Farming practices and Roller *Coracias garrulus* conservation in south-west Spain

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Summary

There are no previous studies supporting the link between the decline of Roller *Coracias garrulus* populations in the Palaearctic and agricultural intensification. We studied the effect of farming practices on Roller reproduction during 1988–1991 in south-west Spain. Nest-boxes were installed on power pylons that crossed six different man-made habitats representing the most characteristic kinds of habitat in the Mediterranean region: pasture fields with and without holm oak *Quercus rotundifolia* trees, cereal fields with and without holm oak trees, scrub fields and irrigated fields. Rollers nesting in nest-boxes erected in unwooded pasture field had the highest breeding success, suggesting that this is the most suitable nesting habitat of Rollers in the region. There were no significant effects of farming practices in habitat adjacent to nests on Roller laying date and clutch size. However, after controlling for laying date, current agricultural practices around nests affected chick mortality, with higher losses in irrigated fields. Breeding success and egg productivity were also affected by farming activities, with the lowest values in irrigated fields. Future conservation plans for Rollers should consider that nest-box provision might increase habitat suitability for Roller reproduction and that highly intensified agricultural practices might have deleterious effects on Roller populations.

Introduction

The Common Agricultural Policy in the European Community has caused major alterations to traditional extensive exploitation systems and grassland habitats (Tucker and Evans 1997). These changes have included tree clearing and removal of original shrubs to favour intensive farming in the Mediterranean forests of Iberia (Marañón 1988, Campos 1993), thus reducing the availability of holes for cavity-nesting birds. Many studies have shown that the abundance of suitable holes is a limiting factor for reproduction in cavity–nesting birds in habitats in which food is abundant (Li and Martin 1991, Newton 1994, Blanco *et al.* 1997). The installation of nest-boxes is a useful tool to overcome shortage of natural nesting places and has often resulted in an increase in the local breeding density of cavity-nesters (Järvinen 1980, Bloom and Hawks 1983, East and Perrins 1988). Moreover, since nest-boxes are easily located after installation, they often provide an opportunity for studies of breeding biology (Cavé 1968, Koening *et al.* 1992, Newton 1994), although the reproductive features of the birds nesting in these artificial sites might be different from those of birds using natural holes (Møller 1989, 1992).

Roller *Coracias garrulus* is a hole-nesting monogamous Coraciiform that in northern Europe usually nests in natural holes in pines and oaks abandoned by

woodpeckers (Cramp and Simmons 1988, Sosnowski and Chmielewski 1996). In southern latitudes, in those areas where the original trees have been cleared and holes are scarce, Rollers are frequent nesters in cavities in buildings (Folch 1996). Nest-box provision increased the population size of nesting Rollers in unwooded habitats of south-west Spain (Avilés *et al.* 1999), while in pine forest in Poland, in which natural holes were abundant, Rollers seldom used nest-boxes when they were installed (Sosnowski and Chmielewski 1996).

Local and regional studies have shown population declines over most of the Roller's range (Hagemeijer and Blair 1997), and although empirical evidence on causal factors is lacking, declines have often been attributed to effects of changing agricultural practices on nest-site and food availability (Tucker and Heath 1994). However, in the only study in which habitat effects on Roller reproduction could be effectively tested, we failed to find a significant association between farming practices around nests and reproductive output in an area of south-west Spain (Avilés *et al.* 2000a). The potential long-term effect on reproduction was not studied in that work (Avilés *et al.* 2000a).

On the basis of a 4 year study, we evaluate in this paper the breeding performance of Rollers nesting in nest-boxes provided in six different habitat types in the Mediterranean region. These habitats spanned all the possible levels of farming intensification from unwooded irrigated fields to pasture with holm oaks *Quercus rotundifolia* that best represented the natural (original) habitat of the species in south Iberia.

Study area and methods

The study area was in the Serena region (39°03′N, 5°14′W), in the mesomediterranean climatic zone (Rivas-Martínez 1981), and covered 74,334 ha. During May and June the mean temperature was 17.7°C and the mean rainfall 11.6 mm. The area was characterized by the predominance of dry pasture fields (39.9%) and cereal fields (31.1%) (mainly wheat, barley and oats). There were also small areas of scrub (18.3%) (mainly *Retama sphaerocarpa*), wooded cereal (5.0%) and pasture fields (4.0%) with holm oak trees and recently introduced irrigated crops (1.7%).

In February and March from 1988 to 1991 nest-boxes with a roof surface of 32 × 18 cm, a height of 19 cm and an opening of 6 × 18 cm were gradually installed on pylons of 43 power lines. Power lines crossed six different patches that represented all the various man-made habitats in the study area (see Table 1 for a detailed description of the number of boxes installed in each habitat type each year): (1) **pasture fields without holm oak trees** exclusively used by livestock (mainly sheep) that fed on grass; (2) **pasture fields with holm oak trees** where sheep and pigs ate holm oak acorns in winter, and sheep fed on grass the rest of year; (3) **cereal fields without holm oak trees** that were sown mainly in November and December each year with oats, wheat and barley. Harvesting of cereal usually occurred after Roller chick fledging in the study area, consequently no changes in habitat physiognomy in those patches with cereal by early harvesting were detected during our study; (4) **cereal fields with holm oak trees** used by livestock only after harvesting; (5) **irrigated crops**, mainly rice and maize; and (6) **scrub fields** (mainly of *Retama sphaerocarpa*) also used by livestock (mainly sheep). We classed pasture and cereal fields with holm oak trees as

Table 1. Number of available nest-boxes for Rollers, with numbers used in parentheses, in different habitats during 1988–1991 in south-west Spain.

	1988	1989	1990	1991	Percentage occupation[a]
Cereal field	10 (7)	54 (37)	172 (77)	199 (95)	49.65
Cereal field with holm oak	–	–	32 (10)	32 (12)	34.37
Pasture field	10 (6)	81 (66)	197 (128)	256 (169)	67.83
Pasture field with holm oak	3 (3)	17 (8)	22 (14)	26 (12)	54.41
Scrub field	15 (13)	58 (41)	116 (56)	117 (56)	54.24
Irrigated field	–	7 (6)	13 (7)	11 (6)	61.29
Percentage of occupation[b]	76.31	72.81	52.89	54.60	

[a]All years pooled.
[b]All habitat pooled.

different habitat types because the presence of trees better fitted the original situation in the Mediterranean region before the drastic tree-clearing of current agricultural practices. The mean ($\pm$ S.D.) abundance of boxes of 9.43 ± 0.26 per kilometre of power line was constant among habitats and study years.

Each nest-box was assigned to the relevant habitat type. As in a previous study (Avilés *et al.* 2000a) we did not consider the last two boxes in each electric power line included in a habitat type in order to avoid the possible effect of the proximity of two habitat types on breeding success. Previous observations suggested that this was a reasonable estimate of Roller hunting territories, since the mean foraging distance from the nest during the nesting period was 165.0 ± 171.2 m ($n = 30$ observations within the study area), and 66.7% of the adult foraging flights occurred within a radius of 100 m.

Those habitats with farmhouses with available holes for nesting were also checked, as were more of the holes in the trees included in pasture and cereal fields. Because we found no evidence of Rollers breeding outside boxes, we assumed that our findings in each habitat type were representative.

In a previous study we found that Rollers showed no clear preference for previously unused nest-boxes when used and recently installed boxes were available in the same area (Avilés *et al.* 2000b). Moreover, nesting success did not vary between these two types of boxes (Avilés *et al.* 2000b).

Density-dependent effects are expected to affect reproduction of a species when resources are scarce or when differences in resource suitability exist. Nest-box provision supposed a large increase in the number of available sites for nesting in the area. Before nest-provisioning most Roller nests were on buildings (55.6%, $n = 9$; Aguilar 1980). However, large parts of the study area remained unwooded and had a low density of buildings, which probably precluded Roller reproduction in suitable areas. After nest-box erection more than 32.0% of the nest-boxes remained unoccupied when Roller chicks fledged, suggesting that those boxes were available to hypothetical late breeders coming into the study area (Table 1). Moreover we checked farmhouses and no Roller reproduction was reported, and no fights between Rollers were recorded at the arrival time, when they first occupied the nest-boxes, or during nest-box monitoring, that might suggest nest competition (pers. obs.). Altogether, evidence suggested that no density-dependent effects affected our results.

Eurasian Kestrels *Falco tinnunculus* also bred in our nest-boxes and started laying at least 1 month before Rollers (Avilés *et al.* 2000c). During the study kestrels occupied only 11.0–18.0% of boxes, but we had no evidence that they affected Rollers.

All boxes were monitored weekly from the first stages of breeding each year from 1988 to 1991. In those boxes occupied by Rollers, visits were increased (one visit every 3–4 days) during the nesting period to determine breeding success more accurately. Laying date for each nest was determined by subtracting the incubation period of the species (18 days; Cramp and Simmons 1988) from the hatching date. Hatching date was determined by experienced observers, who took into account the 2-day laying interval (Cramp and Simmons 1988). We measured **hatching success** as the percentage of eggs within each clutch that hatched; **breeding success** as the number of fledglings per pair that laid at least one egg; number of **fledglings per successful nest** as those nests in which at least one chick fledged; **chick mortality** as the percentage of hatched chicks that died in the nest, and **egg productivity** as the number of fledglings as a proportion of the total number of eggs laid. We assumed that no more than one brood was produced by each pair per year (Cramp and Simmons 1988).

Statistical analyses

Laying date, clutch size, breeding success and fledgling success were log-transformed to fit a normal distribution. Arcsine square-root transformations were performed on proportions (hatching success, chick mortality and egg productivity) (Zar 1996). We ran General Linear Models for checking the effects of the habitat type around the nests on Roller reproductive parameters. To ensure independence we also included the study season in the models since there was more than one breeding pair per year. Firstly, we ran a model with laying date as the dependent variable and habitat type and study season as main effects. Because, within each breeding season, reproductive output declined with laying date (Avilés *et al.* 1999), we included the laying date in the model when analysing the effects on the rest of breeding parameters. Post-hoc comparisons were checked by using Scheffé tests.

Results

Mean laying date of Rollers did not vary among habitats, but it did among years (Table 2), being earlier from 1988 to 1991 (Scheffé tests $P < 0.05$ in all cases; 1988 = 159.0 ± 16.4, $n = 15$; 1989 = 151.9 ± 11.8, $n = 143$; 1990 = 144.7 ± 8.5, $n = 288$; 1991 = 139.4 ± 10.9, $n = 277$). Mean clutch size did not vary among years nor among the different habitat types after controlling laying date (Table 2).

Breeding success and the percentage of eggs that hatched differed among years (Table 2). Yearly differences in hatching and breeding success were due to the exceptionally high values of those breeding parameters in 1991 compared with 1989 and 1990 seasons (Scheffé tests: $P < 0.0001$ in the four cases). Differences among habitats in the percentage of hatched eggs and in breeding success were both marginally significant (Table 2), with Rollers nesting in irrigated fields having the lowest breeding success and those in pasture fields the highest. Surprisingly, the presence of trees seemed to be an important factor determining

Table 2. Results of General Linear Models of Roller breeding parameters in relation to the study year and habitat type around nests in south-west Spain, 1998–1991.

Dependent variable	Independent variable	*df* effect	*df* error	F	*P*
Laying date	Study season	3	59.3	24.3	0.00001
	Habitat type	5	59.1	1.9	ns
	Study season × Habitat type	12	702.0	1.5	ns
Clutch size	Study season	3	80.1	1.2	ns
	Habitat type	5	75.8	1.8	ns
	Study season × Habitat type	12	701.0	1.2	ns
Hatching success	Study season	3	178.6	5.5	0.001
	Habitat type	5	168.4	2.0	ns
	Study season × Habitat type	12	701.0	0.6	ns
Breeding success	Study season	3	232.3	5.0	0.002
	Habitat type	5	219.6	2.0	ns
	Study season × Habitat type	12	701.0	0.5	ns
Fledgling success	Study season	3	86.5	2.2	ns
	Habitat type	5	68.5	0.5	ns
	Study season × Habitat type	12	578.0	1.2	ns
Chick mortality	Study season	3	65.7	2.4	ns
	Habitat type	5	60.1	4.6	0.001
	Study season × Habitat type	12	583.0	1.3	ns
Egg productivity	Study season	3	217.5	5.2	0.001
	Habitat type	5	205.3	2.8	0.018
	Study season × Habitat type	12	701.0	0.5	ns

hatching success, because the lowest percentage of eggs hatched was detected in boxes in cereal fields with holm oaks and the highest percentage in boxes in cereal fields without trees. The number of fledglings per successful nest did not vary among years and was not affected by the habitat type around nests (Table 2).

Chick mortality during the nesting period differed among habitat types (Table 2), but not among years (Table 2). Chick mortality in the irrigated fields was more than twice that in pasture field with holm oaks, cereal fields, pasture and scrub areas (Figure 1; Scheffé tests $P < 0.03$ in the four cases). Chick mortality in irrigated fields was higher than that in cereal fields with holm oak trees (Table 2), but differences only approached formal significance (Scheffé test $P = 0.08$).

The high mortality rate of chicks in the irrigated fields caused the lowest values for egg productivity and breeding success when the data for the four years were pooled (Table 2, Figure 1). Percentage of egg productivity also differed among seasons, with mean values in 1991 ($79.45 \pm 28,98$, $n = 277$) being significantly higher than those in 1989 (63.37 ± 39.82, $n = 143$) and 1990 (61.96 ± 39.98, $n = 288$; Scheffé tests $P < 0.0002$ in both cases), but not in 1988 (76.22 ± 34.99, $n = 15$; Scheffé tests $P > 0.05$). However, inter-season differences in egg productivity were not explained by habitat type around nests (Table 2).

Discussion

Roller reproductive output was affected by habitat transformation by current agricultural practices around the nests. Those Rollers nesting in highly intensified
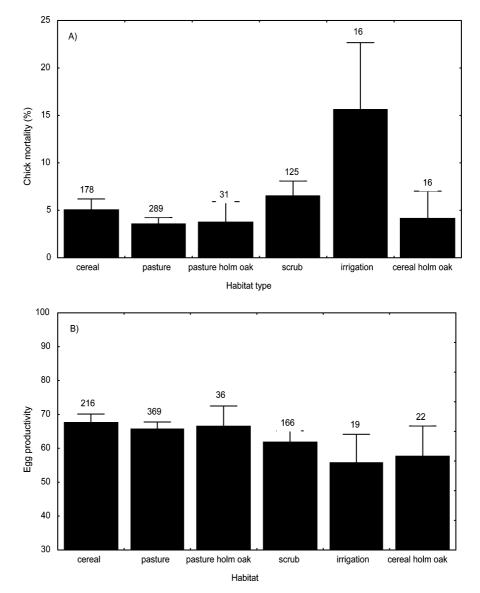
Figure 1. Mean (± S.E.) chick mortality (a) and egg productivity (b) in Roller in relation to habitat type around nests, in south-west Spain, 1988–1991. Sample size is given above the error bars. Habitat types are: pasture fields without holm oak trees; pasture fields with holm oak trees; cereal fields without holm oak trees; cereal fields with Holm oak trees; irrigated crops; and scrub fields.

irrigated fields had the highest chick mortality and the lowest egg breeding success among all the habitat types in the area. Losses were mainly during the chick rearing time, since the number of hatched eggs in irrigated fields did not differ from those in more moderately transformed habitats. On the other hand, unwooded pasture fields seemed to be the most suitable nesting habitat for

rollers in the region since it was the only habitat in which nest-boxes were selected more than expected by chance and because Rollers nesting in that habitat registered the highest breeding success.

Two different explanations are possible for the high chick mortality in irrigated fields. Firstly, the existence of a high density of potential predators in irrigated fields may have influenced chick mortality. A single Raven *Corvus corax* in Brozas (SW Spain) removed all the chicks of 20 consecutive boxes occupied by Rollers (J. C. Nuñez pers. comm.) in a short time period. However, we detected no signs of predation on chicks during nest-box monitoring, and dead chicks were always found within the nest-box in all the habitat types. A second possibility was that the high chick loss rate in irrigated fields was a consequence of the use of insecticides by farmers, which may have killed the chicks directly or removed their food supply. The intensification of farming practices might promote a high abundance of insects, which is often positively correlated with chick survival in insectivorous birds, and is sometimes used to explain the range expansion of some insect-eating species (e.g. Prince and Clarke 1993). Evidence of this relatively high insect-food availability in irrigated fields also exists for the rice-fields in the Ebro Delta in north-east Spain (González-Solis *et al.* 1996). However, agricultural intensification usually also brings an increase in the use of insecticides and can lead to a widespread decrease in the availability of chick-food invertebrates (Brickle *et al.* 2000). This is the case in our study area, where farmers usually applied insecticides on irrigated fields in early summer (mainly 1 June) to avoid insect plagues, mainly of Orthoptera, the main food of Roller chicks (Avilés and Parejo 1997). Hence, we think that the most plausible explanation of high chick mortality in irrigated fields is the sudden decrease in insect availability following insecticide use by farmers. We had no evidence that the chicks were poisoned.

Conservation perspectives

Hagemeijer and Blair (1997) pointed out the scarcity of quantitative data relevant to the conservation of Rollers and on the main factors that have caused its general decline in Europe. Our results showed that farming practices influenced nesting success in Rollers, and suggest that habitat differences resulting from agricultural intensification may lead to differences in Roller densities and reproductive success. One main finding concerning Roller conservation arose from our results: that the type of human management of habitat affects suitability of that habitat for Rollers. We have found clear links between intensive agricultural practices and chick losses. However, experimental studies manipulating different components of habitat suitability (i.e. food availability, nest-hole availability) as affected by agricultural practices are needed to discover the mechanisms involved in the variation in Roller breeding traits among habitats detected in this study.

Acknowledgements

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