Breeding in an agricultural landscape: conservation actions increase nest survival in a ground-nesting bird

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Abstract Agricultural intensification has affected wildlife across Europe, triggering steep declines and regional extinctions of farmland birds. Effective conservation activities are essential for the preservation of biodiversity in an agricultural landscape, but current efforts have not succeeded in halting these declines. Here we investigate a ground-nesting shorebird, the collared pratincole *Glareola pratincola*, which has shifted its habitat use in Central Europe over the last 20 years from alkaline grasslands to intensively managed agricultural fields. We show that nesting success was different between three agricultural habitat types, with the highest nesting success in fallow lands and the lowest in row crops. Nesting success was also associated with the timing of breeding and breeding density, as nests produced early in the breeding season and those in high-breeding-density areas hatched more successfully than those produced later in the season and at low density. We implemented direct conservation measures including marking nests and negotiating with farmers to avoid cultivating the field between nest markers, controlling nest predators and, most recently, creating suitable nesting sites and foraging areas for pratincoles. As a result of these conservation actions, nest survival increased from 11.2% to 83.5% and the size of the breeding population increased from 13 to 56 pairs during 2012–2021. Thus, we show that agricultural landscapes can continue to provide suitable habitats, and targeted conservation actions have the potential to reverse the declines of farmland species.

Keywords Agricultural land use, conservation action, farmland birds, *Glareola pratincola*, nest survival, predator control, shorebirds, waders

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Introduction

Natural habitats are disappearing or degrading at global scales and at an unprecedented rate as a result of the combined effects of current climatic processes and changes in land use during the Anthropocene (Fahrig, 1997; Balmer & Erhardt, 2000; Davidson, 2014; Hu et al., 2017). One of the main driving factors is the expansion of intensive forms of agricultural land use, which has led to the reduction and sometimes even complete disappearance of various native habitats across Europe (O'Connor & Shrubb, 1986; Potter, 1997). These declines are especially severe amongst grassland breeding animals that are considered to be sensitive to environmental changes, as evidenced by recent steep declines of steppe species (Fuller, 2000; Massa & La Mantia, 2010; Ward et al., 2010; Guerrero et al., 2012). As a consequence of the loss of grassland habitats, birds that traditionally bred in open natural habitats now increasingly breed on arable land and in agricultural areas (Galbraith, 1987; Böhning-Gaese & Bauer, 1996; Brady & Flather, 1998).

However, agricultural landscapes can lead to mal-assessment in habitat choice as they appear suitable to prospective breeders but the conditions they offer often result in inferior reproductive success (Székely, 1992), and thus they may be ecological traps (Schlaepfer et al., 2002; Robertson & Hutto, 2006; Pärt et al., 2007; Gilroy et al., 2011; Hollander et al., 2017). Additionally, the intensification of agricultural practices can affect the nesting success of ground-breeding birds in numerous ways, including direct loss of nests, chicks and/or adults through mowing, cultivation by agricultural machinery, use of pesticides, irrigation and/or drainage (Berg et al., 1992; Wilson et al., 2005; Kentie et al., 2013). There are numerous examples of the negative affects of agriculture on ground-breeding birds, including local extinctions of flagship species such as the great bustard *Otis tarda* and grey partridge *Perdix perdix* (Donald et al., 2001; Arroyo, et al., 2002; De Leo et al., 2004; Alonso & Palacín, 2010; Potts, 2012; Gooch et al., 2015). These pressures on farmland birds have intensified as a result of global climate change, which has amplified predation rates in human-modified habitats. Specifically, environmental changes have boosted the populations of mesopredators, which have further reduced the nest or offspring survival rates of ground-breeding birds (Roodbergen et al., 2012; Kentie et al., 2015; Kubelka et al., 2018; Brzeziński et al., 2020). To mitigate these negative effects, targeted conservation actions are needed (Arroyo et al., 2002; Schekkerman et al., 2008; Zámečník et al., 2018).

Here we report the results of a 10-year conservation effort focused on the collared pratincole *Glareola pratincola*, which is affected by habitat alterations and has undergone population declines across many parts of Europe (Yuri et al., 2020). The collared pratincole is a ground-nesting shorebird that used to breed in loose colonies on alkaline grasslands close to wetlands in Central Europe (Cramp & Simmons, 1983), and a large inland breeding population existed in Hungary until the mid 1900s (Aradi, 1979; Kiss et al., 2018). Collared pratincoles feed on flying insects including dragonflies, flies and beetles of various sizes. They scrape their nests into livestock hoofprints or into the bare ground (Beretzk, 1954; Cramp & Simmons, 1983). The collared pratincole is categorized as Least Concern on the IUCN Red List but the global population is declining (BirdLife International, 2021). It has been difficult to assess population changes because of the high dispersal propensity and semi-nomadic strategy of the species, leading to large fluctuations in breeding densities (Yuri et al., 2020). Collared pratincoles are now breeding on agricultural land in Europe (Calvo & Alberto, 1990; Calvo, 1994; Calvo & Furness, 1995; Lebedeva, 1998; Kiss et al., 2017; Yuri et al., 2020), and most breeding attempts now occur on arable farmland even in some of the coastal breeding populations (Vincent-Martin, 2007; Nardelli et al., 2008; Kiss et al., 2017). During the past decade, the Hungarian population has fluctuated between 22 and 65 pairs, at two major breeding sites (the Nagykunság and Kiskunság regions). These sites are the last remaining regular breeding locations of collared pratincoles in the Carpathian Basin (Kiss et al., 2018).

We have four objectives: firstly, to quantify nesting success of the collared pratincole and investigate the ecological variables that could predict nesting success, including habitat type, timing of breeding, proximity to open water and breeding density; secondly, to compare nest survival rates between different agricultural habitats; thirdly, to investigate the effects of conservation measures on nest survival; and finally, to investigate potential associations between predator control and nest survival.

Study area

We carried out data collection and conservation activities in the Nagykunság region in eastern Hungary (Fig. 1). The climate is eastern continental, characterized by dry and warm periods during the breeding season interspersed with short, heavy rainfall of 20–100 mm/h (Hungarian Meteorological Service, 2021). We focused on the southern part of Nagykunság, where the landscape is dominated by

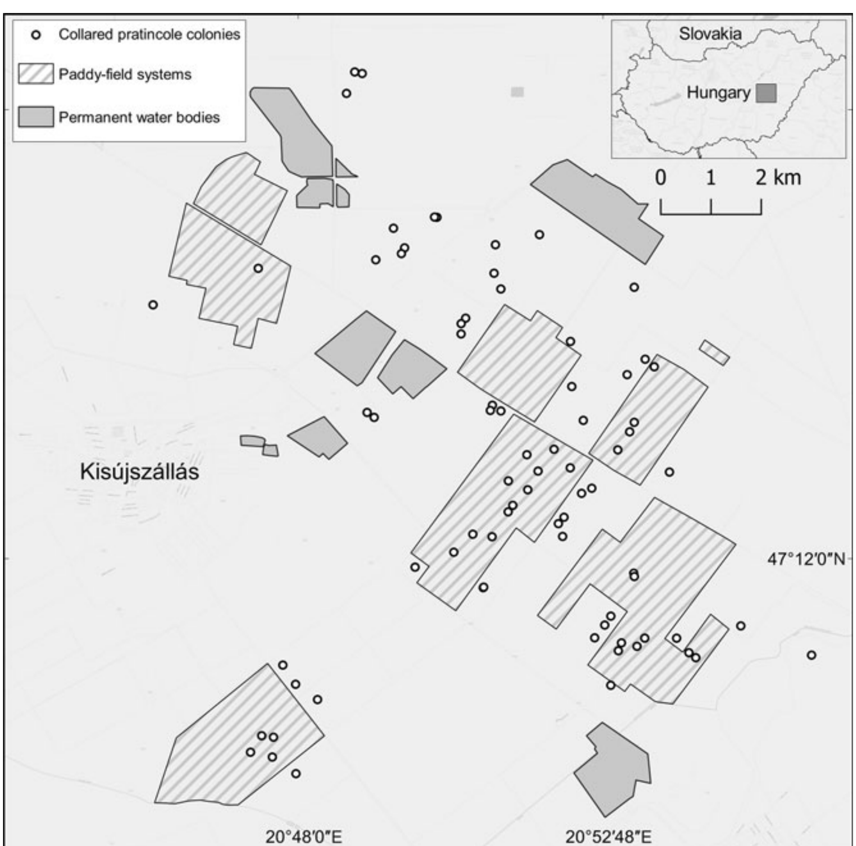

FIG. 1 The c. 12,500-ha study area in eastern Hungary.

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cultivated lands, primarily rice fields (Fig. 1). Because of the requirements of rice cultivation, each year > 1,500 ha of farmland is flooded, providing important habitats for breeding and migrating shorebirds (Kiss et al., 2017). In Nagykunság, the estimated number of collared pratincoles fluctuated between 13 and 56 breeding pairs during 2012–2021 (mean 32.4 ± SE 5.3; data from the database of the Hortobágy National Park Directorate).

Methods

Data collection

Starting in 2012, we collected data on breeding sites, including nest-site location, nesting success and behaviour. We recorded the data using a handheld digital assistant and then transferred the data to *ArcMap 10.1* (Esri, Redlands, USA). We also collected observations in croplands used by collared pratincoles and in shallow wetlands. Using nest points and various agricultural variables we created a map of nest points and shapefiles of arable lands and shallow water bodies.

We prepared maps of nest locations and polygons of croplands and water bodies for further analyses using *ArcMap*. We carried out monitoring activities of birds on potential nesting sites, location and revisiting of nests using binoculars and spotting scopes. We always approached nests to a distance of 8–10 m using four-wheel drive cars (even within agricultural fields) to limit any possible disturbance to incubating birds. In addition to the locations of nests, we identified the agriculture habitat types used for nesting (Plate 1, Supplementary Table 1). We identified these using Calvo's (1994) methodology based on the planting patterns of crops: we classified fields with crops planted in rows at least 60 cm apart as row crops, areas where crops were sown without leaving any row gaps as spring cover crops and areas that were left unsown after tilling as fallow. After locating the nests, we recorded the clutch size, nest cover and location coordinates for each nest and then placed a small stick c. 1 m from the nest to mark the nest location in the field. After locating a new nest, we consulted the owner or manager of the land. To prevent nest destruction by farming activities, we marked a buffer zone around the nests using 1.5 m-tall wooden poles. However, to avoid attracting the attention of potential nest predators, we only placed the nest markers during periods of active agricultural work (Zámečník et al., 2018). The sizes of these oval-shaped nest protection zones were 100 m², which is sufficient to ensure adequate protection from agricultural machinery (Plate 2).

During the incubation period, we checked all of the nests remotely using a spotting scope every other day. The incubation period was 18 days (based on Myhrvold et al., 2015, and our field observations supplemented with use of the egg-floating methodology; see details in Székely et al., 2006), and after the last nest visit, we classified each nest as hatched, predated, abandoned, unknown, flooded or destroyed by agricultural machinery. To identify the fate of each nest, we used the methods of Green et al. (1987) to identify potential nest predators in addition to our field observations (Kiss et al., 2018). We established successful hatching if there were small eggshell fragments or small chick droppings in the nest cup, predation if we found predator tracks or signs of predation by mammals or birds near the nest, desertion if the pair was not nearby and the egg was cold and abandonment because of rainfall if the egg was stuck in mud. We determined a nest successful if at least one chick hatched.

PLATE 1 Main breeding habitats of collared pratincoles *Glareola pratincola* in Hungary: (a) row crop, (b) spring cover crop, (c) fallow land.

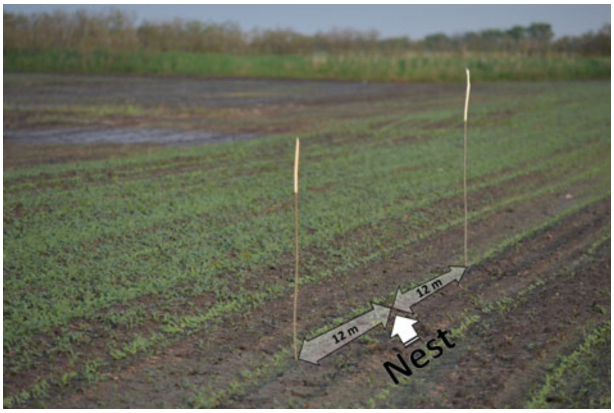

PLATE 2 Protection zone around collared pratincole nest, marked temporarily by 1.5 m-tall wooden poles. This photograph was taken using a telephoto lens that distorts the actual distance between the two wooden poles.

The survival and productivity of ground-nesting birds are influenced by predation (Martin, 1993; Roodbergen et al., 2012; Kubelka et al., 2018). To investigate relationships between pratincole breeding success and number of nest predators removed from the study area, we collected data from hunters. Potential huntable nest predators include mammals (red fox *Vulpes vulpes*, golden jackal *Canis aureus*, European badger *Meles meles*) and birds (Eurasian magpie *Pica pica*, hooded crow *Corvus cornix*). We requested hunting bag data from professional hunters for the period 2017–2021 and we aggregated the number of individuals killed for each year. Hunting bag data relate to the regional hunting district (c. 26,000 ha), which covers c. 65% of collard pratincole nest sites (National Game Management Database, 2022).

Estimating daily and total nest survival

To investigate the effects of year and agricultural habitat on nesting success, we estimated daily and total nest survival rates using calculations provided by Mayfield (1975). We applied this method to estimate the chances of a clutch surviving daily and for the full nesting period (egg laying + incubation period) by defining the daily nest survival rate as the number of failed nests divided by the sum of exposure days (Johnson, 1979). We calculated total nest survival using Mayfield's formula: (daily nest survival)$^{\text{nesting period in days}}$, where the total nesting period is egg laying period + incubation (20 days in total). We defined exposure time as the number of days from finding a nest to the confirmed (or expected) last day of the breeding attempt. The incubation period started when the complete clutch had been laid. For those nests that hatched (i.e. at least one chick hatched), we calculated the exposure time from the day of nest finding to the confirmed (or predicted, using the egg floating methodology; Székely et al., 2006) date of hatching (Mayfield, 1975; Kubelka et al., 2018). For predated nests, we calculated exposure from the day of nest finding until the midpoint between the last positive and the first negative visit to the nest. For all other outcomes (i.e. unknown, abandoned, flooded, destroyed by agricultural machinery), we defined exposure time from the day of nest finding until the last positive nest visit, following standard protocols (Kubelka et al., 2018). We focused trail cameras on 116 nests to identify species of nest predators and the date of hatching.

Statistical analyses

We performed the statistical analyses in *R 3.3.3* (R Core Team, 2021). To identify relationships amongst individual-level reproduction success metrics (i.e. nests hatched or failed and the number of hatched chicks), we used generalized linear models (GLMs) with factors of year, habitat type, Julian day of egg laying, distance from the closest field boundary, distance from the closest water body and colony density. The latter factor represented the mean distance from the focal nest to the three closest nests within the same breeding colony. As nesting success was a binary response variable (hatched or failed), we used a logistic regression GLM with the *logit* link error function. Field boundaries and water bodies were available in shape files. We computed the mean distance from the three neighbouring nests using the *nndist* spatial neighbourhood function available in the *spatstat* package in *R*. For the start of incubation, we used the Julian day of clutch completion at a given nest. We used ANOVA, implemented using the *lm* function, to analyse the associations between (1) clutch size and habitat type, (2) timing of hatching and habitat type, and (3) daily nest survival (aggregated for years and habitats).

Results

Timing of breeding and breeding success

During 2012–2021, we found 315 nests, for 212 of which we also determined the hatching date of the first chick. Egg laying started in late April and terminated in mid July (c. 2.5 months duration), with most nests (60%) laid during 25 May–15 June. The first eggs hatched on 16 May, which implies that the clutch was completed on 29 April. The latest hatch date was recorded on 3 August. The mean hatching date was 15 June ± SE 1 day (n = 212 nests; Table 1, Supplementary Fig. 1).

Collared pratincoles bred in three agricultural habitats: most nests were in row crops (48%), followed by fallow lands (29%) and spring cover crops (23%, n = 315 nests; Table 1). The timing of breeding was different between

TABLE 1 Timing of breeding, clutch size and nesting success of collared pratincoles *Glareola pratincola* in agricultural habitats in Hungary (mean ± SE; Fig. 1). We found 315 nests over our study period, but as we were only able to establish hatching times for 212 of these nests, we show hatching times separately.

	Row crop	Spring cover crop	Fallow land	*Overall*
Timing of hatching (Julian day)	158.5 ± 0.9	164.6 ± 2.3	175.8 ± 1.9	165.6 ± 1.0
Timing of hatching (calendar day)	9 June	15 June	26 June	15 June
Number of nests with known hatching times	94	50	68	212
Clutch size	2.66 ± 0.05	2.58 ± 0.08	2.49 ± 0.08	2.59 ± 0.04
Number of hatched chicks per nest	1.54 ± 0.10	1.50 ± 0.14	1.72 ± 0.12	1.58 ± 0.07
Total number of nests	152	72	91	315

habitat types: nests in row crops or spring cover crops hatched earlier than in fallow lands (one-way ANOVA, $b > 6.311$, $F_{2,210} = 39.02$, $P_{min} = 0.009$; Supplementary Fig. 1). Similarly, clutch size was related to habitat type: the largest clutch sizes were in row crops (one-way ANOVA, $b < -0.0491$, $F_{2,268} = 2.601$, $P_{min} = 0.0254$; Table 1). A total of 75% (n = 68) of nests on fallow lands hatched at least one chick, whereas the corresponding figures were 69% (n = 50) on spring cover crops and 62% (n = 94) in row crops (Table 1). The overall nesting success was 67% (n = 315 nests). Nesting success was related to the type of habitat: nests in spring cover crops or fallow lands were more successful and produced more hatchlings than nests in row crops. In addition, nesting success was also associated with both time in the season and breeding density, as early nests and those in areas with higher breeding densities produced more chicks (Table 2).

Daily nest survival increased significantly over the study period (linear regression, $b = 0.0064$, n = 8, P = 0.0189; Fig. 2). Total nest survival increased from 11.2 to 83.5% (Supplementary Table 2). However, using two-way ANOVAs we found no association between habitat type and daily nest survival (two-way ANOVA, $b = -0.046$, SE = 0.036, P = 0.21) or total nest survival (two-way ANOVA, $b = -0.103$, SE = 0.144, P = 0.48), using year as the unit of analysis. The highest level of total nest survival was recorded in fallow lands (Supplementary Table 2).

Causes of nest failure

Most nest failures (n = 102) were caused by predation (58%), followed by nest abandonment (23%) and flooding by heavy rainfall (17%), with 1% having an unknown fate. As a result of the nest-marking scheme, agricultural machinery destroyed only a few nests (1%; Supplementary Table 3). In total, 83% (n = 49) of all nest predation and 89% (n = 17) of all flooded nests were found in row crops and spring cover crops, respectively. The most common predators of eggs and chicks were red foxes, European badgers, hooded crows, western marsh harriers *Circus aeruginosus* and Caspian gulls *Larus cachinnans*.

Conservation action

During the study period, we directly protected 159 nests (c. 50% of the total) with a protection zone. The number of protected nests fluctuated across years and habitats, although the largest proportion (92%) of protected nests

TABLE 2 Nesting success and the number of hatched chicks of collared pratincoles in Hungary and their relationships to agro-technology, time, space and other ecological variables. Logistic and linear regression analyses were used to explore the relationship between these variables, as appropriate. Significant relationships are indicated in bold.

	Nesting success				Number of hatched chicks			
Variable	Estimate	SE	*z*	P	Estimate	SE	*t*	P
Intercept	−463.12	124.42	−3.72	**< 0.01**	−292.04	63.84	−4.58	**< 0.01**
Agricultural habitat								
Spring cover crops	1.03	0.40	2.56	**0.01**	0.42	0.20	2.11	**0.04**
Fallow lands	1.35	0.45	3.03	**0.01**	0.72	0.22	3.32	**0.01**
Ecology & timing								
Year	0.23	0.06	3.74	**< 0.01**	0.15	0.03	4.62	**< 0.01**
Egg-laying date	−0.01	0.01	−1.36	0.18	−0.01	0.01	−2.29	**0.02**
Field boundary	0.01	0.01	0.95	0.34	0.01	0.01	1.01	0.32
Distance from water body	< 0.01	< 0.01	0.40	0.69	< 0.01	< 0.01	1.56	0.12
Social behaviour								
Breeding density	< 0.01	< 0.01	−1.39	0.16	< 0.01	< 0.01	−2.47	**0.01**

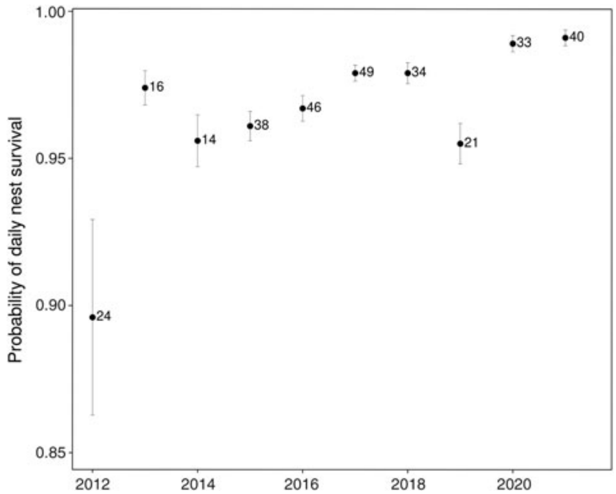

FIG. 2 Daily nest survival (mean ± SE) in relation to the study year (r^2 = 0.55, n = 10 years). The number of nests per year is indicated.

was in row crops (Table 3). Nest protection was successful, as 64% of protected nests produced at least one chick (n = 101; Table 3). The number of nests we rescued via direct protection measures was 150 (Table 3).

Hunters culled a mean of 454 mammals and 655 birds annually in the hunting district that overlapped with our study site (i.e. 1.7 mammals and 2.5 birds per 100 ha; Table 4). Daily nest survival was not predicted by the number of culled avian (linear regression, b = 0.0001, n = 5, P = 0.655) or mammalian predators (linear regression, b = 0.0005, n = 5, P = 0.503).

Discussion

Here we show that the nesting success of a ground-nesting bird is predicted by the agricultural habitat type of its nest as well as breeding density and timing of breeding. We increased daily nest survival of pratincoles over the study period through conservation measures, so that the majority of nests now hatch successfully.

Collared pratincoles that breed on fallow lands and in spring cover crops had significantly higher nesting success than those nesting in row crops. Nesting success for other shorebirds is also influenced by the timing and intensity of agricultural operations. For example, nest losses of northern lapwings *Vanellus vanellus* depend on the timing of spring tillage during the nesting period (independently of crop type; Sheldon et al., 2007). We observed that predation pressure was lower in extensively used habitats compared with intensively treated areas. Similar patterns have been documented in black-tailed godwits *Limosa limosa* (Kentie et al., 2015) and other ground-nesting species (Berg et al., 1992). It is probable that the rise of modern intensive agriculture has favoured generalist predators (Pescador & Peris, 2001). In addition, rainfall was more likely to flood nests in fields of row crops, as the heavy agricultural machines used for these crops compact the soil and thus water drains more slowly in

TABLE 4 Number of predators culled during 2017–2022 in the c. 26,000-ha hunting district that overlaps with the collared pratincole nest sites.

Year	Mammals	Birds	*Total*
2017	280	263	543
2018	488	312	800
2019	415	699	1,114
2020	504	1,046	1,550
2021	582	953	1,535
Total number of culled predators	2,269	3,273	5,542

TABLE 3 Nest protection activities for collared pratincoles in Hungary in relation to year and habitat type (n = 315 nests). Nests rescued refers to nests that would have been destroyed by agricultural machinery without direct protection.

Year	Number of nests	Number of nests protected (%)	Number of nests rescued (%)	Number of protected nests hatched (%)	Number of unprotected nests hatched (%)
2012	24	14 (58)	14 (58)	0	3 (30)
2013	16	9 (56)	9 (56)	5 (56)	5 (71)
2014	14	3 (21)	3 (21)	0	8 (73)
2015	38	31 (82)	31 (82)	17 (55)	7 (100)
2016	46	24 (52)	20 (43)	18 (75)	12 (55)
2017	49	12 (24)	12 (24)	8 (67)	29 (78)
2018	34	17 (50)	17 (50)	12 (71)	14 (82)
2019	21	13 (62)	13 (62)	7 (54)	3 (38)
2020	33	9 (27)	8 (24)	9 (100)	20 (83)
2021	40	27 (68)	23 (58)	25 (93)	10 (77)
Habitat					
Row crops	152	146 (96)	140 (92)	92 (63)	2 (33)
Spring cover crops	72	8 (11)	5 (7)	6 (75)	44 (69)
Fallow lands	91	5 (5)	5 (5)	3 (60)	65 (76)
Total	315	159 (50)	150 (48)	101 (64)	111 (71)

these habitats. The frequency of heavy rains appears to have declined during the study period, which could also have contributed to the higher nest survival we observed over these years.

Collared pratincoles breed in colonies of various sizes, and thus we expected inter-nest distance to be an important predictor of nesting success. A similar pattern was observed by Berg (1992), who found that predation risk was negatively correlated with the number of neighbours within a breeding colony of northern lapwings. Nest predation was also negatively correlated with nest density in other wader species (Macdonald & Bolton, 2008). In another colonial shorebird, the pied avocet *Recurvirostra avosetta*, nesting success was highest at intermediate densities (Hötker, 2000), suggesting that density might have a non-linear effect on breeding success in certain cases.

Several shorebird species are declining in their native breeding habitats across Europe, having been forced to choose riskier breeding sites as their preferred habitats are converted into agriculture (Berg, 1992; Schifferli et al., 2006; Kentie et al., 2015). For the collared pratincole and similar species such as the Eurasian curlew *Numenius arquata*, nesting success tends to be higher in their natural habitats than in agricultural ones (Berg, 1992, Calvo, 1994; Vincent-Martin, 2007). In our study area, pratincoles only occupied agricultural habitats, which allowed us to compare the impacts of various types of human-made habitats on nesting success. However, we have no data on nest survival in the native grasslands of this species because these are now rare. In other studies that did include grasslands, higher nesting success was reported in these natural habitats (Calvo, 1994; El Malki et al., 2013).

Most fields in our study site were managed in different phases during the breeding season; therefore, the peak hatching dates occurred at different times. Nesting strategies were highly dependent on the local agricultural schedule because row crops and spring cover crops were sown first, followed by the ploughing of fallow lands. In row crops and spring cover crops, vegetation grows particularly uniformly and rapidly, reducing the time period during which the pratincoles can nest successfully. By contrast, vegetation on fallow lands grows heterogeneously in mosaic patches, creating more suitable nesting conditions. The highest number of nests was in row crops, which was the most common type of agricultural breeding habitat available for collared pratincoles and other shorebirds at our site.

The clutch size of pratincoles is similar in Hungary, Spain (Bertolero & Martinez Vilalta, 1999) and France (Vincent-Martin, 2007) and higher than that in Ukraine and Morocco (Pozhidaeva & Molodan, 1992; El Malki et al., 2013). However, the number of successfully hatched chicks was lower than in Ukraine (Pozhidaeva & Molodan, 1992) and in Algeria (Bensaci et al., 2014).

Conservation actions

Nesting success was different between the three major breeding habitats, with the results suggesting that the most productive habitats were spring crops and fallow fields. This difference persisted even though conservation measures focused on row crops, which increased the nesting success for this habitat. Separating the impact of conservation actions from that of the nesting habitats themselves would be difficult, as the majority of nest protection measures focused only on row crops. The finding that neither daily nest survival nor total nest survival was different between habitats might seem counterintuitive, although the analyses that we carried out at year level (rather than at the individual nest level as in the other analyses) would have lower statistical power. Nevertheless, we only had accurate data until the chicks hatched, so we can only draw conclusions regarding the effects of the habitats from the incubation period. Direct nest protection interventions increased nest survival similarly to other studies, such as the wood turtle *Glyptemys insculpta* conservation project that found nesting success can be increased by designing appropriate interventions (Bougie et al., 2020). In the absence of direct nest protection, breeding success was probably low in critical habitats, similar to that described by Calvo (1994), who found that as a result of changing agricultural practices, nesting success also improved. Nesting success and the daily survival rate of nests have increased significantly over the past decade probably because of conservation actions.

Although the number of culled predators did not predict nest survival, we believe this is because of the relatively crude nature of the data (i.e. hunting bag data) and small number of sample years. Predator control is likely to be important for the long-term survival of ground-nesting birds (Neuman et al., 2004; Bolton et al., 2007). We are currently designing a project to investigate the effects of predator control on the nesting success of pratincoles. In addition, there are various other natural and human-induced factors that could influence the nest survival of ground-nesting birds, and we need more precise data on the effects of culling on the density of the most common nest predators.

Compared with unmarked nests, we did not find increased predation rates in nests marked with poles, similar to that observed by Zámeĉník et al. (2018), perhaps because the poles were left near nests for only short time periods. Local farmers were supportive of this nest protection, and so none of the known nests were at serious risk during agricultural work. However, the collared pratincole conservation project should be further improved through the establishment of fields and fallow lands that are free from agricultural disturbance. As a result of the current agricultural scheme, agricultural land in Hungary and elsewhere in Europe tends to be used intensively, so arable fields are typically producing crops for most of the year (Tarjuelo et al., 2020).

Hortobágy National Park is involved in a species-focused recovery programme that includes improving alkaline grasslands to attract pratincoles, although the habitat restoration seems to have been unsuccessful so far (Kovács & Kapocsi, 2004). Based on the results presented here, we believe that joint actions by conservationists and farmers are key (Kiss et al., 2018). Maintaining good relationships between farmers and conservationists is essential to achieving success in conservation projects (Logsdon et al., 2015; Homberger et al., 2017). Direct nest protection activities had to be implemented mostly in row crops because these types of agricultural land (especially sunflower and corn fields) are cultivated intensively during the breeding season. By contrast, in spring cover crops and fallow lands (with a few exceptions), we observed no disturbance by agricultural machinery after ploughing or sowing.

On a global scale, human activity can negatively influence the behaviour, productivity and nest survival of ground-nesting birds in various habitats, especially on farmland (Fahrig, 1997; Donald et al., 2001; Colwell, 2010; Ward et al., 2010). We have set ourselves the goal of habitat development at the local level, as a result of which 50–100 ha of fallow lands are created every year to facilitate the settlement of shorebirds on the Nagykunság rice systems. These empty fields are created through disc ploughing from the middle to the end of April, and after the treatment there is no human disturbance during the breeding season. These areas are small in relation to the size of the total habitat, but this seems to be a promising project as increasing numbers of birds have nested and gathered in these fallow areas in recent years. Improvements could be supported through the development of targeted agricultural programmes, which would set management standards specifically for the arable lands used by the species and financially support the conservation efforts of farmers.

Our results suggest that direct conservation activities can achieve desired outcomes even in intensively farmed agricultural habitats. Without such interventions, a large proportion of farmland bird nests could be destroyed by agricultural machinery. We believe that the Eurasian populations of collared pratincoles are threatened considerably by anthropogenic pressures: for instance, even in their native breeding habitats the pratincoles are subject to adverse effects from climate change, pollution and an unnaturally high density of mesopredators. In addition to effective direct nest protection, it will be important to increase the proportion of safe fallow lands in the future as a specific agri-environmental protection measure, so that as many farmland birds as possible have the opportunity to choose this undisturbed agricultural habitat for breeding. As collared pratincoles nest in several places in artificial habitats across Europe, mainly close to wetlands such as rice fields, breeding habitats should be protected or restored more widely to maintain biodiversity in agricultural landscapes.

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Conflict of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

Data availability The dataset is available in the Dryad data repository at doi.org/10.5061/dryad.mgqnk9959.

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