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ORIGINAL ARTICLE

How far from the road should land cover be assessed? A case study on mesopredator mortality on roads

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Abstract
The methods used to assess the significance of land cover in the vicinity of a road for the mortality of mesopredators are diverse. In assessing the effect of land cover along the road on road causalities, scientists use various buffer sizes, or even no buffer along the road. The aim of this study was to verify how results of land cover effects on the mortality of mesopredators on roads may differ when analyzing various buffer sizes from the road. We assessed road causalities in the Warmian-Masurian voivodeship (Poland) from 3 consecutive years: 2015, 2016, and 2017. The roads were divided into equal sections of 2000 m each with buffer size of radius: 10, 250, 500, and 1000 m. We analyzed the number of road kills of red fox and European badger separately in a generalized linear model, whereas explanatory variables we used land cover types (based on the Corine Land Cover inventory) and traffic volume. Mean annual mortality from road collisions amounts to 2.36% of the red fox population and 3.82% of the European badger population. We found that the buffer size determines the results of the impact of land cover on mesocarnivore mortality on roads. The red fox differed from the European badger in response to land cover depending on the buffer size. The differences we have shown relate in particular to built-up areas. Our results indicate a 500-m buffer as best reflecting the land cover effects in road kills of both species. This was confirmed by model evaluation and a tendency to use or avoid the vicinity of human settlements of the analyzed species. We concluded that buffer size will probably affect mostly the significance of cover types that are spatially correlated with roads, positively or negatively. We suggest that the home range size of given species in local conditions should be assessed before determining the size of the buffer for analysis.

Keywords Road kills · European badger · Red fox · Predators mortality · Habitat · Buffer size · Home range

Introduction

Mesocarnivores are one of the most frequently reported victims of road collisions among mammals; their mortality may be as high as 40% of the mortality of all mammal species (Clarke et al. 1998; Grilo et al. 2009). The most common among killed in Europe mesocarnivores is the red fox (*Vulpes vulpes*), whose population numbers are usually the highest (Grilo et al. 2009). This corresponds to the general tendency of higher mortality rates for more abundant mammal species (Cáceres 2011). However, road kills may be a serious source of mortality for other, often much less common species by significantly increasing the overall mortality of the population (Ferreras et al. 1992; Clarke et al. 1998; Grilo et al. 2004). Apart from the impact of traffic on the population numbers and dynamics of mesocarnivores, a distinct restriction on the use of the home range can be observed. The response of mesopredators to the presence of roads, however, is species dependent (e.g., Davis et al. 2011). Sometimes a positive selection of specific road verges is observed, which is an effect of the presence of food resources or prey nearby (Planillo et al. 2018).

Many factors influencing road causalities of mesocarnivores were stated in former studies. Among them is the traffic volume, which in general increases the numbers of road causalities (Clarke et al. 1998; Saeki and Macdonald 2004; Orlowski and Nowak 2006). In contrast Grilo et al. (2009) did not confirm such a relation, which was probably an effect of the low variation in traffic volume between road sections, compared to

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other studies. Probably, the impact of traffic volume on the mesocarnivores' mortality may be species dependent (Grilo et al. 2015). The effect of traffic volume can be modified by local conditions on roads, which can have different effects on the probability of a road collision. This mainly pertains to a limitation in the visibility along the road, i.e., the presence of curves (Grilo et al. 2009) and road topography, where buried or raised roads were examined (Snow et al. 2011; Červinka et al. 2015), but also speed limit, road width, and presence of heavy cars (Smith-Patten and Patten 2008; Barrientos and Bolonio 2009).

Apart from the road structure and usage by humans, important drivers for road causalities of mesocarnivores are land cover and the presence of linear landscape elements. Some mesocarnivores have been proved to be more frequently killed if a watercourse was present near the roads (Saeki and Macdonald 2004; Červinka et al. 2015). This is a result of the tendency of mesocarnivores to walk along a linear element of the landscape, where they probably look for prey or use it as shelter (Saeki and Macdonald 2004; Andersen et al. 2017). The effect of land cover along the road on road kills is much more complicated, as studies can show opposite results for each species. The red fox is tied to human settlements, which can supply its diet with poultry (Gołdyn et al. 2003), and many studies show a higher number of road fatalities near villages (Orlowski and Nowak 2006; Červinka et al. 2015). On the other hand, Grilo et al. (2009) showed a negative relation between red fox road kills and settlements. The road mortality of European badgers was negatively correlated to urban areas and the proximity of other roads, but positively to forest habitats (Grilo et al. 2009; Červinka et al. 2015; Silva et al. 2017). However, according to Fabrizio et al. (2019), landscape connectivity is an important aspect in terms of badger's road mortality, more than habitat suitability. Červinka et al. (2015) has indicated that the distribution of road kills corresponds with the known habitat association of each carnivore species. The habitat generalists were mainly killed in areas with a mixture of agricultural areas and human settlements, while road kills of habitat specialists were mainly found in road sections with a high proportion of forests, grasslands, and water bodies.

The methodology used to assess the significance of habitats in the vicinity of the road for the mortality of mesopredators is diverse. Different authors use different lengths of the analyzed sections (Gryz and Krauze 2008; D'Amico and Román 2015), although the most common length is 1000 m (Grilo et al. 2011; Ascensão et al. 2019). The distance to the road buffer is more diverse. Červinka et al. (2015), Malo et al. (2004), and Grilo et al. (2011) in their study determined circles with a 1000-m radius. Carvalho-Roel et al. (2019) and Grilo et al. (2009) used a 500-m buffer when testing predators. Grilo et al. (2011) in the study on the stone martens (*Martes foina*) used a 200-m-wide buffer, justifying this by the need to find a compromise between species biology and calculations. In some other works, there was a lack of a buffer, and land cover mapping was based in the direct vicinity of the road (Saeki and Macdonald 2004; Orlowski and Nowak 2006; Smith-Patten and Patten 2008; Caro et al. 2000). It seems reasonable to ask whether the results obtained using these different methods are comparable. According to Gunson et al. (2011), the size of the buffer used to study habitats in road events should be species dependent. However, there is no analysis helpful to determine the appropriate size for species (or at least groups of a similar nature) used in current studies.

The first aim of this study was to verify how results may differ when analyzing various buffer sizes from the road. The second aim was to determine the most appropriate buffer size for mesocarnivores. This study is based on data of the red fox (*Vulpes vulpes*, 1134 individuals) and the European badger (*Meles meles*, 649 individuals) killed on the roads of the Masurian lakes in Poland.

Material and methods

Study area

The study was conducted in the Warmian-Masurian voivodeship located in northeastern Poland (Fig. 1). The voivodeship covers an area of 24 173 km^2 and has a population of 1,437,800 people with a population density of 59 people/km^2 (for 2018) (https://stat.gov.pl). The voivodeship is regarded as having a high touristic value due to the presence of numerous lakes and other natural values (Zalech and Kaminska 2014). Tourism takes place mainly during the summer season, and the annual number of tourists reaches 50 people/km^2 (for 2016). The area is, however, dominated by agricultural areas which consist of about 54.4% of the voivodeship area. Forests cover the area of 31.3%, dominated by coniferous trees—67.8% (GUS 2017). The total length of analyzed roads was 1012 km. The mean traffic intensity on the roads was 6591 vehicles per day and ranged between 3450 and 11,950 (for 2015–2017). The average number of sections on each road equaled 42 but differed due to various lengths of roads (range, 8–87) (supplementary material 1). Most of the roads were two-lane, only 207 km of the roads were four-lane, and 132 km of roads were fenced.

Data collection

The data of the road mortality of the European badger (*Meles meles)* and the red fox (*Vulpes vulpes)* was gained from two sources: the General Directorate for National Roads and Motorways in Olsztyn and the nongovernment project "Animals on roads", where information on animal road causalities is collected (https://zwierzetanadrodze.pl). We have

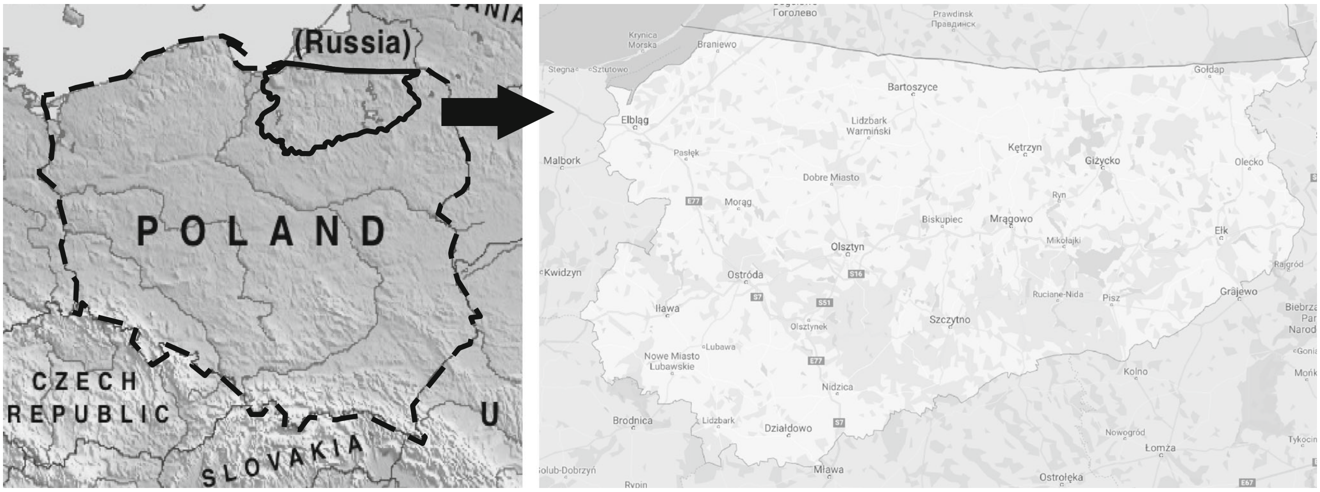

Fig. 1 Location of study site

used data from 3 consecutive years: 2015, 2016, and 2017. Each road incident was supplied with the following information: the species of animal killed, the geographical coordinates, the road type, and the date of the incident. We also obtained information about traffic intensity on each road from the General Directorate for National Roads and Motorways in Olsztyn (https://www.gddkia.gov.pl). To analyze the landscape characteristics in the vicinity of the roads, Corine Land Cover maps (refers to 2012) were used (http://www.gios.gov.pl). Based on the shape files of the map, we have selected 6 main cover types: agricultural areas, coniferous forest, deciduous forests, mixed forests, water bodies, and built-up areas (mainly settlements). Agricultural areas were the dominating cover type along studied roads with a mean share of 62.4% (range: 41.5–82.8%). Most of the other area was covered by forests, with a high proportion of coniferous forest (mean, 15.9%; range, 2.8–38.8%) and a significantly lower proportion of mixed forest (mean, 8.4; range, 2.6–30%) and deciduous forest (mean, 2.6; range, 0–9.3%). The built-up areas covered 8.6% of the buffers' area with a range of 2.5–17.3%, and the smallest share presented was water bodies (mean. 0.1; range, 2–5.3%). The proportion of cover types was calculated on the basis of the mean values of each cover type share in the area of the buffers along road sections (see "Data elaboration and statistics" section). Detailed information about the proportion of each cover type depending on the buffer size is presented in the supplementary material 1.

Data elaboration and statistics

The roads were divided into equal sections of 2000 m each. For each section, a mean traffic volume was calculated, and road causalities for the European badger and red fox were assigned (as a sum of 3-year causalities). A single observation in this analysis was the number of road kills of each species separately on each road section. The length of the segment was determined by the largest buffer. In order to analyze the landscape factors, four buffer types along each road section were designed. We used buffers of sizes: 10, 250, 500, and 1000 m. The 10-m buffer represents no buffer used in former studies, and the use of the narrow buffer is allowed for an automatic designation of land cover types on both sides of a road. To avoid overlapping of buffers of neighboring road sections, we made a buffer based on a correspondingly shorter section inside the 2000-m section. For example, for the 10-m buffer, a shorter section of 1980-m length was created, which let the 10-m buffer on both sides along the road to cover a section of the 2000 m. Buffers of other sizes were designed in the same way, i.e., the inside section equaled 1500 m for the 250-m buffer, 1000 m for the 500-m buffer, and a point for the 1000-m buffer (Fig. 2). For each section we have calculated a proportion of each cover type for each buffer size. All spatial analyses were performed in Quantum Gis (version 3.0.0, https://www.qgis.org/pl). In total we divided all roads into 506 sections, for which four buffers of various sizes were generated (supplementary material 1).

To analyze factors influencing the road kills of the European badger and the red fox, we applied a generalized linear model because the response variable was not normally distributed, and transformation failed. We tested various model types including null models for both species and chose the best models based on AIC values in stepwise backward selection (supplementary material 2). In all models, a negative binomial with log link function presented the best AIC values and met the model assumptions. As a response variable, we set the number of road kills on a given road section. The proportion of each cover type (agricultural areas, coniferous forest, deciduous forests, mixed forests, water bodies, or built-up areas) within the buffer and the traffic volume of the road section were set as covariates. To compare model fitness of various buffers, we counted the sum of squared residuals of each best fit of the four models (of buffer size 10, 250, 500, and 1000 m).

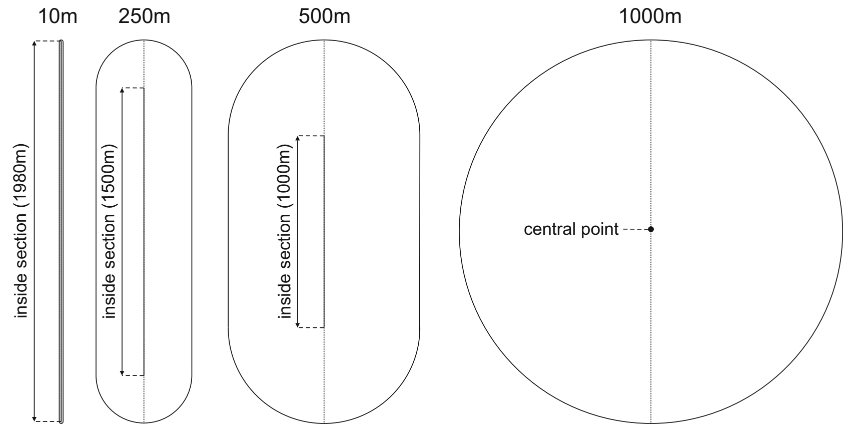

Fig. 2 Design of buffers on the 2000-m sections of the roads

To confirm changes in models with the buffer size, we built eight similar models, four for the red fox and four for the European badger. In these models, we included the same four variables, without model selection (supplementary material 3). We included four variables that were significant when models were selected. All statistics were performed using SPSS (version 24.0, IBM Corporation, Armonk, NY).

Results

In total 1783 individuals were killed on the studied roads of the Masurian lakes during the years 2015–2017, and the red fox accounted for over 60% of traffic incidents. The highest fox mortality was found in autumn, when 40% of road incidents occurred. During this season, 24% of European badger was killed on roads. The European badger showed a high mortality in spring and summer, with 70% of cases (comparing to 38% for red fox) in these two periods together (Table 1).

Only four of the seven variables were found to be statistically significant regarding the red fox mortality on roads in the models selected in the backwards elimination procedure (Table 2). Traffic volume, agricultural areas, and mixed forest proportion were all statistically significant regardless of the buffer size. Moreover, the B coefficient value increased with the buffer size in the case of agricultural areas and mixed forest. Built-up areas were significant in three of four models, and the B coefficient value was decreasing with the buffer size. This variable was excluded as nonsignificant in the model with the largest radius—1000 m. In the smallest buffer, the model also included a proportion of water bodies due to the AIC values; however, this variable was not statistically significant.

Table 1 Number of red fox and European badger killed on studied roads during years 2015–2017

Species	Winter	Spring	Summer	Autumn	Total
Red fox	245	137	298	454	1134
European badger	31	240	223	155	649

The response of the European badger was similar to the red fox in the models selected in the backward elimination procedure, where four of the seven variables were significant in models of the two smaller buffers (10 and 250 m) (Table 3). The B coefficients also presented an increasing trend with the buffer size in the traffic volume, agricultural areas, and mixed forest proportions. The built-up areas proportion was significant only in the models with the smaller buffers (10 and 250 m), but in models with larger buffers, the variable was not significant and excluded in the AIC backward elimination procedure.

In both species, the squared residuals of the two models with smaller buffers present higher values. The lowest values were in the case of the models with a 500-m buffer size, which means a better fit of these models (Fig. 3).

Models with the same set of variables presented a similar trend with the B coefficient (Tab. S3, Tab. S4; supplementary material 3). In both the red fox and the European badger, the built-up areas percentage was not significant in models with larger buffers. In models with a 500-m buffer, species responded differently to land cover nearby the roads.

Discussion

In the studied area, the population numbers have been assessed as 16,034 ind. for the red fox and 5660 ind. for the European badger (Panek, unpublished data). The mean annual mortality from road collisions accounts for 2.36% and 3.82% of the populations, respectively. The European badger showed higher values, despite the fact that the red fox is the most often killed predator on the roads (Najbar et al. 2006; Krauze-Gryz and Gryz 2016). The percentage of the badger population that suffers from road accidents is not large compared to the level reported in other countries, where it can reach over a dozen or

Table 2 Red fox mortality response to traffic volume and land cover depending on buffer size in models selected with backward elimination procedure (*B* coefficient value and statistical significance: *p<0.05, **p<0.01, *NS* nonsignificant but included in the model, N=506 in all cases)

	Buffer size [non-standardized B (±standard error)]			
Source	10m	250m	500m	1000m
Intercept	−0.761 (±0.195)**	−0.983 (±0.199)**	−1.200 (±0.205)**	−1.213 (±0.196)**
Traffic	0.103 (±0.013)**	0.104 (±0.131)**	0.103 (±0.013)**	0.110 (±0. 013)**
Built-up areas	1.173 (±0.309)**	0.907(±0.343)**	0.862 (±0.382)*	-
Agricultural areas	0.981 (±0.198)**	1.291(±0.209)**	1.564 (±0.219)**	1.617 (±0.211)**
Mixed forest	0.959 (±0.376)*	1.270(±0.408)**	1.861 (±0.428)**	1.959 (±0.458)**
Broadleaved forest	-	-	-	-
Coniferous forest	-	-	-	-
Water bodies	*NS*	-	-	-
Model statistics [χ2; df; p]	108.8; 5; <0.001	114.6; 4; <0.001	129.5; 4; <0.001	137.3; 3; <0.001

even 25% of the population (Aaris-Sorensen 1995; Dekker and Bekker 2010; Cheeseman et al. 1989).

The aims of this study were to verify how buffer size impacts the results and to determine the most appropriate buffer size for mesocarnivores. Our results have shown that the buffer size can determine the results of the impact of the land cover on mesocarnivore mortality on roads. The main difference between results in both species was the built-up areas; however, differences in the B coefficient were observed in other cover types. Our finding raises doubts as to the comparability of different studies on the same animal species if not based on a similar buffer size. Some results may of course be an effect of local conditions, but they may also be a result of the methodology used. Moreover, it can be expected that the described phenomenon may also apply to other mammal species. In the case of ungulates, the size of the analyzed buffer in various studies ranges from 100 to 1000 m (Gunson et al. 2011). This may result in conflicting conclusions or problems with interpretation of the results. Therefore, it seems important to be more critical when comparing the results of different studies. The buffer size used in a given study should be highlighted, especially in reviews. Is it possible to determine the buffer of the most appropriate size? Based on the results of our study, the 500-m buffer is the most suitable; this was confirmed by the lowest value of squared residuals (Fig. 3) and suggests a tendency to use or avoid the vicinity of human settlements of the analyzed species. Smaller buffers (10 m, 250 m) show a higher significance of built-up areas, which is tied to the presence of settlements close to the roads. In the case of the European badger, such a result is probably less reliable, because this species in general avoids human settlements in Poland (Obidziński et al. 2013; Mysłajek et al. 2012; Kurek 2011). Differences also occurred between the larger buffers. The largest buffer (1000 m) excluded the significance of built-up areas in both species, whereas the buffer of 500 m excluded this cover only in the case of the European badger. The

Table 3 European badger mortality response to traffic volume and land cover depending on buffer size in models selected with backward elimination procedure (*B* coefficient value and statistical significance: * p<0.05, ** p<0.01, N=506 in all cases)

	Buffer size [non-standardized B (±standard error)]			
Source	10m	250m	500m	1000m
Intercept	−0.887 (±0.211)**	−0.873 (±0.215)**	−0.969 (±0.198)**	−1.132 (±0.211)**
Traffic	0.036 (±0.014)*	0.037 (±0.015)*	0.038 (±0.014)**	0.044 (±0.014)**
Built-up areas	1.103 (±0.336)**	0.782 (±0.381)*	-	-
Agricultural areas	1.060 (±0.223)**	1.102 (±0.213)**	1.286 (±0.223)**	1.422 (±0.233)**
Mixed forest	1.256 (±0.400)**	1.191 (±0.447)**	1.639 (±0.433)**	2.085 (±0.480)**
Broadleaved forest	-	-	-	-
Coniferous forest	-	-	-	-
Water bodies	-	-	-	-
Model statistics [χ2; df; p]	33.39; 4; <0.001	32.71; 4; <0.001	44.39; 3 <0.001	50.02; 3 <0.001

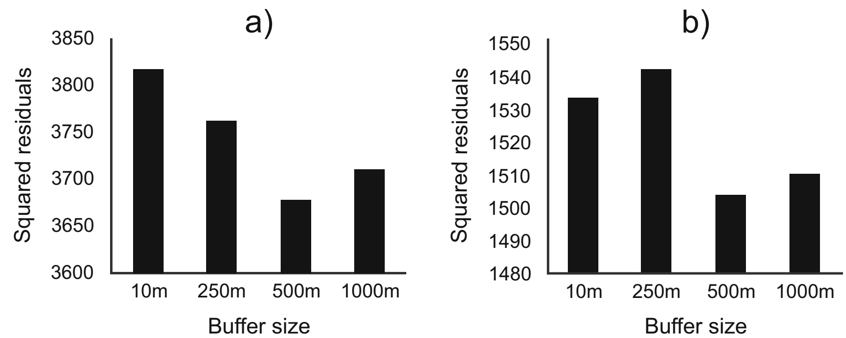

Fig. 3 Values of squared residuals of four models with various buffer size for **a** red fox and **b** European badger

smaller buffers (10 m and 250 m) thus do not reflect ecology of the species because they relate to settlements in a different way, the red fox looks for food, and the badger avoids human settlements. The red fox often uses built-up areas, because rodents (their main prey) also choose human neighborhoods in rural areas. This carnivore is often observed even in cities (Duduś et al. 2014), and its burrows are often found in the vicinity of buildings (Kurek 2011). For this reason, the results of the 500-m buffer, showing that the mortality of the red fox increases with the proportion of this cover type, seem to be the most reliable.

The relatively simple comparison used in our work on the basis of the basic land cover allowed us to show differences in model results. The 500-m buffer differentiates the fox from the European badger, species with different habitat requirements. A 500-m circular plot gives an area of about 80 ha, which corresponds to the most common home range size for a European badger (Kauhala and Holmala 2011). For the red fox, a similar home range dominates in the forest-agricultural landscape, approximately 100 ha, although its range may vary significantly (e.g., Henry and Roeder 2005; Goszczyński 2002). Based on the above, we speculate that the buffer size should reflect the species' home range in the given environmental conditions. For this reason the 500-m buffer is not a general rule for mesopredators but rather suitable for these local conditions and may be different in other areas depending on, e.g., the population structure or the habitat quality (Lucherini and Lovari 1996; Kauhala and Holmala 2011; Šálek et al. 2015). Therefore, it seems reasonable to assess the home range size of given species in local conditions before determining the size of the buffer for analysis. Otherwise some important environmental features may not be noticed in such an analysis, simply because a mismatched buffer size was applied.

The two other cover types (agricultural areas and mixed forest) did not present differences between larger buffers (500 m and 1000 m). Moreover, results were similar in both species, where mortality was increasing with the proportion of agricultural areas and mixed forest. According to Červinka et al. (2015), habitat generalists (such as the red fox) should present a higher road mortality in areas with a mixture of agricultural areas and human settlements, while for specialists (as, e.g., the European badger), it will be higher mainly in areas with a high proportion of forests, grasslands, and water bodies. It is logical that the species analyzed should differ in response to habitats. Thus, it seems reasonable to ask the question why this relation, apart from settlements, was not shown in our results? The lack of a mentioned relation is in our opinion a result of the specific conditions of the study site and tied to the availability of food. The habitat use of carnivores is positively associated with prey abundance (Panek and Bresiński 2002; Davis et al. 2011), natural or human related with some exceptions where prey hunting is disturbed (e.g., Łopucki et al. 2017). In consequence, the abundance of prey may induce greater predator mortality on roads (Barrientos and Bolonio 2009). Scrubs, meadows, and agricultural areas are the most commonly used habitats by the red fox (Cavallini and Lovari 1991). The burrows are often set around open areas and do not show relation to any forest type (Kurek 2011). This suggests that the red fox is a habitat generalist and will use the forest habitats that are the most abundant in food. Rodents are the main prey of the red fox (Jędrzejewski and Jędrzejewska 1992; Gołdyn et al. 2003), and the most common species is the bank voles (*Myodes glareolus*), found in forests with spruce (Sidorovich et al. 2005). Probably for this reason, the red fox mortality presented a correlation with mixed forests, where there is a significant share of spruce. Foxes also look for food in agricultural areas, where the availability of rodents is much higher. The European badger is mainly tied to the occurrence of forests and woodlots (Rosalino et al. 2019; Kauhala and Holmala 2011). The burrows are mostly found in forests (Santos and Beier 2008; Revilla et al. 2000), except for pine monocultures (Kurek 2011). Badgers are mainly associated with mixed and deciduous forests (Matyáštík and Bičík 1999), but food availability is important in choosing the habitat (Zabala et al. 2002). In our study site, coniferous forests, especially pine forests, are the dominant type of stands (Domaszewicz 2017). Moreover, deciduous forests are extremely rare; on average they constituted about 3% of the larger buffer areas. The European badger probably used mainly mixed forests, which also accounted for a small share in the buffer area (on average 8.4%). This species is often looking for food in open areas (Kruuk et al. 1979), which seems more likely under the conditions of the study. Earthworms, which are the main food of the badger (Balestrieri et al. 2004; Goszczyński et al. 2000), may show greater abundance on agricultural areas and meadows, especially if they are periodically flooded (Kasprzak 1979; Pilipiuk 1981).

The results obtained by us should also be approached critically. The limitation of our study is the use of rough land cover categorization, backward selection, and spatial autocorrelation. More detailed categories could show whether other land cover details are also sensitive to the buffer size. If, in different study variants, only the identified built-up areas would significantly change the species response, the buffer effect could be considered marginal. However, we assumed that if there are differences in rough land cover categorization, then they will be visible in the detailed categorization. The backward selection is not perfect and may have resulted in not obtaining the best fit model. This could make the relations slightly different. To confirm the obtained relations in our study, we built models based on the same set of variables (Supplementary 3). We believe that such confirmed results are more reliable. Spatial autocorrelation may result in a lack of independence of individual observations. As a result, there is no real possibility of separating the influence of given cover types (basing on each section) on the analyzed species. However, we assumed that when comparing different models based on the same set of sections, the errors were comparable. It should also be noted that the complementary role of the food base is played by roads; therefore, other cover types analyzed in this study may have less importance. Both these species sometimes feed on carrion of small mammals, birds, or amphibians (Kurek 2011; Duduś et al. 2014), which are easy to find. Although foxes have larger carrion proportion in their diet, especially during winter season (Sidorovich et al. 2005), probably both species are approaching the roads in search of food. This may also have an impact on overall mortality of mesopredators (Santos et al. 2011). It is possible that roadside ecotones may have an impact on the mortality as indicated for ungulates (Keken et al. 2019); however, to our knowledge, mesopredators' mortality was not studied with regard to this aspect. Both ecological aspects could not be analyzed in this study due to the rough land cover categorization.

To conclude, we have found that the buffer size does matter in assessing the land cover effects on road mortality of mesopredators. It can be assumed that the differences in the results may also apply to other groups of animals, and research conducted using a specific buffer may reflect more the methodology used rather than the specificity of local conditions. Our results indicate a 500-m buffer as best reflecting the spatial factors in road kills of both species; however, this is rather an effect of local conditions than a general rule. The differences we have shown relate in particular to built-up areas, because there were no major changes in the other cover types. In our opinion, this is related to the spatial correlation between the settlements and roads (Van Strien and Grêt-Regamey 2016). In other cases, no such strong correlation exists. It can therefore be assumed that the buffer size will probably most affect the frequency of cover types that are spatially correlated with roads, positively or negatively. In the first case, a larger buffer will minimize the significance of the cover type; in the second case, it will increase the significance. We suggest assessing the home range size of given species in local conditions before determining the size of the buffer for analysis.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10344-021-01461-x.

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