# The effect of roadside land-use on the occurrence of deer vehicle collisions

Yan Liu[a*], Maarten Nieuwenhuis[a] and Andrew McCullagh[a]

**Abstract**

Motor vehicle collisions involving deer can have severe consequences, and a proper understanding of factors that entice deer to move onto or across mortorways is essential to take targeted measures to avoid such accidents. Based on the idea that roadside land-use factors influenced deer movement onto or across mortorways, we predicted a relationship between landscape (roadside land-use) and site (where collisions either happened or didn't) conditions and the incidence of sika deer vehicle collisions (DVCs) on mortorways in Co. Kildare in Ireland. Structural landscape features and other variables considered conducive to DVCs were quantified at the DVC locations and at randomly selected points along the roads. Landscape variables were assessed within a 0.4 km radius of each location. A logistic regression was applied to DVC and control site data and this analysis identified that DVCs were more likely to occur on road segments where the distance to the nearest forest on the west side of the road was greater. This suggests that a lack of nearby cover makes it more likely that deer take risks when crossing roads. The findings can serve to identify road segments with a high risk of DVCs, allowing for preventive actions to be taken by wildlife managers and road network managers.

**Keywords:** *Kildare, sika deer, deer vehicle collisions, motorways, structural landscape features.*

## Introduction

The human impact on the fragmentation of nature started many centuries ago, and road networks and transport infrastructures have been spreading substantially ever since motorisation (Markolt et al. 2012, Meisingset et al. 2014, Steiner et al. 2014). The first decade of the 21st century has seen a major extension of the network of major roads in the Republic of Ireland. The dynamic wild mammal populations were affected by road construction, as roads split their home ranges and can block the migration routes of deer. An additional factor that has increased the frequency of DVCs is that many *cervid* populations and their ranges have increased considerably in Ireland during the last two decades (Langbein et al. 2010, Purser et al. 2010, Carden et al. 2011). Undoubtedly, this combination leads to a greater incidence of DVCs and there is anecdotal evidence supporting this increase (Purser et al. 2010). Even though

[a] UCD Forestry, School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4.
[*] Corresponding author: yan-liu@hotmail.com

no DVC accidents fatal to humans have happened so far in Ireland, it is very likely that people will also be killed in the future (Malo et al. 2004).

A large and fast-expanding body of literature exists on the study of the spatial and temporal patterns of DVCs in many countries (Romin and Bissonette 1996, Iverson and Iverson 1999, Gonser et al. 2009, Steiner et al. 2014). A good understanding of the factors which contribute to the occurrence of DVCs is vital to choosing proper mitigation measures, and predictive models are commonly regarded as the key to facilitate the study of DVCs and the wide range of factors that influence their locations and frequency (Malo et al. 2004, Gunson et al. 2011).

A comprehensive study on factors affecting deer movements towards, onto and across roads is needed to mitigate DVCs (Jensen et al. 2014), however, basic analyses of DVC patterns on Irish roads is lacking; research that has been carried out involved only general mammal studies, with a focus on protected species (e.g. Smiddy 2002, Haigh 2012). Purser et al. (2010), in a commissioned report about deer management requirements, stated that there is a need for a national study, as well as county and regional studies, of DVCs, to facilitate decision-makers in the adoption of appropriate mitigation measures.

Factors affecting DVC locations and incidences have been examined in many studies. Found and Boyce (2011a) summarised that those factors can be grouped into three categories: landscape metrics, traffic features and deer densities. Landscape and habitat features along roadsides determine, to a great extent, where *cervids* cross roads (Gunson et al. 2011). Meisingset et al. (2014) further pointed out that roadsides are often associated with deer habitat consisting of nutritious forage. Traffic volumes, speed limits and deer densities were reported to be significant predictors of DVCs in several studies (Finder 1998, Ng et al. 2008, Found and Boyce 2011a). However, in other studies, annual average daily traffic flows, posted speed limits and deer densities were reported as unrelated to the locations of DVCs (Bissonette and Kassar 2008, Markolt et al. 2012).

Various proactive measures have been taken by transportation agencies to avoid DVCs but their effectiveness varies (Donaldson 2005). Knapp et al. (2004) evaluated the effectiveness of the use of deer crossing warning signs, one of the most widely used measures to reduce DVCs, and concluded that they were generally ineffective. However, Found and Boyce (2011b) demonstrated that standard-sized, permanent deer-crossing signs, targeting high collision locations, can be effective at reducing DVCs. Wildlife crossing structures (animal bridges or motorway underpasses) and exclusionary fencing have been adopted in many countries, and while proven to be effective, their high cost has restricted their large-scale utilization (Hedlund et al. 2004, Donaldson 2005, Found and Boyce 2011a).

Sunde et al. (2009) indicated that hunting activities by humans changed the daily behaviour of red deer, and increased their daily movement, even forcing them to leave their home range. Kamei et al. (2010) reported similar results for sika deer, which altered their behaviour when sensing hunting activities. Sunde et al. (2009) also stressed hunting-induced migration as a general response to hunting disturbance, and that increased movement will inevitably increase the incidence of DVCs. Therefore, if considerable hunting activities are occurring close to DVC locations, their influence has to be considered when exploring patterns of DVCs. According to annual deer harvest reports by the National Parks and Wildlife Service (NPWS), a public body responsible for nature conservation, Co. Wicklow has accounted for nearly half of the national deer harvests each year since 2000, with sika deer making up the largest proportion of all deer species. As a neighbouring county of Co. Kildare, this hunting pressure in Co. Wicklow may influence deer dynamics in Co. Kildare, leading to migration into and across the county.

In this study the spatial patterns of DVCs were examined at county level. The purpose of this research was to examine the factors that influence the incidences of DVCs on motorways in Co. Kildare. More specifically, the study aims to explore whether higher proportions of land-uses preferred by sika deer and/or more diversified land-uses (more land-use types in surrounding areas) increase the frequency of DVCs, and whether shorter distances to the nearest forest on both sides of the road decrease the occurrence of DVCs. An analysis was undertaken to identify how general landscape characteristics and specific features increase the risk of DVCs occurring.

The hypotheses of the study were: 1) that higher proportions of land-uses preferred by sika deer increases the frequency of DVCs; 2) more DVCs occur where roadside vegetation is more diversified (i.e. where the land-use entropy index is high); and 3) shorter distances to the nearest forest on both sides of the road increase the occurrence of DVCs.

*Study area*

County Kildare (53.17º N 6.75º W) is in the province of Leinster in Ireland and is part of the midland's region (Figure 1). The county has a total area of 1,695 $km^2$ and according to the 2011 Census of Ireland, 210,312 people reside in the county (Central Statistics Office 2012). Land-use in Co. Kildare is largely agricultural in the rural areas (81.13% of all areas in 2007), and a variety of habitats exist in this county, including bog and heath, fen, forests (5.64%), hedgerows, rivers, lakes and a canal (CAAS Ltd 2011). Naas is the county town, and it, as well as other parts of the county, act as important commuter towns for Dublin, the capital city in Ireland. The distance from Naas is approximately 34 km, and Central Statistics Office (2016) identified that counties bordering Dublin had the longest average commuting time across the whole country; for workers living in Meath and Wicklow, it took, on average, nearly 35 minutes to travel to work, while Kildare commuters took just under 34 minutes. An extensive network of roads is present in the county, and this includes three motorways (M4, M7 and M9) with a total length in the county of 82.76 km. Information on the annual mean or daily mean traffic volume was available from the National Roads Authority (NRA), and this information was used to analyse the influence of traffic volume on the occurrence of DVCs.

Deer fencing occurs at 12 locations, with a standard height of 1.8 m at all locations. The fences were erected for the purpose of total exclusion and are focused on the section of the M7 between junctions 5 and 9 (circa 8 km and marked in yellow in Figure 1). Road sections with a length of 1.5 km have fences on both sides of the roads, while at other locations fences are only present on one side; on the eastern side for a total length of 2.3 km and on the western side for 3.5 km. Two deer warning signs are present along the M7 motorway in Co. Kildare; one located near junction 12 on the westbound side of the road, and the other near junction 11 on the eastbound side (marked with a star symbol in Figure 1).

Co. Kildare shares a large part of its eastern border with Co. Wicklow, which has the highest forest cover (21.72% in 2012) of all counties in Ireland, providing habitat for large deer populations and attracting over a third of all licensed deer hunters in the country. This considerable hunting pressure in Co. Wicklow has to be taken into account when studying deer dynamics in Co. Kildare.

*Data*

Detailed time series records of DVCs (carcasses and the corresponding information) on motorways for the years 2008 to 2014 were obtained from a private individual based in Co. Kildare. The data provided by the person consist of DVC information collected by An Garda Síochána, the Irish police (75% of all the reports of collisions), and the public (25%). Valuable information, such as the locations of the collisions (where the carcasses were found), roadside conditions, deer species, sex, age, and time of day were included in the dataset.

Since there are no reporting requirements for DVCs in Ireland, the records from the Irish police and the public may not be complete, and as estimated by the record keeper, circa 20% of DVC incidents are not reported in Co. Kildare. As with the reporting of DVCs, there are no requirements for the reporting of unauthorised taking of deer (poaching), therefore the reported poaching levels are solely based on registered hunters' observations and the accuracy of such data is questionable. Poaching of deer has been on the increase all over the island in recent years and it has reached high levels in the Dublin and Wicklow mountains (Murphy 2013). Both the poaching and unreported DVC data were not available for this study, and the data provided by the individual were the most complete source in the country.

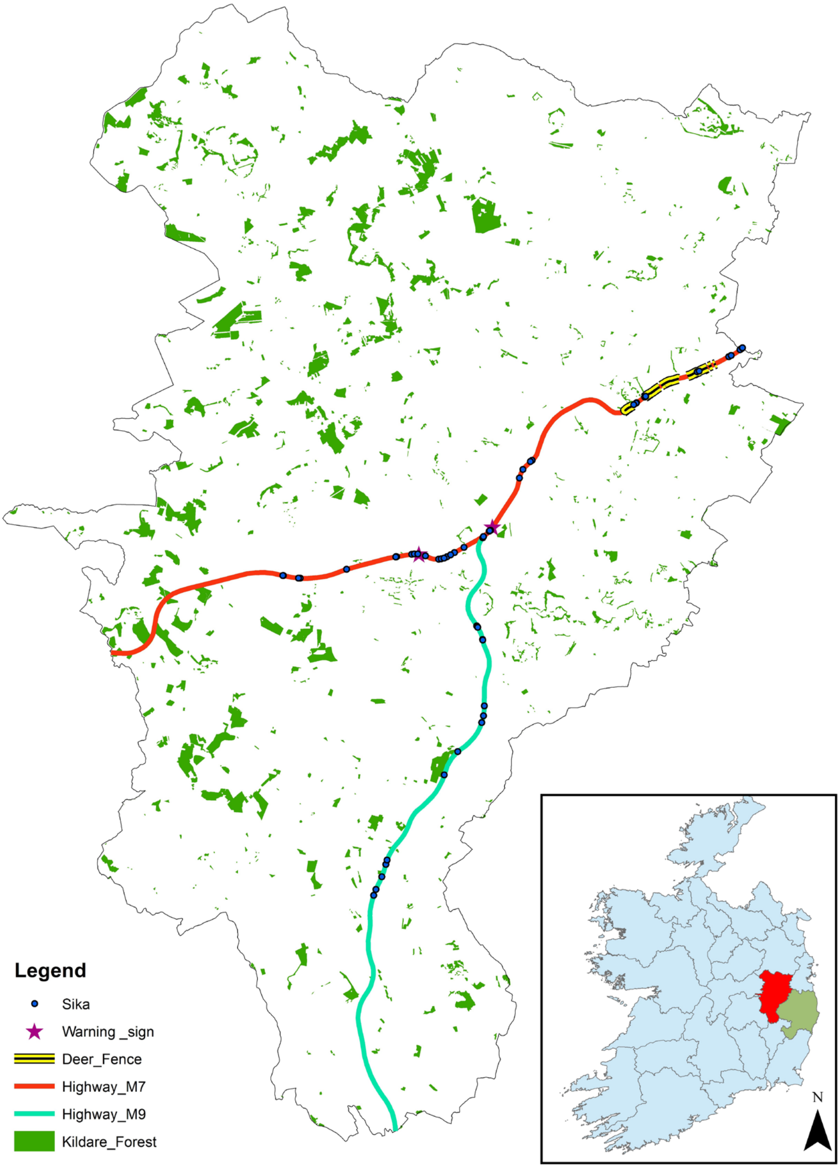


**Figure 1:** *A boundary map of Co. Kildare with DVCs (dots) that occurred on the motorways between 2008 and 2014. The green patches represent forests (based on FOREST07). The map in the lower right inset displays the position of Counties Kildare (red) and Wicklow (green) within Ireland.*

From 2008 to 2014, 74 DVCs, involving one unknown species, two red (*Cervus elaphus*), three fallow (*Dama dama*) and 68 sika deer (*Cervus nippon*), were recorded along Co. Kildare's motorways with location information. There were no records of DVCs during 2008-14 along the M4 motorway, therefore only two motorways with DVC records (M7 and M9) are included. As the large majority of DVCs involved sika deer, this research focused on this species only.

Nine DVCs occurred on the fenced sections, and these DVCs and fenced sections were excluded from the general modelling process as the fencing was thought to interfere with this analysis, and the 9 DVCs were analysed separately. As a result, 59 DVCs remained for the study, of which 6 were randomly selected and retained for validation purposes and not used in the modeling process.

Originating in Japan, sika deer spread through southern Ussuri, Korea, Manchuria, and Eastern China to Vietnam, and were first introduced to Europe circa 150 years ago (Barančeková et al. 2012). Sika deer were first introduced to Ireland in 1860 by Viscount Lord Powerscourt of Co. Wicklow, as a curiosity and for ornamental purposes (Pérez-Espona et al. 2009).

Sika deer can be found in areas with open glades and dense thickets. Traditionally, they were thought to have a preference for the vegetation associated with acid soils, and they will quickly establish in young conifer plantations (Swanson and Putman 2009). They are intermediate feeders (grazers-browsers), feeding upon grasses, heather, broadleaf buds and twigs, fruits, fungi and acorns (Purser et al. 2010). They are the most numerous deer species in Ireland with an estimated population size of 142,460 deer, or 47.1% of the total deer population in the country, and other deer species include fallow deer (41.1%), red deer (7.4%), hybrid deer (red x sika, unknown populations) and muntjac deer (estimated to be <100 animals) (Inter-agency Deer Policy Group 2011). Carden et al. (2011) indicated that in 2008 Counties Kerry, Cork and Wicklow were the population centres of sika deer, while Counties Limerick, Galway, Roscommon, Waterford and Louth had smaller populations of sika deer while populations in other counties were insignificant. In this study, as per the classification methods used by The Deer Initiative for aging wild deer, the ages of the sika deer were grouped into: young deer (<1 year), yearlings (>1 year and <2), adult deer (>2 years and <4) and old deer (>4 years) (The Deer Initiative 2008). GIS information on the motorway network (geographical location, length, starting point, etc.) was obtained from UCD School of Geography, Planning and Environmental Policy. Land-use data were extracted from the findings of the CORINE 2006 Project and more detailed forest information were obtained from FOREST07. The COoRdination of INformation on the Environment (CORINE) program was introduced by the European Commission in 1985, aimed at gathering information relating to the environment for the European Union using satellite images and visual interpretation. CORINE 2006 relates to the update in 2006 of the first land cover database. FOREST07 is a forest GIS cover layer for Ireland, produced by Forest Service, combining the Premiums dataset and the Forest Inventory and Planning System 1998 (FIPS98) forest estate dataset.

**Methods**

Fifty-nine of the reported DVC locations were geo-coded on the motorways in Co. Kildare using ArcGIS 10 (Figure 1). The numbers of deer of different species, age groups and sex and time that accidents happened were summarised, together with the traffic data for each motorway. An equal number of random points were generated on road segments at least 800 m away from all DVC locations and fenced areas; these were labelled non-DVCs. A circular zone with a radius of 400 m (and an area of c. 50 ha) was established around each DVC and non-DVC location to reflect the home range for sika deer of 50 ha, as estimated by Wicklow Mountains National Park (NPWS 2005). All data points were spatially joined with the layers of the CORINE 2006 land-use data and the FOREST07 spatial forest data and any land-use types present in the zones were noted. The same steps were undertaken for the validation dataset.

The CORINE land-use types, defined in an unpublished report by Büttner et al. (2006), that occurred along the motorways in the study area included urban fabric (areas mainly occupied by residents and business buildings), arable land (fallow lands and lands where annually harvested plants grow on a rotation basis), pastures (lands that are fodder-focused and permanently used (at least 5 years)), heterogeneous agricultural areas (areas of mixed annual or permanent crops with natural vegetation or natural areas), forests (areas occupied by woodlands with a canopy closure greater than 30%) and transitional woodland/shrub (areas of naturally developed forest formations). The overall land-use diversity was represented by an entropy index, a commonly used index (Boarnet 2011) that quantifies homogeneity of land-use, considering both the area and the number of different land-uses within a particular area (Hess et al. 2001). In our study, this index was calculated for each DVC and non-DVC site following the procedure in Bordoloi et al. (2013), using Equation 1.

$$\text{Diversity} = \sum_j P_j \times \frac{\ln(P_j)}{\ln(J)} \qquad (1)$$

where $P_j$ = the proportion of total land area in the $j^{th}$ land-use category in each single circular zone being analysed; and $J$ = total number of land-uses in each circular zone (the number may vary between zones).

Liu and Nieuwenhuis (2014) highlighted the great preference that sika deer have for forest cover in their habitat selection; therefore, the role of forest was analysed by computing the distance to the nearest forest, even if the nearest forest was located outside of the 400 m zone. In order to quantify the influence of the high hunting pressure in Co. Wicklow, the forests were classified as occurring on the east side (ES) or on the west side (WS) of the road. The distances to the nearest forest on each side were determined and included in the analysis, together with the land-use variables.

Site status (DVC or non-DVC) constituted the binary response variable in the models. Within each circular zone, the explanatory variables included the following: the area ($m^2$) of all seven different CORINE land-use types present in the study area, the overall land-use entropy index, and the distances from each DVC to the nearest forest on both sides of the road. A suite of models made up of combinations of variables was produced. Model combinations are as follows: 1) all variables; 2) land-use variables only; 3) distance variables only; 4) variables involving human influences (artificial land-use variables and distance variables); 5) variables regarded as "cover" for deer (e.g. forest land and shrub land-use variables); 6) variables regarded as "forage" for deer (e.g. pasture land-use variables). Corrected Akaike's Information Criterion (AICc) values were produced (smaller is better) to select the best model. All the calculations were performed using *proc logistic* in SAS Statistical software (SAS Institute Inc 2008). The logistic regression equation has the form of Eq. 2:

$$\mathrm{Pr[DVC\ site]} = \frac{\exp\,[\beta_0 + \beta_1(x_1) + \beta_2(x_2) + \cdots + \ \beta_n(x_n)}{1 + \exp\,[\beta_0 + \beta_1(x_1) + \beta_2(x_2) + \cdots + \ \beta_n(x_n)} \qquad (2)$$

where $x_1$ are independent variates, $\beta_1$ are parameters.

The best model was selected by comparing the AICc values. The model fit for the best model was further evaluated using Wald[2] statistics (the squared ratio of the Estimate to the Standard Error of the respective predictor), and corresponding *p*-values (the probability that a particular Wald Chi-Square test statistic is as extreme as, or more so, than what was observed under the null hypothesis).

The prediction ability of the model was evaluated using the validation data (consisting of 6 DVCs and 6 non-DVCs). The data were entered into the model equation and the probability was noted. A classification cut-off of 0.50 was applied. A site was classified as a DVC site if the probability was greater or equal to 0.50 and as a non-DVC site if its predicted probability was less than 0.50 (Tappe and Enderle 2007).

## Results

In the data range analysed, 2008 to 2014, similar levels of DVCs were reported annually (on average circa 10 DVCs), except in 2010 when 19 DVCs were recorded and 1 DVC in 2014. Most recorded DVCs involved male (49 animals) and young (33 animals) sika deer (Table 1). DVCs involving males occurred mostly in autumn, while DVCs involving female deer occurred with a summer maximum (Figure 2). The number of young deer (less than one year old) killed in DVCs was relatively uniform in most years, and autumn saw a substantial increase of both yearlings (between one and two years old) and older deer (Figure 3).

**Table 1:** *The gender and age of animals (young deer (<1 year), yearlings (>1 year and <2), adult deer (>2 years and <4) and old deer (>4 years)) involved in deer–vehicle collisions (DVC) from 2008 to 2014 in Co. Kildare (along M7 and M9).*

| | Number of DVCs | | | | | |
|---|---|---|---|---|---|---|
| | Sex | | Age | | | |
| Year | Male | Female | Young | Yearling | Adult | Old |
| **2008** | 13 | 1 | 1 | 8 | 5 | 0 |
| **2009** | 8 | 2 | 3 | 6 | 1 | 0 |
| **2010** | 10 | 9 | 11 | 2 | 3 | 3 |
| **2011** | 5 | 3 | 5 | 0 | 0 | 3 |
| **2012** | 5 | 3 | 5 | 0 | 3 | 0 |
| **2013** | 7 | 1 | 7 | 0 | 1 | 0 |
| **2014** | 1 | 0 | 1 | 0 | 0 | 0 |

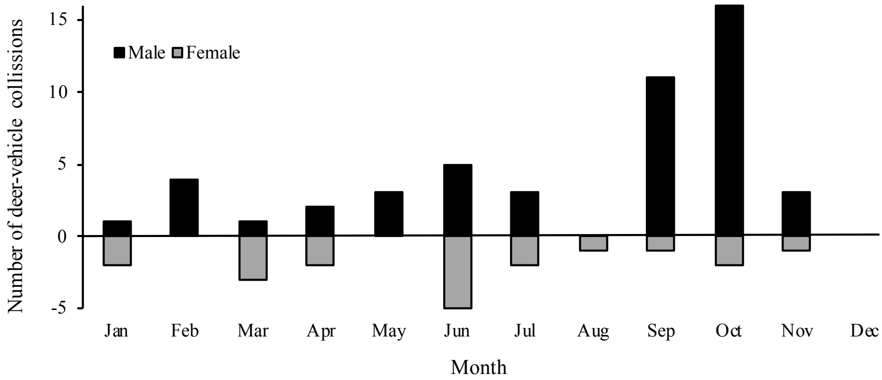


**Figure 2:** *Monthly frequencies of DVCs in Co. Kildare (n = 59) during the period of 2008 – 2014.*

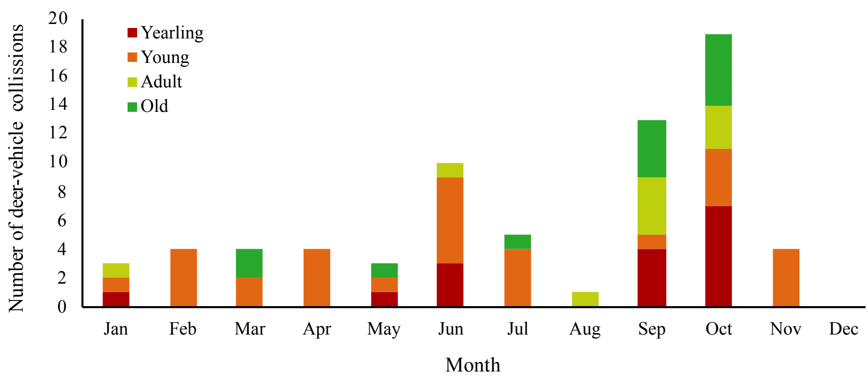


**Figure 3:** *Monthly frequencies of DVCs in each age group in Co. Kildare.*

The traffic volume information was only available for 28 of 68 DVC locations. The mean volume for the 18 DVC locations on the M7 motorway was 48,487 vehicles passing over a 24-hour period, and 26,880 vehicles for the 10 DVCs on the M9. With 50 DVCs occurring on the M7 (45 km in length) and 18 DVCs on the M9 (38 km), it appears that high traffic volumes increase the incidence of DVCs on motorways (1.1 DVCs per km on the M7 vs. 0.5 DVC per km on the M9).

Based on the FOREST07 database, the distances from DVCs to the nearest forest on the ES (ranging from 267 m to 3142 m, average 1028 m) and the WS (ranging from 61 m to 3068 m, average 1336 m) were greater than those for non-DVCs (0 - 3056 m, average 880 m, and 41 - 2413 m, average 946 m, respectively). Based on the CORINE database, the most obvious difference in land-use between DVC and non-DVC locations was the extent of pasture land within the circular zones (Table 2).

Model 1, the model composed of all variables, produced the smallest AICc values (Table 3). This was followed by Model 4, which only included human influences, and then by Model 3, which only included distance variables. The estimates of the significant parameters in Model 1 are listed in Table 4.

**Table 2:** *Comparison between DVCs and non-DVCs in terms of distances (m) to nearest forests (based on FOREST07), proportion (%) of each land-use within 400 m zones and overall land-use diversity (%) in buffer zones (based on CORINE), and diversity (entropy index) (%).*

| | | ES distance | WS distance | Urban fabric | Arable land | Pasture land | Heterogeneous agricultural areas | Forests | Transitional woodland/ shrub | Peat bogs | Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DVC | Mean | 1,028 | 1,336 | 28 | 24 | 38 | 0 | 1 | 1 | 0 | 70 |
| | Max | 3,142 | 3,068 | 78 | 97 | 100 | 1 | 28 | 41 | 9 | 100 |
| | Min | 267 | 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Non-DVC | Mean | 880 | 946 | 21 | 18 | 57 | 1 | 0 | 2 | 0 | 58 |
| | Max | 3,056 | 2,413 | 87 | 100 | 100 | 16 | 0 | 43 | 0 | 100 |
| | Min | 0 | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 00 |

**Table 3:** *Comparison of the 6 models predicting likelihood of a location being a DVC site.*

| Model | AICc | Chi-square | Pr > ChiSq |
|---|---|---|---|
| **1** | 204.52 | 28.54 | <0.0001 |
| **2** | 220.87 | 7.67 | 0.0056 |
| **3** | 213.39 | 14.88 | 0.0001 |
| **4** | 211.20 | 18.91 | <0.0001 |
| **5** | 231.27 | 2.80 | 0.2458 |
| 6 | 229.90 | 1.69 | 0.6372 |

**Table 4:** *Parameter estimates and performance evaluation of Model 1.*

| Variable | Estimate | Standard Error | Wald Chi-Square | Pr > ChiSq |
|---|---|---|---|---|
| Intercept | -3.4865 | 0.4486 | 60.3978 | <0.0001 |
| Pasture land | 1.8951 | 0.9658 | 3.8502 | 0.0497 |
| Distance to nearest forest on the WS | 0.0008 | 0.0002 | 19.3153 | <0.0001 |
| Diversity | -1.7924 | 0.5142 | 12.1494 | 0.0005 |

The resulting model indicates positive relationships between the occurrence of DVC and the amount of pasture in the zone, and the distances to the nearest forests (on the WS). The diversity of the zone has a negative coefficient.

We considered and evaluated 12 variables for their impacts on the locations of DVCs. Three variables, including two land-use variables and one proximity feature, were identified as significantly different between DVC and non-DVC sites. Eight of 12 validation sites (67%) were correctly classified using the full model.

The resulting model permitted a high degree of discrimination between DVC and non-DVC sites. Eighty-three percent (5) of the 6 real DVC sites had a probability of 0.70 or greater of being correctly classified. Fifty percent (3) of the 6 non-DVC sites had a probability of 0.30 or less of being classified as DVC sites (Table 5).

## Discussion

All three hypotheses were tested and hypotheses 2 and 3 were rejected. Our results suggested that pasture was positively correlated with the occurrence of DVCs, while land-use diversity was negatively correlated. These results are partly contrary to the findings of Tappe and Enderle (2007), who concluded that pasture land and vegetation

**Table 5:** *The possibility (Pr) of one site being classified as a DVC site for 6 known DVCs and 6 non-DVCs.*

| Validation point | Category | Pr |
|---|---|---|
| **1** | DVC | 0.43 |
| **2** | DVC | 0.72 |
| **3** | DVC | 0.75 |
| **4** | DVC | 0.76 |
| **5** | DVC | 0.83 |
| **6** | DVC | 0.85 |
| **7** | Non-DVC | 0.15 |
| **8** | Non-DVC | 0.18 |
| **9** | Non-DVC | 0.28 |
| **10** | Non-DVC | 0.56 |
| **11** | Non-DVC | 0.58 |
| **12** | Non-DVC | 0.66 |

diversity within 400 m circles were positively related to the probability of a location being a DVC location. The vegetation diversity in Tappe and Enderle (2007) is generally high in the 400 m circles, with more than five of the 10 land-use classes present in most of the circles (with large differences in proportions) while in our study, 6 land-use classes were applied and most circles contained no more than four land-uses, while the proportions were also much less variable. The result that the distance to the nearest forest on the WS was a positive influencing factor is surprising. This is unexpected and contrary to one of our hypotheses that road segments with forests nearside will have more DVCs. Finder et al. (1999) pointed out that the distance to the nearby forest was negatively related to DVC incidence, as tree cover close to a road (<200 m) will give motorists a short time to spot and react to deer crossing the road, thus causing more DVCs. The distances from the road to the nearest forest in our study were mostly much greater than 200 m, which reduced the reaction time impact.

The site and landscape model showed that DVC locations could be explained by a combination of surrounding land-use variables determining the attractiveness of the area for sika deer, and proximity features that influence their decision to cross motorways. Our findings confirmed the results of previous studies that roadside land-use had a significant influence on the frequency of DVCs (Finder et al. 1999, Hubbard et al. 2000, Found and Boyce 2011a). The supposition by researchers and in social media that high hunting pressure in Wicklow causes deer to move into Kildare could not be proven as the data did not allow for the determination of the direction in which the deer were crossing the road.

Most DVCs occurred in the autumn, and this could be associated with the mating season (normally in October for sika deer) when deer activity increases and males are less wary (Finder et al. 1999). Females usually give birth in late spring and early summer (NPWS 2005), which explained why more yearlings were involved in DVCs after June. Shao et al. (2010) examined the frequency of DVC distribution with respect to the light conditions and found a strong relationship between DVC and light conditions: deer were more mobile at night and around sunset and sunrise, leading to an increase in DVCs. Donaldson et al. (2016) found that the autumn mating season was associated with increased deer movement, which further resulted in more DVCs, and these relationships were strongest in October and November.

Deer fencing was mentioned as an effective measure to prevent DVCs (Seiler 2005). Of the 68 DVCs that were recorded, three occurred on the road segments where both roadsides were protected by fences and those three DVC locations were close to the end of fences (within 50 m). Six other DVCs occurred on road segments with a fence on only one side of the road, and these were concentrated at junction 8 on the M7 where the fence was located on the west side with no protection on the other side. Overall, nine DVCs occurred on 4.3 km fenced road sections (2.0

DVCs per km), while the other 55 DVCs occurred on 78.7 km of unfenced road (0.7 DVCs per km). This indicates that fences are associated with increased rather than decreased DVCs, especially if erected on only one side of the road and/or for only short sections. Further investigation of the surrounding area at junction 8 revealed that, on the section with no fence protection, a patch of pasture land with a width of c. 125 m is present on the western side, immediately adjacent to the road and neighboured by forests. This suggests that the section at junction 8, on which six DVCs occurred, requires immediately effective deer management measures to prevent further DVCs.

A simple comparison was performed on the two motorways, and it appeared that high traffic volumes increased the incidence of DVCs on motorways, with 1.1 DVCs per km on the M7 versus 0.5 DVC per km on the M9. However, Seiler (2005) indicated that the effect of traffic parameters on DVC occurrences was not linear but rather peaked at intermediate speed limits and intermediate traffic volumes, as intensive traffic and the associated noise may repel deer from approaching roads. Thus, the effect of traffic volumes on DVCs in Kildare needs further investigation.

Since inconsistencies existed between the two datasets used in the analysis (CORINE to calculate land-use areas and proportions in zones, and FOREST07 to measure distances from roads to nearest forests), some discrepancies occurred in the analyses. For instance, no forest was found in the 400 m circular zones of non-DVC sites (based on CORINE, which might be too coarse for small scale analysis), when the forest layers overlapped with 400 m circular zones (with no overlaps), while the shortest distance to a forest was 41 m in these non-DVC zones (based on FOREST07). The main reason for these discrepancies is that CORINE has a Minimum Mapping Unit of 25 ha for aerial phenomena, while FOREST07 maps all forested areas over one hectare. Such problems would not occur if a single, consistent dataset had been available.

**Conclusions**

Based on the study, the following conclusions are drawn, and several consequent recommendations are made:

1. The presence of pasture along motorways increases the occurrence of DVCs. If large areas of pasture are present in close proximity to motorways proactive deer management measures should be considered to reduce the risk of DVCs. This can include more targeted and well-designed fencing (e.g. fences erected on both sides of the road and for longer stretches are more effective), intensive culling in a wide zone adjacent to the road, trapping (along roadsides with high DVC risk) and relocation or attracting deer to other areas by providing

favourable plant species for forage and shelter. Active measures should focus on autumn, when most DVCs occurred in Kildare, and intense culling in October could potentially greatly reduce the risk of DVCs occurring. However, intense culling close to roads might result in more crossing activities as deer try to move away from the hunting pressure.

2. Increasing the landscape diversity along motorways would be an effective way to reduce the occurrence of DVCs. The amount of pasture in the zones was positively related to DVC incidence; therefore, transforming pasture to other land-use types would provide a management option to reduce DVCs.

3. More research on the impact of distances from the nearest forest to the motorways is needed in Ireland, especially given the uneven distribution of deer populations and hunting pressures across the country, since the findings in relation to the proximity of forests and the occurrence of DVCs were contrary to the literature. It would also be useful to note the directions that deer cross motorways, which would facilitate the study of how hunting influences DVCs.

4. Fencing was proven to be ineffective along the motorways in Kildare, especially on road segments with fencing only on one side (the section at Junction 8). Measures are urgently required in this area to avoid further DVCs occurring, and fences erected on both sides of the road and for longer stretches would be effective, as would the provision of over or underpasses.

The results from this study and the model that was developed can be used to produce preliminary maps indicating motorway segments with high DVC risks, which could be used in the development of a national deer management framework. However, this study focused on an area where forest cover and deer population pressures are uneven and where the expansion of the species' territory might be taking place as a result of these pressures and the different intensities of hunting in Wicklow and Kildare. In order to produce maps on a national basis more research is needed to account for these factors as well as for different road types and for the range of deer species present.

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