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Edge effects on nest predation in Mediterranean fragmented forests

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Edge effects on predation of artificial avian nests were studied in a forest archipelago mixed with agricultural land in Central Spain. Predation rates were lower on farmland than in the forest habitat. There was a trend towards lower predation on the forest edge than in the interior. This edge–core predation gradient differed from the usual pattern of nest predation found in other temperate fragmented forests. Predation by rodents was almost completely restricted to the forest habitat. We suggest that in very small fragments, such as those studied here, a 'packing effect' of small specialist forest predators could be the cause of high predation rates throughout the forest.

INTRODUCTION

Theoretical and experimental research in 'insularization', the process of island formation through fragmentation of original habitats (Wilcox, 1980), has focused on its consequences for the conservation of populations and species (Janzen, 1986; Wilcove *et al.*, 1986). Most analyses have been devoted to forest habitats and vertebrate populations because they are apparently more sensitive to harmful effects of fragmentation (Whitcomb *et al.*, 1981; Harris, 1984; Wilcove, 1985).

It has been suggested that edge effects cause some of the main problems for forest bird species in fragmented environments. Nest success may decrease near edges because of the increase in small generalist predators and a higher incidence of parasitism than in forest interiors (Gates & Gysel, 1978; Andrén *et al.*, 1985; Wilcove *et al.*, 1986; Andrén & Angelstam, 1988; Temple & Cary, 1988; Møller, 1989). Another consequence of fragmentation is a geometric reduction of forest core habitat, free of edge effects, and therefore a reduction in the proportion of high-quality territories for forest interior birds (Temple & Cary, 1988). Some authors, however, have pointed out a lack of negative consequences associated with fragmentation (Angelstam, 1986; Ratti & Reese, 1988; Yahner *et al.*, 1989). Since habitat fragmentation and accompanying edge increase are major problems faced by wildlife (Temple & Wilcox, 1986), more research is needed to understand their effects in relation to a variety of factors (location, predator type, fragmentation intensity, etc.), and to design suitable management practices (Ratti & Reese, 1988; Yahner, 1988).

We investigated the effects of fragmentation on artificial bird nests in an archipelago of very small forest tracts surrounded by agricultural land in a Mediterranean environment. The aims were (1) to compare the nest predation rates inside and outside forest fragments, and (2) to test whether predation gradients associated with habitat edges are similar to those found in other studies.

STUDY AREA

The study area is located in Villamayor de los Montes, Burgos province, in Central Spain (42°5'N, 03°45'W), at an altitude of 850 m. Farming has drastically reduced the original habitat to an archipelago with forest fragments ranging from 0·1 to 21 ha. Core–edge distance in the largest tract does not exceed 100 m. Holm oaks *Quercus rotundifolia* and Lusitanian oaks *Q. faginea* form a 5·5-m high tree stratum with 35% coverage. The

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shrub layer (33% coverage) is dominated by *Cistus* spp. and several chamaephytes of the genera *Thymus* and *Lavandula*.

Bird communities were censused throughout spring 1988 using the line-transect method (Järvinen & Väisänen, 1975) along a 3·9-km fixed itinerary. Twenty-five forest bird species bred in the study area. Fifteen were passerines, which accounted for 90% of the breeding community (maximum densities were 44·1 birds/10 ha). Six migrants (subalpine *Sylvia cantillans*, Orphean *S. hortensis* and Bonelli's *Phylloscopus bonelli* warblers, nightingale *Luscinia megarhynchos*, tree pipit *Anthus trivialis* and ortolan bunting *Emberiza hortulana*) formed 60% of the passerine group. The rest included nine resident species (wood lark *Lullula arborea*, blackbird *Turdus merula*, robin *Erithacus rubecula*, great and blue tits *Parus major* and *P. caeruleus*, chaffinch *Fringilla coelebs*, serin *Serinus serinus* and cirl bunting *E. cirlus*).

The mammalian nest predators living in the study area are wild boar *Sus scrofa*, red fox *Vulpes vulpes*, badger *Meles meles*, weasel *Mustela nivalis*, European polecat *M. putorius*, western hedgehog *Erinaceus europaeus*, and several species of rodents including wood mouse *Apodemus sylvaticus* and garden dormouse *Eliomys quercinus*. Corvids include carrion crow *Corvus corone*, magpie *Pica pica* and jay *Garrulus glandarius*. The ocellated lizard *Lacterta lepida* was the only reptilian predator observed.

METHODS

Fieldwork was carried out with open nests during spring 1988: artificial canary nests were used after being muddied to camouflage them from predators (Martin, 1987). The nests were placed on the ground (n=64) and above ground level in the tree substratum (n=192) in four distance classes from the forest edge: 0–10 m, 11–25 m, 26–50 m and 51–100 m (see Table 1 for sample sizes). Additional nests (n=60) were placed in the farmland surrounding the forest patches, at a minimum distance of 30 m from the edges. Each nest was baited with two commercial Japanese quail *Coturnix coturnix* eggs. The nests were uniformly arranged approximately 30 m from one another and exposed to predators for eight days. Nests in which one or two eggs had been broken or had disappeared were considered depredated. Although predation on artificial nests is not comparable to that in natural conditions, the rates obtained may be used as indices if nests with a similar appearance are compared (Martin, 1987).

Rodents were the only predators leaving clear signs of predation, namely toothmarks and faeces (Bang & Dahlström, 1972; Green *et al.*, 1987). The majority were attributable to garden dormice, while the wood mouse was a minor predator.

RESULTS

Predation rates were higher in forest patches than on agricultural land (87·5% vs 50%, χ^2=40·997, d.f.=1, p<0·001). In ground-level nests, predation rates were also higher in forest patches (76·6% vs 50%, χ^2=8·336, d.f.=1, p<0·01). These differences were clear regardless of the distance from the edge of the forest nests, but not for the predation rate of ground nests nearest to the edge (0–10 m; Table 1).

Within the forest habitat, predation rates were homogeneous (χ^2=3·071, d.f.=3, p>0·3) in spite of lower losses of nests nearer the edge (Table 1). Similar results were obtained for ground nests and tree nests considered separately (χ^2=2·184, d.f.=3,

Table 1. Numbers of predated nests according to habitat, distance to edge (in m), nest location, and rodent predators

Habitat type	Tree nests					Ground nests					Total	
	No. placed	No. predated	%	No. predated by rodents	%	No. placed	No. predated	%	No. predated by rodents	%	No. predated	%
Farmland	—	—	—	—	—	60	30	50·0	1	1·7	30	50·0
Forest												
Distance from edge												
0–10	49	37	75·5	10	20·4	16	8	50·0	3	18·8	45	69·2
11–25	47	44	93·6	10	21·3	16	13	81·3	5	31·3	57	90·5
26–50	48	48	100·0	10	20·8	16	13	81·3	7	43·8	61	95·3
51–100	48	46	95·8	7	14·6	16	15	93·8	8	50·0	61	95·3

$p>0{\cdot}3$ and $\chi^2=1{\cdot}874$, d.f.=3, $p>0{\cdot}5$, respectively), and with the nests pooled in two distance classes: 0–10 m and 11–100 m or 0–25 m and 26–100 m ($p>0{\cdot}08$ in all tests). Predation on tree nests was higher than on ground nests (91·1% vs 76·6%, $\chi^2=8{\cdot}048$, d.f.=1 $p<0{\cdot}01$).

The effects of rodent predators were much greater in the forest habitat than on farmland (Table 1), both for all nests (23·4% vs 1·7% depredated nests; $\chi^2=13{\cdot}425$, d.f.=1 $p<0{\cdot}001$) and ground nests (35·9% vs 1·7%; $\chi^2=21{\cdot}158$, d.f.=1, $p<0{\cdot}001$). Rodent predation within the forest fragments did not change with distance from the edge ($p>0{\cdot}3$ in three tests).

DISCUSSION

In contrast to general trends, several authors working in fragmented forests surrounded by agricultural land found no difference between nests placed at different distances from the forest edge (Yahner & Wright, 1985; Angelstam, 1986; Ratti & Reese, 1988; Yahner *et al.*, 1989). The landscape structure was, however, very different in these studies, since the forest was the dominant element and edge contrasts were not equivalent to farmland–forest ecotones of extensive agricultural landscapes.

Edge effects may thus vary with landscape matrix and edge type. Agricultural matrices are responsible for increases in generalist nest predators (corvids and certain mammal species in temperate latitudes; Andrén *et al.*, 1985; Angelstam, 1986), and edge contrast (abrupt vs feathered) may affect predation rate via habitat structure (Ratti & Reese, 1988). Furthermore, in very small patches of forest any edge effect could be precluded by a lack of genuine forest interior (Wilcove *et al.*, 1986; Andrén & Angelstam, 1988; Temple & Cary, 1988). The edge effects could thus differ within these tiny patches and in larger tracts.

Our results fit this context. First, nest predation was higher in forests than in the farmland habitat (open field), the opposite of the expected pattern (Ricklefs, 1969; see, however, O'Connor & Shrubb, 1986). Secondly, contrary to evidence from previous studies in similar landscapes, predation rates did not decrease towards the centre of the forest habitat; although differences were not significant, both tree and ground nests showed a clearer trend towards lower predation risks near edges than in the forest interior (Table 1).

In a landscape similar to our study area, Møller (1989) reported lower predation rates in farmland habitat than forest interior, but the highest rates occurred on the edges. The high nest predation found in our forest tracts could be caused by the small size of all fragments, with the edge effect influencing the entire forest area (Wilcove *et al.*, 1986). In this context, the predation gradient found is not inconsistent with 'normal' predation responses to edge and fragmentation in larger forest patches in the study area. In fact, arguments for normal predation patterns arose from experimental work on a set of forest patches ranging from 0·2 to 270 ha, in which densities and predation incidence by mice maintained an inverse relationship to forest size (Tellería *et al.*, 1991). The pattern of nest predation in wooded islands is studied further by Tellería and Santos (in press) with special reference to the significance of forest size.

We may assume therefore that edge and size effects were present in the archipelago, probably acting as an 'ecological trap' for many forest species, although in a different way from that claimed by Gates and Gysel (1978) across field–forest ecotones. Evidence gathered in agricultural ecosystems of Central Spain has pointed to a concentration of generalist rodents such as wood mice in wooded areas under winter conditions (Alcántara, 1986; Tellería *et al.*, 1991). In more specialist forest species, this 'packing effect' could be more constant and heavier (Whitcomb *et al.*, 1981; Rosenberg & Raphael, 1986).

The rodent presumably involved in our study, the garden dormouse, is a typical forest-dweller in the field–forest landscape of the study area (González & Román, 1988). The concentration of this species and other unidentified forest predators in the forest interior may have been responsible for the observed gradient in predation. If this is the case, the importance of 'habitat specialist' forest interior predators should be recognized. This contradicts the edge-effect pattern currently cited in the fragmentation processes studied in more northerly regions where generalist edge predators are involved (Gates & Gysel, 1978; Andrén *et al.*, 1985; Wilcove *et al.*, 1986; Andrén & Angelstam, 1988; Møller, 1989). Moreover, the restricted activity of forest predators in the edges could be partly explained as an avoidance of predation interference and competition with the larger generalist predators, whose activity is mainly concentrated on the edges (e.g. red foxes, badgers, weasels, carrion crows; personal observations; see also Angelstam, 1986).

Two conclusions may be drawn from a conservation perspective. First, the high rate of nest predation may be characteristic of very small patches of forest with consequent problems in the conservation of bird fauna in highly fragmented habitats. Forest fragmentation is, however, a general trend in temperate latitudes (Wilcove *et al.*, 1986), and of increasing concern in many agricultural areas in Spain.

Second, distinctive patterns of nest predation emerge in different regions, probably depending on the composition of the predator community (Ratti & Reese, 1988; Yahner *et al.*, 1989) and on the landscape structure and dynamics (Forman & Godron, 1986). The instability and heterogeneity of Mediterranean landscapes caused by natural processes and human management (Le Houérou, 1981; Forman & Godron, 1986; see also Ministerio de Agricultura, 1978, and Rivas-Martínez, 1981, for Spain) could trigger off fast changes in predator communities. In Spain, extensive recent changes in agriculture are affecting the structure of the landscape matrix (Baldock & Long, 1987). Therefore, some particular predation features found in this study could be temporal, and associated with differences in predator community dependent on the zoogeographical context and the current landscape dynamics of the study area.

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