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Relationship between spatial distribution of sika deer–train collisions and sika deer movement in Japan

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Abstract: Collisions between trains and sika deer (*Cervus nippon*) cause various problems involving animal and humans safety, as well as economic cost. A better understanding of deer crossing railway lines and deer–train accidents is necessary to develop effective mitigation measures. We investigated the collisions among habitat selection, railway-line crossing movement, and deer–train collisions. We predicted that the risk of deer–train collisions would increase with increasing probability of deer crossing railway lines, which is related to habitat selection surrounding in those areas. Deer stayed in forests to rest during the day and moved to grasslands or rice paddy fields to forage at night. Deer made exploratory crossings of rail lines and returned to the main side in a short time. The probability of crossing had negative effects on the risk of deer–train collisions because of trains' high visibility to deer. The risk of deer–train accidents increased with increasing forest cover, indicating that deer density might be the main factor causing deer–train collisions. Our study suggests that integrated studies on deer habitat selection, movement, and deer–train collisions are useful for wildlife management and transportation agencies to plan mitigation measures. The reduction of deer density within high-accident risk areas will reduce collisions.

Key words: *Cervus nippon*, deer–train collisions, habitat selection, human–wildlife conflict, Japan, movements, railway line crossings, sika deer, spatial distribution

Expanding deer distribution, increasing deer population, and the development of transportation infrastructure has led to an increased number of deer–vehicle collisions and has become a serious social issue in many countries, especially in Europe and North America (Bruinderink and Hazebroek 1996, Romin and Bissonette 1996). Deer–vehicle collisions have caused various problems, including animal and human death (Forman et al. 2003, Langbein et al. 2011) and economic loss (Putman 1997). In a census of European countries, excluding Russia, the estimated annual number of wild ungulate-related traffic accident was 507,000. These collisions resulted in 300 human deaths, 30,000 human injuries, and material damage of $1 billion (Bruinderink and Hazebroek 1996). In the United States, the annual number of deer–vehicle collisions increased from 200,000 in 1980 to 500,000 in 1991 (Romin and Bissonette 1996). In Japan, the sika deer (*Cervus nippon*; Figure 1) distribution has expanded by approximately 70% during the last 25 years (Biodiversity Center of Japan 2004), and sika deer–vehicle collisions are a serious social problem (Ohtaishi et al. 1998). In Hokkaido, the annual number of Yezo deer (*Cervus nippon yesoensis*)–vehicle collisions was 1,818 in 2013 (Hokkaido Prefecture 2014), and the amount paid by motor vehicle insurance companies reached about $3 million in 2014 (General Insurance Association of Japan 2015).

To develop effective mitigation measures for reducing deer–vehicle collisions, it is first necessary to identify the factors involved in their occurrence (Malo et al. 2004; Seiler 2004, 2005). The spatial distributions of deer–vehicle collisions are not random but are spatially clustered because significant region-specific factors exist (Joyce and Mahoney

2001, Dussault et al. 2006, Danks and Porter 2010). Once the regional factors are revealed, it should be possible to identify high-risk areas and propose measures to improve traffic safety (Putman 1997).

Deer population density is one of several factors known to be related to the occurrence of deer–vehicle collisions (Joyce and Mahoney 2001, Seiler 2004, 2005, Dussault et al. 2006). Driver visibility along a highway is also related to the occurrence of white-tailed deer (*Odecoileus virginianus*)–vehicle colliaions (Bashore et al. 1985). In addition, the risk of deer accidents is related to habitat, such as the amount of forest surrounding roads and the proximity of the road to the forest edge (Bashore et al. 1985, Finder et al. 1999, Malo et al. 2004, Seiler 2005) and grassland (Hubbard et al. 2000, Seiler 2005). Species-specific resources also are associated with the risk of deer–vehicle collisions; for example, in Canada, moose (*Alces alces*)–vehicle collisions frequently occurred in areas where at least 1 brackish pool of water was present; such pools are attractive to animals as natural mineral licks (Dussault et al. 2006). These habitat-related factors may be the cause of animal movement and may influence the incidents of deer–vehicle collisions.

Figure 1. Sika deer (*Cervus nippon)* with collar.

Combining animal movement data with animal accident data is useful to evaluate accident risk in given areas (Neumann et al. 2012). Animal movement data is useful to identify and predict animal crossing sites and to help establish strategies to encourage and maintain deer population connectivity and to reduce accidents (Lewis et al. 2011). Deer likely cross roads to seek access to resources, such as pastures and highly concentrated sources of sodium (Dussault et al. 2006, Gagnon et al. 2007, Meisingset et al. 2013). Information on habitat selection by target animals is necessary to assess the relationship of animal-crossings and traffic collisions and to implement appropriate mitigation measures. To date, however, no study has simultaneously analyzed the relationships between habitat selection, crossing movement in relation to habitat features, and traffic accident sites.

The Kisei Main Line in Mie Prefecture of western Japan is one of the most frequent deer accident areas in Japan. The sika deer population density in Mie Prefecture has increased steadily from

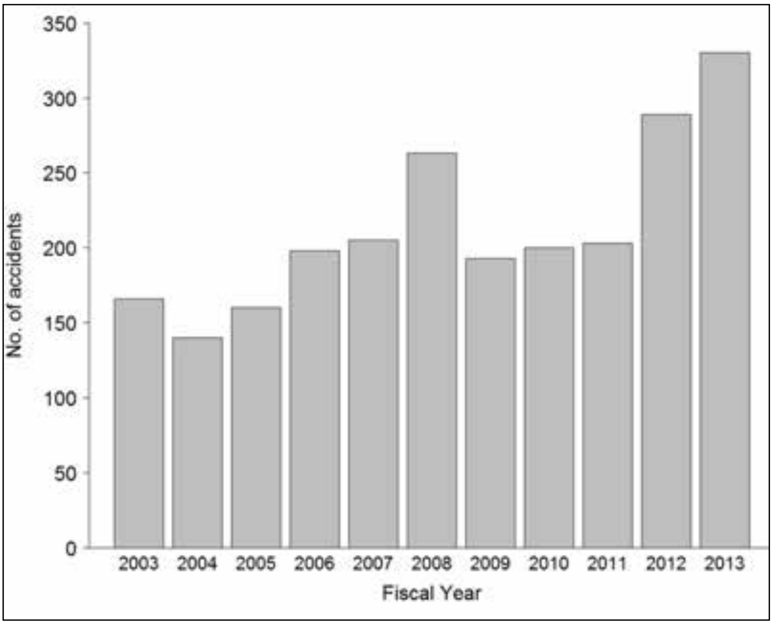

Figure 2. Annual number of sika deer–train accidents along the Kisei Main Line in Mie Prefecture from 2003 to 2013. The fiscal year begins in April and ends the following March.

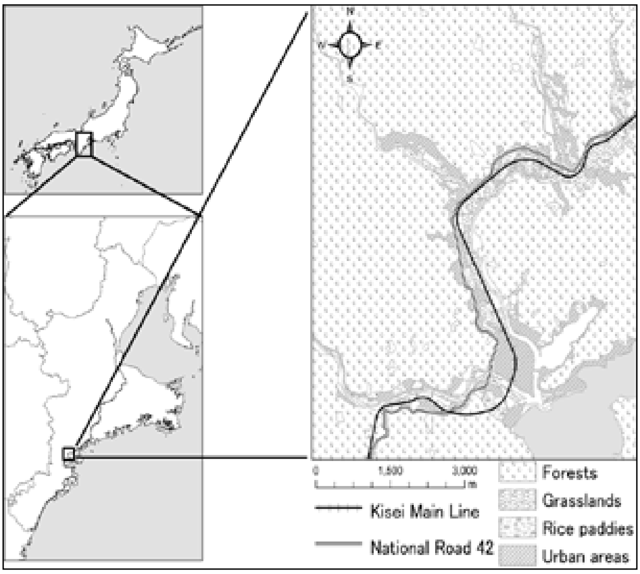

Figure 3. Map of the Funatsu study site situated in parts of Mie Prefecture, central Japan.

about 2003 (Mie Prefecture 2012). The number of harvested deer, which can be an indication of deer population density, increased from 6,289 in 2003 to 15,393 in 2010 (Mysterud et al. 2002, Seiler 2004). The number of deer–train collisions in the Kisei Main Line (180 km) has increased from 166 in 2003 to 330 in 2013 (Figure 2), making it a significant problem for railway line managers. A better understanding of the factors leading to deer railway crossing movement and deer–train accidents is necessary for managers to develop effective mitigation measures and reduce the risk of accidents.

We investigated the relationships among deer habitat selection, railway crossing movement, and accidents, using both global positioning system (GPS) location data from female sika deer and sika deer–train collision data along the Kisei Main Line. Our purpose was to determine whether deer crossed railways in preferred areas and whether deer–train collisions occurred in the areas where deer were likely to cross railway lines. We predicted that deer–train collision risk would increase with increasing railway crossing probability in relation to habitat selection in areas surrounding railway lines.

Study area

We selected the Funatsu area (Kihoku district; 34°8' N, 136°13' E; Figure 3) in Mie Prefecture, western Japan, as the study area because there are frequent deer–train collisions along the Kisei Main Line. From April 2003 to March 2014, average monthly temperatures ranged from 4.5° C in January to 28.4° C in August. The annual precipitation ranged from 2.6 m to 5.3 m, and maximum snow depth throughout winter was about 5 cm during the study period. Dominant forest stands include plantations of Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtusa*) in the Funatsu area. Trains pass 1 to 3 times per hour between 0500 and 2200 hours in this area. The Funatsu area is located between Funatsu and Aiga stations (about 4.3 km), and the number of accidents per year was 12.6 (5.2% of the total collisions). Japan National Route 42 runs parallel to the west of the railway line. The habitat approximately 1 km from the center of the railway line is mostly comprised of forests (60%), the rice paddy fields, grasslands; the percentage of urban areas concentrated near the railway line is small.

Methods

Data collection

To study habitat selection and movement of sika deer, we captured 3 adult females and equipped them with GPS-collars (Tellus5H1D; Followit, Sweden) in Funatsu. The average location errors of the Tellus5H1D were 3.98 m (Takeda, unpublished data). The GPS collars were programmed to record a location at 1-hour intervals, and during an intensive fixed sampling time, which was the first 5 days of every month, they were programmed to record a location at 15-minute intervals from 1700 to 0700 hours. We collected location data from November 23, 2008, to June 28, 2009. Locations obtained during the first 24 hours after marking were deleted to exclude the effects of capture on deer movement. Among GPS fix locations from 3 deer, we used only recorded data that were 3-dimensional (3D) fixes to increase location accuracy.

We derived habitat data from digital vegetation maps with a scale of 1:25,000 (Ministry of the Environment of Japan (<http://

www.vegetation.biodic.go.jp/index.html>). We classified the vegetation maps into 7 habitat types: forests, grasslands, paddy fields, urban areas, water (rivers and streams), farms, and others.

We accessed deer–train collision data along the Kisei Main Line collected by the Central Japan Railway Company for April 2003 to March 2014. Train drivers are required to record information related to deer–train accidents, such as date, time, and location of the accident. We used Arc GIS 10.0 (ESRI, Redlands, Calif.) for processing spatial data.

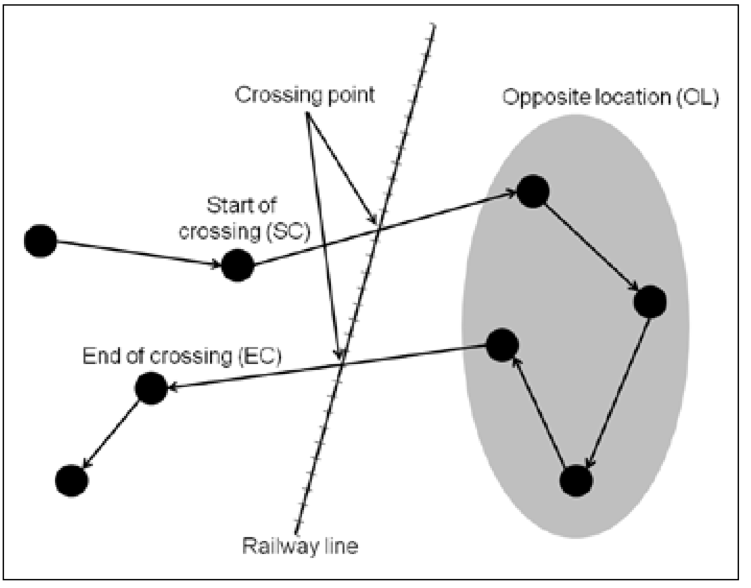

Figure 4. Example of sika deer locations (●) in a series of a railway line crossing. We connected successive locations with a straight line and assumed the crossing point to be at the intersection between the connected location lines and the railway line. We classified the locations of a series of railway line crossings: start of crossing (SC), opposite locations (OL), and end of crossing (EC).

Statistical analysis

Habitat selection. We assessed habitat selection of GPS-marked deer by estimating selection ratios for each individual (Manly et al. 2002). The use and availability of resource units were measured separately for each deer. The selection ratio (w_i) was calculated as the proportion of the GPS-fixed locations of habitat type divided by the proportion of available habitat type within the home range. When deer used habitat types (i) in proportion to their abundance, they preferred habitat type i when $w_i > 1$, and they avoid habitat type i when $w_i < 1$. We calculated the standard errors of selection ratios with the 95% confidence intervals and determined when selection ratios were significantly different from 1.0 (Manly et al. 2002).

Deer commonly changed habitat use according to light conditions, using open habitat, such as pastures at night and closed habitat during the day (Beier and McCullough 1990, Godvik et al. 2009). We grouped GPS-fixed location data depending on a light condition (day or night). Light conditions were categorized based on the daily time of sunrise and sunset for the study area from the National Astronomical Observatory of Japan (<www.nao.ac.jp>). For each deer, we estimated the availability of resource units by calculating the proportion of 7 habitat types within a 100% minimum convex polygon for day and night home ranges. For habitat selection analyses, we used only 1-hour interval GPS location data. In preliminary analyses, we tested the seasonal changes in movements and habitat selection, and we found no seasonal changes; thus, we pooled these data for analysis.

Railway crossing. We used all deer-location data, including the intensive fixed-time data to obtain precise railway crossing points. For defining a deer railway crossing, we connected successive locations with straight lines and assumed that the railway crossings occurred where these lines intersected the railway line (Figure 4). To determine the motivation for deer to cross railway lines, we classified the locations of a series of railway line crossings as start of crossing (SC), opposite locations (OL), and end of crossing (EC), and extracted 7 habitat types in each location (Figure 4).

We defined the crossing points of the railway line as sites where deer step-lines intersected a railway line (Meisingset et al. 2013). To increase the precision of crossing-point estimates, we deleted all crossing points between GPS locations with a sampling interval that was >120 minutes and where connecting positions before and after crossing were >1,000 m apart (Meisingset et al. 2013). Deer cross narrow roads of relatively low traffic volume during routine daily movements within an established home range (Langbein et al. 2011). We assumed that deer in this study also cross the railway line in a similar manner. Therefore, to clearly define the habitat characteristics of the deer-crossing points, we selected a suitable-sized circular buffer area. We calculated the daily home range from the GPS-marked deer in Funatsu. We found that the mean size of their daily home range was 0.2 ± 0.26 (±SD) km^2. We then selected a 250-m circular buffer area for the analyses of deer-crossing points and deer–train collision points, because it is the approximate value for the radius of a circle for a mean daily home range of 0.2 km^2. We generated an equivalent number of random points as the number of crossing points along a railway line within home range, and set a 250-m circular buffer around each random point. We calculated the proportions of habitat types within the circular buffer areas and the distance to the nearest habitat types from each point.

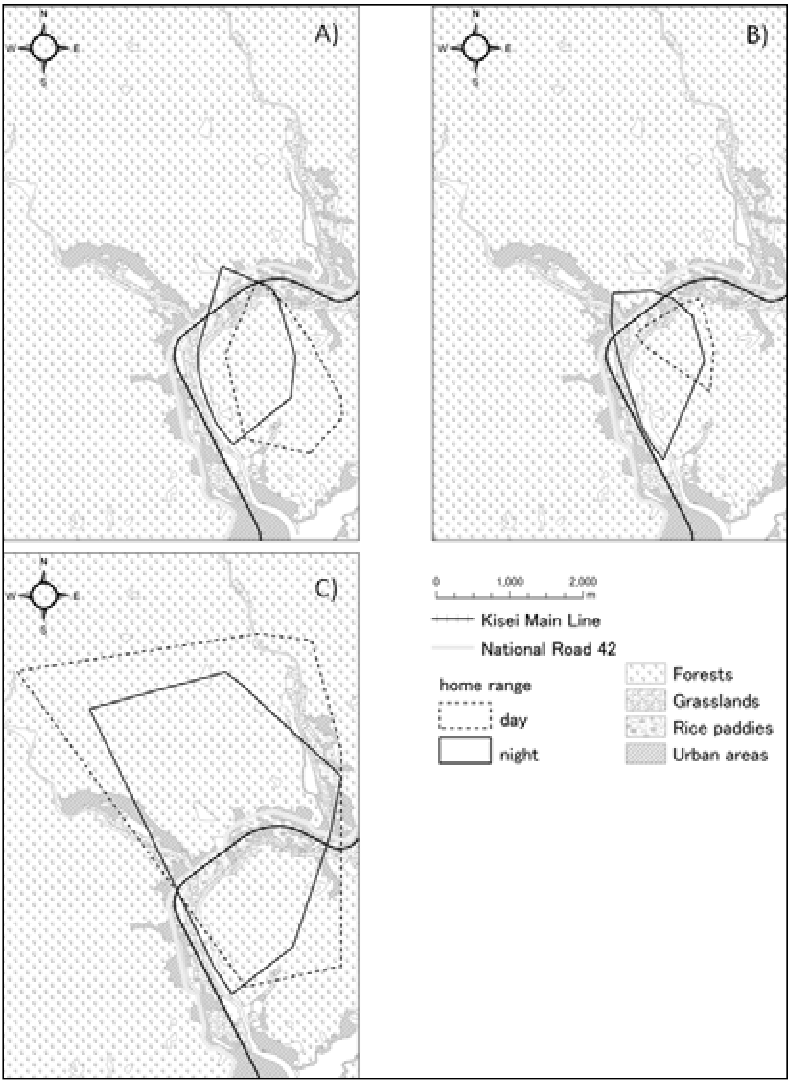

Figure 5. The home ranges in different light conditions (day or night) for 3 GPS-marked deer in Funatsu, Mie Prefecture: (A) FA3, (B) FA4, and (C) FA5.

To identify the relationships between crossing points and environmental variables around the railway line, we used a logistic regression model, which has been generally used in the analysis of the relationships between ungulate road crossing movements and environments surrounding roads (Gagnon et al. 2007; Dussault et al. 2007; Meisingset et al. 2013, 2014). Deer crossing points and random points were used as response variables and the proportions of forests, grasslands, and paddy fields, the distance to forests, grasslands, and paddy fields from each point, the squared value of the proportion of grasslands, and the shape of railway line (curved or straight) were used as predictor variables. Arcsine-transformed habitat type proportions were used to compensate for skewed distributions (Zar 1999). We tested for correlations among the predictor variables, and eliminated the proportion of forests because it was highly correlated with the distance to forests. To select the most parsimonious model, we used stepwise selection methods based on the Akaike's Information Criterion (AIC). We selected the final models by $\Delta AIC \leq 2$ criterion.

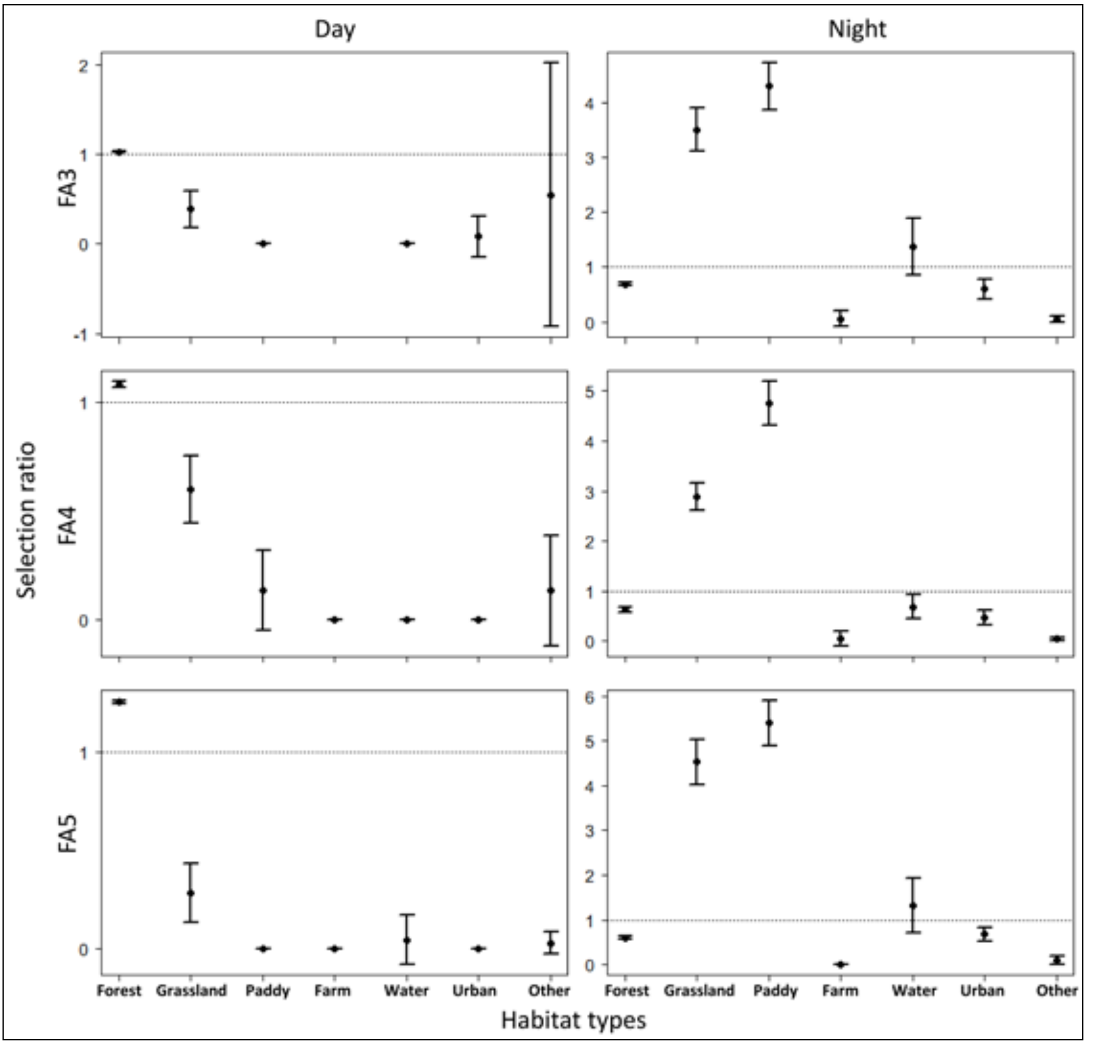

Figure 6. Comparison of habitat selection in different light conditions for three GPS-marked sika deer in Funatsu, Mie Prefecture. Estimates are selection ratios ±95% confidence intervals. The dotted line indicates where selection ratios are equal to 1, which means no selectivity. The x-axis shows the different habitat types.

Deer–train collisions. To analyze deer–train collision data in relation to the movement of GPS-marked deer, we used accident data within the combined 100% minimum convex polygon home range of the GPS-marked deer in Funatsu from November 1, 2003, to June 30, 2013. We used pooled data on deer–train collisions for this period because of small data sets. We calculated the proportions and distances of habitat types with the randomly generated points and the 250-m buffer areas to characterize the environment surrounding the collision points, just as we did for the railway crossing points. Using a probability model, we calculated the probability of deer crossing at each collision and random point.

Logistic regression models were used to analyze the relationships among accident points and the probability of crossings, as well as the environmental variables surrounding the railway line. Deer–train collision points and random points were used as response variables. The predictor variables were the probability of crossing, the proportions of habitat types that were not related to the probability of crossing, and the presence of fences. Habitat type proportion and probability of crossing data were transformed using the arcsine transformation (Zar 1999). To select the most parsimonious model, we used stepwise selection methods based on the AIC. We selected the final models

Table 1. The total number of locations of a series of three sika deer railway line crossings according to habitat types in Funatsu, Mie Prefecture, from November 2008 to June 2009: (A) start of crossing, (B) opposite location, and (C) end of crossing.

Series of railway crossings	Forest	Grassland	Paddy fields	Farm	Water	Urban	Other	Total
(A) Start of crossing	9	19	27	0	0	11	0	66
(B) Opposite location	6	0	8	2	0	53	4	73
(C) End of crossing	7	13	32	0	0	14	0	66

when ΔAIC ≤ 2. We performed all statistical analyses using R version 2.14.1 (R Development Core Team 2011) for windows.

Results

We collected 19,606 locations derived from GPS-marked deer in Funatsu. The average fixed success rate was 94.4%. The home range of 3 GPS-marked female deer were comprised mostly of forests, overlapping between day and night (Figure 5). Two deer remained in the forests during the day and sometimes crossed the railway line at night. The remaining deer behaved similarly; however, they stayed opposite to the area of the railway line for 4 days. We collected 2,641 deer–train collision data from April 2003 to March 2014 for the Kisei Main Line. The length of the railway lines within GPS-marked deer home ranges (100% minimum convex polygon) was 2.8 km. Between November and June, we recorded 62 deer–train collisions, all of which occurred at night, from sunset to sunrise.

Habitat selection

Habitat selection patterns were related to the changes in light conditions (Figure 6). During the day, the lower 95% confidence limit of GPS-marked deer selection ratios of forest habitat were >1, indicating that deer preferred forested areas during the day (Figure 6). At night, the upper 95% confidence limit of all GPS-marked deer selection ratios of forests were <1, and the lower 95% confidence limit of GPS-marked deer selection ratios of grasslands and paddy fields were >1, indicating that deer would leave forests and use grasslands and paddy fields during the night (Figure 6). Regardless of the light conditions, deer avoided urban areas (Figure 6).

Railway crossing

Approximately 99% of the locations of the GPS-marked deer in Funatsu were distributed on the east side of the railway line. The deer crossed the railway line from east to west 67 times. On 66 of 67 crossings, deer returned from west to east within 2 hours, and on 61 crossings, they returned to the original side within an hour.

We extracted the habitat types at the locations of a series of crossings (Table 1A, B, and C); 46 SC points (71%) were located in grasslands or paddy fields (Table 1A); 53 points out of 73 OL points (70%) were located in urban areas (Table 1B); and 45 EC points (70%) were located in grasslands or paddy fields (Table 1C). When deer crossed railway lines, they moved from habitats with grasslands or paddy fields to urban areas and returned to the same habitats at SC points.

Habitat characteristics of crossing points of GPS-marked deer in Funatsu were different from the random points along the railway line (Table 2). Two models were selected as final models (ΔAIC ≤ 2; Table 2). The most parsimonious model, which had the lowest AIC value, included all variables except the proportion of paddy fields within the 250-m circular buffer area around a point was excluded from the full model (Table 2). The probability of railway line crossing increased with increasing distance to forests and decreased with increased distance to grasslands and paddy fields. Deer were less likely to cross the railroad line where it was curved. Probability of deer crossing a railway track peaked at the points with about 13% of grasslands within the 250-m circular buffer area (Table 3; Figure 7).

Table 2. Sika deer railway line crossing points versus random points along the railway line in Funatsu, Mie Prefecture, from November 2008 to June 2009, fitted with a logistic regression model with maximum likelihood estimates. The table shows degrees of freedom (df), log likelihood (logLik) values, Akaike's Information Criterion (AIC) values, ΔAIC values and weights for the final models (2 > ΔAIC). For each model, + shows whether the specific parameter is included in the model.

Model	Distance to forest	Distance to grassland	Distance to paddy fields	Proportion of grassland	Proportion of grassland(sq)
1	+	+	+	+	+
2	+	+	+	+	+

Model	Proportion of paddy fields	Shape of railway line	df	logLik	AIC	ΔAIC	Weight
1		+	7	-152.835	319.670	0.000	0.429
2	+	+	8	-152.139	320.277	0.607	0.317

Deer–train collisions

The stepwise logistic regression identified the habitat characteristics of deer–train accident points within the home range of GPS-marked deer (Table 4). The proportion of paddy fields within the 250-m circular buffer area around a point was excluded from the full model (Table 4). The risk of deer–train collisions increased with increasing proportions of forests and the occurrence of fences, and decreased with increased probability of crossing (Table 5).

Discussion

Habitat selection

The GPS-marked female sika deer showed similar home ranges and habitat selection patterns in selecting forests during the day and grasslands and paddy fields during the night (Figures 5 and 6). Cederlund and Okarma (1988) suggested that the small home range size with low variability of female moose in Grimsö Research Area in south central Sweden resulted from the fact that all females occupied the same range and had access to equal resources. In our study, the capture sites of the GPS-marked deer were within 350 m, which suggests that the deer might be individuals from the same herd and that they likely have the same home range and use equal habitat types.

The GPS-marked deer showed similar habitat selection patterns according to light conditions (Figure 6). In general, similar behavior has been observed in mule deer (*Odocoileus hemionus*; Kufeld et al. 1988) and white-tailed deer (Beier and MuCullough 1990). Deer tend to move from closed habitats during the day to open habitats during the night. Female red deer (*Cervus elaphus*) preferred pastures during the night (Godvik et al. 2009). Sika deer avoided agricultural fields during the daytime due to human activities (Sakuragi et al. 2002).

Railway crossing

We observed 134 railway crossings by our GPS-equipped deer, which indicated that the deer crossed railway lines about every 5 days. This crossing rate was lower than that of red deer in Norway (i.e., about 2 crossings per day; Meisingset et al. 2013). The low number of crossings and the fact that deer crossed railway lines and returned to main areas in a short time (≤2 hour) indicated that deer did not depend on the resources from the opposite areas of the railway lines.

Although deer in our study did not cross the railway line frequently, crossings were more likely to occur close to grasslands and paddy fields (Table 3). In our study, grasslands were highly selected by deer during night (Figure 6). In previous studies, it was shown that road crossings were likely to occur at sites closer to pastures (Gagnon et al. 2007, Meisingset et al. 2013). We assumed that distance to the nearest grasslands was selected in the most

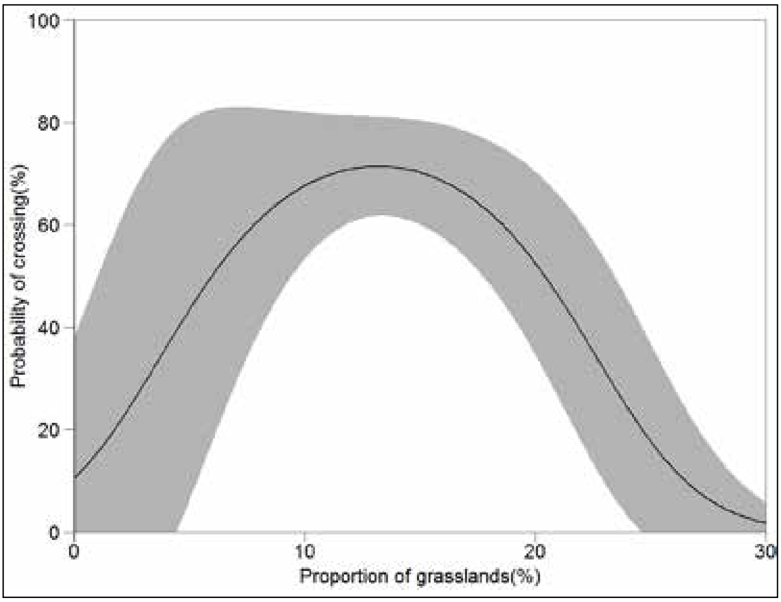

Figure 7. Relationship between the predicted probability of crossing and the proportion of grasslands within a 250-m circular buffer area around points. The grey area around the curve represents 95% confidence intervals.

parsimonious model because it reflected the use of grasslands as foraging sites before crossing and the subsequent return to main areas. Distance to the nearest paddy fields was also selected in the most parsimonious model for reasons similar to grasslands.

Crossing points of deer in our study were close to grasslands and paddy fields and far from forests (Table 3). In contrast to our study, red deer selected a greater proportion of productive forests (Meisingset et al. 2013), and moose chose dense forest stands (Dussault et al. 2007) when they crossed roads. The amount and proximity of forests provide cover and forage and affects the risk of moose–vehicle collisions (Seiler 2005). Because the minimum distance to the nearest forests was about 100 m in our study area, forests did not play a role in the occurrence of crossings.

Deer were less likely to cross at points where the railway line curved (Table 3). Ungulates have been shown to be more vigilant in habitats with low visibility and high incidence of escape obstructions (Halofsky and Ripple 2008, Valeix et al. 2009, Kuijper et al. 2014). We assumed that because the points on the curved lined seemed to have low visibility, deer in our study were more vigilant and avoided those points.

Deer–train collisions

We predicted that points with a high probability of crossing have high risk of deer–train collisions. Unexpectedly, the probability of crossing had negative effects on the risk of deer–train collisions in our study. The patterns for moose and red deer crossing sites also differed considerably in space from those of collision sites (Neumann et al. 2012, Meisingset et al. 2014). Our deer used crossing points that were closer to grasslands and paddy fields,

Table 3. Variables in the most parsimonious logistic regression model contrasting sika deer railway line crossing points with random points along the railway line in Funatsu, Mie Prefecture, from November 2008 to June 2009. Estimates of factor variables are shown along with their standard errors (SE), Z values, and *P* values.

Parameter	Estimate	SE	Z	*P*
(Intercept)	-3.580	1.703	-2.102	0.036
Distance to forest	0.021	0.007	2.962	<0.01
Distance to grassland	-0.008	0.004	-2.186	0.029
Distance to paddy fields	-0.024	0.007	-3.463	<0.01
Proportion of grassland	41.596	15.687	2.652	<0.01
Proportion of grassland (sq)	-176.720	51.508	-3.431	<0.01
Shape of railway line (curve versus straight)	-1.686	0.524	-3.217	<0.01

Table 4. Sika deer–train accident points versus random points along railway line in Funatsu, Mie Prefecture, from 2003 to 2013, fitted with a logistic regression model with maximum likelihood estimates. The table shows degrees of freedom (df), log likelihood (logLik) values, Akaike's Information Criterion (AIC) values, ΔAIC values and weights for the final models (2 > ΔAIC). For each model, + shows whether the specific parameter is included into the model.

Model	Occurrence of fences	Proportion of forest	Proportion of paddy fields	Probability of crossing	df	logLik	AIC	ΔAIC	Weight
1	+	+		+	4	-67.782	143.564	0.000	0.455
2	+	+	+	+	5	-66.860	143.712	0.147	0.422

and far from forests and straight railway lines (Table 3). These points consequently had high visibility. Visibility probably affects the ability for both train driver and deer to detect each other in time to avoid accidents. The risk of animal–vehicle collisions also decreased with visibility in white-tailed deer (Bashore et al. 1985, Nielsen et al. 2003), moose (Seiler 2005), roe deer (Capreolus capreolus), and wild boar (*Sus scrofa*; Malo et al. 2004).

In our study, the risk of deer–train collisions increased with increasing proportions of forests (Table 5). In both Europe and North America, the amount and proximity of wooded areas were identified as key factors associated with higher accidents rates (Finder et al. 1999, Hubbard et al. 2000, Nielsen et al. 2003, Langbein et al. 2011).

Management implications

Our study revealed that deer were attracted to and crossed the railway lines to access grassland and paddy areas. The risks of deer–train collisions were not consistent with the probability of railway line crossing, but rather might be influenced by visibility along the railway line and the amount of forest. DeNicola and Williams (2008) demonstrated that reduction of local deer densities through the implementation of a sharpshooting management program could reduce the number of deer–vehicle collisions in various counties. We suggest that one of the best strategies to reduce the risk of deer–train accidents is to reduce the number of deer in areas of high risk. Mitigation measures, such as fencing for the prevention of deer crossings, should be employed in high-risk areas (Langbein et al. 2011). In the southeast Norway railroad line, a fence was nearly completely effective in eliminating collisions with moose (Andreassen et al. 2005).

The results from the 3 analyses related to the occurrence of deer–train collisions (i.e., habitat selection, crossing movement, and accident points) could help railway line managers in the identification of factors related to the occurrence of deer–train collisions and the design of mitigation measures. The habitat selection analysis identifies the important resources that attract deer and motivate them to approach railway lines, while the investigation of deer crossing movements allows the identification of high crossing-probability points by taking into account accident risk and environmental variables. We recommend this study design as the first step in the future plan for mitigation measures to be designed by traffic route managers.

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Literature cited

Andreassen, H. P., H. Gundersen, and T. Storaas. 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. Journal of Wildlife Management 69:1125–1132.

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of dee–vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769–774.

Beier, P., and D. R. McCullough. 1990. Factors influencing white-tailed deer activity patterns and habitat use. Wildlife Monographs 109:5–51.

Biodiversity Center of Japan. 2004. National Survey on the Natural Environment: report of the distribution of Japanese animals (mammals). I Ministry of Environment, Tokyo, Japan. [In Japanese]

Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10:1059–1067.

Danks, Z. D., and W. F. Porter. 2010. Temporal, spatial, and landscape habitat characteristics of moose–vehicle collisions in western Maine. Journal of Wildlife Management 74:1229–1241.

DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. Human-Wildlife Conflicts 2:28–33.

Dussault, C., J. P. Ouellet, C. Laurian, R. Courtois, M. Poulin, and L. Breton. 2007. Moose movement rates along highways and crossing probability models. Journal of Wildlife Management 71:2338–2345.

Dussault, C., M. Poulin, R. Courtois, and J. P. Ouellet. 2006. Temporal and spatial distribution of moose–vehicle accidents in the Laurentides Wildlife Reserve, Quebec, Canada. Wildlife Biology 12:415–425.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning 44:77–85.

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

Gagnon, J. W., T. C. Theimer, N. L. Dodd, S. Boe, and R. E. Schweinsburg. 2007. Traffic volume alters elk distribution and highway crossings in Arizona. Journal of Wildlife Management 71:2318–2323.

General Insurance Association of Japan. 2015. A total amount of claims related to yezo deer paid by motor vehicle insurance companies. http://www.sonpo.or.jp/about/action/branch/hokkaido/1501_01.html >. Accessed March 15, 2015. [in Japanese].

Godvik, I. M. R., L. E. Loe, J. O. Vik, V. Veiberg, R. Langvatn, and A. Mysterud. 2009. Temporal scales, trade-offs, and functional responses in red deer habitat selection. Ecology 90:699–710.

Halogsky, J. S., and W. J. Ripple. 2008. Fine-scale predation risk on elk after wolf reintroduction in Yellowstone National Park, USA. Oecologia 155:869–877.

Hokkaido Prefecture. 2014. Statistics of yezo deer–vehicle accidents, <http://www.pref.hokkaido.lg.jp/ks/est/koutuujikoH25.pdf>. [in Japanese]. Accessed July 15, 2015.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. Journal of Wildlife Management 64:707–712.

Joyce, T. L., and S. P. Mahoney. 2001. Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. Wildlife Society Bulletin 29:281–291.

Kuijper, D. P. J., M. Verwijmeren, M. Churski, A. Zbyryt, K. Schmidt, B. Jędrzejewska, and C. Smit. 2014. What cues do ungulates use to assess predation risk in dense temperate forests? PLoS ONE 9:e84607.

Langbein, J., R. Putman, and B. Pokorny. 2011. Traffic collisions involving deer and other ungulates in Europe and available measures for mitigation. Pages 215–259 in R. Putman, M. Apollonio, and R. Andersen, editors. Ungulate management in Europe: problems and practices. Cambridge University Press, Cambridge, United Kingdom.

Lewis, J. S., J. L. Rachlow, J. S. Horme, E. O. Garton, W. L. Wakkinen, J. Hayden, and P. Zager. 2011. Identifying habitat characteristics to predict highway crossing areas for black bears within a human-modified landscape. Landscape and Urban Planning 101:99–107.

Malo, J. E., F. Suarez, and A. Diez. 2004. Can we mitigate animal–vehicle accidents using predictive models? Journal of Applied Ecology 41:701–710.

Meisingset, E. L., L. E. Loe, O. Brekkum, B. Van Moorter, and A. Mysterud. 2013. Red deer habitat selection and movements in relation to roads. Journal of Wildlife Management 77:181–191.

Meisingset, E. L., L. E. Loe, O. Brekkum, and A. Mysterud. 2014. Targeting mitigation efforts: the role of speed limit and road edge clearance for deer–vehicle collisions. Journal of Wildlife Management 78:679–688.

Mie Prefecture. 2012. Specified wildlife conservation and management plan (sika deer), third period (Mie Prefecture), <http://www.pref.mie.lg.jp/MIDORI/HP/shizen/ikimono/hogokanri/tokutei/pdf/nihonjika03.pdf>. Accessed March 15, 2015. [in Japanese].

Mysterud, A., N. C. Stenseth, N. G. Yoccoz, R. Langvatn, and G. Steinheim. 2002. Large-scale habitat variability, delayed density effects and red deer populations in Norway. Journal of Animal Ecology 71:569–580.

Neumann, W., G. Ericsson, H. Dettki, N. Bunnefeld, N. S. Keuler, D. P. Helmers, and V. C. Radeloff. 2012. Difference in spatiotemporal patterns of wildlife road-crossings and wildlife–vehicle collisions. Biological Conservation 145:70–78.

Nielsen, C. K., R. G. Anderson, and M. D. Grund. 2003. Landscape influences on deer–vehicle accident areas in an urban environment. Journal of Wildlife Management 67:46–51.

Ohtaishi, N., M. Ibe, and H. Masuda. 1998. Measures for wildlife-related traffic accidents. Hokkaido University Press, Sapporo, Japan. [in Japanese].

Putman, R. J. 1997. Deer and road traffic accidents: Options for management. Journal of Environmental Management 51:43–57.

R Development Core Team. 2011. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Romin, L. A., and J. A. Bissonette. 1996. Deer and road traffic accidents: options for management. Journal of Environmental Management 38:799–807.

Sakuragi, M., H. Igota, H. Uno, K. Kaji, M. Kaneko, R. Akamatsu, and K. Maekawa. 2002. Comparison of diurnal and 24-hour sampling of habitat use by female sika deer. Mammal Study 27:101–105.

Seiler, A. 2004. Trends and spatial patterns in ungulate–vehicle collisions in Sweden. Wildlife Biology 10:301–313.

Seiler, A. 2005. Predicting locations of moose–vehicle collisions in Sweden. Journal of Applied Ecology 42:371–382.

Valeix, M., A. J. Loveridge, S. C. Jammes, Z. Davidson, F. Murindagomo, H. Fritz, and D. W. Macdonald. 2009. Behavioral adjustments of African herbivores to predation risk by lions: spatiotemporal variations influence habitat use. Ecology 90:23–30.

Zar, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice Hall Inc., Upper Saddle River, New Jersey, USA.

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