Transportation Research Part D 38 (2015) 6–14

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Effectiveness of an acoustic wildlife warning device using natural calls to reduce the risk of train collisions with animals

Joanna Babińska-Werka, Dagny Krauze-Gryz *, Michał Wasilewski, Karolina Jasińska

Warsaw University of Life Sciences – SGGW, Department of Forest Zoology and Wildlife Management, Nowoursynowska 159, 02-776 Warsaw, Poland

ARTICLE INFO

Keywords:
Railway lines
Animal–vehicle collisions
Acoustic warning device
Roe deer

ABSTRACT

The subject of study was the effectiveness of the UOZ-1 device – which emits the natural warning calls of animals – in protecting animals living near railway tracks. We performed the investigations in central Poland between 2008 and 2012 at two study sites along the E 20 line where the UOZ-1 devices had been installed. We used digital cameras to register animal activity 24 h a day, resulting in 2262 mammal observations (involving 2956 individuals). In 76% of the observations, no rail transport was observed. When a train did approach and acoustic signals were emitted, most of the wild mammals escaped (93–85% of cases, depending on the species). Regarding the most numerous species, the roe deer, the effectiveness of the device was tested by comparing the animals' reactions when a train approached with the device switched on or off. With sound signals emitted, animals escaped more often (84% vs. 68%), and their reaction to an oncoming train was 20 s faster. We found no proof that animals habituated to the warning signals because the proportion of roe deer that showed no reaction was similar in the first and last year of the study. There was also no difference between the reaction time to an oncoming train (on average 35 s). The results of this research indicate that the UOZ-1 is more effective in reducing the risk of train–animal collision, by prompting animals to leave the railway track faster and with greater frequency, than only the sound of an oncoming train.

Introduction

As Poland's railway lines are modernised, it is required to assure safety of passengers but also to maintain the effect of rail transport on the environment as reduced as possible. Numerous studies addressed the negative influence of technical infrastructure on the populations of different groups of vertebrates and on their environments in relation to new road developments (review in Spellerberg, 2002; review in Forman et al., 2003; Steiner et al., 2014). Research on possible collisions between trains and wildlife focussed mainly on medium or large mammals (Wasilewski et al., 2009; Kušta et al., 2011; Jasińska et al., 2014, review in: Steiner et al., 2014), including the Sika deer *Cervus nippon* (Ando, 2003) and the moose *Alces alces* (Modafferi, 1991; Jaren et al., 1991; Andersen et al., 1991; Child et al., 1991; Gundersen et al., 1998).

Several technical devices aiming to deter animals from roads, railway lines, airports or cultivated fields have been invented. Most of these devices make sounds, including, for example, ultrasonic whistles that emit soundwaves at frequencies above 20 kHz. However, tests of these devices on animals such as the white-tailed deer (*Odocoileus virginianus*) (Curtis et al., 1995; Belant et al., 1998), black-tailed deer (*Odocoileus hemionus*) (Romin and Dalton, 1992; Putman, 1997), dingo

* Corresponding author. Tel.: +48 22 59 38 145.
E-mail addresses: joanna_werka@sggw.pl (J. Babińska-Werka), dagny.krauze@wl.sggw.pl (D. Krauze-Gryz), michal_wasilewski@sggw.pl (M. Wasilewski), sep.wedrowny@gmail.com (K. Jasińska).

http://dx.doi.org/10.1016/j.trd.2015.04.021
1361-9209/

(*Canis lupus dingo*) (Edgar et al., 2007) and birds (Woronecki, 1988) have indicated that they are ineffective. There are other devices that produce noise, such as various types of rattles, klaxons and sirens, whistles, recordings of human voices, and explosions or fired shots (Woronecki, 1988; Koehler et al., 1990; Ujvári et al., 2004). They might be effective, but have only produced the desired effect over very short periods (Woronecki, 1988; Koehler et al., 1990; Ujvári et al., 2004). Indeed, irrespective of type, frequency or intensity of the emitted sound, experiments have usually showed a steady process of habituation (Bomford and O'Brien, 1990). Under these circumstances, devices that use natural calls and other sounds made by animals might be the most promising. However, little research on this topic has been conducted (Koehler et al., 1990; Gilsdorf et al., 2002).

A device that fills this gap is the UOZ-1 (in which UOZ stands for *urządzenie ochrony zwierząt*, meaning "animal protection device"). It is produced in Poland by NEEL Ltd. (www.neel.com.pl access on 10.10.14). The assumption is that natural warning calls used in UOZ-1 can modify the behaviour of wild animals by hastening their escape from rail track in advance of an oncoming train. Emitted sound signals are supposed to produce natural reactions in animals because they are translated as a warning of growing danger and a direct threat to life. The sound sequence in the UOZ-1 combines several natural alarm calls known to animals. These are: the warning call of the jay *Garrulus glandarius*, the sound made by a frightened brown hare *Lepus europaeus*, the growling and barking of the dog *Canis familiaris*, the howl of the wolf *Canis lupus*, the squeal of the wild boar *Sus scrofa*, and the warning voice of roe deer *Capreolus capreolus*. In natural conditions, these animal sounds would usually be associated with a growing threat to animals, aggression within a species, predatory behaviour, or even death (Kossak, 2007).

The UOZ-1 device is cylinder-shaped, 110 cm high and 30 cm wide in diameter (Fig. 1). It is prepared to work in a range of temperatures from −40 to +55 °C. They are installed in groups every 70 m, each one on the alternate side of the railway tracks and permanently mounted on concrete foundations. This distance is assumed to be a minimal effective operational range of a single UOZ-1 device; hence, it ensures a continuous protected area. The complete animal protection system consists of UOZ-1 devices installed adjacent to the rail tracks and interoperating with UOZ-MDS control modules, installed in containers of the automatic block signal system or in specialised KUOZ containers. The sound emission is activated by signals received from an automatic railway system; just before (usually 60 s, time is set in the range of 30 s to 3 min) the arrival of a train at a given location, the device switches on and emits a sequence of sounds, switching off again as a train passes. Power is provided to the device via cables from the KUOZ container or automatic block signal system container, with a 230 V 50 Hz separated voltage. The maximum amount of power drawn by a single UOZ-1 device is approximately 40 VA, which is the highest setting of signals emitted. The actual average amount of power drawn while in standby mode is approximately 25 VA (www.neel.com.pl, access on 10.10.14). An average installation cost of one device (in Poland) is from 30,000 to 50,000 PLN (approximately 8000–14,000 USD), including projects, equipment and installation. The more devices are installed in one place the lower unit cost. The maintenance cost includes service check twice a year, two technicians can service up to 30 devices in one day (Stolarski M., pers. inf.).

The aim of this study was to determine the reactions of mammals to sound signals emitted by the UOZ-1 device before the passing of a train, and thus characterise its effectiveness by comparing the frequency and speed of different reaction to an approaching train with the UOZ-1 devices switched on and off. Our study also focused on animal reactions in successive years to determine whether animals would begin to react differently to the emitted signals over time, suggesting that they have become accustomed to the acoustic stimuli.

Study area

We performed the research in central Poland along a modernised part of the E 20 line between Mińsk Mazowiecki and Siedlce (ca. 50 km). The track here runs through a field-forest mosaic. Approximately half of the distance (24.4 km) was surrounded by a mosaic of the following habitat types: small and fragmentary patches of woodland (42%), open areas (mostly

Fig. 1. Installation of UOZ-1 protective devices along the railway line.

cultivated fields, 35%), shrubs (15%), meadows (4%) and dispersed buildings (5%). The other half was adjacent to a rather densely built up area (in total, the immediate vicinity of the line included 11 small localities inhabited by approx. 20,000 people in total), roads and railway stations. Trains run almost all day with a break between the hours 00^{00}–04^{00}. On average, there was a train every 16 min, with freight trains travelling approximately 70 km/h every 60 min, passenger trains (at c. 100 km/h) every half-hour, and express trains (at c. 120 km/h) every 85 min (Polskie Koleje Państwowe, 2014).

The acoustic UOZ-1 animal protection devices were installed in 2005 at 10 locations along the line under study. The locations had been indicated in the environmental decision issued for the investment. Overall, approximately 3.7 km of line were safeguarded by installing 62 UOZ-1 devices (Fig. 1).

The study area was characterised by the presence of ungulates – moose, red deer *Cervus elaphus*, roe deer and wild boar, as well as medium-sized mammal species such as brown hare, fox *Vulpes vulpes*, badger *Meles meles*, raccoon-dog *Nyctereutes procyonoides*, martens *Martes* spp. and otter *Lutra lutra.* Both forests and fields were also frequented by stray dogs and cats *Felis silvestris catus* (Nadleśnictwo Mińsk Mazowiecki, 2014; Nadleśnictwo Siedlce, 2014).

Methods

On the basis of snow tracking, we selected two (of ten) stretches on the line E20 that were safeguarded by UOZ-1 devices, where we registered the most numerous animal tracks crossing the railway tracks. Our assumption was that this would result in a sufficient number of observations during the study period. The study sites were approximately 20 km from one another (Rudka 52°9′N, 21°50′E and Stawy Broszkowskie 52°10′N, 22°5′E). Both were surrounded by forest on both sides of the railway track, and the nearest buildings were approximately 300 m away, in the case of Rudka, and 1000 m away at Stawy Boszkowskie. There were fish ponds approximately 50–500 m from the line at the Stawy Broszkowskie site (Fig. 2).

Each of the studied stretches of line was fitted with 4 UOZ-1 devices distributed along both sides of the track and separated by distances of 70 m (Fig. 3). In total, approximately 350 m of a line were safeguarded. We monitored the presence of animals by or on the lines all day, throughout the year, using 2 sets of IQEye 755 series digital cameras of 5 megapixel resolution equipped with motion-sensors. Each set comprised two cameras arranged opposite one another, 230 m apart; the cameras, with infra-red illuminators, were mounted on power-line poles (Fig. 3). The cameras were able to observe the entire 230 m length of rail line separating them. Additionally, they could observe up to 100 m past the other camera during the day and approximately 20 m past the other camera at night. Additionally, it was possible to monitor the immediate vicinity of the rail line up to approximately 15 m from the tracks on both sides. Thus, cameras monitored longer stretches of line (approximately 350 m) from dawn to dusk, and approximately 230 m at night, indicating that the length of a monitored stretch was 230–350 m. Recorded images with the emitted sounds from the UOZ-1 were registered using the *Milestone XProtect Viewer* program. At both locations, we collected data between August 2008 and November 2012. While the UOZ-1devices were active for the entire observation period at the Broszkowskie Ponds (52 consecutive months), the cameras at Rudka were switched off between April 2011 and October 2012 so that the reactions of animals when the devices were switched off (altogether 19 months) and on (33 months) could be compared.

We noted all cases of animals present on or near the railway line that were recorded. Animals were not marked. Each recorded sighting was counted as the presence of a single specimen or a group of animals of a given species. In relation to the location of animals prior to a train passing, we differentiated between: 1 escape from the track to the line's immediate surroundings, i.e., to the forest where animals were able to shelter; 2 escape across the track, crossing the line to shelter in forest on the other side, and 3 no reaction – continued feeding, a break in feeding activity or a raising of the head. We calculated the amounts of the different reactions displayed by the observed animal species for which we collected a sufficient number of observations as a train approached and the UOZ-1 device came into operation. Additionally, in relation to roe deer as the most abundant species, we calculated how fast these animals escaped after the UOZ-1 devices switched on, and how long before the train arrived when this escape occurred. To test the effectiveness of the UOZ-1 devices, we compared the data collected when the UOZ-1 devices were turned on and when they were turned off, including: 1 the amount of different reactions displayed by the roe deer, 2 the time in advance of the train arrival which caused them to escape. To test the possibility that animals were becoming accustomed to the warning signals over time, we compared for roe deer: 1 the number of different reactions to emitted sounds that were observed in consecutive years of study, 2 the mean escape times in advance of the arrival of an approaching train with UOZ-1 devices operating. These analyses were conducted only for the years 2008–2011 on account of the small number of observations made in 2012 (during the entire year UOZ-1 devices were experimentally switched off in one of the study sites).

To test the significance of observed differences between the number of reactions displayed by animals to an approaching train (i.e., wild vs. domestic animals, roe deer with UOZ-1 devices switched on and off, or reactions of roe deer in consecutive years), we used a chi-square test. In relation to the mean escape times of roe deer with the UOZ-1 device either operational or non-operational, a Mann–Whitney test was used. We tested the mean escape times of roe deer in response to acoustic signals in consecutive years using a one-way ANOVA. All the tests were conducted using *Statgraphics Plus 4.1*.

Results

We recorded 2262 cases of animals crossing or coming near railways, with 2956 individual animals observed: 11 wild and 2 domesticated animal species. Roe deer, foxes and hares were the most frequent species near the tracks, with 1074, 559 and

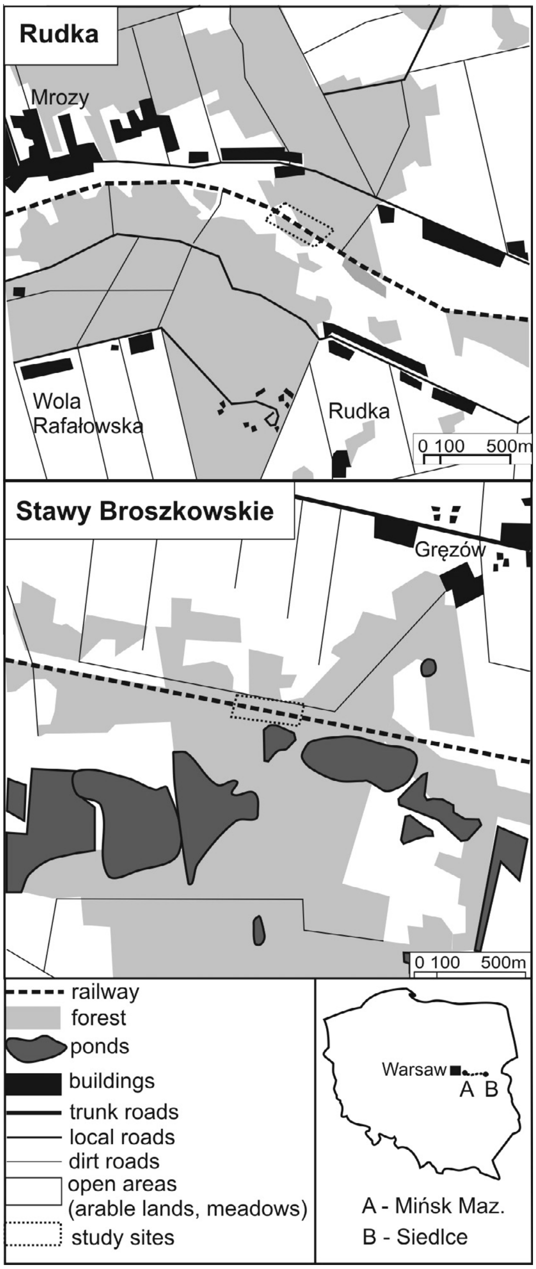

Fig. 2. The location of the study area with the two study sites enclosed by a dotted line.

200 cases, respectively. Observations of cats and dogs (128 and 137, respectively) were less frequent. Large mammals, such as wild boar and moose, were observed in 59 and 35 cases, respectively. Other species included red deer, badgers, raccoon-dogs, martens, red squirrels *Sciurus vulgaris* and otters.

Most (approximately 76%) observations related to situations in which animals fed or wandered near or on the railway line during the intervals between train arrivals. Remaining cases concerned the behaviour of animals at times when trains were approaching or passing, and the warning device was either in operation or switched off. During the periods when UOZ-1 were switched on, we observed 443 cases of animals reacting to the sound signals. For all species, the dominant reaction to the natural warning calls was to escape (this involved either movement away from the tracks into the surrounding area or flight across the line to the other side; see video). The reactions of wild animals ($n = 377$) were between 93% and 85%, whereas domestic animals ($n = 54$) were significantly less likely to escape (48–50%, chi-square test, $\chi 2 = 110.14$, $df = 2$, $p < 0.0001$) (Fig. 4).

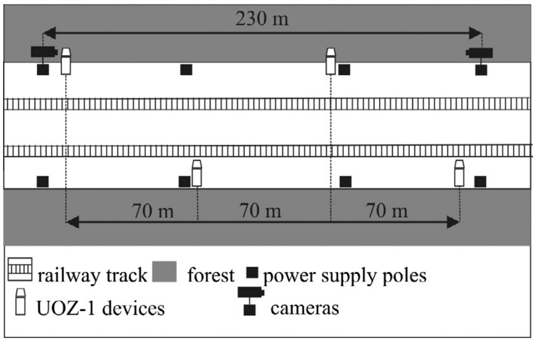

Fig. 3. Deployment of the array of digital cameras along the studied rail line.

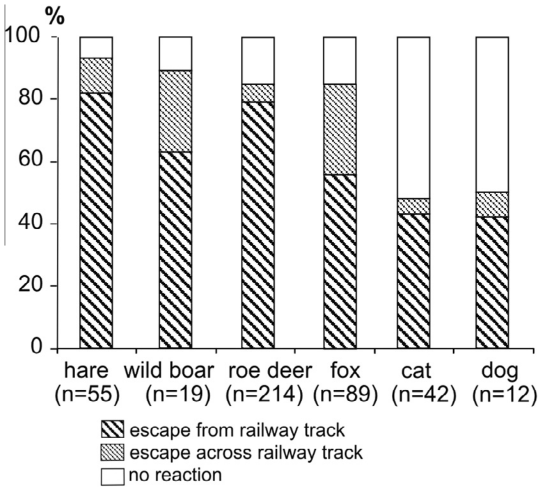

Fig. 4. Behaviour of the most frequently observed animal species along the studied sections of the E20 rail line with trains arriving following the warning signals from the UOZ-1 device in the years 2008–2012.

Most often we observed that wild mammals escaped from the tracks in the direction of the immediate vicinity (mostly into the forest). This explained approximately 80% of reactions in brown hares and roe deer, and between 63% and 56% of cases in wild boars and foxes, respectively. For dogs and cats, this figure was lower (approximately 40%). Less often, animals escaped across the track. This occurred more frequently in red foxes and wild boar (29% and 26%, respectively), whereas for other species, this figure was between 5% and 11%. Our data revealed only 3 cases in which moose were associated with an oncoming train. All these animals escaped, two away from the tracks and one across them. No response to the UOZ-1 device was most commonly noted in domestic pet species, i.e., dogs and cats (50–52%), whereas for wild species this was between 7% and 15% (Fig. 4).

Individuals of the commonest species – the roe deer – escaped on average 50 s (SD = 43.3, $n = 43$) after the device switched on and 35 s (SD = 38.3, $n = 47$) before the train arrived.

Next, we compared the number of reactions of roe deer to train arrival with sounds emitted from the UOZ-1 device ($n = 146$) and with the UOZ-1 device experimentally turned off ($n = 104$). When warning signals were emitted, we found that animals significantly responded (84% vs. 68%) to an approaching train by escaping (from the tracks or across the tracks). The proportion of cases in which roe deer showed no reaction to the arrival of a train was far lower when the UOZ-1 device was turned on compared to when it was switched off (16% vs. 32%) (chi square test, $\chi 2 = 9.9$, $df = 2$, $p < 0.01$) (Fig. 5).

The next comparison concerned the mean amount of time taken by roe deer to escape from an oncoming train, either when the warning device was in operation ($n = 47$) or when the devices had been switched off experimentally ($n = 63$). When the UOZ-1 device was turned on, animals reacted faster by more than 20 s (35 s vs. 9 s), ($W = 906.5$; $p < 0.001$; Mann–Whitney test).

To determine whether animals become accustomed to the warning signals emitted by the UOZ-1, we examined the proportions of different reactions of roe deer to the UOZ-1 sound signals in consecutive years (Fig. 6). The proportion of animals that did not react to acoustic signals was highest in the first and the last year (26% and 32% of cases, respectively), compared to 11–12% in the years 2009–2010. Roe deer escaped (from and across the railway track in total) in 88–89% of cases in the

Fig. 5. Comparison of the reactions of roe deer to an oncoming train when the UOZ-1 device was on (+) or off (−) (chi-square = 9.9, *df* = 2, $p < 0.01$). Sampling period was 33 and 19 months, respectively.

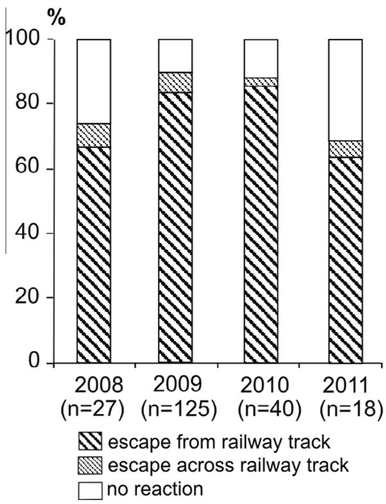

Fig. 6. Reactions to acoustic signals emitted by the UOZ-1 device observed most often in roe deer in successive years of the study (chi-square test, $\chi 2 = 8.16$, *df* = 3, $p < 0.05$, escape from and across the track combined).

years 2009 and 2010 and less often in the first year (74%) and the last (69%) (chi-square test, $\chi 2 = 8.16$, *df* = 3, $p < 0.05$, escape from and across the track were combined because of the low number of observations).

To check whether the reaction time changed over time, we compared times of escape of roe deer in advance of the arrival of a train when the UOZ-1 device was turned on (Table 1). In consecutive years, roe deer escaped 10–47 s before train arrival, the earliest in the first year and the latest in the second, but this difference was not statistically significant (one-way ANOVA, $F = 2.6$, $p > 0.05$).

Table 1
Comparison for consecutive years regarding the time of escape of roe deer in advance of train arrival with the UOZ-1 devices turned on.

Year	Escape time		
	n	Mean	SD
2008	26	47.2	44.1
2009	7	9.9	15.0
2010	9	20.0	25.6
2011	5	34.4	21.6
Sum/mean	47	35.1	38.3
One-way ANOVA	$F = 2.6$, $p > 0.05$		

Discussion

When railways or roads are modernised, solutions to safeguard against collisions with animals are sought. With fences, underpasses and overpasses need to be built to minimise habitat fragmentation. This makes this option often the most expensive (Glista et al., 2009), so it is only justifiably used for the routes most frequently used (Putman, 1997). An alternative is the deployment of devices (acoustic or optical) in which the task is to warn animals against approaching danger. For most mammal species, audible signals are of greater stimulatory significance than visual ones (e.g., Zieliński et al., 1991, 1995; Werka et al., 2004). In turn, either animals fail to react to artificial emitted sounds, or the effectiveness of the latter appears to be short lived (Woronecki, 1988; Curtis et al., 1995; Putman, 1997; Belant et al., 1998; Ujvári et al., 2004; Edgar et al., 2007). As Koehler et al. (1990) and Gilsdorf et al. (2002) have shown, animals should react to devices emitting natural sounds. This assumption was justified in practice (Kužir and Mužinić, 1998; Bender, 2005; Biedenweg et al., 2011).

The UOZ-1 device tested in this study used natural sounds, and in most cases animals such as moose, red deer, roe deer, wild boar, brown hares and foxes responded with an escape reaction to the sounds emitted from the UOZ-1. Animals usually escaped away from the tracks into the immediate vicinity (i.e., a forest where they could find a shelter). However, some animals also reacted by escaping across the rail tracks – a behaviour presumably associated with the presence of some type of known refuge area on the other side of the line.

With roe deer, the experimental deactivation of the UOZ-1 device confirmed a high level of effectiveness in reducing the risk of a collision, with the animals' speed of reaction to an oncoming train being three times greater with the device turned on and a higher frequency of escape reactions. It may be assumed that sounds from the UOZ-1 devices featured additional acoustic stimuli (other than vibration of the ground and increasing noise as a train approaches) acting shortly before a train arrives, serving as an additional factor warning animals of approaching danger earlier than the train itself. This is of particular importance where high-speed trains are involved.

The method tested here does not violate continuity of ecological corridors and migration routes. During the periods when trains are not passing, the UOZ-1 devices remain inactive, ensuring that animals can move freely down the tracks with no disturbance. Indeed, the sections of line fitted with the UOZ-1 had significantly more tracks left by mammals than did stretches of line without them as recorded through snow tracking (Jasińska et al., 2014). However, five years of observations showed that of 25 cases of wildlife–train collisions that occurred on the studied line, only one occurred near the UOZ-1 device when a red deer chased by dogs was killed as it ran across the path of an oncoming train (Wasilewski et al., 2009; Jasińska et al., 2014).

It is probable that the device under study is effective because it uses several different sounds issued naturally by a range of animal species, each carrying subtly different information capable of being "read" by individuals of both the emitter and other species (for a review, see Carrasco and Blumstein, 2012). For example, mammals (i.e., red squirrels) are known to react to warning calls of a jay (Randler, 2006). The noise made by a brown hare attacked by a predator acts as a warning signal for individuals of its own species, but likely may be interpreted in an identical, appropriate way by other mammals with whom it shares predators (Carrasco and Blumstein, 2012). In central Poland's mosaic of woods and fields, it is free-ranging dogs that occupy the carnivore niche, certainly influencing populations of roe deer or hares by active predation (Misiorowska and Wasilewski, 2012; Krauze-Gryz and Gryz, 2014), as well as smaller carnivores such as foxes in this or other ways (Krauze-Gryz et al., 2012), therefore dog barking can be expected to be a strong stimuli. However, some of the sounds emitted – notably the cry of a hare being attacked by a predator – can potentially draw carnivores (Okarma and Tomek, 2008). Predators seeking more accessible food (i.e., because of a higher population density of prey, Barrientos and Bolonio, 2009) or a form of a carrion are known to become victims of collisions with higher frequency (review in Little et al., 2002). In our study, analysis of video footage from the monitored stretches of rail line did not confirm cases of animals being drawn to the railway track. Because only one collision occurred in the immediate vicinity of the UOZ-1 devices (Jasińska et al., 2014) there was no carrion to attract carnivores. However, most foxes that were observed near rail tracks escaped when sounds from the UOZ-1 devices were emitted.

The remaining question concerns the possibility of animals becoming accustomed to the natural sounds that are emitted by the UOZ-1. Our findings over 5 years of study showed that roe deer reacted with similar escape frequency in the first and the last year of study, and the time with which they reacted did not change. By contrast, the results of work performed at permanent supplementary feeding stations frequented by roe deer, red deer and wild boar show that animals rapidly became habituated to emitted stimuli in the form of the same natural sounds that emitted by the UOZ-1 (Kowalczyk, unpublished results). This can be explained by the observation that the acoustic signals – initially interpreted as conveyed information regarding a direct threat to life and resulting in fear and escape from the area – are reacted to less and less over time when no threat actually materialises. This is not the case for the railway line where the natural sounds that are heard always give way to the trembling of the ground, noise and then the appearance of the speeding train. Any adaptation to a real emerging threat like this would be maladaptive and has not been observed to occur in practise. This is consistent with the results of various experiments involving artificial sounds to scare animals away, which confirms that the relative best results are obtained where the sounds are reinforced by the appearance of genuine danger (Bomford and O'Brien, 1990).

The results of our study is not directly comparable with other data. Thus far, most studies have focused on ways to keep animals away from roads by testing different types of stimuli. One of the few studies that did concern railway lines involved moose, in which the use of ultrasound-emitting whistles fitted to locomotives was tested. The results obtained suggested that these devices might be effective; however, further follow up studies were required (Muzzi and Bisset, 1990). Studies comparable with ours, that were performed along roads but involved visual stimuli, indicated a relatively high level of efficacy of the UOZ-1 device. D'Angelo et al. (2006) reported that white-tailed deer (*O. virginianus*) only showed a very limited reaction to light-based warning devices that were installed along roads (only between 1 and a maximum of 20% of individuals were observed to react predictably).

In summary, acoustic devices employing the natural warning calls of several species can be regarded as an effective way to reduce risk of animals being hit by trains: (1) they increased the frequency of an escape reaction, (2) animals reacted by escaping earlier before the train approaches, and (3) based on the current sampling period, animals did not become accustomed and habituated to the natural sounds that the UOZ-1 emits.

Acknowledgments

We would like to thank P. Lurz, M. Gryz, J. Gryz and three anonymous Reviewers for their valuable comments on the manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.trd.2015.04.021.

References

Andersen, R., Wiseth, B., Pedersen, P.H., Jaren, J., 1991. Moose–train collisions: effects of environmental conditions. Alces 27, 79–84.
Ando, Ch., 2003. The relationship between deer–train collisions and daily activity of the sika deer, *Cervus nippon*. Mammal Study 28, 135–143.
Barrientos, R., Bolonio, L., 2009. The presence of rabbits adjacent to roads increases polecat road mortality. Biodivers. Conserv. 18, 405–418.
Belant, J., Seamans, T., Tyson, L., 1998. Evaluation of electronic frightening devices as white-tailed deer deterrents. In: Baker, R.O., Crabb, A.C. (Eds.), Proceedings of the Eighteenth Vertebrate Pest Conference, 2–5 March 1998, Costa Mesa, California. University of California at Davis, Davis, CA, USA, pp. 107–110.
Bender, H., 2005. Effectiveness of the eastern grey kangaroo foot thump for deterring conspecifics. Wildlife Res. 32, 649–655.
Biedenweg, T.A., Parson, M.H., Fleming, P.A., Blumstein, D.T., 2011. Sounds scary? Lack of habituation following the presentation of novel sounds. PLOS ONE 6, <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0014549> (accessed 24.02.14).
Bomford, M., O'Brien, P.H., 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. Wildlife Soc. Bull. 18, 411–422.
Carrasco, M.F., Blumstein, D.T., 2012. Mule deer (*Odocoileus hemionus*) respond to yellow-bellied marmot (*Marmota flavivenstris*) alarm calls. Ethology 118, 243–250.
Child, K.N., Barry, S.P., Aitken, D.A., 1991. Moose mortality on highways and railways in British Columbia. Alces 27, 41–49.
Curtis, P.D., Fitzgerald, C., Richmond, M.E., 1995. Evaluation of the Yard Gard ultrasonic yard protector for repelling white-tailed deer. In: Eastern Wildlife Control Conferences, vol. 7, pp. 172–176.
D'Angelo, G.J., D'Angelo, J.G., Gallagher, C.R., Osborn, D.A., Miller, K.V., Warren, R.J., 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. Wildlife Soc. Bull. 34, 175–183.
Edgar, J.P., Appleby, R.G., Jones, D.N., 2007. Efficacy of an ultrasonic device as a deterrent to dingoes (*Canis lupus dingo*): a preliminary investigation. J. Ethol. 25, 209–213.
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, DC, USA.
Gilsdorf, J.M., Hygnstorm, S.E., VerCauteren, K.C., 2002. Use of frightening devices in wildlife damage management. Integr. Pest Manage. Rev. 7, 29–45.
Glista, D.J., DeVault, T.R., DeWoody, J.A., 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Lanscape Urban Plan. 91, 1–7.
Gundersen, H., Andreassen, H.P., Storaas, T., 1998. Spatial and temporal correlates to norvegian moose–train collisions. Alces 34, 385–394.
Jaren, V.R., Anderson, R., Ulleberg, M., Pederson, P., Wiseth, B., 1991. Moose–train collisions: the effects of vegetation removal with a cost-benefit analysis. Alces 27, 93–99.
Jasińska, K., Werka, J., Krauze-Gryz, D., Wasilewski, M., 2014. Urządzenia akustyczne UOZ-1 sposobem na ograniczenie kolizji z udziałem zwierząt na liniach kolejowych. Sylwan 158, 143–150 (in Polish).
Koehler, A.E., Marsh, R.E., Salmon, T.P., 1990. Frightening methods and devices/stimuli to prevent mammal damage – a review. In: Davis, L.R., Marsh, R.E. (Eds.), Proceedings of the Fourteenth Vertebrate Pest Conference, 6–8 March 1990, Costa Mesa, California. University of Kalifornia at Davis, Davis, CA, USA, pp. 168–173.
Kossak, S. 2007. Zasada działania atrapy bodźców kluczowych zastosowanej w urządzeniu UOZ-1 wypłaszającym zwierzęta z torów kolei szybkiego ruchu. In: Jackowiak, B. (Ed.), Oddziaływanie infrastruktury transportowej na przestrzeń przyrodniczą. Warszawa – Poznań – Lublin, Poland, pp. 173–187 (in Polish).
Krauze-Gryz, D., Gryz, J., 2014. Free-ranging domestic dogs (*Canis familiaris*) in Central Poland: density, penetration range and diet composition. Polish J. Ecol. 62, 183–192.
Krauze-Gryz, D., Gryz, J., Goszczyński, J., Chylarecki, P., Żmihorski, M., 2012. The Good, the Bad and the Ugly: space use and intraguild interactions among three opportunistic predators – cat *Felis catus*, dog *Canis familiaris* and fox *Vulpes vulpes* – under human pressure. Can. J. Zool. 90, 1402–1413.
Kušta, T., Ježek, M., Keken, Z., 2011. Mortality of large mammals on railway tracks. Sci. Agric. Bohem. 42, 12–18.
Kužir, S., Mužinić, J., 1998. Birds and air traffic safety on Zagreb airport (Croatia). Environmentalist 18, 231–237.
Little, S.J., Harcourt, R.G., Clevenger, A.P., 2002. Do wildlife passages act as prey-traps? Biol. Conserv. 107, 135–145.
Misiorowska, M., Wasilewski, M., 2012. Survival and causes of death among released brown hares (*Lepus europaeus* Pallas, 1778) in Central Poland. Acta Theriol. 57, 305–312.
Modafferi, R.D., 1991. Train moose-kill in Alaska: characteristics and relationship with snowpack depth and moose distribution in lower Sustina Valley. Alces 27, 193–207.
Muzzi, P.D., Bisset, A.R., 1990. Effectiveness of ultrasonic wildlife warning devices to reduce moose fatalities along railway corridors. Alces 26, 37–43.
Nadleśnictwo Mińsk Mazowiecki, 2014. Nadleśnictwo Mińsk Mazowiecki homepage. <http:// minsk.warszawa.lasy.gov.pl> (accessed 25.02.14).
Nadleśnictwo Siedlce, 2014. Nadleśnictwo Siedlce homepage. <http://Siedlce.warszawa.lay.gov.pl> (accessed 25.02.14).
Okarma, H., Tomek, A., 2008. Łowiectwo. Wydawnictwo Edukacyjno-Naukowe H2O. Kraków, Poland (in Polish).
Polskie Koleje Państwowe (PKP S.A.), 2014. PKP S.A. Homepage. <http://pkp.pl> (accessed 25.02.14).
Putman, R.J., 1997. Deer and road traffic accidents: options for management. J. Environ. Manage. 51, 43–57.

Randler, C., 2006. Red Squirrels (*Sciurus vulgaris*) Respond to Alarm Calls of Eurasian Jays (*Garrulus glandarius*). Ethology 112, 411–416.
Romin, L., Dalton, L., 1992. Lack of response by mule deer to wildlife warning whistles. Wildlife Soc. Bull. 20, 382–384.
Spellerberg, I.F., 2002. Ecological Effects of Roads. Science Publishers Inc, Enfield, NH, USA.
Steiner, W., Leisch, F., Hackländer, K., 2014. A review on temporal pattern of deer-vehicle accidents: Impact of seasonal, diurnal and lunar effects in cervids. Accid. Anal. Prevent. 66, 168–181.
Ujvári, M., Baagøe, J., Madsen, A.B., 2004. Effectiveness of acoustic road markings in reducing deer-vehicle collisions: a behavioral study. Wildlife Biol. 10, 155–159.
Wasilewski, M., Babińska-Werka, J., Nasiadka, P., 2009. Możliwość wykorzystania sygnałów dźwiękowych do odstraszania zwierząt od torów kolejowych. Studia Materiały Centrum Edukacji Przyrodniczo-Leśnej 2 (21), 97–104 (in Polish).
Werka, T., Walasek, G., Świrszcz, K., 2004. Effects of stimulus modality on the shuttle activity in rats. Behav. Brain Res. 151, 327–329.
Woronecki, P.P., 1988. Effect of ultrasonic, visual, and sonic devices on pigeon numbers in a vacant building. In: Crabb, A.C., Marsh, R.E. (Eds.), Proceedings of the Thirteenth Vertebrate Pest Conference, 1–3 March 1988, Costa Mesa, California. University of California at Davis, Davis, CA, USA, pp. 266–272.
Zieliński, K., Werka, T., Nikolaev, E., 1991. Intertrial responses of rats in two-way avoidance learning to visual and auditory stimuli. Acta Neurobiol. Exp. 51, 71–88.
Zieliński, K., Werka, T., Wilson, W.J., Nikolaev, E., 1995. Inhibition of delay of the two-way avoidance response and warning-signal salience. Animal Learn. Behav. 23 (4), 438–446.