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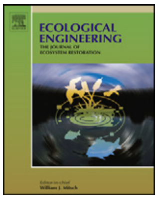

Evaluation of the effectiveness of a wildlife roadkill mitigation system in wetland habitat

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ABSTRACT

This study assessed the effectiveness of a wildlife protection system (WPS) installed along a 15.7 km section of a federal highway in southern Brazil, which crosses through a federally protected area. The WPS has three sections and includes 19 underpasses, fences along two sections, and stock guards at the beginning and end of each section. Monitoring was carried out from 1995 to 2002. The changes in the roadkill rate (number of individuals/km/day) and the community of vertebrates affected by the WPS were analyzed. A total of 32 taxonomic units (TUs) were identified. Mammalia was the class with the highest richness of TUs affected before ($S = 12$) and after ($S = 13$) the installation of the WPS. For both pre- and post-WPS stages combined, mammals had the most roadkilled individuals (92.2%), followed by reptiles (5.2%). The highest roadkill rates were observed in winter 1995 (0.38 ± 0.291 ind./km/day), winter 1998 (0.20 ± 0.130 ind./km/day), and autumn 2002 (0.17 ± 0.123 ind./km/day). Overall, the WPS reduced the mortality of the main species affected, *Myocastor coypus*; however, except for this species, the roadkill rates remained steady. Several modifications in the initial design are suggested to improve the system.

1. Introduction

Roads are vectors of socio-economic development and are vital for the growth of a country. However, roads also have negative impacts such as habitat degradation, dissemination of exotic species, and loss of biodiversity through roadkill and landscape fragmentation (Trombulak and Frissell, 2000). When these effects occur within or around protected areas, the problem becomes more serious because such areas usually have higher concentrations of species and large numbers of individuals (Bager, 2003). Forman et al. (2003) stated that rather than worrying about the impacts of roads on a particular species, it is more important to consider one of the greatest contemporary problems for conservation, which is the loss of ecological processes at the population, community and ecosystem levels. Roads, as well as other linear projects, can acutely affect all of these levels, generating both short-term, high-intensity impacts as well as chronic impacts of varying intensities.

Strategies taken to mitigate the impacts of roads may include the installation of speed reducers, active or passive signals, fences, air passages, and underpasses (Dodd et al., 2004; Glista et al., 2009; Grilo et al., 2010; Romin and Bissonette, 1996). These strategies are aimed toward the reduction of wild-animal mortality that results from roadkills, but they must also permit the maintenance of ecological processes such as movement, genetic change, and connectivity. To ensure efficiency, these measures must consider the specific requirements of the focal species (Forman et al., 2003). Mitigation systems can be implemented to protect one species (Cain et al., 2003), a few species (Aresco, 2005) or the entire community affected by roadkills (Dodd et al., 2004). It is obviously most difficult to protect an entire community, which requires knowledge about the species involved, including body size, habitat, movement capacity and geographic distribution.

Studies on the use of passages and fences have increased, though only a few works have analyzed the effectiveness of a mitigation system after its implementation (Mata et al., 2005). When effectiveness analysis is realized a new problem that arises is the inappropriate experimental design, without prior information and control areas, making the data insufficient and inconclusive (Lesbarrères and Fahrig, 2012) and discuss the importance of Before-After-Control-Impacts (BACI) design studies. BACI design has been widely used to assess impact on streams (Roley et al., 2012), wind farm (de Lucas et al., 2005), power lines (Barrientos et al., 2012), but despite the potential there are few examples for roads (Goosem et al., 2001; Lesbarrères and Fahrig, 2012). Our study has all elements of a BACI design (see Roedenbeck et al., 2007) and had the objective of assess the effectiveness of a mitigation system installed in a Brazilian protected area.

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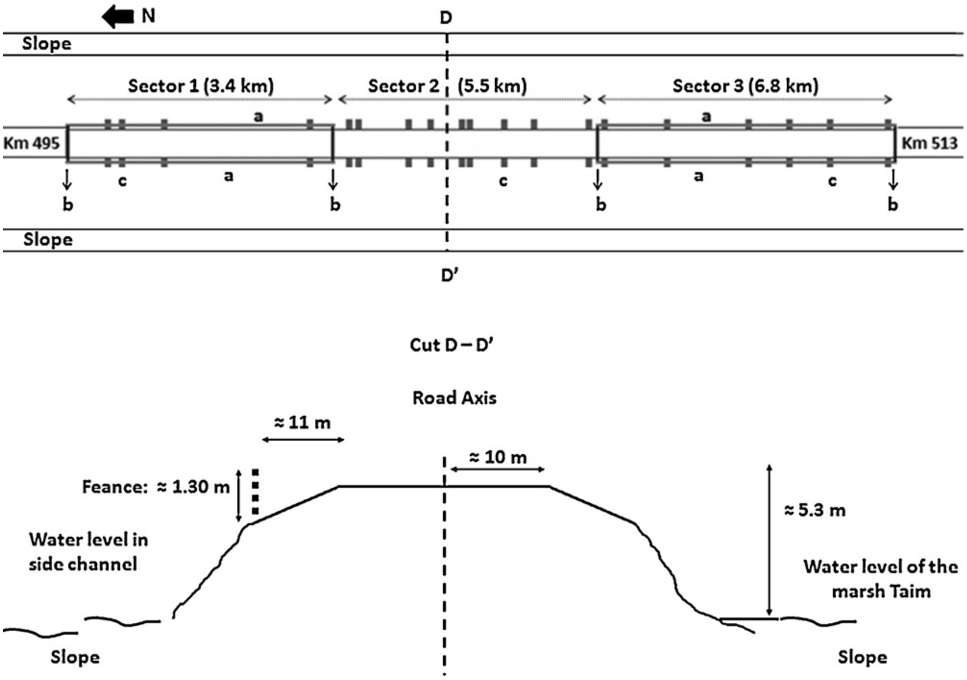

Fig. 1. Schematic representation of the section of highway BR 471 where the wildlife protection system (WPS) was implemented in the Taim Ecological Station. The road was divided into three sectors, with underpasses along its length (c), four stock guards (b), and fences in sectors 1 and 3 (a). The road is bordered by wetlands and ponds (Cut D – D′).

This system was proposed to minimize roadkills of *Myocastor coypus* and *Hydrochoerus hydrochaeris*, although this is not documented. For many years, there was public pressure on the administrators of the protected area, due to the omnipresence of large mammal carcasses along road edges and because occasional serious accidents resulted in human mortality and extensive property damage. Although the primary focus is on these two species, there was always the expectation that this system can be effective for multi-species, including of small size and birds. Thus, we define a complementary aim to analyze the changes in roadkill rates and the faunal community before and after the implementation of the system.

2. Materials and methods

2.1. Study area

The Taim Ecological Station (Taim ESEC) (32° 32′ 14.44″S; 52° 32′ 18.67″W) is a federal protection area located on the coastal plain of the state of Rio Grande do Sul, Brazil. The ecological station has an area of 33,818 ha; the relief is low and flat and wetlands are predominant, though open fields and dunes are present too. The climate is mild, with a cold, rainy winter and a warm, dry summer. The mean annual precipitation is 1100 mm, and the mean temperature is 18 °C (Nimer, 1989).

This highway is more than 600 km long, with a 15.7 km stretch passing through the park. In this section, the highway has two lanes and is approximately 25 m wide, considering the shoulders. It was constructed by excavating soil along the route and forming a borrow ditch along each side; the pavement is approximately 5.4 m above water level. In addition to the borrow ditches, the surrounding area contains extensive wetlands and flooded grassland. During the autumn-winter rainy season, these fields may remain underwater for several months. In 1998, a wildlife protection system (WPS) was installed in Taim ESEC along the federal highway BR 471. The WPS comprises three sectors. Sector 1, in the northern part of the system, is 3.4 km long, with a continuous fence along both sides of the road. The middle sector, sector 2, is 5.5 km long and unfenced. Sector 3, to the south, is again fenced along its entire 6.8 km length. Sectors 1 and 3 are located where BR 471 is tangent to the edge of the Taim ESEC, and in sector 2, the road cuts through the protected area. The fences were installed on a concrete base that is 0.2 m above the ground and is buried to a depth of 0.4 m. The lower portion of each fence, which is 0.65 m high, is composed of square, 50 mm mesh, while the upper portion of the fence consists of 100 mm mesh that is 0.45 m in height. At the beginning and end of each sector, a stock guard was installed to prevent animals from entering the fenced sector and to reduce the probability that they will move along the road. These stock guards are 11.2 m wide and 2.4 m long. The WPS also has 19 round underpasses that are 1.6 m in diameter; there are four underpasses in sector 1, nine in sector 2, and six in sector 3. The arrangement of these underpasses was established by the engineering company that constructed the WPS (Fig. 1).

2.2. Roadkill survey

Technicians from the Taim ESEC carried out daily road monitoring from July 1995 through June 2002. Over this 84-month time period, no monitoring occurred in 11 months (January, November and December 1996; January 1997; February 1998; and June, July, August, September, November and December 1999).

Samples taken from July 1995 through September 1998 were considered to be part of the period before the installation of the wildlife protection system (pre-WPS), whereas samples taken from October 1998 through June 2002 were in the post-installation phase (post-WPS). Sampling was performed from a car, at an average speed of 50 km/h, by two to four observers, along the 15.7 km stretch where highway BR 471 passes through the Taim ESEC. A total of 619 monitoring runs were made during the pre-WPS, and

571 monitoring runs were made during the post-WPS. Monitoring took place at different times of day. The date, species, and the kilometer where the carcass was found were documented. After they were recorded, the carcasses were removed from the road to prevent them from being recounted. The classes of animals monitored were mammals, birds and reptiles. The carcasses were identified to the lowest possible taxonomic level.

2.3. Data analysis

Considering the BACI design our study focuses on the effectiveness of fences. The assessment of the underpasses was not included due to absence of specific data collection and control areas. Because the technicians who identified the animals have only basic biological training, we opted to group some species. The species were placed in the following groups: the canids *Cerdocyon thous* and *Lycalopex gymnocercus*; turtles in the Chelidae family (*Phrynops hilarii*, *Acanthochelys spixii* and *Hydromedusa tectifera*); armadillos in the Dasypodidae family (*Dasypus novemcinctus*, *Dasypus septemcinctus* and *Euphractus sexcinctus*); and Rodentia, which included all small rodents. Bird species in the Charadriiformes order and all reptiles in the Snake suborder were grouped together. Because of this grouping system, we opted to use the term “taxonomic units” (TUs) rather than species. Although the WPS does not intend to protect birds, this class was included in the analysis because the main species road-killed have low flight capacity and WPS may have influenced their displacement.

The data were converted to roadkill rate (number of individuals/km/day). For the spatial analysis, the data were grouped by sector or by kilometer, and for the temporal analysis, the data were grouped by season; the months from January to March were considered to be summer, the months from April to June were considered to be autumn, etc. The Kruskal–Wallis test was applied for the analyses, and when three or more variables were involved, the Mann–Whitney test with post hoc Bonferroni correction was used.

For the spatial comparisons, we adopted the Brazilian Department of Transportation (Departamento Nacional de Infra-Estrutura de Transportes, DNIT) design, where the first kilometer (to the north) is the 497 km marker, and the last one (to the south) is the 512 km marker. The roadkill rates along each kilometer in the pre-WPS and post-WPS were compared using the 2-Sample Permutation Test, a part of the Coin package in R software R Development Core Team (2011). This analysis was used because of the large number of zeros in the data. All of the analyses used a significance level of 0.05.

Whittaker diagrams were constructed to evaluate the changes in the relative distribution of roadkill species before and after the establishment of the WPS. We also compared the community structure in each sector and in each phase using cluster analysis with the minimum variance method (Wards). For the cluster analysis, Euclidean distance was used as the distance measurement among the variables.

3. Results

3.1. TUs roadkilled in pre- and post-WPS periods

A total of 32 TUs were identified (Table 1). Mammals showed the highest TU richness affected both before and after the installation of the WPS (12–13 TUs). The second richest class was birds (11–10 TUs), followed by reptiles (4 TUs). For the different periods, mammals had the most roadkilled individuals, with a mean of 92.2% (range 87.3–95.6%), followed by reptiles (mean 5.2%; range 2.27–10.2%). The total of TUs, 22 TUs occurred in both periods, and 27 TUs occurred in each period. *Galictis cuja*, *Coscoroba coscoroba*, *Guira guira* and *Passer domesticus* occurred only in the pre-WPS period, whereas Rodentia, Dasypodidae, Charadriiformes, *Caracara plancus* and *Tyto alba* were found only in the post-WPS period. Of the 27 TUs found in the pre-WPS period, five occurred once and four were found twice, whereas in the post-WPS period, 12 TUs occurred only once and two occurred twice.

Despite having a high TU richness, only nine TUs had roadkill rates above 0.001 ind./km/day. This rate represents approximately 6 individuals per year along the 15.7 km of road. Three TUs reached this rate in the pre-WPS, two reached this rate in the post-WPS, and four reached this rate in both periods.

Of the 10 TUs that were most affected in the pre-WPS period, seven had the same ranking in the post-WPS period: *M. coypus*, *H. hydrochaeris*, *Cavea* sp., Canidae, *Trachemys dorbigni*, *Tupinambis merianae*, and Serpentes. *Lontra longicaudis*, a threatened species that occupied tenth place among the most-affected TUs in the pre-WPS phase, showed a reduction from seven to one roadkilled specimens. However, the roadkill rate of *Leopardus geoffroyi*, another threatened species, doubled from three to six individuals in the post-WPS period.

A total of 1457 roadkilled animals were identified (0.153 animals/km/day; range 0.063–1.401; SD 0.156) in the pre-WPS period, while 905 roadkilled animals were identified (0.103 animals/km/day; range 0.063–0.7; SD 0.072) in the post-WPS period; the overall roadkill rates were significantly different ($H_{1,1190} = 55.252$; $P < 0.001$). However, if *M. coypus* is excluded from the analyses, there was no difference between the two periods ($H_{1,1190} = 1.769$; $P = 0.184$). For the different classes of animals considered, the roadkill rate declined for birds (<50%) and mammals (<37%) but increased for reptiles (>38%).

M. coypus and *H. hydrochaeris* always constituted more than 75% of all the roadkilled animals in the Taim ESEC (mean = 83%). Both species showed reductions in their roadkill rate after the implementation of the WPS, although only *M. coypus* showed a significant reduction ($H_{1,1190} = 31.282$; $P < 0.001$). Although there was no statistical evidence for a relationship between the roadkill rate of *M. coypus* and precipitation, the mortality rate of this TU changed in periods when the rainfall accumulation exceeded 500 mm (Fig. 2). This effect was more evident for the pre-WPS period, which ended in the winter of 1998. For *H. hydrochaeris*, no apparent relationship between mortality and precipitation was observed.

Among the reptiles, *T. dorbigni* and *T. merianae* roadkill rates increased until 400% e 500%, respectfully, between pre- and post-WPS period. The highest roadkill rates (ind./km/day) considering all TUs were observed in the winter of 1995 (0.38 ± 0.291), winter of 1998 (0.20 ± 0.130) and autumn of 2002 (0.17 ± 0.123) (Fig. 3). Birds with larger reduction of mortality were those with short and low flight, mainly *Gallinula chloropus* and Rallidae.

The rankings of several of the species affected by roadkills changed after the WPS was installed. Excluding *H. hydrochaeris* and *M. coypus*, in the pre-WPS period, 55% of the species affected were small (<500 g), whereas the post-WPS roadkill percentage was reduced to 15%. The TUs that contributed the most to this change were *C. torquata*, *C. chinga*, *L. geoffroyi*, *T. dorbigni* and *T. merianae*.

3.2. Location of roadkills

Before the installation of the WPS, the roadkill rate in sector 3 was lower than in the other sectors (Table 2). After the WPS was installed, the roadkill rates in sectors 1 and 3 were significantly lower than in sector 2. The effect of the WPS implementation (pre × post) was significant for each sector. However, sectors 1 and

Table 1
Roadkill rates (individuals/100 km/day) of the taxonomic units in each sector of highway BR 471 associated with the Taim Ecological Station, before and after the implementation of the Wildlife Protection System.

	Sector 1		Sector 2		Sector 3		All Sectors	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Birds								
Ardeidae	0.03	0.00	0.01	0.00	0.00	0.00	0.04	0.00
Pitangus sulphuratus	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Charadriiforme	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Chauna torquata	0.02	0.02	0.01	0.05	0.00	0.01	0.03	0.08
Coscoroba coscoroba	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Cygnus melancoryphus	0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.01
Falconiformes	0.00	0.01	0.03	0.00	0.00	0.01	0.03	0.02
Gallinula chloropus	0.05	0.01	0.02	0.00	0.02	0.00	0.09	0.01
Guira guira	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Passer domesticus	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Polyborus plancus	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Rallidae	0.02	0.00	0.03	0.06	0.08	0.00	0.14	0.06
Tyto alba	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Vanelus chilensis	0.01	0.01	0.00	0.00	0.01	0.00	0.02	0.01
Mammals								
Canidae	0.08	0.06	0.06	0.01	0.12	0.02	0.26	0.09
Cavea sp.	0.08	0.03	0.18	0.03	0.09	0.03	0.36	0.10
Conepatus chinga	0.01	0.05	0.02	0.06	0.00	0.06	0.03	0.16
Didelphis albiventris	0.01	0.00	0.02	0.01	0.02	0.01	0.05	0.02
Galictis cuja	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Hydrochoerus hydrochaeris	1.78	0.92	1.72	3.21	1.68	0.89	5.18	5.02
Leopardus geoffroyi	0.00	0.01	0.00	0.05	0.03	0.01	0.03	0.07
Lepus capensis	0.00	0.01	0.01	0.00	0.01	0.00	0.02	0.01
Lontra longicaudis	0.03	0.00	0.02	0.00	0.02	0.01	0.07	0.01
Lutreolina crassicaudata	0.01	0.00	0.04	0.00	0.02	0.01	0.07	0.01
Myocastor coypus	3.37	0.14	3.20	3.05	1.68	0.42	8.25	3.60
Procyon cancrivorus	0.00	0.00	0.00	0.01	0.02	0.00	0.02	0.01
Rodentia	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Dasypodidae	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.05
Reptiles								
Chelidae	0.01	0.00	0.02	0.02	0.02	0.01	0.05	0.03
Snakes	0.02	0.01	0.09	0.02	0.01	0.03	0.13	0.07
Trachemys dorbigni	0.07	0.06	0.07	0.31	0.08	0.10	0.23	0.47
Tupinambis merianae	0.04	0.02	0.05	0.25	0.00	0.05	0.09	0.32
TOTAL	5.69	1.36	5.63	7.20	3.97	1.73	15.28	10.29
S	19	14	20	19	19	18	27	27
H’	1.13	1.34	1.26	1.26	1.40	1.64	1.28	1.41

3 (fenced) showed a reduction in the roadkill rate, whereas sector 2 (unfenced) showed an increase (Table 2).

The kilometer areas with the highest mortality rates in the pre-WPS period were those of sector 1 and two kilometers of sector 2. 500 km had the highest mortality rate, followed by 505 km, and 498 km (Table 3). Because sector 1 begins at 497 km and ends at 500.5 km, it is impossible to determine whether the roadkills that occurred in 500 km refer to sector 1 or 2. Sector 3 had the lowest roadkill rates in the different kilometers, ranging from 0 to 0.11 ind./km/day.

In the post-WPS period, the kilometer areas with highest mortality rates occurred in sector 2. Four of the 5.5 km of this sector (501–504 km) had higher roadkill rates in the post-WPS period than in the pre-WPS period. 500 km continued to be the section with the highest mortality rate. In sector 1, the roadkill rates in all of the kilometers were significantly reduced, whereas in sector 3, the last two kilometers showed an increase in mortality (511–512 km).

Except for sector 1, where the richness of roadkilled TUs declined from 19 to 14, TU richness remained steady in the other sectors, although some TU substitution was observed between the pre- and post-WPS periods. The diversity indices in the fenced sectors (1 and 3) increased, and the equitability in the roadkill rate within these sectors was higher (Fig. 4). Of the eight canids that were found killed after the implementation of the WPS, seven (88%) were in sectors 1 and 3. For *Conepatus chinga*, 64% of the post-WPS roadkills were in sectors 1 and 3; the number of deaths in sector 2 increased by 150%.

Cluster analysis showed that the community structure of sector 2 remained steady post-WPS (Fig. 5). Sectors 1 and 3, in which different communities were affected in the pre-WPS period, were

Table 2
Roadkill rates (mean, min, max) for *M. coypus*, *H. hydrochaeris* and other TUs in different sectors for each period. The lower case letters in column H represent differences among the sectors in the pre-WPS period, the capital letters represent differences in the post-WPS period, and the asterisks indicate significant differences within the same sector between different periods.

				M. coypus		*H. hydrochaeris*		Other species	
	Pre-WPS	Post-WPS	H	Pre-WPS	Post-WPS	Pre-WPS	Post-WPS	Pre-WPS	Post-WPS
Sector 1	0.26 (0–4.41)	0.06 (0–1.18)	a,A*	0.15	0.01	0.08	0.04	0.02	0.01
Sector 2	0.16 (0–1.64)	0.20 (0–1.09)	a,B*	0.09	0.08	0.05	0.08	0.02	0.02
Sector 3	0.09 (0–0.88)	0.04 (0–0.44)	b,A*	0.04	0.01	0.04	0.02	0.01	0.01

Table 3
Roadkill rates per kilometer in the pre- and post-WPS periods. The position of the kilometer area within each sector is shown. The number of underpasses within each kilometer is represented by *N*.

Km	Pre	Post	Sector	*Z*	*P*	*N*
497	0.210	0.065	1	5.861	<0.001	2
498	0.229	0.028	1	7.047	<0.001	1
499	0.163	0.035	1	5.304	<0.001	0
500	0.341	0.298	1,2	1.226	0.235	1
501	0.160	0.215	2	−2.046	0.041	2
502	0.145	0.208	2	−2.364	0.017	2
503	0.108	0.222	2	−4.805	<0.001	2
504	0.113	0.165	2	−2.169	0.032	2
505	0.241	0.100	2	5.652	<0.001	1
506	0.113	0.014	3	6.397	<0.001	1
507	0.108	0.014	3	6.336	<0.001	1
508	0.087	0.025	3	4.336	<0.001	0
509	0.034	0.023	3	1.095	0.335	2
510	0.021	0.033	3	−1.192	0.258	1
511	0.002	0.021	3	−2.805	0.003	0
512	0.006	0.037	3	−3.637	<0.001	1

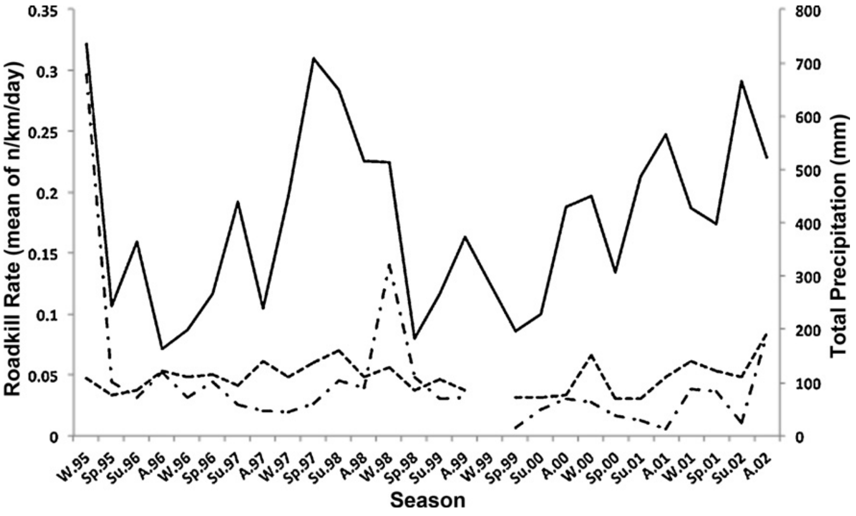

Fig. 2. Seasonal variation in the *Myocastor coypus* (dotted line with circles) roadkill rate, the *Hydrochoerus hydrochaeris* (plain dotted line) roadkill rate, and precipitation (solid line) on highway BR 471 in the Taim Ecological Station. W. – winter, Sp. – spring, Su. – summer, A. – autumn.

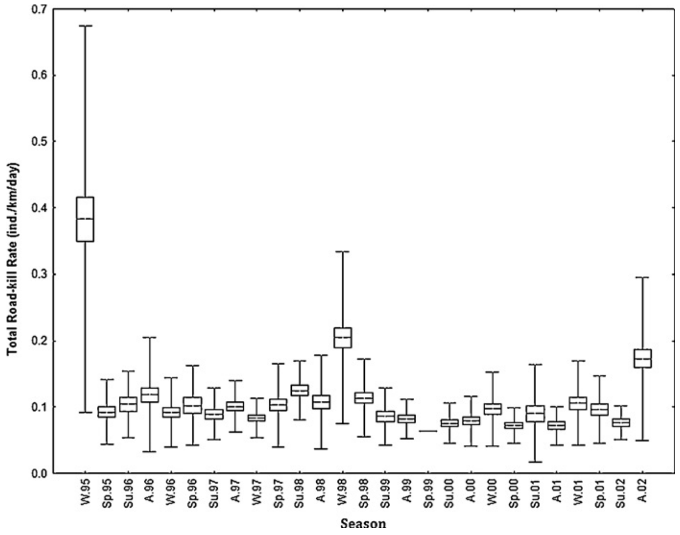

Fig. 3. Variation in the roadkill rate along highway BR 471, Taim Ecological Station, from winter of 1995 to autumn of 2002. The boxplots represent the mean, standard error and standard deviation. W. – winter, Sp. – spring, Su. – summer, A. – autumn.

similar in the post-WPS, indicating that the system protected some species but was inefficient for others.

4. Discussion

The structure of the highway in the segment that cuts off part of the Taim ESEC differs from the other segments of BR 471. At this point, the road was constructed through wetlands and ponds, with fill taken from along the road to construct its base. This method of construction created two water-filled borrows ditches, with a narrow strip of land between the pavement and these ditches. This feature must have reduced the vertebrate richness along the road edges, favoring species that are tolerant to anthropogenic disturbances and could adapt to the water and/or the sloping terrain near the highway. The TU richness observed ($S = 32$) reflects these characteristics of the road because the sampling performed around the Taim ESEC identified more than 100 species of roadkilled vertebrates. In this study, several TUs include two or more species; i.e., the real richness in terms of species is up to 50% higher, but most of these species had low occurrences.

The main TUs affected in the pre-WPS period were *M. coypus*, *H. hydrochaeris*, *Cavea* sp., Canidae, *T. dorbigni* and Serpentes. The birds were excluded from this list because of their low mortality rates. Of the above mentioned TUs, *Cavea* sp., Serpentes and

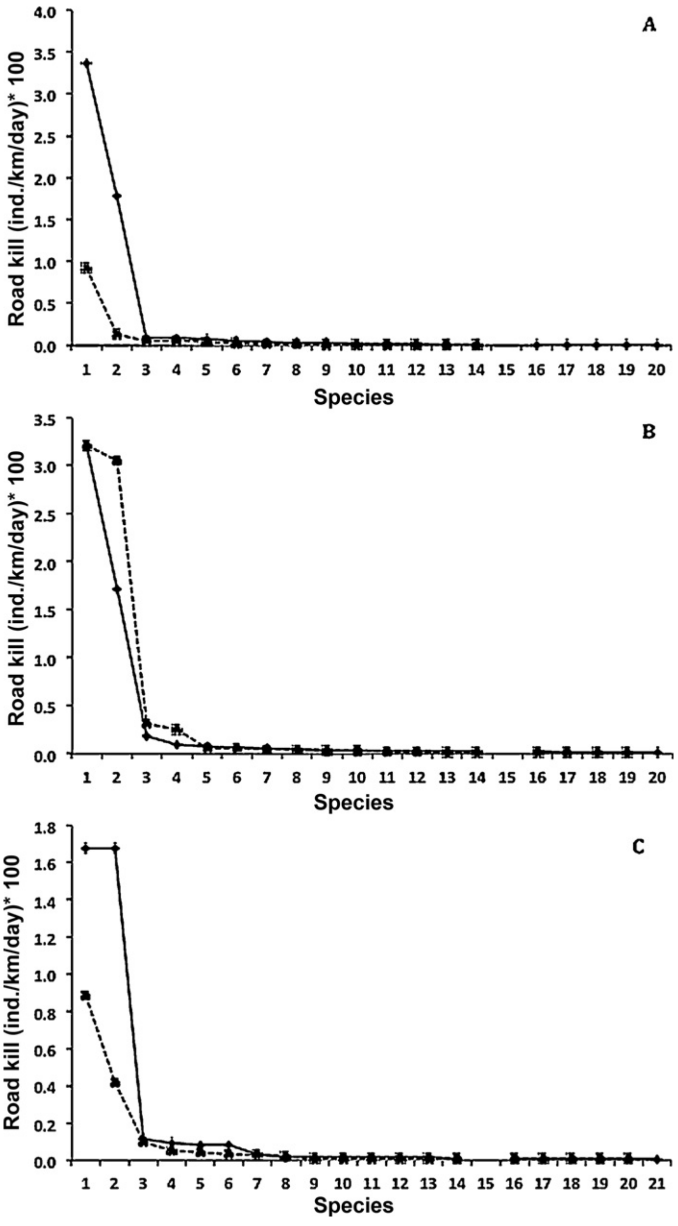

Fig. 4. A Whittaker diagram of the roadkill rates for each TU roadkilled on highway BR 471 in the Taim Ecological Station. Solid line.- pre-WPS; plain dotted line.- post-WPS. A. – Sector 1; B. – sector 2; C. – sector 3.

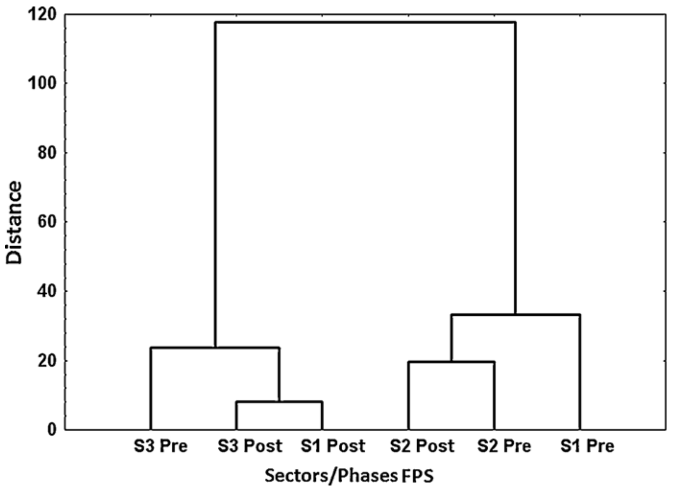

Fig. 5. Cluster analysis of roadkilled wildlife in the different sectors along Highway BR 471 before and after implementation of the WPS.

T. dorbigni are small animals. Thus, the implementation of underpasses with a diameter of 1.6 m is not justified for these species. These considerations imply that the WPS was designed to minimize the mortality of *H. hydrochaeris*, *M. coypus*, and as a non-target benefit, Canidae. In the pre-WPS period, the 3 km with the highest roadkill rates of these three mammal TUs were 500 km (16%), 498 km (12%) and 505 km (11%). Although these areas together accounted for 39% of roadkills, only one faunal passage was installed in each section, i.e., 17% of the total underpasses. Sector 3 accounted for 17.5% of the roadkills of these TUs and received six underpasses (32%). The large number of underpasses in sector 3 is consistent with the logic of maintaining connectivity between the two sides of the road because fences increase fragmentation. However, if the larger number of underpasses were correlated with the presence of fences, sector 2 would not have received nine underpasses. The large number of underpasses in sector 2 was an attempt to increase the probability that the target species would use the underpasses instead of crossing on the road surface. This strategy was not efficient, as shown by the increased mortality in this section. The absence of fences in sector 2 was a decision of the administration to maintain the connectivity of the protected area because this section of the road crosses the Taim Reserve.

The WPS did not reduce the richness of affected TUs but rearranged the order of roadkills; however, it did result in a 30% overall reduction in the roadkill rates of wildlife in the Taim ESEC. Nevertheless, this reduction in the roadkill rate occurred for one species, *M. coypus*. The roadkills of the second most affected species, *H. hydrochaeris*, only changed location, occurring predominantly in sector 2. *Myocastor coypus* proved to be more susceptible during periods of high precipitation, when burrows become flooded and nutrias move to the road banks. Despite the significant reduction in nutria roadkills in sectors 1 and 3, the nutrias as well as the capybaras, *H. hydrochaeris*, must be negatively influenced by the presence of fences when the water level approaches the fence. At that point in time, they become trapped between the fence and the water, leaving them unable to reach refuge areas (Bager, pers. obs.). Therefore, the WPS may have reduced the number of roadkills, but future studies should assess whether it contributed to the stability of the population. *H. hydrochaeris* was also favored by the implementation of the WPS with respect to vehicle collisions. In contrast to *M. coypus*, *H. hydrochaeris* showed an increase of 50% in sector 2 roadkills. This increase may be related to this species' high movement capacity (Herrera et al., 2011), allowing it to abandon fenced areas and move to sector 2 to cross the road.

Studies with effectiveness of fence showed different results, may reduce (Seiler, 2005; Clevenger et al., 2001) or increased roadkill rates (Colino-Rabanal et al., 2010). Jaeger and Fahrig (2004) afirmam que road fences normally contribute to reduce roadkill but also increase barrier effect, and traffic mortality, degree of road avoidance, population size tendência, among others factor must be considered before install fences. Colino-Rabanal et al. (2010) discuss that fences act as selective filters but do not have the same effectiveness for all species, being confirmed by our results.

Although the WPS was proposed to protect medium-sized and large species, the number of collisions in this group increased after its installation. Among the mammals, the main increases in roadkills occurred for *C. chinga* and *L. geoffroyi*, which are apparently able to scale the fence and its support walls (Brashear et al., 2010; Manfredi et al., 2006; Sousa and Bager, 2008) or use the native vegetation next to the fence to bypass the protective structure. For reptiles, the fence definitely blocks the passage of *T. dorbigni*, with no roadkills occurring in the middle kilometers of the sectors with a fence. However, sector 2 and the first two kilometers in sectors 1 and 3 accounted for 92.5% of all mortality of this TU in the post-WPS. This finding reflects the inefficiency of the stock guard because *T. dorbigni* and several mammal species were able to pass over or around them. The roadkill rates of *T. merianae* showed the same pattern as *T. dorbigni*, with 96% of the mortality occurring in sector 2 and at the periphery of the fenced areas.

The WPS of the Taim ESEC is the only apparatus installed in the 15.7 km stretch where highway BR 471 crosses this area. Analyzing the WPS as a whole, we conclude that the WPS was efficient in reducing the mortality of the main species considered, *M. coypus*; however, excluding this species results in a steady roadkill rate. Moreover, the WPS did not reduce the number of roadkilled species but reordered them. The system was not appropriate for *H. hydrochaeris*, which had the second-highest number of deaths because an extensive area (sector 2) remained unfenced and the underpasses were installed without fences. The presumption that the areas with a fence should have fewer underpasses was a conceptual misunderstanding, which undoubtedly increased the barrier effect for most of the species. Similarly, the installation of a large number of underpasses in sector 2, without fences, increased the mortality rate in this section. Dodd et al. (2004) stated that the presence of fences guiding animals to passages increases their use. The group analysis showed that the WPS was selective, and sectors 1 and 3 allowed the same species to be killed after its installation. The stock guards were inefficient for most species, and the position of fences in relation to the water level may be impacting reptiles and mammals in different ways.

Currently, the WPS is an inefficient mitigation system, but it could be improved through the implementation of specific changes. Instead of continuous fences in sectors 1 and 3, individual fences should be installed around each underpass. If each underpass has 200 m of fence on each side, then more than 8 km of road will be protected by the system. In contrast to the current design, the fences must guide the fauna to the entrance to the underpass. Because the existing fences are inefficient in reducing feline mortality, the other species affected (capybaras, nutrias, and turtles) have a low capacity to cross obstacles, and the region is important for sightseeing and appreciation of the natural landscape, it is suggested that the 1.3 m-high fence system be replaced with Jersey barriers. These barriers require less maintenance, are easy to install, and if they are complemented with a short fence (~40 cm) with a small mesh and sloped toward the outside of the road (~45°), will impede nearly all the species affected by roadkills in the Taim ESEC, except for the birds. The use of Jersey barriers will allow the installation of fencing in higher areas as well as along road edges, which will extend the area available in case of flooding and preserve freshwater turtles' nesting area.

More than 10 years after the installation of the proposed system modifications, we suggest a roadkill monitoring period for *H. hydrochaeris* and *M. coypus* to determine where these species are present in high densities. Special attention must be given to the stretches of highway from 497 km to 500 km and from 500 km to 505 km, which may require the installation of new underpasses. The stock guards proved to be inefficient and should be removed. Speed detectors, which fine vehicles that travel above the speed limit, are often used to reduce the speed of vehicles in areas where roads pass through villages. This system should be installed in the highway sections with high mortality rates and without fences that would limit the crossing of animals. Unfortunately, the underpasses were not monitored to evaluate their effectiveness for the different species. This monitoring will be essential in deciding whether different structures should be installed. The last system modification is the establishment of cooperation between the administration of the Taim ESEC and the highway patrol, which would require motorists to obey the 60 km/h speed limit along this section.

5. Conclusion

The wildlife protection system was ineffective in reducing roadkill rates for all the sectors examined, but where fences are present, roadkill rates decreased. Only one species, *M. coypus*, a non-threatened rodent that is locally abundant, benefited from the WPS. Major problems include the WPS design, which consists of continuous fences, fences that do not direct the fauna toward the underpasses, and short distances between the water and the fences. The underpasses were located inappropriately, increasing fragmentation, with unknown effects on several species. We propose to reduce the length of the fences to 200 m on each side of each underpass, install new underpasses, monitor the capybara and nutria populations, and conduct sampling to evaluate the efficiency of the underpasses in protecting different mammal species.

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References

Aresco, M.J., 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida lake. J.Wildl. Manage. 69, 549–560.

Bager, A., 2003. Repensando as medidas mitigadoras impostas aos empreendimentos viários associados às unidades de conservação. In: Bager, A. (Ed.), Áreas Protegidas. Conservação no âmbito do Cone Sul, Pelotas, pp. 159–172.

Barrientos, R., Ponce, C., Palacín, C., Martín, C.A., Martín, B., Alonso, J.C., 2012. Wire marking results in a small but significant reduction in avian mortality at power lines: A BACI designed study. PLoS ONE 7, e32569.

Brashear, W.A., Dowler, R.C., Ceballos, G., 2010. Climbing as an escape behavior in the American hog-nosed skunk, *Conepatus leuconotus*. West. N. Am. Naturalist. 70, 258–260.

Cain, A.T., Tuovila, V.R., Hewitt, D.G., Tewes, M.E., 2003. Effects of a highway and mitigation projects on bobcats in southern Texas. Biol. Conserv. 114, 189–197.

Clevenger, A.P., Chruszcz, B., Gunson, K.E., 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildl. Soc. Bull. 29, 646–653.

Colino-Rabanal, V.J., Lizana, M., Peris, S.J., 2010. Factors influencing wolf *Canis lupus* roadkills in Northwest Spain. Eur. J. Wildl. Res. 57, 399–409.

de Lucas, M., Janss, G.F.E., Ferrer, M., 2005. A bird and small mammal BACI and IG design studies in a wind farm in Malpica (Spain). Biodivers. Conserv. 14, 3289–3303.

Dodd, C.K., Barichivich, W.J., Smith, L.L., 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biol. Conserv. 118, 619–631.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C., 2003. Road Ecology: Science and Solutions. Island Press, Washington.

Glista, D.J., DeVault, T.L., Woody, J.A., 2009. Factors influencing wolf *Canis lupus* roadkills in Northwest Spain. Landscape Urban Plan. 91, 1–7.

Goosem, M., Izumi, Y., Turton, S., 2001. Efforts to restore habitat connectivity for an upland tropical rainforest fauna: a trial of underpasses below roads. Ecol. Manage. Restor. 2, 196–202.

Grilo, C., Bissonette, J.A., Cramer, P.C., 2010. Mitigation measures to reduce impacts on biodiversity. In: Columbus, F. (Ed.), Highways: Construction, Management and Maintenance. Nova Science Publishers, New York, pp. 73–114.

Herrera, E.A., Salas, V., Congdon, E.R., Corriale, M.J., Tang-Martinez, Z., 2011. Capybara social structure and dispersal patterns: variations on a theme. J. Mammal. 92, 12–20.

Jaeger, J.A.G., Fahrig, L., 2004. Effects of road fencing on population persistence. Conserv. Biol. 18, 1651–1657.

Lesbarrères, D., Fahrig, L., 2012. Measures to reduce population fragmentation by roads: what has worked and how do we know? Trends Ecol. Evol. 27, 374–380.

Manfredi, C., Soler, L., Lucherini, M., Casanave, E.B., 2006. Home range and habitat use by Geoffroys cat (*Oncifelis geoffroyi*) in a wet grassland in Argentina. J. Zool. 268, 381–387.

Mata, C., Hervás, I., Herranz, J., Suárez, F., Malo, J.E., 2005. Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. Biol. Conserv. 124, 397–405.

Nimer, E., 1989. Climatologia do Brasil. Departamento de Recursos Naturais e Estudos Ambientais, Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Brasil.

R Development Core Team, 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria http://www.R-project.org

Roedenbeck, I.A., Fahrig, L., Findlay, C.S., Houlahan, J.E., Jaeger, J.A.G., Klar, N., Kramer-Schadt, S., van der Grift, E.A., 2007. The Rauischholzhausen agenda for road ecology. Ecol. Soc. 12, 11.

Roley, S.S., Tank, J.L., Stephen, M.L., Johnson, L.T., 2012. Floodplain restoration enhances denitrification and reach-scale nitrogen removal in an agricultural stream. Ecol. Appl. 22, 281–297.

Romin, L.A., Bissonette, J.A., 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildl. Soc. Bull. 24, 276–283.

Seiler, A., 2005. Predicting locations of moose-vehicle collisions in Sweden. J. Appl. Ecol. 42, 371–382.

Sousa, K.S., Bager, A., 2008. Feeding habits of Geoffroys cat (*Leopardus geoffroyi*) in southern Brazil. Mamm. Biol. 73, 303–308.

Trombulak, S.C., Frissell, C.A., 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14, 18–30.