Potential effects of avian predators on the behaviour of the Little Bustard *Tetrax tetrax* during the display season in a cereal pseudo-steppe

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The Little Bustard *Tetrax tetrax* is an endangered steppe bird whose last remaining breeding populations in Catalonia (NW Spain) are located in the Lleida plains. Although the decline in this population is mainly associated with habitat loss and degradation due to agricultural intensification and urban encroachment, the proliferation of predators, some favoured by humans, may also be having negative effects on this population, either through direct predation or indirect effects on behaviour and survival. Here, we describe the type of behavioural response exhibited by Little Bustards during the display season when they encounter a potential avian predator and discuss the possible indirect effects of these interactions. During counts carried out in the springs of 2010–2022 in three Special Protection Areas in the Lleida plains, 88 encounters between Little Bustards and eight species of avian predators were recorded. Among them, the Western Marsh Harrier *Circus aeruginosus,* Montagu's Harrier *C. pygargus* and the Yellow-legged Gull *Larus michahellis* were the most frequent species involved in these encounters, although only the Yellow-legged Gull conducted deliberate attacks in a consistent way. Irrespective of the predator or its attitude, most encounters resulted in the Little Bustard being flushed. The number of encounters were higher at the beginning of the mating season, which may prevent Little Bustards from settling in otherwise suitable areas of habitat. The flushing of the bustards may increase the risk of collision with power lines and reduce mating success. Since the number of encounters between Yellow-legged Gulls and Little Bustards seems to have increased in recent years in the study area, we believe that there is a need to conduct further studies to understand how these interactions affect the population dynamics and conservation of this endangered species.

Key words: *Tetrax tetrax*, Little Bustard, farmland intensification, indirect predator-prey interactions, Lleida plain.

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The Little Bustard *Tetrax tetrax* is a ground-nesting bird that inhabits pastures, steppes and herbaceous croplands from Western Europe to Western China (Morales & Bretagnolle 2022a). A recent review of its population status and trends have detected alarming declines

throughout the world (Morales & Bretagnolle 2022b). In Iberia, the stronghold of the European population, Little Bustard populations have decreased by c.50% of breeding males in the past 10 years (García de la Morena *et al.* 2018, Silva *et al.* 2018). In Catalonia, this bustard is found in the Lleida plains, where its population has experienced a similar decline over the past two decades (Cuscó *et al.* 2021a). It is listed as Vulnerable in Europe and as Near Threatened on a global scale (BirdLife International 2018), and has recently been upgraded from Vulnerable to Endangered on the official catalogue of Spanish birds (Ministerio para la Transición Ecológica y el Reto Demográfico 2023). Agricultural intensification (Iñigo & Barov 2010, BirdLife International, 2018, Traba & Morales 2019, Mañosa & Morales 2021, Silva *et al.* 2022) and urban and industrial development (Arroyo *et al.* 2022, Silva *et al.* 2022) are regarded as the main drivers of this decline. These anthropogenic factors result in partial or complete habitat loss and a reduction in habitat carrying capacity, leading to a sharp decrease in reproductive success and/or survival (Lapiedra *et al.* 2011, Cuscó *et al.* 2021b, Marcelino *et al.* 2018). Although human-induced mortality (illegal hunting or collisions with power lines) may in some cases be responsible for reducing survival rates to below unsustainable levels, predation is in fact the main source of mortality in the Little Bustard (Marcelino *et al.* 2018). However, the effects that predators have on this species may go beyond direct mortality given that the presence of predators may induce changes in bustards' behaviour (Lima 1998, Cresswell 2008), with additional indirect consequences on population dynamics (Cresswell 2011, Voelkl *et al.* 2016). Such indirect effects include birds being disturbed from feeding, resting, displaying or any other activity, or being forced to move, all of which will entail associated energy costs, unexpected risk of mortality (collisions, exposure to other predators) and greater stress levels (Tarjuelo *et al.* 2015, Tarjuelo *et al.* 2022). Agricultural intensification and urbanisation may also be associated with increases in the populations of anthropophilic and opportunistic predators (e.g. Cardador *et al.* 2011), so the potential for disturbance caused by these predators will probably have increased in recent years. However, very little attention has been devoted to analysing the potential indirect effects of the presence of potential predators on the behaviour of Little Bustards. Our objective here is to describe the type and frequency of behavioural interactions between Little Bustards and avian predators during the display season in the Lleida plains and to discuss the possible indirect effects of these interactions on the conservation of this endangered bird.

Material and methods

The study was carried out in three Special Protection Areas (SPAs) designated for steppe-bird conservation in the Lleida Plains: Secans de Belianes-Preixana, Secans de Bellmunt and Secans de Plans de Sió (Mañosa *et al.* 2021). Within each of these protected areas, 1–4 sampling areas covering a total of 12 359 ha (Fig. 1) were selected, in which counts of breeding males were conducted. From 2010–2022, in each of these sampling areas, car-counts were conducted on spring mornings (mid-April to mid-May) Little Bustard (see Tarjuelo *et al.* 2017). Most counts (96%) were conducted by the same single observer (RG). On each session, the date and week of the year, the duration of the count (hours) and the number of Little

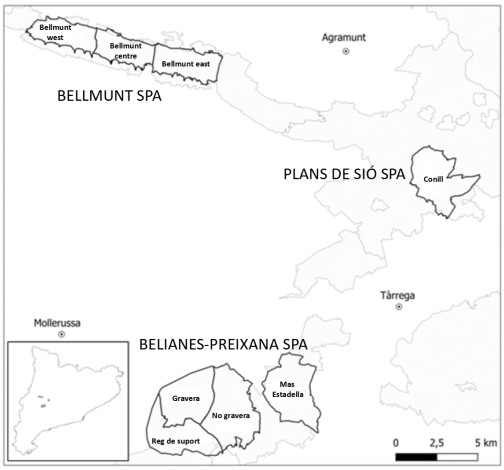

Figure 1. Location of the eight study areas in Catalonia (inset). Shaded areas indicate the limits of the Special Protection Area (SPA). The location of several major towns is shown for reference.
Localització de les vuit àrees *d'estudi a Catalunya (requadre). Les zones ombrejades indiquen els límits de l'àrea de protecció especial (ZEPA). La ubicació de diverses ciutats importants es mostra com a referència.*

Bustards detected were recorded. Each time a Little Bustard was detected, its location (latitude and longitude), time of day, sex and number of birds detected were recorded. When a potential encounter with an aerial predator was observed (i.e. when a Little Bustard and a predator were observed in close proximity), (i) the number of individuals of the predator involved, (ii) the behaviour of the predator – recorded as passive (no approach to the Little Bustard) or active (diving or persistently harrying the Little Bustard) – and (iii) the reaction of the Little Bustards in response to the presence of a potential predator – from less to more elusive, no response, alert (raising the head and watching, or hiding in the vegetation but not flushing) or flushing – were also recorded. An encounter was classified as an actual interaction if it involved any active behaviour by the predator or elicited a response in the Little Bustards (either alert or flush). Although some encounters involved more than one Little Bustard (average = 1.5; min = 1, max = 5), all individuals within a group were considered as non-independent, so we treated each group as a single encounter event. The Little Bustard reaction assigned to each event was rated according to the highest elusive response observed in the group. However, in all but one encounter, all Little Bustards in a group reacted in the same way.

Statistical analyses

To analyse the spatial and temporal changes in the occurrence of encounters, the relative number of encounters (nº of encounters/hour·100 little bustard) was calculated for each counting session and sampling area. We used permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001, 2017) to test for differences in the relative frequency of encounters between SPA, sampling areas, three-year periods and weekly trends. Grouping by three-year periods (2010–2013, 2014–2016, 2017–2019 and 2020–2022) was used because the large number of zeros prevented analyses on a yearly basis. All these factors were considered

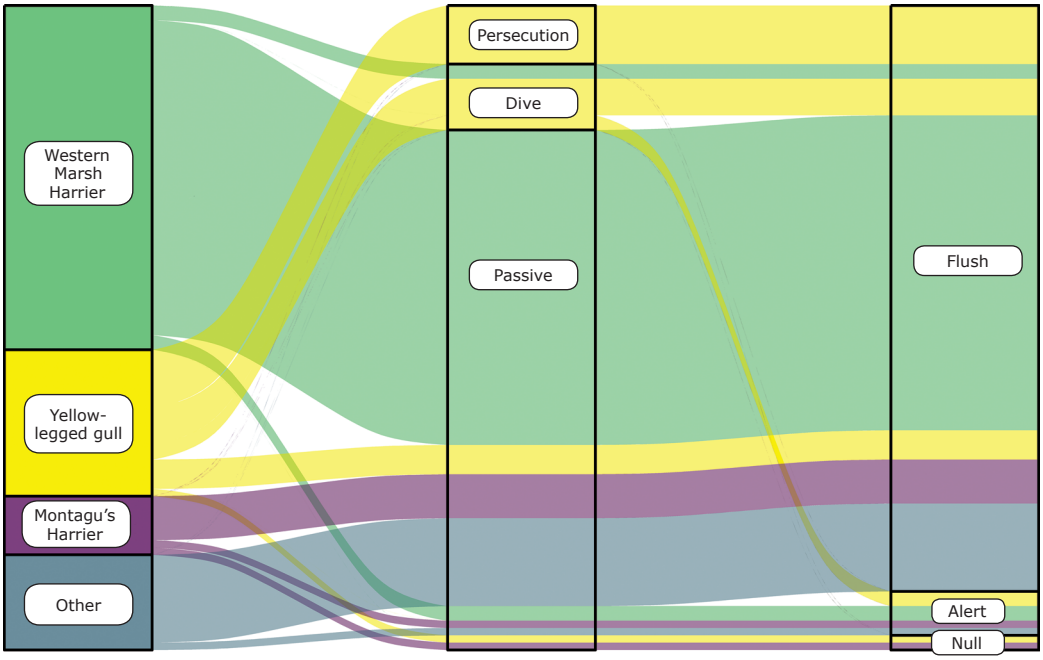

Figure 2. Diagram classifying the 88 encounters between Little Bustards and several aerial predators recorded during the Little Bustard male counts in the Lleida Plains between 2010–2022, showing the predator (left-hand column), its attitude (middle column) and the reaction of the Little Bustards (right-hand column).
Diagrama que mostra la classificació de les 88 trobades entre sisons i diversos depredadors alats enregistrades durant els recomptes de mascles de sisó a la plana de Lleida entre 2010-2022, agrupades en funció de l'espècie (columna esquerra), la seva actitud (columna central) i la reacció dels sisons (columna dreta).

Table 1. Classification of the 88 encounters between Little Bustards and aerial predators recorded during the male counts in the Lleida Plains in 2010–2022 by predator, its attitude and the reaction of the Little Bustards. *Classificació de les 88 trobades entre sisons i diversos depredadors alats enregistrats durant els recomptes de mascles de sisó a la plana de Lleida entre 2010-2022, agrupats en funció de l'espècie, la seva actitud i la reacció dels sisons.*

		Little bustard response			TOTAL
		Null	Alert	Flush	
Western Marsh Harrier	Passive	0	2	43	**45**
	Dive	0	0	2	**2**
	Persecution	0	0	0	**0**
Yellow-legged Gull	Passive	1	0	4	**5**
	Dive	0	2	5	**7**
	Persecution	0	0	8	**8**
Montagu's Harrier	Passive	1	1	6	**8**
	Dive	0	0	0	**0**
	Persecution	0	0	0	**0**
Other	Passive	0	1	12	**13**
	Dive	0	0	0	**0**
	Persecution	0	0	0	**0**
TOTAL		2	7	79	**88**

as fixed effect factors, with sampling area nested in SPA but crossed with period and week. Due to the empty cells, neither triple interactions nor double interactions with the week factor were considered. All analyses were performed using the software PRIMER 7 with PERMANOVA+ (Anderson *et al.* 2008), choosing n = 9999 permutations. Figure 2 layered alluvial plot was created with 'ggplot2' in R package (Brunson & Read 2023).

Results

A total of 8933 Little Bustards (90% males, 10% female types) were recorded during 1572.73 counting hours in 367 sessions, during which 88 encounters with avian predators (Table 1) were reported (0.06 encounters/hour). These encounters involved 112 male and 18 female Little Bustards and eight avian predator species, namely, Western Marsh Harrier *Circus aeruginosus* (47 interactions), Yellow-legged Gull *Larus michahellis* (20), Montagu's Harrier *Circus pygargus* (8), Black Kite *Milvus migrans* (6), Common Buzzard *Buteo buteo* (3), Red Kite *Milvus milvus* (2), European Honey-Buzzard *Pernis apivorus* (1) and Golden Eagle *Aquila chrysaetos* (1). On most occasions (98%), encounters resulted in some type of interaction, of which 80% involved passive behaviour from the predator and 20% deliberate attacks. The

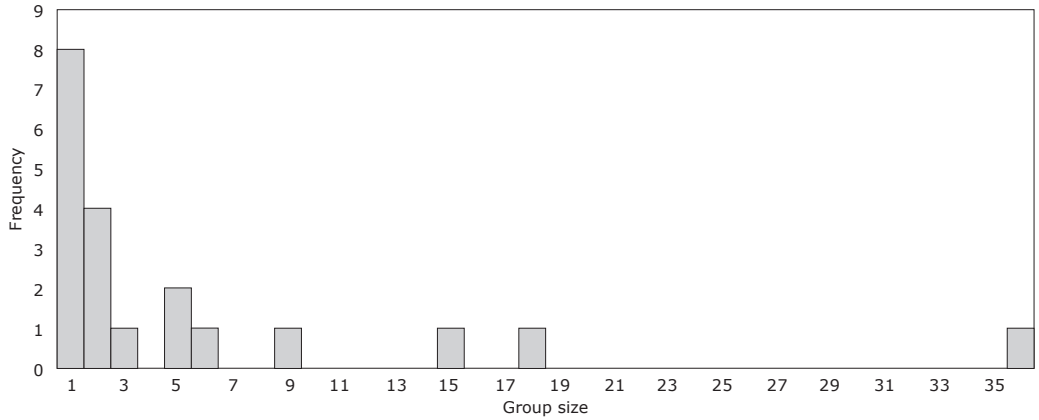

Figure 3. Distribution of the size of Yellow-legged Gulls groups involved in encounters. *Distribució de la mida del grup de gavians de potes grogues implicats en les interaccions.*

latter consisted of either single dives, recorded in the Western Marsh Harrier (4% of all Western Marsh Harrier encounters) and Yellow-legged Gull (35% of all Yellow-legged Gull encounters), or persistent persecutions (40% of all Yellow-legged Gull encounters). Most encounters (98%) produced a reaction in the Little Bustards. Passive encounters produced no response in 3% of cases, alert behaviour in 6% and flight in 91%, while deliberate attacks always produced a response, either alert behaviour (12%) or flushing (88%) (Fig. 2). Most Yellow-legged Gull encounters involved groups of gulls (60%), usually pairs (four cases), but also groups of 3–36 individuals (Fig. 3), while encounters with other species always involved single birds, except in one case, where a Western Marsh Harrier pair was involved.

PERMANOVA analyses showed no differences in encounter rates for any factor (SPA, sampling area, three-year period and week, main effects or interactions) in the case of the Western Marsh Harrier. In the case of the Montagu's Harrier, significant differences were only detected between sampling sites ($P = 0.044$), the frequency of encounters being higher in West Bellmunt (Fig. 5 and Fig. 6). Finally, in the case of the Yellow-legged Gull, significant differences were found between sampling sites ($P = 0.034$), triennia ($P = 0.013$) and weeks ($P = 0.009$), with the interaction between three-year periods and week also being significant ($P = 0.016$),

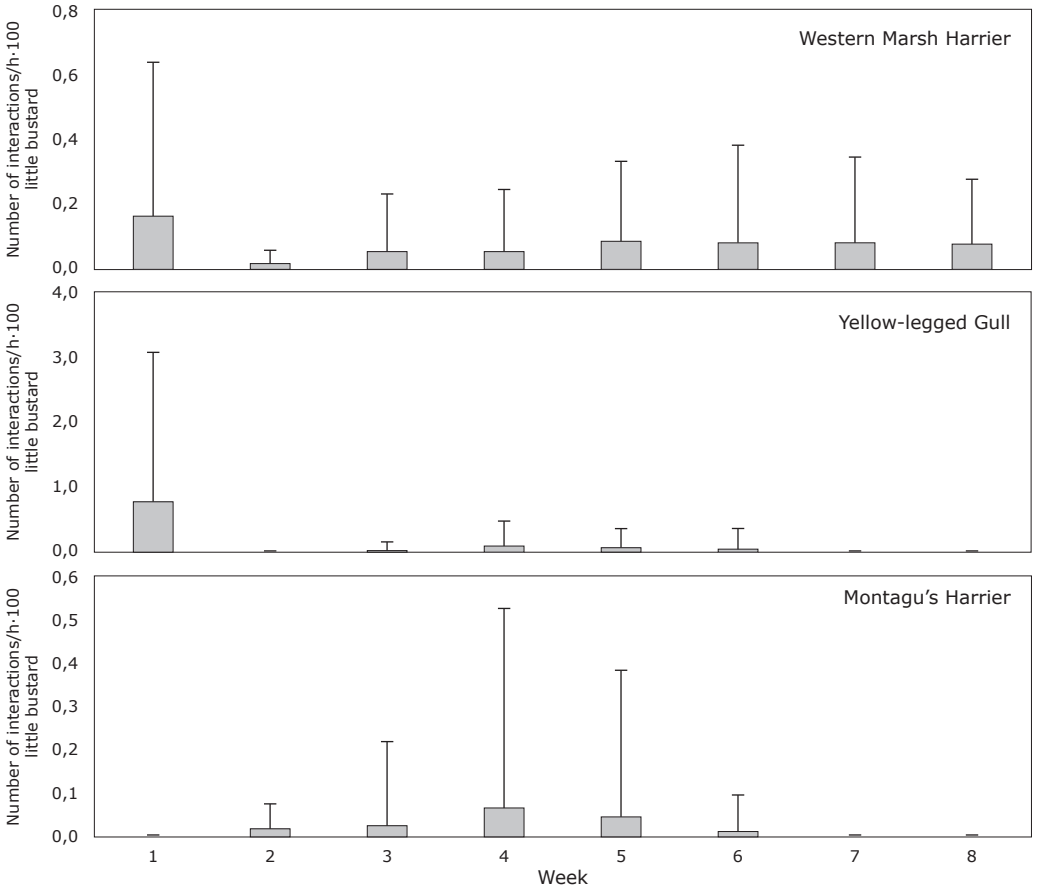

Figure 4. Frequency of interactions per 100 Little Bustards (mean and standard deviation) with the three main aerial predators recorded in the study areas in each week (1 = first week of April, 2 = second week of April etc., until 8 = fourth week of May).
Freqüència d'interaccions per cada 100 sisons i hora d'observació (mitjana i desviació típica) amb els tres principals predadors alats de les àrees *d'estudi segons la setmana (1: primera setmana d'abril, 2: segona setmana d'abril, i així succesivament fins a 8: quarta setmana de maig).*

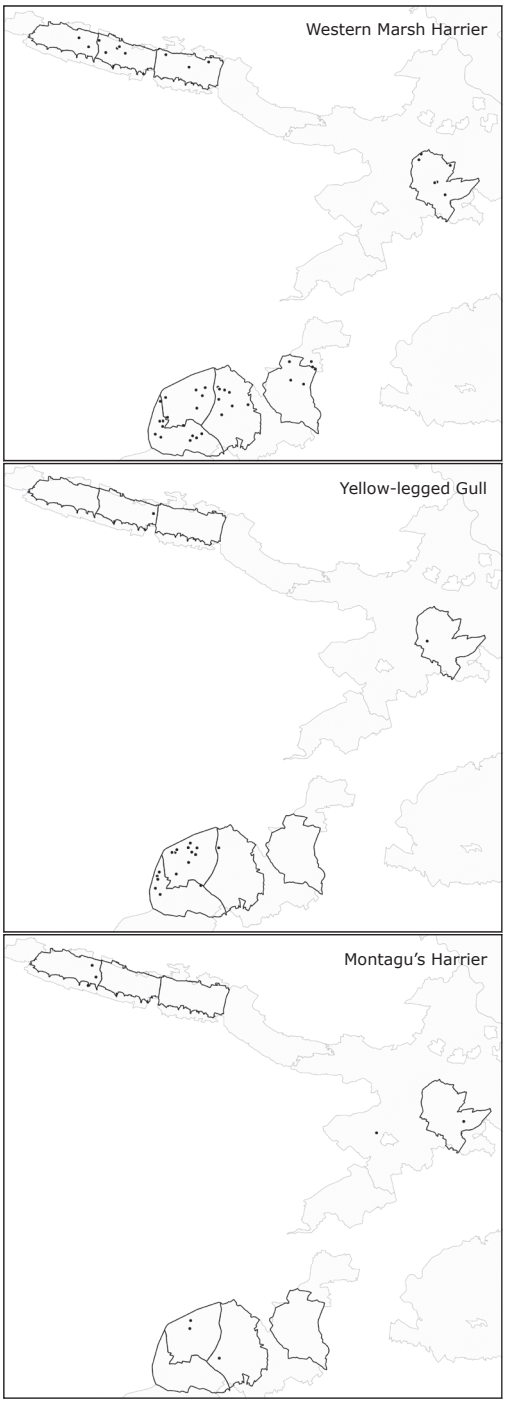

Figure 5. Spatial distribution of Little Bustard encounters with the three main aerial predators in the study area.
Distribució espacial dels encontres entre els sisons i les tres principals espècies de depredadors alats a l'àrea d'estudi.

indicating that the weekly trend in the number of interactions may change between years. The frequency of Yellow-legged Gull encounters was higher in Reg de Suport and Gravera (Fig. 5 and Fig. 6), in the final two three-year periods (Fig. 7) and in the first week of the season (Fig. 4).

Discussion

The interactions between avian predators and Little Bustards involved the three commonest medium-to-large aerial predator species present in the study area: Western Marsh and Montagu's Harriers, and Yellow-legged Gulls. All three are species with a characteristic flight-searching strategy, which explains why other avian predators that are also common in the study area (e.g. Common Buzzard), which use a sit and wait strategy, were not involved in so many encounters. Although the interactions with kites were infrequent during our study, they may increase in importance as the breeding and wintering populations of kites increase in the study area (Franch *et al.* 2021). All of these species are potential and efficient egg predators and the Montagu's Harrier has been reported to prey on Little Bustard eggs (Corbacho *et al.* 2005). Although we have not witnessed any actual predation on Little Bustards by any of these species, the Western Marsh Harrier and the Yellow-legged Gull are both powerful opportunistic predators that include birds as part of their diets (e.g. Cardador *et al.* 2012, Méndez 2020) and could kill a Little Bustard adult or chick. Although we have detected Western Marsh Harriers feeding on fresh Little Bustard carcasses, we have never recorded any actual predation on adult bustards. Yellow-legged Gull attempted to attack Little Bustards, so we cannot rule out the possibility that actual mortality due to gull predation may take place.

Irrespective of the species, these encounters usually result in direct interactions, which in most cases consists of the Little Bustard's being flushed. During the daily peak of activity in the display season, Little Bustard males devote most of their time (78%) to vigilance (Bretagnolle *et al.* 2022), indicating that this species has an innate preventive response to the presence of predators based on vigilance and escape. It is difficult to evaluate at this stage the real impact of the reported interactions with the Little Bus-

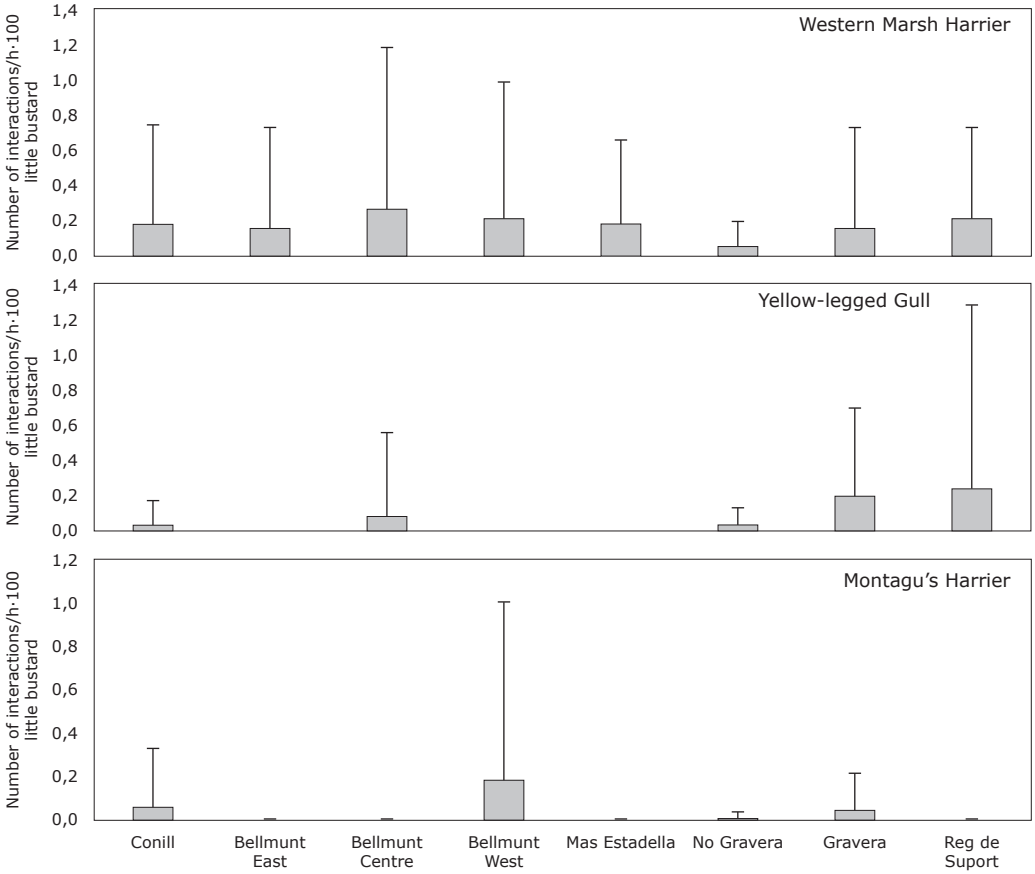

Figure 6. Frequency of interactions per 100 Little Bustards with the three main aerial predators (mean and standard deviation) in the different sectors sampled.
Freqüència d'interaccions per cada 100 sisons i hora d'observació (mitjana i desviació típica) *en els diferents sectors mostrejats amb els tres principals predadors alats.*

tard population in the area. Although deliberate attacks were only frequent when Yellow-legged Gulls were involved in the encounters, our results indicate that Little Bustards do not show any evident discrimination in their responses to predators and that they flush irrespective of whether or not the predator behaves aggressively. As female Little Bustards tend to nest and brood within the territories of displaying males (Morales *et al.* 2013), it remains to be seen whether this flushing behaviour is a simple escape reaction or a distraction tactic aimed at protecting nests or chicks from predation. In the case of males, this behaviour would represent parental investment and could change our understanding of the mating system of the Little Bustard (see Bretagnolle *et al.* 2022). Whatever the case, the Little Bustard has been shown to be very sensitive to stress derived from other types of disturbances (Tarjuelo *et al.* 2015) and predator disturbance is likely to cause similar stress. Although the estimated cumulative number of interactions resulting in reaction by Little Bustards (considering a 12 daylight hours/day) only reaches an estimated 0.70 interactions per day in the study area, the potential effect might not be negligible. Given that many Yellow-legged Gull interactions take place at the beginning of the display season, Little Bustards may be prevented from settling in otherwise good breeding areas by the presence of gulls. In our study area, this could reduce the effectivity of the set-aside fallow conservation practices launched in recent years that aim to counterbalance the decline

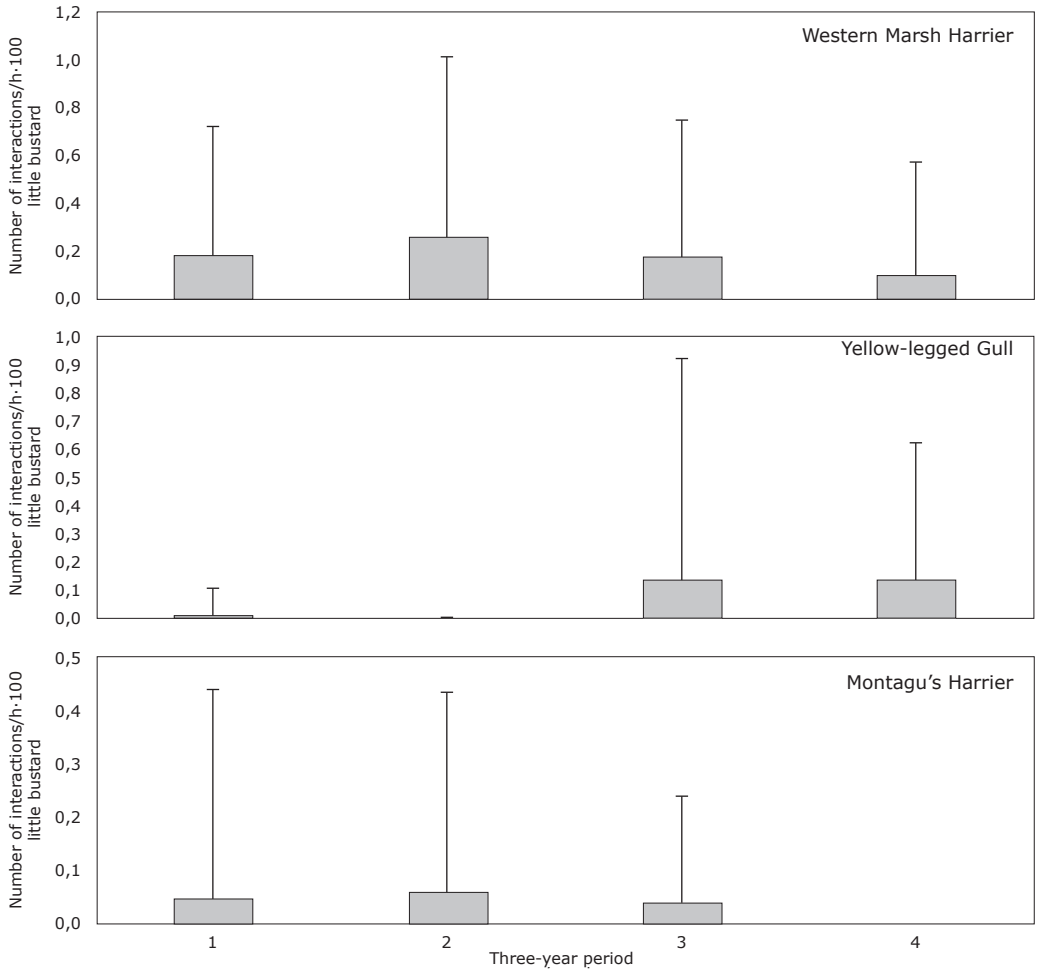

Figure 7. Frequency of interactions per 100 bustards per hour (mean and standard deviation) with the three main aerial predators recorded in the study areas in each three-year period.
Freqüència d'interaccions per cada 100 sisons i hora d'observació (mitjana i desviació típica) *al llarg dels quatre triennis per a cadascun del tres depredadors alats.*

of the bustard population (Mañosa *et al.* 2021, Mañosa & Bota 2023). The presence of aerial predators increases the flight frequency of Little Bustard males, as has been reported for other types of disturbances (Casas *et al.* 2009). Uncontrolled flushing elicited by the presence of aerial predators could increase the risk of collision with power lines, to which the little bustard is very vulnerable (Marcelino *et al.* 2018). Moreover, during the daily peak of activity in the display season, Little Bustard males devote most of their time to vigilance and only 13% to foraging, 5.6% to displaying and 1.6% to preening (Bretagnolle *et al.* 2022). Any reduction in the time devoted to these maintenance or reproductive activities may have potential consequences for condition or mating success.

The populations of the main avian predators involved in these encounters have increased in the area over the past two decades (Franch *et al.* 2021). However, only the number of interactions with Yellow-legged Gulls has increased in recent years. This difference is probably linked to the local distribution of and habitat selection by these predators in the study area, and need to be investigated further. In particular, the growing presence of the Yellow-legged Gull in the Lleida plains, probably associated with the

presence rubbish dumps, new wetlands (Estany d'Ivars i Vila-sana) and artificial water bodies (irrigation ponds as part the Segarra-Garrigues irrigation system), may have indirect consequences on the conservation of steppe birds such as the Little Bustard. Our study suggests that further research is needed to understand the potential consequences of the described interactions for the Little Bustard population in the Lleida plains.

Resum

Efectes potencials de la presència de depredadors alats sobre el comportament del sisó *Tetrax tetrax* durant la temporada d'aparellament en una pseudoestepa cerealista

El sisó *Tetrax tetrax* és un ocell estepari en perill d'extinció que té les seves últimes poblacions reproductores a Catalunya a la plana de Lleida. Tot i que el declivi d'aquesta població és causat per la pèrdua d'hàbitat i la degradació derivada de la intensificació agrícola i la urbanització, la proliferació de depredadors, alguns d'ells propiciats pels humans, també pot tenir efectes negatius sobre la població, ja sigui per depredació directa o pels efectes indirectes sobre diversos aspectes del comportament i la supervivència dels sisons. En aquest treball descrivim el tipus de resposta conductual desenvolupada pels sisons durant la temporada d'aparellament quan es troben amb un potencial depredador alat i discutim els possibles efectes indirectes d'aquestes interaccions. Durant els censos de sisó realitzats a la primavera entre 2010–2022 a tres zones ZEPA de la plana de Lleida es van registrar 88 encontres amb 8 espècies diferents de depredadors alats. L'arpella vulgar *Circus aeruginosus*, el gavià de potes grogues *Larus michahellis* i l'arpella cendrosa *Circus pygargus* van ser les espècies implicades amb més freqüència en les interaccions, però només el gavià va dur a terme atacs deliberats de manera consistent. Independentment del depredador o de la intenció, la majoria de les trobades van derivar en una reacció de fugida de part del sisó. El nombre de interaccions amb el gavià sembla ser més gran a l'inici de l'època d'aparellament, cosa que pot impedir que els sisons ocupin zones d'hàbitat adequades. L'envol precipitat dels sisons també podria augmentar el perill de col·lisió amb les línies elèctriques i podria interferir en l'èxit d'aparellament. Atès que el nombre d'interaccions entre els gavians i els sisons sembla estar augmentant en els darrers anys, plantegem la necessitat d'estudiar amb més detall les possibles conseqüències d'aquest fenomen sobre la dinàmica poblacional i la conservació d'aquesta espècie amenaçada.

Resumen

Efectos potenciales de la presencia de depredadores alados sobre el comportamiento del sisón *Tetrax tetrax* durante la temporada de apareamiento en una pseudoestepa cerealista

El sisón *Tetrax tetrax* es un ave esteparia en peligro de extinción cuyas últimas poblaciones reproductoras en Cataluña se encuentran en los llanos de Lleida. Aunque la disminución de esta población es causada por la pérdida de hábitat y la degradación derivada de la intensificación agrícola y la urbanización, la proliferación de depredadores, algunos de ellos favorecidos por los humanos, también podría tener efectos negativos sobre la población, ya sea a través de la depredación o por los efectos indirectos sobre varios aspectos del comportamiento y supervivencia de los sisones. Nuestro objetivo es describir el tipo de respuesta conductual desarrollada por los sisones durante la temporada de cortejo cuando se encuentran con un potencial depredador alado y discutir los posibles efectos indirectos de estas interacciones. Durante los recuentos de sisón realizados en las primaveras de 2010–2022 en tres zonas ZEPA de los llanos de Lleida se registraron 88 encuentros con 8 especies diferentes de depredadores alados. El aguilucho lagunero occidental *Circus aeruginosus*, la gaviota patiamarilla *Larus michahellis* y el aguilucho cenizo *Circus pygargus* fueron las especies involucradas con mayor frecuencia en las interacciones, pero solo la gaviota patiamarilla realizó ataques deliberados de manera consistente. Independientemente del depredador o la intención, la mayoría de los encuentros derivaban en una reacción de huída por parte del sisón. El número de interacciones con gaviotas parece ser mayor al comienzo de la temporada de apareamiento, lo que puede impedir que el sisón ocupe áreas de hábitat que de otro modo serían adecuadas. El vuelo precipitado provocado por los depredadores podría aumentar el peligro de colisión con líneas eléctricas y también interferir en el éxito de apareamiento. Dado que el número de interacciones entre la gaviota patiamarilla y el sisón parece estar aumentando en los últimos años en el área de estudio, planteamos la necesidad de estudiar con más detalle las posibles consecuencias de este fenómeno sobre la dinámica poblacional y la conservación de esta especie amenazada.

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