



Original article

Road network in an agrarian landscape: Potential habitat, corridor or barrier for small mammals?

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ABSTRACT

If the negative effects of road networks on biodiversity are now recognized, their role as barriers, habitats or corridors remain to be clarified in human altered landscapes in which road verges often constitute the few semi-natural habitats where a part of biodiversity important for ecosystem functioning may maintain. In human-dominated landscape, their roles are crucial to precise in comparison to other habitats for small mammal species considered as major natural actors (pests (voles) or biological control agents (shrew)).

We studied these roles through the comparison of small mammal abundance captured (418 individuals belonging to 8 species) using non-attractive pitfall traps ($n = 813$) in 176 sampled sites distributed in marginal zones of road and crop, in natural areas and in fields. We examined the effect of roadside width and isolation of sites.

We found the higher small mammal abundances in roadside verges and an effect of width margins for shrews. The significant effect of the distance to the next adjacent natural habitat at the same side of the road on the relative abundance of *Sorex coronatus*, and the absence of a significant effect of distance to the next natural habitat at the opposite side of road, suggest that highway and road verges could be used as corridor for their dispersal, but have also a barrier effect for shrews. Our results show that in intensive agricultural landscapes roadside and highway verges may often serve as refuge, habitat and corridor for small mammals depending on species and margin characteristics.

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1. Introduction

Road networks have strongly expanded over large areas with human population growth (Watts et al., 2007) so that the majority of the total area for the more developed countries is under their influence (Reijnen et al., 1995; Forman 2000; Selva et al., 2011). Unfortunately, roads are known to have major negative impacts on species and ecosystem dynamics, modifying landscape structure, through habitat destruction, alteration and fragmentation (Forman and Alexander, 1998; Sauvajo et al., 1998; Trombulak and Frissell, 2000; Liu et al., 2008). One major impact identified is the reduction of populations size of a wide variety of species (Fahrig and

Rytwinski, 2009; Benítez-López et al., 2010; Rytwinski and Fahrig, 2012) through increase in mortality by collision (Shuttleworth, 2001), fragmentation of home ranges, habitat destruction, disturbance of foraging and reproductive behaviours (Siemers and Schaub, 2011) and barriers to movements which decrease landscape connectivity (Rico et al., 2007a,b). This fragmentation may result in the ultimate division of the population adjacent to roads into smaller isolated subpopulation involving a decrease in the genetic diversity of such isolated population (Rico et al., 2009). However, the potential biological value of road verges in anthropogenic altered landscape has also long been recognized (Way, 1977). Sides of linear transport structures, i.e. linear areas of semi-natural vegetation, may provide refuges and/or corridors (Davies and Pullin, 2007) to a large number of taxa (Hansen and Jensen, 1972; Bennett, 1990; Merriam et al., 1990; Hodkinson and Thompson, 1997; Penone et al., 2012). In some cases, they are

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known to significantly contribute to the conservation of indigenous flora (Spooner et al., 2004; O'Farrell and Milton, 2006) and fauna (Meunier et al., 2000; Ries et al., 2001).

Actually, their role as refuges may depend on their surrounding landscape: in natural habitats, generally supporting a high species diversity, road verges do not provide particular habitat to threatened local species (O'Farrell and Milton, 2006). Ranta (2008) showed that the usual extensive management techniques were not sustainable for the survival of endangered species on a roadside site. Roads network even can have negative effects, especially in favouring invasion by exotic species (Hansen and Clevenger, 2005; Brown et al., 2006). By contrast, in human dominated areas such as intensive agricultural landscapes, where non-agricultural habitats (e.g. edges) are sparse and critical to the conservation of biological diversity and ecological processes (Burel, 1996), road verges should play a crucial role as a refuge and ecological corridors (Dawson, 1994, 2002; Tikka et al., 2001; Le Viol et al., 2008, 2012; Penone et al., 2012).

Hence, there is a crucial need to assess the roles of road verges as refuges, corridors or barriers, and more particularly for small mammals in agrarian landscapes that are supposed to take an important place in the ecosystem functioning. Small mammals are indeed known to be major natural actors of agrarian ecosystems: some of them are considered as pests (Sullivan et al., 1998) while others strongly regulate invertebrate populations in fields and grasslands (Churchfield et al., 1991). These are crucial to ensure good agricultural production (Schoener, 1988; Spiller and Schoener, 1990; Dial and Roughgarden, 1995) because they control for low pest species abundances (Maisonneuve and Rioux, 2001). However, while small mammals are regularly observed or trapped in field margins of agrarian landscapes, the role of road verges as refuge or corridor in comparison to other habitats at the landscape scale has rarely been assessed and results are still scarce and often contradictory. In some studies, small mammals have been observed to spread tens of kilometres along highway roadsides (Getz et al., 1978). Roadsides are thus considered as effective corridors for them (Suckling, 1984; Bennett, 1990; Verkaar, 1990). Other studies showed that roads could be a significant barrier to dispersal of many animals (Rico et al., 2007a,b), particularly in the case of high traffic rates (Harris and Silva-Lopez, 1992). Given the high potential impact of these animals on local agricultural economies, it is important to better understand the role of roadsides among other habitats on the population dynamics of small mammals. In this way, according to the results on the ecological importance of road verges in agricultural landscapes, it will be possible to determine how much roadside management should take into account populations of small mammals.

The aim of the present study is to assess the role of road verges as habitats, corridors or barriers for small mammal species in an intensive agricultural ecosystem. First, their role as habitat was evaluated by comparing the relative abundance of small mammals in road verges, according to their characteristics (width ...) and compared to their abundance in other habitats such as fields, field margins and woods. Second, in order to evaluate their potential corridor effect, we investigated the relationship between small mammal abundances in portions of verges and their distance to the closest adjacent (= connected) natural habitats (such as woods or meadows). Finally, we attempted to identify barrier effects by defining the relationships between small mammal abundance in portion of verges and their distance to the nearest natural habitat adjacent to the verge of the other side of the road and compare it to the relationship with distance to the natural habitats of the same side of the road.

2. Materials and methods

2.1. Study area

The study area is an intensive agricultural plain located in the region Ile-de-France in the surroundings of Paris (48° 51' North - 2° 21' East, Fig. 1). It is thus mainly composed of urban areas covering 18.2% of the global area and of agricultural fields used for intensive cropping, especially wheat, sugar beet and rapeseed covering 49.0%). The main "natural" habitat is woodland representing about 23.7% of land cover (see Appendix A). In the study area, the road network is 38,906 km long, i.e. 3.23 km of highways and roads per km². Road network verges (highway or roadside) and field margins are herbaceous strip mowed once or twice each year, differing mainly by their width (15.7 ± 6.6 m [10.0 – 21.5] for highway verges, HV, 7.2 ± 3.4 m [4.3 – 14.6] for road verges, RV, and 4.0 ± 0.4 m for [2.0–10.0] for field margin, FM). The average height of grass strips is less than 1 m in June while five plant species dominate this communities (*Dactylis glomerata*, *Festuca* ssp, *Heracleum sphondylium*, *Galium* ssp, *Plantago lanceolata* have an occurrence exceeding 50%). All sampled sites (highway, roads and fields) are close to crops typical of intensive agrarian landscape (wheat and rape totalized 81% of crops in the sampling, with no obvious bias among site types: Fisher's exact test, $P = 0.31$). We also verified that studied highway verges and road verges have similar distance ranges to woods (490 ± 83 m [10 – 2100] for highway verges, HV, and 973 ± 118 m for [80–4450] for road verges, RV). Verges of this road network represent 1.6% of the total area of the region (highway verges: 0.4%, road verges: 1.2%) and field margins (margins comprised between two adjacent agricultural fields), 1.5% of the territory.

2.2. Sampling design

To examine the habitat, corridor and barrier roles of road verges, we sampled the two types of road verges: we studied 31 sites along highways (noted HV) and 48 sites along roads (noted RV). A site consisted of 5 traps placed linearly every 20 m along the way in the middle of the verges (for more details see Le Viol et al., 2008; Redon (de) et al., 2009).

To assess the relative importance of verges for small mammals in the landscape, we also sampled the main habitat present in this area: fields, $n = 65$ sites and wood, $n = 32$. Fields margins and inside field were sampled (Fig. 1) as following: margins (65 fields, noted FM) each consisting of three traps placed around the field separated from each other by at least 100 m; inside fields at 25 m from the hedges (65 fields, noted F25, consisting of two traps with a distance of 20 m), and inside field at 50 m from the hedges (56 fields, noted F50, consisting of two traps with a distance of 20 m). Woods (32 sites, noted WD) were sampled with one trap randomly placed in each studied wood (Fig. 1). A total of 864 traps were thus installed in the 176 sites, but 813 traps installed were recovered (Table 1). Most traps destroyed during the sampling period were located within or around the fields: in field margins (FM: 4% of traps destroyed), fields-25 m (F25: 15%) and fields-50 m (F50: 21%).

2.3. Small mammals capture and determination

The number of caught individuals was used as a proxy to estimate their relative abundance in the sites. Sampling was carried out simultaneously in 2006 from May the 2nd to June the 4th, (i.e. 31 nights of trapping for each site). For more technical details see Appendix B and Le Viol et al., 2008; Redon (de) et al., 2009; Vergnes et al., 2013). Each animal was dissected and identified mainly using its morphological cranial characteristics, such as teeth, according to Chaline et al. (1974).

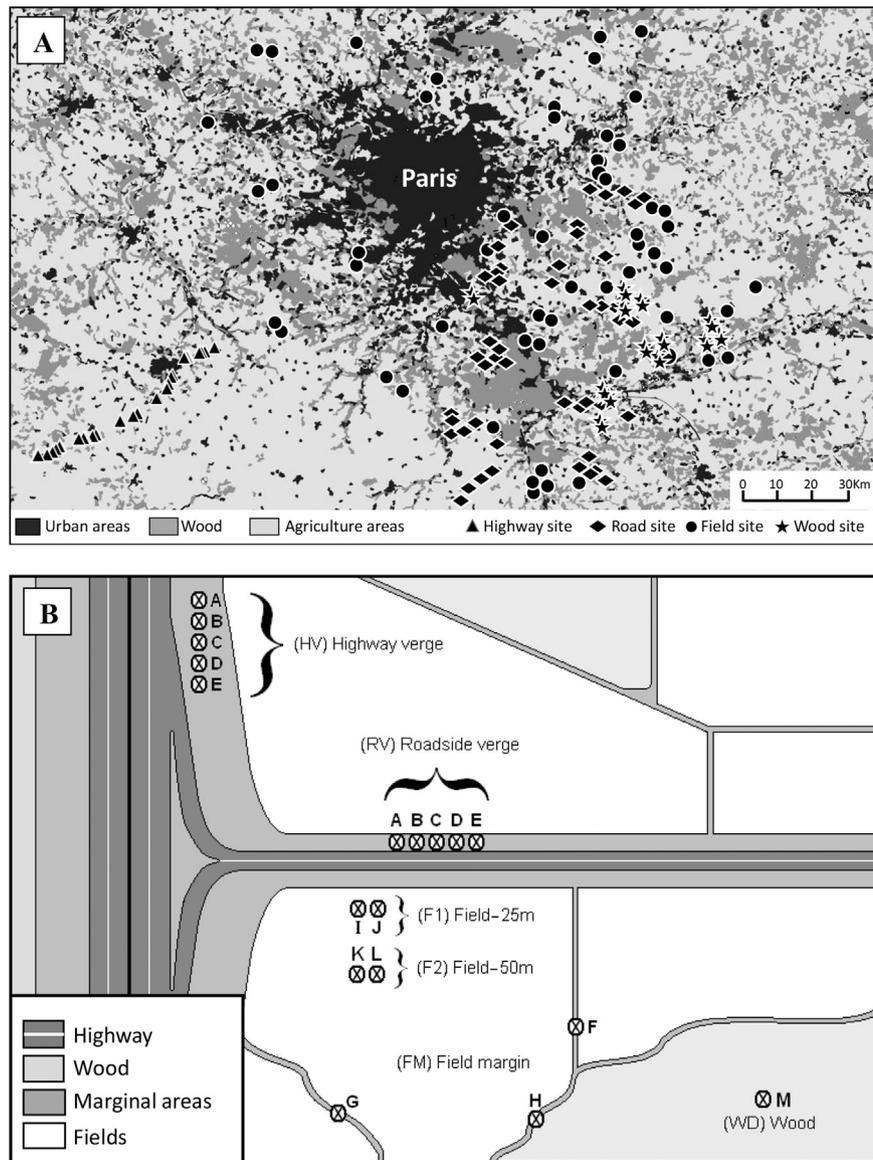


Fig. 1. A, Map of site locations, showing the 176 sites sampled during one month in May 2006. B, schematic design of layout of non-attractive traps (Barber pitfall traps) installed in different habitats (marginal areas, woods and fields) to capture small mammals.

2.4. Data analysis

2.4.1. Variation of species richness among habitat

In order to estimate potential differences in richness among habitats, we assessed an estimated richness per habitat using species accumulation method (Kindt et al., 2006; R package vegan, function: specaccum) which allow to estimate the number of species from a certain number of sampled sites (here a random sample of 30 traps for each habitat: HV, RV, FM, F25, F50 & WD).

2.4.2. Verges and margins as habitats

To identify the habitats preferentially used by small mammals, we evaluated their relative abundance (particularly that of the two most observed species: *Microtus arvalis* and *Sorex coronatus*) at the trap scale in the habitats (HV, RV, FM, F25, F50 & WD). According to the hierarchical structure of the sampling design (traps within site), we used a Generalized Linear Mixed Model (GLMMs, package lme4, Zuur et al., 2009) with a Poisson error distribution (count data) and with a random effect of sites. This approach allows accounting for

potential spatial pseudoreplication, linked to the hierarchical structure in the sampling design (Crawley, 2009). We explore data for potential spatial autocorrelation using a variogram tool (R package spatial, Bivand et al., 2008) and according to the slight spatial trend detected, we added an autocovariate (i.e., a distance-weighted function of neighbouring response values, here weights by the square of inverse distance; Dormann et al., 2007; Penone et al., 2013) with the autocov dist function in R (package spdep, Roger Bivand).

2.4.3. Environmental variables influencing the abundance of *M. arvalis* and *S. coronatus* on highway and road verges

To go further, we focused on highway and road verges at the site scale. We assessed how abundances of *M. arvalis* and *S. coronatus* were influenced by margin types (HV, RV) compared to other environmental variables. These latest were car traffic (CT), margin width (MW), distance to nearest wood (distance as the crow flies NW), distance to the nearest crop (distance as the crow flies NC), proportion of forest habitat in a 250 m buffer (W250), proportion of

Table 1
Mammal species captured in traps settled in the different habitats.

Zones	Habitats	Sites	Trap by site	Traps recovered	Mice		Voles			Shrews			Estimated richness
					<i>Apodemus flavicollis</i>	<i>Apodemus sylvaticus</i>	<i>Clethrionomys glareolus</i>	<i>Microtus agrestis</i>	<i>Microtus arvalis</i>	<i>Crossidura russula</i>	<i>Sorex coronatus</i>	<i>Sorex minutus</i>	
Natural areas	Woods	32	1	32	0	1	2	2	0	2	6	0	4.65 ± 0.49
Marginal areas	Highway verges	31	5	155	0	4	0	0	37	13	98	6	4.27 ± 0.69
	Road verges	48	5	240	5	8	0	4	71	22	63	0	4.55 ± 0.84
	Field margins	65	3	187	0	8	0	0	18	5	10	0	3.44 ± 0.71
Fields	Fields 25 m	65	2	110	0	5	0	0	9	1	1	0	2.51 ± 0.66
	Fields 50 m	56	2	89	0	3	0	0	6	0	0	0	1.75 ± 0.43
Total		297		813	5	29	2	6	141	43	178	6	

forest habitat in a 500 m buffer (*W500*) and crop type in the field (*CT*). We simultaneously took into account all habitat variables in the analysis using Hierarchical Partitioning (R package *hier part*, Chris Walsh), a multiple regression analytical method that allows to identify the most likely causal factors while alleviating multicollinearity problems (Mac Nally, 2000).

In a second step, we focused on the potential influence of margin width among *HV*, *RV* and *FM* on the relative abundance of mammals using the same GLMM modelling structure than previously. The only difference was that the effect of margin width was adjusted to the distance to the nearest crop for *S. coronatus*; and to the crop type in the field for *M. arvalis*, according to Hierarchical Partitioning results (see 3.3). In addition, we used a Generalized Additive Model (GAM, package *mgcv*, Hastie and Tibshirani, 1990) to identify graphically the potential non-linear effects of margin width on the relative abundances of mammals.

2.4.4. Highway and road verges as corridors

If small mammals move along their territories located in preferred natural habitats through the verges, we should expect more captures in verges located in the neighbourhood of natural habitats. Thus, we focused at the site scale (sum of the 5 traps/site), with a restriction to highway and road verges and calculated the

distance between each verge site (*HV* & *RV* sites) and the nearest adjacent (= connected) meadows or woods (distance noted *DC*, Fig. 2) and tested its effect, on the relative abundance of *M. arvalis* and *S. coronatus* using a GLM. This effect was adjusted to the margin width and to the distance to the nearest crop for *S. coronatus*; to the margin width and to the crop type for *M. arvalis* according to Hierarchical Partitioning result (see 3.3). For each species, we performed Generalized Linear Models (GLM), a first one for road sites and a second for highway sites. Since *S. coronatus* is a territorial species (Neet and Hausser 1990), we used a second approach to evaluate the effect of the distance to the nearest adjacent natural habitat. According to Cantoni (2002), its population densities are about 10.8 individuals per ha i.e. a territory can be approximately represented by a disk of 926 m², we then sorted verge sites in two categories: sites near a natural habitat (sites A), i.e. less distant than ten territories diameters (343 m), and sites far from a natural habitat (sites B), i.e. more distant than ten territories diameters. We then tested for differences in species abundance between the two site categories with a GLM.

2.4.5. Highway and roadside verges as barrier for *S. coronatus*

If roads and highways are barriers for *S. coronatus* and if the previous hypothesis is verified (i.e. significant effects of distance to nearest adjacent habitat, *DC*, on shrew abundance), we should find no effect of distance to the nearest natural habitat located on the other side of the road on the abundance of *S. coronatus*. Thus we calculated the distance between each verge of *RV* and the next natural habitat of the other side of the road (distance noted *DX*, Fig. 2). As previously, we sorted verges in two categories (A: <343 m and B: >343 m) and ran GLM to test the difference of abundance of shrews between the sites of the two categories. Since wood or meadows are expected not to be a favourable habitat for voles (agrarian species) we are not able to test effect of road as corridor for these species.

All linear models (GLMs and GLMMs) were performed using R (R Development Core Team, 2010) and with a Poisson error distribution (count data). For GLMs, results were evaluated using a type II ANOVA with an F-test (R package *car*; Fox and Weisberg, 2011) and *P*-values were corrected for potential overdispersion following Faraway (2006).

3. Results

3.1. Variation of species richness among habitat

A total of eight species were trapped among the different habitats: three shrew species (*Crossidura russula*, *S. coronatus* and *Sorex minutus*), three vole species (*Clethrionomys glareolus*, *Microtus*

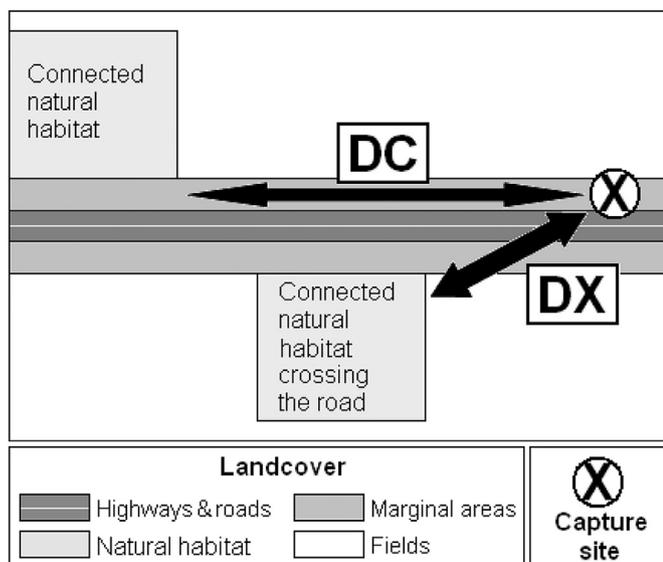


Fig. 2. Distances between capture sites and nearest connected natural habitats (*DC*) or opposite nearest natural habitat (*DX*).

agrestis and *M. arvalis*) and two mice species (*Apodemus flavicollis* and *Apodemus sylvaticus*). According to estimated richness (Table 1), woods, highway verges and road verges, exhibited a quite similar richness. However their richness are higher than fields and field margins. Two species (*M. arvalis* and *S. coronatus*) represented 78% of collected individuals (Table 1), and we further only focused on these two species. Sample sizes for the other species were too small to be properly analysed.

3.2. Verges and margins as habitats

GLMMs indicated that the relative abundance of *M. arvalis* (Fig. 3a) in roadside verges did not differ significantly from their abundance in highway verges (t-value = 0.648; $P = 0.52$), respectively HV: 0.24 ± 0.05 SE and RV: 0.30 ± 0.02 SE individuals/trap. In field habitats, densities are significantly lower (See Table 1; F25: z-value = -2.389 ; $P = 0.02$; F50: z-value = 2.321 ; $P = 0.02$). In field margins, which are very similar habitat to highway and roadside verges (z-value = -1.945 ; $P = 0.04$) their density was also slightly lower. *M. arvalis* was not detected in woods (WD).

S. coronatus (Fig. 3b) varied in abundance among habitats. They were abundant in verge habitats but significantly more in highway than in road verges (HV: 0.63 ± 0.08 SE & RV: 0.26 ± 0.05 SE individuals/trap; t-value = -4.189 , $P < 0.0001$). In fields, their abundances were very low (FM: 0.05 ± 0.02 SE individuals/trap)

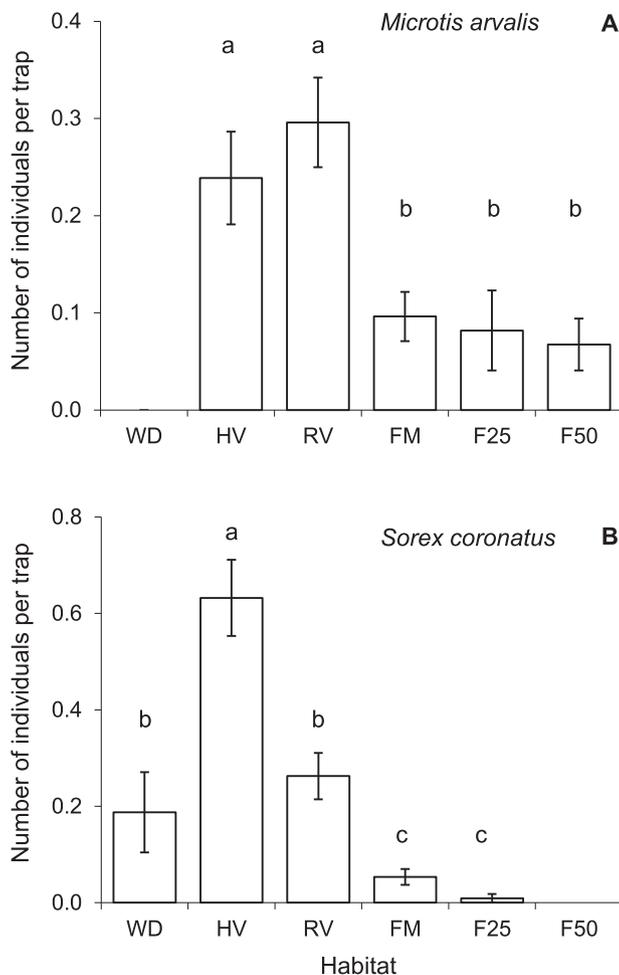


Fig. 3. *Microtis arvalis* (Fig. 3A) and *Sorex coronatus* (Fig. 3B) exhibit significant differences in relative abundance between habitats. Different letters signal significant differences between average numbers of capture per trap.

and significantly lower than in highway verges (FM: t-value = -3.384 ; $P < 0.0001$; F25: z-value = -5.212 ; $P < 0.0001$; none was captured in field-50 m, F50). This species was detected in woods but significantly at lower rate than in highway verges (WD: 0.16 ± 0.08 SE individuals/trap; t-value = -2.439 ; $P = 0.02$).

3.3. Environmental variables influencing the abundance of *M. arvalis* and *S. coronatus* on verges and margins

The main variable influencing the abundance of *M. arvalis* is the crop type in the field and margin width, whereas for *S. coronatus* margins types (HV vs RV), distance to the nearest crop and margin width appeared to have a similar importance (Table 2). The influence of the distance to the nearest wood, the proportion of forest habitat in a 250 or 500 m buffer and the car traffic were weak predictors of abundance for both species (Table 2).

The margin width did not influence the relative abundance of *M. arvalis* ($Chisq = 1.262$; $df = 1$; $P = 0.26$), note that crop type was not significant ($Chisq = 5.786$; $df = 2$; $P = 0.06$). For *S. coronatus*, we detected a significant positive effect of margin width on shrew abundance ($Chisq = 7.973$; $df = 1$; $P = 0.005$), again the variable of adjustment (here distance to the nearest crop) was not significant ($Chisq = 1.144$; $df = 1$; $P = 0.28$). We further detected a non-linear pattern: the abundance of shrew increased drastically with an increase of margin width until 12 m (see Appendix C for pattern of with effect on relative abundance).

3.4. Verges and margins as corridors

In the HV sites, we did not detect any effect of the distance to the nearest adjacent natural habitat, (DC) neither for *S. coronatus* ($F_{1,26} = 0.52$; $P = 0.47$) nor for *M. arvalis* ($F_{1,26} = 0.36$; $P = 0.55$). In the RV sites, *S. coronatus* abundance was negatively correlated to the distance to the nearest adjacent natural habitat, DC ($F_{1,44} = 2.21$; $P = 0.03$) whereas no effect was detected for *M. arvalis* ($F_{1,43} = 2.67$; $P = 0.11$). When considering the difference between verge sites separated in two categories of distance (i.e. sites less distant than ten territories diameters (site A), versus sites far from a natural habitat (sites B)), the pattern was even strengthened for *S. coronatus*: In HV sites and for *S. coronatus*, we again did not detect an influence of the distance to the nearest connected natural habitat, DC ($F_{1,26} = 0.78$; $P = 0.39$; Fig. 4). But in RV sites, abundances of *S. coronatus* were negatively correlated to the distance to the nearest connected natural habitat, DC ($F_{1,43} = 25.06$; $P < 0.001$; Fig. 4).

3.5. Roads as barrier for shrews

Because we did not found any effect of connected distance (DC) on shrew abundances in highway verges, we focused these analyses on road verges and found no correlation between shrew densities

Table 2
Independent contribution of each variable, assess by the Hierarchical Partitioning of variance.

	<i>M. arvalis</i>	<i>S. coronatus</i>
Margins types (HV vs RV)	1.3	28.0
Margin width	21.1	21.4
Distance to the nearest crop	7.7	22.7
Distance to nearest woods	11.2	4.1
Proportion of forest habitat in a 250 m buffer	7.9	1.2
Proportion of forest habitat in a 500 m buffer	13.2	9.9
Type crop in the field	25.0	1.1
Car traffic	12.4	11.6

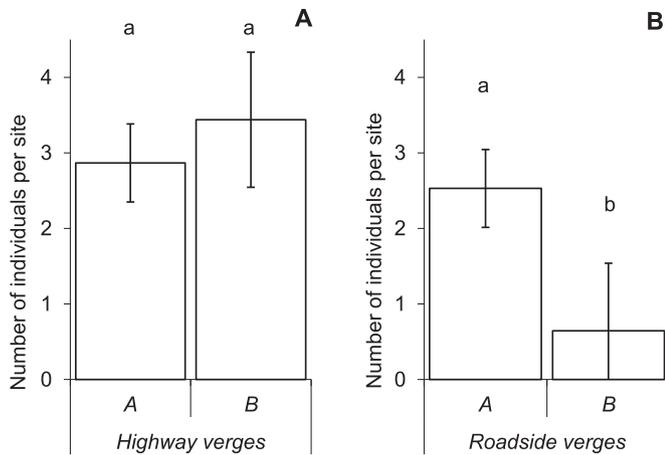


Fig. 4. In highway verges, no significant correlation between relative abundance of *S. coronatus* and distance between capture sites and the nearest connected natural habitat (DC) were detected, average number of capture within site near natural habitat (A) did not differ from sites far from a natural habitat (sites B, i.e. more distant than ten territories diameters, 343 m) (Fig. 4A). However, this relation is verified for road verges where the average number of capture within sites far from a natural habitat (B) is lower than site near natural habitat (A) (Fig. 4B). Different letters signal significant differences.

and the distance to the nearest adjacent natural habitat situated on the opposite side of road (DX) ($F_{1,47} = 0.50$; $P = 0.48$).

4. Discussion

This set of experiment was conducted with traps usually used for soil arthropods, during another experiment (Le Viol et al., 2008) which had unfortunately led to the capture of small mammals. For monitoring most terrestrial small mammals, the Sherman live trap has become the standard foldable; however, pitfalls work also well (Hoffmann et al., 2010). Their placement is often rewarded by the capture of small shrews less sampled with any other method (Kalko and Handley, 1993; Nicolas and Colyn, 2006). In addition, pitfall set-up and results can sometimes be shared with entomologists and herpetologists who might be working on the same inventory (Hoffmann et al., 2010). Despite our sampling covers only 1 month at a suboptimal period (the best time for effective trapping of small terrestrial mammals being in autumn), given the number of animals collected ($n = 418$) and efficient sampling plots ($n = 813$), statistical analyses were possible, and hypothesis concerning the ecological role of verges could be tested, in assuming that, at least for two of the species, the number of mammals collected was a good proxy of their densities or rate of passage in the study sites (see Redon (de) et al., 2009, a study using such pitfall capture and that allow identify effects of roadside verges on vole outbreaks).

First, confirming previous published observations (Adams and Geis, 1983), densities of small mammals were important in verge habitats compare to neighbouring habitats (wood, fields and field margins). Furthermore, when looking at richness highway verges and road verges present a similar diversity than natural areas (woods) and a greater diversity than fields. This suggest the importance of these marginal areas to host small mammals in intensive agrarian landscapes and the role they could play for biodiversity conservation. Nevertheless, whereas both frequented by voles (*M. arvalis*) and shrews (*S. coronatus*), the role of these margins seemed to differ between these species. Thus, our results confirmed that the ecological functions of different elements of a landscape are strongly species dependant (Noss, 1987; Beier and

Noss, 1998).

4.1. Verges as habitat for voles

Higher relative abundance of voles (*M. arvalis*) were found in marginal zones compared to those in fields, in accordance with Adams and Geis' study (1983). We suggest that these margins represent the main habitats of the landscape used by these species. Thus the presence of such verges maintains a reservoir of rodents considered as agricultural pests in the neighbourhood of the fields. Delattre et al. (1999) showed for this species that the dynamics of abundance cycles depended on landscape structure. Indeed, vole populations display pluri-annual density variations whose amplitude is greater in large open fields. This could be due to difference in predation pressure. Rodent predators (mustelidae, raptors) may be more efficient in small fields using linear marginal areas or fixed hunting posts (such as edges, poles ...) than in large uniform fields, because predator generally avoid to cross such open habitat (Hansson, 1988; Meunier et al., 2000; Rondinini et al., 2006). As a consequence, vole populations could be better regulated in margins. Local extinctions could more often occur in smaller fields and population's outbreaks more chronic only in large fields. This result was confirmed in the same study area where previous work found a negative relationship between variation in local vole abundance and roadside network densities (Redon (de) et al., 2009).

4.2. Verges and margins as habitat and corridor for shrews

The results suggest that highway verges appears as a habitat widely used by *S. coronatus* in the study landscape because among the habitat harbours the highest abundance of individuals captured among the sampled habitats. The suitability of highway verges (e.g. margins of a large width) as habitat for shrews is also supported by our captures of *S. minutus*, considered as one of the small mammals the most sensitive to habitat degradation and agriculture intensification (de La Peña et al., 2003) and here only recorded in highway verges.

The abundance of *S. coronatus* was lower in road verges than in highway verges, and we detected a significant influence of the distance to the nearest adjacent natural habitat. Vergnes et al., 2013 showed that the probability of shrew occurrence in garden was negatively correlated to the distance to woodlot and to corridors (these corridors included railway and road verges). Thus we rather believe that roadside verges could be used as corridor for their dispersal and are of lower habitat quality than highway verges for this species. Those results are in accordance with the biology of *S. coronatus* which move intensively all along their life because it is a very active territorial animal with important energetic needs (Genoud, 1984) and whose males disperse to meet females during the reproductive season, (Cantoni, 2002). Oxley et al. (1974) already reported that road networks often attract small mammals by facilitating access to food or increasing food supply, in our study we found that invertebrate biomass (potential preys of shrew) was higher in margins (see Appendix C)

Tischendorf and Wissel (1997) found that corridor widths have strong effects on small mammal dispersion. In our study area, highway and road verges were very similar in plant composition and management (Le Viol et al., 2008; Redon (de) et al., 2009). They may differ by noise, soil pollution and ground vibration caused by car traffic, but in our case we showed that the main factor influencing the abundance was the margin width, which was also the main difference between highway and road verges. We may hypothesize that highways verges, thanks to their wideness, are more used by shrews as habitat but also as corridor than road verges. In

field margins, which are even narrower than road verges (4.0 ± 0.4 m), we captured even less *S. coronatus*.

4.3. Roadside verges as barrier

The significant effect of the distance to the next adjacent natural habitat at the same side of the road (DC) on the relative abundance of *S. coronatus*, and the absence of a significant effect of distance to the next natural habitat at the opposite side of road (DX), might suggest a barrier effect of the roads for shrews. This result should be confirmed by more direct methods, e.g. based on capture-recapture or radio-tracking data. However, this result fits with other studies that used a variety of methodological approaches but always concluded that the roadway prevents movement of small mammals from one side to the other of the road because of their particularly unfriendly habitat (Oxley et al., 1974; Mader, 1984; Swihart and Slade, 1984; Merriam et al., 1989; Kirby, 1997; Brehme, 2003; Rytwinski and Fahrig, 2012). This barrier effect could be a driver of small mammal assemblages' differences between natural habitat patches isolated by urban matrix (see Fernández, 2013)

4.4. Management policies and small mammals

In the European Common Agricultural Policy implemented from 2002, environmental objectives to preserve biodiversity were introduced into the process of agrarian subsidies: farmers have to choose between different environmental practices to obtain financial helps. One of those practices is the establishment of new margins around crop fields, with an expected increase of biodiversity within agricultural landscapes. Such policies should be strongly encouraged because they may also increased ecosystem services by maintaining populations of agriculture pest predators, such as shrews, which feed mainly on beetles, caterpillars and slugs (Pernetta, 1976; Churchfield, 1982; Bellocq and Smith, 1994; Maisonneuve and Rioux, 2001) and stabilising vole dynamics by avoiding cycling outbreaks (Delattre et al., 1999; Redon (de) et al., 2009).

Because (i) our result suggest that roads might play a role of barriers for small mammals, because (ii) we found that shrews densities are highly correlated to the distance to adjacent natural habitats, because (iii) culverts have strong effects on shrews dispersal between the two sides of the road (Yanes et al., 1995) and because (iv) they limit small mammal road casualties (Lodé, 2000), we also recommend to purchase the implementation of underground passages in order to help maintaining shrew communities in verges.

According to Meunier et al. (1999) and because verges could represent important conservation areas for small mammals in intensive agrarian landscapes, it should be also interesting to encourage their extensive management. Finally, this paper deals with the role of roads in agricultural areas, but these are not the only ecosystems where roads may play an ecological role, suburban, open, and forested landscapes are shown to hold markedly different road effects on species, habitat, water, soil, and atmosphere (Forman and Hersperger 1999, Forman 2000).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.actao.2014.12.003>.

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