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ORIGINAL ARTICLE

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Edge effect on bird nest predation in the fragmented caldén (*Prosopis caldenia*) forest of central Argentina: an experimental analysis

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Abstract Clearing of caldén (*Prosopis caldenia*) forests for agriculture and cattle raising in east-central La Pampa Province, central Argentina, has created a highly fragmented landscape, a condition that has resulted in adverse effects on birds in other forests, mainly through increased predation rates near forest edges. We evaluated bird nest predation rates using artificial nests, assessing the effects of forest fragment size, distance to the edge and nest height. We measured survival rate of 570 artificial nests located in trees, in bushes and on the ground, at different distances from the edge, in six forest fragments ranging in size from 2.1 to 117.6 ha, during two consecutive breeding seasons. Nest predation rates were significantly related with the number of days of exposition of the nest, nest height and distance to the edge, whereas fragment size and year of the experiment were not associated with predation rates. Ground nests were less likely to be predated than those located in bushes and trees. Predation rates decreased with the distance to the edge, showing a pattern consistent with the existence of an edge effect.

Keywords Artificial nests · Fragmentation · Predation · Semiarid forest · *Prosopis caldenia*

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Introduction

Nest predation is the major cause of bird population declines in fragmented forests (Saunders et al. 1991; Andrén 1992; Keyser 2002). Predation rates usually increase from the interior of the forest towards the edge, mainly because forest edges usually offer appropriate habitats for generalist predators (Gates and Gysel 1978; Brittingham and Temple 1983; Wilcove 1985; Robinson 1992; Martin 1993; Paton 1994; Robinson and Wilcove 1994; Zanette and Jenkins 2000), which frequently use them as they move among the different types of patches (Andrén 1992; Suarez et al. 1997). Furthermore, nests can be more visible in the edge than into the forest for predators inhabiting the matrix surrounding forest, and therefore can be more vulnerable there. However, higher nest predation rates at edges have been questioned as a general pattern (Paton 1994; Suarez et al. 1997; Vetter et al. 2013). Some researchers have pointed out the shortage of studies that investigate the importance of the nature and physical structure of the edge in determining predation rates (Paton 1994; Suarez et al. 1997; Lahti 2001). For example, the magnitude of the edge effect is often related to the level of contrast between the matrix and the original habitat, and also to matrix area (Lindenmayer and Franklin 2002).

The use of artificial nests is not appropriate in order to estimate natural predation rates because several factors acting on natural nests cannot be considered (e.g., adult activity, nest defense) (Martin 1987; Willebrand and Marestrom 1988; Zanette 2002; Burke et al. 2004; Faaborg 2004; Moore and Robinson 2004). However, artificial nests may be useful to compare predation rates among different habitat types (Reitsma 1992; Tellería and Díaz 1995; King et al. 1999; Estrada et al. 2002; Villard and Pärt 2004). Artificial nests have some advantages over natural nests; for example, a higher number of nests can be deployed at precise microsites allowing implementation of complex experimental designs (Estrada et al. 2002).

The caldén (*Prosopis caldenia*) is an endemic tree that comprises almost monospecific forests (locally called "Caldenal") characteristic of the Espinal biome in the semi-arid pampas of central Argentina (Cabrera 1976). The fragmentation of the caldén forests began in early 20th century, after the Desert Conquest campaigns and later settlement. New inhabitants started the building of dirt and forest roads, and with the arrival of tillage tools caldén areas were cleared for farming, resulting in an increase in farmland habitat from 8952 to 1088451 hectares (for La Pampa Province) between 1895 and 1914. Forest fragmentation and farmland expansion have generated a landscape with an increased proportion of sharp edges mostly contiguous to croplands (Sosa 2008). Highest fragmentation rates can be found in the east-central part of the province, where small patches of mature forest are surrounded by a matrix of agricultural and cattle raising lands. To the west larger forest areas occur in a variety of successional stages that are utilized to cattle ranching and hunting and are fragmented by dirt paths and roads. Nest predation rates in this system could change according to the degree of forest fragmentation and the edge effect associated, although this relationship has not been studied so far. We hypothesized that fragmentation level and edges have a detrimental effect on nest survival because of enhanced predation rates. The goal of this study is to evaluate bird nest predation rates using artificial nests, assessing the effects of forest fragment size, distance to the edge and nest height location.

Methods

The study site was located in La Primavera Ranch, an agriculture and livestock area 25 km north of Santa Rosa, La Pampa Province (36° 23′S, 64° 20′W; Fig. 1). Caldén is the dominant tree in the forest, with heights above 8 m, and molle (*Schinus fasciculatus*) and chañar (*Geoffroea decorticans*) are also present. In this area the habitat is an open forest with a relatively dense shrub stratum that includes piquillín (*Condalia microphylla*), llaolín (*Lycium chilense*), and small young caldén trees. The herbaceous stratum has a high cover, and is mostly represented by *Stipa* spp. (Sosa 2008).

We evaluated nest predation rates by using a total of 570 artificial nests during 2003 (258 nests) and 2004 (312 nests) breeding seasons. We placed nests at three heights and at different distances from the edge in six forest fragments ranging in size from 2.1 to 117.6 ha (Fig. 1).

Nests were open cups built especially for the authors with jute twine resembling those made by the most common bird species that breed in open nests in the forest (Table 1). We chose jute because it is malleable and easily stained, and it simulates herbaceous fibers used by the birds for nest construction in the study site (de la Peña 1987; Narosky and Salvador 1998; Sosa 2008). Average (±SE) nest diameter was 6.93 ± 0.82 cm, with a depth of 3.73 ± 0.32 cm. Nests were camouflaged coloring them (with color and texture resembling those of bird species at the study site) using natural dyes to avoid predator attraction (Reitsma 1992). In order to eliminate the characteristic scents of thread and dye used, nests were washed with water for three days and then dried in the shade (to avoid shrinkages). Later, nests were submerged in a humid mixture of lichens and caldén bark and leaves. This task, as well as nest placement in the field, was carried out with gloves to avoid contamination with human scents.

Nests were located at three heights, corresponding to the main strata in the forest: (1) on the ground, in grassy patches; (2) in bushes (height: 1.34 ± 0.26 m); and (3) in trees (2.81 ± 0.28 m) (Fig. 2). Nests in bushes and trees were held with fine wire carefully camouflaged among

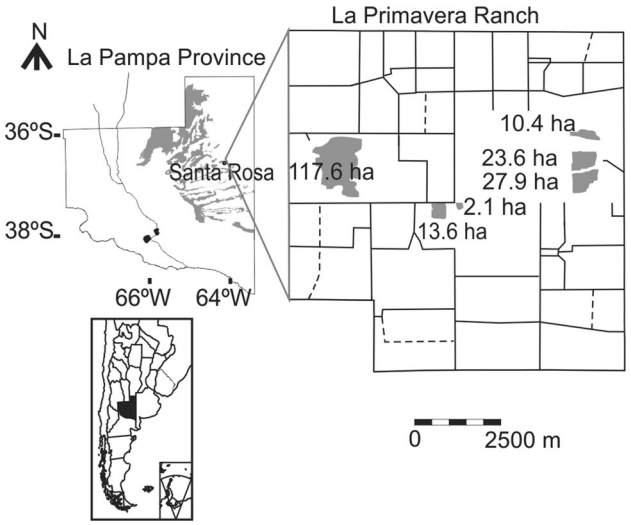

Fig. 1 Location of the study area in *La Pampa Province*, central Argentina. Caldén (*Prosopis caldenia*) forests are shown in *gray*. The size of each fragment studied is indicated

Table 1 Common bird species breeding in open nests in fragments of caldén forests in La Pampa Province, Argentina

Common name	Scientific name
White-crested elaenia	*Elaenia albiceps*
Small-billed elaenia	*Elaenia parvirostris*
Southern scrub-flycatcher	*Sublegatus modestus*
Suiriri flycatcher	*Suiriri suiriri*
Straneck's tyrannulet	*Serpophaga griseicapilla*
Vermilion flycatcher	*Pyrocephalus rubinus*
Yellow-billed tit-tyrant	*Anairetes flavirostris*
Greater wagtail-tyrant	*Stigmatura budytoides*
Tropical kingbird	*Tyrannus melancholicus*
White-winged black-tyrant	*Knipolegus aterrimus*
Fork-tailed flycatcher	*Tyrannus savana*
White-tipped plantcutter	*Phytotoma rutila*
Masked gnatcatcher	*Polioptila dumicola*
Saffron finch	*Sicalis flaveola*
Grassland yellow-finch	*Sicalis luteola*
Rufous-collared sparrow	*Zonotrichia capensis*
Double-collared seedeater	*Sporophila caerulescens*
Hooded siskin	*Spinus magellanicus*

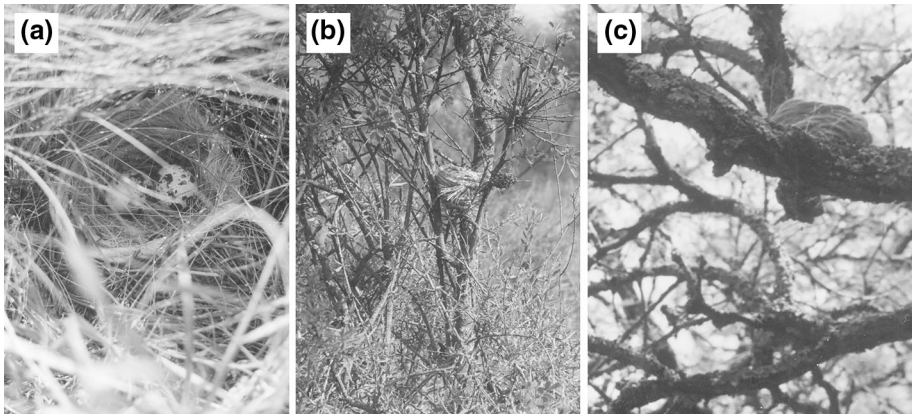

Fig. 2 Artificial nests located on the ground (**a**), in bushes (**b**), and in trees (**c**) in fragments of caldén forests in La Pampa Province, Argentina

the branches (Brand and George 2000; Eriksson et al. 2001; Piper and Catterall 2004). Nests were placed at 50-m intervals along transects located from the edge towards the interior of the fragment (depending on the size of the fragment, maximum transect length was 250 m). Transects contained from two nests in small fragments, to five nests in large fragments. All transects were randomly located in fragments which were separated at least by 100 m. Nests on the ground were placed at each point along the transect whereas nests in bushes and trees were placed 25 m to the left and the right sides of the point, at random. Therefore, nests located on plants were always separated for at least 50 m.

Following Marini et al. (1995), nests were left empty during three days after installation, and then two quail (*Coturnix* sp.) eggs were placed in each nest using gloves. Nests were checked at 5, 10 and 15 days after the placement of the eggs (Martin 1987; Saracco and Collazo 1999; Githiru et al. 2005; Zuria et al. 2007), spanning the duration of the incubation period of the most common breeding bird species of the study site (de la Peña 1987; Narosky and Salvador 1998; Sosa 2008).

It was considered that a nest had been predated when at least one of the eggs was chopped, broken or had disappeared; or when the nest showed signs of having been chewed or it had disappeared. Although predator identification was not the primary purpose of this study, we considered that pecked eggs had been predated by birds and broken ones had been predated by mammals. Missing eggs and nests, probably predated by snakes (Söderström et al. 1998), were conservatively assigned to non-identified predators. Footprints were analyzed where ground nests had been predated, and on some occasions we were able to identify predators by scent in the nest (e.g., armadillos, foxes, southern hog-nosed skunks). Finally, to identify potential predators inhabiting the forest fragments, we placed trap-cameras in bushes and trees at random sites within the fragments. Trap-cameras where active for 15 days, and we follow the same protocol than for artificial nests in order to avoid researcher-related influences.

We evaluated the relationship between nest predation rates and distance to the edge, fragment size, nest height, days of exposition and year of the experiment by means of a Multiple Logistical Regression Analysis (Quinn and Keough 2002; Lewis 2004). We use the InfoStat software for statistical analysis (Di Rienzo et al. 2011).

Results

Nest predation rates were significantly related to the number of days of exposition of the nest, nest height and distance to the edge; whereas fragment size and year of the experiment were not associated with predation rates (Table 2). Out of the 258 nests placed during 2003, 41.5% were predated by day 5, 71.7% by day 10, and 86.8% by day 15. Nests located on the ground were less predated (76.7%) in comparison to those located in bushes (82.6%) and trees (100%). During 2004, 44.5% of the 312 nests were predated by day 5, 68.6% by day 10, and 83.1% by day 15. Ground nests were less predated (62.8%) than those located in bushes (79.1%) and trees (97.7%). In both 2003 and 2004, predation rates decreased with the distance to the edge, showing a pat-

Table 2 Results of the Multiple Logistical Regression Analysis evaluating the relationship between nest predation rates and days of exposition, nest height, distance to the edge, fragment size and year of the experiment in fragments of caldén forests in La Pampa Province, Argentina

Variables	Coefficient	SE	Odd	−2 (L0−L1)	*P*
Days of exposition	1.03	0.08	2.81	212.96	< 0.0001
Nest height	0.63	0.07	1.87	78.23	< 0.0001
Distance to the edge	−0.005	0.0008	1.00	34.36	< 0.0001
Fragment size	0.08	0.06	1.09	2.15	0.1427
Year	0.11	0.90	0.90	0.81	0.3669
Log. verisimilitude				−887.26	

Values of the coefficient, standard error (SE), crossed products (Odd), the difference between logarithms of verisimilitude of the reduced pattern (L0) and the complete pattern (L1), and significance level are shown

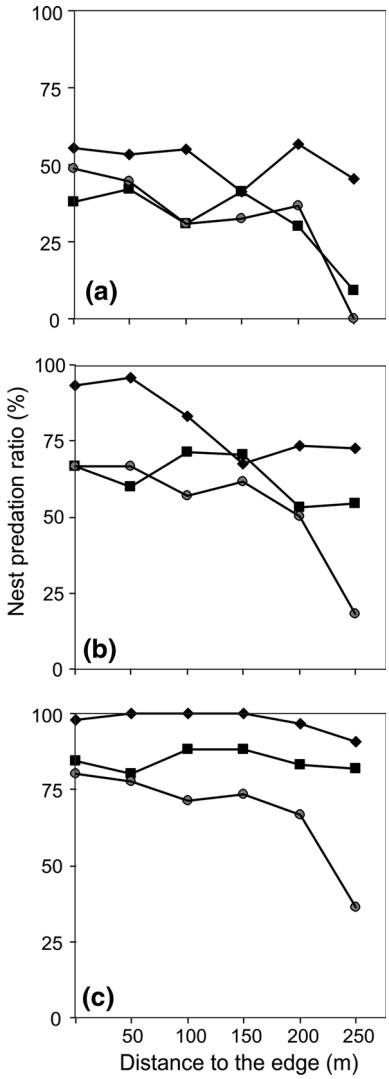

Fig. 3 Nest predation rates in trees (*rhomboid*), bushes (*square*) and on the ground (*circle*), after 5 days (**a**), 10 days (**b**) and 15 days (**c**) in relation to distance to the edge in fragments of caldén forests in La Pampa Province, Argentina

tern consistent with the existence of an edge effect. This trend was more marked in the ground nests (Fig. 3).

We observed the following species predating nests during the study: rufous hornero (*Furnarius rufus*) and brown cacholote (*Pseudoseisura lophotes*), among the birds, and larger hairy armadillo (*Chaetophractus villosus*), little grison (*Galictis cuja*), skunk (*Conepatus* sp.) and domestic cats (*Felis catus*) among the mammals. We also observed in the study area some species that have been previously reported predating on eggs and chicks, which we consider potential nest predators in the caldén forest (Table 3).

In nests located in trees, 88.9% of the eggs disappeared without trace, hindering predator identification. Only 8.9% of the predation could be attributed to birds, and 2.2% to mammals. For nests located in bushes these figures were 91.1, 5.6 and 3.3%, respectively. Finally, 15.4% of the ground nests were predated by mammals (76.1% of them by *Chaetophractus villosus*), 1.7% by birds and 82.9% disappeared and could not be attributed to a specific predator.

Discussion

The high artificial nest predation rates recorded during this study suggest that predators have important levels of activity in these fragmented forests. Nest predation rates were, however, independent of fragment size, as previously reported for several tropical and temperate forests (e.g., Wilcove 1985; Yahner and Scott 1988; Nour et al. 1993; Hannon and Cotterill 1998; Zanette and Jenkins 2000). Low influence of fragment size on nest predation could be reflecting an elevated impact of the agricultural matrix surrounding fragments. Moreover, studied fragments may not have been large enough to prevent the full expression of predators' impact on nests.

We found a significant edge effect on nest predation, indicating that these semiarid caldén forests are similar

Table 3 Species of birds, mammals and reptiles inhabiting caldén forest fragments in La Pampa Province, Argentina, that could predate bird eggs and chicks

Birds	Mammals	Reptiles
Polyborus plancus[d]	*Thylamys pusila*[c]	*Bothrops ammodytoides*
Milvago chimango[b]	*Didelphis albiventris*	*Bothrops alternatus*
Athene cunicularia[a,b]	*Chaetophractus villosus*[d]	*Philodryas* sp.
Upucerthia certhioides[a,b]	*Pseudalopex* sp.[d]	*Lystrophis dorbignyi*
Furnarius rufus[d]	*Oncifelis geoffroyi*	*Lystrophis semicinctus*
Pseudoseisura lophotes[b,d]	*Galictis cuja*[b,d]	
	Conepatus sp.[d]	
	Felis catus[d]	

[a] Reported in Mezquida and Marone (2002)
[b] Reported in Cueto and Mezquida (2001)
[c] Bragagnolo L (personal communication)
[d] Recorded during this study

to tropical and temperate ones in this respect (Andrén and Angelstam 1988; Linder and Bollinger 1995; Fenske-Crawford and Niemi 1997; Söderström et al. 1998; Brand and George 2000; Piper and Catterall 2004). The decrease in predation rates of ground nests at 250 m from the edge resembles the pattern recorded by Wilcove et al. (1986) and Andrén and Angelstam (1988) in temperate forests of North America and Europe, respectively, whereas the low predation rates of bush nests are similar to the trend observed in tropical, subtropical, temperate and deciduous-conifer mixed forests in North America, Europe and Australia (Söderström et al. 1998; Brand and George 2000; Piper and Catterall 2004).

Although in most cases we could not identify predators, there was a trend for mammals to be more important for ground nests, and for birds in nests located in trees and bushes. These nests are more conspicuous to aerial predators (Piper and Catterall 2004), and birds are more efficient at finding nests in vegetation than on the ground (Martin 1987; Yahner and Cypher 1987; Martin 1993). The lower predation rates of nests located on the ground can be at least partially attributed to the high cover of herbaceous plants that characterizes these fragments (Sosa 2008), which reduces nest visibility, as was previously found in other studies (Leimgruber et al. 1994; DeLong et al. 1995; Fleming and Giuliano 2001).

High nest predation rates on edges appear to be a consequence of the high predator abundances associated with the agricultural matrix surrounding fragments (Wilcove et al. 1986; Andrén and Angelstam1988; Linder and Bollinger 1995; Fenske-Crawford and Niemi 1997; Söderström et al. 1998; Brand and George 2000; Piper and Catterall 2004). Crop fields surrounding fragments in the study area constitute an appropriate habitat for nest predators like *Chaetophractus villosus*, a mammal scarcely present in forest areas (Wetzel 1985). Other generalist and opportunist predators, such as the domestic cat (Lepczyk et al. 2003), increase their abundance with fragmentation and extensive farming in forest areas (Santos and Tellería 1992; Crooks and Soulé 1999; Schmidt 2003; Pangau-Adam et al. 2006). Determining the identity of predators, as we did in this case, is important in studies of nest and egg predation (Ibañez-Álamo et al. 2015).

Our results show a clear edge effect on bird nest predation in fragments of caldén forests. Future studies should evaluate predation rates and success of natural nests in order to corroborate our findings, as well as the real impact of edge effects on the reproductive success of birds.

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