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ORIGINAL PAPER

Spatio-temporal patterns of vertebrate roadkills in a suburban area in northern Japan

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Abstract

We investigated the roadkills of vertebrates in Ishinomaki City, northern Japan, for 1 full year (from April 2020 to March 2021), and attention was paid to (1) locations where the roadkill occurred, (2) the relationship between roadkill frequency and traffic volume, and (3) seasonality of roadkills and relationship with life events of target species. Over the study period, we recorded 1059 roadkill cases (2.9 records/day) from at least twenty-six vertebrates, among which three mammals (raccoon dog *Nyctereutes procyonoides*, domestic cat *Felis catus*, and sika deer *Cervus nippon*) accounted for more than 75% of the total cases. The locations where frequent roadkills occurred were species-specific as follows: suburban areas for raccoon dogs, within urban areas for cats, and forests, especially peninsula areas, for deer. Roadkill frequency (per kilometer) for raccoon dogs and cats showed a positive correlation with traffic volume, indicating that the prevention of animals from crossing roads would be an effective strategy of mitigating roadkills of these animals. Roadkills of raccoon dogs occurred frequently during fall (September–October), a season that corresponds to their dispersal period. Such seasonality was not found for roadkills of cats (probably due to altered life as pets) and deer (attributed to low seasonal changes in home range utilization). We suggest that management strategies can be adopted to mitigate roadkills from the viewpoint of the behavioral characteristics of target mammals.

Keywords Domestic cat · Ishinomaki · Raccoon dog · Satoyama · Sika deer

Introduction

With the development of road networks, the fragmentation of forests has coincided with road construction (Freitas et al. 2010; Liu et al. 2019), and animal mortality on roads caused by vehicles (roadkill) has become a severe problem worldwide (Canova and Balestrieri 2019; Kreling et al. 2019). Roadkill decreases the population size of animals (Grilo et al. 2021) and causes significant damage to vehicles, drivers, and passengers, in addition to considerable economic impact (Lester 2015; Ascensão et al. 2021; Shinoda et al. 2022). To plan for roadkill mitigation, it is necessary to quantitatively evaluate the spatio-temporal pattern of the occurrence. Information on roadkill in Japan has accumulated over the past 2 decades (e.g., Saeki and Macdonald 2004; Osaka and Okamura 2012; Tatewaki and Koike 2016), and recent studies have attempted to evaluate the environmental characteristics of locations where roadkills occurred (Nishio et al. 2013; Miyamoto et al. 2021). Previous studies, however, have analyzed roadkill data obtained from limited type of roads (e.g., expressway and national highway), and few have examined spatio-temporal pattern in roadkills occurred citywide.

We addressed the issue of spatio-temporal distribution of road accidents involving animals taking advantage of large data set collected systematically by various authorities of Ishinomaki City, Miyagi Prefecture, Japan. There are an expressway, national highways, prefectural roads, and municipal roads in the city, and the total length of roads is 2404.5 km (Miyagi Prefecture 2022b). Construction and repair of roads have been carried out at a very fast pace as reconstruction projects after the Great East Japan Earthquake (occurred in March 2011), and the traffic volume of the city (especially expressways) has increased in recent

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decades (Ministry of Land, Infrastructure, Transport, and Tourism of Japan 2022). Although Ishinomaki City has rich forests and diverse wildlife habitats (Furukawa et al. 2022), the recent increase in traffic can have a negative impact on wildlife. Since the national ministry and prefecture have branches in Ishinomaki City, we can easily collect information on roadkills collected by various agencies at the same time.

In this study, we address the present situation of vertebrate roadkills in Ishinomaki City by paying special attention to (1) location of roadkills, (2) relationship between roadkills and traffic volume, and (3) seasonality of roadkills. Specifically, we evaluated the following three predictions:

(1) Roadkill frequency is higher in urban area.
(2) Roadkill frequency is proportional to traffic volume.
(3) The frequency of roadkills is related to the life events of animals (such as dispersal).

Materials and methods

Study site

Ishinomaki City (N 38°26′, E141°18′) is the second largest city in Miyagi prefecture, and its population in 2022 is ca. 140,000 (Ishinomaki City 2022) (Fig. 1). The city extends near the estuary of the Kitakami River. The eastern part of the city and Oshika Peninsula are located at the southernmost tip of the Kitakami Mountains and have ria coasts. The mean temperature and annual rainfall of the city during the study period (April 2020–March 2021) were 15.9 °C (range: 12.0–20.5 °C) and 1294 mm, respectively (Japan Meteorological Agency 2022), which were similar to those of an average year. The roads included an expressway (Sanriku expressway, length within the city: 20.7 km), national highways (three routes, total length: 79.2 km), prefectural roads (30 routes, total length: 247.9 km), and many municipal roads (total length: 2056.7 km) (Miyagi Prefecture 2022b) (Fig. 1). There are several roadkill mitigation measures, such as setting guard rails and wildlife warning reflectors (Miyagi Prefecture 2022a, b), but their effectiveness has not been examined.

Gathering information on roadkill

In this study, we defined wildlife mortality on the road caused by contact with automobiles as "roadkills." Roadkill information was available at nine offices of traffic agencies that manage roads within the city: Sanriku Expressway Maintenance Branch Office, Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, and Sendai River National Highway Office for Sanriku expressway; Ishinomaki National Highway Maintenance Branch Office for national highways; Eastern Miyagi Prefecture Civil Engineering Office for prefectural roads; Ishinomaki City Living Environment Department Waste Management Division; and five branch offices (Monou, Kanan, Kahoku, Oshika, and Kitakami) for municipal roads. Staff of each office retrieve animal carcasses during road

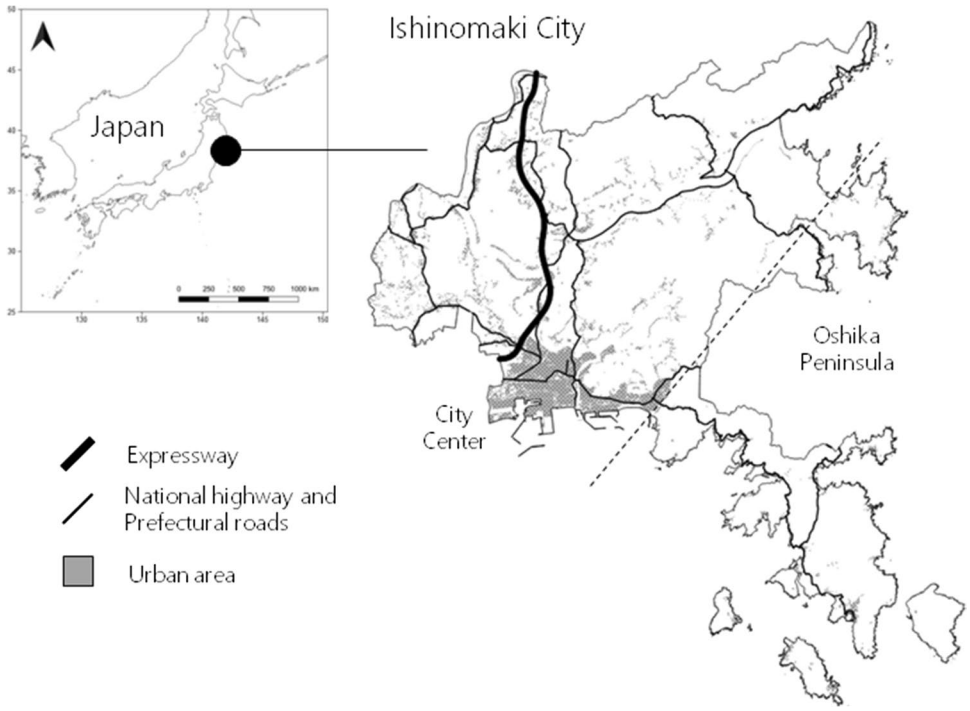

Fig. 1 Map of Ishinomaki City, northern Japan. Gray part represents urban area, tick lines represent expressway, and thin lines represent national highway and prefectural roads. Municipal roads are not displayed owing to their enormous number. The area south of a dotted line is regarded as the Oshika Peninsula

patrol and when receiving a report from residents, and they record the location and animal species they removed. We contacted each office once every 3 months and collected information on the roadkills. We could not obtain roadkill information on municipal roads in one branch (Ogatsu) because the branch did not collect carcasses.

From the collected information, we extracted the following data: (1) date when carcasses were collected, (2) route ID in which roadkill occurred (except for municipal roads), (3) location where the roadkill occurred, and (4) animal species.

Traffic volume

Information on the traffic volume (# cars/day) of each route passing through Ishinomaki City, except for municipal roads, was extracted by referring to the traffic reports shown by the Ministry of Land, Infrastructure, Transport and Tourism of Japan (2015). In the report, traffic volume survey in each route was conducted by dividing the route into several sections (range: 1–21); hence, we averaged them without considering difference in number of lanes and speed limits. Information on the traffic volume of the municipal roads was not available in Ishinomaki City, and we alternately used the value obtained from Tsuruoka City, Yamagata Prefecture (next to Miyagi Prefecture) (Yamagata Prefecture 2016) whose population (as of 2022: 121,000) was similar to that of Ishinomaki City.

Data analyses

For each species, we counted the number of the roadkills inside/outside the city center (Fig. 1) to assess spatial patterns in the roadkills. To address the relationship between traffic volume and roadkill (# roadkills per kilometer), we conducted Spearman's rank correlation tests between the number of roadkills in each route during the study period and the traffic volume of the given route. In the analyses, we did not include a route with no roadkill. To assess seasonality (monthly basis) in the frequency of roadkill, we conducted chi-square goodness-of-fit tests for target animal species and compared the actual and expected values (total number of roadkills over the study period/12). For post hoc tests, we conducted chi-square tests with Bonferroni's adjustment. In this study, we conducted statistical analyses using R ver. 4.0.0. (R Development Core Team, 2020). The level of significance (α) was set at 0.05.

Results

During the study period (April 2020–March 2021), we collected 1059 roadkill records (2.9 records/day) of at least twenty-six vertebrates (mammals, birds, and reptiles) in Ishinomaki City (Table 1). Among them, three mammals, raccoon dog *Nyctereutes procyonoides* (351 records, 1.0 records/day), domestic cats *Felis catus* (345 records, 0.9 records/day), and sika deer *Cervus nippon* (104 records, 0.3 records/day), were dominant: three species accounted for > 75% of the roadkill cases. Therefore, we performed the analyses only for these three species.

Roadkills occurred widely in the city but were distributed mainly in the western part (Fig. 2a). We visually found species-specific patterns in locations. The raccoon dog roadkills frequently occurred in suburban areas, especially along the Sanriku expressway ($n = 88$) (Fig. 2b). In contrast, the majority of the cat roadkills occurred in the city center ($n = 267$) (Fig. 2c). Finally, deer roadkills occurred mainly on the Oshika Peninsula ($n = 52$) and did not occur in the city center (Fig. 2d).

We found significant positive correlations between the traffic volume and number of roadkills per kilometer for raccoon dogs (Spearman's rank correlation test, $r_s = 0.62$, $df = 21$, $p < 0.001$) and domestic cats ($r_s = 0.54$, $df = 15$, $p = 0.025$). We found no such relationship for sika deer ($r_s = 0.19$, $df = 9$, $p = 0.582$) (Fig. 3).

A significant monthly difference in the number of roadkill was found in raccoon dogs, and the roadkills occurred frequently in September and October (chi-square test, $\chi^2 = 36.6$, $df = 11$, $p < 0.001$). Post hoc tests showed that the roadkill frequency in October was significantly greater than that in June, July, August, and January (Fig. 4a). There was no significant monthly difference in the number of the cat roadkills ($\chi^2 = 16.1$, $df = 11$, $p = 0.137$) and the deer roadkills ($\chi^2 = 11.1$, $df = 11$, $p = 0.436$) (Fig. 4b, c).

Discussion

Among twenty-six vertebrate species, majority of roadkills consisted of only three mammalian species: raccoon dogs (351 out of 1059 cases), domestic cats (345 cases), and sika deer (104 cases). A higher frequency of raccoon dog roadkills has been reported also in other sites (Tatewaki and Koike 2018; Jingu et al. 2019; Kondo 2019). The higher frequency of raccoon dog roadkills could be attributed to their unique behavioral traits: they often freeze when surprised, making them vulnerable to road accidents (Saeki 2022).

Majority of the raccoon dog roadkills occurred in suburban areas, especially along the Sanriku expressway (88 out of 351 cases). Raccoon dogs prefer landscapes between mountain foothills and arable flat lands, called Satoyama, and their density there is high (Tatewaki and Koike 2018). The Sanriku expressway was developed to pass through Satoyama, and raccoon dogs along the expressway might not have been habituated to the recent environmental alterations. Another possibility is the attractiveness of

Table 1. List of roadkilled animals collected in Ishinomaki City, northern Japan, during the study period (April 2020 to March 2021)

Species	Family	Common name	No. of Roadkills
Mammals			
Nyctereutes procyonoides	Canidae	Raccoon dog	351
Vulpes vulpes		Red fox	23
Canis lupus familiaris		Domestic dog	7
Mustela itatsi	Mustelidae	Japanese weasel	10
Meles anakuma		Japanese badger	8
Martes melampus		Japanese marten	2
Felis catus	Felidae	Domestic cat	345
Paguma larvata	Viverridae	Masked palm civet	36
Cervus nippon	Cervidae	Sika deer	104
Sus scrofa	Suidae	Wild boar	2
Lepus brachyurus	Leporidae	Japanese hare	8
Muridae sp.	Muridae	Murid	2
Sciurus lis	Sciuridae	Japanese squirrel	1
Others			8
Subtotal			907
Aves			
Anas spp.	Anatidae	Duck	32
Cygnus sp.		Swan	1
Larus spp.	Laridae	Gull	2
Corvus spp.	Corvidae	Crow	34
Phasianus versicolor	Phasianidae	Japanese pheasant	8
Ardeidae spp.	Ardeidae	Heron	9
Passer montanus	Passeridae	Tree sparrow	1
Motachilla sp.	Motacillidae	Wagtail	1
Hirundo rustica	Hirundinidae	Barn swallow	1
Milvus migrans	Accipitridae	Black kite	22
Strix uralensis	Strigidae	Ural owl	3
Streptopelia orientalis	Columbidae	Eastern turtle dove	11
Raptors			4
Others			20
Subtotal			149
Reptiles			
		Turtle	3
Total			1059

the road as a feeding place because the roadside contains food resources (e.g., small animals and shrub fruits) (Planillo et al. 2018). Roadkilled animals also might attract raccoon dogs. On the contrary, the cat roadkills occurred frequently at urban area (on municipal roads) (267 out of 345 cases). Cats are housed as pets or cared for by the local community as feral ones in urban areas. Thus, compared to wild mammals, cats seem to cross the roads more frequently (Saeki and Macdonald 2004). Finally, the deer roadkills were concentrated in the Oshika Peninsula (52 out of 104 cases). This is simply related to the present distribution of sika deer in Miyagi Prefecture: deer population in Oshika Peninsula has increased to 24.3 individuals/km^2 in 2022, and crop/forest damage caused by deer has become more severe (Miyagi Prefecture 2022a). Deer often search for food at roadsides and sometimes jump into roads to cross, leading to roadkills. In summary, our first prediction: roadkill frequency is higher in urban area, was partly supported.

The frequency of raccoon dogs and cat roadkills showed positive correlations with its traffic volume. This implied that the risk of being roadkill is much greater in higher traffic volume (e.g., Sanriku expressway and national highway). On the contrary, we found no significant correlation between deer roadkills and traffic volume, probably owing to the small number of prefectural roads that passed through the Oshika Peninsula, and there are few opportunities for deer to go to major national highways. In summary, our second

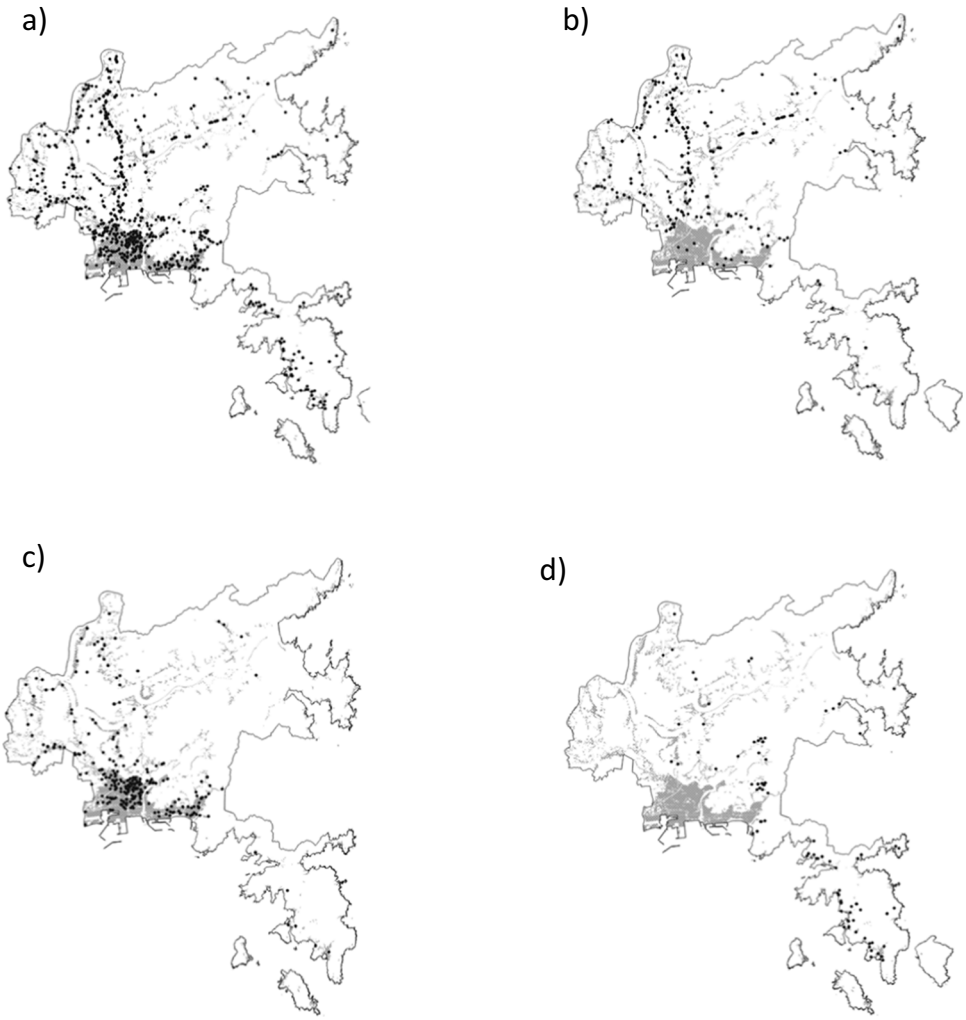

Fig. 2 Locations of roadkill occurrence of **a** all animal species, **b** raccoon dogs, **c** domestic cats, and **d** sika deer. Each point represents a roadkill case. Gray part represents urban area

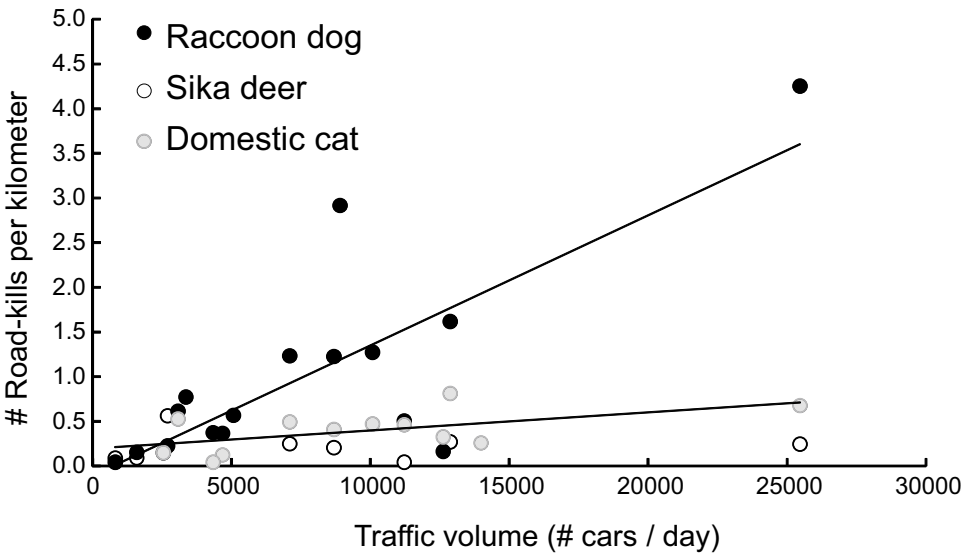

Fig. 3 Relationships between traffic volume (cars/day) and number of roadkills per kilometer. Each point represents one route. Black circle, raccoon dogs; gray circle, domestic cats; white circle, sika deer

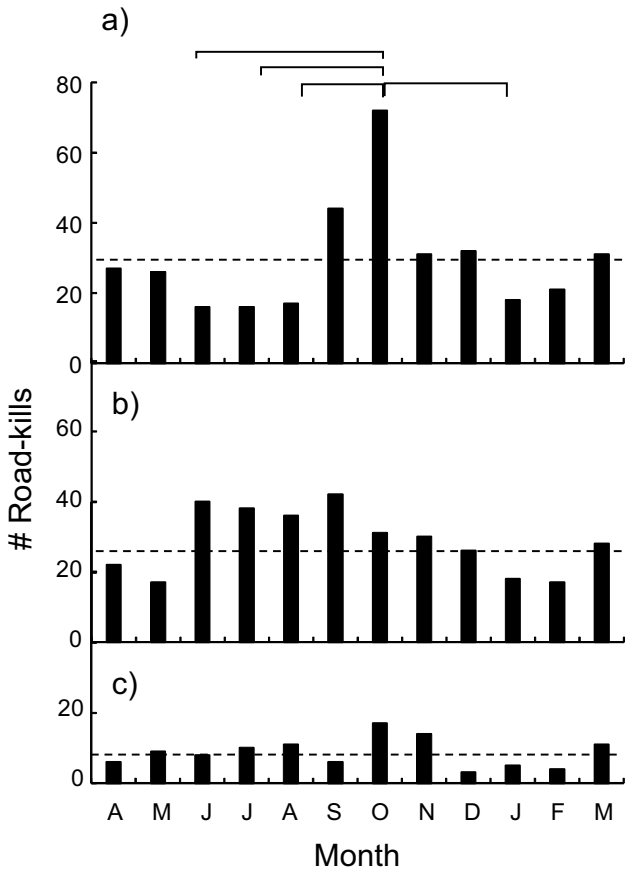

Fig. 4 Monthly change in the roadkill cases of **a** raccoon dogs, **b** domestic cats, and **c** sika deer. Dashed lines represent annual mean. Month combined by bars represent significant differences (Bonferroni's adjustment, $p < 0.05/{}_{10}C_2$ (0.0011)) between given combinations

prediction: roadkill frequency is proportional to traffic volume, was partly supported.

The raccoon dog roadkills in Ishinomaki occurred frequently during fall (September and October), and a similar trend has been reported for other sites (Noguchi and Kaneko, 2012; Kondo, 2019). Fall corresponds to the dispersal season for juvenile raccoon dogs (Ikeda 1983): in other study sites, less-experienced juveniles who are searching for new habitats became victim of roadkills (Kinoshita and Yamamoto 1996; Saeki et al. 2007). Contrary to our prediction, we found no monthly changes in the occurrence of cat roadkills. The likely reason for the lack of the seasonality for the cats is their healthy nutritional condition: they receive sufficient amount of highly nutritious and easily digestible foods every day. Therefore, compared to wild mammals, the locations of feeding sites, home range area, and activity budgets of cats would be stable, regardless of the season (MacDonald et al. 1984; Plantinga et al. 2011; Kays et al. 2020). Deer roadkills also occurred all year-round. This would be attributed to their high population density: in habitats with higher deer density, owing to seasonal food shortages (such as herbs and shrubs), deer move to peripheral parts (Kaji and Iijima 2017), including roadsides, to search for food, and thus suffer accidents. In summary, our third prediction: the frequency of roadkills is related to the life events of animals, was partly supported.

For the raccoon dogs and cats, setting guard rails, fences, and nets to prevent animals for entering roads, especially in routes with higher traffic volume, is effective roadkill mitigation (Rytwinski et al. 2016). In the case of the raccoon dogs, their roadkill might be related to their life history (i.e., dispersal of juveniles in fall). Prevention campaigns against the roadkill during fall, therefore, could be considered. To mitigate the cat roadkills in urban area, physically or psychologically slowing traffic (e.g., speed bumps) also might be effective (Magnus et al. 2004).

Deer roadkill, which can sometimes lead to personal injury and vehicle damage, is a severe problem in the Oshika Peninsula (Miyagi Prefecture, 2022a). Thus, roadkill mitigation should be prioritized in the peninsula area. Awareness-raising activities, such as setting up of wildlife warning reflectors and calling for slow driving near curves with poor visibility, are necessary (Rytwinski et al. 2016). Setting fences and escape ramps that can be used for deer when they get trapped on the road would be another option. For short-term roadkill mitigation, mowing of grass along roads would be effective. A recent study, however, mentioned that frequent mowing increases roadkill of small animals (such as insects), likely due to food environment round the road (e.g., Skórka et al. 2015). A decision to mow must take into account these factors. Finally, deer population management (Miyagi Prefecture 2022a) should be continued as a long-term roadkill mitigation measure.

In this study, we described the present situation of roadkills in Ishinomaki City and addressed the spatio-temporal patterns of roadkills for three mammals. Subsequently, we need to develop an efficient management plan to mitigate roadkills while maintaining transportation and logistics through traffic. We found that the locations of roadkills varied among animal species. Therefore, to reduce roadkills, it is necessary to conduct area-specific roadkill mitigation measures, e.g., installing the warning sites, fences, or green bridges. Moreover, raising the local people's awareness concerning the yearly number of road accidents involving animals may further help in reducing roadkills. Our results will contribute to better understanding the causality of roadkills and the effectiveness of mitigation measures.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analyses were performed by Yumeko Takahashi and Fuma Suzuki. The first draft of the manuscript was written by Yamato Tsuji and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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