Wildlife road mortality in a plain landscape of high conservation value (Eastern Po Valley, Northern Italy)

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Abstract

Road infrastructures are one of the biggest manmade changes to the natural environment. They promote the loss of biodiversity in a constantly threatened world. This study set out to estimate the road mortality of vertebrates (roadkill) along two roads (the RA8 and Via Comacchio) in the Eastern Po River plain that lead from the city of Ferrara to the Northern Adriatic coast, crossing a territory rich in natural areas. The goals were to investigate which factors enhance or, on the contrary, reduce vertebrate mortality and ultimately to study possible mitigation measures that could help to contain the phenomenon. The RA8 is a highway used by high levels of trucks and cars, while Via Comacchio is a provincial road mainly used by local residents. The RA8 was affected by 46 roadkills ($km^{-1}year^{-1}$). Via Comacchio was affected by 10 roadkills ($km^{-1}year^{-1}$). The most important explanatory variables were the road morphology (such as the presence of underpasses and road barriers and the level of the road), the proximal habitat (such as rows of trees and reed beds) and the intensity of the traffic. Mitigation measures should focus on factors that decrease the numbers of casualties, for example underpasses, external fences and rows of trees. This kind of study could make it possible in the future to understand how to contain roadkill and how to decrease the ecological barrier effect of roads. Ecological, economic and road safety benefits could be relevant.

Key words: Road ecology, vertebrates, roadkill, Po River delta.

Riassunto

Mortalità stradale della fauna selvatica nei pressi di aree di interesse conservazionistico nella Pianura Padana orientale

Le strade rappresentano una delle maggiori alterazioni apportate dall'uomo agli ambienti naturali e favoriscono la perdita di biodiversità in un mondo ricco di altre minacce. Questo studio vuole stimare e confrontare la mortalità stradale dei vertebrati lungo due strade (RA8 e Via Comacchio) nella Pianura Padana orientale che collegano la città di Ferrara alla costa adriatica settentrionale, attraversando il medesimo territorio ricco di aree naturali. Lo scopo è quello di individuare quali fattori incrementano o, al contrario, diminuiscono la mortalità dei vertebrati e di fornire elementi per trovare possibili mitigazioni per contenere il fenomeno. RA8 è un raccordo autostradale intensamente percorso da automobili e camion, mentre Via Comacchio è una strada provinciale percorsa per lo più da traffico locale. RA8 ha fatto registrare 46 vittime $km^{-1}anno^{-1}$ contro le 10 vittime $km^{-1}anno^{-1}$ della Via Comacchio. Le variabili esplicative più influenti sono risultate la morfologia stradale (con la presenza di barriere e sottopassi e l'elevazione della strada), le caratteristiche degli habitat prossimali (come la presenza di alberi e canneti) e l'intensità di traffico. Le misure di mitigazione dovrebbero concentrarsi sui fattori che riducono il numero di vittime, per esempio sottopassi, barriere esterne e filari di alberi. Con questo tipo di studi in futuro sarà possibile comprendere come contenere i roadkill e come diminuire l'effetto barriera ecologica delle strade. I benefici ecologici, economici ed in termini di sicurezza potrebbero essere rilevanti.

Parole chiave: ecologia delle strade, vertebrati, mortalità stradale, Delta del Po.

Introduction

Ecosystems around the world are constantly threatened by several factors such as climate change, introduction of allochthonous species, habitat destruction and fragmentation (Bawa & Markham, 1995; Shea & Chesson, 2002; Tabarelli *et al.*, 1999). The greatest concerns are related to the loss of biodiversity.

Road infrastructures are a connection system for humans. In 2012 the average European citizen had travelled almost 11437 km in a year by means of land transport, where cars represent 72.2% of the total (European Union, 2014). But roads can also be real barriers that prevent wildlife moving in its natural environment or promote road mortality, commonly called roadkill, although roads can also be ecological corridors if their length is used by animals (Seiler, 2001). Car accidents involving wildlife can also be dangerous to car drivers (Ciabò *et al.*, 2015).

Road ecology is the study of the ecological impact of roads and highways (Forman *et al.*, 2003). Its final aim is to find solutions applicable in the initial design phase or to mitigate the effects of already existing roads (Forman *et al.*, 2003; Ciabò *et al.*, 2015). Complexity and interactions between road effects and traffic are unexpected and systematic research is required: road ecology will improve when projects carried out in different states are combined and integrated (Spellerberg, 1998; Trombulak & Frissel, 2000; van der Ree *et al.*, 2011).

In Italy most goods and passengers travel by road (Ufficio statistica M.I.T., 2016). Road accidents with damage to transport caused by wildlife represent 3% of the total number of claims (Cerofolini, 2006) and have an important impact on the economy, society and biodiversity. When a medium-large sized animal is killed, the economic damage to the vehicle is between 370 and 2200 euro (Bacci *et al.*, 2005). Any animal species could be involved, but some, such as generalist species living in anthropized environments or animals with a large home range, are more vulnerable than others because of their ecology (Scoccianti *et al.*, 2001).

In Italy a few projects have been carried out to specifically monitor roadkill. For example "Gufi e Strade" monitored owls hit by vehicles with citizens' cooperation (Galeotti *et al.*, 2001). The results of some monitoring programs were presented in 2008 at a meeting on road ecology (Fabrizio, 2010). Other data can be inferred from atlases on the regional or provincial distribution of species (Battisti *et al.*, 2012). The European project "Life STRADE" monitored roads in 3 regions (Ciabò *et al.*, 2015) while "Italian Road Mortality" uses an online platform called "iNaturalist" to record voluntary reports of roadkill (Gilio, 2015). Some other studies are sparse and almost hidden inside "grey" scientific literature, such as internal reports written for some requesting Authorities (for instance, a study in the province of Trieste: Albano, 2009). In the same area of our study, a paper by Pagnoni & Santolini (2006) analysed vertebrate road mortality during one week of the reproductive season inside the Natura 2000 SPA "Valli del Mezzano".

This study is part of the "Delta Road Kill" project (http://storianaturale.comune.fe.it/826/delta-road-kill-animali-investiti-sulle-strade-del-delta-del-po), created and overseen by the Museum of Natural History of Ferrara (Italy). The aim is to monitor vertebrate roadkill on roads near the Po river delta, in the territories of Ferrara, Rovigo and Ravenna, in the Eastern Po River plain. The project began in February 2016. It also involves a part of citizen science as it invites citizens to report casualties with the aid of the smartphone app "i-Naturalist" (http://www.inaturalist.org), in accordance with some Authors who forecast fundamental development in the study of the roadkill phenomenon thanks to smartphone technology (Vercayie & Herremans, 2015; Heigl *et al.*, 2016). The Museum has collected almost 650 observations in two years (Corazza *et al.*, in press).

Researchers in other countries have conducted several studies on the effect of roads on animal abundance (Fahrig & Rytwinski, 2009). In one study, scientists found 1856 dead and 591 living amphibians (detected by their singing) in 506 km of Canadian roads. They saw that number of living amphibians decreases as traffic increases (Fahrig *et al.*, 1995). In England 48.8% of the total number of dead badgers (*Meles meles*) is attributable to roadkill (Harris *et al.*, 1992). Out of 30 monitored Iberian lynxes (*Lynx pardinus*) in the National Park of Doñana in Spain most died due to human cause and 16.7% due to roadkill (Ferreras *et al.*, 1992): recent actions on roads have reduced lynx mortality (Simon *et al.*, 2012).

To minimize damage to wildlife it is important to identify key factors that influence the response of animals to roads. These factors could be infrastructural or environmental. Different types of roads in terms of traffic, layout and landscape attributes can have different effects in terms of animal mortality (Clevenger *et al.*, 2003).

Mitigation measures could help to solve the roadkill problem. For road planners it is difficult to decide which type of measures should be used, because of the lack of good scientific information and because different measures can vary in terms of costs (Rytwinski *et al.*, 2016). However, there is general agreement that the construction of underpasses could help but, to be effective, they need to be frequent (every 150-300 metres) to provide a way for animals (except birds) to cross safely (Clevenger *et al.*, 2003). It is also important to add external fences to roads: underpasses without external fences are ineffective (Rytwinski *et al.*, 2016). Birds are less involved in accidents when there are rows of trees on the sides of the roads: they are induced to fly above trees and in doing so they avoid roads (Clevenger *et al.*, 2003). However, for generalist bird species (such as Corvidae, Passeridae, Columbidae, Turdidae, Motacillidae) that can eat the carcasses of dead animals or the remains of food abandoned by humans, roads can be attractive places (Battisti & Zocchi, 2010). The identification of infrastructural or environmental factors that influence the phenomenon can lead to low cost measures and conservation plans (Planillo & Malo, 2018).

This study sets out to quantify vertebrate road mortality in two roads, the RA8 and Via Comacchio, that both lead from Ferrara to the Adriatic coast and cross a territory rich in natural lands, especially wetlands. Roadkill along the two roads is dangerous to animals and also to drivers: the Province of Ferrara informed us that in four years (2013-2015) they received 3 requests for compensation for damage on the roads in question caused by accidents with animals, two hares and one fox.

The aim of the paper is to identify the infrastructural and environmental factors that cause differences in roadkill between the two roads. The ultimate goal is to find possible mitigation measures that could help to contain the phenomenon on the basis of the results obtained. In our hypothesis, we expected to find an increase in animals killed on both roads travelling from Ferrara towards the coast because of the intensification of natural areas rich in biodiversity; moreover, higher road mortality on the RA8 compared to via Comacchio, especially for birds, was expected, because of the more intensive and faster traffic flow on the former and because of the presence of road barriers (e.g. the central Jersey barriers) that could increase the probability of accidents with animals (Clevenger & Kocionek, 2013).

Materials and methods

This study was conducted in the Ferrara province, in North-Eastern Italy. The study area encompasses urban, agricultural and natural areas. The protected "Parco del Delta del Po" and

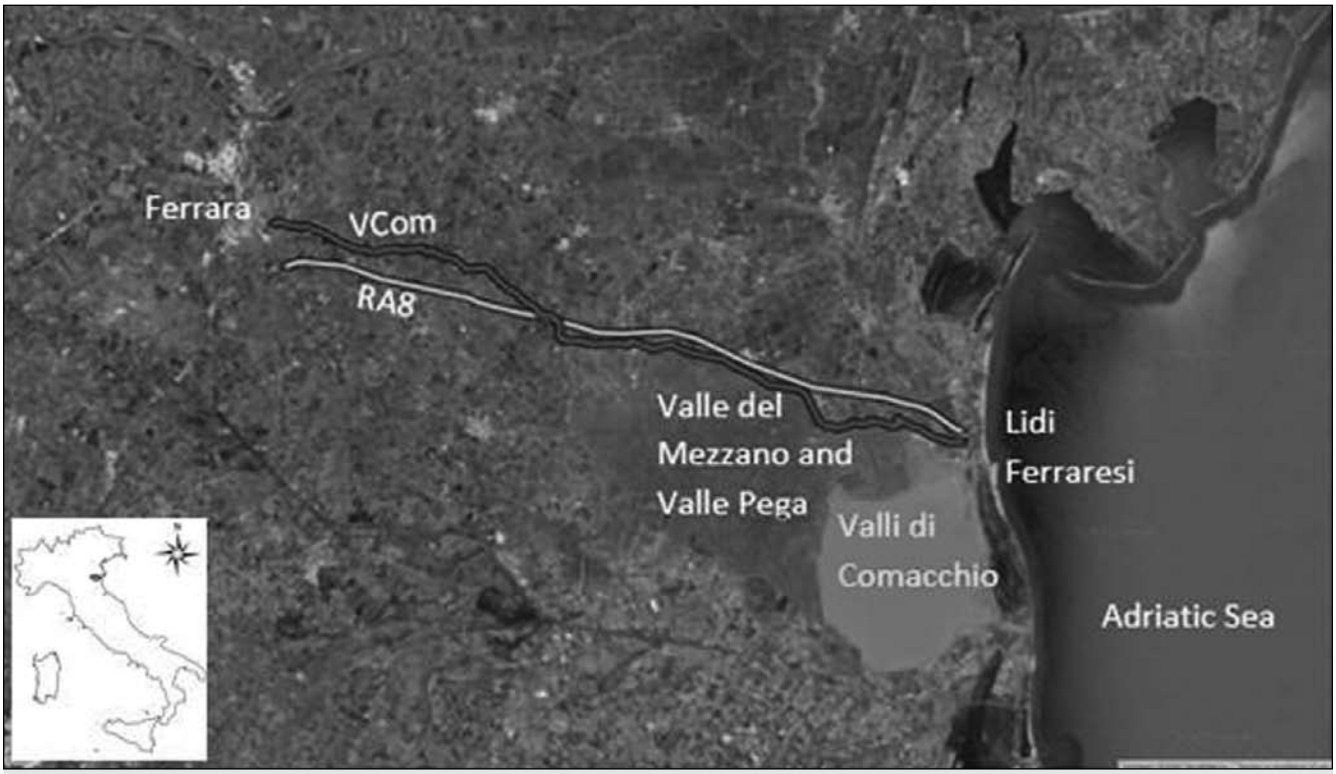

Fig. 1. Satellite image of the study area with the detail of the protected areas near the two roads Via Comacchio (VCom) and RA8. Scale 1: 500.000, Google image processed with QGIS 2.14.22 Essen.

two *Natura 2000* sites (SPA IT4060008 – "Valle del Mezzano, Valle Pega"; SAC/SPA IT4060002 – "Valli di Comacchio") are near the two roads. The selected roads travel in parallel from Ferrara to Lidi Ferraresi on the Adriatic coast. The RA8 is a highway 48 km long with intense car and truck traffic. It has two carriageways, each with two lanes. Via Comacchio is 55 km long: it is a provincial road affected by local traffic and it has one carriageway with two lanes (Fig. 1).

The two roads differ in terms of road morphology, traffic, vehicle speed, adjacent habitats and adjacent land uses.

The work involved monitoring the two roads to determine the number of animals killed by road vehicles. From 1st December 2017 to 16th February 2018 both roads were travelled along on the same day once a week by car, for a total of 11 monitoring days. The two roads had been divided into 9 sections each, defined by milestones such as exits and entrances to the RA8 (Fig. 2). The section was our experimental unit. In order to increase the possibility of spotting animals, the car was driven at the speed of 50/60 kmh^{-1}, at or below the maximum limits (Clevenger *et al.*, 2003). Three observers performed the survey, one driving and the other two spotting the dead animals.

We counted animals in each direction: for each section the number of dead animals was recorded on special collection forms, to locate them in space. We annotated the vertebrate classes, trying to identify the animals down to the species level and if possible taking photographs. Since we counted dead animals separately for each direction, we considered the two directions as two replicas of the same road.

The scarcity of rest areas along these roads often makes it impossible to safely stop the car and makes it difficult to precisely identify the animals, but it could also result in double observations from one week to the next. In literature the removal of the carcass or its marking with coloured spray could solve the issue of counting the same animal twice or more times (Clevenger *et al.*, 2003). When possible we used a GPS camera (Sony DSCHX400VBC) to virtually mark each carcass. Otherwise, in each section we compared the number of the same species collected the previous time with the next. These methods made it possible to check, according to the geographical location, if the dead animal was the same as the previous weeks: double observations were removed.

We collected data on explanatory variables that could explain the roadkill phenomenon.

A level road is at the same level as the surrounding ground. A raised road is at a higher level. A buried road is at a lower level. Combined situations were possible (Clevenger *et al.*, 2003, Ciabò *et al.*, 2015). We measured the length of each category of road with a GPS device.

In the hypothesis that water channels passing under the roads and other kinds of underpasses and overpasses could be used by animals to safely cross, we recorded the number of water channels passing under the roads belonging to the land reclamation system of the Ferrara territory using georeferenced maps in QGIS 2.14.22 Essen. The number of road underpasses and overpasses was counted with Google Earth.

We measured the length of any kind of central and lateral barriers like Jersey barriers) or guardrails (traffic barriers) with QGIS 2.14.22 Essen.

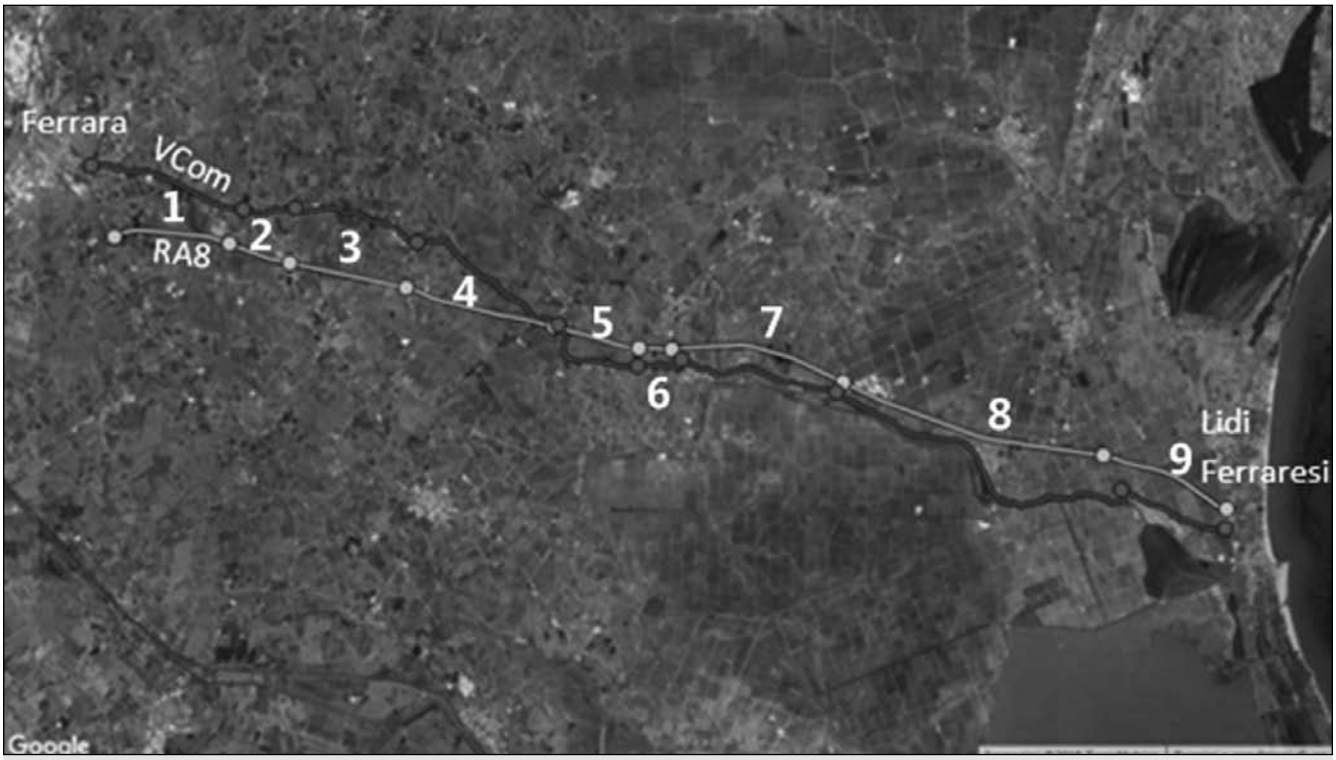

Fig. 2. Satellite image of the study area with details of the subdivision into 9 sections of the two roads Via Comacchio (VCom) and RA8. Scale 1: 300.000, Google images processed with QGIS 2.14.22 Essen.

We measured external fences with a GPS device, i.e. a smartphone running the app "Kmh counter" by APK. The fences were nets positioned to protect the roads, about 1.5 m tall at a distance of about 1.5-3 m from the lanes. Since we had no way of directly measuring it, vehicle speed was considered as the maximum speed limit in each section: the speed limit on the RA8 is 90 kmh^{-1} all the way along, while the limits along Via Comacchio vary between 50 and 70 kmh^{-1}, with a few sections at 70 kmh^{-1} . On the RA8 vehicle speed is not continuously controlled and cars often exceed the limit, but in Via Comacchio the controls are efficient and the morphology of the road also discourages exceeding the limits. The traffic was measured as the number of transiting vehicles in three different points of each road in each direction, recorded by a mechanical counter that was run for half an hour: counting was repeated on three different days for each point. Then we calculated a traffic trend line with Microsoft Excel in order to obtain an approximate number of vehicles transiting every hour in every section of the roads. The associated equation provided an estimate of the number of vehicles transiting per hour per section. Adjacent area habitats were mapped using *OpenLayers* plugin air photographs with QGIS 2.14.22 Essen. Only habitats within a distance of about 10 metres from the roads were considered. Adjacent habitats were divided into: tree rows, arboreal-shrubby hedges and reed beds. We also measured adjacent land use as the length of road edge for the following categories: urbanized areas, woods, water channels, orchards, parks, rice fields, arable land and wetlands.

Since the different sections have different lengths, all data, excluding vehicle flow, were standardized per kilometre or as a proportion of total section length, in order to compare the sections.

In the preliminary phase we tried to understand which explanatory variables influence the number of victims, to eliminate statistically insignificant variables from the subsequent analyses. We did this with simple linear regressions using only one explanatory variable each time, considering the total number of dead animals, the number of dead mammals and of dead birds as a dependent variable. Also in this case we standardized data per kilometre as the road sections are different lengths. Then, in more complex analyses, we considered more than one explanatory variable at the same time. As suggested by Schielzeth (2010), in these analyses all explanatory variables were standardized further by subtracting the mean and dividing by the standard deviation to facilitate the interpretation of our results. In this way the variables have the same units and it is possible to numerically compare their effect. In the multiple linear regression we initially added all explanatory variables and their pairwise interactions. We then simplified each model by removing, one at a time, any variables and interactions that were not statistically significant. Homogeneity and normality of the distribution of errors were verified for each model. In this analysis we used lm() and anova() functions using R 3.4.3 software (Zuur & Ieno, 2016).

Results

Out of a total of 1143 vertebrates recorded as roadkills, we observed only mammals and birds, but found neither reptiles nor amphibians. Mammals represent 65% of the total number of deaths, and birds 28%. On the RA8 61% of the roadkills were mammals and 33% were birds and the roadkill index was estimated as 46 dead animals ($km^{-1}year^{-1}$). In Via Comacchio 84% were mammals and 10% birds and the estimated roadkill index for this road was lower (10 dead animals $km^{-1}year^{-1}$). Roadkills were thus more frequent on the RA8 than on Via Comacchio, particularly for birds. The most affected species (Tab. 1) are the coypu (*Myocastor coypus*), the common European hedgehog (*Erinaceus europaeus*), the common buzzard (*Buteo buteo*) and the common barn owl (*Tyto alba*).

An increasing trend is clear particularly for the RA8 from section 1 to section 9, from Ferrara to the coast. On both roads there was a final surge in the last section (Fig. 3).

The traffic count showed that 352 vehicles travelled along the RA8 on average every hour in each section compared to 164 vehicles in Via Comacchio.

The explanatory variable effect may be positive or negative on the number of animals killed. Some explanatory variables do

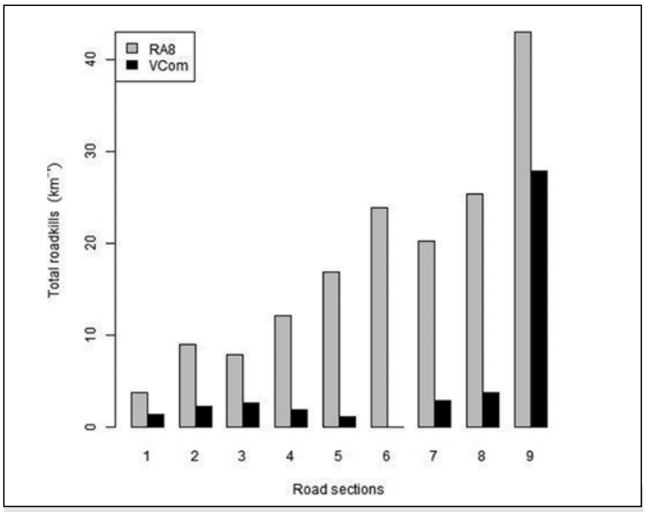

Fig. 3. Histogram on the standardized number per km of total animals killed in each road section (see Fig. 2) of the two roads RA8 and Via Comacchio (VCom).

SPECIES	Number of deaths on Via Comacchio	Number of deaths on the RA8
Barn owl (*Tyto alba*)	0	16
Black rat (*Rattus rattus*)	3	6
Brown rat (*Rattus norvegicus*)	1	8
Common black-bird (*Turdus merula*)	2	0
Common buzzard (*Buteo buteo*)	1	23
Common kestrel (*Falco tinnunculus*)	1	7
Common moorhen (*Gallinula chloropus*)	0	1
Common pheasant (*Phasianus colchicus*)	0	4
Common Pigeon (*Columba livia domestic form*)	3	23
Coypu (*Myocastor coypus*)	137	415
Domestic cat (*Felis catus*)	2	4
Eurasian collared dove (*Streptopelia decaocto*)	2	8
Eurasian jay (*Garrulus glandarius*)	0	2
Eurasian magpie (*Pica pica*)	0	2
European hare (*Lepus europaeus*)	0	5
European hedgehog (*Erinaceus europaeus*)	36	20
European rabbit (*Oryctolagus cuniculus*)	0	1
Generic bird	11	115
Generic bird of prey	1	76
Generic mammal	14	94
Little owl (*Athene noctua*)	0	7
Long-eared owl (*Asio otus*)	0	14
Not determined	16	58
Red fox (*Vulpes vulpes*)	0	1
Sparrowhawk (*Accipiter nisus*)	0	1
Sparrow (*Passer* sp.)	1	0
Yellow-legged gull (*Larus michahellis*)	0	1
Total	**231**	**912**

Tab. 1. Number of dead animals in the two roads Via Comacchio and RA8 with details of the species killed.

Variation sources	Sum of squares	Df	F	P
Road length	6386.40	1	19.38	< 0.01***
Traffic	2245.10	1	6.81	0.01 *
Level road	2687.80	1	8.15	0.01 **
Raised road	3600.20	1	10.92	< 0.01 **
Tree rows	2234.50	1	6.78	0.01 *
Reed beds	6749.50	1	20.48	< 0.01***
Residual	9558.70	29		

Tab. 2. Sum of squares, degrees of freedom, F value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Total roadkills". Legend: " . < * < ** < * " significance level.**

Parameter	Estimate	s.e.	P
Intercept	-1.39	8.24	0.87
Road length	5.93	1.35	< 0.01***
Traffic	-14.53	5.57	0.01 *
Level road	64.78	22.68	0.01 **
Raised road	74.95	22.68	< 0.01 **
Tree rows	-15.87	6.09	0.01 *
Reed beds	19.82	4.38	< 0.01***

Tab. 3. Estimated parameters, standard error, t value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Total roadkills". Legend: " . < * < ** < * " significance level.**

not appear in the final multiple regression models because their effect was not statistically significant so they were dropped from the models. All the models show a very high explained variance fraction, with an R^2 ranging between 80% and 90%.

The total number of dead animals (Tab. 2 and 3) is not significantly different between the two roads. Almost all the significant variables increased the number of animals killed, except traffic and rows of trees, which decreased it (Fig. 4).

Dead mammals (Tab. 4 and 5) were more frequent in Via Comacchio than on the RA8: in each section in the period of time considered there were 229 more mammals killed on average in the former road. Looking at the general numbers of deaths, mammals seem less affected in Via Comacchio than on the RA8 (Tab. 1). This apparently contradictory result can be interpreted as the effect of also considering the other explanatory variables: when the effect of the other explanatory variables is kept equal, the model estimates 229 more mammals killed in Via Comacchio than on the RA8. The central Jersey barrier significantly increased the number of deaths but underpasses and external fences decreased it (Fig. 5).

Dead birds (Tab. 6 and 7) in Via Comacchio were less frequent than in the RA8: in each section in the period of time considered there were 19 fewer birds killed on average in this specific model. The presence of rows of trees and arboreal-shrubby hedges along the road decreased the number of dead birds (Fig. 6).

Discussion

Reptile or amphibian species are probably missing from our data set because the survey was carried out in winter, which

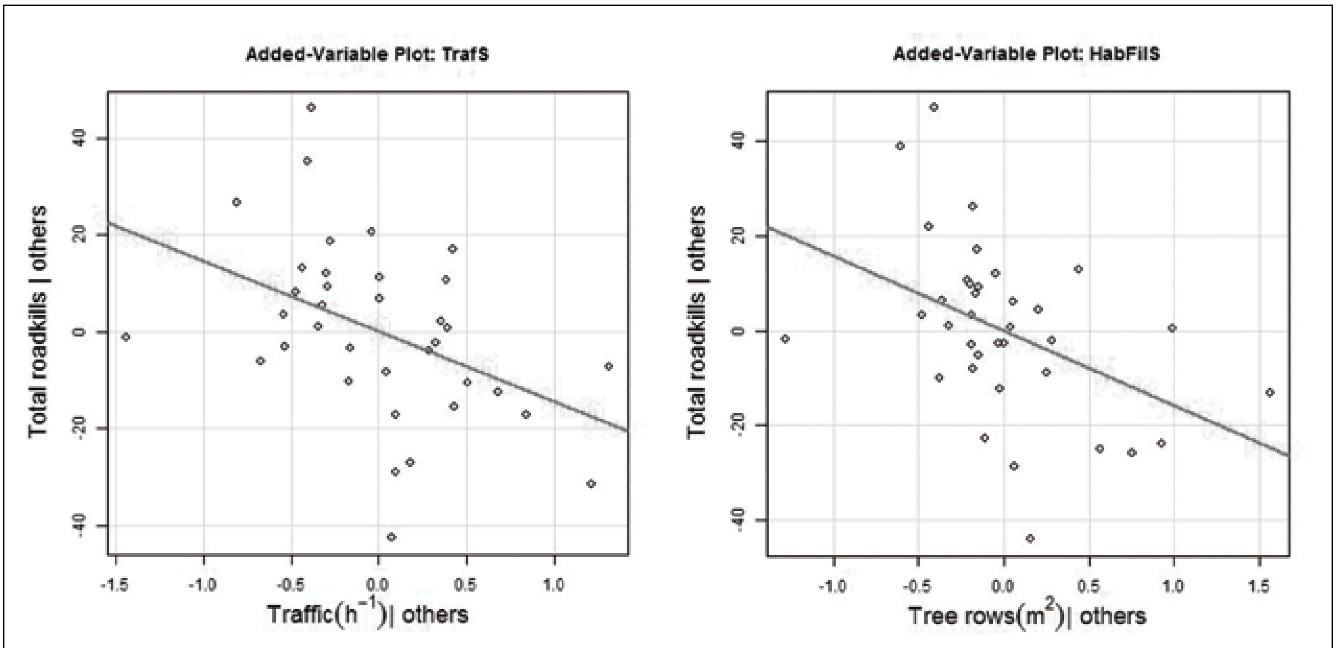

Fig. 4. Added plots of the multiple linear regression with assumed additivity of the standardized independent variables "Traffic" and "Tree rows" on the dependent variable "Total roadkills".

Variation sources	Sum of squares	Df	F	P
Road	2511.20	1	12.84	< 0.01 **
Raised road	1520.00	1	7.77	0.01 **
Underpasses	2012.00	1	10.28	< 0.01 **
Central Jersey barrier	2486.80	1	12.71	< 0.01 **
External fences	2248.40	1	11.49	< 0.01 **
Reed beds	3709.20	1	18.96	< 0.01 ***
Residual	5673.20	29		

Tab. 4. Sum of squares, degrees of freedom, F value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Mammal roadkills" Legend: " . < * < ** < *** " significance level.

Parameter	Estimate	s.e.	P
Intercept	-93.81	32.06	0.01 **
Via Comacchio	229.13	63.95	< 0.01 **
Raised road	10.15	3.64	0.01 **
Underpasses	-11.74	3.66	< 0.01 **
Central Jersey barrier	122.20	34.27	< 0.01 **
External fences	-10.43	3.08	< 0.01 **
Reed beds	15.92	3.66	< 0.01 ***

Tab. 5. Estimated parameters, standard error, t value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Mammal roadkills". Legend: " . < * < ** < *** " significance level.

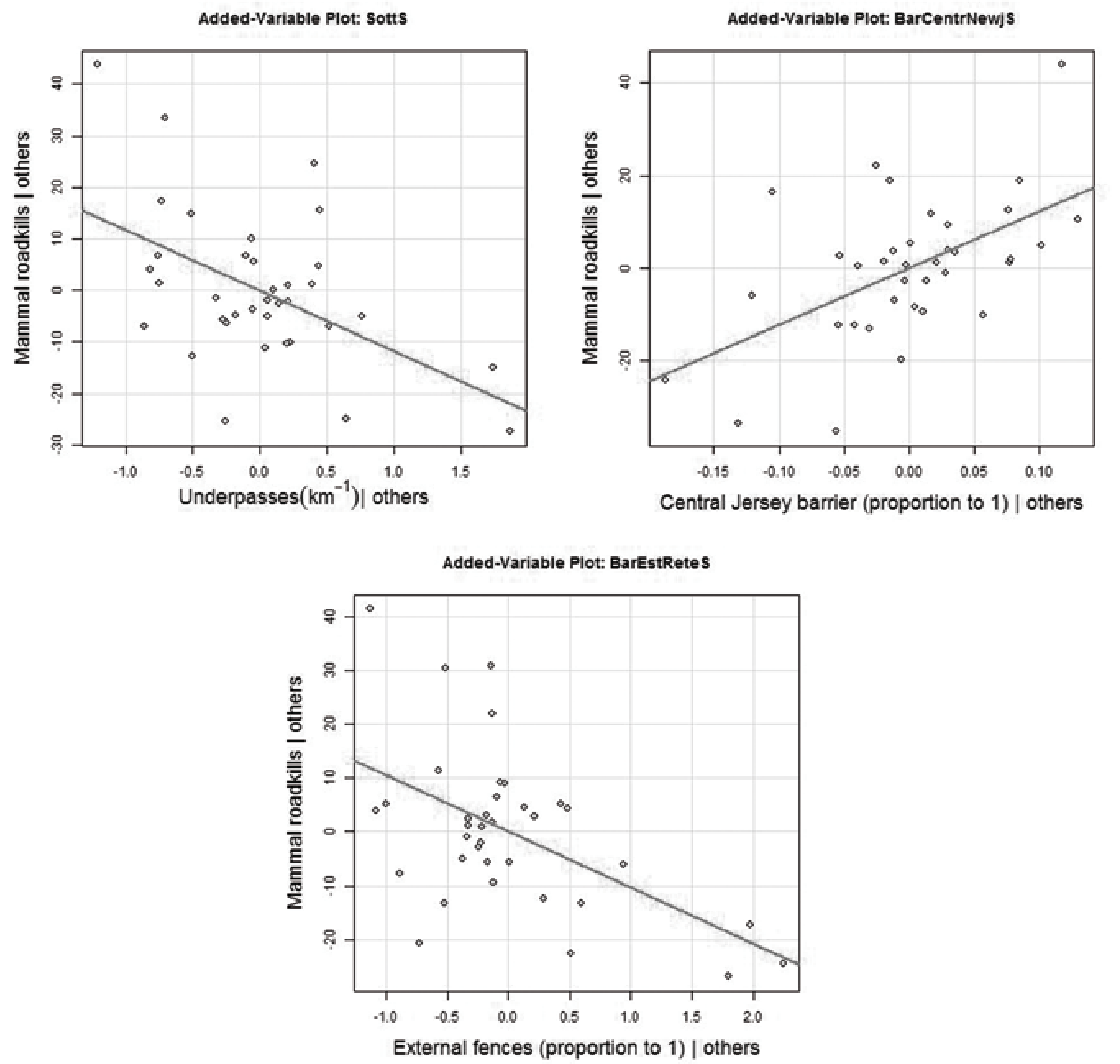

Fig. 5. Added plots of the multiple linear regression with assumed additivity of the standardized independent variables "Underpasses", "Central Jersey barrier" and "External fences" on the dependent variable "Mammal roadkills".

Variation sources	Sum of squares	Df	F	P
Road	721.35	1	29.01	< 0.01 ***
Road length	709.30	1	28.53	< 0.01 ***
Traffic	106.94	1	4.30	0.05 *
Level road	128.99	1	5.19	0.03 *
Raised road	148.47	1	5.97	0.02 *
Tree rows	158.86	1	6.39	0.02 *
Arboreal hedges	115.33	1	4.64	0.04 *
Residual	696.24	28		

Tab. 6. Sum of squares, degrees of freedom, F value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Bird roadkills". Legend: " . < * < ** < * " significance level.**

Parameter	Estimate	s.e.	P
Intercept	7.90	3.10	0.02 *
Via Comacchio	-19.43	3.61	< 0.01 ***
Road length	1.96	0.37	< 0.01 ***
Traffic	-4.03	1.95	0.05 *
Level road	15.56	6.83	0.03 *
Raised road	16.55	6.77	0.02 *
Tree rows	-4.44	1.76	0.02 *
Arboreal hedges	-4.08	1.89	0.04 *

Tab. 7. Estimated parameters, standard error, t value and P-value of the multiple linear regression with assumed additivity of the standardized independent variables on the dependent variable "Bird roadkills". Legend: " . < * < ** < * " significance level.**

is a period of non-activity for these animals (Neil, 1948). Moreover, the monitoring method we adopted does not promote the sighting of small animals such as amphibians and reptiles, which after an accident may be very squashed and barely visible from the car: for instance, data collected up to now with the citizen science project "Delta Road Kill" (unpublished, open data) show that out of 73 toads (*Bufotes balearicus* and *Bufo bufo*) observed, 51 were not seen from the car but on foot or by bike and all the 12 lizards (*Podarcis* spp.) listed were observed while moving slowly on foot or by bike.

The roadkill indices are high compared to other studies. On the RA8 an index of 46 dead animals ($km^{-1}year^{-1}$) is up to 4 times higher than comparable roads with high levels of traffic in Poland (Orlowski, 2006). Even Via Comacchio, the road with less traffic, has an estimated index of 10 dead animals ($km^{-1}year^{-1}$), which is comparable to roads with high levels of traffic in Poland (Orlowski, 2006). Extending these indices for a total of 103 km for both roads to a whole year, up to 5730 animals may be run over each year, which seems a rather shocking number.

Mammals were more frequently killed on Via Comacchio, which is less busy and noisy. This can be explained by the deterrent effect of the high levels of traffic and noise (Clarke *et al.*, 1998; Clevenger *et al.*, 2003). This effect may be the reason why we found an average of 229 fewer dead animals per section in 11 weeks on the RA8 compared to Via Comacchio.

Coypu (*Myocastor coypus*) was the most affected species, with a total of 552 dead individuals on the two roads in two and a half months of monitoring. The coypu was introduced to Italy in 1928 for fur farming (Cocchi & Riga, 2001) and is

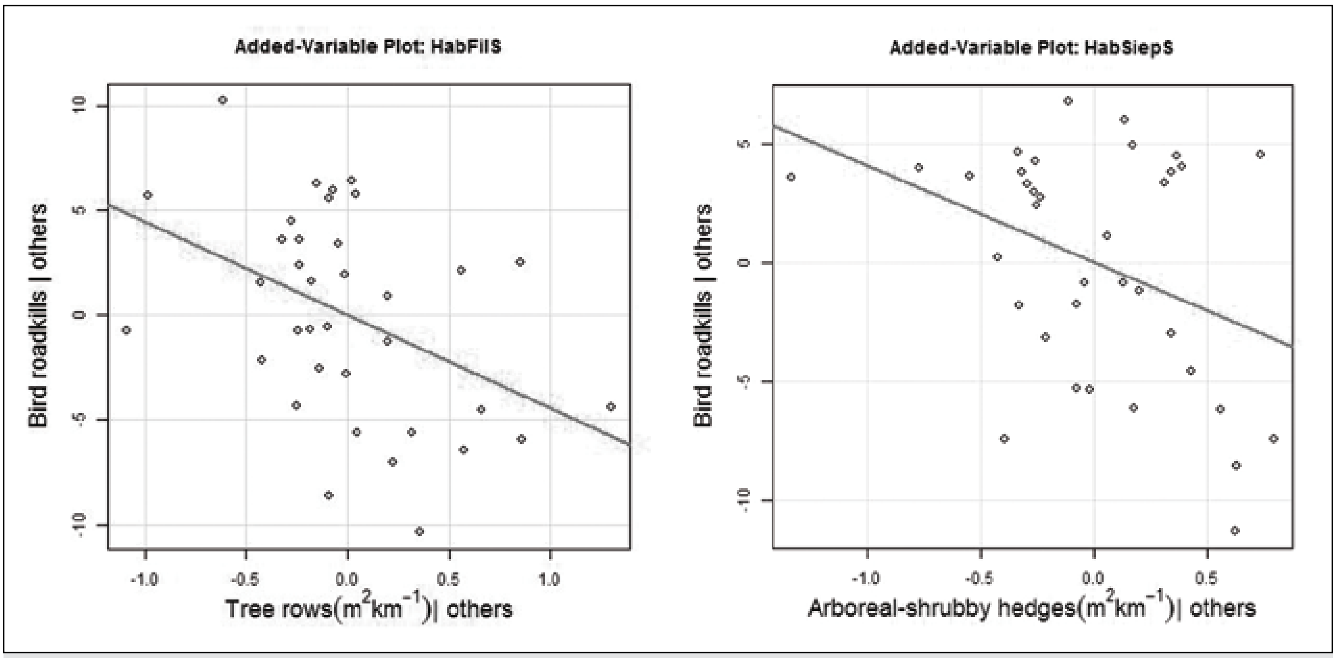

Fig. 6. Added plots of the multiple linear regression with assumed additivity of the standardized independent variables "Tree rows" and "Arboreal-shrubby hedges" on the dependent variable "Bird roadkills".

now considered a pest, due to the damage it causes to water vegetation, crops and river banks. According to the Italian law (2014/116) passed to facilitate eradication actions it is no longer considered "wild fauna". There is no great threat to the world's coypu population (Bertolino, 2005), but roadkill and predation could affect up to 52% of the total mortality of a single coypu population (Martino *et al.*, 2008). So, roadkill may appear to be a method for controlling coypu populations, but dead coypus can attract predaceous, protected animals such as owls, buzzards and hawks towards the roads (Battisti & Zocchi, 2010). In our data, the RA8 with 415 dead coypus has a total of 144 birds of prey killed, while Via Comacchio with 137 dead coypus has a total of 21 birds of prey killed. Moreover, coypus are dangerous for drivers: from the data that the Province of Ferrara provided (2011-2015), we found that the coypu is responsible for 24% of the 36 requests for compensation for damage due to accidents caused by animals throughout the entire province.

56 dead hedgehogs (*Erinaceus europaeus*) were recorded. Although in some areas significant numbers of hedgehogs are killed by vehicle collisions on roads, it is unlikely that this causes population decline (Huijser, 1999). Hedgehogs are more frequently killed in Via Comacchio.

Among the species we observed, the hedgehog is the only mammal species whose roadkill trend is similar to the general mammal trend for deaths on less busy roads (Clevenger *et al.*, 2003).

On the contrary, bird kills prevail on the RA8, because of their vulnerability to busier roads (Bekker *et al.*, 1995). We estimated an average difference of 19 more birds killed per section in 11 weeks on the RA8 than on Via Comacchio. For buzzards (*Buteo buteo*) we counted a total of 24 individuals killed on the two roads. Birds of prey are probably attracted by roads. They select the edges of roads as hunting areas for small mammals (Meunier *et al.*, 2000). This could increase the probability of collision with vehicles on roads. The barn owl (*Tyto alba*) presented 16 killed individuals. Major threats for barn owl species are the transformation of the nesting habitat and collisions with vehicles on roads or air cables (Peronace *et al.*, 2012). In this study both species are killed more frequently on the RA8. So, this result agrees with the general trend for birds to be more frequently killed on busier roads reported by Clevenger *et al.* (2003).

The effectiveness of road overpasses and underpasses in decreasing the number of dead animals, especially for mammals, is acknowledged in several studies (Yanes *et al.*, 1995; Clevenger *et al.*, 2003; Rytwinski *et al.*, 2016). However, to be effective they have to be designed for exclusive use by animals. In our study area the crossings are not designed for this purpose, but are road and rail passes. Nevertheless, underpasses decrease the numbers of dead mammals, as mammals probably use them to pass to the opposite side of the road, without crossing it directly.

The probability of animals being killed increases with the presence of central barriers. In this study there is only a barrier on the RA8 in the form of a central Jersey barrier. Its presence increases the numbers of dead mammals but it has no effect on birds. For every extra percentage point of Jersey barrier per section, 2.77 more mammals are killed. Central Jersey barriers are safety devices that help to prevent cars invading the opposite lane (Leonardi & Pappalardo, 2000). However, it is proven that they could increase the risk for wildlife to be involved in vehicle collisions (Clevenger & Kocionek, 2013). Animals could be trapped and confused, looking for a point to cross.

We speculated whether the road width could affect those numbers. In literature we found conflicting evidence. Clevenger *et al.* (2003) consider the distributions of animals killed on roads to be 1-dimensional as the width of the roads (always measurable in metres) is not influential compared to the total length of the roads (measured in tens or hundreds of thousands of metres). Smith-Patten & Patten (2008) saw that two-lane roads were more affected but only in certain periods and, in other periods, four-lane roads presented more deaths. They concluded that, the wider the road the lower the connectivity and mammals are more discouraged to cross due to the higher presence of obstacles. Forman & Alexander (1998) noted that medium sized mammals were more affected in two-lane roads. This is the opposite of what was found by Oxley *et al.* (1974) which was that the wider the road the more medium-sized or large mammals were run over. They thought that there are probably more influential variables on the phenomenon of roadkill. Finally, it seems that the road width could affect the roadkill number not in itself, but because it correlates with other aspects such as the speed limit, an important factor influencing roadkill (Hobday & Minstrell, 2008).

External fences to roads could decrease large mammal roadkill by 54% on average (Rytwinski *et al.*, 2016). However, they may not be effective for small mammals (Planillo & Malo, 2018) who could easily cross the fences. In this study external fences made of nets reduce dead mammal numbers and their absence increases them. The general external fence mitigation effect reported in literature by Rytwinski *et al.* (2016) is confirmed for mammals, as they probably prevent them reaching the road. We do not have enough data to confirm this for small mammals, like mice or other micromammals. It is possible that in this study small mammals were rarely recorded because of the monitoring method chosen, which does not promote the sighting of small animals, which after an accident may be very squashed and have a very high carcass degradation rate (Santos *et al.*, 2011).

Traffic volume is considered an important factor for explaining the roadkill phenomenon (Trombulak & Frissel, 2000). Clarke *et al.* (1998) write that high traffic levels seem to decrease the numbers of dead mammals as they are afraid to cross roads as a consequence of the noise that could frighten them. In this study traffic decreases the total number of dead animals even considering its interaction with the Jersey barrier. This result could confirm that some animals may be frightened by the traffic. The Jersey barrier could act as a sounding board for traffic noise. Nevertheless, when traffic interacts with other variables, it increases the number of dead birds. In fact, birds are vulnerable to busier roads (Oxley *et al.*, 1974).

Adjacent habitats can affect the roadkill phenomenon (Bekker *et al.*, 1995; Clevenger *et al.*, 2003; Planillo & Malo, 2018). In this study lateral reed beds seem to increase the numbers of deaths of all the animals considered. However, rows of trees and arboreal-shrubby hedges decrease bird deaths. Reed beds could be a suitable habitat for species that live in wetlands. Furthermore, coypu lairs could be in the water channels near the two roads and near the reed beds (Panzacchi *et al.*, 2007). Coypu numbers could affect the total animal results, as they are the most frequent group. Rows of trees and arboreal-shrubby hedges could induce birds to fly above tree crowns. In this way birds avoid the danger of the road below (Bekker *et al.*, 1995).

The presence of natural areas, like wetlands, does not affect the phenomenon as we expected. The presence of protected wetlands near the two roads had led us to think that the high biodiversity (Rete Natura 2000, 1995; 1999) in these lateral areas could increase roadkill numbers. Their effect may have been included and hidden by the reed bed variable, which is a suitable habitat for many wetland species. However, the high number of total roadkills and the observed increasing trend of dead animals from Ferrara towards the coast could still be due to the increasing presence of wetlands.

Conclusions

The most important variable for explaining the roadkill phenomenon is the road morphology with underpasses, central Jersey barrier and external fences, the nearby habitat with rows of trees and reed beds and traffic. Underpasses and external fences decrease the number of dead mammals. Jersey barriers increase it. Rows of trees decrease the number of dead birds. Reed beds increase it and also affect the total number of dead animals. Traffic decreases the total number of dead animals. The variables that appear less important are infrastructural intersections such as water channels and overpasses, the maximum speed limit and the adjacent land use. Based on these results, we can therefore say that only some environmental or infrastructural features affect the number of animals killed. Compared with the expected results, the increasing trend of roadkill from Ferrara to the coast is confirmed, but it seems not to be due to the presence of natural wetlands but because of road morphology and because of adjacent habitats. Then, the higher road mortality on the RA8 compared to Via Comacchio is confirmed, especially for birds which are more affected by busier roads than mammals (Clevenger *et al.*, 2003).

A road upgrading process could help to contain the phenomenon. The installation of new underpasses and external fences could be good mitigation measures for mammals (Rytwinski *et al.*, 2016). External fences should be installed along the road and they should only be interrupted at the underpasses, so that mammals are encouraged towards the underpasses. In this way they can safely reach the other side of the road and reduce the risk of collision for cars. Tree rows along the roads are important for birds. Trees should be quite tall so that birds can fly over them to avoid the road danger below (Bekker *et al.*, 1995; Clevenger *et al.*, 2003). In Italy rows of trees are considered a danger for motorists. The current law requires a minimum distance of 6 metres between trees and the road (Regolamento Nuovo Codice della Strada, 1992). On these two roads the trees are closer to the road than the distance required by law, as they were planted before the approval of the regulation. We do not know if the reducing effect on the numbers of birds killed would be effective even with trees positioned at a greater distance from the road.

In the future this kind of study will help to understand at a capillary level how to contain the roadkill phenomenon and how to decrease the ecological barrier effect of roads. The benefits will be ecological for biodiversity protection but also economic and safety-related, for a desirable reduction of accidents on the roads.

Author contributions

"Delta Road Kill – Animali investiti sulle strade del Delta del Po (DRK)" is a project of the Museum of Natural History of Ferrara, created and coordinated by Carla Corazza. The monitoring and collection of data were conducted by Stefano Aldrovandi, Giulia Finotti and Federica Milioni as a part of DRK. The manuscript is based on Stefano Aldrovandi's master degree dissertation in Ecology and Nature Conservation at the University of Parma. Stefano Leonardi was his supervisor. All the authors have contributed to, seen and approved the manuscript.

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