

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

3 **Ádám Kiss^{1,2}, Zsolt Végvári^{3,4}, Vojtěch Kubelka⁵, Ákos Monoki², István Kapocsi², Szilvia**
4 **Gőri² & Tamás Székely^{1,6}**

5 ¹ELKH-DE Reproductive Strategies Research Group, Department of Evolutionary Zoology and
6 Human Biology, University of Debrecen, Egyetem tér 1, H-4032, Debrecen, Hungary

7 ²Hortobágy National Park Directorate, 2 Sumen ut, Debrecen, H-4024, Hungary

8 ³Centre for Ecological Research, Institute of Aquatic Ecology, Karolina u. 29, H-1113,
9 Budapest, Hungary

10 ⁴Senckenberg Deutsches Entomologisches Institut, D-15374, Müncheberg, Germany

11 ⁵Department of Zoology and Centre for Polar Ecology, Faculty of Science, University of South
12 Bohemia, Branišovská 1760, České Budějovice, 370 05, Czech Republic

13 Corresponding authors:

14 **Ádám Kiss** kissadam@hnp.hu ORCID 0000-0002-7342-159X

15 **Tamás Székely** T.Szekely@bath.ac.uk ORCID 0000-0003-2093-0056

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23 Agricultural intensification has affected wildlife across Europe, usually prompting steep
24 declines and regional extinctions in farmland birds. Effective conservation activities are
25 essential for preservation of biodiversity in agricultural landscape, but despite the efforts, the
26 halting (or reversing) the decline of farmland species are still rare. Here we investigate a
27 ground-nesting shorebird, the Collared Pratincole (*Glareola pratincola*) that has switched its
28 habitat preferences in Central Europe in the last 20 years from alkaline grasslands to intensively
29 managed agricultural landscapes. We show that nest success was different between three habitat
30 types, with the highest nest success in fallow lands whereas nests in row crops showed the
31 lowest hatching success. Nest success was also associated with timing of breeding and breeding
32 density, since nests produced early in the breeding season and those in dense breeding sites
33 hatched more successfully than those later in the season and low breeding density, respectively.
34 Importantly, since 2012 direct conservation measures have been implemented that include the
35 marking of nests and negotiating with farmers to avoid the usage of agricultural machinery
36 around the marked areas, controlling nest predators and most recently creating suitable nesting
37 sites and foraging areas for the Pratincoles. Due to these direct conservation actions, the
38 probability of both nest survival increased from 0.11 in 2012 to 0.83 in year 2021, and the size
39 of breeding population increased from 16 pairs in 2013 to 56 in 2021. Taken together,
40 agricultural areas can continue providing important habitats for various organisms, and with
41 targeted conservation actions we can reduce or even halt the decline of farmland species.

42

43 **Keywords:** agricultural land-use, farmland birds, shorebirds, waders, *Glareola pratincola*, nest
44 survival, predator control

45 **Introduction**

46 Natural habitats are disappearing or degrading at global scales at an unprecedented rate, which
47 is a result of the combined effects of current climatic processes and land use change during the
48 Anthropocene (Fahrig, 1997; Balmer & Erhardt, 2000; Davidson, 2014; Hu et al., 2017). One
49 of the main reasons is the expansion of intensive forms of agricultural land-use that has led to
50 negative changes or the complete disappearance of various habitats across Europe (O'Connor
51 & Shrubbs, 1986; Potter, 1997). These declines are especially severe in grassland (or steppe)
52 breeding animals, considered as highly sensitive for environmental changes, as many species
53 declined dramatically during the past decades (Fuller, 2000; Massa & La Mantia, 2010; Ward
54 et al. 2010; Guerrero et al., 2012). As a consequence of the loss of grassland habitats, birds that
55 traditionally bred in open natural habitats, increasingly occupy arable lands and cultivated areas
56 during reproduction (Galbraith, 1987; Böhning-Gaese & Bauer, 1996; Brady & Flather, 1998).

57 However, breeding in agricultural landscapes may be costly, as these habitats may not be
58 productive enough due to the mal-assessment of the habitat by prospective breeders (Székely
59 1992), and thus serve as ecological traps (Schlaepfer, et al., 2002; Robertson & Hutto, 2006;
60 Pärt et al., 2007; Gilroy et al., 2011; Hollander et al., 2017). Additionally, the intensification of
61 agricultural practices can affect nesting success of ground-breeding species in numerous ways,
62 including direct elimination of nests, chicks and/or adults by mowing, cultivating by
63 agricultural machineries, use of pesticides, irrigation, or drainage (Berg et al., 1992; Wilson et
64 al. 2005; Kentie et al., 2013). Unfortunately, there are abundant examples showing the negative
65 impacts of agriculture, with local species extinction from extensive areas that are full or
66 occasional breeders of agricultural habitats including the Great Bustard (*Otis tarda*) and Grey
67 Partridge (*Perdix perdix*) (Donald et al., 2001; Arroyo, et al., 2002; De Leo et al. 2004; Alonso
68 & Palacín, 2010; Potts, 2012; Gooch et al. 2015). Furthermore, these pressures have been
69 intensified owing to global climatic changes, coupled with increased predation rates in human-

70 modified habitats. Specifically, environmental changes have boosted the populations of meso-
71 predators which have further impacted the nest or offspring survival rates of ground-breeding
72 birds (Roodbergen et al. 2012; Kentie et al., 2015; Kubelka et al., 2018; Brzeziński et al., 2020).
73 To mitigate these negative effects, targeted conservation actions are needed (Arroyo et al.,
74 2002; Zamečník et al, 2008; Schekkerman et al., 2008).

75 Here we report the results of a 10-years conservation effort focused on the Collared Pratincole
76 (*Glareola pratincola*) that is affected by habitat alterations and has undergone a population
77 decline across many parts of Europe (Yuri et al., 2020). The Collared Pratincole is a ground-
78 nesting shorebird that historically bred in loose colonies in alkaline grasslands close to wetlands
79 in Central Europe (Cramp and Simmons, 1983). The largest inland breeding population in the
80 Carpathian Basin existed during the early 1900s (Aradi 1979; Kiss et al., 2018). Collared
81 Pratincoles feed on flying insects including dragonflies, flies and various-sized *Coleoptera*
82 species, and they build their nest into a hoofprint or on bare ground (Beretzka, 1954; Cramp and
83 Simmons, 1983). The global population is declining (IUCN Red List, 2017) although it has
84 been hard to assess the change of abundances of the species due to their high dispersal
85 propensity and semi-nomadic strategies, leading to high fluctuations in breeding densities (Yuri
86 et al., 2020). Collared Pratincoles have been shown to use agricultural lands for breeding in
87 several parts of Europe in the past centuries (Calvo & Alberto, 1990; Calvo, 1994; Calvo &
88 Furness, 1995; Lebedeva, 1998; Kiss et al., 2017; EBBA 2, 2020), and recently most breeding
89 attempt occurs on arable farmland (Nardelli et al., 2015; Kiss et al., 2017; Vincent-Martin,
90 2007). During the past decade, the Hungarian population has fluctuated between 22 and 65
91 pairs, and it split between two regular breeding sites in the Nagy-kunság and Kiskunság regions.
92 These breeding sites became the last remaining breeding locations for the species within the
93 Carpathian basin (Kiss et al., 2018).

94 We had four objectives in our study. First, to quantify Collared Pratincole nest success and
95 investigate the ecological and behavioural variables that may predict nest success including
96 habitat type, timing of breeding, proximity to open water surfaces as a proxy for water
97 availability and breeding density. Second, to compare nest survival rates between different
98 agricultural habitats. Thirdly, to investigate the effects of conservation measures on nest
99 survival, and finally to investigate potential associations between predator control and nest
100 survival.

101 **Methods**

102 **Study area**

103 Data collection and conservation activities were carried out in the Nagykunság region, located
104 in the middle of the Hungarian Great Plain, Eastern Hungary (N47.2, E20.9, Figure 1). The
105 climate is eastern continental, characterised by dry and warm periods during the breeding
106 season, interspersed with short, heavy rainfalls of 20 – 100 mm/hour (Hungarian
107 Meteorological Service, 2021). We focused on the southern part of the region, where the
108 landscape is dominated by cultivated lands, primarily rice fields (Plate 1). Due to the
109 requirements of rice cultivation, each year more than 1500 hectares of farmland is artificially
110 flooded, providing important habitats for breeding and migrating shorebirds (Monoki & Kiss,
111 2017).

112 The estimated number of breeding pairs of Collared Pratincoles fluctuated strongly between 13
113 and 65 pairs, between 2012 and 2021 (33.25 ± 14.61) (database of the Hortobágy National Park
114 Directorate).

115 **Data collection**

116 Starting in 2012, we continuously collected Collared Pratincole field observation records for
117 breeding sites, including nest-site selection, nest success and behaviour. We recorded these data

118 in field using a handheld Trimble Personal Digital Assistant, which were later processed in
119 Arcmap 10.1. Data were also collected in i) croplands used by Collared Pratincoles and ii)
120 shallow wetlands. Using nest points, and different agricultural variables we created a map of
121 nest points, shapefiles of arable lands and shallow water bodies.

122 Nest locations, polygons of croplands and water bodies were prepared for further analyses using
123 ArcMap 1.0 software. Monitoring activities of the potential nesting sites, localization and
124 revisiting of nests were assisted by high-quality binoculars and spotting scopes. Nests were
125 always approached to a distance of 8-10 meters by 4WD cars – even within agricultural fields
126 – to avoid any disturbance of incubating shorebirds, allowing the observation of Collared
127 Pratincole behaviour. In addition to the location of nests, we identified the type of land used for
128 nesting, which were classified into three categories based on preparation and management
129 technologies (Supplementary Table 1, Figure 2). After locating the nests, we recorded clutch
130 size, nest cover, GPS coordinates for each nest, which we completed by positioning a small
131 wooden twig 1 meter apart from each nest to be able to relocate them. After finding each new
132 nest or colony, we consulted the owner or manager of the land. To prevent nest destruction by
133 farming activities, we marked a buffer zone using 1.5 m tall, 2 cm thick wooden poles around
134 the nest. However, to prevent predators from learning these signals, we only placed these
135 markers during active agricultural work (based on a method of Zamečník et al. 2018). The mean
136 size of these oval-shaped buffer zones amounted to 0.01 hectares, which is of sufficient size to
137 ensure adequate protection of the nest from agricultural machinery (Figure 3).

138 During the incubation period, all active nests were checked using spotting scope in every second
139 day, but we revisited all nests in 2 – 3 times per week on average. After the last visit, we
140 classified the hatching success of the nests as i) hatched; ii) predated; iii) abandoned; iv)
141 unknown. v) flooded; vi) destroyed by agricultural machineries. To identify the fate of each
142 nest, we used Green's methods (1987) in addition to our field observations (Kiss et al., 2018).

143 Trail cameras were applied for 116 nest to identify the species of nest predators and the date of
144 hatching.

145 Survival and productivity of ground-nesting birds is influenced by predation (Martin, 1993;
146 Rodbergen et al., 2012; Kubelka et al., 2018). To investigate relationships between breeding
147 success and the number of huntable predators killed by professional hunters in the study area,
148 we collected data from hunters. Predatory mammals include Red Fox (*Vulpes vulpes*), Golden
149 Jackal (*Canis aureus*) and European Badger (*Meles meles*) and birds are represented by
150 European Magpie (*Pica pica*) and Hooded Crow (*Corvus cornix*). We requested data from
151 professional hunters between 2017 and 2021, and we aggregated the numbers of shot
152 individuals for each year. Data on hunting activities were collected from the ca. 26,000 hectares
153 large regional hunting districts which overlapped with more than 65% of the breeding sites
154 (National Game Management Database, 2022).

155 **Estimating daily and total nest survival**

156 To investigate the effects of years and agricultural habitats on nesting success, we estimated
157 daily and total nest survival rates using Mayfield's calculations (1975). The Mayfield's method
158 (1975) is applied to estimate the chances of a clutch surviving the daily and full nesting period
159 by defining daily nest survival rate as the number of failed nests divided by the sum of exposure
160 days. Total nest survival was calculated using Mayfield's formula: $\text{daily nest survival}^{\text{nesting period}}$
161 in days . The computation of nest survival rates requires information on total exposure time, which
162 was defined as the number of days from finding to the day of confirmed or expected day of
163 final fate of the nest. For all nests where signs of hatching were observed, the exposure time
164 was calculated from the day of finding to the confirmed or predicted date of hatching. For those
165 nests which has become depredated, this interval was calculated as starting from the day of
166 finding until the midpoint between the last positive and the first negative visit to the nest. For
167 all other outcomes (unknown, abandoned, flooded, destroyed by agricultural machineries), the

168 exposure time was defined from the day of finding until the last positive visit, following the
169 standard protocols (e.g. Kubelka et al., 2018).

170 **Statistical analyses**

171 To identify relationships among individual-level reproduction success metrics, i) nests which
172 hatched or failed and ii) number of hatched chicks, we performed Generalised Linear Models
173 (GLM), entering year, habitat type, julian day of egg-laying start as well as distance to the a)
174 nearest field edge; b) closest water body and c) mean distance of the three closest nests within
175 the same colony as fixed factors. As the nest success response (hatched or failed) is a binary
176 variable, we conducted a logistic regression-type GLM, applying 'logit' link error function.
177 Field boundaries and wetlands were available in shape file formats, using our own field
178 mappings. The mean distances of the three neighbouring nests were computed applying the
179 'nndist' spatial neighbourhood function available in the 'spatstat' package for spatial statistics.
180 Egg-laying start was defined as the julian day of the record, defined as the number of days
181 counted from 1 January each year, considering the first day for incubation for individual
182 clutches.

183 Further, we analysed the relationship between i) clutch size and habitat type; ii) timing of
184 hatching and habitat type iii) daily nest survival metric (aggregated for years and habitats) based
185 on the number of culled predators by official hunters, applying ANOVA-tests implemented
186 using the 'lm' function. All statistical analyses were performed within the R v. 3.3.3 statistical
187 programming environment (R Core Team, 2021).

188 **Results**

189 **Breeding success and timing of breeding**

190 The breeding season of Collared Pratincoles lasted from late April to early August. The first
191 eggs have hatched on 16 May, which implies that the clutch was completed on 29 April. The
192 latest hatch date was recorded on 3th August. The mean egg-hatching date was found on 15
193 June \pm 1.2 days over the study period, and most nests were produced between 25 May and 15
194 June (n = 212 nests, Supplementary Figure 2).

195 Collared Pratincoles bred in three types of habitats. The majority of nests were found in row
196 crops (48%), followed by fallow lands (29%) and spring cover crops (23%) (total n = 315 nests,
197 Table 2). Timing of breeding was different between crop types: nests in row crops or spring-
198 cover crops hatched earlier than in fallow lands (One-way ANOVA, $b > 6.311$, $F_{2,210} = 39.02$,
199 $p_{\min} = 0.009$, Supplementary Figure 1). Similarly, clutch size was significantly related to habitat
200 type: the largest clutch sizes were found in row crops (One-way ANOVA, $b < -0.0491$, $F_{2,268} =$
201 2.601 , $p_{\min} = 0.0254$). The number of successful hatchings per all nesting in different
202 agricultural habitats was 74.7% (n = 68) in fallow lands, 69.4% (n = 50) on spring cover crops
203 and 61.8% (n = 94) in row crops. The total number of clutches hatched successfully was 67.3%
204 (n = 212 nests).

205 Nest success was related to the type of habitat: pairs that chose spring-cover crops or fallows
206 showed higher nest success and more hatched chicks, compared to pairs that bred on croplands.
207 In addition to crop type, nest-success was associated with time in the season and breeding
208 density, since early nests and those that had higher breeding densities produced more chicks.
209 (Table 2).

210 **Nest survival and causes of nest-failure**

211 Nest failures were caused by predation (56.7%), nest abandonment (23.1%), flooding by heavy
212 rainfalls (18.3%), and unknown (0.9%) (total n = 104 nests). As a result of the nest-marking

213 scheme, agricultural machinery destroyed relatively few nests (0.9%) (Supplementary table 2).
214 83.1% of all nest predation (n = 49) and 89.5% (n = 17) of all flooded nests were found in row
215 crops and spring cover crops. The most common nest and fledgling predators included
216 mammalian predators that include Red Fox, European Badger and birds, especially Hooded
217 Crow, Western Marsh Harrier (*Circus aeruginosus*), and Caspian Gull (*Larus cachinnans*).
218 Daily nest survival significantly increased over the study period (linear regression, $b = 0.0064$,
219 $N = 8$, $p = 0.0189$, Figure 4), but there was no significant association found between habitat type
220 and daily survival (Two-way ANOVA, $b = -0.0457$, $SE = \pm 0.0355$, $p\text{-value} = 0.209$) or total
221 nest survival (Two-way ANOVA, $b = -0.0917$, $SE = \pm 0.1592$, $p\text{-value} = 0.569$). The highest
222 level of total nest survival was recorded for pairs nesting in fallow lands (Supplementary table
223 3).

224 **Conservation action**

225 Daily nest survival was not predicted by either the number of avian predators (linear regression,
226 $b = 0.0001$, $N = 5$, $p = 0.655$) not by the number of mammalian predators (linear regression, b
227 $= 0.0005$, $N = 5$, $p = 0.503$); however, we had data only for five years. The hunting pressure
228 increased over the study period as indicated by the increasing number of removed predators
229 between 2017 and 2021. (Supplementary material Table 4).

230 During the study period, we needed to carry out direct conservation interventions in the form
231 of a buffer-zone designation at 159 nests (50%, $n = 315$). The number of directly protected nests
232 fluctuated among the years and habitats, although the largest proportions of nests which had to
233 be protected were located in croplands (92% $n = 159$, Table 3).

234 **Discussion**

235 Our key findings are that i) habitat and the density of colony correlated with nest-success, ii)
236 nest success, and daily survival rate increased constantly over the years and iii) survival rates
237 showed similar levels for nests found in row crops as the other two habitat types, where large-
238 scale protection zones had to be established to protect them.

239 Maintaining good relationships between farmers and conservationists is essential to achieve
240 success of conservation projects (Logsdon et al., 2015; Homberger et al., 2017). Similarly to
241 our study species, many other shorebirds have experienced a decline in their optimal breeding
242 habitats across Europe, and thus they have been forced to choose riskier breeding sites in terms
243 of survival chances as majority of traditional habitats were converted for agricultural use (Berg,
244 1992; Schifferli et al., 2006; Kentie et al., 2015). In the case of Collared Pratincole, some studies
245 compared the artificial and natural habitats in terms of nest-site selection and survival (El Malki
246 et al., 2013) and found higher nesting success in natural habitats (Calvo, 1994; Vincent-Martin,
247 2007). In our study area, the species only occupied agricultural habitats, which allowed us to
248 compare various habitats that were created using several types of agricultural treatments as well
249 as various types of soil structures and vegetation cover. Most fields were used in different
250 phases during the breeding season of the species, therefore the peak of hatching dates were
251 observed at different times. Nesting strategies were highly dependent on the local agricultural
252 schedule because row crops and spring cover crops were sown first and were followed by the
253 ploughing of fallow grounds. In row crops and spring-sown fields, vegetation grows
254 particularly uniformly and rapidly, reducing the time period in which Collared Pratincoles are
255 able to nest successfully. By contrast, vegetation on fallow land grows heterogeneously in
256 mosaic spots, creating better nesting conditions. The highest number of nests was found in row
257 crops, which was the most abundant type of agricultural breeding habitat available for Collared
258 Pratincoles and other shorebirds in any given year. Average clutch size was similar to those
259 found in Mediterranean areas such as in Spain (Bertolero & Martinez-Vilalta, 1999) and France

260 (Vincent-Martin, 2007), and higher than those breeding in northern coastal areas of the Azovian
261 Sea (Pozhidaeva & Molodan, 1992) and in Moroccan coastal wetlands (Elmalki et al., 2013).
262 Average number of hatched chicks were lower than in the coastal habitats of the Azov Sea
263 (Pozhidaeva & Molodan, 1992) and in Algeria (Bensaci et al., 2014).

264 We found that Collared Pratincoles that chose fallow lands and spring-cover crops had
265 significantly higher nest-success during breeding season than those nesting in row crops. Nest
266 survival rates were also influenced strongly by the timing and intensity of agricultural
267 operations for other shorebirds. For example, in the case of Northern Lapwing (*Vanellus*
268 *vanellus*), nest losses depended on the timing of spring tillage during the nesting period but was
269 independent of crop type (Sheldon et al., 2007). We observed that predation pressure was lower
270 in extensively used habitats, as compared with intensively treated areas. Similar patterns have
271 been documented in Black-tailed Godwit (*Limosa limosa*) (Kentie et al., 2015) and other
272 ground-nesting species. It is likely that the rise of modern intensive agriculture has favoured
273 generalist predators by providing opportunities to colonise more readily in the riskier breeding
274 sites (Pescador & Peris, 2011). In addition, large amounts of rapid rainfall (> 20 mm / hour)
275 were less likely to flood nests in fallow fields, as the repeated compaction of soil during
276 agricultural management reduces the ability of water to freely drain.

277 Collared Pratincole frequently breed in colonies with various sizes, thus inter-nest distance was
278 expected to be an important predictor of nest success. In the case of a similar species, the Pied
279 Avocet (*Recurvirostra avosetta*), nesting success was lower in both denser and less dense
280 colonies, and higher at intermediate densities, as observed by Hötcker (2000). The number of
281 breeding Collared Pratincoles in Hungary is significantly smaller in comparison to other
282 populations in Europe, so these effects presumably did not apply.

283 We found no difference between either daily and total survival rate of nests and habitat type.
284 Nests threatened by agricultural machinery (mainly in row crops) were effectively protected,
285 and thus intensive conservation activities buffered the difference in nest survival rates between
286 different habitats. Nest survival rates could have been influenced by predation and heavy
287 rainfalls between habitats, but these effects were quite low over the years. Direct nest protection
288 interventions allowed the spectacular increase of the level of survival rates. Similar effects were
289 experienced in the Wood Turtle (*Glyptemys insculpta*) conservation project, which found that
290 nest success can be increased spectacularly applying adequately designed interventions (Bougie
291 et al., 2020). In the absence of direct nest protection, breeding success would have also been
292 low in critical habitats, similar to that described by Calvo (1994), who found that as a result of
293 changing agricultural practices, nesting success could also improve. Nest-success and daily
294 survival rate of nests has increased significantly over the past decade, probably due to the
295 qualitative and practical development of nest search, and conservation practice. Moreover, the
296 intensity of agricultural practice has noticeably decreased in Hungary in the past decades (Báldi
297 & Batáry, 2011).

298 **Conservation activities**

299 Since the Collared Pratincoles abandoned their traditional breeding habitats in alkaline
300 grasslands, the Hortobágy National Park Directorate has made several attempts to improve their
301 natural habitats in order to re-establish the species' breeding populations, so far without success,
302 but see (Kovács & Kapocsi, 2005). In addition to restoration efforts, the national park also
303 carried out a parallel search and protection of colonies and solitary pairs nesting in their active
304 breeding sites. Accordingly, these breeding grounds are managed by an intensive agricultural
305 land use scheme, thus the system of conservation management requires a composed and precise
306 cooperation between conservationists and farmers (Kiss et al., 2018). Direct nest protection

307 activities had to be implemented mostly in row crops, because these types of agricultural land
308 (especially sunflowers, corn fields) are cultivated intensively during the breeding season. In
309 contrast, on spring-cover crops and fallow lands – with a few exceptions – we detected no
310 disturbance by agricultural machineries after ploughing or seeding. Although we didn't find a
311 significant correlation between the numbers of shot predators and the daily or total survival
312 rates of nests, this probably as a result of inaccurate data and small sample size, we chose to
313 continue managing this activity, as targeted lethal and non-lethal predator removal programs
314 are important for long-term conservation of ground-nesting bird species, especially shorebirds,
315 proven by successful conservation programmes for many species (Neuman et al., 2004; Bolton
316 et al., 2007). It is likely that there was a positive change in the efforts of predator hunting
317 (increase in the number of hunting days, and growing level of efforts to hunt game predators),
318 although no written resources, but only verbal information was available to explain this pattern.
319 Thus, a more thorough investigation into the relationships among predator removal and
320 breeding success of Collared Pratincole in the coming years.

321 We did not experience significant nest mortality by predators in nests marked with poles as
322 opposed to unmarked nests, similar to that observed by Zámečník et al. (2018), as poles were
323 left near nests only during critical, endangered periods. Thanks to the positive attitude of local
324 farmers, the organization of protection was feasible and effective, and none of the known nests
325 were at serious risk during agricultural work. However, the long-term protection of Collared
326 Pratincoles should be further improved by the establishment of fields and fallows free from
327 agricultural disturbance. As a result of the current agricultural scheme, agricultural land in
328 Hungary and Europe is typically used too intensively, arable fields typically do not remain
329 without crops for a significant part of the year (Tarjuelo et al., 2020).

330 On global scales, human activity can negatively influence the behaviour, productivity, and nest
331 survival of ground-nesting birds in various habitats, especially on farmlands (Fahrig, 1997;
332 Donald et al., 2001; Colwell, 2010, Ward et al., 2010). We have set ourselves the goal of habitat
333 development at the local level, as a result of which 50-100 hectares of fallow land are created
334 every year to facilitate the settlement of shorebirds on the Nagykunság rice systems. These
335 barren fields are created by disc-ploughing during the end of April, and after the treatment there
336 is no human disturbance during the breeding season. These areas are considered insignificant
337 in relation to the size of the total habitat, but this seems to be a promising project as a variable
338 number of birds have nested and gathered in these fallow areas in recent years. An improved
339 solution could be supported by the development of targeted agricultural programs, which would
340 specifically set management standards for the arable land used by the species, and also provide
341 financial support to farmers' efforts.

342 Taken together, our results suggest that it is worth maintaining intensive conservation activities
343 to protect rare or endangered species, as we can achieve success even in intensively managed
344 habitats. Without such interventions, large proportions of farmland bird nests are lost to
345 agricultural machinery and the remaining Eurasian population of Collared Pratincole out of
346 Hungary might be considerably threatened by anthropogenic pressure. In addition to effective
347 direct nest protection, it is important to increase the proportion of safe fallow lands in the future
348 as a specific agri-environmental protection measure so that as many farmland birds as possible
349 have the opportunity to choose this undisturbed agricultural habitat for breeding. As Collared
350 Pratincoles nest in several places in artificial habitats in Europe, mainly close to secondary
351 wetlands, such as rice fields, the breeding habitat protection or restoration should be more
352 widely implemented to maintain biodiversity in agricultural landscapes.

353 **Author contributions**

354 Study design and fieldwork: ÁK, ÁM, IK, TSz, SzG; data analysis and writing the article; ÁK,
355 ZsV, VK, ÁM, IK, SzG, TSz.

356 **Conflict of interest**

357 None

358 **Ethical standards**

359 None

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- 541

542

543 Table 1. Clutch size and nest-success in agricultural habitats of Collared Pratincoles in Hungary

544 (mean \pm SE).

545

	Row crop	Spring crop	cover	Fallow land	<i>Overall</i>
Clutch size	2.66 0.05	\pm 2.58 \pm 0.08		2.49 \pm 0.08	2.59 \pm 0.04
Number of hatched chicks per nest	1.54 \pm 0.1	1.5 \pm 0.14		1.72 \pm 0.12	1.58 \pm 0.07
Number of nests	152	71		92	315

546

547

548

549 Table 2. Relationships between hatching success (A.) and the number of hatched chicks (B.),
 550 fitted by a logistic and linear regression analyses (GLM) as a function of agro-technology, time,
 551 and space, and ecological variables. Significant relationships are indicated in bold.

552

Variables	A.				B.			
	Esti- mate	SE	z- value	p- value	Esti- mate	SE	t- value	p- value
Intercept	-463.119	124.423	-3.722	< 0.001	-292.035	63.835	-4.575	< 0.001
Agricultural								
Spring-cover crops	1.032	0.403	2.560	0.010	0.423	0.200	2.114	0.035
Fallow lands	1.354	0.447	3.029	0.002	0.719	0.216	3.321	0.001
Ecology and timing								
Year	0.231	0.062	3.741	< 0.001	0.146	0.032	4.624	< 0.001
Egg-laying start	-0.012	0.009	-1.357	0.175	-0.011	0.005	-2.285	0.023
Field boundary	0.003	0.003	0.954	0.340	0.001	0.001	1.006	0.316
Distance to water body	< 0.001	< 0.001	0.403	0.687	< 0.001	< 0.001	1.559	0.120
Social behaviour								
Breeding density	< 0.001	< 0.001	-1.391	0.164	< 0.001	< 0.001	-2.468	0.014

553

554

555 Table 3. Relationships between direct conservation efforts and agricultural habitat types (n=315
 556 nests).

A-Year	Nests found	Direct nest protection interventions	Nests failed	Nests which would be destroyed without protection
2012	24	14 (66%)	21 (88%)	14 (66%)
2013	16	9 (56%)	6 (38%)	9 (56%)
2014	14	3 (21%)	6 (43%)	3 (21%)
2015	38	31 (82%)	14 (37%)	31 (82%)
2016	46	24 (52%)	16 (35%)	20 (43%)
2017	49	12 (24%)	12 (24%)	12 (24%)
2018	34	17 (50%)	8 (24%)	17 (50%)
2019	21	13 (62%)	11 (52%)	13 (62%)
2020	33	9 (27%)	4 (12%)	8 (24%)
2021	40	27 (67.5%)	5 (13%)	23 (58%)
B-Habitat				
Row crops	152	146 (96%)	58 (38%)	140 (92%)
Spring seeded crops	72	8 (11%)	22 (31%)	5 (7%)
Fallow lands	91	5 (5%)	23 (25%)	5 (5%)

557
 558

559 **Figure legend**

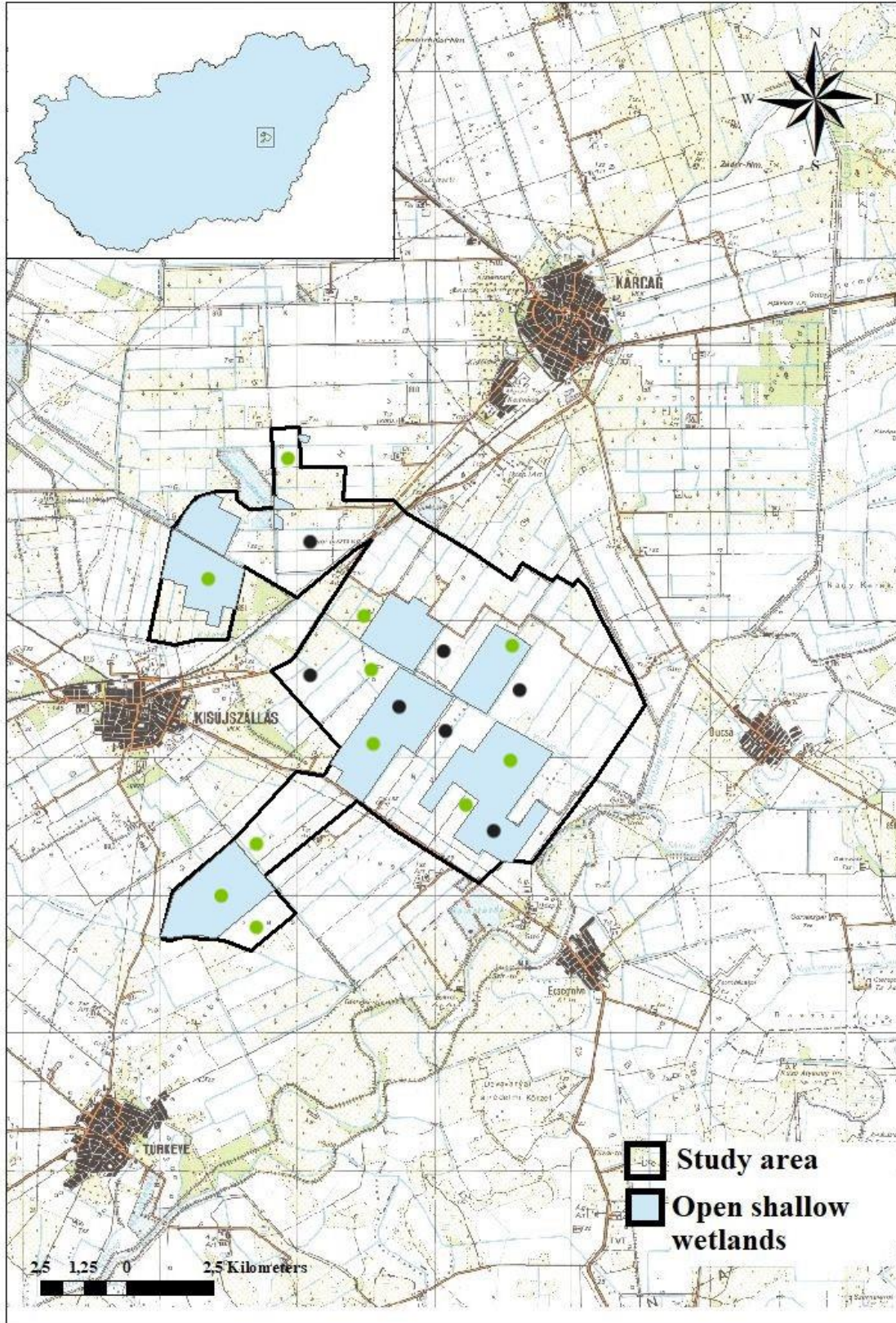
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561 Figure 1. A map of the study area (12 500 hectares, black solid line), and paddy fields (blue
562 polygons). Black dots = standard, green=alternative breeding sites.

563 Figure 2. Agricultural habitats, (A) Row crop, (B) Spring-cover crop, (C) Fallow land

564 Figure 3. A standard-sized buffer zone indicating the nest location.

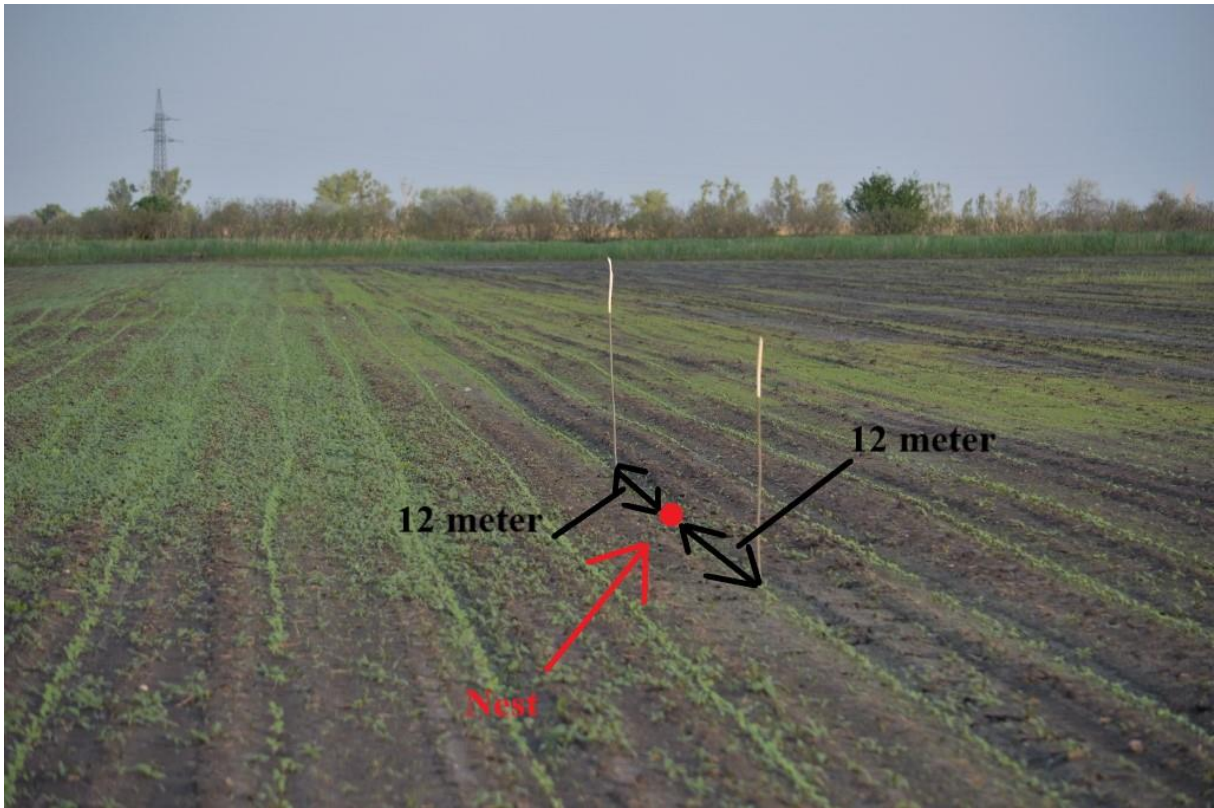
565 Figure 4. Daily nest survival (mean \pm SE) and the number of nests (in parentheses) during the
566 study years ($r^2=0.5482$, $n = XX$ years).





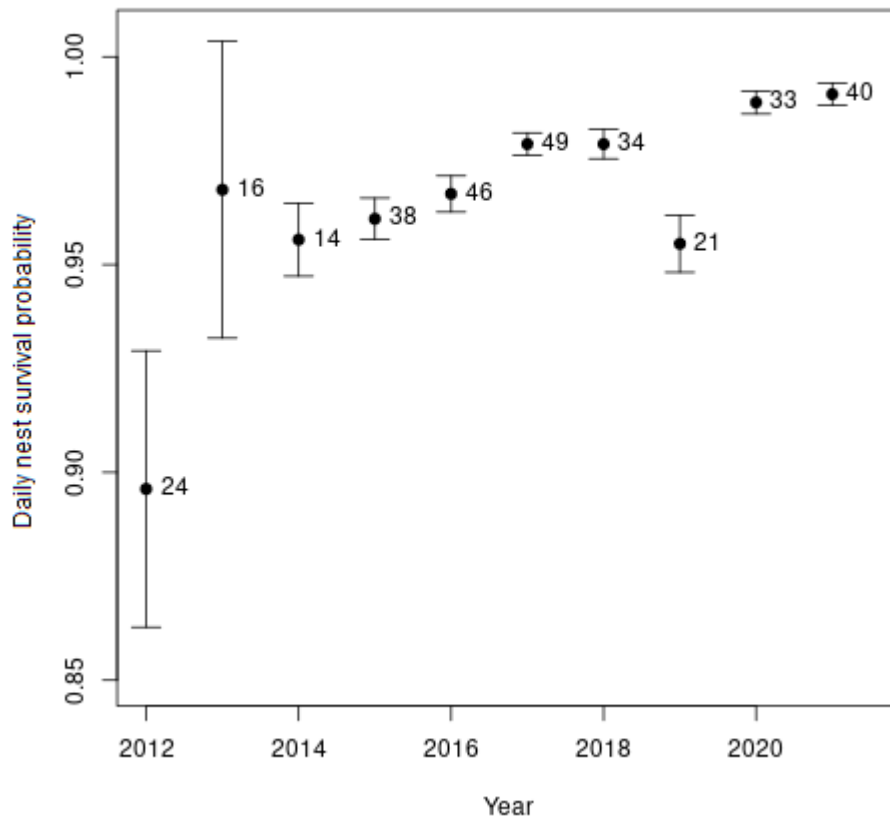
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