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Research paper

Effect of implementation of irrigation on raptor and corvid populations in a Mediterranean agrosystem

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Abstract

Effect of implementation of irrigation on raptor and corvid populations in a Mediterranean agrosystem. We analyzed changes in the composition of the community of birds of prey and corvids in a rainfed agrosystem after the transformation of 37.2% of the sampled area into irrigated land between 2005 and 2020. We sampled 57 transects (372 km per year) and fitted generalized linear mixed models (GLMM) to study changes in species occurrence. Our results showed that specific richness and the Shannon index did not vary significantly between rainfed and irrigated transects, but there was a certain positive trend when comparing the years 2005 and 2020. Regarding the differences detected for each species, the occurrence of Montagu's harrier *Circus pygargus*, hen harrier *Circus cyaneus*, Eurasian short-toed eagle *Circaetus gallicus*, griffon vulture *Gyps fulvus* and carrion crow *Corvus corone* was significantly lower in irrigated land than in rainfed land, while magpie *Pica pica*, Western marsh harrier *Circus aeruginosus*, common kestrel *Falco tinnunculus* and black kite *Milvus migrans* showed a significantly higher occurrence in the irrigated transects. In addition, our findings confirm a significant decrease in occurrence between 2005 and 2020 both in rainfed and irrigated areas for Montagu's harrier, hen harrier and magpie, while Western marsh harrier, golden eagle *Aquila chrysaetos*, common buzzard *Buteo buteo*, red kite *Milvus milvus*, griffon vulture *Gyps fulvus*, red-billed chough *Pyrrhocorax pyrrhocorax* and Western jackdaw *Coloeus monedula* were detected significantly more frequently in 2020 than in 2005. These results suggest that assessment of the impact of a new irrigation system should focus on the most characteristic species of rainfed agrosystems because the apparently positive effect on other species, equally protected but more generalist, may mask the real effect on conservation.

Key words: Agriculture-intensification, Census, Harrier, Steppe

Resumen

Efecto de la implementación de regadíos en la población de rapaces y córvidos de un agrosistema mediterráneo. Analizamos los cambios en la composición de la comunidad de rapaces y córvidos de un agrosistema de secano provocados por la transformación entre 2005 y 2020 del 37,2% de la superficie muestreada en tierra de regadío. Para ello, realizamos 57 transectos (372 km anuales) y utilizamos modelos mixtos lineales generalizados (GLM) para estudiar los cambios en la presencia de las especies. Los resultados mostraron que la riqueza específica y el índice de Shannon no variaron significativamente entre los transectos de secano y regadío, pero sí mostraron una cierta tendencia positiva al comparar los años 2005 y 2020. En cuanto a las diferencias detectadas respecto de cada especie, la presencia del aguilucho cenizo *Circus pygargus*, el aguilucho pálido *Circus cyaneus*, la culebrera europea *Circaetus gallicus*, el buitre leonado *Gyps fulvus*, y la corneja *Corvus corone*, fue significativamente menor en los regadíos que en los secanos, mientras que la presencia de la urraca *Pica pica*, el aguilucho lagunero occidental *Circus aeruginosus*, el cernícalo vulgar *Falco tinnunculus*, y el milano negro *Milvus migrans*, fue significativamente mayor en los transectos de regadío. Además de esto, se ha podido confirmar un descenso significativo de la presencia entre 2005 y 2020 tanto en secano como en regadío del aguilucho cenizo, el aguilucho pálido y la urraca, mientras que el aguilucho lagunero occidental, el águila real *Aquila chrysaetos*, el busardo ratonero *Buteo buteo*, el milano real *Milvus milvus*, el buitre leonado *Gyps fulvus*, la chova piquirroja *Pyrrhocorax pyrrhocorax*, y la grajilla *Coloeus monedula*, se detectaron con una frecuencia significativamente mayor en 2020 que en 2005. Estos resultados sugieren que la evaluación del impacto de un nuevo sistema de regadío debería centrarse en las especies más características de los agrosistemas de secano, ya que el efecto aparentemente positivo en otras especies, igualmente protegidas, pero más generalistas, podría enmascarar el efecto real en la conservación.

Palabras clave: Intensificación de la agricultura, Censo, Aguilucho, Estepa

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Introduction

The area dedicated to agriculture occupies almost 50 % of the total land area of Europe and its management can thus have significant conservation consequences (Halada et al 2011). Traditional agriculture has made agro-pastoral systems one of the most biodiverse habitats in Europe (Halada et al 2011, Vos and Meekes 1999, Pärtel et al 2005), especially those in the Iberian Peninsula (McMahon et al 2010). However, agricultural transformations that have taken place in recent decades have posed a serious challenge for biodiversity conservation (Ormerod et al 2003, Brotons et al 2004, Morelli 2013). The intensification of agriculture has tended to increase the size of plots (Fernández et al 1992, Baessler and Klotz 2006, De Frutos et al 2015), with the consequent loss of boundaries and small patches of natural vegetation (Donázar et al 1993, Petit and Firbank 2006, Morelli 2013). Such structures play a fundamental role in conserving the biodiversity of agrosystems since not only do numerous species nest therein but they also provide shelter from predators and meteorological phenomena, and maintain the seed bank of wild plants that allow the recolonization of the land after harvest (Lindenmayer 2019). Another of the most important and widespread changes is the introduction of new irrigation systems (Brotons et al 2004, Ursúa et al 2005, De Frutos et al 2015, Giralt et al 2021, Cabodevilla et al 2022). These systems are associated with a significant simplification of the habitat, the establishment of monocultures (for example, maize), and a clear increase in the application of phytosanitary products (Rodríguez-Estival et al 2010, Cabodevilla et al 2021). All these changes have resulted in a drastic drop in the availability and quality of trophic and nesting resources needed for species linked to extensive rainfed agrosystems, such as raptors (Ursúa et al 2005, De Frutos et al 2015) and corvids (Blanco et al 1998).

As predators and scavengers, raptors and corvids play a key role in many ecosystems, including farmland, regulating the populations of prey species and removing carcasses (Newton 1979, Selva 2004, Webb et al 2004, Donázar et al 2016). Being in the upper part of the food chain, they are the first to show changes in the size of their populations in response to environmental factors. Therefore, they can be considered good 'sentinels' of environmental quality (Newton et al 1993, Sergio et al 2005, 2006, Rattner 2009). Furthermore, their large size, easy identification and cultural heritage make this group of birds a good option to arouse the interest of the general public (Webb et al 2004, Kovács et al 2005, Movallie et al 2008, Donázar et al 2016). Nevertheless, as knowledge about the population trends of these large birds is still insufficient, long-term monitoring work is of vital importance (Kovács et al 2005, Donázar et al 2016, Derlink et al 2018). In Spain there is no specific monitoring plan for this group of birds. Specific censuses exist only for certain groups or species (Palomino and Valls 2011) or data extracted from the SACRE program (Escandell and Escudero 2019), which does not use the most appropriate methodology to censor this group of birds (Kovács et al 2005).

In the present study, we analyzed the impact of introducing irrigation systems in the community of birds of prey and corvids in an agricultural area in the north of the Iberian Peninsula. We compared surveys performed in 2005 with data recorded in 2020, 15 years after a very high percentage of land devoted to traditional rainfed crops was transformed into irrigation. The main goals of this work were, i) to determine whether the richness and composition of the community and the occurrence probability of species changed in this period of time, ii) to identify which species experienced the greatest changes, and iii) to assess the role of transformation into irrigation in the changes that occurred. We expected to find a change in the occurrence of species in 2020 associated with irrigation, a negative response in those species more typical of pseudo-steppe habitats, and a less marked or even positive response in the generalists.

Methods

Study area

The field work was carried out in ten 10 x 10 km UTM grids in the Navarre region, in the northwest of Spain (fig. 1). These 10 grids were grouped into two zones (6 and 4 grids respectively) separated by less than 50 km and with a similar habitat. The area has a Mediterranean climate, with an average rainfall of around 400 ml/m² and an average temperature of around 13 °C. Most of the land is occupied by agricultural crops, and the natural vegetation formations are limited to small masses of pseudosteparic vegetation (*Artemisia* spp, *Thymus* spp, *Lygeum spartum*) in the least productive plots, small forests of *Pinus halepensis* or *Quercus ilex* on the slopes or riparian forests of *Populus* spp, *Salix* spp and *Fraxinus* spp along the rivers.

Traditionally, the predominant crops were rainfed cereals (wheat and barley), vineyards and olive trees, but the installment of new irrigation systems over the last 15 years has led to these traditional crops being replaced by maize, irrigated tree orchards, or vegetable crops (mainly broccoli and red pepper).

Bird censuses

Vehicle transects were the chosen census method (Fuller and Mosher 1981). This method has been widely used for raptors (Santos and Tellería 1981, Viñuela 1999, Sanchez-Zapata et al 2003, Bustamante and Seonae 2004, Cardiel 2006, Palomino 2006, Carrete et al 2009, Zagorski and Swihart 2021) and corvids (Dean and Ollakindia 2003), being very suitable in open environments (Santos and Tellería 1981, Palomino and Valls 2011, Zagorski and Swihart 2021) like the agrosystems where the present work was undertaken. Censuses were carried out in June in order to guarantee that migratory breeding species were already established in their territories. Two experienced ornithologists participated in the surveys, one driving a car and the other prospecting with binoculars (8 x 32 or 10 x 42). We recorded both sides of the road, covering a strip of 100 m on each side. All specimens observed, both perched and in flight, were recorded. The design of

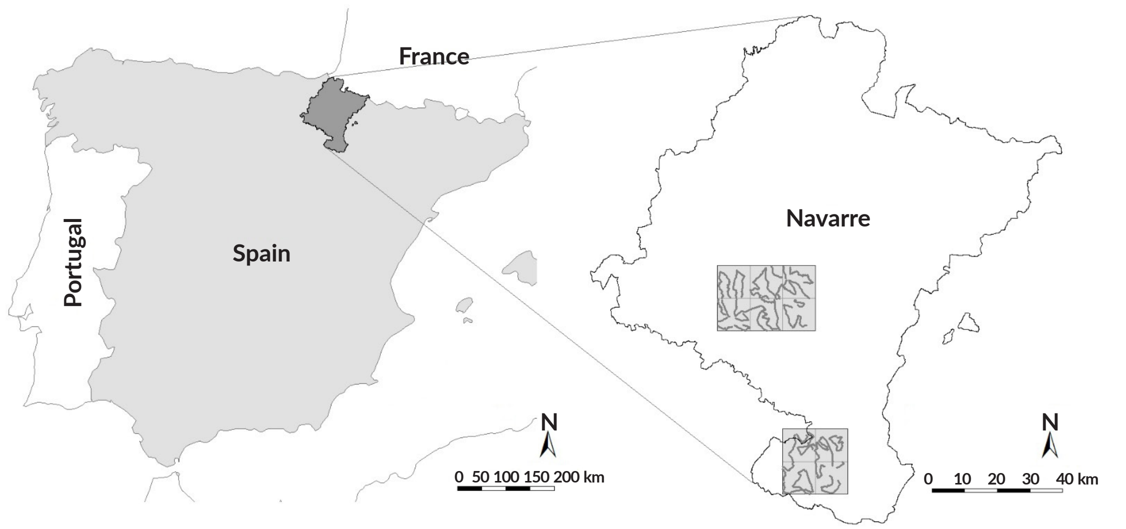

Fig. 1. Study area and census transects.

Fig. 1. *Área del estudio y transectos de censo.*

transects and the experience of the observers made it possible to avoid double contacts. The census schedule ran from 9:00 am to 12:00 pm in order to cover the period of maximum activity of the raptors. The annual sampling effort consisted of a minimum of 30 km per 10 x 10 km UTM grid (Palomino and Valls 2011). This produced a total of 372 km traveled, distributed among 57 transects. This monitoring scheme was carried out in 2005 and repeated by the same ornithologists in 2020 following exactly the same transects (see fig. 1 and table 1 for details).

Data analyses

Each transect was assigned to the either the category 'irrigated' or 'rainfed' according to the land use information downloaded from the IDENA website (https://idena.navarra.es/navegar/) and completed or corrected during fieldwork. A transect was assigned to one category or another when more than 90 % of the included plots were irrigated or rainfed.

A kilometric abundance index (KAI) was calculated for each of the species in each transect and year as the quotient between the number of detected specimens divided by the length of the transect in kilometers. In this way, the KAI represents the number of individuals of a species for every kilometer of the census. This method does not give a total census of the population but it allows comparisons between different zones and dates (Tellería 1986). This information is presented in table 1. We also estimated the Shannon diversity index (*H*') (Carrete et al 2009)

Data analysis was carried out using GLMM models in a Bayesian framework (*stan_glmer* function of *rstanarm* package in R; Gabry and Goodrich 2018). First, we fitted two GLMM models to assess whether there were any changes in species richness (a model with a Poisson error and log link function) and in Shannon index (a model with a Gaussian error and identity link function) between rainfed and irrigated transects and also between years. To do this we used species richness or Shannon index as response variable and irrigation (true/false), year, the interaction between them, and the transect length as explanatory variables. Moreover, transect ID was included as a random factor. We also fitted a GLMM model with a binomial error and logit link function per species to assess the changes in their occurrence probability. In this case, we transformed count data into detection/non-detection data for use as a response variable in these models. We used the same explanatory variables as for the previous models and the transect ID as random factor. We only analyzed the occurrence of species with ≥5 detections.

The *stan_glm* function performs Bayesian estimation via a Markov chain Monte Carlo process.

By default, four Markov chains with 2,000 iterations each are set and as a warm-up process 1,000 interactions per chain are burned. The convergence of the models was evaluated visually (from the trace plots) and using Gelman Rubin's R-hat statistics (Gelman and Rubin 1992, Gelman and Shirley 2011). From the models, mean values and their 95 % and 50 % credible intervals (hereafter CI) were extracted using the *modelbased* package in R (Makowski et al 2020). All analyses were carried out with R v4.1.3 (R Core Team 2022).

Results

In 2005, 87.08 % of the sampled area (6,476 ha) corresponded to rainfed land and 12.91 % (960 ha) to irrigated crops. In 2020, the percentage of land occupied by rainfed agrosystems decreased to 62.82 %

Table 1. Mean KAI of each species in irrigated and rainfed transects in each survey year (2005 and 2020): * species with ≤ 5 contacts.

Tabla 1. *Promedio del índice kilométrico de abundancia de cada especie en los transectos de regadío y secano en los años del estudio (2005 y 2020): * especies con ≤ de 5 contactos.*

	2005				2020			
	Rainfed		Irrigated		Rainfed		Irrigated	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N° transects	47		10		33		24	
Lenght and surface	323.8 km	6,476 ha	48 km	960 ha	233.6 km	4,672 ha	138.2 km	2,764 ha
*Athene noctua**	0.000	0.000	0.000	0.000	0.015	0.083	0.000	0.000
Gyps fulvus	0.000	0.000	0.000	0.000	0.063	0.154	0.000	0.000
*Neophron percnopterus**	0.000	0.000	0.000	0.000	0.002	0.013	0.000	0.000
*Accipiter gentilis**	0.000	0.000	0.000	0.000	0.007	0.040	0.014	0.068
Aquila chrysaetos	0.004	0.028	0.014	0.044	0.025	0.054	0.016	0.059
Aquila pennata	0.036	0.093	0.029	0.090	0.029	0.064	0.028	0.086
Circaetus gallicus	0.008	0.030	0.000	0.000	0.016	0.043	0.006	0.031
Buteo buteo	0.048	0.087	0.042	0.096	0.075	0.110	0.086	0.127
Circus aeruginosus	0.025	0.090	0.057	0.181	0.157	0.210	0.225	0.322
Circus cyaneus	0.042	0.124	0.000	0.000	0.008	0.032	0.000	0.000
Circus pygargus	0.057	0.138	0.000	0.000	0.009	0.036	0.000	0.000
*Milvus milvus**	0.017	0.119	0.000	0.000	0.013	0.043	0.029	0.143
Milvus migrans	0.424	0.883	0.491	1.051	0.331	0.755	0.463	0.754
Falco tinnunculus	0.108	0.126	0.147	0.212	0.100	0.124	0.155	0.153
*Falco naumanni**	0.000	0.000	0.000	0.000	0.043	0.180	0.005	0.027
*Corvus corax**	0.009	0.042	0.000	0.000	0.000	0.000	0.000	0.000
Corvus corone	0.086	0.193	0.014	0.045	0.065	0.114	0.031	0.106
Coleus monedula	0.000	0.000	0.000	0.000	0.092	0.300	0.068	0.331
Pica pica	0.117	0.211	1.221	1.793	0.198	0.405	0.402	0.637
Pyrrhocorax pyrrhocorax	0.165	1.129	0.000	0.000	0.052	0.116	0.042	0.120

(4,672 ha) of the sampled area, while irrigated crops increased to 37.18 % (2,764 ha) (table 1).

During the censuses, we identified 322 specimens of 10 species of raptors and 171 specimens of 4 species of corvids in 2005, and 349 specimens of 15 species of raptors and 191 of 4 species of corvids in 2020. Five of the detected species (4 raptors and 1 corvid) with a low number of contacts (≤ 5) were considered unsuitable for the analysis (table 1).

All the species detected in irrigated areas were also found in rainfed areas, while 6 species were only detected in rainfed zones (table 1). However, only 34 transects were sampled in irrigated areas compared to the 80 in rainfed areas (including both years).

Initial exploratory analysis on species richness and Shannon index reported no significant differences between rainfed and irrigated areas, whereas we found higher species richness and Shannon index in 2020 than in 2005 (fig. 2), although this difference was only observed in the 50 % CI.

On the other hand, Montagu's harrier *Circus pygargus*, hen harrier *Circus cyaneus*, and carrion crow *Corvus corone*, showed higher occurrences in the rainfed transects in both years (50 % CI). Moreover, the short-toed snake eagle *Circaetus gallicus* showed higher occurrences in the rainfed transects in 2005 and griffon vulture *Gyps fulvus* showed higher occurrences in the rainfed transects in 2020 (fig. 3). In contrast, magpie *Pica pica* was the only species with significantly higher occurrence in the irrigated area in both years. The Western marsh harrier *Circus aeruginosus*, common kestrel *Falco tinnunculus* and black kite *Milvus migrans* also showed significantly higher occurrences in the irrigated transects in 2020 according to 50%CI.

Regarding the differences in species occurrence found between 2005 and 2020, we detected a significant (50 % CI) decrease in the occurrence of Montagu's harrier and magpie. The hen harrier also showed a clear negative change, although it was not significant at 50 % CI (fig. 2). The occurrence of other species, such as Western marsh harrier, golden eagle *Aquila chrysaetos*, common buzzard *Buteo buteo*, red kite *Milvus milvus*, griffon vulture, red-billed chough *Pyrrhocorax pyrrhocorax* and Western jackdaw *Coloeus*

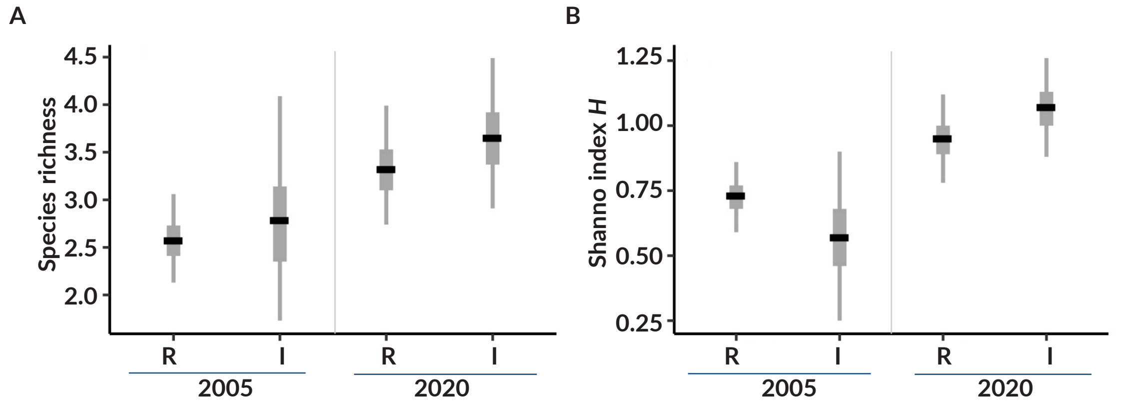

Fig. 2. Effect of irrigation and year on species richness (A) and Shannon index (B). The horizontal black lines show the mean (across all Markov Chain Monte Carlo method iterations), the boxes show the 50 % CI and the vertical lines delineate the 95 % CI. Light gray indicates no differences between rainfed and irrigated areas within a specific year: R, rainfed, I, irrigated.

***Fig. 2.** Efecto del riego y el año en la riqueza de las especies (A) y el índice de Shannon (B). Las líneas negras horizontales indican la media (en todas las iteraciones del método de Montecarlo basado en cadenas de Markov), los cuadros indican el intervalo de confianza (IC) del 50 % y las líneas verticales delimitan el IC del 95 %. El color gris claro indica que no hay diferencias entre las áreas de secano y las de regadío en un año específico: R, secano; I, regadío.*

monedula increased in 2020 compared to 2005 (fig. 2). In the case of black kite, a decrease in its occurrence was observed in rainfed areas while its occurrence increased in irrigated areas.

The rest of the species with more than 5 contacts showed no significant changes in their occurrence (not at 95 % CI or 50 % CI) in relation to land use or year, although they did show slight variations (fig. 2).

Discussion

The 15 species of raptors and 5 species of corvids identified constitute practically all of those species recorded in the area according to the atlas of breeding birds (Molina et al 2022), and the recorded abundance is comparable to that observed in Navarra during the national raptor census (Palomino and Valls 2011) and that in specific corvid monitoring studies (Dean and Ollakindia 2003). These results suggest that the methodology used in the present work is suitable for monitoring relative abundance of these groups of birds, as suggested in several previous studies (Santos and Tellería 1981, Viñuela 1999, Dean and Ollakindia 2003, Sanchez-Zapata et al 2003, Bustamante and Seonae 2004, Cardiel 2006, Palomino 2006, Carrete et al 2009, Zagorski and Swihart 2021).

The initial comparison of the values of specific richness and the Shannon diversity index did not show significant differences between the rainfed and irrigated transects but showed a certain positive trend when comparing the 2005 censuses with those of 2020. These results, in our opinion, are due to the different response of each species to agricultural intensification (Brotons et al 2004, Ursúa et al 2005, Cardador et al 2011, De Frutos et al 2015, Giralt et al 2021, Cabodevilla et al 2022). The reason for this would be opposite trends within species, meaning that the increase in some generalist species could mask the decrease in the more specialist species (Giralt et al 2021), highlighting the need to analyze the response of each species separately. By doing so, we have been able to confirm how, in our study area, the most characteristic raptor species of extensive rainfed agrosystems showed significantly lower occurrences in the irrigated land and a clear decline in their occurrences between 2005 and 2020, while the more generalist species showed a significantly higher presence in the irrigated land and a positive trend.

The most obvious comparison would be that of Montagu's harrier and the hen harrier with the Western marsh harrier, apparently similar species but with a very different response to agricultural intensification. The two former are typical species of pseudosteppes (Brotons et al 2004, Giralt et al 2021) and show great dependence on cereal fields for making their nests and on fallows for searching for food (Arroyo et al 2019), while the marsh harrier is capable of surviving in environments transformed by human action (Cardador and Mañosa 2015). A result of the implementation of irrigation in our study area is that barley and wheat crops have been substituted by set-aside systems for the intensive cultivation of maize, tree orchards and horticultural plants (Government of Navarra 2020). These changes have caused the disappearance of a high-quality habitat for Montagu's harrier and hen harriers, simultaneously favoring the creation of numerous small masses of reeds on the edges of the fields and in the ditches. This change has notably increased the availability of nesting sites for the marsh harrier, which is able to nest in these reed beds regardless of their size (Cardador et al 2011). In addition, the decline in the population of Montagu's harrier and hen harrier in our study area has not been limited to transects transformed into irrigated land, but has also occurred in transects that have been kept as rainfed. This result suggests that the impact of implementing an irrigation system is not limited to transformed land and may have an effect on a larger scale, as confirmed in various steppe species in the study of Giralt et al (2021). This situation has not been exclusive to our region, and has occurred in a large part of the Iberian Peninsula (Brotons et al 2004, Santangeli et al 2014, Giralt et al 2021, Cabodevilla et al 2022) and even at a European level (Arroyo et al 2002, Koks and Visser 2002), being reflected in a highly significant decrease in Montagu's harriers and hen harriers (Arroyo et al 2019, Birdlife 2023) and in a simultaneous increase in marsh harriers (Torralvo and Justo 2022, Birdlife International 2023).

The situation observed for the rest of the generalist raptor species, such as the black kite, the common buzzard and the common kestrel, was similar to that experienced by the marsh harrier, with a greater presence detected on irrigated transects and an increase in their occurrences between 2005 and 2020. In our opinion, this result could reflect, on the one hand, the great adaptability of these species to degraded environments, even those with a high human presence; they are able to nest on the periphery of towns (Bustamante and Seoane 2004) or within urban areas (Riegert et al 2010), while they also benefit from the greater abundance of rodents in irrigated land (Jareño et al 2015) Nevertheless, we should be cautious when interpreting this apparent positive effect of implementing irrigation we observed because previous studies carried out in the same region have found the opposite response, that is, a negative effect on the presence of black kite and common kestrel, and a neutral effect on the presence of common buzzard (Cabodevilla et al 2022). Interpretation of the census results could be improved with a more direct design of censuses, with control transects more separated from each other and not interspersed within the area transformed into irrigated land (Tellería 1986), and with more information about other factors such as the presence of landfills (Blanco et al 2003) and nest boxes (Paz-Luna et al 2020) in the area.

In the case of corvids, it is surprising that the most typical species of pseudo-steppe environments, such as the red-billed chough (Blanco et al 2022a), have significantly increased in occurrence in line with the increase in irrigation. This species depends on fallows and low grasslands to find food (Blanco et al 1998), so, a priori, reduction of these habitats due to the establishment of irrigation should pose a negative effect. However, irrigated crops suffer from increases in the abundance of rodents that may be agricultural pests (Jareño et al 2015) which, in our study area, are controlled by installing artificial nests for barn owls *Tyto alba* (Paz-Luna et al 2020), and these nests are also used by red-billed choughs (Villanúa et al 2023). Given that the availability of safe nesting points is an important limiting factor for this species (Banda and Blanco 2009), the installation of nesting boxes in the newly irrigated lands could be enabling this unexpected increase in the occurrence of the species in an, a priori, unfavorable habitat.

The other corvid species detected are considered more generalist and adaptable, so it may be expected that they would better tolerate a change in their habitat as profound as the transformation into an irrigated area. However, not all species showed the same response to irrigation. The magpie showed higher occurrences in the irrigated transects than in the rainfed transects, which corresponds with data recorded in the Atlas of Reproductive Birds of Spain (Molina-Morales and Martínez 2022). Therefore, it could be expected that the increase in irrigated area between 2005 and 2020 should have favored this species. However, the censuses have shown a significant decrease in magpie, a finding coinciding with the work of Cabodevilla et al (2022), who verified how the establishment of a new irrigation area caused a significant decrease in the occurrences of a high number of species, including this one. This suggests that the decrease in their occurrence, rather than being caused by the transformation into irrigated land, could be caused but by some other factor that has not been identified. In the case of the carrion crow, the results were more consistent, with a significantly higher occurrence in the rainfed transects and a lower occurrence in the irrigated areas, which coincides with the situation described by Cabodevilla et al (2022) in Navarre, by Arce (2022) for the whole of Spain, and in general at a European level (BirdLife International 2023). Despite being a species with high adaptability capable of occupying humanized environments and even cities (Arce 2022), this crow needs grasslands or fallows less than 15 cm high to search for food (Randler 2007), a generally scarce habitat in intensive irrigated crops. In addition, the establishment of irrigation often entails the removal of trees on the edges (Petit and Firbank 2006), trees that are needed by the carrion crow to establish its nests (Arce 2022), thus creating another limitation for this species.

Finally, the Western jackdaw has shown a significant increase in its occurrence between 2005 and 2020 both in the dry land and irrigated transects. This improvement contrasts with the more general data that reflects a sharp decline in their populations in Spain (Frías et al 2022), reaching a 75 % decline in certain areas in just over 20 years (Blanco et al 2022b). As in the case of the red-billed chough, the increase detected in our area could be due to the local effect of the installation of artificial nests for birds of prey, nests that are also used by Western jackdaws (Dulisz et al 2022). This local management could offset the decline in populations at a general level.

In summary, our work has revealed the response to the establishment of irrigation by the species of raptors and corvids present in a traditional extensive rainfed agrosystem in southern Europe. Our observations highlight how the most threatened and specialized raptors are negatively affected by irrigation while the more generalist and, in general, more common species, are less affected and even benefit from these installations. For this reason, monitoring programs prior to the establishment of new irrigation systems should focus on the most characteristic birds of prey and corvids of cereal agrosystems, leaving aside the positive effects of agricultural changes in on species that are equally protected, but less threatened.

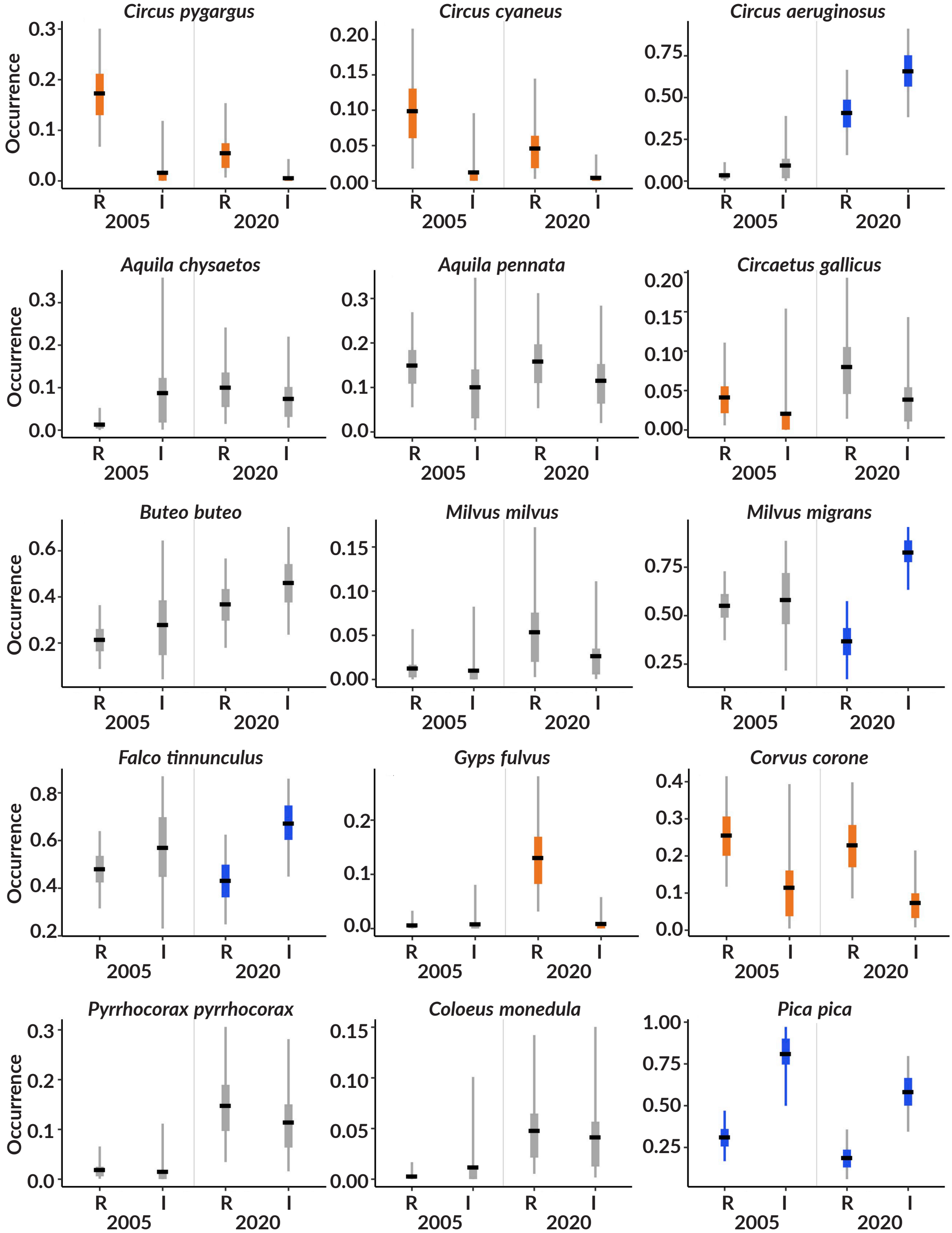

Fig. 3. Effect of irrigation and year on the occurrence probability of each species. The horizontal black lines show the mean (across all Markov Chain Monte Carlo method iterations), the boxes show the 50 % CI and the vertical lines delineate the 95 % CI. Light gray indicates no differences, orange indicates higher occurrence probabilities in rainfed areas, while blue indicates higher occurrence probabilities in irrigated areas. Orange or blue boxes with a gray vertical line indicate weak differences: R, rainfed, I, irrigated.

Fig. 3. *Efecto del riego y el año en la probabilidad de presencia de cada especie. Las líneas negras horizontales indican la media (en todas las iteraciones del método de Montecarlo basado en cadenas de Markov), los cuadros indican el intervalo de confianza (IC) del 50 % y las líneas verticales delimitan el IC del 95 %. El color gris claro indica que no hay diferencias, el naranja indica una mayor probabilidad de presencia en la superficie de secano y el azul indica una mayor probabilidad de presencia en la superficie de regadío. Los cuadros naranjas o azules con una línea vertical gris indican una diferencia débil: R, secano; I, regadío.*

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Author contributions
D. Villanúa and J. Ardaiz designed the monitoring protocol. D. Villanúa, J. Ardaiz and A. Lizarraga performed fieldwork. Statistical analyses were performed by A. Zuñarre and X. Cabodevilla carried out the statistical analyzes. D. Villanúa wrote initial draft of the manuscript. All authors participated equally in the discussion and preparation on the final version of the manuscript.

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