How to manage a hedgerow as an effective ecological corridor for mammals: a two-species approach

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ABSTRACT

In European agricultural landscapes, forest fragmentation is one of the most serious threats to wildlife populations viability. Ecological corridors are the management tool used to mitigate the effects of this phenomenon and, in agro-ecosystems, they are traditionally represented by hedgerows. Hedgerows vary dramatically in their internal structure and quality and their effectiveness as corridors depends both on their physical features, such as width and continuity, and internal habitat conditions. Moreover, the ecological requirements related to hedgerow structure are strongly species-specific. In this study, we evaluated which characteristics make a hedgerow suitable for two mammal species sensitive to forest fragmentation at two very different spatial scales: the European Badger and the Hazel Dormouse. The study was carried out in a wide lowland area of northern Italy. Following a stratified cluster sampling design, we surveyed 55 hedgerows. For each hedgerow, we collected both structural and floristic variables and we evaluated how differently they affect hedgerows use by the European Badger and Hazel Dormouse. Our results suggested that, in order to simultaneously increase landscape connectivity for both mammal species, a hedgerow should be wide and continuous. Moreover, it should be managed to promote development of the shrub layer and to avoid monopolization by the invasive locust tree. The information we obtained by this two-species approach provided crucial suggestions for a correct management of hedgerows, which could be used for the conservation of any species with similar ecological requirements and a similar response to fragmentation.

KEYWORDS

Connectivity, Conservation, Hedgerows Management, European Badger, Hazel Dormouse.

1 INTRODUCTION

Forest fragmentation is one of the most important human-induced phenomena threatening the viability of wild populations (Crooks and Soulé 1999; Fahrig 2003; Fischer and Lindenmayer 2007). Fragmentation alters the structure and dynamic of populations, subdividing them into smaller and isolated sub-populations, and making them particularly sensitive to the negative effects of genetic, demographic and environmental stochasticity (Gilpin and Soulé 1986). This is particularly noticeable in European lowland areas, where natural or semi-natural elements suitable for wildlife, such as woodlands and hedgerows, dramatically decreased during the past decades due to the wide conversion of original habitats to intensively cultivated areas (Arnold 1983; Darby 1956; Williams 2002). The management tool designed to mitigate the negative effects of forest fragmentation consists of ecological corridors, i.e. linear structures that could restore and enhance the connectivity among forest remnants (Forman and Gordon 1986; Šálek et al. 2009). In particular, they should facilitate the gene flow through sub-populations enabling individual dispersal (Červinka et al. 2013; Mech and Hallet 2001). In lowland agro-ecosystems, ecological corridors are traditionally represented by hedgerows, defined as lines of closely spaced shrubs and trees. Although the effectiveness of hedgerows and other ecological corridors in mitigating the effect of forest fragmentation has been widely debated over the past two decades (Davies and Pullin 2007; Tattersall et al. 2002), some authors clearly pointed out their importance in providing shelter, breeding sites and food resources for wildlife (Bennett 1999; Hilty and Merenlender 2004). In particular, several studies highlighted that hedgerows could represent not only effective ecological corridors, but also suitable habitats for different species, especially for birds and small mammals (Arnold 1983; Gelling et al. 2007; Hinsley and Bellamy 2000; Laurance and Laurance 1999; Silva and Prince 2008; Wolton 2009). Moreover, recent studies have demonstrated that, in agricultural landscapes, hedgerows are also preferentially used by several carnivore species, in particular by mustelids (Červinka et al. 2013; Šálek et al. 2009). However, hedgerows can have different origins and structures. They may be residuals of native woodlands or new plantations, and they may suffer different management strategies. This leads to a dramatic dissimilarity in their internal structure and quality (Gelling et al. 2007) and, thus, in their suitability for wildlife. Indeed, the effectiveness of hedgerows as ecological corridors or suitable habitats depends on their structural features, such as width, continuity and internal habitat conditions (Šálek et al. 2009, Silva and Prince 2008). For examples, poor-quality and discontinuous hedgerows resulted detrimental to some farmland birds (Hinsley and Bellamy 2000) and small mammals (Bright 1998), while narrow hedgerows without trees seem to be unsuitable for carnivores (Hilty and Merenlender 2004). Therefore, it is important to define which structural features should be preserved in order to ensure the effectiveness of hedgerows in restoring or enhancing landscape connectivity. Since the ecological requirements related to hedgerow structure are strongly species-specific, it would be appropriate, where possible, to apply a multi-species approach.

In this study, we evaluated which internal characteristics make a hedgerow suitable for two mammal species particular sensitive to fragmentation in Northern Italy, the European Badger (*Meles meles*) and the Hazel Dormouse (*Muscardinus avellanarius*). We chose to investigate the ecological requirements of these two species, in terms of structural and floristic characteristics of hedgerows, because of their sensitivity to forest fragmentation at two very different spatial scales (50 km^2 vs 5 km^2). Indeed, the dispersal magnitude of these two species is strongly different (European Badger: 500 m - 8 km, Kowalczyk et al. 2006, Macdonald and Barret 1993; Hazel Dormouse: 150 m - 300 m, Mortelliti et al. 2012). Moreover, it is well known that both species are particularly linked to hedgerows (Ehlers 2012; Elliot et al. 2015; O'Brien et al. 2016; Wolton 2009;). Within our study area, it was demonstrated that they perceive hedgerows not only as ecological corridors but also as preferential habitats (Dondina et al. submitted; Dondina et al. unpublished). The information provided by this two-species approach could generate important suggestions for a correct management of hedgerows, which might guarantee the conservation of the two target species and, virtually, of any other species with analogous ecological requirements and that responds to fragmentation at similar spatial scales.

2 MATERIAL AND METHODS

2.1 Study area

The study area (Figure 1) is a typical European lowland agro-ecosystem, located in Western Lombardy (45°21' N 8°80' E, northern Italy). It is about 1,300 km^2 wide and it is bordered by three main rivers, the Sesia, Po and Ticino. The total surface is largely covered by intensive cultivated crops, which represent 74% of the area and consist mainly of rice paddies. The remaining surface is covered by built-up areas (9%), reforestations and other arboreal cultivations (7%), and original broadleaved forest remnants (7%, 99% of which are smaller than 1 km^2). Most of the original forest cover falls within the boundaries of the Ticino Natural Park, a 220 km^2 wide protected area located in the eastern part of the study area. The remaining 3% of the surface is covered by hedgerows, which are often distributed along the crop field borders and ditches. Overall, the territory included in the study area was strongly influenced by human activity. In the last fifty years, as often occurs in agro-ecosystems (Bani et al. 2009; Donald et al. 2001; Henle et al. 2008; Sokos et al. 2013), landscape exploitation due to the increasing demand of agricultural productivity has led to an impoverishment of landscape heterogeneity and to an important reduction of wildlife biodiversity.

2.2 Sampling design

The data collection followed a stratified cluster sampling design, defined within a project aimed at evaluating the effect of forest fragmentation on mammal species and identifying an effective ecological network for the study area (Dondina et al. submitted). Basically, we overlapped a 2-km grid to the study area and, within each cell, we calculated five environmental variables: percentage of forest cover, distance from the Ticino Natural Park (considered as a source area), density of hedgerows, density of main roads and degree of habitat fragmentation calculated by means of a Modified Proximity Index (Bani et al. 2006). Subsequently, using a k-means cluster analysis, the 2-km cells were grouped into 10 homogeneous Landscape Units (LUs) according to the five environmental variables considered. Among the 325 2-km cells of the study area, we randomly selected 30 cells (covering about 10% of the study area), allocated in each LU in a number proportional to its size (Figure 1). The 30 2-km cells represented the primary sampling units in the sampling design. Within each primary sampling unit, we randomly selected six 250-m cells, which represented the secondary sampling units. For this study, we considered every hedgerow falling within a secondary sampling unit, for a total of 55 hedgerows within the study area.

2.3 Environmental variables

In order to evaluate which internal characteristics of hedgerows would make them suitable for the European Badger and the Hazel Dormouse, we collected both structural and floristic variables. For each hedgerow we considered physical continuity, average width (calculated averaging three measures taken at both ends and in the middle point of the hedgerow portion included into the secondary sampling unit), average diameter of 20 trees randomly selected within the hedgerow, average shrubs height, percentage of shrub cover, average grass height and percentage of grass cover as structural variables. The last four variables were visually evaluated by the same person (OD) to avoid differences in the estimates (Červinka et al. 2013). Moreover, in order to characterize each hedgerow from a floristic point of view, we identified all shrub and tree species, within the hedgerow portion included into the secondary sampling unit. Each hedgerow was visited in spring during two consecutive years (March-

July 2014 and 2015), and the environmental variables were measured during the first year of data collection.

2.4 Mammal data collection

In order to evaluate the use of hedgerows by the European Badger, we collected data between April and July in 2014 and 2015 performing surveys along linear transects (Krebs 1999). We walked alongside each hedgerow and noted all signs of species presence (i.e. latrines, setts, and footprints) (Sadlier et al. 2004). A hedgerow was considered to be used by the European Badger if any signs of presence were detected on at least one visit. In order to detect the presence and abundance of the Hazel Dormouse, we placed nest-tubes in every hedgerow. In order to keep a constant sampling effort, we used a number of nest-tubes proportional to hedgerow length within each secondary sampling unit, for a maximum of eight nest-tubes per cell. The nest-tubes were placed 50 m apart from each other, in order to include each of them in an individual's home-range (Juškaitis 2008, 1997; Mortelliti et al. 2011). We placed 173 nest-tubes in 38 secondary sampling units, which were inspected during European Badger surveys. A nest-tube was considered used if we observed any individuals inside it on at least one visit, or if we found any nests or feeding signs on the hazelnuts that we left to attract dormice. The relative abundance of the Hazel Dormouse within each hedgerow was calculated as the maximum number of simultaneously occupied nest-tubes detected during the first or the second survey year, and it was related to the total number of nest-tubes places within that hedgerow. During the survey period, four hedgerows were completely or largely cut. In those cases, we considered only the data collected during the first year for both species.

2.5 Statistical analyses

We considered the 55 hedgerows as Statistical Units (SUs) for our analyses on both the European Badger and the Hazel Dormouse .

For the European Badger, we performed a presence model. We considered as independent variables only those concerning hedgerow structure, thus excluding the categorical variable describing the physical continuity of hedgerows, as it is unlikely that this variable might affect the use of a hedgerow by a species that usually crosses open areas. In order to account for the possible effect of the fragmentation degree of the landscape in which each hedgerow was located (Červinka et al. 2013), we also considered three other variables, i.e. the total surface occupied by hedgerows in a 2-km buffer surrounding each hedgerow, the abundance of suitable habitat (i.e. woodlands, poplar cultivations and hedgerows) in hectares, and the Connectance Index (Fragstats 4 ; McGarigal et al. 2002) calculated on those landscape elements (i.e. woodlands, poplar cultivations, hedgerows and biomasses) used as connectivity elements by the European Badger (Dondina et al. unpublished). The value of the last two variables for each hedgerow was calculated using a mowing window with a 2-km radius (a buffer area that moves from pixel to pixel in the whole landscape) and averaging the values calculated within each primary sampling unit. As we collected data following a hierarchical sampling design (Crawley 2007), we ran a Generalized Linear Mixed Model (GLMM) with a binomial error distribution. We used the presence/absence of the European Badger as the response variable, the primary and secondary sampling units as nested random effects, and the environmental variables as fixed. However, since the random effects explained a very low percentage of the variance of the dependent variable, we removed them and re-ran the model as a GLM with a binomial error distribution. As the Moran's I Test performed with 999 permutations (Cliff and Ord 1981) revealed spatial autocorrelation both in the response variable and in model residuals, we added the spatial coordinates of the centroid of each hedgerow to the model as covariates. In this way, we were able to remove the residuals spatial autocorrelation, as confirmed by the following Moran's I Test. All continuous independent variables were standardized using an autoscaling procedure. We selected the variables following an Information-Theoretic Approach (Anderson et al. 2001, 2000; Anderson and Burnham 2002; Burnham and Anderson 2002) by means of the Akaike Information Criterion (AIC) (Akaike 1973; Burnham and Anderson 2002). The explanatory power of the best model was evaluated by means of the explained deviance D^2 (Boyce et al. 2002; Crawley 1993; Zuur et al. 2009, 2007), and its ability to distinguish between occupied and unoccupied hedgerows was tested using the area under the curve of the Receiver Operating Characteristic plot (ROC curve) (Fawcett 2006; Pearce and Ferrier 2000).

For the Hazel Dormouse, we performed both a presence and abundance model. In both cases, we considered both structural and floristic features as independent variables, as we hypothesized that floristic characteristics could have a great influence on a species which typically feeds on berries and builds nests using vegetal products, such as moss and leaves (Juškaitis 2008). We also took into account the total surface occupied by hedgerows within a 250-m buffer (considering continuous and discontinuous hedgerows separately), the amount of suitable habitat (i.e. woodlands and hedgerows) in hectares, and the Connectance Index calculated on those landscape elements (i.e. woodlands, hedgerows, poplar cultivations, biomasses and reforestations) used as connectivity elements by the Hazel Dormouse (Dondina et al. submitted). The last two variables were calculated using a mowing window with a 250-m radius and averaging the values calculated in correspondence to the nest-tubes located in the same hedgerow. In order to perform the presence model, we ran a GLMM using the presence/absence of the species as the response variable, the primary and secondary sampling units as nested random effects, and the environmental variables as fixed effects. However, since the random effects did not explain any percentage of the variance of the dependent variable, we applyed a GLM without considering any random effect. We excluded the presence of spatial autocorrelation in the Hazel Dormouse presence data by means of the Moran's I Test. All continuous independent variables were standardized and selected following an Information-Theoretic Approach by means of the AIC. The explanatory power of the best model was evaluated by means of the explained deviance D^2, and its ability to distinguish between occupied and unoccupied hedgerows was tested using the area under the ROC curve.

Finally, in order to perform the abundance model for the Hazel Dormouse, we modelled the proportion of occupied nest-tubes, considered as a relative index of abundance. Once again, we did not run a GLMM, since the random effects did not explain any percentage of the dependent variable variance, and we applied a GLM using a two-vector response variable (occupied versus non-occupied nest-tubes placed in the hedgerow) with a binomial error distribution, without taking into account any random effect. We excluded the presence of spatial autocorrelation in the Hazel Dormouse abundance data by means of the Moran's I Test. All continuous independent variables were standardized and selected by means of the AIC. Even in this case, the explanatory power of the best model was evaluated by means of the explained deviance D^2.

For all three models we performed a Kolmogorov-Smirnov test to check for residual normality (Legendre and Legendre 1998) and a Durbin-Watson test to check for their independence (Crawley 1993; Savin and White 1977). Moreover, we checked the variables for collinearity by means of the VIF (Variance Inflation Factor, using the *usdm* package in R (Naimi 2015). All analyses were performed using R v. 3.1 (R Core Team 2014).

3 RESULTS

3.1 European Badger presence model

Overall, 18 out of 55 hedgerows were found to be used by the European Badger within the study area. The best presence model selected by the Information-Theoretic Approach explained 39% of the deviance. The model highlighted a significant positive effect of hedgerow width on the probability of occurrence of the European Badger, while the percentage of grass cover played a negative effect (Table 1). The ROC plot analysis showed that the discriminatory ability of the model was good ($AUC = 0.872$, $P < 0.001$). Model residuals were normally distributed (Kolmogorov-Smirnov test, $D = 0.166$, $P = 0.097$), independent (Durbin-Watson test, $DW = 2.30$, $P = 0.779$) and there was no collinearity between variables ($VIF < 3$; Zuur et al. 2009).

3.2 Hazel Dormouse presence model

Overall, 21 out of 55 hedgerows were found to be used by the Hazel Dormouse within the study area. The best presence model selected by the Information-Theoretic Approach explained 21% of the deviance. The most important variables among those selected in the best model were the percentage of shrub cover and the total surface occupied by continuous hedgerows within a 250-m buffer, both with a positive effect on the probability of occurrence of the Hazel Dormouse, and the presence of oaks, with a negative effect (Table 2). The discriminatory ability of the model was good ($AUC = 0.809$, $P < 0.001$). Model residuals were normally distributed (Kolmogorov-Smirnov test, $D = 0.155$, $P = 0.147$), independent (Durbin-Watson test, $DW = 1.80$, $P = 0.194$) and there was no collinearity between variables ($VIF < 3$; Zuur et al. 2009).

3.3 Hazel Dormouse abundance model

The mean Hazel Dormouse abundance within the occupied hedgerows was 1.33 ± 0.12 nest-tubes. The best abundance model explained 39% of the deviance and the most important variable with a positive effect was, once again, the percentage of shrub cover. Conversely, the presence of the locust tree *Robinia pseudoacacia* (an alien species introduced in Europe in 1601) in the shrub layer and the percentage of grass cover had a negative effect on the abundance of the species (Table 3). Model residuals were normally distributed (Kolmogorov-Smirnov test, $D = 0.164$, $P = 0.109$), independent (Durbin-Watson test, $DW = 1.80$, $P = 0.151$) and the collinearity between variables was negligible ($VIF < 4$).

4 DISCUSSION

In agricultural landscapes, hedgerows play an important ecological role for several mammal species, both as corridors and as additional reproductive habitats (Červinka et al. 2013; Gelling et al. 2007; Laurance and Laurance 1999; Šálek et al. 2009; Silva and Prince 2008). However, the effectiveness of hedgerows as ecological corridors or reproductive habitats depends on their internal features, such as floristic and structural characteristics (Šálek et al. 2009; Silva and Prince 2008). The influence of the internal characteristics of hedgerows in determining their use is strongly species-specific and, thus, the application of a multi-species approach could allow obtaining more comprehensive information. In this study, we analyzed which hedgerows characteristics facilitate or discourage their use by the European Badger and the Hazel Dormouse.

According to our analyses, width is the most important structural characteristic that makes a hedgerow suitable for the European Badger. The same result was obtained in other studies regarding both wildlife in general (Hilty et al. 2006), and small and medium-sized carnivores in particular (Hilty and Merenlender 2004). Indeed, wider corridors may have several diverse microhabitat structures, fulfilling more species-specific ecological requirements (Hilty and Merenlender 2004). For the European Badger, hedgerows are important in providing shelter (O’Brien et al. 2016) and food (Gelling et al. 2007; Thomas and Marshall 1999) and, obviously, a wider hedgerow is safer and richer of trophic resources than a narrow one. Our results also suggest that the European Badger avoids hedgerows with a high percentage of grass cover. This finding could be linked to a preference for hedgerows with a high shrub cover. Indeed, even though shrub cover was not found to be significant in our analyses, it is often reported as a very important factor in determining the use of hedgerows as corridors by carnivores (Mangas et al. 2008).

As regards the Hazel Dormouse, both the presence and abundance models clearly highlighted the strong importance of shrub cover in determining the suitability of a hedgerow for the species. Several authors (Bright et al. 1994; Juškaitis and Šiožinytê 2008; Ramakers et al. 2014) showed that a high percentage of shrub cover was important to satisfy the ecological requirements of the Hazel Dormouse. Indeed, this species needs safe shelters where nests can be built away from predators (Bright 1998; Bright and Morris 1991), vegetal materials for nest construction (Berg and Berg 1998; Wolton 2009) and food resources, such as berries, seeds and insects (Bright and Morris 1992, 1991, 1990). These requirements can only be found in a hedgerow with a well-developed shrub layer, and the higher the percentage of shrub cover is, the larger is the Hazel Dormouse population that the hedgerow can support.

The presence model also revealed a positive effect of the cover of continuous hedgerows within a 250-m buffer on presence probability of the Hazel Dormouse. This finding highlighted the importance of physical continuity in making hedgerows suitable for the Hazel Dormouse. Indeed, discontinuous hedgerows have been proved to be detrimental for several species (Gelling et al. 2007). Specifically, radio-tracking studies carried out in UK by Bright (1998) showed a significant difference in the crossing frequency of different size gaps within hedgerows by the Hazel Dormouse. In particular, one meter gaps were crossed in 55% of the cases, three meter gaps only in 6%, while gaps over six meters were never crossed during the study period. The presence model also showed that the presence of oaks within a hedgerow negatively affects the probability of presence of the Hazel Dormouse. Both the Pedunculate Oak (*Quercus robur*) and the Sessile Oak (*Quercus petraea*) are tree species with an average height ranging between 30 and 35 meters and a wide canopy. Hedgerows hosting these species are often characterized by a poorly developed shrub layer, in favor of a wider herbaceous cover. The negative effect of a high percentage of grass cover on the Hazel Dormouse was explicitly highlighted by the abundance model. As for the European Badger, this probably depends on the preference for hedgerows characterized by a high shrub cover, and, thus, by a lower cover of the grass layer. Finally, the abundance model revealed the negative effect of the locust tree in the shrub layer on the Hazel Dormouse. This tree species negatively affected only the abundance of the Hazel Dormouse, and not its occurrence probability, as the locust tree shrub layer probably determines a hedgerow structure suitable for this small mammal. However, this invasive tree species tends to colonize the entire shrub layer, making it monospecific and offering scarce food resources. This kind of habitat cannot host a high density of Hazel Dormouse individuals.

5 MANAGEMENT IMPLICATIONS

In this study, we evaluated which hedgerow characteristics facilitate or discourage their use by two mammal species responding to fragmentation at two different spatial scales: the Hazel Dormouse and the European Badger. In order to identify proper management measures aimed at making hedgerows suitable for a larger part of the entire community, it is fundamental to consider species responding to different spatial scales. In particular, we identified some management practices that should be applied in order to make a hedgerow an effective ecological corridor for the European Badger, the Hazel Dormouse, and any other species with similar ecological requirements and that responds to forest fragmentation at similar spatial scales. The fact that, overall, only eight out of 18 and 21 hedgerows occupied by the European Badger and Hazel Dormouse, respectively, were simultaneously occupied by the two species, suggests that these two mammals have different ecological requirements and that the current management of hedgerows in the study area is only partially adequate to make them suitable for both species.

Based on our results, we suggest that, in lowland areas characterized by a high degree of forest fragmentation, hedgerows should be kept as wide as possible in order to increase landscape connectivity and habitat availability. This is consistent with the findings of Hilty and Merendlener (2004), who suggested that, in agricultural landscapes, the maintenance of wider hedgerows is crucial in order to protect more wildlife species with different ecological requirements. It is interesting to point out that if we had used only the Hazel Dormouse as a target species, this result would not have emerged. On the other hand, considering the Hazel Dormouse allowed us to highlight another crucial factor, i.e. hedgerow continuity, and the importance to fill hedgerow gaps with trees and shrubs. Hedgerows should also be managed in order to increase the shrub layer cover, and if the locust tree is one of the species in this layer, it should be removed before it becomes prevalent species.

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REFERENCES

Akaike, H., 1973. Information theory as an extension of the maximum likelihood principle, in: Petrov, B.N., Csaki, F. (Eds.), Second International Symposium on Information Theory. Akademiai Kiado, Budapest, pp. 267-281.

Anderson, D.R., Burnham, K.P., Thompson, W.L., 2000. Null hypothesis testing: problems, prevalence, and an alternative. J. Wildl. Manage. 64, 912-923.

Anderson, D.R., Link, W.A., Johnson, D.H., Burnham, K.P., 2001. Suggestions for presenting the results of data analyses. J. Wildl. Manage. 65, 373-378.

Anderson, D.R., Burnham, K.P., 2002. Avoiding pitfalls when using information-theoretic methods. J. Wildl. Manage. 66, 912-918.

Arnold, G.W., 1983. The influence of ditch and hedgerow structure, length of hedgerows, and area of woodland and garden on bird numbers on farmland. J. Appl. Ecol. 20, 731-750.

Bani, L., Massimino, D., Bottoni, L., Massa, R., 2006. A multiscale method for selecting indicator species and priority conservation areas: a case study for broadleaved forests in Lombardy, Italy. Conserv. Biol. 20, 512-526.

Bani, L., Massimino, D., Orioli, V., Bottoni, L., Massa, R. 2009. Assessment of population trends of common breeding birds in Lombardy, Northern Italy, 1992–2007. Ethol. Ecol. Evol. 21, 27-44.

Bennett, A.F., 1999. Linkages in the landscape: the role of corridors and connectivity in wildlife conservation. IUCN, Gland, Switzerland.

Berg, L., Berg, A., 1998. Nest site selection by the dormouse *Muscardinus avellanarius* in two different landscapes. Ann. Zool. Fenn. 35:115-122.

Boyce, M.S., Vernier, P.R., Nielsen, S.E., Schmiegelow, F.K., 2002. Evaluating resource selection functions. Ecol. Model. 157, 281-300.

Bright, P.W., 1998. Behaviour of specialist species in habitat corridors: arboreal dormice avoid corridor gaps. Anim. Behav. 56, 1485-1490.

Bright, P.W., Morris, P.A., 1990. Habitat requirements of dormice Muscardinus avellanarius in relation to woodland management in southwest England. Biol. Conserv. 54, 307-326.

Bright, P.W., Morris, P.A., 1991. Ranging and nesting behaviour of the dormouse, *Muscardinus avellanarius*, in diverse low-growing woodland. J. Zool. (London). 224, 177-190.

Bright, P.W., Morris, P.A. 1992. Ranging and nesting behaviour of the dormouse, *Muscardinus avellanarius*, in coppice-with-standards woodland. J Zool (London). 226, 589-600.

Bright, P.W., Mitchell, P., Morris, P.A., 1994. Dormouse distribution: survey techniques, insular ecology and selection of sites for conservation. J. Appl. Ecol. 31, 329-339.

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edn. Springer, New York.

Červinka, J., Šálek, M., Padyšáková, E., Šmilauer, P., 2013. The effects of local and landscape-scale habitat characteristics and prey availability on corridor use by carnivores: A comparison of two contrasting farmlands. J. Nat. Conserv. 21, 105-113.

Cliff, A.D., Ord, J.K., 1981. Spatial processes, Pion, p. 63-5.

Crawley, M.J., 1993. GLIM for ecologists. Blackwell Scientific Publications, Oxford, Boston.

Crawley, M.J., 2007. The R Book. John Wiley & Sons, Ltd, West Sussex, England.

Crooks, K.R., Soulé, M.E., 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature. 400, 563-566.

Darby, H.C., 1956. The clearing of the woodland in Europe, in: Thomas, W.L. Jr (Ed), Man's Role in Changing the Face of the Earth. University of Chicago Press, Chicago, USA, pp 183-216.

Davies, Z.G., Pullin, A.S., 2007. Are hedgerows effective corridors between fragments of woodland habitat? An evidence-based approach. Landsc. Ecol. 22, 333-351.

Donald, P.F., Gree, R.E., Heath, M.F., 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. Proc. Biol. Sci. 268, 25-29.

Ehlers, S., 2012. The importance of hedgerows for hazel dormice (*Muscardinus avellanarius*) in Northern Germany. Peckiana. 8, 41-47.

Elliott, S., O'Brien, J., Hayden, T.J., 2015. Impact of human land use patterns and climatic variables on badger (Meles meles) foraging behavior in Ireland. Mammal Research. 60, 331-342.

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Evol. Syst. 34, 487-515.

Fawcett, T., 2006. An introduction to ROC analysis. Pattern. Recogn. Lett. 27, 861-874.

Fischer, J., Lindenmayer, J.B., 2007. Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265-280.

Forman, R.T.T., Gordon, M., 1986. Landscape Ecology. John Wiley & Sons, New York.

Gelling, M., Macdonald, D.W., Mathews, F., 2007. Are hedgerows the route to increased farmland small mammal density? Use of hedgerows in British pastoral habitats. Landsc. Ecol. 22, 1019-1032.

Gilpin, M.E., Soulé, M.E., 1986. Minimum Viable Populations: Processes of Species Extinction, in: Soulé, M.E., (Ed) Conservation Biology: The Science of Scarcity and Diversity. Sinauer, Sunderland, Massachusetts, USA, pp. 19-34.

Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R.F.A., Niemelä, J., Rebane, M., Wascher, D., Watt, A., Young, J., 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe–A review. Agric. Ecosyst. Environ. 124, 60-71.

Hilty, J.A., Merenlender, A.M., 2004. Use of riparian corridors and vineyards by mammalian predators in Northern California. Conserv. Biol. 18, 126-135.

Hilty, J.A., Lidicker, W.Z., Merenlender, A.M., 2006. Corridor ecology: The science and practice of linking landscapes for biodiversity conservation. Island Press, Washington.

Hinsley, S.A., Bellamy, P.E., 2000. The influence of hedge structure, management and landscape context on the value of hedgerows to birds: A review. J. Environ. Manage. 60, 33-49.

Juškaitis, R., 1997. Ranging and movement of the common dormouse Muscardinus avellanarius in Lithuania. Acta Theriol. 42, 113-122.

Juškaitis, R., 2008. The Common Dormouse Muscardinus avellanarius: Ecology, Population Structure and Dynamics. Institute of Ecology of Vilnius University Publishers, Vilnius.

Juškaitis, R., Šiožinytê, V., 2008. Habitat requirements of the common dormouse (Muscardinus avellanarius) and the fat dormouse (Glis glis) in mature mixed forest in Lithuania. Ekologia. 27, 143-151.

Kowalczyk, R., Zalewski, A., Bogumila, J., 2006. Daily movement and territory use by badgers Meles meles in Bialowieża Primeval Forest, Poland. Wildl. Biol. 12, 385-391.

Krebs, C.J., 1999. Ecological methodology. 2nd edn. Benjamin/Cummings, Menlo Park.

Laurance, S.G., Laurance, W.F., 1999. Tropical wildlife corridors: use of linear rainforest remnants by arboreal mammals. Biol. Conserv. 91,231-239.

Legendre, P., Legendre, L., 1998. Numerical ecology. 2nd English edn. Elsevier, Amsterdam, New York.

Macdonald, W., Barrett, P., 1993. Mammals of Britain and Europe. London Harper Collins.

Mangas, J.G., Lozano, J., Cabezas-Diaz, S., Virgós, E., 2008. The priority value of scrubland habitats for carnivore conservation in Mediterranean ecosystems. Biodivers. Conserv. 17, 43-51.

McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E., 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. University of Massachussets, USA.

Mech, S.G., Hallett, J.G., 2001. Evaluating the effectiveness of corridors: A genetic approach. Conserv. Biol. 15, 467-474.

Mortelliti, A., Amori, G., Capizzi, D., Cervone, C., Fagiani, S., Pollini, B., Boitani, L., 2011 Independent effects of habitat loss, habitat fragmentation and structural connectivity on the distribution of two arboreal rodents. J. Appl. Ecol. 48, 153-162.

Mortelliti, A., Santarelli, L., Sozio, G., Fagiani, S., Boitani, L., 2012. Long distance field crossings by hazel dormice (Muscardinus avellanarius) in fragmented landscapes. Mamm. Biol. 78, 309-312.

Naimi, B., 2015. *usdm*: Uncertainty Analysis for Species Distribution Models. R package version 1.1-15. URL https://CRAN.R-project.org/package=usdm.

O'Brien, J., Elliott, S., Hayden, T.J., 2016. Use of hedgerows as key element of badger (Meles meles) behaviour in Ireland. Mamm. Biol. 81, 104-110.

Pearce, J., Ferrier, S., 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecol. Model. 133, 225-245.

R Development Core Team, 2014. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ramakers, J.J.C., Dorenbosch, M., Foppen, R.P.B. 2014. Surviving on the edge: a conservation-oriented habitat analysis and forest edge manipulation for the hazel dormouse in the Netherlands. Eur. J. Wildl. Res. 60, 927-931.

Sadlier, L., Webbon, C.C., Baker, P.J., Harris, S., 2004. Methods of monitoring red foxes *Vulpes vulpes* and badgers *Meles meles*: are field signs the answer? Mamm. Rev. 34, 75-98.

Šálek, M., Kreisinger, J., Sedláček, F., Albrecht, T., 2009. Corridor vs. hayfield matrix use by mammalian predators in an agricultural landscape. Agric. Ecosyst. Environ. 134, 8-13.

Savin, N.E., White, K.J., 1977. The Durbin-Watson test for serial correlation with extreme sample sizes or many regressors. Econometrica. 45, 1989.

Silva, M., Prince, M.E., 2008. The Conservation Value of Hedgerows for Small Mammals in Prince Edward Island, Canada. Am. Midl. Nat. 159, 110-124.

Sokos, C.K., Mamolos, A.P., Kalburtji, K.L., Birtsas, P.K., 2013. Farming and wildlife in Mediterranean agroecosystems. J. Nat. Conserv. 21, 81-92.

Tattersall, F.H., Macdonald, D.W., Hart, B.J., Johnson, P., Manley, W., Feber, R., 2002. Is habitat linearity important for small mammal communities on farmland? J. Appl. Ecol. 39, 43-652.

Thomas, C.F.G., Marshall, E.J.P., 1999. Arthropod abundance and diversity indifferently vegetated margins of arable fields. Agric. Ecosyst. Environ. 72, 131-144.

Williams, M. 2002. Deforesting the Earth: From Prehistory to Global Crisis. University of Chicago Press, Chicago, USA.

Wolton, R., 2009. Hazel dormouse Muscardinus avellanarius (L.) nest site selection in hedgerows. Mammalia. 73, 7-12.

Zuur AF, Ieno EN, Smith GM (2007) Analysing Ecological Data. Springer Science + Business Media, LLC, New York.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and extensions in ecology with R. Springer, New York.

Table 1. Best presence model for the use of hedgerows by the European Badger in Northern Italy. East: longitude (UTM, WGS84_32N) of each hedgerow centroid. SE: standard error of estimates. z: Wald statistic for testing the hypothesis that the corresponding estimate is equal to zero (null hypothesis). Pr(>|z|): probability that the null hypothesis is true. The model explained 39% of the null deviance.

Predictors	**Estimate**	**SE**	**z**	**Pr(>|z|)**
(Intercept)	-1.335	0.475	-2.808	0.005
Width	2.496	0.869	2.872	0.004
Percentage of grass cover	-1.878	0.797	-2.357	0.018
Total hedgerows cover (buffer 2-km)	0.712	0.453	1.574	0.115
East	-3.208	1.136	-2.825	0.005

Table 2. Best presence model for the use of hedgerows by the Hazel Dormouse in Northern Italy. SE: standard error of estimates. z: Wald statistic for testing the hypothesis that the corresponding estimate is equal to zero (null hypothesis). Pr(>|z|): probability that the null hypothesis is true. The model explained 21% of the null deviance.

Predictors	**Estimate**	**SE**	**Z**	**Pr(>|z|)**
(Intercept)	0.649	0.843	0.770	0.441
Poplar spp._Tree layer	1.593	1.145	1.390	0.164
Oak spp._Tree layer	-2.477	1.328	-1.865	0.062
Locust tree_Shrub layer	-1.354	0.929	-1.457	0.145
Percentage of shrub cover	0.898	0.414	2.173	0.029
Continuous hedgerows cover (buffer 250-m)	0.765	0.446	1.714	0.086
Discontinuous hedgerows cover (buffer 250-m)	-0.605	0.469	-1.291	0.197

Table 3. Best abundance model for the use of hedgerows by the Hazel Dormouse in Northern Italy. SE: standard error of estimates. z: Wald statistic for testing the hypothesis that the corresponding estimate is equal to zero (null hypothesis). Pr(>|z|): probability that the null hypothesis is true. The model explained 39% of the null deviance.

Predictors	**Estimate**	**SE**	**z**	**$Pr(>\lvert z\rvert)$**
(Intercept)	-2.095	1.858	-1.127	0.260
Alder_Tree layer	1.739	1.476	1.178	0.239
Poplar spp._Tree layer	1.569	1.531	1.025	0.305
Oak spp._Tree layer	-2.869	2.166	-1.325	0.185
Locust tree_Tree layer	2.338	2.201	1.062	0.288
Willow spp._ Tree layer	-1.759	1.798	-0.978	0.328
Locust tree_Shrub layer	-2.237	1.277	-1.752	0.079
Percentage of shrub cover	0.847	0.509	1.663	0.096
Average grass height	0.720	0.611	1.179	0.238
Percentage of grass cover	-0.780	0.474	-1.646	0.099
Suitable habitat amount (buffer 250 m)	-0.454	0.562	-0.808	0.419
Continuous hedgerows cover (buffer 250-m)	0.653	0.589	1.109	0.267

Figure captions

Figure 1

Study area

Study area in Northern Italy (45°21' N 8°80' E). The gray color represents hedgerows, whereas the black color shows the original broadleaved forest remnants. The gray squares are the 2-km primary sampling units.