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Article

A New Approach to Ecological Sustainability through Extensive Aquaculture: The Model of *Veta la Palma*

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Introduction. A brief overview of the history of Isla Mayor del Guadalquivir Island

Isla Mayor is an island located in the southwestern quadrant of the Iberian Peninsula, between the Southern Eurasian continent and Northern Africa. Geographically, it lies at the center of the River Guadalquivir Estuary and is bounded on the east by the river and on the west by Doñana National Park. This location, in the heart of the most extensive, representative, and dynamic ecosystem of Doñana - the Marsh - and just a few kilometers to the mouth of the river, determines marked annual variations in Isla Mayor's natural cycles. The vastness of the landscape, the influence of prevailing southwestern wind, and the flooding characteristics of the marshes, with water levels depending mainly on seasonal rainwater, make Isla Mayor a wild and rough territory, difficult for settlement and agricultural livestock production.

Largely described as a huge and muddy no-man's land, Isla Mayor is situated in an area that, approximately twenty centuries ago, was a large inner lake—known as Ligur Lake by the Phoenicians and *Lacus Ligustinus* under Roman Empire—that resulted from the closing of an earlier bay, the Baetican Gulf, by successive coastal sands bars. River-born sediments and marine deposits laid down by the tide were silting up the lake, forming the base of the Marshes (Jardín 2006). The River Guadalquivir, in its way through this forming alluvial plain, was branched off in one arm on the left bank (Brazo del Este), which created Isla Menor Island, and another branch on the right bank (Brazo de la Torre), which formed Isla Mayor (**Figure 1**). According to Pomponius Mela,"… [The Baetis] forms a great lagoon and […] branches in two arms running with so great flow rate in each one as that brought in a single [the main] channel" (in Monfort 2001).

The input of sediments from watercourses draining in the old *lacus* formed the present topography of the whole area, characterized by an essentially flat relief with a shallow hydrographical network (Jardín 2006). Abel Chapman, in his *Unexplored Spain*, describes the Marsh, perhaps wrongly termed as lower Delta, as "…a vast area of semi-tidal saline ooze and marsh, extending over forty or fifty miles in length, and spreading out laterally to untold leagues on either side of the river." More ahead, the author depicts this landscape in terms of "… practically a uniform dead-level of alluvial mud, only broken by *vetas* [levees], or low grass-grown ridges seldom rising more than a foot or two above the flat, and which vary in extent from a few yards to hundreds of acres." At present, more than a hundred years after Chapman´s visit, the most outstanding element of perception in this landscape is still the lack of relief.

The uneven topography is, therefore, responsible for Marsh singularity, a landscape often portrayed as monotonous, desolate, or even deceptive. Chapman (*Unexplored Spain*) further writes, "Should our attempted description read vague, we may plead that there is nothing tangible to describe in a wilderness devoid of salient feature. Nor can we liken it with any other spot, for nowhere on earth have we met with a region like this - nominally dry all summer and inundated all winter, yet subject to such infinite variation according to varying seasons."

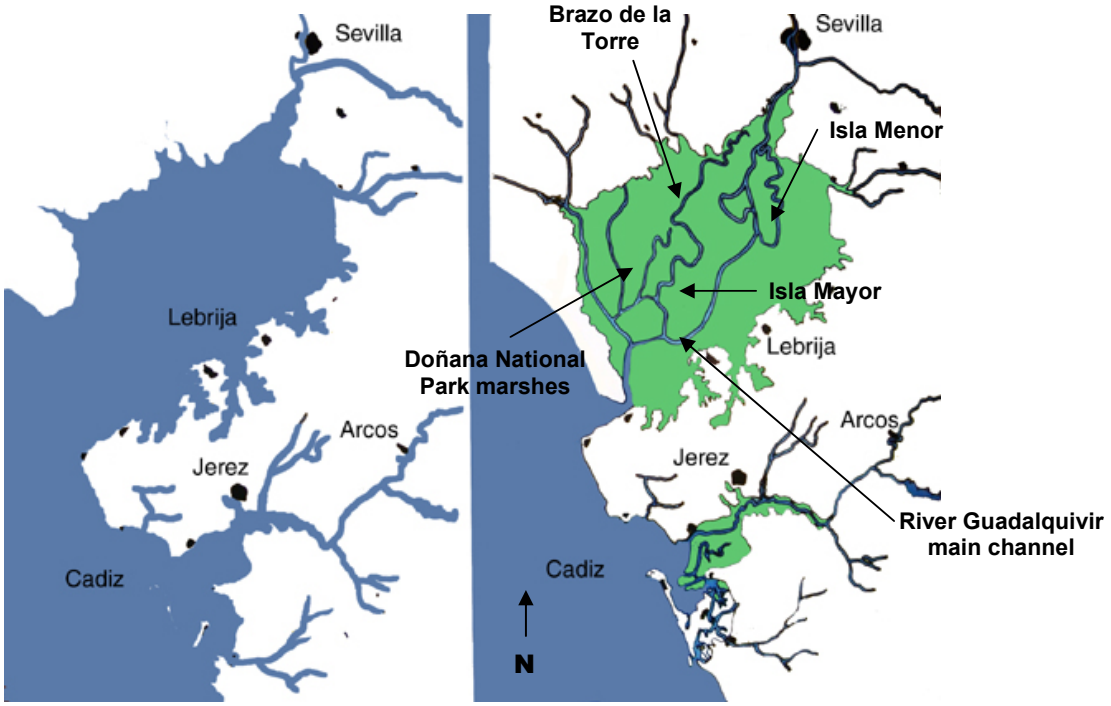

Figure 1. Evolution of ancient Lacus Ligustinus to the modern hydrological network of the Guadalquivir Marshes, where new islands lying between river's branches (Isla Mayor and Isla Menor) are shown. The Veta la Palma Estate extends over the southern half of Isla Mayor. Adapted from www.jerez2020.com/jerezrvh/origen_geografico.htm.

But such physical uniformity does not resist a detailed ecological analysis. In addition to a high primary productivity, this apparently flat land hides a mosaic of microhabitats defined by variations in soil conditions and humidity: high or salty marsh, partially or exceptionally flooded, dominated by succulent halophytes (*almajos* from the *Chenopodiaceae* family as glasswort *Salicornia ramossissima* with *Arthrocnemum macrostachyum, A. perenne* and seablite *Suaeda* sp.); and lower-lying areas (sweet marshland) with a stronger seasonal variation and a more varied vegetation like bulrush (*Cyperus* sp.), sea club-rush (known locally as *castañuela*, *Scirpus maritimus*), rushes (*Juncus* sp.), crowfoot (*Ranunculus baudotii*), broad-leaf cattail (*Typha* sp), common reed (*Phragmites australis*), etc (García Novo, 1997). In normal years, these areas stay flooded from October to May-June and congregate a myriad of bird species, particularly waterbirds, while raptors, steppe-habitat birds, mammals (hares, mice, and shrews), amphibians (frogs, toads, and newts), and snakes are usually found in the high salty marshland. *Lucios* and *vetas* represent both extremes of topographic and hydrologic gradients. In the *lucios* (depressions which hold wet season lagoons), no vegetation can grow due to the high salt content of the soil, while the *vetas* are islands rising above the plain, where cattle and wild fauna find refuge during flooding periods.

Isla Mayor, Isla Menor, and the other areas stretched among River Guadalquivir branches, as well as the remaining marshland areas to the east of Brazo del Este and to the west of Brazo de la Torre, have a long history of natural evolution by silting-up and by man made transformations, including reservoir construction and drainage works in the main Guadalquivir channel, interruption of connections (*cortas*) between different branches, further works carried out around Doñana National Park involving Brazo de la Torre bank channeling to control the extension of floodable area, etc., that has largely affected the original hydrology (Jardín 2006). The whole area is currently a floodable plain composed of depressions that depend on seasonal rains to fill them and are surrounded by natural

drainage canals (*caños*) and artificial waterways bordering smaller, slow-moving interfluves (*esteros*). The flood plain's flat relief is only interrupted by old levees (*vetas*) and islets (Novo 1988).

However, *Isla Mayor* shows a more delayed morphological evolution than neighbouring areas bordered by streams. In this island, the process described above develops from north to south and is not yet finished, seemingly a young, dynamic territory. Hence, further management works in the island (channel and wall construction, drainage for agricultural purposes, etc.) have altered the natural evolutionary pattern (Novo 1988). Some areas in the southern part of *Isla Mayor* still maintain their natural functionality and preserve original physiognomic types of marshes, established along the flood and topographic gradients. In some relict spots, it is also possible to catch a glimpse of former large, wet depressions, known as *Lucio Real*, *Lucio del Caño Nuevo,* and *Lucio del Caño de la Sal*, that extended over the island before human transformations.

This "… viewless waste …" that strongly impressed Chapman (*Unexplored Spain*), emerged in a territory economically structured around the *Lacus Ligustinus*. Latin authors Avienus, Pliny the Elder, and Pomponius Mela described this area as characterized by a diversified economy, supplying farming and fishing products destined for local consumption and marketing. Neighboring villages such as *Caura* (present *Coria del Río*) made their living through fishing *sábalos*, barbels, mullets, eels, lampreys, and sturgeons (*sollos*) in the lagoon, while vineyards and olive trees covered its shores (Monfort 2001). Strabo and Columella gave vivid testimonies of the importance and extension of vineyards and olive trees in the area (Monfort 2001). As long as the continuous input of sediments was gradually filling the lagoon, people from the surrounding towns were introducing their cattle in the new "…land randomly formed [Isla Mayor Island]…" (Monfort 2001). Extensive livestock management in the *vetas*, fishing in *caños* and *lucios*, and waterfowl hunting became major land uses, while salt mines, charcoal production, and *almajos* burning for soap manufacture proliferated as minor customs (Vélez 2000).

After a long historical parenthesis, in 1253 King Alfonso X the Sage donated Isla Mayor and other parts of the River Guadalquivir marshes to the Council of the City of Seville and in 1272 to the inhabitants of La Guardia (present Puebla del Río), giving documentary evidence of a territory abounding in pastures. Afterward, the Catholic kings decided to rent Isla Mayor, a public land till that time, with the aim of supporting the costs of the war for the conquest of the Kingdom of Granada. Isla Mayor was given back to the Council of Seville some years later and many surrounding towns (Alcalá del Río, Salteras, La Rinconada, La Algaba, Santiponce, Coria del Río, Puebla del Río…) granted the land for common usage of the pastures. That was a time when many farmers illegally introduced their livestock to the island, constructed reed-built huts in the *vetas*, and raised fences for the initial crops.

The first attempts to transform Isla Mayor into farm land date back to the 19th century, when the best territories of the island were ruled , with some speculative aims, by important figures of the local upper class, as the Marqués de Casa Riera. However, such projects were quickly given up because of the land's barrenness, and livestock seemed to be the only profitable business in this land.

In 1923, the British company Islas del Río Guadalquivir Limited acquired Isla Mayor and initiated major works to prevent annual flooding in order to transform the area for cereal agriculture. The construction of settlements and the initial success of cereal crop stimulated the arrival of people from different areas of the Iberian Peninsula. The first rural communities, like the Village of Alfonso XIII, arose in the area at that time. However, the excessive operating costs combined with climate harshness and succeeding losses of cereal

harvest forced the company to abandon a project that had been supported by the Spanish Monarchy as a real colonization plan.

Rice was introduced as an alternative crop for the poor soils of the marshes in 1937, when Rafael Beca, an important local landowner, arrived to *Isla Mayor* with the order, made by Franco´s General Queipo de Llano, to initiate the culture of rice in the marsh. The Village of Alfonso XIII was equipped with stores as well as medical and religious service, becoming the only rice storehouse of the War National zone, since the main historic rice area in Spain, Valencia, was still in Republican hands. Soon after the Conflict, rice culture was encouraged in the whole area, favoring the construction of new settlements like El Puntal (present Village of Isla Mayor, the most important town of the Island), whose rapid social and economic growth attracted people from Valencia that knew the techniques for rice cultivation.

In the 40's and 50's of 20th century, rice growing became the main activity in the River Guadalquivir marshes, including the North of Isla Mayor. Firstly based on traditional methods (permanent care of the land, labourers and foremen living together at the foot of the big estates, etc.), crop management was gradually mechanized (direct sowing, use of chemicals, combine harvesters, etc.) determining an extraordinary increase in the volume and quality of the harvest. Today, a vast area of 400 km^2 divided by the Guadalquivir is dedicated to this activity. On the left side, rice fields extend from the fertile valley of Puebla del Río in the North to the limit of Veta la Palma Estate in the South, bordering with the rivers Guadalquivir (east) and Guadiamar (west). On the right bank, the crop occupies most of Isla Menor and other marshland areas. Average output reaches 310,000 metric tons, approximately 40% of Spain rice production (data obtained from the Federación de Arroceros de Sevilla).

The works undertaken by British owners on Isla Mayor to control periodic flooding of the River Guadalquivir, included the construction from 1926 to 1928 of a wall surrounding the whole of the island. In 1966, 10,300 ha of southern Isla Mayor (the present Veta la Palma Estate) were sold to the company Agropecuaria del Guadalquivir, managed by a rich Argentine family (rice growing extended over the remaining 14,000 ha, out of the total 25,000 ha of the island). Agropecuaria del Guadalquivir improved the flood defenses and used this traditional grazing land for cattle breeding.

The project was undertaken in two stages. Firstly, between 1966 and 1969, former wet depressions (*lucios*) were drained by means of a 230 km drainage channel network. Next, 110 km of roads, a peripheral breakwater, and different facilities for livestock were constructed. The main goal of second stage was to substitute natural marshland pasture for improved cereals destined to feed livestock. The ecological consequences were the drying of *lucios* and an almost total interruption of tidal influence (except during very high tides, locally called *botamentos*). Tidal marshland practically disappeared and grasses invade the dried *lucios*. In areas conserving a short flooding regime, halophytes (particularly *Arthrocnemum macrostachyum*) dominated. The construction of flood gates enabled improved control of the hydrological network and allowed artificial inundation of small areas (during *botamentos*) for waterfowl hunting and traditional fishing (eel, shrimp, etc.) (Novo 1988).

Further work plans by Agropecuaria del Guadalquivir were never carried out. In 1978, part of the Estate (approximately 8,000 ha) was declared a protected area by the National Administration under the figure of Eastern Prepark of Doñana.

In 1982, Agropecuaria del Guadalquivir was bought by Hisparroz, S.A. and renamed as Pesquerías Isla Mayor, S.A. (PIMSA), which is also the present owner of Veta la Palma Estate. The substitute of marshland pasture by cereal agriculture was abandoned, and the

former drainage network was improved and used in a reverse way, that is, as irrigation channels to restore dried *lucios* and create shallow lagoons for aquaculture purposes.

The initial research in aquaculture was undertaken on the property from 1982 to 1984 by the Department of Ecology at the University of Sevilla, following a collaboration contract signed with the Estate's ownership. Trials were made in nine small cultivation ponds outside the limits of the Eastern Prepark of Doñana, and cultivated species were carp (*Cyprinus parpio*), eel (*Anguilla anguilla*), tilapia (*Oreochromis* sp.) and shrimp (*Palaemonetes varians*). In spite of good results, poaching forced researchers to give up the project. Meanwhile, different, larger ponds were prepared and flooded in other areas of the Estate for the cultivation of sea bass (*Dicentrarchus labrax*), eel, shrimp and king-prawn (*Penaeus kenathurus*) under provisional permissions by the Fishing Authority of the Local Autonomous Administration (Novo 1988). In 1989, the whole area of Veta la Palma, lying between the River Guadalquivir on the east and south and its right Brazo de la Torre branch on the west, was included in the new Doñana Natural Park created by the Administration.

Considering the favorable preliminary research results, PIMSA decided to initiate an ambitious aquaculture project in Veta la Palma in 1990, under definitive approval by Fishing administrators, according to the Plan for the Use and Management of Doñana National Park (PRUG) regulations. Some 3,200 ha of the Estate were flooded with first-rate water from the Guadalquivir Estuary. The result was a carefully managed wetland supporting a rich and nourished flora and fauna as well as particularly dense communities of invertebrate species, which are the basis for a vast range of extensive aquaculture products. Cultivated species are typical of the estuary, including sea-bass, sea-bream (*Sparus aurata*), meagre (*Argyrosomus regius*), sole fish (*Solea solea, S. senegalensis*), shrimp (*Palaemonetes varians*), eel (*Anguilla anguilla*) and mullets (*Mugil cephalus, Liza ramada*). Some 4,600 ha of Veta la Palma extension is marshland pasture for extensive livestock operations, producing horses and brave bulls. On the remaining 2,500 ha, dry cereal is grown on a rotational basis.

As a consequence of land drainage work started by the British and improved by Agropecuaria del Guadalquivir, the area of Veta la Palma and the whole of Isla Mayor lost many of their original, physical wetland features, such as seasonal flooding, resulting in a dramatic decrease in their natural diversity of aquatic birds. Isla Mayor was no longer a "…surface carpeted with waterfowls […] dreary zone would offer but little attraction was it not for its feathered inhabitants" described by Chapman (*Unexplored Spain*). This situation remained the same until PIMSA rescued and transformed Veta la Palma into what is a model of integrated management for aquaculture and conservation that has restored and enhanced the natural ecology of this area.

Aquaculture as a base for sustainability: the inspiring example of Veta la Palma

The most remarkable part of the Veta la Palma is the fish farming area, which is divided into 45 rectangular, 70 ha ponds that are connected to one another by the rivers Guadalquivir and Brazo de la Torre by means of a complex 300 km irrigation and drainage channel network. To maintain oxygenation and water quality, one million cubic meters of water are pumped daily from the river through the whole system, which is designed to work both in open and close circuit depending on environmental and operational circumstances.

Veta la Palma is much more than a fish farm. Extensive aquaculture ponds and surrounding marshland pastures effectively support a number of environmental services for the hydrology and ecology of the River Guadalquivir marshes and the area as a whole. The aquaculture operation has been managed to restore the damage to the original wetland produced by former land-uses, minimizing its own ecological footprint and combining the economic benefits of aquaculture with conservation objectives (**Figure 2**).

Figure 2. Satellite photograh of Veta la Palma Estate. The other images illustrate the extensive aquaculture, the main current activity of the property, and its contribution to conservation.

Extensive fish farming ponds are characterized by their stability regarding flooded surface (3,200 ha), average depth (40-50 cm), water flow rate (up to 1 hm^3/day in summer), and salinity, although salt content may fluctuate according to the season and the amount of rain (6-15 g/l in wet periods and 15-25 g/l during the driest episodes). This stability allows buffers changes in the salinity, water flow, and nutrient concentration of the Guadalquivir Estuary, promoting a massive development of phytoplankton (primary producers) that quickly assimilate excess nitrogen and phosphorus in the water.

Veta la Palma is located in an area of mild Mediterranean climate with an Atlantic influence that moderates temperatures. In such conditions, the continuous input of organic matter in the water favors, via phytoplankton, the development of salt tolerant saprophytic bacteria and phytobenthos (mainly sediment algae), periphyton (mixture of diatoms, cyanobacterial filaments and detritus that attach to the submerged surface of aquatic vegetation), and aquatic macrophytes such as *Ruppia* sp. and *Potamogeton* sp.

Primary consumers predating on phytoplankton and phytobenthos are represented by zooplankton organisms: protozoans, planktonic rotifers (mainly *Brachionus plicatilis*), and microcrustaceans such as copepods (*Arctodiaptomus salinus*) and cladocers (*Daphnia magna*, *Moina sp*). Associated with the benthonic compartment, a microfauna composed of benthonic rotifers, nematodes, aquatic worms (oligochaets and polychaets as *Nereis* sp.), chironomids (*Chironomus salinarius*, mosquito larvae, etc.), isopods (*Synidotea* and *Lekanesphaera*), amphipods (*Corophium orientale*), and aquatic hemipters (*Corixa*) included in the herbivorous/detritivorous trophic level can be found.

The next trophic level, omnivorous organisms, include crustaceans, such as mysid shrimps (*Mesopodopsis* sp. *and Neomysis* sp.) and shrimps (mainly *Palaemonetes varians* but occasionally *Palaemon longirrostris* and *P. serratus*), and fishes, such as mullets (*Liza ramada, Mugil cephalus*). Sea bream (*Sparus aurata*) is in a second step inside this level.

Carnivores are represented by small fishes, such as *Pomatochystus microps*, *P. minutus* and *Fundulus heteroclitus*, whose diet is composed mainly of larvae, active predators (sea bass, *Dicentrarchus labrax*, and meager, *Argyrosomus regius*) that feed on crustaceans and other fishes, and eel (*Anguilla anguilla*). Sole fish (*Solea solea, S. senegalensis*) is usually found associated with the benthonic compartment.

Therefore, the single combination of water, light, and nutrients, through the effect of photosynthesis combined with a careful management of water flow, generates a highly stable and productive aquatic ecosystem distinguished by its diversity and ubiquitous multitrophic interactions (PIMSA 1995; Pérez and Green 2003).

Sanitary management of the ecosystem

Improvement of Guadalquivir Estuary water quality

Veta la Palma aquaculture ponds behave like huge water treatment plants, where the excess of nutrients (nitrogen, phosphorus, etc.) and organic matter of biological origin are removed from the water and transformed into living biomass by means of natural processes. This biomass is finally extracted from the system via commercial fishing and predation by birds.

In water, inorganic nitrogen is present in several forms: ammonia, nitrite, and nitrate. All these forms are biochemically convertible, according to the oxidation and reduction state of the water and the activity of organisms (mainly bacteria and cyanobacteria) that are capable of fixing nitrogen from the air into a form available to the remainder of the biota. Ionized ammonium (NH_4^+) and ammonia (NH_3) are usually found in equilibrium in water. The equilibrium is governed by pH. Above pH 9.5, ammonia may be predominant and, at a concentration among 0.1 – 0.2 mg/l, it may be toxic for aquatic organisms. When an aquatic plant or animal dies, or an animal excretes, the initial form of nitrogen is organic. Then, bacteria (or in some cases, fungi) convert the organic nitrogen into ammonia (ammonification).
In Veta la Palma fish farming ponds, where pH is usually under 9.5, ammonium is present mainly in the ionized form and at a concentration rarely above 0.1 mg/l. In this extensive and shallow water sheet, ammonia is chemically and biologically converted to nitrate. The primary stage of nitrification is the oxidation of ammonia to nitrite (NO_2^-), an intermediate form of nitrogen whose accumulation (continuous values above 0.5 mg/l) is toxic for life. The second stage is the oxidation of the nitrites into nitrate (NO_3^-), an essential nutrient for photosynthesis that is assimilated by aquatic plants and algae. Recorded nitrite values in the ponds are always under 0.2 mg/l, explaining to a large extent that water flow management in the fish farm allows a total performance of nitrification process.

Phosphorus is the primary nutrient limiting biological productivity in aquatic systems. The cycling of phosphorus is complex in aquaculture ponds, with the majority being bound up in the particulate phase as living biota (i.e. algae and bacteria). Labile compounds are excreted by the algae and bacteria. The compounds, algae, and bacteria combine with one another to form a snot-like (colloidal) material. Most of this colloidal material is lost from the productive zone by sedimentation in the bottom of the ponds, leaving a minimum portion in the form of soluble orthophosphate (PO_4^{3-}). Orthophosphate is quickly assimilated by algae and macrophytes living in the water and covering pond banks and channels, so final concentration of this phosphorous form usually remain at almost untraceable levels (0.01 - 0.34 mg/l). In addition, the huge ecological productivity of fishing ponds, and particularly the high renovation rate of phytoplankton, help maintain soluble orthophosphate concentration at a very low level.

Therefore, the hydrologic system operating in the Veta la Palma installation contributes to the maintenance of oxygenation and water quality and to avoid eutrophication caused by the increase in the amount of nitrogen and phosphorous compounds. In addition, the strength of nitrogen and phosphorus cycles in this aquatic system allow effective control of the the amount of nutrients in water, particularly phosphorous, that are applied to surrounding agricultural lands as fertilizers and are finally carried into estuary water with runoff.

The natural lagoon technology for water purification running in Veta la Palma assures that the water pumped daily from the River Guadalquivir is given back to the estuary with an improved microbiological, physical, and chemical quality, according to data obtained in periodic analyses made in the water by national laboratories credited for environmental tests.

Soil disinfection and prevention of wetland-associated epidemic diseases

In the last remnant of the original lower Guadalquivir marshes, currently covering 27,000 ha of Doñana National Park, marked seasonal variations in water level and the effect of severe droughts that periodically occur in the area, combined with high temperatures and an increase in the salinity of the water during the summer season, produce strong oxygen depletions in stagnant waters that can trigger epidemic outbreaks of *Clostridium* or *Salmonella*, eventually leading to bird death. Occurrence of avian botulism outbreaks has been reported in Doñana in different occasions along recent past, causing the die-off of some 30,000 birds in 1986.

Veta la Palma hydrological management allows the 3,200 ha of fish farm extension, including ponds and the irrigation and drainage channel network, to be flooded or dried up in a maximum of 48 hours, maintaining the system in optimal sanitary conditions. This is essential for fish farming operations and for achieving a complete ecological integration with the surrounding landscape.

In addition, after finishing a culture cycle, each pond is totally emptied and the excess sediment is removed from the vessel. This operation is usually undertaken at the beginning of summer, once every 4 or 5 years, rotating over the 45 existing ponds, so that the organic content of soil, including bacterial spores, mineralize via photoxidation.

Consequently, this managed wetland behaves as a sanitary shelter, with an optimum environmental quality, against possible epidemic outbreaks.

Landscape improvement

As a result of major land drainage works made before 1982, the area of Veta la Palma could no longer be described as a wetland. The ecological and functional mosaic created in the Estate by PIMSA, inundating the formerly dried up marshland for aquaculture purposes and

preserving the surrounding high-marsh areas for extensive livestock grazing, has restored the natural ecology and landscape of the area.

Since 1990, the Estate owner has also invested important material and human resources to further improve Veta la Palma's ecology through the following initiatives:

- A 300 ha bird protection area has been established in a central northern part of the Estate known as Lucio del Bocón. The area includes several shallow lagoons with islands and areas with different ecological types of marshland (PIMSA, IIMA, and EURODUCK 1992).
- A 500 ha biological reserve has been created for research purposes in the southwest of the property, in an area of high marsh vegetation (PIMSA 2000).
- More than a 100 islands and walls have been built within fish farming ponds to serve as bird sanctuaries and nesting sites for waterfowl (PIMSA 2000).
- A total of 150 km of pond shores and embankments have undergone extensive revegetation.

Islands and walls have been designed with irregular shapes and generally smooth slopes. Each island presents a central area covered by marshland shrub vegetation (mainly the *almajo Arthrocnemum macrostachyum* with seablite *Suaeda* sp.), bordered by emergent macrophytes such as common reed (*Phragmites australis*) and cattail (*Typha* sp.). *Potamogeton* sp.*, Ruppia* sp. and other submerged aquatic plants are dominant in channels and open water areas of ponds.

Islands are less than 1.5 m high and are built using sediment removed from the ponds during periodical maintenance operations. This material is composed mainly of slime and clay coming from the Guadalquivir Estuary and contains plant seeds, so it can be used as substrate for revegetation. In just a short time, new islands become covered by a rich carpet of halophytes and marshland shrubs, offering a new and heterogeneous habitat to aquatic birds.

Buffering of seasonal and interannual water variability effects in Doñana National Park

The Doñana wetland exhibits a hydrologic regime that includes a high water table and extensive flooding from October to May-June, followed by strong summer drying. To prevent epidemic outbreaks, the Authorities of Doñana National Park boost natural drying of marsh areas by means of artificial drainage at the beginning of each summer. As a result, thousands of waterfowl and coot broods have to seek flooded areas in surrounding sites. These birds cross the Brazo de la Torre that separates Veta la Palma from the National Park, finding food and suited physical conditions to continue growing in the 3,200 ha fish farming ponds and bordering marshland areas of the Estate.

Similarly, at the end of the summer and the beginning of autumn, the marshes of Doñana National Park are still dry, and the clean, oxygenated, and nutrient rich water of Veta la Palma Estate offers shelter for thousands of early migratory birds.

The flooding and drying cycle managed in the fish farming ponds also determines which bird species can be found in this artificial wetland. Thus, the ponds in drying stage attract big contingents of waders, particularly during migratory passes when it is possible to record flocks of over 5,000 waders feeding in the ponds.

Severe cyclic droughts are usual in the Doñana area. **Figure 3** shows a comparison between population sizes of some bird species recorded in Veta la Palma and Doñana National Park during the dry period from 1973 to 2001.

As a consequence of all described above, managed wetlands of *Veta la Palma* play a fundamental role as a buffer zone in the Doñana area, providing food and water for waterfowl, herons, gulls, and other varied bird fauna of Doñana during moulting time, breeding season, and post-breeding annual migration, as well as during particularly dry interannual periods.

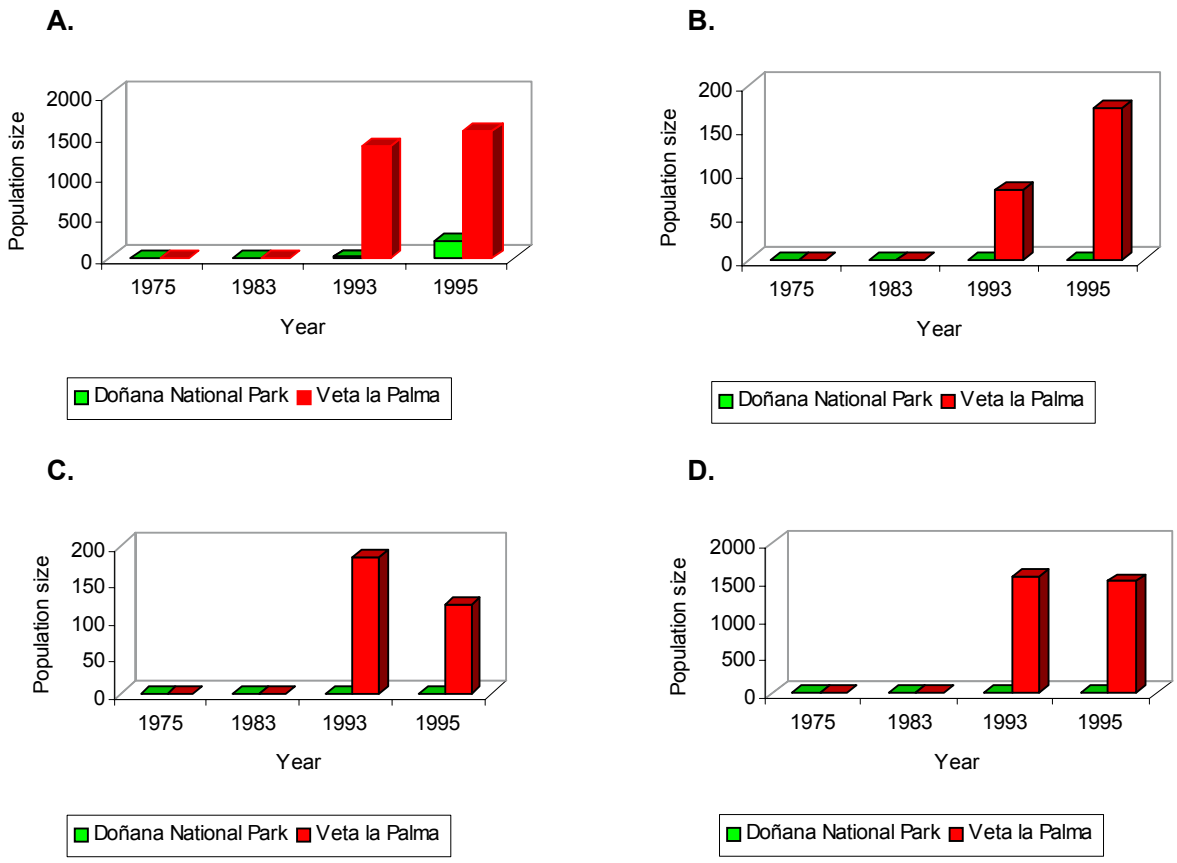

Figure 3. Population sizes of some relevant bird species in Veta la Palma and Doñana National Park during the period from 1973 to 2001 (only dry years are shown). A) Black-necked grebe (*Podiceps nigricollis*). B) Purple heron (*Ardea purpurea*). C) Avocet (*Recurvirostra avosetta*). D) Gull-billed tern (*Gelochelidon nilotica*).

Bird sanctuary: increase of avian population and diversity

It is necessary to emphasize the extreme importance of Veta la Palma Estate for the conservation of European birds.

Since 1986, the number of both nesting and migrating birds living in Veta la Palma, especially those considered *endangered*, *vulnerable* or *rare* according to International Union for Conservation of Nature (IUCN) criteria, has increased so significantly **(Figure 4**) that the Estate is currently regarded as the most important area of private land for aquatic birds throughout Europe (Otero and Bailey 2003).

The first assessment of the bird community's response to the flooding of the formerly dried up Veta la Palma marshland for aquaculture purposes was carried out in 1989 by the Department of Zoology, Complutense University of Madrid (Fernández-Cruz *et al*. 1989). The study showed that shortly after aquaculture began in the Estate, the bird population utilizing the 500 ha initially flooded surface reached more than 60,000 individuals, a number

higher than the threshold of 20,000 aquatic birds that the Ramsar Convention requires for a wetland to be proposed as an 'Important Bird Area'.

Presently, at any time during year, more than 250,000 birds congregate in the 3,200 ha of Veta la Palma extensive ponds, the 4,600 ha of surrounding marshes preserving the original biotopes, and the remaining 2,500 ha dedicated to cereal growing, including at least 1% of the world population of some species required by the Ramsar Convention.

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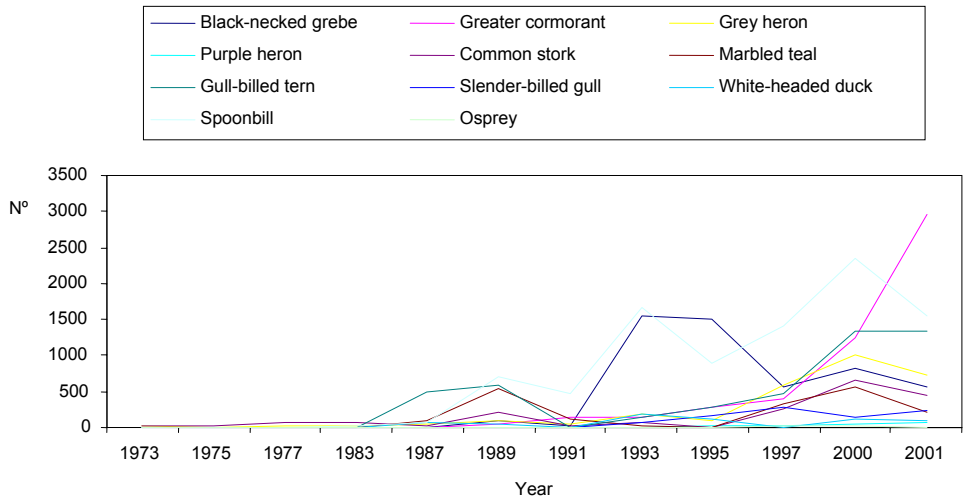

Figure 4. Evolution of the population of some relevant species of birds in Veta la Palma from 1973 (prior to the aquaculture project when the marshes were still dried for cattle grazing) to 2001.

During winter season (November to February), pre-breeding migration (February to March) and breeding season (April to June), a dense and varied bird community is attracted by the 45 ponds of Veta la Palma. During these stages of the annual cycle, birds use pond banks, shorelines, islands, and the surrounding preserved original marshland for feeding, resting, and breeding. Avocets (*Recurvirostra avosetta*), black-winged stilts (*Himantopus himantopus*), slender-billed gulls (*Larus geneii*), little terns (*Sterna albifrons*), gull-billed terns (*Gelochelidon nilotica*), and many other species reproduce here in great numbers.

From July to October (post-breeding migratory pass), the number of ducks and waders recorded at the Estate has an extraordinary qualitative and quantitative importance in the context of international bird conservation. By this time, the 3,200 ha permanently flooded area of Veta la Palma represent the last point of water in the whole Doñana marshes and the only site that is able to provide food and shelter for early migratory birds such as shoveler (*Anas clypeata*) and black-tailed godwit (*Limosa limosa*)(Herruzo and Márquez 1996; EBD 2000).

More than 250 species of birds can currently be recorded in Veta la Palma, almost 50 of them considered endangered or critically endangered, such as osprey (*Pandion haliaetus*), white-headed duck (*Oxyura leucocephala*), red-knobbed coot (*Fulica cristata*), and marbled teal (*Marmaronetta angustirostris*); in lower risk, such as flamingus (*Phoenicopterus rubber*), avoset (*Recurvirostra avosetta*), and slender-billed gull (*Larus geneii*); or vulnerable, such as spoonbill (*Platalea leucorodia*), gull-billed tern (*Gelochelidon nilotica*), and little tern (*Sterna albifrons*).

The total bird population size reaches its maximum between August and October. Census data by the Doñana Biological Station recorded a total of 600,000 birds in Veta la Palma in October of 2002, which represented 80% of all birds of Doñana by that time (EBD 2000; EBD 2004).

Veta la Palma has been categorized as an 'Important Bird Area' within the Ramsar Convention and has an enormous biogeographical importance for international wetland conservation. The Estate is an 'Important Bird Area' for the following species: black-necked grebe (*Podiceps nigricollis*), common egret (*Egretta garzetta*), common stork (*Ciconia ciconia*), greater flamingo (*Phoenicopterus ruber*), mallard (*Anas plathyrhynchos*), pintail (*Anas acuta*), shoveler (*Anas clypeata*), red-crested pochard (*Netta rufina*), marbled teal (*Marmaronetta angustirostris*), white-headed duck (*Oxyura leucocephala*), black-winged stilt (*Himantopus himantopus*), avocet (*Recurvirostra avosetta*), collared pratincole (*Glareola pratincola*), Kentish plover (*Charadrius alexandrinus*), dunlin (*Calidris alpina*), black-tailed godwit (*Limosa limosa*), gull-billed tern (*Gelochelidon nilotica*), and little tern (*Sterna albifrons*).

Protection of Guadalquivir Estuary fish fauna

During the last 50 years, diversity and population size of fish species in the lower Guadalquivir Estuary have dramatically decreased as a consequence of river pollution, obstacles against free migration, and over fishing. Incidence of these factors has been especially remarkable for migratory species such as sturgeon (locally known as *sollo*, *Acipenser sturio*) and some members of the *Clupeidae* family (*sábalo*, *Alosa alosa* and *saboga, Alosa fallax*), as present considered extinct in the area.

Regulation works in the river have inevitably caused significant changes in the physical and chemical characteristics of the river. In response, fish communities have also changed towards an increasing abundance of alien species and decreasing abundance of native ones. In addition, fishing activities in the Guadalquivir Estuary have never been appropriately regulated, and over fishing has largely affected fish populations and the important nursery function of the estuary (maximum estuarine recruitment of juveniles of many fish species occurs during glass eel and shrimp fishing season, for example).

As mentioned above, the carefully managed aquatic ecosystem of Veta la Palma is characterized by its highly structured trophic network. The 3,200 ha of extremely productive extensive ponds play an important role in the protection of autoctonous species of the Guadalquivir Estuary, such as *Pomatoschistus microps*, *Atherina boyeri*, catadromous species (eel, mullets…), and species that spend part of their natural life cycle in the estuary, such as sole fish, sea bass, meagre, sea bream, and relatives of sea bass (*Dicentrarchus punctatus*). Alien species *Fundulus heteroclitus* and *Gambusia* holbrooki are also common, and some marine species, such as *Engraulis encrasicholus*, *Dicologoglossa cuneata*, or *Lithognathus mormyrus*) have been recorded during dry periods when the salinity of the water increases. Apart of cultivated species, the juveniles of which are bought in commercial hatcheries and released in the ponds (sea bass, sea bream, meagre and sole fish), larval stages and juveniles of most mentioned fish species are usually found in Veta la Palma.

Therefore, Veta la Palma's first-rate water layer, together with other restored marshland areas located in the region (Novo and Gallego 2003), contribute to the protection (and eventual recovery) of fish fauna associated with the Guadalquivir Estuary.

A widely recognized economic and conservation model

Veta la Palma has gained wide international recognition for its creative approach to sustainability based on the combination of economic benefits of aquaculture with conservation goals.

The aquaculture production methodologies applied here are included in what the Directorate General for Fisheries and Maritime Affairs of the European Commission has termed aqua-environmental measures. As defined in the European Fisheries Fund (EFF), aqua-environmental measures aim to promote aquaculture techniques which help to protect and improve the environment and to conserve nature (EU 2007). Such technologies have to be ecologically efficient and respectful under hardest environmental exigencies within the framework of NATURA 2000.

On the other hand, extensive fish farming systems have a long tradition in Europe. Those aquaculture practices may restore disturbed salt marshes or coastal wetlands and use low-quality resources in the production of animal protein, playing a useful role in integrating economic activity with protection of biodiversity at a landscape level.

PIMSA and Veta la Palma Estate have the recognition and support of a number of international institutions, such as WWF, the Royal Society for the Protection of Birds and Wildlife Trust, Euroduck Internacional, the European Landowners Organization, and the Spanish MAB (Man and Biosphere) Committee (UNESCO).

The Estate has been awarded by the Junta de Andalucía (Local Autonomous Administration), Euroduck Internacional, and Anders Wall Foundation (in cooperation with the European Commission – D. G. Environment) in recognition of the creation of a positive rural environment. The property has been visited by national and international politicians, landowners, and leaders of conservation societies and is included as a study area in a number of research projects on marshland flora and fauna, aquatic ecology, bird biology, etc., in collaboration with the Doñana Biological Station (CSIC), the University of Seville, and other institutions.

Finally, the works of Otero (2000) and Otero and Bailey (2003) illustrating the multiple contributions of Veta la Palma to nature conservation have prompted the inclusion of the Estate among the 61 most important privately managed sites in Europe where landscape diversity, habitat, land use, and management policies are applied to balance the environmental, economic, and community needs.

Conclusion. *Veta la Palma* as a guarantee for the future of balance between conservation and development in Doñana marshes

Veta la Palma is a highly successful model of integrated management for aquaculture and conservation as well as an integral part of Doñana National Park. The areas of extensive aquaculture ponds, natural marshland, and cereal farming constitute an ecosystem of great wealth, where balanced human management has recovered a former wetland, one that was largely destroyed by a former flood control scheme, and has increased natural gradients of heterogeneity (hydrologic, topographic, etc.).

Extensive fish farming activity maintains the River Guadalquivir marshes in a favorable conservation state and provides very valuable support of Doñana, representing a compromise with the future of conservation and development in the area. In the words of Dr. Delibes de Castro, former Director of Doñana Biological Station, “Veta la Palma is adapting a new outlook on conservation objectives. It intends being dynamic and creative in designing a model for management which must be both practical and productive in order to guarantee survival in the future” (Otero and Bailey 2003).

Described as “the lungs, larder and hospital for aquatic birds”, Veta la Palma is a visionary undertaking that provides tangible meaning to sustainability. It is economically successful and supplies real support to the environment and to the local economy (Cranbrook 2002).

Nevertheless, this huge environmental success has come at an economic cost. Extensive aquaculture activity in the area has caused a formidable increase in not only the population size of relevant bird species, but also of those others whose overload can spoil the viability of the production system itself. This is the case of greater cormorant (*Phalacrocorax carbo*), constituting a serious threat for aquaculture producers in most of the European Union. Census data from 1991 showed an exponential increase in the cormorant population in Veta la Palma. This situation is causing very severe damages on the Estate production system that seriously jeopardize its future potential to support new environmental services. Bird populations, mainly greater cormorant, are responsible for significant fish losses (20% according to estimations by the PIMSA Production Department). Additionally, there are enormous losses of shrimps, mullets, and eels caused by other aquatic birds, such as herons, egrets, and storks, feeding in this habitat.

This situation could be balanced with economic reparations by local administrators. According to the Council of Europe´s Regulation 1198/2006, every effort made to develop production methods that enhance the environment should be compensated in order to guarantee its economic feasibility. Following the opinion of Durá and Castroviejo (2007), Veta la Palma constitutes an interesting and efficient study case in relation to the modern safekeeping of the territory, in which private initiative based on investment in productivity solutions generating both economical and ecological outcomes, makes an enormous contribution to the conservation of natural resources. As these authors claim, "…public administrations must deliver a clear effort to generously support a private sector that is contributing in such an evident way to the general interest, looking for effective stimulation measures."

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