

Monitoring and Evaluation

the key to the Doñana 2005 Restoration Project

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Evaluating the success of the Doñana 2005 hydrological and ecological restoration project requires an extensive monitoring and follow up programme that, first of all, allows scientists to identify the state of the system prior to the project, during the project and, then, to provide information on the response of the natural system after these interventions. To this end, Doñana 2005 has a monitoring and evaluation programme that will be implemented by different teams of specialists³⁹, who will study aspects considered important for the natural dynamics of the Doñana Marshes.

Of the abiotic factors, attention will focus on hydro-geo-morphological changes in the area affected by the project and water quality. On the other hand, and as part of the biotic factors, both land and water communities of plankton and plants will also be studied, together with fresh water and estuarine macro-invertebrate communities: fish, amphibians, reptiles, birds and mammals, hence including representatives of most of the links in the food chain of the marshland biocenosis.

At the same time, information will be made available from other research and monitoring projects in course that may provide additional information on the dynamics of the surface and groundwater, pollutants transported in by water flowing into the Doñana Marshes and changes that may occur to landscapes.

The final success of the restoration project depends on obtaining favourable results in ecological and biological terms, by eliminating the main processes of degradation that are identified. In this regard, Wetlands International establishes spatial reduction, alteration of the water regimen, reduction of water quality, the introduction of exotic species, unsustainable use and management and restoration as the main processes that lead to the deterioration of wetlands globally, and which also affect the Doñana Marshes⁴¹.

Eliminating the processes of degradation and their associated stress factors and impacts, which affect natural processes and biological communities, is the priority objective of the restoration project, in order to work towards a final scenario offering a double result. Initially, the recovery of ecological processes that are

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The invasion of introduced species is one of the causes for the reduction and extinction of native species. Apart from the carp, an early introduction, and the brown rat (*Rattus norvegicus*), the exotic species that are causing the greatest ecological damage in Doñana are the eucalyptus, the Louisiana crayfish, the ruddy duck, the water fern *Azolla filiculoides* and the Florida red eared slider (*Trachemys scripta*) are potential dangers. In the photo, a specimen of the common pond turtle (*Emys orbicularis*), which is being displaced by the red eared slider.

Photograph: CENEAM files.

currently impeded and, later on, a favourable response from the biological communities. With all this, and apart from the objectives set, any restoration intervention implies uncertainties that can be reduced by research and monitoring, but they cannot be eliminated totally, basically because these natural systems are so complex.

MAIN PROCESSES OF ECOLOGICAL DEGRADATION AND THEIR EFFECTS ON BIOLOGICAL COMMUNITIES

Reduction of the area of wetland

Transforming the lands for farming, forestry, industry, urban development and the shipping traffic to Seville in the Lower Guadalquivir River has led to a considerable loss of natural marshland area, which is the main origin and source of the impacts suffered by Doñana for over two centuries.

This loss of area has had a direct and decisive influence on the loss of habitat, with the natural marshland ecosystem being reduced from 1780 km² to some 300 km², and thus constraining the abundance and distribution of plant and animal communities²⁵.

It has also indirectly determined key ecological aspects like the water regime and quality.

Before restoration started within the Doñana 2005 Project, a total of 557 ha and 17.5 km of water courses (Sotos 307 ha, Partido 950 ha, Gallega marsh 1800 ha, Caracoles 2665 ha and Torre Branch 17.5 km) were cut off from Doñana's natural system, either fully or in part, thus generally affecting the marsh ecosystems as a whole and some of the areas of stable sands.

With regard to the Gallega marsh and Torre Branch (*Brazo de la Torre*), isolated from their natural systems, the rest of Doñana marshes and the River Guadalquivir respectively, they have suffered a loss of biological potential in comparison with the estuary environment, in both cases, because they have been cut from these and the flooding dynamics have been altered²³. Recovering or restoring these areas will increase the area of marshlands in a natural state, which should generally favour their biological communities.

Altering the water regimen, restoration and management

Human activities and the loss of space, together with restoration and management activities undertaken in the protected area since it was first created, have had a notable impact on altering the regimen of both surface and subterranean waters. The most obvious consequences are the increasingly severe floods and droughts, with higher levels of flooding of larger areas in winter, shorter periods of flooding during the mating and breeding season in the National Park and a reduction of rains and water resources in general, during spring and autumn outside the National Park.

With regard to the surface waters, since the Doñana Marshes were first transformed, the influence of the floods of the main



Hunting of water fowl in the Doñana area may be affecting endangered species like the marbled teal and the crested coot, as they are often misidentified because they are very similar in appearance to other species that can be hunted, like the teal and the coot. In the photograph, a crested coot.

Photograph: CENEAM files.

TABLE 1

Main interventions of hydrological restoration in the Doñana National Park - 1973-1998.

Year	RESTAURATION UNDERTAKING
1974	Marilópez, Lobo and Almajal wells. Artificial flooding.
1981	Hydrological regeneration.
1984	Restoration of <i>Montaña de Río</i> levee New sluices built. South-North intervention.
1986	Traveso Nuevo Canal
1986-1990	Old riverbeds regain flow. Restoration of Cangrejo Chico pond. Control of trenches in levees to Estuary.
1998 -	Doñana 2005 Project. Guadamar "Green Corridor" Project.

branches of rivers, Brazo del Noroeste and the two branches that formed the Guadamar channel, has gradually been reduced. In the 1950s, the inputs of water that spread out through the northern part of the current marshlands of the National Park were eliminated, so they now flow basically along the Entremuros canal, built to drain the waters into the sea as quickly as possible.

Since the National Park was created, different restoration projects (Table 1) have been undertaken to off-set the negative effects caused to the area of protected marshland by the transformation work done on the Lower Guadalquivir.

Until 1973, the main water inputs flowing into the Marshes of the National Park came from Entremuros, to the south of the Cangrejo Chico pond, the channelled part of the Guadamar and the Gallega marsh, Cañada Mayor, El Partido and La Rocina streams and the channels flowing from the stabilised sands to the west of the National Park.

Three wells were dug in 1974 to flood Marilopez and Lobo ponds, situated in the Guadamar Reserve, with water from the aquifer. At first, the wells were used in autumn and late spring to extend the floods, but they were later used only in autumn. The large flocks of birds attracted in these years have had a decisive influence on the area by almost completely eliminating all the vegetation from the ponds.

The reconstruction of the *Montaña del Río* levee in 1984 is presented as "The Natural Mountain" and described by Bayan and Delibes¹⁷ as "an elevation of the land scarcely one metre high, that, on the one hand, closed off the Marshes, preventing them from draining into the Guadalquivir (with the exception of a few canals) and, on the other, in the opposite direction, made it impossible for the salt waters of the Lower Guadalquivir from penetrating into the Marshes in any great quantities when the tide came in".



Restoration experiences in areas as complex and sensitive as wetlands indicate that success is closely linked to the development of an evaluation and monitoring system that enables managers to correct undesired causes and effects in real time. For this reason, and in order to guarantee the hydrological and ecological objectives of the "Doñana 2005" restoration project, an extensive monitoring programme has been designed that, first of all, makes it possible to identify the initial state of the system, its state during the actions and later, it provides information on the responses of the natural system to the interventions. In the picture, a partial view of the area of action concerning the control and creation of new connections between the Doñana Marshes and the neighbouring River Guadalquivir, the Torre Branch (Brazo de la Torre) and Entremuros.

Photograph: AYESA.

The destruction of the river levee must have happened due to the combined effect of several factors: the erosion produced by major floods in wet years, as larger amounts of water were confined in the south of the Doñana Marshes along Entremuros, the effect of large ships sailing along the Guadalquivir and the dredging of the river²⁰.

The Travieso Nuevo canal was finished in 1986, which will feed a considerable flow of water into Doñana Marshes in wet years, from south of Cangrejo Grande pond, which caused damage to the Montaña del Rio levee due to the action of wind, opening breaches and hence draining the marshes easily and without control through these breaches.

Penetration of the Montaña del Rio levee has caused an excessive elevation of the height of the water level with widespread flooding throughout the Marshes, including islets and elevations, and an acceleration of the silting up process³⁷. As a consequence, the huts of wardens have been flooded in the Marshes, something that had never happened in the past. In the period 1986-1990, the canals were finally restored and cleaned, and new ones built, to allow the Marshes to drain rapidly in the event of botulism epi-

demics that could have a disastrous effect on the waterfowl.

On the other hand, the Doñana Marshes have almost completely lost the influence of the flooding from the River Guadalquivir, although they do have a decisive effect on the water dynamics, especially in wet periods, as they prevent the Marshes from draining when the water level of the river is too high.

Concerning the groundwater, pumping for domestic and agricultural uses is causing the water table to steadily fall, which, in consequence, reduces the water input from the ecotone (La Vera) into the Marshes and from La Rocina stream²¹ (Committee of Experts 1992). Moreover, a widespread loss of natural up-welling points (*ojos*) has also been recorded in the Marshes, which used to be a refuge for fish, amphibians and reptiles during the summer, making natural droughts to be more severe⁴⁴.

The transformation of the water network and harnessing the aquifer seem to have shortened the wet season of the Marshes. Although this has to be verified quantitatively, the consequences can already be detected in the marsh biocenosis.

The combined action of reducing the area of the Marshes, altering the water dynamics and restoration actions taken global-



Excessive grazing in the National Park has reduced the vegetation in some areas, affecting birds and mammals. Some researchers suggest that the water rat's distribution has been limited in La Vera, an area of contact between the Marshes and the Sands, as there are no reeds for the rats to spread through, because these have all been trampled down by livestock. In the picture, a magnificent Mostrenca breed bull.

Photograph by José María Pérez de Ayala.

ly, have had repercussions on the water regimen of the Doñana Marshes. On the one hand, this combination has produced excessive flooding, especially in the winters of wet years, and, on the other, it has shortened the period of flooding in spring-summer, as the connection between ponds to the north of the Marshes, now transformed, and those to the south, have been lost. Some indications provided by an analysis of the presence of some species of water fowl in the Marshes of the National Park, suggest that the Marshes dry out earlier since the canals have been restored.

A digital analysis of the time series of satellite images will give us more accurate information on the changes that have occurred to the duration of the wet season in winter and spring and the area that is flooded in the Marshes. But, with the existing information about the flood area, the height of the water column and time taken for the Marsh to dry out⁷ (National Park Reports 1997, 1998 and 1999), it can be said that the level of the water and the area of flooding have a negative impact on the biological communities of the Marshes.

In the period 1986-1998, it has been found that the high level of flooding had a negative impact on the wintering bird colonies as a whole, as well as harming some mammal communities. In the 95/96 and 96/97 seasons, a decline in the total number of birds

spending the winter here was observed, especially among the geese, which was attributed to the high level of flooding³⁵. The mammals, especially buck and hares, suffered a high mortality rate in years with extremely high levels of flooding, such as in the 89/90 and 95/96 seasons. Furthermore, excessive levels of flooding seems to have a negative impact on breeding among birds, with birds delaying the moment they lay their eggs, which reduces the mating season. The flamingo population has seen a fall in the number of nesting pairs trying to breed, which suggests that they have been affected by the high levels of flooding in wet years, during the period between the opening of the Nuevo Travieso canal (1986) and the construction of the extension of the Montaña del Río (1998). The crested coot also has also shown a tendency to postpone the moment to lay its eggs when flood waters are too high (Field Diaries of the Doñana Biological Station).

The changes in the duration of the winter and spring floods have also had a negative effect on plant communities, with an increase in mortality among shrubby sea bright and a reduction of the cover of submerged macrophytes being observed in wet years with high levels of flooding^{36,42}.

Shortening of the flood period seems to be responsible for at least some of the changes in the bird life and the vegetation.

Valverde³⁸ described the vegetation of the channels in general terms, recording the presence of bulrushes, a species that indicates the period of flooding, as it requires a prolonged period of swampy ground and, although it can survive short periods of drought, it needs to keep the roots damp to maintain its population numbers. Sanchez, in 1974, recorded the presence of bulrushes in Caño Travieso³⁸ and there are also records, in the field diaries of the Doñana Biological Station, of breeding colonies of purple herons in the bulrushes of the Guadiamar channel. This species has disappeared almost completely from the natural channels of the Marshes of the National Park, and only maintains large populations in artificially managed sites.

With regard to the birds and the shortening of the period of floods, the marbled teal, a globally endangered species, has been observed to lay its eggs early and has had lower breeding success rates in comparison with the rates observed in periods in which flooding occurred later²⁶.

The planned interventions, like recovering Caracoles estate and its connection to the Travieso channel and making Montaña del Rio permeable to tides and water discharge to estuary, should reduce the level of the flood.

Reduction of the water quality

In Doñana, all river courses have brought in some kind of contamination to a greater or lesser extent¹⁵. Heavy metal pollution directly affects and limits the abundance and living conditions of the aquatic flora, invertebrates, fish, amphibians, birds and mammals. Some heavy metals and pesticides bio-accumulate, so they can move up the food chain to higher levels, thus increasing their area of influence to include other species^{16,22,24,32,34,40}.

An excessive inflow of nutrients, particularly of N and P, stimulates the growth of phytoplankton to the extreme that it causes harmful explosions of algae that can be extremely toxic and can kill birds and mammals^{19,27}. In Doñana, the high mortality rate among water fowl is well known, put down to epidemics caused presumably by botulism. But one should not rule out the influence of toxic algae in these events.

Water fowl have been described as important vectors of nutrients into aquatic systems¹⁶. Certain indications of this phenomenon occur in Doñana in late spring, when the birds tend to concentrate in the few places where the flood waters remain. A concentration of birds during the process of changing their feathers promotes the explosion of blooms of toxic algae.

The submerged aquatic vegetation is a key factor in a whole range of natural processes, due to the roles it plays in the ecosystem, like stabilising and immobilising sediments, as primary producers and as habitats-refuges for fish fingerlings, and providing food

for a large number and variety of herbivore waterfowl. Large amounts of sediment in suspension also limit the growth of macrophytes, hence affecting the entire food chain of the wetland ecosystem.

Improving water quality is the aspect that creates the greatest uncertainty in the restoration project. On the one hand there appears to have been a clear improvement in water quality in the El Rocio Marsh, after the waste water treatment plant was brought into operation, and one would expect that water conditions will improve in a similar fashion throughout the Doñana district in the near future. But, on the other hand, it has proved impossible to date, to eliminate the transport of sediments in suspension into the marshes from Los Sotos and Laguna de los Reyes streams. With regard to the behaviour of agricultural pollutants, to date, the impact that the input from Entemuros will have since it has been restored and re-connected with the Doñana Marshes, is unknown.

UNSUSTAINABLE EXPLOITATION OF RESOURCES

Although the exploitation of resources does not form part of the Doñana 2005 Project, these activities can affect the state of some biological communities that are among the objects of the project.

There is unsustainable fish farming in the Torre Branch and around Doñana, which is particularly serious with regard to the capture of young fish, causing an inevitable affect on the population dynamics of several species¹⁸.

Hunting of water fowl in the Doñana area is also affecting endangered species like the marbled teal and the coot¹⁸.

Overgrazing in the National Park has reduced the vegetation in some areas, affecting birds and mammals. The distribution of the water rat in La Vera - a contact zone between the Marshes and the scrubland - seems to be limited as there are no reeds for them to disperse through, as they have all been trampled down by the livestock³⁷.

INTRODUCTION OF EXOTIC SPECIES

The introduced species that are causing most ecological harm in Doñana are the eucalyptus, the Louisiana crayfish and the ruddy duck. There is also a potential danger from the water fern *Azolla filiculoides* and the Florida red eared slider (*Trachemys scripta*). These latter two species could affect both the abundance of submerged macrophytes and the populations of native turtles.

The introduction of the Louisiana crayfish in 1974 has wrought a change in the Doñana Marsh food chain, benefiting and increasing the populations of its predators (herons, sea



High mortality rates among water fowl are well known in Doñana. These have been put down to epidemics caused by botulism, but one should not rule out the possible influence of toxic algae in these deaths, and in the deaths of birds of prey that are often found during the breeding season. In the picture, the courtship of a pair of avocets in Doñana.

Photograph by José María Pérez de Ayala.



The potential nesting sites of some birds are limited as the vegetation has been decimated by overgrazing. This is the case of the purple heron that started nesting in Juncabalejo as soon as a herbivore exclusion area was created. In view of the favourable results, at least for some endangered species and for communities of macrophytes included in the objectives of the Doñana 2005 project, it can be deduced that precautions should be taken to avoid excessive flooding of the marshes after restoration, and that special attention should be paid to the quality of the inflowing waters.

Photograph CENEAM.

gulls, glossy ibis, spoonbills, storks), most probably to the detriment of other herbivorous species like ducks and coots, and possibly to small wading birds that suffer from greater competition from these other crayfish consumers²⁸.

The ruddy duck may endanger the white headed duck. Fortunately, control programmes seem to be limiting the spread of the species.

SOME PRELIMINARY RESULTS OF THE DOÑANA 2005 RESTORATION PROJECT

During this initial period of the Project, endangered species that had disappeared almost completely, or which only nested sporadically and in small numbers have been recovered as nesting species. The bittern disappeared as a nesting species in the 60s, but it returned to nest in the Marshes of the National Park in the springs of 2002 and 2003, with 7 and 8 breeding areas being located respectively. The crested coot has undergone a spectacular recovery, with 40-42 pairs nesting in 2002 to between 68 and 74 pairs in 2003. The marbled teal, a globally endangered species, seems to have started the process of recovering its breeding population numbers, with an estimated 86 to 103 breeding pairs identified in 2002 and between 68 and 84 in 2003.

The negative aspects detected in this period include the appearance of the exotic fern species *Azolla filiculoides*, which is spreading alarmingly in the Doñana Marshes.

On the other hand, there was an elevated mortality rate among flamingo chicks born in Doñana in 2000, caused by them eating toxic algae¹⁴, hence confirming the danger that cyanobacteria can represent for the biological communities, highlighting the importance of water quality in this project.

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