío pilgrimage (2014), the presence of the antibiotic ciprofloxacin constituted an ecotoxicological risk. The presence of the antibiotic flumequine and the anti-epileptic carbamazepine in red swamp crayfish (*Procambarus clarkii*) individuals during sampling from 2011 to 2016 indicates persistent pollution, the main sources of pharmaceuticals in the park being urban wastewater and livestock activities (Camacho-Muñoz et al. 2010a, 2010b; Kazakova et al., 2021). The extensive use of Ivermectin on livestock in Doñana has led to a significant loss in the biodiversity of coprophagous invertebrates and a reduction in the ecosystem service they provide as decomposers of livestock excrement (Verdu et al., 2018). It is not known how this product can be transmitted and potentially affect other organisms in the food chain. In addition, it has been proven that storks and seagulls in Doñana import plastics and antibiotic-resistant bacteria into Doñana from landfills near this protected area (López-Calderón et al., 2023; Sacristán-Soriano et al., 2024).

## THE ACTIONS

The Guadalquivir River Basin Management Plan for the period 2022-2027 (*Annex 11 Programme of Measures*), which has also been included in the Framework Document of Actions for Doñana (MITERD, 2022) includes the following 8 measures to address the problem:

- Extension of the Matalascañas WWTP (29.3 million euros)
- Adaptation of the Seville WWTP treatment to allow discharge into a sensitive area in the Doñana area (82.9 million euros)
- Grouping of discharges and a new WWTP in Isla Mayor: by agreement (the Guadalquivir River Basin Authority will contribute 6.063 million euros; the rest will be provided by the Andalusian Regional Government; total 17.2 million euros)
- Grouping of discharges and construction of a WWTP in Gerena (7.2 million euros)
- Drainage network in the Doñana area (various municipalities in Aljarafe) (1.1 million euros)
- Drainage and water treatment in the Doñana area (Condado Huelva II) (1.1 million euros)
- Upgrading of the Lucena del Puerto WWTP (3.5 million euros)
- Study to locate sources of chemical pollution in the Guadiamar river basin (0.1 million euros)

For its part, the Guadalquivir River Basin Authority indicates that throughout the district (it has not been possible to quantify what part corresponds to Doñana) it plans to invest 117 million euros in measures to tackle diffuse pollution, including extending the compulsory application of action programmes in vulnerable areas to zones outside these, and studying the main sources of pollution and assessing measures to correct the environmental impact of nitrogen fertiliser use in areas vulnerable to nitrate pollution in Andalusia.

It has not been possible to elaborate further on what these measures will consist of due to the lack of sufficient information in the River Basin Management Plan documents (2021-2027).

In general, there has been limited implementation of measures to address the pressures linked to diffuse and point sources of pollution that were foreseen in the previous plan. The current revision intends for all the actions included in the programme of measures to be completed before 2027, when the fourth revision of the River Basin Management Plan will be drawn up on the basis of a new assessment of the status of the water bodies in the Guadalquivir district.

The Natural Resources Management Plan and the Master Plan for the Use and Management of the National Park include recommendations for promoting a reduced diffuse pollution risk, encouraging reduced fertiliser and phytosanitary product use, as well as studies on pollution.

# ASSESSMENT AND PROPOSALS

The eutrophication of Doñana's tributaries and marshes near the inlets of rivers and streams has accelerated in recent decades, often reaching levels incompatible with the conservation of biodiversity. There are significant concentrations of anti-inflammatory drugs, antibiotics and other pharmaceuticals in the waters and sediments of the La Rocina and El Partido streams, and the Guadiamar and Guadalquivir rivers, which sometimes exceed the limits for toxic effects in animals and plants.

The competent administrations should:

- Ensure the proper functioning and maintenance of all urban-industrial wastewater treatment plants
- Reduce diffuse pollution through ambitious programmes to limit the use of fertilisers and agrochemicals, and promote good practices to prevent agricultural soil erosion.
- Avoid overgrazing as this removes vegetation —particularly riparian vegetation, which helps hold nutrient pollution— and increases pollution from veterinary products. Limit livestock numbers on the marsh, reduce the use of antibiotics and pesticides, and establish or reinforce monitoring of riparian vegetation.
- Improve water quality monitoring, especially in the streams entering Doñana and in the Guadalquivir estuary. To capture turbidity episodes and characterise the forcing agents in the estuary, measurements are required on at least a weekly scale in all stretches of the estuary, whereas to capture salinity episodes, this measurement frequency is required only in the upper stretch; in the lower stretch where the tide has a greater influence, a monthly frequency is sufficient (Contreras et al., 2012). In streams, there needs to be more extensive monitoring of pharmaceuticals and nutrients, combined with good flow measurements, including from WWTPs in the catchment areas. It is very important to be able to calculate the actual mass of N, P, and so on entering Doñana, not just the concentration per litre.
- Improve the representativeness of groundwater quality sampling. Samples are usually taken from piezometers or old wells with very wide mouths, meaning it is possible that the analysis does not correspond to the real contamination values in the aquifer. The network of groundwater quality measurements needs to be redefined by taking samples from active abstraction wells. Without this action, it is difficult to have a realistic idea of the chemical state of the aquifer.
- Follow the guidelines of the guide for water status assessment<sup>5</sup> in terms of evaluation.
- The state of the water entering the marsh through the La Rocina and El Partido streams is so poor that specific measures must be designed to treat it before it reaches the National Park. This could include, for example, the creation of treatment ponds with emergent vegetation along the El Partido stream.

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<sup>5</sup> Detailed information can be found at the following link: <https://www.miteco.gob.es/es/agua/publicaciones/guia-para-evaluacion-del-estado-aguas-superficiales-y-subterraneeas-tcm30-514230.Ddf>

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# IMPACTS OF OVEREXPLOITATION OF WATER IN THE AQUIFER THAT FEEDS DOÑANA

The role of groundwater in the Doñana National Park is very important. Once the flooding season is over, animal life is made possible, in large part, by groundwater inputs. Without these, the important ecological reserve of Doñana could not be maintained, nor would it have developed (Junta de Andalucía, 1988).

## THE PROBLEM

The Doñana aquifer has been suffering from the **local overexploitation of its resources** in the areas of El Rocío, Matalascañas and Los Hatos since the 1990s (e.g., Junta de Andalucía, 1988 and 2003), an issue that has subsequently spread to the strawberry-growing area in the north. The main cause is the increase in abstractions for irrigation, a dynamic that the authorities intended to reduce with the approval of the Doñana Land-use Plan (Junta de Andalucía, 2003b) and subsequently with the Special Management Plan for the irrigated areas located north of the Forest Crown of Doñana (commonly known as the 'Strawberry Plan', Junta de Andalucía, 2014).

However, these **plans have not been fully implemented**, and therefore have not had the expected effects. Irrigation has continued to increase and, according to the latest available mapping (SAR 21), the irrigated area currently covers 9,418 hectares in the strawberry-growing area, meaning an increased pressure from 3,418 hectares more than those existing in 2009 (estimated at around 6,000 hectares), compared to the water management plan of the first cycle (2009-2015). According to data from WWF Spain, this includes 1,232.2 hectares, presumably illegal, which have been irrigated in the 2022-2023 campaign, in addition to the **more than 1,700 irrigation ponds in the Doñana area** that are filled from the aquifer, **taking up water that should reach the marshes** (WWF, 2009; WWF, 2016, WWF, 2023; Paredes et al., 2021). The irrigation sector has also grown in the area around the lower Guadiamar and Los Hatos.

To **avoid declaring the entire aquifer 'overexploited'**, the Guadalquivir Water Management Plan 2016-2021 (CHG, 2015) divided the aquifer into five groundwater bodies; plus a groundwater body located within the Tinto, Odiel and Piedras River Basin District, but which is hydrogeologically connected to Doñana. According to the 2022-2027 Guadalquivir Water Management Plan (CHG, 2022), the quantitative status of three of the groundwater bodies (*La Rocina, Almonte and Marismas*) is poor ('overexploited') while it is good for the other two bodies (Marismas de Doñana and Manto Eólico de Doñana), despite the significant effects of pumping for abstraction, and the fact that many of the lagoons in these areas are suffering from a lack of water.



Process of evolution (for the years 2001, 2009, 2016), fragmentation and location of the Groundwater Bodies (GB) that make up the Doñana aquifers. Source: Kofahl et al., 2019.

## KNOWLEDGE OF THE AQUIFER

The Almonte-Marismas aquifer is one of the best studied aquifers in Spain, for which there are some long series of monitoring data, a large number of sampling points, studies and different models. However, significant uncertainties remain in terms of flow estimation between the different groundwater bodies (the boundaries are administrative) and the calculation of the *Exploitation Index*. These uncertainties are even greater because it is not known with certainty how much water is abstracted from the entire aquifer, making it impossible to properly calibrate the aquifer model (Guardiola-Albert et al., 2016; Guardiola-Albert, pers. comm., 2022).

Among many others, Olías Álvarez & Rodríguez-Rodríguez (2013) show that in deep piezometers (confined aquifer) worrying declines are being detected. According to official data (CHG, 2020b) *"a marked piezometric decrease is evident in a 5 to 10 km wide south-west to north-east oriented band bordering the western limits of the National Park and centred on two large piezometric depression cones, one located north of El Rocío and the other south of Villamanrique de la Condesa."*

According to the declaration of bodies at risk of not attaining the quantitative status, corresponding to the Almonte groundwater body (CHG, 2020) in the northern area of the marshes, just where the North ecotone is located, there is a piezometric cone of depression that dropped by about 20 metres cumulatively between 1976 and 2017. The piezometric level in more than half of the piezometers is at or near its historical minimum. In several of the piezometers, a steady decline has been observed with a cumulative value of up to 9 metres. In slightly less than half of the analysed piezometers in the northern ecotone, deep levels seem to have stabilised around the historical minimum value of the last 8 years (CHG, 2021). This is indicative of a progressive decrease in flows associated with the northern ecotone.

The Guadalquivir River Basin Authority report (CHG, 2021) also shows that in the vicinity of the La Rocina stream several piezometers have ceased to be upwelling since 2010, the last wet year. Since the end of the 1990s there has also been a reversal of the hydraulic potential and, approaching the mouth of the marshes, there has been a piezometric drop of up to 4 metres in the deep levels. At other points on the right bank of the La Rocina stream, heavily influenced by nearby abstractions, the Guadalquivir River Basin Authority report (CHG, 2021) shows intra-annual oscillations of more than 5 metres in the deep levels, indicating that they are directly connected with the pumping. On the left bank of the La Rocina stream, Guadalquivir River Basin Authority data (CHG, 2021) shows a gradual drop in level, from a few metres to more than 10 metres. A cone of depression has been identified in this area since at least 2000, with its centre to the north of El Rocío. To the east, this cone joins up with the pumping cone to the south of Villamanrique.

The increased abstraction is coupled with reduced water inflows associated with the impact of climate change. In the period 1975-2016, aquifer recharge values have varied significantly with respect to maximum precipitation, indicating their dependence on soil health, land uses and spatial heterogeneity, and the temporal distribution of precipitation. Average recharge values were significantly reduced in the periods 1975-1995 and 1996-2016 due to the concentration over fewer rainy days. Intense rainfall events lead to proportionally less recharge than lighter but more prolonged precipitation (Naranjo-Fernandez et al., 2020).

In relation to the future impact of climate change, Guardiola-Albert & Jackson (2011) estimate that aquifer recharge in 2080 will be associated with an average decrease of 14-57% compared to historical data (1975-1998), linked to a drop in the piezometric level of the aquifer of up to 17 metres. Simulations indicate that discharges to streams such as La Rocina (between -55 and -25%) and La Marisma (between -68 and -43%) will also drop significantly.

For the RCP 4.5 scenario for 2039, more current modelling estimates an average recharge reduction of 8.5% compared to the 1980-2018 average, and values between 8% and 9%, and more than double that for the RCP 8.5 scenario: 18.2% on average and ranging between 17.6% and 18.8% (CHG, 2021).

## THE EFFECTS

Groundwater abstraction has caused multiple ecological impacts to temporary ponds and marshes in Doñana, as well as to terrestrial vegetation and associated flora and fauna, and should be urgently reduced (Green et al., 2024). The Natural Resources Management Plan (Plan de Ordenación de Recursos Naturales; PORN, Junta de Andalucía, 2016) states that: *"... the general decline in piezometric levels has implications for the distribution and status of phreatophytic vegetation in Doñana. In general, the available data seems to show that despite the negative trend in piezometric levels in certain areas of the aquifer, aggravated by the periodic inter-annual droughts typical of the Mediterranean climate, the system as a whole remains stable, showing a reduction in the downward trends reflected in the historical series and even showing positive developments in the oscillation of piezometric levels in some sectors considered to be of concern."*

Contrary to the Natural Resources Management Plan's assessment, the situation in Doñana is far from stable. The latest report on the aquifer by the Guadalquivir River Basin Authority (CHG, 2022b) indicates that there are areas with a markedly lower piezometric level than would be expected in line with the rainfall, and exhibiting a significant downward trend. These include the catchment area of the El Partido stream and most of the La Rocina stream. Of particular interest is the 5-10 km wide band bordering the limits of the National Park between El Rocío and Villamanrique de la Condesa, with two large cones of piezometric depression in relation to the elevations measured in 1995, one located to the North of El Rocío and the other to the South of Villamanrique. It includes the sectors, North Zone, North of the La Rocina stream, North of the El Rocío, Intermediate Sector, North Ecotone, South of Villamanrique-free aquifer and southern headwaters of the La Rocina. It also includes the coastal sector, with a lower than expected "IE" (Exploitation index) value and a significant decreasing trend, although with no data from the large area south of Matalascañas. Recently, research has also been carried out on the possible impacts of groundwater extraction on ground movements in the area (González-Jiménez, 2023).





Example of an irrigation pond in the Doñana area, fed by abstractions from the aquifer. © WWF Spain

The 2020 monitoring report (CHG, 2020) already indicated that the lowering of the water table in the La Vera-Retuerta ecotone was sufficiently important to affect the watercourses, to eliminate surface water features (e.g., lagoons and springs) and to move capillary water away from the reach of plant roots. The deep levels clearly show a decrease of up to 6 metres in some cases. There are also wells that have ceased to be upwellings and which are now showing a reversed hydraulic potential. As the deep level decreases, the shallow level is now feeding both the marsh and the different ecosystems as well as the deeper levels.

This reduction in the groundwater has effects on vegetation. Muñoz-Reinoso (2001) reported that since 1970 there has been a change towards more xerophytic vegetation, due to reduced water availability: “*Water abstractions in the Doñana area have favoured more xerophytic plant communities (Cistus libanotis, Lavandula stoechas, Rosmarinus officinalis, Halimium commutatum, Halimium halimifolium) over more hygrophilous communities such as heathland (Erica scoparia, Calluna vulgaris, Ulex minor, Genista anglica, Myrtus communis), grasslands (Mentha pulegium, Cynodon dactylon, Eleocharis palustris, Juncus spp., Scirpus holoschoenus), and mixed scrub (Ulex australis, Halimium halimifolium, Asparagus aphyllus).*” During the 2005 drought, Lloret et al. (2016) found significant changes in the vegetation of the National Park with an increase in the *monte blanco* and *sabinar* vegetation. Coastal juniper has also spread over the last 40 years, even in traditionally wet areas (García et al., 2014). This may be due to the lowering of the aquifer, as juniper does not tolerate a high water table.

In the riparian woodland of La Rocina stream, an increase in the presence and density of ash trees, as opposed to willow trees, has been observed since 2005, both species being indicators of the state of the water table. The narrow-leaved ash (*Fraxinus angustifolia*) reflects the impact of the drought on its annual growth (Rodríguez-González et al., 2021), while the grey willow (*Salix atrocinerea*), a species more dependent on soil moisture conditions, has shown a tendency towards population decline (Rodríguez-González et al., 2017).

# THE ACTIONS

Most of the actions from the Measures in the 2022-2027 Guadalquivir Water Management Plan, mentioned in the section corresponding to surface water bodies in this document, could be included in this section. As regards the Framework of Actions in Doñana, those referring to groundwater can be specifically included:

- 1.1. The closing of illegal wells and improvement of governance, with strict control of pumping, including remote sensing and remote monitoring of meters, and increased security work (3.8 million euros).
- 1.2. Groundwater user communities to be set up for aquifers at risk of not reaching good quantitative or chemical status. Drafting of an action programme (4 million euros).
- 2.1. Acquisition of land with rights for the restoration of water bodies in the Doñana area (100 million euros).
- 2.2. Decommissioning of wells and development of alternative water sources. Substitution of groundwater for surface water through the transfer of resources in accordance with Law 10/2018 (15 million euros).
- 2.3. Substitution of groundwater for surface water from the El Agrío reservoir (30.0 million euros).
- 2.4. Reduction of the impact caused by water abstractions to supply Matalascañas. First phase (1.2 million euros).
- 2.5. Reduction of the impact caused by water abstractions to supply Matalascañas. Second phase. Transfer to Matalascañas from the Tinto drinking water treatment plant in the Tinto in the Tinto, Odiel and Piedras River Basin District (10 million euros).
- 8.2 Improving knowledge of hydrological processes in Doñana: groundwater and surface water (1 million euros).
- 8.3 Model of aquifer function and surface hydrology in the perimeter of the Doñana forest crown (0.25 million euros).
- Expansion, improvement and automation of the piezometric control network (2.7 million euros).

The current revision of the Water Management Plan intends for all the actions included in the programme of measures to be completed before the end of the cycle, when the fourth revision of the Water Management Plan will be initiated as well as a new assessment of the status of the water bodies in the Guadalquivir district. In theory, the Framework of Actions for Doñana and the measures these include should be completed in parallel with the district's Water Management Plan.

# ASSESSMENT AND PROPOSALS

For the conservation of the biodiversity in this area it is fundamental that the Doñana aquifer is in a good state. However, it has been seriously deteriorated for years. The competent administrations should:

- Ensure the control and measurement of water used for irrigation. Despite a regulation in force since 2009<sup>6</sup>, the actual abstractions are unknown. This prevents adequate calculations being made of the exploitation rates and the state of the aquifer.
- Increase efforts to control and eradicate illegal water use in the irrigated area.
- Adapt irrigation abstractions to recharge, passing on their reduction due to climate change, as proposed by the Safe Operating Space (Green et al., 2017).
- Review and adjust aquifer balances, eliminating errors that overestimate the available water. It is necessary to evaluate and update groundwater status monitoring and the methodology used to define

<sup>6</sup> Order ARM/1312/2009, of 20 May, regulating the systems for effectively controlling the volumes of water used by water exploitations in the public water domain, of the returns to the aforementioned public water domain, and of the discharges to it. <https://www.boe.es/eli/es/o/2009/05/20/arm1312>

its conservation status by the Guadalquivir River Basin Authority, which averages the index for several piezometers, and buffers the picture of how the aquifer's status is deteriorating. For example, in France<sup>7</sup> a *Standardised Precipitation Index* (SPI) indicator is used, based on the statistical information of the series. On the other hand, recharge is overestimated and this must be taken into account when assessing the available water resources. Concentrating rainfall over fewer days as a result of climate change will impact the estimated recharge, requiring the estimates in the Water Management Plans to be updated (Naranjo-Fernandez et al., 2020).

- Monitor the effects of overexploitation through remote sensing and field work, habitat and species monitoring, including riparian vegetation, establishing indicators and evaluating these regularly.
- Conduct a geological study to determine the depth of the aquifer and design and implement an intrusion control network.
- The current excessive compartmentalisation of the aquifer into 5 groundwater bodies, as proposed by the Guadalquivir River Basin Authority, and the Condado groundwater body, pertaining to the Tinto, Odiel and Piedras district, makes it difficult to obtain a global vision of the system. Coordination between the two water authorities is necessary to improve the state of knowledge and properly manage the

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<sup>7</sup> Further information in: <https://www.brgm.fr/en/reference-completed-project/standardised-piezometric-level-indicator-spli-water-resource-management>

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# IMPACTS ON DOÑANA ECOSYSTEMS FROM WATER ABSTRACTIONS FOR MATALASCAÑAS TOURIST AREA

## THE PROBLEM

The peridune lagoons of the Doñana Biological Reserve are one of the best studied parts of the whole zone and there is a long time series available. Concern about the effects that authorised abstractions, up to a maximum of 2.75 hm<sup>3</sup>/year of **water for Matalascañas** (for domestic use, tourism, and irrigating gardens and green spaces) may have *on the lagoons and their environment dates back to the late 1980s and is reflected in the “Hollis Report”* (Hollis et al., 1989) as well as in the Territorial Coordination Master Plan for Doñana and its Surroundings (Plan Director Territorial de Coordinación de Doñana y su Entorno; PDTTCDE). Despite this, the **area of urbanisation** expanded considerably during the 1990s. In addition, a **golf course** was built that was supposed to use reused water to irrigate its grass, but until 2016 it was illegally extracting water from the aquifer, partly due to insufficient wastewater treatment. In addition, in 1990-1991, the company then in charge of supplying Matalascañas (PROSEIN S.A.) recognised higher abstraction volumes than those authorised: 3.2 and 3.0 hm<sup>3</sup>/year of groundwater (Serrano & Serrano, 1996).

There is now a consensus among scientists —and this was recognised by the European Court of Justice ruling C-559<sup>8</sup>— that there is a direct and significant link between water abstractions, the **lowering of water levels in the aquifer** (groundwater body 05.51 Almonte Marismas) and the **deterioration of the lagoons**. This is aggravated by the effects of increased evaporation caused by a rise in the air temperature (by 0.11 degrees per decade (Casana-Barrera & Olivares, 2020), of 1 degree in 13 years during the spring months (Tragsatec, 2016; Tragsatec- CHG, 2015), and increased vegetation cover (+0.54%/year) (Rodríguez-Rodríguez et al., 2021).

Even official documents recognise that in the peridune lagoon area there has been a downward trend from 1995 to the present of about 2 to 3 metres (CHG, 2021), comparing the values of 2021 with those of the greatest drought ever recorded in Doñana (1994/1995).

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<sup>8</sup> Sentencia del Tribunal de Justicia (Sala Primera) de 24 de junio de 2021. Comisión Europea contra Reino de España. <https://eur-lex.europa.eu/legal-content/ES/TXT/?uri=CELEX%3A62019CJ0559> y <https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:62019CJ0559&from=ES>



Satellite image showing the location of the best-studied peridune lagoons in the Doñana Biological Reserve: El Brezo (BRE), El Charco del Toro (CTO), El Zahillo (ZAH), El Taraje (TAR), La Dulce (DUL) and Las Verdes (LVE) are all temporary hydroperiod lagoons together with the lagoon complex of Las Pajas (LPA), while Santa Olalla (SOL) is permanent. The location of the wells pumping water from the aquifer to supply Matalascañas is shown in yellow. © Google Earth

## THE EFFECTS

The most evident consequences of the drop in aquifer levels on the peridune lagoons are the complete desiccation that some of the lagoons have experienced, and the reduction of their annual flooding period (Díaz Paniagua & Serrano, 2015), an issue that has been verified through remote sensing (Gómez-Rodríguez et al., 2010, Díaz-Paniagua & Aragonés, 2015). While it was initially thought that deep water abstraction would not impact the shallow aquifers that feed the lagoons, several authors have already explained that the reversal of groundwater flows can cause the deep aquifers to stop feeding the shallow aquifers. This explains why lagoons such as El Brezo and Charco del Toro have ceased to be aquifer discharge areas and have become aquifer recharge areas.

The peridune lagoons are dependent on discharge from the aquifer. Those closest to Matalascañas are the most heavily affected by the abstractions of water pumped to supply the urbanisation. In general, all the peridune lagoons have seen a gradual reduction in their flooded area, which is not explained by the variation in rainfall in those same years (e.g., Díaz-Paniagua & Aragonés, 2015; Serrano et al., 2008<sup>9</sup>). In three of the lagoons (Charco del Toro, Zahillo and Taraje), there has been a drop in mean the piezometric levels of between 3.1 and 6.7%, if we compare the periods 1994-2004 and 2005-2015 (Rodríguez-Rodríguez et al., 2021). The lagoon closest to Matalascañas, the Laguna del Brezo, began to dry up around 1976, and is currently covered by pine trees and scrubland; in the Charco del Toro lagoon, desiccation was first detected at the end of the 1990s (Coletto, 2003); the Zahillo and Taraje lagoons are currently significantly altered, with their basins colonised by reeds, scrubland and young pine trees in the former, and by *tamarisk* in the latter (Díaz-Paniagua et al., pers. comm., 2023).

All the lagoons, both temporary and permanent—including the Santa Olalla lagoon— completely dried up during the summer of 2022, after a decade with no wet years.

9 In 5 of the 8 lagoons, in a range of between 52% and 99%.

More than 200 plant species, 80 microcrustaceans and rotifers, 128 macroinvertebrates, 11 of the 13 species of amphibians described from western Andalusia, two species of water snakes and the only two species of terrapins native to the Iberian Peninsula have been described in the Doñana lagoon system (Díaz-Paniagua et al., 2015).

The species most affected by the shortening of the lagoonal hydroperiod are those that require longer aquatic periods to complete either their life cycles or their reproductive phase, as very few lagoons still have a long hydroperiod. Species characteristic of this type of lagoon include terrapins (*Mauremys leprosa* and *Emys orbicularis*), newts (*Pleurodeles waltl*), and spadefoot toads (*Pelobates cultripes*), as well as many species of dragonfly and damselfly (odonates) that have long larval stages. Among the plants, there are floating species and some submerged species, such as *Hydrocharis morsus-ranae*, which is currently considered extinct in Doñana (García Murillo et al., 2000), *Potamogeton lucens*, *P. polygonifolius*, and *P. natans*, which are currently only found in artificially deepened lagoons (“zacallones”) as these remain flooded for longer due to their increased depth (Díaz-Paniagua et al., 2019).

In the 1960s, the spadefoot toad (*Pelobates cultripes*) was one of the most abundant species in Doñana (Valverde, 1967), and huge numbers were frequently observed when the lagoonal flooding cycle began with the first heavy rainfall after the summer. However, at present, its population has declined considerably, with large concentrations of individuals not having been observed since the 1990s, and its range has been reduced in the park by 22% compared to that described in 2003 (Díaz Paniagua et al., unpublished data, pers. comm. 2023). Its regression is generalised<sup>10</sup> and can be explained, on the one hand, by the introduction of the red swamp crayfish, but it is particularly related to the loss of reproductive habitats, and to the reduced lagoon hydroperiod, as this species has the longest larval period. Occasionally, the mortality of all spawns has also been observed in lagoons affected by acidification processes. This has been detected in the Charco del Toro and Zahillo lagoons where, after the first post-summer rains, pH values of less than 4 have been detected in the first pools that form. This is a result of the oxidation of the pyrite contained in the sediments, as the lowering of the water table exposes it to oxidising conditions. Since the breeding season coincided with these acidification events in 2006 and 2007, the complete loss of the reproductive investment of these toads was observed in the Charco del Toro lagoon, in addition to most of the eggs they laid in the Zahillo lagoon (Serrano et al., 2016).

Odonates are excellent indicators of the conservation status of aquatic environments (Oertli, 2008) as their larval period is aquatic. Additionally, some species are characteristic of temporary environments, while others require flooding periods of more than one year. Doñana is considered a privileged location for odonates in the Iberian Peninsula. From 1959 to the present day, 43 species of odonates have been recorded in Doñana. However, 15 species detected prior to 2000 are no longer being recorded, despite intensive surveys and even monthly counts over the last decade. Among the cited taxa that are currently not found in this area are threatened species, including *Brachytron pratense*, listed in Spain and Europe as endangered, *Coenagrion mercuriale* (vulnerable, Bern Convention Annex II), and *Orthethrum nitidinerve* (vulnerable) (Díaz Paniagua et al., 2014).

Together with other factors such as the presence of the red swamp crayfish (*Procambarus clarkii*), the impact of livestock, and the increased temperatures, the shortening of the lagoonal hydroperiod affects the presence of certain aquatic plants. In particular, the indicators of more permanent water are currently scarce, and species such as *Ricciocarpos natans*, *Lemna trisulca*, *Spirodela polyrhiza*, *Wolffia arrhiza*, *Potamogeton lucens* and *P. natans*, are now only observed in the artificially deepened lagoons (“zacallones”) in Doñana (Díaz Paniagua et al. 2015). Other important species are considered extinct in Doñana such as the *carnivorous plants of the genus Utricularia* and the nymphaeid *Hydrocharis morsus-ranae* (García Murillo et al., 2000; de Felipe et al., 2022; Díaz-Paniagua et al., 2022).

Fish are not usually found in Doñana’s temporary lagoons, but they do colonise them in years of heavy flooding, and in some isolated spots, such as the “zacallones”, or in the large lagoons, isolated pockets may remain. Of the seven species found in these unstable and fragile environments, three are native species: the Southern Iberian spined loach (*Cobitis paludica*), the European eel (*Anguilla anguilla*), and the killifish (*Aphanius baeticus*) and four are exotic: the Eastern mosquitofish (*Gambusia holbrooki*), the common carp (*Cyprinus carpio*), the pumpkinseed (*Lepomis gibbosus*) and the mummichog (*Fundulus heteroclitus*). In years of high

10 The 2013-2018 assessment report on the conservation status of this species evaluates its decline throughout its biogeographic range (<https://eunis.eea.europa.eu/species/752>).

rainfall and, consequently, high connectivity with the marsh, the main source of these taxa, these species will occasionally colonise a variable number of temporary lagoons in Doñana's wind mantle, with the exception of the mummichog as this is linked to tidal processes.

In the past, this process must have been exclusive to eels and loaches, and perhaps to some other species, now rare or extinct in the area, such as *Squalius pyrenaicus*. Currently, from a quantitative perspective, the most numerous species in the lagoons are exotic. The high abundance and biomass of invasive fish recorded in some lagoons, such as Santa Olalla and Dulce, have not only substantially modified their ecological functioning, but also provide food for aerial predators for which these species are a trophic resource that can, from time to time, be of great importance. These predatory species, otters, herons and other waders, could exert some control over invasive fish species (Prenda, 2015). It should be noted that in recent years, with the desiccation of all the lagoons, including Santa Olalla in 2022, all the fish found in them have died, both exotic fish, such as the mosquitofish, and native fish, including endangered species such as the eel and the killifish.

The water instability of the lagoons and their reduced hydroperiod favours more opportunistic species, with lower ecological requirements and shorter life cycles, typical of exotic ichthyofauna. It is foreseeable, therefore, that far from diminishing or stabilising, the invasion of these water bodies by exotic fish will increase and native fish species will become extinct, as is already happening (Lennox et al., 2019).

Four species of aquatic reptiles have been recorded in Doñana. The viperine water snake (*Natrix maura*) was considered very abundant in all types of lagoons in the 1960s, but today they are only sporadically detected in lagoons with a longer hydroperiod, as well as in the marsh (Díaz-Paniagua et al., 2019). The terrapin populations were considered among the best conserved on the Iberian peninsula (Da Silva, 2002, Keller & Andreu, 2002). Iberian pond turtles were mainly found in peridune ponds, while European pond turtles were also found in many temporary ponds and in "zacallones" throughout the park (Keller et al., 1995). The current desiccation of many of these temporary lagoons has led to a considerable reduction in the numbers of this former species, and we have detected its disappearance in 30% of the places where it had been found in previous decades (Díaz Paniagua, pers. comm. 2023).

At least 140 macroinvertebrate taxa are known to be present in the lagoons of Doñana. The Doñana lagoons are important because many of the aquatic macroinvertebrate species that are abundant or frequent in them are considered rare in other areas of the Iberian peninsula (e.g., *Haliphus andalusicus*, *Agabus conspersus*, *Ilybius montanus*, *Rhantus hispanicus*, *Dytiscus circumflexus*, *Cybister tripunctatus africanus*, *Hydrochara flavipes*, etc.) (Díaz-Paniagua et al., 2019). There is no data on the possible deterioration of all these species. Apart from water quantity-related impairment, the presence of the Eastern mosquitofish (*Gambusia holbrooki*) seems to have an important influence on the functional and taxonomic composition of the macroinvertebrate group in Doñana's temporary lagoons; the red swamp crayfish (*Procambarus clarkii*) affects their taxonomic composition, and the freshwater bladder snail *Physella acuta* affects functional diversity without impacting taxonomic composition. The main taxa affected by these invasive species are *Cloeon* spp., *Corixa affinis*, and Notonectidae and Gerridae larvae (Soto García et al., 2021).





Group of flamingos in one of Doñana's lagoons at sunset. © Diego López / WWF Spain

Most of the lagoons in Doñana are small, but they are classified as priority habitats by the European Union (Mediterranean temporary ponds, code 3170 of the Habitats Directive). In years of high rainfall, more than 3000 temporary ponds have been mapped in the Doñana National Park wind mantle (Gómez-Rodríguez et al., 2010; Gómez-Rodríguez et al., 2011). A recent remote sensing study utilising satellite images has detected the loss of flooding since 2013 in 60% of the lagoons (larger than 900 m<sup>2</sup>) (de Felipe et al., 2023), and another study based on direct field observations has detected that around 60% of temporary lagoon basins have been incaded by terrestrial scrub and pine trees, mainly in the northwest area of the national park (Díaz- Paniagua et al., under review). The decrease in the time that water remains on the surface greatly accelerates the natural process of colonisation of the fertile sediment of a dried-up lagoon by scrub vegetation and even by trees such as tamarisks and pines (Muñoz-Reinoso, 2001; Serrano & Zunzunegui, 2008). Between 1970 and 2016, water abstractions in the Doñana/Matalascañas area favoured more xerophytic plant communities. Juniper (*Juniperus phoenicea*) is also spreading over areas historically considered to be scrubland (Muñoz Reinoso et al., 2020; Muñoz Reinoso, 2001).

An additional consequence of water abstractions from the aquifer could be increased salinity. However, to date, no saline intrusions have been detected in the Doñana aquifer (Serrano Hidalgo & Fernández Ayuso, 2021).

# THE ACTIONS

The draft of the Guadalquivir Water Management Plan for the period 2022-2027 includes, in the Programme of Measures, two actions to tackle the problem of Matalascañas and the peridune lagoons:

- *“Change of borehole locations for the Matalascañas supply to reduce the impact on the Doñana natural park”* (with code ES050\_3\_Guadalquivir5490 and a budget of 1.2 million euros).
- *“Transfer to Matalascañas from the PWTP from the Tinto in the Tinto, Odiel and Piedras River Basin District”* (with code ES050\_3\_Guadalquivir5483 and a planned investment of 10 million euros)

In addition, the draft Framework of Actions for Doñana (MITERD, 2022) includes the following measure to address the problem: *“Reduction of the impact caused by water abstractions to supply Matalascañas”*.

There is no reference to specific actions in the National Park’s Master Plan for Use and Management.

# ASSESSMENT AND PROPOSALS

The relocation of water extraction wells for domestic and tourist use in Matalascañas is a measure that will alleviate the pressure on the peridune lagoons of the Doñana Biological Station. In fact, this was first contemplated in the experts’ report more than 30 years ago (Hollis et al., 1989). However, as this transfers the pressure to another area within the Doñana Natural Area, where there are also many temporary lagoons (Ruiz-Labourdette et al., 2005), and these could suffer the same effects as those described for the peridune lagoons, a detailed study should be carried out before the works are implemented, and other actions with less potentially negative effects should be prioritised.

The competent administrations should:

- Promote reduced water consumption in Matalascañas, with measures to increase efficiency, environmental education for users, and volumetric pricing to promote savings, even restricting supply in periods of drought.
- Supply Matalascañas from sources that would have less impact than the borehole relocation, taking into consideration the desalination of seawater or measures with less impact in the existing water transfer rules from the Tinto and Odiel basins and encouraging reuse.
- Add the monitoring data on the flora, fauna, flooding surface and hydroperiods of the Doñana lagoons to that of the piezometric levels to warn of the need to restrict abstractions in periods that are critical for maintaining the lagoonal water cycles.
- Assess the pine forest (*Pinus pinea*) and, if appropriate, reduce it through active management. This could reduce evapotranspiration by up to 20%, especially in summer (Escribano & Fernández, 2018).
- Conduct an in-depth geological study of the aquifer on the coast near the abstractions and design and implement an intrusion control network.

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# IMPACTS OF RISING SEA LEVELS

## THE PROBLEM

The Doñana ecosystem was generated in the transition zone between the rivers and the sea. This interaction has been significantly reduced since the 1980s with the construction of the *Montaña del Río*, an artificial heightening of the natural elevation with floodgates —reinforced in the late 1990s— which now isolates the Doñana marshes from the Guadalquivir River.

The management of the Guadalquivir River basin exacerbates this uncoupling as **high water demand for irrigation reduces the flow of freshwater** causing significant erosion and pollution along the course of the river.

However, sea level rise is one of the climate change effects that may reverse this process, albeit at the cost of reducing the area of fresh marshland, one of Doñana's outstanding assets. As a result of sea level rise associated with global warming (Moomaw et al., 2018), **most of the coastal wetlands in the Mediterranean region are expected to be lost** over the next 70 years (Spencer et al., 2016). As a graphic example, the predicted flooding with a 1 m rise<sup>11</sup>, a limit that could easily be exceeded this century, can be consulted and the estimated effects checked.

There is an **enormous lack of knowledge regarding the Guadalquivir estuary** and a lack of interest by the competent authorities in terms of the eco-hydrological management of the estuary, reflected, for example, by the absence of data and specific management measures in the Guadalquivir Water Management Plan and the Guadalquivir Flood Risk Management Plan. There is also no official strategy or document analysing the **management options for Doñana in the face of the projected rise in sea level**, and it is necessary to update the protected area's management instruments, integrating the effects of climate change, as is being done in other protected areas.

## DATA AND INFORMATION REFLECTED IN OFFICIAL MANAGEMENT DOCUMENTS

The 2015-2021 River Basin Management Plan (CHG, 2021) determines that there are 3 natural **coastal water bodies**. According to the latest available data (2015-2019), two of the three coastal bodies are in poor ecological condition, *Pluma del Guadalquivir* and *Doñana-Matalascañas*, with non-compliance in physico-chemical indicators, specifically nutrients. For the third planning cycle, indicators of benthic macroinvertebrates (BOPA index), phytoplankton (chlorophyll-A) and nutrients (ammonium, nitrates, nitrites and phosphates) have been assessed. Although this is an important step forward compared to the second planning cycle, the degree of confidence in the assessment process is medium, as hydromorphologically altered elements have not been taken into account.

In Doñana, the 2015-2021 Water Management Plan considers 4 **transitional water bodies**; all of these are classified as "*highly modified*": the *Marismas de Bonanza* are in poor condition (the BO2A index of benthic macroinvertebrates has not been assessed, but the ITWf index of phytoplankton has been); the *Desembocadura de Guadalquivir- Bonanza* is in poor condition (in this case both the BO2A index of benthic macroinvertebrates and the ITWf index of phytoplankton have been assessed); the *Brazo del Este* water body is also in a poor condition (in this case the BO2A index and the ITWf index have both been assessed); and the *Guadiamar-Brazo del Oeste* water body is in a poor condition (the ITWf index and the BO2A index have been assessed as being in poor).

<sup>11</sup> This information is available at: <https://flood.firetree.net/>



Panoramic view of the Guadalquivir estuary at Trebujena. © Rafael Seiz / WWF Spain

Nutrients (ammonium, nitrates, nitrites and phosphates) have also been assessed in the four transitional water bodies; all of these have revealed problems with ammonium and nitrates, so their status is poor with respect to these indicators. The Plan does not establish reference conditions for these water bodies, with the exception of certain physico-chemical quality indicators. Neither macrophytes nor fish are considered among the biological quality elements, and hydromorphological quality indicators have not been assessed. The degree of confidence in the assessment is therefore medium.

On the other hand, according to the River Basin Management Plan, a sea level rise is expected throughout the 21st century, which on the Doñana coast could increase its level with respect to the local average level by between 7% and 12% up to 2045, and by between 25% and 37% by 2100, depending on the RCP scenario applied. In the estuary, this rise would result in the increased presence of saline water in the marsh, which would affect the ecosystem distribution within the estuary (CHG, 2021b). This could directly affect the ecology of the estuary as well as that of the marshland area, especially in the Doñana National Park, where there could be significant changes in the distribution of ecosystems (CHG, 2022).

In the diagnostic section of the Natural Resources Management Plan (Plan de Ordenación de los Recursos Naturales; PORN), reference is made to "*a foreseeable rise in sea level*" and its effects on the ecosystems of the Natural Area including sediment balances. The qualitative vulnerability index for the Andalusian coast in terms of potential sea level rise establishes very high levels of vulnerability for the whole of the Playa de Castilla beach, from Matalascañas to the Punta del Malandar, as well as for an important part of the Guadalquivir estuary. The vulnerability of the coastal stretch between Mazagón and Matalascañas is assessed, in general terms, as moderate.

# KNOWLEDGE ABOUT GUADALQUIVIR ESTUARY

Previously, the tides entered the marshes through the natural cuttings in the Montaña del Río and the spillways of the Brazo de la Torre, flooding the Los Ansares and Membrillo lakes and the Las Nuevas, Brenes and Figuerola channels (Valverde, 1960; Vanney, 1970). This tidal influence also allowed the contact and exchange of different biological communities between the marsh and the Guadalquivir estuary at certain times of the year, an ecological phenomenon of vital importance for the distribution and proliferation of the different species in the fish community (Valverde, 1960; Fernández Delgado et al., 2000).

In 2010, the Spanish National Research Council (CSIC) analysed the general state of the Guadalquivir River over its final 110 kilometres and reached alarming conclusions. These include: a) the freshwater flow is minimal, being 60% less than 70 years ago and five times less than necessary; and b) 85% of the spaces that used to be flooded by the tides in alternating cycles, the tidal flats, have disappeared (CSIC, 2010).

Some large estuaries (e.g., the Guadalquivir, Ebro and Verdugo in Vigo) present decreased tidal elements. The root cause of these changes is the loss of freshwater flows from their catchment areas, although sea level rise over the last 20 years may have also contributed to this deterioration. Flow changes impact saline intrusion, stratification and the viscosity distribution of vertical eddies. The tidal range in the Guadalquivir is greater in its headwaters (0.001 cm/year) but reduced at the mouth, possibly due to the deepening of the navigation channels (Diez-Minguito et al., 2018).

An analysis of four vulnerability indices characterising estuaries indicates a reduction in exchanged mass flux and tidal energy between 2000 and 2015 in most Spanish estuaries, although the significance of the changes was greater in the southwest Atlantic, especially in the Guadalquivir and Guadiana. There has been a sharp reduction in freshwater flows in rivers in recent years, leading to increased saline intrusion in all Iberian estuaries (Serrano et al., 2020).

In different future scenarios, the effect that deepening the current channel due to dredging for navigation to the Port of Seville, and sea level rise, which would increase the amplitudes of the elevations, the tidal prism and, to a lesser extent, the saline intrusion in the estuary, are of particular importance. The tangential stress increase on the bed and banks would favour greater local erosion rates and, therefore, increase the concentration of suspended sediments and turbidity (Diez-Minguito et al., 2019).

## THE EVOLUTION OF THE DUNE ECOSYSTEM AND ITS VEGETATION

In two areas the mobile dunes have disappeared and have been colonised by the Portuguese crowberry (*Corema album*), xerophytic scrub and pines (*Pinus pinea*, intensively planted since the 19th century), due to reduced winds (resulting from the construction of Matalascañas), the slowed advance of the mobile dunes from 2.37 m/year (in the period 1956-1977) to 1.27 m/year (1977-2001), the lack of sand contribution caused by the construction of the breakwater in the Tinto-Odiel estuary, the changes in winds, and the growth of vegetation (Muñoz Reinoso et al., 2020; Muñoz Reinoso, 2001).



Aerial view of the Doñana dune system. © Héctor Garrido / EBD-CSIC

## THE EFFECTS OF ESTUARY DETERIORATION AND SEA LEVEL RISE ON DOÑANA'S ECOSYSTEMS

The current conditions of low dissolved oxygen with high levels of CO<sub>2</sub> and suspended solids, as well as the lack of stable intertidal habitats, limit the biodiversity of the Guadalquivir to a greater extent than in other estuaries (Ruiz et al., 2015).

Recent studies have further explored the scant knowledge available on the phytoplankton in the Guadalquivir estuary. Twelve functional groups of phytoplankton species have been identified, whose distribution is mainly influenced by the estuarine salinity gradient (Cañavate et al., 2019), with seasonality having a minor influence and high nutrient concentration exerting a negligible effect. Cyanobacteria and chlorophytes are more abundant in the oligohaline reaches, while haptophytes and dinoflagellates (non-toxic) become more abundant in the phytoplankton community from mesohaline values onwards. These phytoplankton dynamics mean that the nutritional value of primary production in the estuary becomes higher as salinity increases (Cañavate et al., 2021). Trophic transmission efficiency to consumers is therefore directly related to estuarine salinity.

The meso-zooplankton has undergone significant changes in composition over recent decades and is dominated by two euryhaline species, *Calanipeda aquaedulcis* and *Acartia clausi*. The former, which is adapted to extreme environments, dominates large areas of the estuary (Tagliatalata et al., 2014).

Between 1997 and 2009 there was no significant inter-annual variability in the presence of fish, in particular fry, in the estuary area, which was related to the variability of rainfall and hence freshwater discharge from the river. However, turbidity (a side effect of water scarcity and soil erosion in the catchment area) affects both the structural and functional characteristics of the fish community (González Ortegón et al., 2015).



The Spanish National Research Council (CSIC, 2010) reported on the effects that the physico-chemical situation of transitional waters has on some coastal waters closer to the mouth of the river: “... *The impact of high CO<sub>2</sub> concentrations is seen on both the zooplankton community and the benthic fauna... [resulting in a] low specific richness of the benthos in the estuary. The limitation of the dissolved oxygen concentration extends to the banks along the last stretch of the estuary, the mouth and the adjacent littoral zones. These events can lead to the emergence of coastal ‘dead zones’.*” To this must be added the morphological imbalance of the coast due to human intervention.

There is no specific information or projections for Doñana on predicted flooding in line with sea level rise, but the effects expected elsewhere in the world can be seen on the Doñana website <https://flood.firetree.net/>. The inflow of seawater into the marsh and the associated salinity increase would reduce the species richness of aquatic plants and aquatic invertebrates (Frisch et al., 2006; Green et al., 2002). It would negatively impact endangered bird species such as the red-knobbed coot and anatids in general (Green et al., 2002; Rendón et al., 2008). It would change the composition of the waterbird community, benefiting some wader species, but causing declines in other waterfowl (Ramírez et al., 2018).

## THE ACTIONS

The Flood Risk Management Plan (FRMP) indicates that the main impacts identified on the coast are flooding and erosion, which depend on the waves, meteorological tide and mean sea level rise. Sea level rise has typically been identified as the main driver of climate change impacts on the coast. However, a proper assessment of coastal impacts should also take into account changes in the waves and meteorological tide. At present, the Guadalquivir River Basin Authority considers that decisions associated with climate change adaptation strategies on the coast must be made within an uncertain framework, which requires methodologies and existing information to be improved in order to limit uncertainty and thus make a more accurate and efficient use of available resources.

To update the information generated during the first implementation cycle of the Floods Directive and to comply with the obligations imposed by the European Union related to incorporating the impact of climate change on coastal flooding, the Institute of Environmental Hydraulics at the University of Cantabria has developed new databases of regional climate change projections of marine variables to estimate the impact on coastal flooding. This work has made it possible to compare the projected extreme coastal flooding events with historical ones, for each of the profiles and limiting the uncertainty when determining the impact of climate change on coastal flooding in Spain. For this purpose, the climate scenarios RCP 4.5 and 8.5, different time periods (1985-2005, 2026-2045, 2081-2100), climate models, MSLR distribution function (mean sea level rise) and return periods (10, 50, 100 and 500 years; the last two are those established as a minimum by the Floods Directive) have been used.

The results for the Guadalquivir indicate that the Relative Increases in Elevation (RIE) and Flood Distance (FD), increase fundamentally over the long term period (2081-2100), and also as the return period value increases (10, 50, 100 and 500 years). The differences between the results of the two climate scenarios studied (RCP 4.5 and 8.5) are, in general, not very important, although those of RCP 8.5 are always greater.

Specifically, the maximum relative increases in the RIE and FD for the medium term (2026-2045) have a very high variability throughout the River Basin District. The greatest RIE values range from approximately 15% increments for the 10-year return period of RCP4.5 to around 45% for the 500-year return period of RCP8.5. On the other hand, the largest values for FD range from approximately 25% increments for the 10-year return period of RCP4.5 to about 50% for the 500-year return period of RCP8.5. The maximum relative increases in RIE and FD over the long term (2081-2100) are higher than those for the medium term and also vary greatly across the river basin district. The greatest RIE values range from approximately 30% increments for the 10-year return period of RCP4.5 to around 80% for the 500-year return period of RCP8.5. On the other hand, the largest values for FD range from approximately 50% increments for the 10-year return period of RCP4.5 to about 165% for the 500-year return period of RCP8.5.

Despite the uncertainties of the proposed results for marine flooding, no new hazard and risk mapping has been prepared for the revision of the FRMP in this second cycle; instead the mapping available from the first cycle, prepared by the Directorate General for Coastal and Marine Sustainability, has been considered adequate. In relation to the proposed measures, it is envisaged that the implementation of the Programme for the maintenance, conservation and improvement of watercourses will continue and be stepped up, with an average annual investment of approximately 3 million euros over the whole period. The positive effects of this programme, focused on watercourses, are due to hydrological-forestry restoration and agri-hydrological management actions in the basin. One of the novelties of this cycle is the inclusion of a Sediment Continuity Programme in this area. According to the Guadalquivir River Basin Authority, the objective is to improve knowledge of how sediment dynamics alter in the basin as well as the geomorphological imbalances that occur, characterise and map these processes by identifying priority areas where the problems are most pronounced, and finally propose measures to mitigate them, all in compliance with the new Law on Climate Change and the Energy Transition.

With regard to the regulations for managing the operation of reservoirs that significantly impact the hydrological regime, in this cycle it is planned to implement a new dam safety programme in accordance with Royal Decree 264/2021, of 13 April, approving the technical safety regulations for dams and their reservoirs, and to improve coordination between dam outlet flows and possible downstream effects, as well as floodability studies of the areas of significant potential flood risk (Áreas con riesgo potencial significativo de inundación; ARPSIs) from downstream areas and carried out within the framework of the National Floodplain Mapping System (Sistema Nacional de Cartografía de Zonas Inundables; SNCZI), in general, on the basis of more up-to-date and accurate information and with more advanced calculation tools. No further details are provided in the FRMP Report on these specific measures for the restoration of watercourses. With regard to specific actions related to marine and/or tidal flooding, one typology of measures contemplated in the FRMP (*Typology 11 —15.01.01*) is aimed at establishing or improving meteorological warning systems, including systems for measuring and forecasting marine storms; this has a budget of around 5 million euros. This measure includes drawing up a “*Protocol for action between the State Meteorological Agency (Agencia Estatal de Meteorología; AEMET) and the Directorate General for Water (Dirección General del Agua; DGA) for the exchange of hydrometeorological information*”, the inclusion of new parameters subject to warning in the Metealert Plan and the improvement of the meteorological observation network. This measure is also included in the 2022-2027 Water Management Plan with the following code *ES050\_3\_Guadalquivir5579*.

No further specific information is provided on other concrete measures for tackling this problem in the Doñana area, except for a study on “*Consultancy and engineering services for flood prevention in the town of Coria del Río (Seville)*” with a budget of barely 80,000 euros.

The Guadalquivir Water Management Plan for the period 2022-2027 (CHG, 2022) includes the following measures for addressing the problem:

- In the third planning cycle, a study will be carried out to elucidate the consequences of sea level rise in more detail. No other actions are currently foreseen.
- Measures to improve longitudinal permeability in the lower Guadalquivir River (*ES050\_1\_Guadalquivir0321*), which includes actions at the Alcalá del Río and Cantillana dams. No measures have been included involving the recovery of tidal flats or any measures that directly affect the hydromorphological conditions in the estuary.
- There is a measure on the “*Study and control of ecological flows*” (*ES050\_1\_Guadalquivir0472*) that affects all the water bodies in the district. It is not specified how this will be applied in the estuary, despite the repeated flow regime revision proposals that have been presented in the public consultation process of the 2022-2027 Water Management Plan. There is a measure to develop a “*Methodology for considering coastal and marine ecosystems in ecological flows*” (Code *ES050\_3\_Guadalquivir5633*) but with the low level of detail provided in the Programme of Measures it is not possible to know its scope.

These measures are an improvement on the previous 2015-2021 planning cycle, but as they have not yet been initiated (the 2022-2027 plan was approved in January 2022) no progress can be assessed at this stage.

There is no reference to specific actions in the National Park’s Master Plan for Use and Management.

# ASSESSMENT AND PROPOSALS

According to current projections, sea level rise will cause the loss of most coastal wetlands in the Mediterranean region over the next 70 years, with significant impacts on Doñana (Spencer et al., 2016; Geijzendorffer et al., 2018). However, despite its enormous importance, there is a very little knowledge of the Guadalquivir estuary and a lack of interest on the part of the competent authorities in terms of its eco-hydrological management; there is also a lack of analysis and debate on the management options for Doñana in the face of rising sea levels. On the other hand, freshwater management in the Guadalquivir basin is already having important repercussions on the quality and conservation of the estuary.

A specific study modelling sea rise and its consequences in the Guadalquivir marshes and estuary is necessary (e.g., following Kulp & Strauss, 2019).

Sedimentation processes in deltas are very positive measures for counteracting sea level rise (Giosan & Syvitski, 2014). In contrast, in the Guadalquivir, the canalisation causes the sediments to wash out to sea instead of being deposited in the delta. Many other sediments are trapped behind dams in the basin. Measures that restore sedimentation processes in the delta should be considered, similar to those implemented in the Mississippi, for example (Xu et al., 2019).

The competent administrations should implement the following:

- To counteract salinity and tidal influence effects, significant freshwater inputs from the Alcalá del Río reservoir should be assured and tidal flat areas restored in the lower estuary (Diez-Minguito et al., 2019).
- Develop a strategy and management measures, including monitoring, to analyse the risks and benefits of the effects of sea level rise on the different ecosystems in Doñana, as well as on the natural area as a whole.
- Study how sea level rise would affect the aquifer (increased risk of intrusion).

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# INVASIVE SPECIES IN DOÑANA

## THE PROBLEM

Alien and invasive species constitute a **risk for the conservation of biodiversity** in Doñana. These taxa are favoured by ecosystem deterioration, as well as by activities that may bring these species to the area, such as **maritime transport** and **sporting activities**.

## DATA AND INFORMATION REFLECTED IN OFFICIAL MANAGEMENT DOCUMENTS

With regard to alien species, the Provisional Scheme of Important Issues in the latest revision of the Guadalquivir Water Management Plan (2022-2027) explicitly refers to their introduction via the transfer of vessels of international origin to the Port of Seville, as well as other indirect causes.

The 2022-2027 Guadalquivir Water Management Plan specifically refer to invasive alien species in the protected area of Doñana. Reference is made to the fact that in the case of the district *"... the problem has been growing in recent decades. Invasive alien species (IAS) have been found in 141 river and reservoir type bodies of water, 9 transitional bodies of water and 3 irrigation canals."*

There is no specific mention of Doñana, so it is not possible to infer how dedicated the Guadalquivir River Basin Authority is going to be in terms of preventing and controlling alien species in the National Park or in the protected natural area. The only near reference to this in the Report states that *"... In 2021, the presence of Wels catfish (*Silurus glanis*) was confirmed in the Guadalquivir, below the Alcalá del Río dam<sup>12</sup>. This is an introduced invasive alien species whose presence is particularly worrying in the area of the Guadalquivir marshes, where the very few remaining populations of marbled teals, white-headed ducks, ferruginous duck and red-knobbed coots, all of which are endangered birds, are found."* No specific measures have been established for this species, nor for the other invasive alien species that have been detected.

In its diagnosis, the Natural Resources Management Plan (PORN) for the Doñana Natural Area recognises the problem of invasive species of "medium" importance and explicitly mentions some species of fish, red swamp crayfish and plants, and relates these to the deteriorated state of the river ecosystems, as well as to navigation. It calls for prevention and early detection as the tools that can best mitigate the potential negative effects of these biological invasions.

The Guiding Plan for Use and Management (Plan Rector de Uso y Gestión; PRUG) refers to exotic and invasive species when it talks about management criteria, *"favouring the establishment of mechanisms and systems for detection and early warning where necessary"*. Likewise, *"the continuation of the work programme for eradicating eucalyptus plantations and the subsequent restoration of the plant and soil cover will be promoted in line with that specified in the existing planning"* and *"the development of restoration and regeneration measures will be promoted on forested land and areas of marsh and wetland that present conservation problems."* It also envisages other measures such as awareness-raising and informational measures.

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12 There is evidence at of these fish being present in the area since at least 2015 (Sáez Gómez, Pers. Comm . 2023).

# THE KNOWLEDGE

The conservation status of native fish in the Guadalquivir basin is poor. Of the total of 18 species found in 2008, the overall predominance of introduced species was 25%, which is considered a high value. The most common introduced species were the Eastern mosquitofish (*Gambusia holbrooki*) and the pumpkinseed (*Lepomis gibbosus*) with 10% predominance. In 2014, in the sampling carried out by the Natural Processes Monitoring Team at the Doñana Biological Station, 16 fish species were recorded throughout the Doñana area, of which 6 (37.5%) were exotic. In the lagoon samples, the richness obtained was 9 species, 6 of which were exotic (67%). Finally, in the peridune lagoons only 4 fish species were detected, of which 3 were non-native (75%).

Currently, the penetration of alien species has increased, making this the most threatened segment of biodiversity in Doñana (Prenda, 2022). It is associated with a change in the agricultural model towards intensification, linked to very high soil erosion rates, considerable water abstraction and flow regulation in dams and canals, as well as the presence of pollutants such as pesticides that eliminate fish from stretches of river on the plain. Fish such as the three-spined stickleback (*Gasterosteus aculeatus*) as well as most of the migratory species (sturgeon, *Acipenser sturio*; sea lamprey, *Petromyzon marinus*; allis shad, *Alosa alosa*; twait shad, *Alosa fallax*) have also disappeared. The native species, which until recently were very abundant, have a markedly reduced distribution, including the European eel (*Anguilla anguilla*) and *Iberochondrostoma lemmingii* (Sáez-Gomez et al., 2020; Sáez-Gómez and Prenda, 2022).

There is very little information on the fish in the temporary lagoons in Doñana. Of the six species found in these unstable and fragile environments, three are native species: the Southern Iberian spined loach (*Cobitis paludica*), the European eel (*Anguilla anguilla*), and the killifish (*Aphanius baeticus*) and three are exotic: the Eastern mosquitofish (*Gambusia holbrooki*), the common carp (*Cyprinus carpio*), and the mummichog (*Fundulus heteroclitus*). Currently, from a quantitative perspective, the most numerous species in the lagoons are exotic (Prenda, 2015).

The presence of the Eastern mosquitofish (*Gambusia holbrooki*) seems to have an important influence on the functional and taxonomic composition of the macroinvertebrate group in Doñana's temporary lagoons; the red swamp crayfish (*Procambarus clarkii*) affects their taxonomic composition; and the freshwater bladder snail *Physella acuta* affects functional diversity without impacting taxonomic composition. The main taxa affected by these invasive species are *Cloeon* spp., *Corixa affinis*, and Notonectidae and Gerridae larvae. (Soto García et al., 2021). The introduction of the crayfish affects the food webs in the lagoons, the water quality and macrophyte biomass deteriorate, it alters the zooplankton composition and preys on amphibian larvae (Arribas et al., 2014).

In addition, four new species of fish have recently been introduced into the Guadalquivir basin: the chameleon cichlid (*Australoheros facetus*), the black bullhead (*Ameiurus melas*), the Wels catfish (*Silurus glanis*) and a minnow (*Phoxinus* spp.) of unknown origin. Since the first report of the black bullhead in 2007, it has expanded significantly, including into the Doñana National Park, with shoals of several thousand specimens being observed in La Rocina 2010 (Sáez-Gomez & Prenda, 2019).

Other exotic species having an impact are the water boatman *Trichocorixa verticalis* (a predator, which excludes some native corixid species and may affect native crustaceans, Céspedes et al., 2019) and the brine shrimp *Artemia franciscana* (which eliminates native *Artemia* species, and implies a loss of endoparasite biodiversity; Horvath et al., 2018).

Since the 1990s, the Argentine ant (*Linepithema humile*) has been very slowly invading the surroundings of a small permanent human settlement, although its advance is very limited to a set of cork oak trees (Castro-Cobo et al., 2019).

The invasion of the water fern *Azolla filiculoides* produces dense layers on the water surface; this reduces the entry of light into the water column, causing the elimination of macrophytes, reducing pH and oxygen levels, and increasing the concentration of nutrients in the water, which in turn affects the development of amphibian larvae living in the invaded environments (Pinero-Rodríguez et al., 2017).

The invasion of the cord grass *Spartina densiflora* excludes native emergent plants such as the purple nutsedge or candelilla, which has been expanding in Isla Mayor in recent decades (Bustamante et al., 2016). Any measures to increase connectivity between the estuary and the marsh are likely to be highly favourable to this species, and it has already completely colonised some restored areas in the estuary.

*Cotula coronopifolia* is an invasive plant that colonises much of the marsh in dry years, competing with *Ranunculus* and many other native species (Costa et al., 2009; Gassó et al., 2012).

In addition to the more well-known invasions of both plants and animals, there is increasing evidence of the increased susceptibility of temperate aquatic ecosystems to colonisation by tropical micro-organisms as a consequence of changes in environmental conditions caused by climate change (Paerl & Huisman, 2008; Carey et al., 2012; Lurling et al., 2017; Mantzouki et al., 2018). This may be the case of several tropical species of invasive cyanobacteria, many of which are toxin-producing; these are favoured by climate change in environments with suitable conditions, such as eutrophicated lakes and lagoons (Paerl & Otten, 2013; Rigosi et al., 2014; Thomas & Litchman, 2014). These toxins could, for example, affect fauna that drink in lentic environments, having both acute and chronic effects (Codd et al., 2017; Fastner et al., 2018).

## THE ACTIONS

The 2022-2027 Guadalquivir River Basin Management Plan specifically refers to invasive alien species in the protected area of Doñana. The Programme of Measures contains a *generic measure for "Monitoring and Control of Measures against Alien Species in the Guadalquivir basin"* (ES050\_3\_Guadalquivir5471 with a budget of 2 million euros) and another referring to the *"Pilot study for the control of bryozoans and other organisms with adverse effects on filters, pipes and other water distribution and application structures, both in irrigation and supply"* (ES050\_1\_Guadalquivir0414 with a budget of 1.2 million euros).

The Natural Resources Management Plan (PORN) for the Doñana Natural Area includes a *proposed measure that refers to "Control and surveillance to prevent the expansion of already detected invasive alien species and the appearance of new ones."*

There is no reference to specific actions in the Master Plan for the Use and Management of the Natural Area, which is limited to management criteria and lines of action. The Park's 2023 Work Plan (Consejería de Sostenibilidad, 2022) includes measures such as continuing control and surveillance work on invasive alien species, maintaining monitoring to ensure early detection of new introduced species of flora and fauna, such as the raccoon (*Procyon lotor*), whose presence has been noted in streams near Doñana, with some incursions having already been observed in the Doñana Natural Area, and elimination where appropriate. Monitoring of recently introduced fish species such as the black bullhead (*Ameiurus melas*) and other species will also continue. In addition, there are plans to increase the surface area of the habitats of Community interest characteristic of the river and riparian ecosystems of the Natural Area.

## ASSESSMENT AND PROPOSALS

The Guadalquivir River Basin Management Plan for the period 2022-2027 does not establish any specific measures to tackle the proliferation of exotic species in the Doñana area. From the information contained in the Programme of Measures, it is not possible to establish whether or not specific actions will be carried out in Doñana.

The competent administrations should:

- Boost the restoration of natural ecosystems, promoting their resilience to invasions by alien species.

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# CONCLUSIONS

For decades, Doñana has been the crown jewel of nature conservation in Spain, and one of the most iconic sites for European biodiversity. However, increasing pressures linked to water pollution, overexploitation of the aquifer and overgrazing of the marshes have significantly deteriorated Doñana's ecosystems, and in particular those water-dependent ecosystems that characterised the outstanding natural value of this unique site for biodiversity conservation.

This has been recognised and highlighted for decades by a large group of people linked to the world of scientific research, and WWF Spain —just as it did with its prominent role in the creation of the National Park in 1969— has tried to promote strategies and actions to conserve its ecosystems and biodiversity, not only in the protected area, but also in the immediate surroundings and the estuary of the Guadalquivir River by committing to sustainable development strategies.

However, the managers of Doñana continue to ignore for European biodiversity the decisions they make. While some policies —such as proposals to legalise illegal irrigation. While some policies openly promote the deterioration of natural assets, many of the conservation and restoration projects that are included as actions in government plans are not implemented. For example, some actions in the *"Doñana 2005"* project have never been completed. Nor has a complete regime of environmental flows been defined and implemented in the watercourses that feed this area and which are essential for guaranteeing the water supply to the different areas of the marsh. The responsible authorities have not been able to control all the water abstractions for irrigation, and this has contributed to the spread of illegal water use in the area, aggravating the pressures on the water in the aquifer that supports a large proportion of Doñana's habitats.

The competent authorities also had lacked robust strategies and action plans for preserving ecosystems and biodiversity in the face of the impacts of climate change that are already becoming evident in Doñana, and which are putting additional pressure on habitats and species; these are having a significant negative impact on the availability of sufficient water inputs in the medium term.

The proposals detailed in the various sections of this report can be summarised as follows:

1. Use the most up-to-date scientific knowledge as the basis for managing, restoring and monitoring Doñana in the face of the challenges that lie ahead for the conservation of its natural assets.
2. Improve knowledge of pressures (e.g., effectively measuring all water abstraction for irrigation) and their effects on ecosystems and biodiversity.
3. Restore the functions and structure of Doñana's degraded ecosystems.
4. Develop a management strategy for the area that addresses the current pressures to which it is subjected and provides ways to adapt to the impact of climate change, which is already becoming evident in Doñana.

WWF Spain argues that it is imperative to urgently address the environmental problems affecting Doñana in an integrated manner in order to halt the worrying deterioration trends associated with unsustainable land management in the area. The effects of climate change will put additional pressure on Doñana's natural assets and pose a major challenge for the managers responsible for this unique site, which is essential for biodiversity. It is time to open our eyes to the scientific evidence indicating the deterioration of this area, so that we can, once and for all, implement ambitious actions and make firm commitments for the recovery of this wetland. There is no time to lose.



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