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Edge effects and patterns of winter abundance of wood mice *Apodemus sylvaticus* in Spanish fragmented forests

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This paper analyzes the winter pattern of abundance of wood mice *Apodemus sylvaticus* (Linnaeus, 1758) as related to the distance from forest edges in two Spanish fragmented forests. Mouse abundance was measured by means of pitfall traps located at a range of distances from forest edges in large forests, in small woodlots, and in the agricultural matrix surrounding both woodlots and forests (both close to forest edges and far from them). Mouse abundances were larger in forests than in croplands, and tended to become larger in woodlots and forest edges as compared to forest interior, and close to woodland as compared to far from it in the croplands surrounding forests. Overall, wood mouse distribution appeared as clearly affected by edge effects, the species behaving as a typical ecotonic, soft-edge species, as expected by its generalist habitat selection behaviour. The implications of this pattern of winter distribution are discussed in relation to the well-documented increased abundances of wood mice in fragmented forests, as well as to the potential negative effects of wood mouse populations on forest species through predation and exploitative competition.

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Introduction

The reduction and fragmentation of forest areas is one of the main causes of concern for the conservation of animals and plants both in temperate and tropical regions (eg Saunders *et al.* 1991). Changes in the composition and structure of

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animal communities inhabiting fragmented forests are caused by a host of biotic and abiotic processes associated with habitat fragmentation (changes in predation or food availability, microclimatic effects, loss of genetic variation, and lack of recolonization following local extinctions; see eg Opdam 1991, Saunders *et al.* 1991). Some of these processes are usually dependent on the distance to the border of forest fragments (see Murcia 1995 for a recent review), so that they are often referred to as 'edge effects' (Saunders *et al.* 1991, Malcolm 1994, Laurance and Yensen 1991, Murcia 1995). This term emphasizes that some processes impoverishing habitat quality within woodlots are ultimately caused by the exposure of forest interior to the climatic and biological conditions of the external habitat matrix in which woodlots are immersed (Janzen 1986). As the relative amount of edge is inversely related to fragment size (fragment shape being constant), such edge effects tend to increase as forest fragmentation becomes more intense.

The responses of organisms to edge effects appear to be species-specific, closely depending on their biological characteristics (Murcia 1995). Species which are habitat generalists, exploiting both the forests and the external habitat matrix, and which are able to move between woodlots by crossing such matrix (soft-edge species of Stamps *et al.* 1987), would be favoured by edge effects in such a way that their abundances are enhanced by forest fragmentation. These 'ecotonic' species tend to reach their largest abundances along the borders of woodlots (Murcia 1995). On the other hand, 'forest' species are not capable to exploit the external matrix, and are often unwilling to cross such matrix to reach woodlots nearby (hard-edge species of Stamps *et al.* 1987). These latter would thus be negatively affected by forest fragmentation, their abundances decreasing as both woodlot size and distance to forest edge decrease (Mills 1995, Murcia 1995).

Most studies on the impact of edge effects on the spatial distribution of species in fragmented habitats have been concentrated on forest species, largely neglecting the ecotonic ones (reviewed by Murcia 1995, but see also Heske 1995, Sekgoroane and Dilworth 1995). This situation does not take into account the potential effect of these ecotonic species both on the population abundances of forest species (through process of competence and/or depredation; see eg Tellería and Santos 1992, Santos and Tellería 1991, 1994) and even on the whole long-term dynamics of woodlots (through interferences in the regeneration of trees; Clarkson and Mills 1994, Santos and Tellería 1994, 1995).

In this paper, we analyze the winter distribution of the wood mouse *Apodemus sylvaticus* (Linnaeus, 1758), a typical ecotonic species (Tew *et al.* 1992), as related to distance from forest edges in two Spanish fragmented forests. This species appears to exert a strong effect on the winter populations of some forest bird species through competition for food (Smith and Balda 1979, Santos and Tellería 1994), and even to influence the regenerative potential of woodlot trees through predation of their seeds (Santos and Tellería 1991, 1994). Specifically, we address whether mouse abundance increases towards forest edges, and whether mice are able to exploit and to cross the habitat matrix between forest fragments.

Material and methods

Data were collected during a study on the body condition and reproductive traits of wood mice populations wintering in Spanish fragmented forest (M. Díaz *et al.*, in prep.). Field work was carried out in winter 1995 (February–March) in two fragmented forests: (1) Northern-near the localities of Santa Elena de Jamuz-La Bañeza (León province, northwestern Spain; 42°15'N, 5°52'W, 750–900 m a.s.l.) and (2) Southern-near Villatobas-Corral de Almaguer (Toledo province, central Spain; 39°50'N, 3°10'W, 700–730 m a.s.l.). Both forests were dominated by holm oaks *Quercus ilex*, with scattered Pyrenean *Q. pyrenaica* and Lusitanian oaks *Q. faginea* in the north. The main understory shrub species (apart from tree saplings) are *Cistus laurifolius* and *Erica* spp. in the north, and *C. ladanifer*, *Thymus* spp. and *Lavandula* spp. in the south. These vegetation traits, as well as climatic characteristics of the study areas (mild summers and cold wet winters in the north, and hot dry summers and mild winters in the south; Elías and Ruiz 1977), are representative of the supramediterranean (north) and mesomediterranean (south) bioclimatic stages of the Iberian Peninsula (Rivas-Martínez 1981). The matrix surrounding the forests and woodlots was devoted mainly to extensive cereal cultivation. Some scattered old fields and vineyards were also present, the first ones especially in the north and the second ones in the south.

Wood mice were trapped in 28 and 27 woodlots and forests from the northern and southern study areas, respectively, ranging in size from 0.02 to 400 ha. Six to 40 trapping points, whose distance to the nearest edge was measured, were established in each woodlot according to a logaritmic scale of its size. Four additional points were set out outside of the woodlots less than 2 ha in size at distances of 1, 3, 5, and 10 m, in order to evaluate the use of the external matrix close to the woodlots by mice. Finally, we established 100 points in the cropland matrix of each study area. These points were more than 100 m from the nearest forest edge, and were set out at 45–50 m intervals along 3–4 lines per area.

We placed a pitfall trap (9 cm in diameter, 29 cm in depth) at each trapping point. We used pitfall traps because of its easy maintenance and lack of problems of capture saturation (Tellería 1986). Traps were half-filled with water saturated with salt to avoid freezing and odours, to kill rapidly the

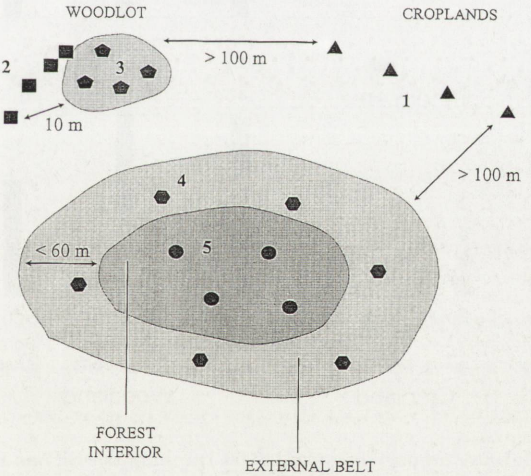

Fig. 1. Schematic representation of the location of traps in relation to distance from edges of forest and woodlots surrounded by croplands. See text for explanations.

individuals trapped in order to avoid unnecessary suffering, and to preserve corpses between visits. Such corpses were needed for measures of the body condition and reproductive parameters of individuals which are presented elsewhere (M. Díaz *et al.*, in prep.). Traps were open during a whole moon cycle (28 nights) to avoid moonlight effects on the mobility and trappability of small mammals (Jensen and Honess 1995). The number of individuals captured by each trap was taken as an index of mouse abundance around the trapping point.

The dependency of mouse abundance on the distance from forest edge within woodlots was analyzed by simple regression against the log-transformed distance between traps and edges. Distribution patterns at both sides of the edge were analyzed by one-way ANOVAs followed by Tukey tests (Zar 1984). We considered five distance categories (Fig. 1): (1) traps located in croplands, more than 100 m from the nearest edge (triangles); (2) traps located in croplands close (1–10 m) to the edge (squares); (3) traps in woodlots less than 15 ha and less than 120 m in its shortest dimension (pentagons), and (4) traps located in the 0–60 m external belt of larger woodlots and forest (hexagons); (5) traps located in large woodlots and forest more than 60 m from the edge (circles). The distance of 60 m was chosen because of: (a) it is close to the distance at which edge effects measured in other Spanish fragmented forests appear to act (Santos and Tellería 1992; see Murcia 1995 for a full review); and (b) woodlots less than 15 ha in size (and less than 120 m in their shortest dimension) maintain significantly larger mouse populations during winter than larger woodlots and forests (Tellería *et al.* 1991).

Results

Overall, we caught 590 wood mice with a sampling effort of 29 508 trap-nights, most of them (76.27%) within woodlots and forests. Mouse abundance was

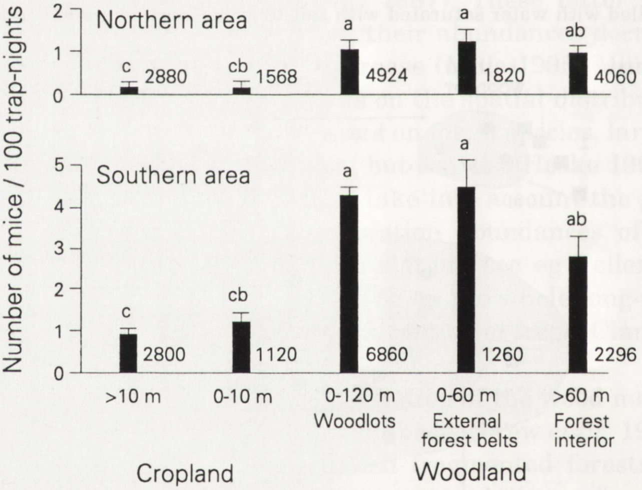

Fig. 2. Wood mice abundances (number of rodents/100 trap-nights +SE) as related to distance from forest edges both towards forest interior (woodland) and towards the agricultural matrix (cropland) in the two fragmented forests studied (north and south). Letters on top of bars indicate results of *a posteriori* Tukey tests (Zar 1984), categories sharing the same letter not differing significantly. Figures near the bars indicate trapping effort (number of trap-nights), each trap being opened during a whole moon cycle (28 nights).

inversely related to the distance to edge within forests in both study areas, although this relationship was statistically significant only in the south ($r = -0.039$, $p = 0.373$, $n = 520$ for the northern study area, and $r = -0.125$, $p = 0.005$, $n = 513$ for the southern study area). Differences among distance categories were significant for both study areas ($F_{4,\,515} = 6.288$, $p = 0.0001$, and $F_{4,\,508} = 13.118$, $p < 0.0001$, for the northern and southern areas, respectively).

Mouse abundance tended to become greater at forest edges in both study areas, followed by small woodlots and forest interior (Fig. 2). Wood mice were also found in croplands, both close to woodlot edges and far from them. Abundances close to woodlots did not differ from abundances in the forest interior, whereas abundances within the cropland matrix far from forests were the lowest recorded. These patterns were similar in both study areas, in spite of the lower abundances found in the north (Fig. 2). Differences in abundance among study areas can be attributed to their climatic characteristics, which appear to have caused an advanced reproduction in the south (M. Díaz *et al.*, in prep.).

Discussion

The wood mouse was the dominant small mammal species inhabiting the fragmented forests studied (authors unpublished data). This species is also dominant in cereal crop landscapes of mid-Spain (Tellería *et al.* 1992), where it shows a pattern of habitat selection which is markedly seasonal. During summer, mice forage and reproduce across the whole agricultural landscape. In winter, however, they concentrate in uncultivated patches such as field margins and old fields with some shrub cover (Alcántara and Tellería 1991, Díaz 1992, Tellería *et al.* 1992), apparently because of their need for stable refuges and safe foraging places (Díaz 1992). This winter dependency on uncultivated patches after a widespread summer reproduction in cultivated fields has been also found in other European populations (Ryszkowski 1982, see also Loman 1991), and it seems to be the cause of the large winter population densities reached by this species in woodlots (Geuse *et al.* 1985, Tellería *et al.* 1991).

The winter distribution of wood mice in Spanish fragmented forests appear to be mediated by edge effects (Murcia 1995), since mouse abundance tended to be larger at edges than in the forest interior. This effect appears to be more pronounced in our southern study area, apparently due to weather-driven earlier reproduction (M. Díaz *et al.*, in prep.). The wood mice behaved as a soft-edge species (Stamps *et al.* 1987) since they exploited the cropland matrix close to woodlots, and were able to cross croplands (see also Kikkawa 1964). This behaviour agrees with the generalist habitat selection strategy of wood mice. Further, wood mice appear to be capable of exploiting simultaneously (or following circadian rythms) contiguous habitats providing complementary resources such as food and shelter (Hoffmeyer and Hansson 1974, Montgomery and Gurnell 1985). Our results showing that mouse abundance tended to become larger in croplands close to woodlots than far from them, as well as in forest edges in comparison with forest interior, would agree with this idea, suggesting that mice would benefit from the combination of good food conditions in croplands (where winter seed abundances are usually large; Díaz 1994) and good shelter conditions in forest edges.

The ecotonic character of wood mice would explain the large abundances of this species in fragmented forests. Since the proportion of edge increases with fragmentation as forest size decreases, mouse abundance should increase with forest fragmentation, as has been widely documented (Geuse *et al.* 1985, Tellería *et al.* 1991, M. Díaz *et al.*, in prep.). In fact, we found no differences between wood mouse abundance in the external edges of large forests and wood mice abundance in woodlots, thus suggesting that large abundances in small fragments would be a consequence of their almost complete lack of forest interior.

Finally, larger winter abundances of wood mice at forest edges would cause negative edge effects on forest species through competition and/or depredation. These processes have been documented by comparing small woodlots and large forests as regards to the abundances of avian frugivores (Santos and Tellería 1994, 1995), the predation rates of tree seeds (Wästljung 1989, Santos and Tellería 1991, 1994), and the recruitment of forest trees (Santos and Tellería 1994, 1995). Thus, it might be worth testing whether these processes were also edge-dependent and whether they correlate with mouse abundances in order to further ascertain the role of wood mice in the dynamics of fragmented forests.

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