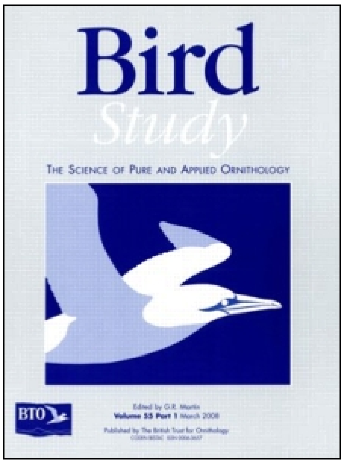

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Formation and growth of a heronry in a managed wetland in Doñana, southwest Spain

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Capsule A newly created wetland has been beneficial for the breeding of five heron species and for the settlement and expansion of Glossy Ibises in the region.
Aim To determine whether created wetland would lead to the establishment of a heron and ibis breeding colony, and if so, to determine its effects on the distribution of these species in the wider region.
Methods Number of pairs breeding at the new wetland and in the region were estimated annually from 1996 to 2008. We investigated whether the growth of the new colony was explained by redistribution of breeding pairs within the region.
Results Purple Herons, Squacco Herons and Glossy Ibises colonised the new wetland in 1996. Black-crowned Night Herons settled in 1998, while Cattle and Little Egrets were the last species to establish in the mixed colony in 2001. The population increase was particularly marked for Glossy Ibises (which had bred in Doñana only sporadically through the 20th century). Our findings suggest that simple redistribution of pairs does not explain the formation and growth of the new colony. Since the first year of establishment numbers of Glossy Ibises and Purple Herons have shown a significant growth trend at both the new colony and in Doñana.
Conclusion The creation and management of a new wetland has been successful for the conservation of heron and egret species and promoted the expansion of the Glossy Ibis population across the western Mediterranean region.

Loss and degradation of wetlands are occurring worldwide and are particularly severe in the Mediterranean region, threatening many species of migratory birds (Moser *et al.* 1996, Gibbs 2000, Green *et al.* 2002, Cuttelod *et al.* 2008). To compensate for past and future wetland loss, it is important to investigate how management of remaining habitats and habitat restoration can enhance conservation of waterbirds.

In 2006, Doñana Natural Space (DNS), a protected area (about 108 087 ha) including the Doñana National Park (DNP) and the Natural Park in southwest Spain (Fig. 1) was created. The area is also designated as a Biosphere Reserve (UNESCO), a Wetland of International Importance of the Ramsar Convention, an Important Bird Area (IBA), a World Heritage Site and a Natura 2000 site. The wetlands (about 27 000 ha) of DNS, located in the Guadalquivir Marshes, have long been recognised as some of the most important for waterbirds in the western Palaearctic (Chapman & Buck 1910). Doñana is particularly well known for its wintering waterbirds (Rendón *et al.* 2008), but it is also extremely important for breeding colonial waterbirds such as herons and ciconiformes (storks, ibises and spoonbills) (Máñez & Rendón-Martos 2009).

A steadily increasing proportion of remaining wetlands within the estuary of the river Guadalquivir have been protected since 1969, yet they are negatively affected by water extraction from the watershed, alien species, overgrazing, and other problems (García Novo & Marín Cabrera 2005, Fernández-Delgado 2006). As a consequence, the extension of Bulrushes *Typha* spp. and Common Reeds *Phragmites australis* has undergone a major reduction in this area, limiting the area of suitable nest habitat for herons and ibises. This has been partially offset by the development of emergent vegetation in the 'Lucio de la FAO' a system of three interconnected semi-artificial

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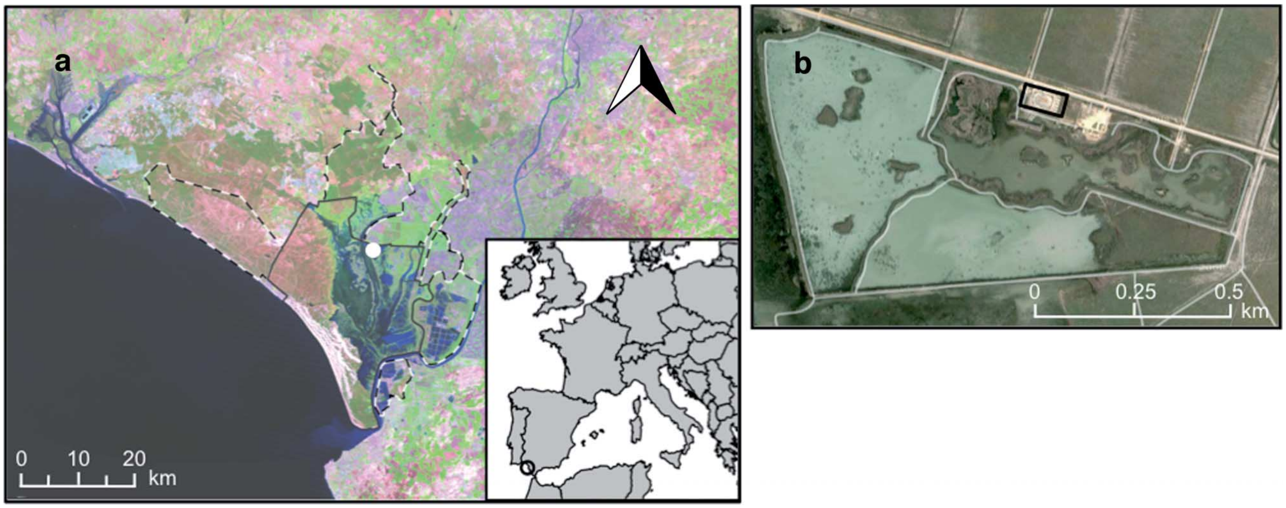

Figure 1. Geographical location of the study area and satellite image of (a) the Doñana Natural Space (DNS) that includes the Doñana Natural Park (dashed lines) and the Doñana National Park (solid line); and (b) the Lucio de la FAO showing the three ponds. The whole breeding colony nests in the pond closer to the José Antonio Valverde Visitor Centre (highlighted as a rectangle). The white dot in (a) corresponds to the Lucio de la FAO.

ponds (Fig. 1), hereafter referred to as FAO, which now holds a major mixed colony of Glossy Ibis *Plegadis falcinellus* and five heron species: Squacco Herons *Ardeola ralloides*, Purple Herons *Ardea purpurea*, Little Egrets *Egretta garzetta*, Cattle Egrets *Bubulcus Ibis* and Black-crowned Night Herons *Nycticorax nycticorax*. Glossy Ibises and Squacco Herons are found in the Spanish Red Data Book (Madroño *et al.* 2004) and other species are of conservation concern in Europe (BirdLife International 2004).

In this study, we analysed a 13-year dataset (1996–2008) of counts of colonial waterbirds in the FAO and the rest of the DNS. We aimed to: (1) describe the formation and build up of the FAO colony; (2) determine if this growth is related to increases in the overall number of breeding pairs in the DNS or alternatively to the redistribution of pairs already breeding in Doñana – our working hypothesis was that there would be redistribution as indicated by negative correlations between numbers of pairs in the FAO and the rest of the DNS; (3) establish the influence of the flooded area of natural wetlands in the DNS (the major feeding habitat) on the number of breeding pairs; and (4) discuss the conservation implications of our findings.

METHODS

Study area

The 'Lucio de la FAO' (37° 04′ N, 6° 22′ W) (Fig. 1) is a system of three interconnected ponds covering a total surface area of about 50 ha and flooded by both direct precipitation and groundwater pumped from the underlying aquifer. Groundwater is pumped into the pond adjacent to 'José Antonio Valverde Visitor Centre' (inaugurated in 1994) known as the 'Lucio de las Casas' and then subsequently flows into the other two ponds via sluice gates. This artificial system was set up in 1981. The heronry is located in the 'Lucio de las Casas', which provides dense vegetation cover suitable for nesting, especially *Typha* that is only present in this pond and is very scarce in the rest of Doñana. This pond also contains areas of *Tamarix* spp., which are the second most used nesting substrate. The other two ponds are almost free of emergent vegetation, probably due to the shallower depth, and higher variability in hydroperiod and salinity.

The visitor centre provides excellent views of the heronry and is one of the most interesting tourist attractions in Doñana (Fig. 2; the area can be observed from a webcam in the roof of the centre: http://icts.ebd.csic.es/irListaCamarasAction.do). It is situated on the northern boundary of the park, with natural, temporary marshes to the south and mainly agricultural areas (including ricefields) to the north. The area of natural marshes varies greatly between years in response to rainfall fluctuations (Fig. 3), and in particularly dry years the FAO is one of the few areas holding water in the spring and summer. The herons and ibises in the colony feed mainly in the natural marshes lying to the south of the colony and in the nearby ricefields (see

Figure 2. (a) View of the breeding colony in the Lucio de la FAO from the Visitor Centre; (b) José Antonio Valverde Visitor Centre.

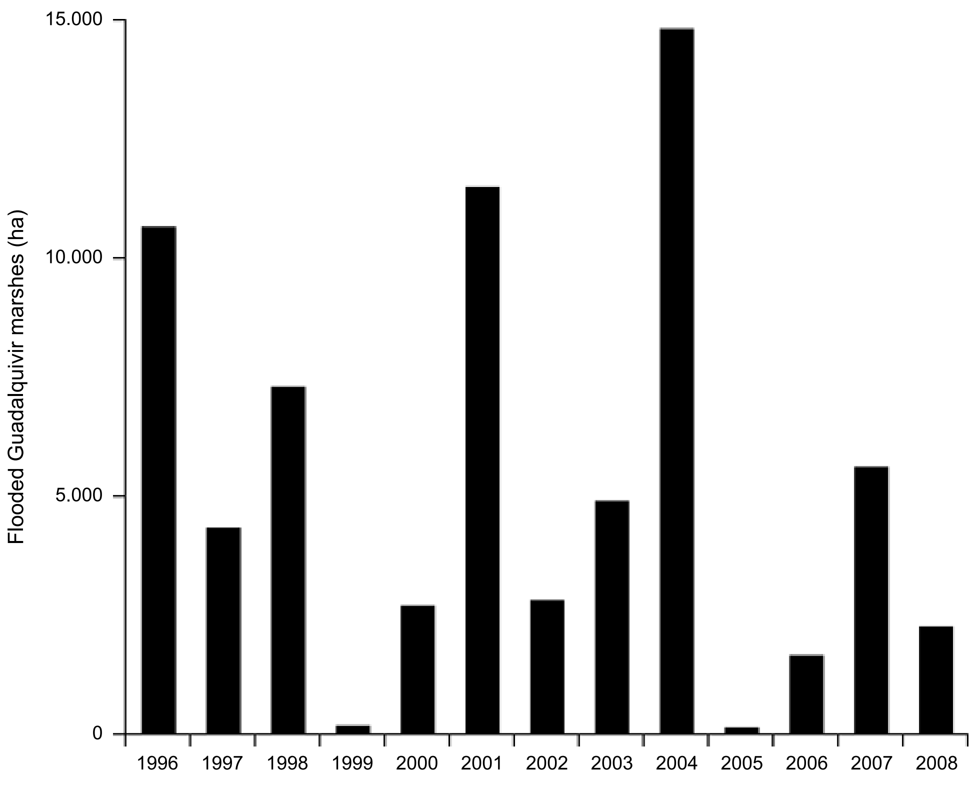

Figure 3. Mean flooded area (ha) in June of marshes in Doñana National Park from 1996 to 2007.

Macías *et al.* [2004] and Montesinos *et al.* [2008] for details). The climate is Mediterranean sub-humid with rainy winters and dry summers (for more details of the study area see Serrano *et al.* [2006], Rendón *et al.* [2008] and Kloskowski *et al.* [2009]).

Survey methods

Since 1996, ornithologists from the Natural Processes Monitoring Team of Doñana Biological Station have annually estimated the number of pairs of the different species breeding in the FAO and other sites inside the DNS. This well-trained team checks systematically and exhaustively all the DNS from the ground and also uses light aircraft to improve estimates of population abundance and to search for new breeding colonies.

In the FAO, estimates were made by both counting nests during ringing operations and estimating visually the number of breeding pairs of each species from the visitor centre roof (about 100 m from the edge of the colony) and other vantage points. The proximity to the visitor centre permitted us to count the individuals on a very regular basis without disturbing the colony. We compared counts from ringing operations and vantage points to make the best estimates of the number of breeding pairs in the colonies. We used repeated counts performed throughout the breeding season to establish the minimum number of pairs of each species. Pairs that established later in the season tended to colonise new areas of vegetation, facilitating estimation of the total number of nests and pairs in the colony.

Little bittern *Ixobrychus minutus* is abundant in the FAO (estimates range from a few pairs to a maximum of about 100 pairs in 2002) but data are not presented here owing to the greater methodological difficulties in counting this species.

Statistical analysis

In the 1980s some sporadic breeding by Purple Heron was recorded in the FAO, but it was not until 1996 that a reproductive colony of Glossy Ibises, Purple Herons and Squacco Herons became established. More recently, other species began to breed in the FAO: Black-crowned Night Herons from 1998 and both Little and Cattle Egrets from 2001. In the early 1990s, there were some failed breeding attempts by Glossy Ibises in the DNS (Máñez & Rendón-Martos 2009), but an extreme drought between 1991 and 1995 had a strong negative impact on all colonial waterbirds.

For each bird species, we tested for increasing or decreasing trends in the abundance of breeding pairs at FAO and in the rest of the DNS as well as in the whole DNS over the 13-year study period (1996–2008) with the non-parametric Mann–Kendall test (Mann–Kendall function from Kendall package in R [McLeod 2005, R Development Core Team 2009]).

There was a clear effect of drought years (1999 and 2005) on the breeding of waterbirds in Doñana when natural wetlands were almost dry and almost no pairs bred in the area (see Figs 3 & 4). However, since our main interest was in detecting short-term linear trends for years when breeding was possible, we excluded these years from our analyses since they can be expected to reduce the chances of detecting population trends. Nevertheless, we report later those cases in which trends were qualitatively different when these drought years were also included in the analyses.

Temporal autocorrelation may potentially produce a spurious correlation between population size and time. Thus, for positively autocorrelated data, Hatfield *et al.* (1996) recommend to reject the null hypothesis unless the test is significant at $\alpha < 0.01$. Hence, we tested for autocorrelation in numbers of breeding pairs of each species in the FAO and in DNS (ACF function from statistics package in R). Given that we investigated trends by excluding data from 1999 and 2005, we did the same when testing for autocorrelation.

As a measure of the relative importance of the FAO colony within the DNS as a whole, we calculated the mean percentage of all breeding pairs in the DNS that were present in the FAO, for each species and each year throughout the study period. Finally, to test how the population trend in the FAO was related to that in the rest of the DNS, we tested the correlation in population size between both areas for each species since the year of first breeding in the FAO (two-tailed Spearman rank correlation, COR.TEST function from statistics package in R).

We tested for correlations between breeding populations in the whole DNS and the flooded area of temporary natural marshes during the breeding season (two-tailed Spearman rank correlation, COR.TEST function from statistics package in R), using the mean flooded area for June (data from Remote Sensing and Geographic Information Systems Lab, Doñana Biological Station; http://last-ebd.blogspot.com/). We performed these correlation analyses by including drought years, nevertheless we did not find any qualitatively different results when excluding those years.

Data were collected over 13 years, representing a limited sample size that may restrict our capacity to

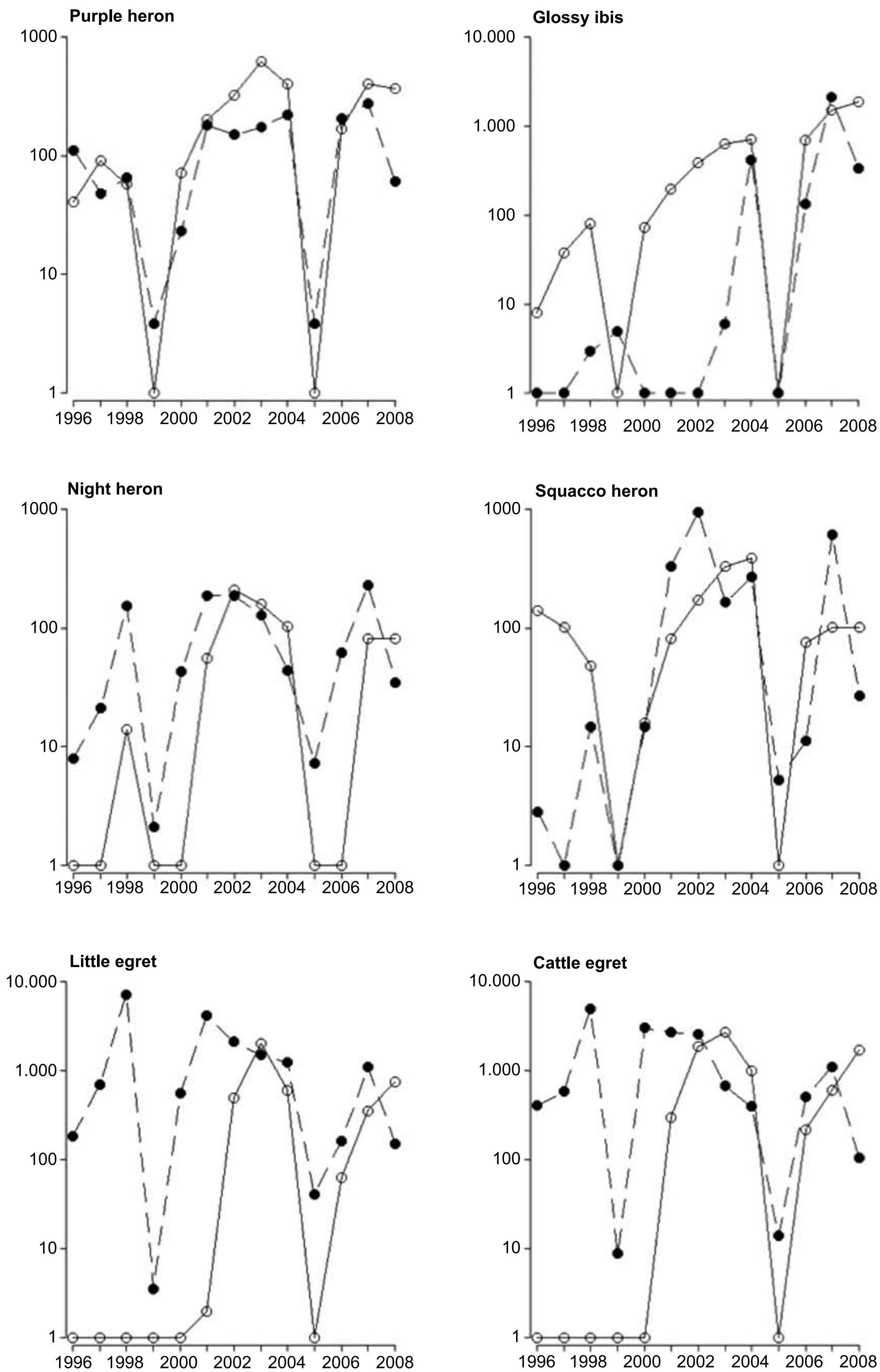

Figure 4. Breeding population dynamics (log population size +1) in the Lucio de la FAO (open circles) and other colonies in the Doñana Natural Space (DNS) (full circles). Note the change in scale on the y-axis.

detect biologically relevant correlations. We thus calculated how large the Pearson correlation coefficient had to be for a two-tailed correlation in order to be detectable with a power of 0.8 (i.e. so as to detect an existing correlation as significant in 80% of the analyses), using a significance threshold of 0.05 ('five-eighty convention', see Cohen [1988]) and the sample sizes used in our analyses. Calculations were made in G*POWER 3.0.10 (Faul *et al.* 1996).

RESULTS

Population dynamics

Apart from the near cessation of all breeding activity in the drought years 1999 and 2005, there was considerable variation in population dynamics between species and area (FAO versus the rest of the DNS, Fig. 4). A positive autocorrelation (lag = 1, $r = 0.62$, $P < 0.05$) was only recorded for Glossy Ibises in FAO. Even with a more restrictive value of (0.01 instead of 0.05) we found a positive trend in size of the Glossy Ibis breeding population both in the FAO and the rest of the DNS, as well as in the whole of Doñana (Table 1). The breeding population of Purple Herons increased significantly in the Lucio de la FAO and in the whole DNS, but in the rest of the DNS its increase was marginally significant (Table 1). No other species showed significant trends over the period of study (Table 1).

When including drought years, trends were still significant for the Glossy Ibis populations in the FAO, the rest of the DNS, and in the whole DNS (respectively, $r_s = 0.66$, $n = 13$, $P = 0.002$, $r_s = 0.53$, $n = 13$, $P = 0.02$ and $r_s = 0.61$, $n = 13$, $P = 0.004$). Trends for Purple Herons were no longer significant, although the trend in the FAO approached significance ($r_s = 0.42$, $P = 0.058$).

Glossy Ibises were the species with the highest proportion of breeding pairs in the FAO, which held an overall mean of 86% of the DNS population. Squacco Herons were also highly concentrated in the FAO (mean = 81.4%) while Cattle Egrets and Purple Herons were more variable in the extent of concentration at the FAO with high values in some years (e.g. 84.0% of Cattle Egrets at FAO in 2008 and mean = 40.8%, 97.1% of Purple Herons in 2006 and mean = 35.6%). The FAO was less important for Little Egrets and Black-crowned Night Heron (means = 24.5% and 7.3% of DNS pairs, respectively).

Contrary to our predictions, no negative correlations were found between the number of breeding pairs in the FAO and the rest of Doñana, and positive correlations were recorded for two species: Glossy Ibises ($r_s = 0.74$, $n = 13$, $P = 0.003$) and Purple Herons ($r_s = 0.74$, $n = 13$, $P = 0.003$). Black-crowned Night Heron and Squacco Heron breeding pairs in the FAO showed a marginally significant relationship to those outside (in that order, $r_s = 0.56$, $n = 11$, $P = 0.07$, $r_s = 0.5$, $n = 13$, $P = 0.08$). Numbers of Cattle and Little Egrets in the FAO and rest of the DNS showed no relationship (respectively, $r_s = 0.26$, $n = 8$, $P = 0.54$, $r_s = 0.17$, $n = 8$, $P = 0.70$).

Relationship with the flooded area

Contrary to our expectations, only three species showed a relationship between breeding numbers and the flooded area of natural marshes: Black-crowned Night Herons ($r_s = 0.74$, $n = 13$, $P = 0.005$), Cattle Egrets ($r_s = 0.74$, $n = 13$, $P = 0.005$) and Little Egrets ($r_s = 0.80$,

Table 1. Trends of populations (number of pairs) breeding in the Lucio de la FAO, in the rest of the Doñana Natural Space (DNS) and in the whole DNS, based on breeding season counts from 1996 to 2008.

	Locality								
	Lucio de la FAO			Rest of DNS			DNS		
Species	Kendall's τ	P	n	Kendall's τ	P	n	Kendall's τ	P	n
Glossy Ibis	+0.93	< 0.0001	11	+0.67	0.009	11	+0.89	0.0002	11
Night Heron	+0.11	0.75	9	+0.27	0.28	11	+0.27	0.28	11
Squacco Heron	+0.15	0.58	11	+0.37	0.14	11	+0.2	0.44	11
Cattle Egret	−0.05	1	7	−0.34	0.16	11	−0.09	0.76	11
Little Egret	+0.24	0.55	7	−0.27	0.28	11	−0.09	0.76	11
Purple Heron	+0.59	0.015	11	+0.42	0.087	11	+0.49	0.043	11

Two drought years (1999 and 2005) when there were few or no breeding pairs in the area have been excluded from the analysis; the number of years considered varies for the FAO because some species did not begin breeding until 1998 or 2001.

n = 13, P = 0.002). The other species showed positive, but non-significant, correlations with flooded area (Glossy Ibises: r_s = 0.33, n = 13, P = 0.26, Squacco Herons: r_s = 0.15, n = 13, P = 0.63, Purple Herons: r_s = 0.29, n = 13, P = 0.33).

Power analysis

Sample sizes used in our analyses, depending on the species and area considered, were: n = 7, 8, 9, 11, and 13. From the smallest sample size to the highest, the minimum correlation coefficients detectable as statistically significant with a power of 0.80 would have been, respectively: r_P = 0.80, 0.77, 0.74, 0.69, 0.65.

DISCUSSION

Glossy Ibises were breeding in Doñana at the end of the 19th century in small numbers and their abundance reduced abruptly until extinction in 1909, although some breeding attempts were recorded through the 20th century (Valverde 1960, Castroviejo 1993). The reasons for local extinction could include the loss of habitats owing to overexploitation and diversion for irrigation of the streams feeding the marshes (Serrano *et al.* 2006), as well as hunting pressure and other forms of human disturbance prior to the declaration of protected areas. Glossy Ibises were the species that took advantage of the Lucio de la FAO restoration and the one to show the strongest increase across the whole Doñana Natural Space (DNS) since 1996 (Table 1). However, the recent colonisation by Glossy Ibises of Spain is not only related to the creation of the FAO. Successful reproduction was recorded in 1994 in Valencia and, in 1996, simultaneously with the recolonization of Doñana, a smaller colony became established in the Ebro Delta (Figuerola *et al.* 2003). Nevertheless, the high productivity of this species in Doñana (Máñez & Rendón-Martos 2009) has probably fuelled further expansion in France (Kayser *et al.* 2008), Portugal (Equipa Atlas 2008) and Algeria (Boucheker *et al.* 2009).

The Lucio de la FAO has existed since the early 1980s, and there are various reasons that may explain why the breeding colony did not settle before 1996. The *Typha* beds were not planted, but established slowly on their own, and had perhaps not reached sufficient cover and density in previous years. A particularly severe drought in 1991–1995 led to a large reduction in the size of all breeding waterbird populations in Doñana. Furthermore, unknown external factors may have impeded the earlier establishment of Glossy Ibises or other species in the FAO (e.g. the status of breeding sites or low reproductive success elsewhere in the range of the biogeographical population). Glossy Ibises tend to associate with other waterbirds, particularly herons, to breed (Davis & Kricher 2000). The presence of a growing population of Glossy Ibises may have drawn individuals of this and other species towards the FAO leading to the formation of a large, mixed colony (see review in Brown & Brown [2001]).

The available evidence suggests that the creation of the FAO ponds and the suitable breeding habitat within it has had a positive influence on the size of the bird populations in the whole of Doñana. This is supported by the strong positive trends in numbers of Ibises and Purple Herons, and the lack of evidence for redistribution of breeding pairs to the FAO from elsewhere in the DNS. Furthermore, there has been a general increase in the numbers of all these species in Doñana since the late 1970s (Aguilera & Sañudo 1986, García *et al.* 1989, Máñez 1991). The number of breeding pairs of some of these species in the FAO itself during our study period has been greater than the numbers found in the whole Doñana area in the 1980s. As indicated from our power analysis, the short period considered in the present study makes it hard to detect statistically significant population trends. Nevertheless, Glossy Ibises and Purple Herons showed significant increase during the study period.

The FAO has represented a new and important habitat suitable for herons and ibises, but aerial counts indicate long-term increases in wintering numbers of other wading birds (Grey Herons *Ardea cinerea*, White Storks *Ciconia ciconia*, Greater Flamingos *Phoenicopterus roseus* and Eurasian Spoonbills *Platalea leucorodia*) in Doñana since 1978 (Rendón *et al.* 2008). None of these other species breed in the FAO, suggesting that there are also other causes to the long-term increases recorded for the species studied in this paper, such as increases in the surface area of artificial wetlands such as ricefields and fish ponds (see Rendón *et al.* [2008] for more discussion).

The positive correlation for Glossy Ibis between trends in the Lucio de la FAO and elsewhere in the Doñana Natural Space reflects the increase of the breeding population that affected simultaneously the number of pairs in the FAO and their redistribution in other sites inside Doñana. For Purple Herons, some local population limitation owing to scarcity of breeding sites may have been occurring prior to the creation of the FAO.

Such a shortage could have been because of the lack of emergent vegetation in the rest of the DNS owing to drought, water extraction and/or overgrazing (Soriguer *et al.* 2001, Manzano *et al.* 2005). Another factor promoting recent population increases is likely to be the fencing off of an area within the natural marshes in the DNS. In 1995 Juncabalejo, a *Phragmites* bed, was fenced off to provide protection against overgrazing and terrestrial predation (particularly wild boar *Sus scrofa*). Since then it has become an important breeding site for Purple Herons, ibises and other waterbirds, and this has probably contributed to the positive trends for these species outside the FAO.

Ideally, we should have studied the possible redistribution of birds between different colony sites using mark–recapture techniques. However, good mark–recapture data only exist for Glossy Ibises, and are strongly biased towards the FAO colony, given the practical advantages of ringing and observing there. These data confirm that ibises born in the FAO sometimes nest elsewhere in the DNS and *vice versa*. Nevertheless, the population increase recorded for this species in the FAO cannot be explained by redistribution within DNS, since Glossy Ibises started breeding in the FAO before beginning a later expansion to other parts of the DNS (Fig. 4).

The flooded area of natural marshes available as feeding habitat has a strong influence on all the species studied by preventing breeding during extreme drought conditions. Furthermore, there was a general positive relationship between the area of feeding habitat and the number of breeding pairs of Cattle Egrets, Little Egrets and Black-crowned Night Herons, suggesting strong local control of their population size. Squacco Herons and Purple Herons did not show such a relationship, possibly because these are the species that chiefly winter away from Doñana ('Registro ornitológico' in: Monitoring Group of Natural Processes of the Doñana Biological Station databases; http://www-rbd.ebd.csic.es/Seguimiento/mediobiologico.htm) and hence are more affected by conditions on their wintering grounds or migration routes. In western Europe, the Purple Heron breeding population can be affected by drought conditions on the wintering grounds in tropical West Africa (Cavé 1983, den Held 1981). Similarly, the breeding population of Squacco Herons in western Europe has been related to drought in the Sahel (den Held 1981, Hafner & Wallace 1988). Many Glossy Ibises winter locally in Doñana, and a relationship between breeding populations and flooded marsh area will perhaps become apparent in the future when the general population growth phase is completed.

Overall, the management of the FAO wetlands has been very beneficial given the size of the breeding populations there and the conservation status of the species present (Table 2). The importance of the FAO is underlined by the high proportions of the entire Doñana populations that are breeding there. Additionally, the creation of the FAO has probably promoted the expansion of Glossy Ibises across the western Mediterranean and contributed to longer-term increases in the breeding populations of other species.

Conservation and management implications

Doñana is extremely important for the six bird species studied, with peak breeding populations greatly exceeding the 1% criteria used to identify wetlands of international importance (Table 2). Numbers of those species considered to be declining in Europe are particularly high in the DNS (Table 2). In terms of maximum counts

Table 2. Species abundance in Lucio de la FAO and the whole Doñana Natural Space (DNS) and their conservation importance. Minimum and maximum number of breeding pairs in the FAO colony and in the whole DNS between 1996 and 2008 are reported.

	Locality						
	FAO		DNS				
Species	Min.	Max.	Min.	Max.	Status in Europe	1% population thresholds (Spain)	1% population thresholds (biogeographical population)
Glossy Ibis	7	1900	7	3643	Declining	4	570
Night Heron	13	210	78	2391	Depleted	33	790
Squacco Heron	15	389	20	430	Declining	10	40
Cattle Egret	219	2700	902	5930	Secure	600	2800
Little Egret	1	2000	496	7816	Secure	150	1300
Purple Heron	40	620	136	2206	Declining	20	120

For each species the number of DNS breeding pairs is only reported for years when there were breeding pairs in the FAO colony; values for dry years (1999 and 2005) are not considered; status in Europe and populations in Spain for 1998–2002 (BirdLife International 2004) and bio-geographical wintering populations (Wetlands International 2006).

during the period of study, the DNS holds more than 50% of the Spanish breeding population of all species except Cattle Egrets and Squacco Herons (Table 2), which also have important breeding populations in the middle Tajo basin (Garrido 2003).

The Jose Antonio Valverde Visitor Centre represents a successful example of wetland management with both ecological and educational functions (Fig. 2). The creation of the FAO is particularly noteworthy for the reestablishment of Glossy Ibises in the area, although it was not a specific initial management aim. This species is of conservation concern and in decline in Europe (BirdLife International 2004) and is considered IUCN Vulnerable in Spain (Figuerola *et al.* 2003) largely because of its concentration in a uniquely important colony at the FAO. The risk of epidemiological or catastrophic events makes the concentration of one species in a single locality a potentially serious threat for its conservation (IUCN 2001). For example, toxic algae outbreaks occur in some years in the FAO and other parts of Doñana, resulting in catastrophic mortality to waterbirds (Alonso-Andicoberry *et al.* 2002, Lopez-Rodas *et al.* 2008).

Glossy Ibises and Squacco Herons are at risk by focusing their reproductive effort on one breeding site and thus it would be advisable to diversify the breeding habitat available for these species in Doñana. Although it is difficult to attract individuals from a good breeding site to another new one (Perennou *et al.* 1996), the ongoing protection of additional areas in the DNS (e.g. Juncabalejo) from overgrazing by cows so as to permit the recovery of emergent vegetation is certain to benefit herons and ibises. Glossy Ibises are already showing a tendency to reduce the proportion of breeding pairs in the FAO with respect to the rest of Doñana (Fig. 4), and Juncabalejo is increasing its importance for this and other species.

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REFERENCES

Aguilera, E. & Sañudo, J. 1986. [Pasado y presente de las colonias de Ciconiformes en Doñana y Odiel.] *Bios* **2:** 11–13 (in Spanish).

Alonso-Andicoberry, C., García-Villada, L., Lopez-Rodas V. & Costas, E. 2002. Catastrophic mortality of flamingos in a Spanish national park caused by cyanobacteria. *Vet. Rec.* **151:** 706–707.

BirdLife International. 2004. *Birds in Europe: population estimates, trends and conservation status.* BirdLife International, Wageningen, The Netherlands.

Boucheker, A., Nedjah, R., Samraoui, Menaô, R. & Samraoui, B. 2009. Aspects of the breeding ecology and conservation of the Glossy Ibis in Algeria. *Waterbirds* **32:** 345–351.

Brown, C.R. & Brown, M.B. 2001. Avian coloniality: progress and problems. *Curr. Ornithol.* **16:** 1–82.

Castroviejo, J. 1993. [Mapa del parque nacional de Donana.] Consejo Superior de Investigaciones Cientificas, Seville, Spain (in Spanish).

Cavé, A.J. 1983. Purple Heron survival and drought in tropical West Africa. *Ardea* **71:** 217–224.

Chapman, A. & Buck, W.J. 1910. *Unexplored Spain.* E. Arnold, London.

Cohen, J. 1988. *Statistical Power Analysis for Behavioural Sciences.* Academic Press, New York.

Cuttelod, A., García, N., Abdul Malak, D., Temple, H. & Katariya, V. 2008. The Mediterranean: a biodiversity hotspot under threat. In Vié, J.C., Hilton-Taylor, C. & Stuart, S.N. (eds) *The 2008 Review of the IUCN Red List of Threatened Species*: 89–101. IUCN, Gland, Switzerland.

Davis, W.E. & Kricher, J. 2000. Glossy Ibis (*Plegadis falcinellus*). In Poole, A. & Gill, F. (eds) *The Birds of North America*, Vol. 545. The Birds of North America, Inc., Philadelphia, PA.

Den Held, J.J. 1981. Population changes in the Purple Heron in relation to drought in wintering area. *Ardea* **69:** 185–191

Equipa Atlas 2008. [*Atlas das Aves Nidificantes em Portugal (1999–2005)*] Instituto da Conservação da Natureza e da Biodiversidade, Sociedade Portuguesa para o Estudo das Aves, Parque Natural da Madeira e Secretaria Regional do Ambiente, Assírio & Alvim, Lisbon, Portugal (in Portuguese).

Faul, F., Erdfelder, E., Lang, A. & Buchner, A. 1996. G*Power3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* **39:** 175–191.

Fernández-Delgado, C. 2006. Conservation management of a European natural area: Doñana National Park, Spain. In Groom, M.J., Meffe, G.K. & Carroll C.R. (eds) *Principles of Conservation Biology*, 3rd edn: 536–543. Sinauer Associates, Sunderland, MA.

Figuerola, J., Máñez, M., Ibáñez, F., García, L. & Garrido, H. 2003. [Morito Plegadis falcinellus.] In Martí, R. & del Moral J.C. (eds) *Atlas de las Aves Reproductoras de España*: 124–125. Dirección General de Conservación de la Naturaleza-SEO/BirdLife, Madrid, Spain (in Spanish).

García, L., Calderón, J. & Castroviejo, J. 1989. [*Las aves de Doñana y su entorno.*] EBD, CSIC, Cooperativa Marismas del Rocío, Seville, Spain (in Spanish).

García Novo, F. & Marín Cabrera, C. 2005. *Doñana, Water and Biosphere.* Confederación Hidrográfica del Guadalquivir, Ministerio de Medio Ambiente, Madrid, Spain.

Garrido, J.R. 2003. [Garcilla bueyera, *Bubulcus Ibis*.] In Martí, R. & del Moral J.C. (eds) *Atlas de las Aves Reproductoras de España*: 112–113. Dirección General de Conservación de la Naturaleza-SEO/BirdLife, Madrid, Spain (in Spanish).

Gibbs, J.P. 2000. Wetland loss and biodiversity conservation. *Conserv. Biol.* **14:** 314–317.

Green, A.J., Hamzaoui, M.E., El Agbani, M.A. & Franchimont, J. 2002. The conservation status of Moroccan wetlands with particular reference to waterbirds and to changes since 1978. *Biol. Conserv.* **104:** 71–82.

Hafner, H. & Wallace, J.P. 1988. Population changes in Camargue Ardeids. The effect of climatic conditions in the wintering areas. *Bull. Col. Waterbirds Soc.* 12–29.

Hatfield, J.S., Gould, W.R., Hoover, B.A., Fuller, M.R. & Lindquist, E.L. 1996. Detecting trends in raptor counts: power and type I error rates of various statistical tests. *Wildlife Soc. Bull.* **24:** 505–515.

IUCN 2001. *Red List Categories and Criteria Version 3.1*. IUCN Species Survival Commission, Gland, Switzerland.

Kayser, Y., Gauthier-Clerc, M., Bechet, A., Poulin B., Massez G., Cherain Y., Paoli J., Sadoul N., Vialet E., Paulus G., Vincent-Martin N., Pilard P. & Isenmann P. 2008. [Compte rendu ornithologique camarguais pour les années 2001–2006.] *Rev. Ecol-Terre Vie* **63:** 299–349 (in French).

Kloskowski, J., Green, A.J., Polak, M., Bustamante, J. & Krogulec, J. 2009. Complementary use of natural and artificial wetlands by waterbirds wintering in Doñana, south-west Spain. *Aquat. Conserv.* **19:** 815–826.

Lopez-Rodas, V., Maneiro, E., Lanzarot, M.P., Perdigones, N. & Costas, E. 2008. Mass wildlife mortality due to cyanobacteria in the Donana National Park, Spain. *Vet. Rec.* **162:** 317–318.

Macías, M., Green, A.J. & Sánchez, M.I. 2004. The diet of the Glossy Ibis during the breeding season in Doñana, southwest Spain. *Waterbirds* **27:** 234–239.

Madroño, A., González, C. & Atienza, J.C. 2004. [*Libro Rojo de las Aves de España*.] DGB (MIMAM) & SEO/BirdLife, Madrid, Spain (in Spanish).

Máñez, M. 1991. [Estado actual en el Parque Nacional de Doñana de las especies de aves incluidas en la Lista Roja de los Vertebrados de Españadentro de las categorías 'En peligro' y 'Vulnerable'.] In *Andalus, Fundación Bios y Finca el Retiro. Actas de las I Jornadas sobre Zonas Húmedas Andaluzas. Fuente de Piedra, abril 1990*: 41–49. Málaga, Spain (in Spanish).

Máñez, M. & Rendón-Martos, M. (eds). 2009. [*El morito, la espátula y el flamenco en España. Población en 2007 y método de censo*.] SEO/BirdLife, Madrid, Spain (in Spanish).

Manzano, M., Custodio, E. & Mediavilla, C. 2005. Effects of localised intensive aquifer exploitation on the Doñana wetlands (SW Spain). In *International Association of Hydrogeologists, Selected Papers*, Vol. 7. *Intensive Use of Groundwater*: 209–219. Balkema, Leiden, The Netherlands.

McLeod, A.I. 2005. *Kendall: Kendall rank correlation and Mann–Kendall trend test.* R package version 2.0. Available at: http://www.stats.uwo.ca/faculty/aim (accessed 17 August 2010)

Montesinos, A., Santoul, F. & Green, A.J. 2008. The diet of the Night-Heron and Purple Heron in the Guadalquivir marshes. *Ardeola* **55:** 161–167.

Moser, M., Prentice, C. & Frazier, S. 1996. A global overview of wetland loss and degradation. In UNFCCC (ed.) *Technical Session B of the Ramsar Conference of Parties (COP)*: 253–260. UNFCCC, New York.

Perennou, C., Sadoul, N., Pineau, O., Johnson, A. & Hafner, H. 1996. Management of nest sites for colonial waterbirds. In Tour du Valat (ed.) *Conservation of Mediterranean Wetlands*, No. 4. Tour du Valat, Arles, France.

R Development Core Team. 2009. *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org (accessed 17 August 2010)

Rendón, M.A., Green, A.J., Aguilera, E. & Almaraz, P. 2008. Status, distribution and long-term changes in the waterbird community wintering in Doñana, south-west Spain. *Biol. Conserv.* **141:** 1371–1388.

Serrano, L., Reina, M. & Martín, G. 2006. The aquatic systems of Doñana (SW Spain): watersheds and frontiers. *Limnetica* **25:** 11–32.

Soriguer, R.C., Rodríguez Sierra, A. & Domínguez, L. 2001. [*Análisis de la incidencia de los grandes herbívoros en la marisma y vera del Parque Nacional de Doñana*.] Organismo Autónomo de Parques Nacionales, Madrid, Spain (in Spanish).

Valverde, J.A. 1960. [Vertebrados de las marismas del Guadalquivir.] In CSIC (ed.) *Archivos del Instituto de Aclimatación*, Vol. 9: 1–168. CSIC, Almería, Spain (in Spanish).

Wetlands International 2006. *Waterbird Population Estimates*, 4th edn. Wetlands International, Wageningen, The Netherlands.

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