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Louis de Redon, Isabelle Le Viol, Frédéric Jiguet, Nathalie Machon, Olivier Scher, Christian Kerbiriou

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Redon (de), Louis[1, 2]; Le Viol, Isabelle[2]; Jiguet, Frédéric[2]; Machon, Nathalie[2]; Scher, Olivier[3]; Kerbiriou, Christian[2*].

[1] AgroParisTech-ENGREF, 19 av. du Maine, 75 015 Paris, France.

[2] Muséum National d'Histoire Naturelle. Conservation des Espèces, Restauration et Suivi des Populations - UMR 7204 MNHN-CNRS-UPMC, 55 rue Buffon, 75005 Paris, France.

[3] Conservatoire des Espaces Naturels de Languedoc-Roussillon, 474 allée Henri II de Montmorency, 34 000 Montpellier -

* Corresponding author; Fax: (+33) 140 79 38 35; E-mail: kerbiriou@mnhn.fr;

Abstract (248 words)

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 *S. 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.

Keywords

Dispersal; marginal areas; roadside; road management; *Sorex coronatus*; *Microtus arvalis*.

Highlights

We assess abundance of small mammals in road verges, fields, field margins and woods.

One of the most important factor influencing abundance was the margin width

Results suggest a corridors effect and a barrier effect of roads for small mammals

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 Frissel 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 behaviors (Siemers and Schaub 2011) and barriers to movements which decrease landscape connectivity (Rico et al. 2007). 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 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 favoring 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; Tikka et al. 2001; Dawson 2002; 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. 2007), 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 km^2. 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 meter 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 twenty meters along the way in the middle of the verges (for more details see Le Viol et al. 2008; Redon (de) et al. 2010).

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 meters); inside fields at 25 m from the hedges (65 fields, noted *F25*, consisting of two traps with a distance of twenty meters), and inside filed at 50 m from the hedges (56 fields, noted *F50*, consisting of two traps with a distance of twenty meters). 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-25m (*F25*: 15%) and fields-50m (*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. 2010; Vergnes 2013). Each animal was dissected and identified mainly using its morphological cranial characteristics, such as teeth, according to Chaline et al. (1974).

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 neighboring 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 meters buffer (*W250*), proportion of forest habitat in a 500 meters 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 926m², we then sorted verge sites in two categories: sites near a natural habitat (sites *A*), *i.e.* less distant than ten territories diameters (343m), 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*: <343m and *B*: >343m) 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 a 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 (*Crocidura russula*, *S. coronatus* and *S. minutus*), three vole species (*Clethrionomys glareolus*, *Microtus 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) 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-50m, *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 meters 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 meters (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 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 & Handley, 1993; Nicolas & 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 one 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. 2010).

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 harbors 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)

Tichendorf 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. 2010). 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 ± 0.4m), 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 Riou, 2001) and stabilising vole dynamics by avoiding cycling outbreaks (Delattre et al. 1999; Redon (de) et al. 2010).

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 & Hersperger 1999, Forman 2000).

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

					Mice		Voles			Shrews			
Zones	**Habitats**	**Sites**	**Trap by site**	**Traps recovered**	*Apodemus flavicollis*	*Apodemus sylvaticus*	*Clethrionomys glareolus*	*Microtus agrestis*	*Microtus arvalis*	*Crossidura russula*	*Sorex coronatus*	*Sorex minutus*	Estimated Richness
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 25m*	65	2	110	0	5	0	0	9	1	1	0	2.51 ± 0.66
	Fields 50m	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	

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

	M. arvalis	*S. coronatus*
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 meters buffer	7.9	1.2
Proportion of forest habitat in a 500 meters buffer	13.2	9.9
Type crop in the field	25.0	1.1
Car traffic	12.4	11.6

Figure 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.

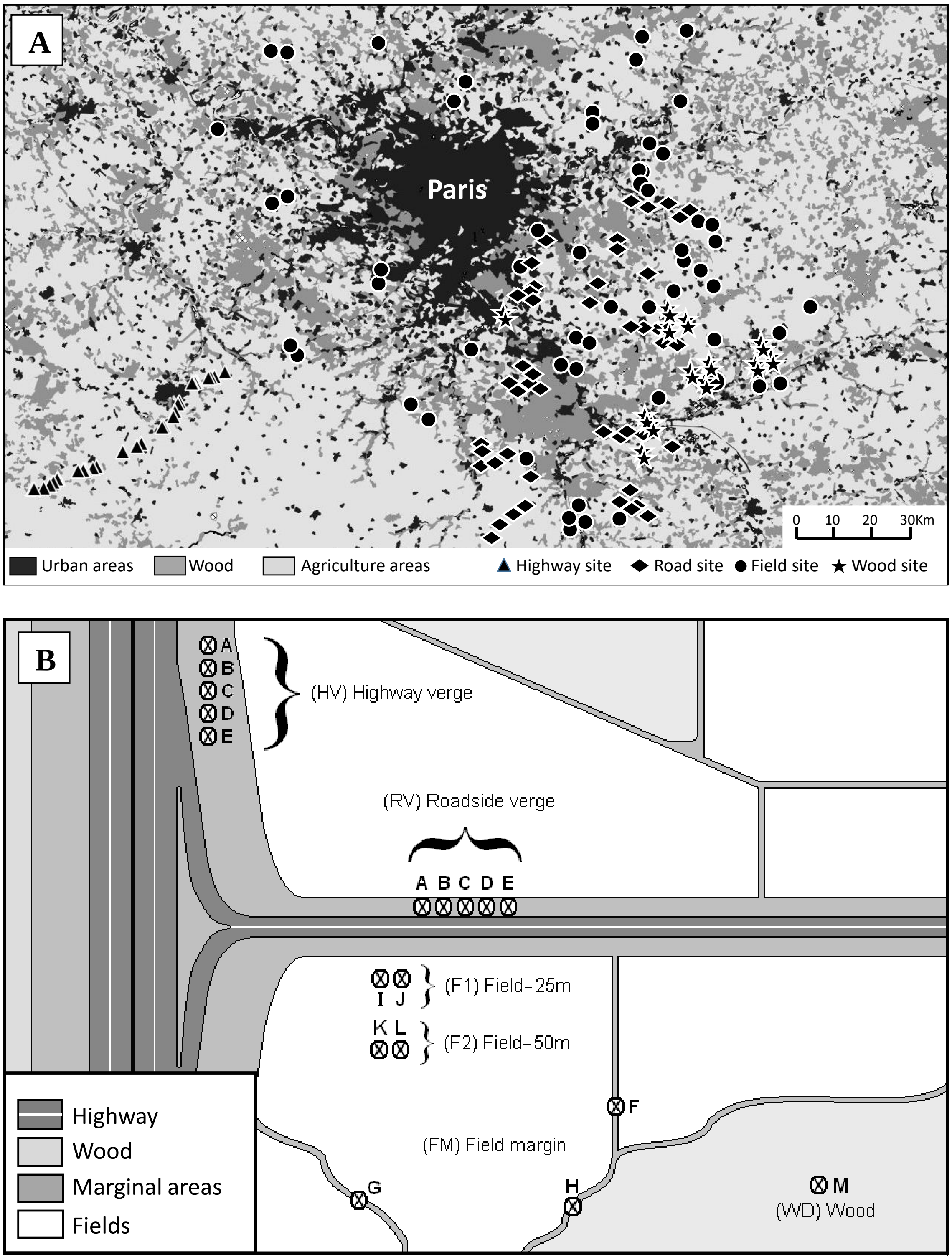

Fig. 2. Distances between capture sites and nearest connected natural habitats (*DC*) or opposite nearest natural habitat (*DX*).

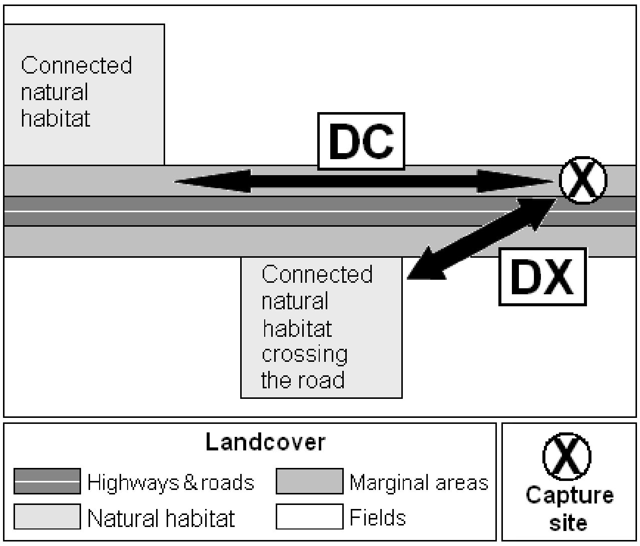

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Fig. 3. *Microtus arvalis* (Fig. 3A) and *Sorex coronatus* (Fig. 3B) exhibit significant differences in relative abundance between habitats. Different letters signal significant differences between average numbers of capture per trap.

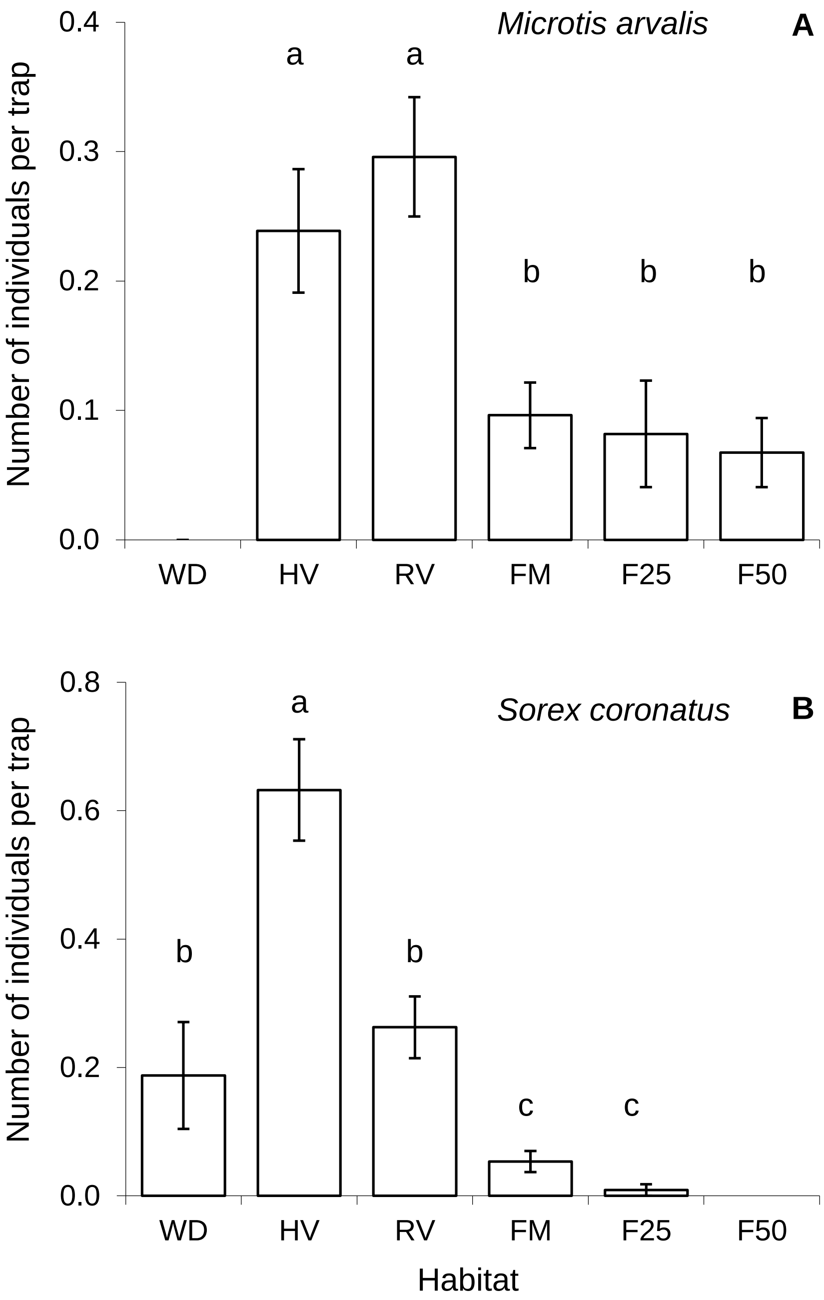

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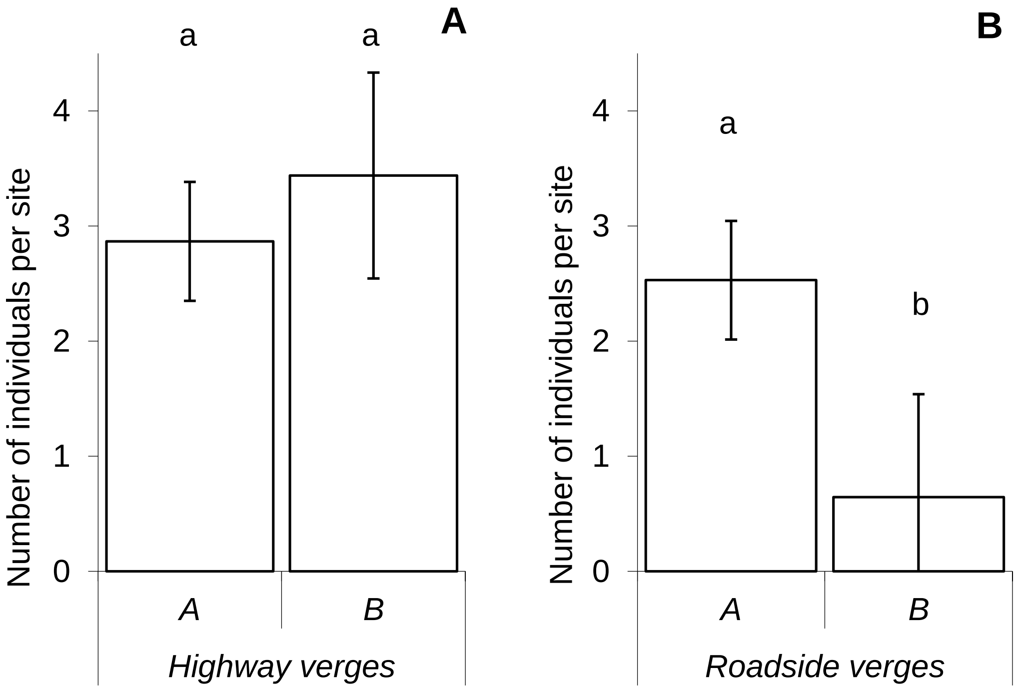
Fig. 4. In highway verges, no significant correlation between relative abundance of *S. coronatus* and distance between capture sites and the nearest connected natural habitat (*DC*) were detected, average number of capture within site near natural habitat (A) did not differ from sites far from a natural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



Electronic Supplementary Material - Appendix A

Table A1: Ile de France region is mainly composed by fields, forests and urban areas. Marginal areas as field margins, roadside and highway verges represent non-negligible areas

Landcover		**Area (km^2)**	**Percentages**	
Urban areas	*Buildings*	*2083*	*17.3%*	**18.2%**
	Transports	*104*	*0.9%*	
Natural areas	*Woods*	*2850*	*23.7%*	**29.7%**
	Meadows	*587*	*4.9%*	
	Water	*148*	*1.2%*	
Marginal areas	*Highway verges*	*46*	*0.4%*	**3.1%**
	Road verges	*144*	*1.2%*	
	Field margins	*180*	*1.5%*	
Fields		*5908*	*49.0%*	**49.0%**

Electronic Supplementary Material - Appendix B: Details on small mammal sampling.

Traps

The traps were *Barber* pitfall traps, i.e. 450 mL plastic pots (10.2 cm height & 7.5 cm diameter) inserted into the ground, containing a 155 mL solution composed with 75 mL of water, 75 mL of conservative (monopropylene glycol), 5 mL of surfactant (dishware soap) and 15 g of NaCl, and protected from rain by plastic transparent covers (15 cm×15 cm) supported by wood sticks 10 cm above the ground. For this study, we used the data of the small mammals incidentally fallen in the traps with the hypothesis that their abundance in the traps was correlated to their abundance in the verges. This hypothesis is supported by the fact that the solution inside the pots is neither attractive nor repulsive. It is not the most common trapping method for small mammal sampling but was shown relevant to highlight some distribution patterns and trends (see de Redon et al. 2010).

Potential bias in trap line

Given that captured both the individuals cannot be recaptured in another trap, we tested the independence of trap. Using similar modelling of abundance at the trap scale we test if trap identity could influence abundance (GLMM, with an autocov distance function, an error poisson distribution and a random effect on site).

Table B1: Effect of trap identity

	S. coronatus	*M. arvalis*
Highway	*Chisq*=7.974 ; *df*=4 ; *P*=0.09	*Chisq*=2.501 ; *df*= 4; *P*=0.64
Road	*Chisq*=0.738 ; *df*= 1 ; *P*=0.3903	*Chisq*=6.683 ; *df*= 4 ; *P*=0.15

We did not detected any obvious bias, so, we can reasonably consider the hypothesis of independence respected. Small mammals are not attracted or avoid the traps based on the presence of other congeners, or when an individual is captured by the first trap in the trapline it does not affect the following traps.

Potential attractiveness of collected invertebrates on small mammals captures

We can hypothesize that small mammals can be attracted by the presence of invertebrates fallen to the bottom of the trap: the traps with many invertebrates could be more attractive. We test the potential effect of the number and the biomass of invertebrates on the abundance of small mammals through the comparisons of captures of mammals and invertebrates in 51 traps. Biomass (*B*) was approximated as follow:

$$B = \Sigma_{i,}\ a_i\ .\ s_i$$

Where a_i is the abundance of species i and s_i is the size of the specie i

This subsample corresponds to traps for which we had information on both invertebrates and small mammals captured. We assess this potential effect using a GLM (with Poisson error distribution according to the nature of data: count). We did not detect any obvious correlations between invertebrate number /biomass and small mammals (Table B1).

Table B1: Effect of invertebrate collected on small mammals captures

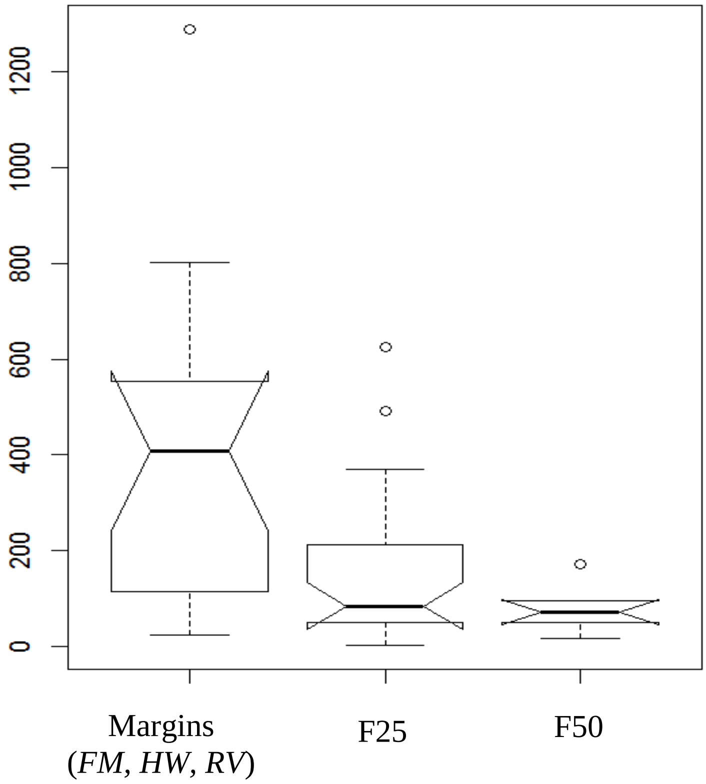
	Sorex coronatus	*Microtus arvalis*	Small mammal total
Invertebrate biomass	$F_{1,49}$ = 0.473;	$F_{1,49}$ = 2.131;	$F_{1,49}$ = 2.463;
	P = 0.492	P = 0.144 =	P = 0.117
Invertebrate number	$F_{1,49}$ = 0.619;	$F_{1,49}$ = 2.274;	$F_{1,49}$ = 2.778;
	P = 0.432	P = 0.132	P = 0.096

References:

De Redon, L., Machon N., Kerbiriou C., Jiguet, F. 2010. Possible effects of roadside verges on vole outbreaks in an intensive agrarian landscape. Mammalian Biology 75, 92-94.

Variation of invertebrate biomass among habitat

Invertebrate biomass (potential preys of shrew) is higher in margins (*FM*, *HW*, *RV*) than in Fields (F25 and F50) ($F_{2,48}$=11.121; P<0.0001).



Electronic Supplementary Material - Appendix C

Figure C1: Influence of width margins (meters) on relative abundance of *Sorex coronatus* (A) and *Microtus arvalis* (B) using Generalized Additive Model (GAM, package *mgcv*).