An analysis of habitat-use patterns of fallow and sika deer based on culling data from two estates in Co. Wicklow

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Abstract

Deer harvest data are commonly used to reconstruct deer-forest dynamics and predict trends in relative abundance and potential damage. This study investigated the spatial distribution of deer harvest locations for two adjacent estates, Ballycurry and Cloragh, in Co. Wicklow, Ireland. The purpose of this study was to determine if and how spatial factors (e.g. habitat types and distributions) affect the frequency and locations of culling events. Particularly, we tested the role of spatial heterogeneity in determining the occurrence of culling events; factors analysed were land use, forest type and forest age. A nearest neighbour analysis was applied first, followed by a kernel density analysis and a multi-ring buffer analysis, for fallow deer (*Dama dama*) and sika deer (*Cervus nippon*) separately, to determine the factors that attracted the two deer species to specific locations. Finally, the hunting effort (hours per deer) in each season and the degree to which different deer species avoid areas of public disturbance (main roads) were examined.

Keywords: Dama dama, Cervus nippon, *harvest data, deer-forest dynamics, spatial heterogeneity, culling locations*.

Introduction

In Ireland, the populations of the three main deer species, red deer (*Cervus elaphus*), fallow deer (*Dama dama*) and sika deer (*Cervus nippon*), experienced exceptional growth between 1978 and 2008 (Carden et al. 2011). Many factors have contributed to the great increase in deer population in Ireland: translocations and secondary releases of animals by man, high reproductive rates and the substantially increased forest cover (Genovesi and Putman 2006, Carden et al. 2011). Many threats to forests have resulted from these exploding deer populations, including bark striping and browsing, which have caused serious economic loss (Côté et al. 2004). As only sika and fallow deer were present at the study site, some background on these two species is provided below.

Fallow deer

Fallow deer originated in the eastern Mediterranean region. Over the centuries, they were introduced to areas of northern and western Europe as a source of food and as a decorative animal (Chapman and Chapman 1980). Fallow deer were the first non-native species to dwell in Ireland; presumably, they were introduced to Ireland by the

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Anglo-Normans during the medieval period (McCormick 1999). In Ballycurry, the fallow deer population originates from the deer park on the estate, which was founded in 1878 and contained over 200 deer in 1944 (Whitehead 1950). The deer park was abandoned later and the deer escaped.

Fallow deer prefer deciduous and mixed woodland habitats with a developed understorey as well as open pastures. Some populations thrive in habitats predominated by agricultural land but incorporating small woods and shrubs (Nugent 1990). Fallow deer are most active at dawn and dusk, but frequent disturbance may result in deer making more use of open spaces during the night (Caldwell et al. 1983). They are grazers or non-selective bulk feeders, supplementing their diet with acorns, fruits, nuts, bramble and fungi, when available (Purser et al. 2010). Fallow deer are the most geographically widespread species in the country and the second most numerous, with an estimated population size of 124,390 or 41.1% of the total deer population in the country (Inter-agency Deer Policy Group 2011).

Adult female deer (does) spend most of their time in family groups with subadults and fawns. These groups are very stable in time and space (Apollonio et al. 1998). However, they select significantly different habitat during the three main annual stages: the breeding season, calving season and the remainder of the year (McElligott et al. 2001, Ciuti et al. 2006). The breeding season (pre-rut and rut) for fallow deer runs from late August to November, with mating occurring from mid-October to the start of November (McElligott et al. 1998). During the breeding season, female fallow deer prefer to live in open pasture, with adjacent shrubs and open woodland (McElligott et al. 2001). They give birth to a single fawn generally during the first two weeks of June (San José and Braza 1992). The habitat choices of calving does differ from those of non-calving does, from May (late pregnancy), through parturition, until the next breeding season. In particular, the ungulate mothers prefer marshes (providing good concealment for fawns) and avoid meadows (open areas) to reduce any potential dangers (Ciuti et al. 2006). Therefore, in this study the calving season is defined from May to late August from the perspective of habitat selection. In the remainder of the year, fallow deer prefer open grasslands, small clearings, woods and marshes, so there is a trade-off between selection of food and cover depending on the specific living conditions (Apollonio et al. 1998, Mysterud and Østbye 1999).

Male deer are sedentary in all seasons, except in the rutting period (mid October to the start of November), when they remain at the rutting sites (Apollonio et al. 1992).

Sika deer

Originating from Japan, sika deer spread through the southern Ussuri, Korea, Manchuria, and Eastern China to Vietnam, and sika deer were first introduced to

Europe ca. 150 years ago (Barančeková et al. 2012). Sika deer were first introduced to Ireland in 1860 by Viscount Lord Powerscourt of Co. Wicklow for ornamental purposes (Powerscourt 1884).

Sika deer can be found in areas with open glades and dense thickets; as they have a preference for acid soils, they will quickly establish in young conifer plantations (Swanson and Putman 2009). Generally, sika deer are crepuscular in their movement patterns, visiting feeding areas at dawn and dusk. 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 (Inter-agency Deer Policy Group 2011).

Sika deer prefer to inhabit dense coniferous forest in spring, mainly open grassland and dense coniferous forests in summer and autumn, while their winter habitat selection depends on the severity of the weather (Maeji et al. 1999). A rumen content analysis by Yokoyama et al. (2000) concluded that no major differences were detected between males and females. Compared with fallow deer, sika deer are more sedentary and show limited movement in their summer and winter range (Genovesi and Putman 2006). In Europe, the rutting season for sika is generally in the autumn (September to November) and females will normally give birth to one calf between April and June (Baiwy et al. 2013).

To make comparisons between fallow and sika deer, the same annual stages were adopted: breeding season (from 20th August to 10th November), calving season (1st May to 19th August), and the remainder of the year.

Study objectives

The purpose of this study was to determine if and how spatial factors (e.g. habitat types and distributions) affect the frequency and location of deer culling events. The hunting records, together with the local geographical and land use data, were analysed with a series of spatial analysis methods, to decide the spatial distribution patterns of both deer species and the factors that contributed to these distributions. The hypotheses were: 1) deer culling would occur mainly at the boundary between forests and fields, as well as in young forest stands before canopy closure; 2) a high proportion of sika deer culls would be in conifer forests; 3) a high proportion of fallow deer culls would occur in agricultural fields; 4) both deer species would stay away from human disturbances.

Materials and methods

Site description

The study area comprises two adjacent estates, Cloragh Estate (53°1' N, 6°8' W) and Ballycurry Estate (53°1' N, 6°7' W). Both estates were categorised into two land-use types: forest and field. The forests were then subdivided into broadleaf high forest (BHF), coniferous high forest (CHF) and mixed high forest (MHF). The high forest system is defined as a silvicultural system in which the stands are managed on rotations long enough to produce trees large enough for timber production (Nieuwenhuis 2010). The first estate, Ballycurry, covers approximately 224 ha and consists of 148 ha of agricultural land and 76 ha of forests, comprising less complex woodland types that include coniferous plantations, MHF and small broadleaved stands. The second estate, Cloragh, is 314 ha in size, of which 198 ha is forest consisting of a range of woodland types, including recently planted (grant-aided) coniferous woodland, old native woodland and plantations on old woodland sites now in the form of CHF and MHF. The remaining areas (116 ha) are agricultural lands, mainly distributed in the northwest corner and southeast corner. CHF makes up the largest proportion of the forests in both estates: 27% and 48% of the total area in Ballycurry and Cloragh, respectively (Table 1). Ballycurry has more MHF (4%) but less broadleaf high forest (BHF) (3%) compared with 3% of MHF and 11% of BHF in Cloragh. A total of 264 ha in the two estates are used for agriculture, mainly sheep farming.

In this study, the two estates were combined to perform the spatial analyses, since no barriers exist between the two sites and both deer species can move freely from one estate to the other.

Deer culling management plan

The overall aim of the deer harvest programme in the study area was to cull as many animals as possible. However, the owners of the two estates had different reasons to initiate this culling programme: in Cloragh, the objective was to reduce deer numbers to allow for natural regeneration of the forest to occur; in Ballycurry, to reduce deer numbers to minimise the potential for deer infecting agricultural animals with TB. The culling programme started in 2000 in Cloragh and in 2006

Table 1: *Forest areas (Conifer High Forest (CHF), Broadleaf High Forest (BHF), Mixed High Forest (MHF) and scrub) and agricultural lands in Ballycurry and Cloragh, in 2006.*

		Forest areas					Agricultural lands	Total
		CHF	**BHF**	**MHF**	**SCRUB**	**Total**		
Ballycurry	Area (ha)	59.94	5.92	8.63	1.63	76.11	148.39	224.50
	Proportion (%)	*26.70*	*2.64*	*3.85*	*0.72*	*33.90*	*66.10*	*100.00*
Cloragh	Area (ha)	149.53	35.04	7.93	5.41	197.90	115.80	313.70
	Proportion (%)	*47.67*	*11.17*	*2.53*	*1.72*	*63.09*	*36.91*	*100.00*
Total	Area (ha)	209.47	40.96	16.56	7.03	274.02	264.18	538.20
	Proportion (%)	*38.92*	*7.61*	*3.08*	*1.31*	*50.91*	*49.09*	*100.00*

in Ballycurry. The hunter used various makes of riffle, with calibres from 56 x 57 to 270, and a normal shooting range of 50 to 100 m, with a maximum of 200 m. He was not paid for his efforts, and he covered the whole area of both estates to reduce the overall numbers, instead of focusing on specific areas.

Almost all stalking was "still stalking" done on foot, both on roads and tracks and in the forest stands. The high seats present on the estates were used very infrequently, with fewer than 5% of the deer harvested shot from these seats. A number of locations where he had culled and had observed deer frequently in the past were visited more often for a period afterwards. However, this approach was successful for a short period only; the deer appeared to change their behaviour over time and eventually stayed away from these locations. If only one animal was spotted, it would be shot, unless it was a particularly good fallow buck. If more animals were observed, the aim was to shoot female animals. The hunter did not adopt different shooting strategies during annual stages, and the territorial behaviour of the deer did not affect the hunting style.

Data collection

Two datasets were used in this study: the culling data from 2000 to 2012 and the geographical and forestry data. The culling data were collected by the sole hunter, in Cloragh Estate and Ballycurry Estate, from 2000 to 2012 and 2006 to 2012, respectively. The deer harvest data contained valuable information such as harvest locations, weather conditions, conditions of the harvested deer (e.g. species, ages, sex, foetus sex, health conditions and weight), time of a day and general observations. For this study, the hunter marked all the harvest locations on copies of printed maps of Ballycurry and Cloragh, based on his recorded information. The harvest locations, together with the corresponding characteristics of the harvested deer such as age and sex, were then geo-coded separately by species using ArcGIS software. A shooting season in this study was defined as running from the 1st September to 31st August next.

The basic geographical information of Ballycurry and Cloragh were obtained from a forest management consultant involved in the management planning on both estates. This information included the boundaries of the two estates, roads and other infrastructure information, and the sub-division of the forest areas with detailed stand and habitat information for each sub-compartment.

Landscape classification

Generally, the landscape can be categorised into four types following the deer habitat rating system in PractiSFM (Barrett et al. 2005): providing food (forage), providing shelter (cover), providing both food and shelter (both) and providing no habitat (neutral). Based on the land-use types, the study areas were classified as field, scrub and forest, and the forest was then sub-divided into sub-compartments and these were allocated to 5-year age classes, from 1 to 70 years old, or to forest older than 70 years. The 5-year age classes were adopted because forest stands, especially conifer plantations, undergo significant structural and habitat changes over these short periods (Botkin et al. 1972) and longer age classes would not allow to capture this. Scrub was defined as stands consisting of small or stunted trees with inferior growth and shrubs, which are generally un-merchantable (Nieuwenhuis 2010). As deer culling was conducted over a 12-year period, the age of every forest stand was calculated on an event-by-event basis, i.e. for each culling event, the age of the relevant forest stand was calculated relative to the year of the event.

In addition to the age class classification, a forest type classification was used (i.e. CHF, BHF and MHF; see Site Description). The combination of forest type and age class determined the habitat provision of forest stands.

Spatial analysis

<u>Nearest neighbour analysis</u>

To determine whether the culling locations were randomly distributed or not, the nearest neighbour analysis method was applied. Nearest neighbour analysis creates an index based on the distance of each feature to its closest neighbouring feature (Scott and Tout 1989). Nearest-neighbour statistics on culling events were compared in this study to identify the distribution patterns, a method previously used to explore relative dune development (Bishop 2010). In ArcGIS, the average nearest neighbour tool measures the distance between each feature centroid and its nearest neighbour's centroid location; it then averages all these nearest neighbour distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analysed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed (McCoy and Johnston 2001). The outcome of nearest-neighbour analysis was expressed as an index of the ratio of the observed distances between harvest locations divided by the expected distances (for a hypothetical random distribution). The index was standardized into Z-scores for tests of significance.

To verify that the nearest neighbour results were sound, 102 points (representing 102 sika deer) and 420 points (representing 420 fallow deer) were generated separately using a random-point generator in ArcGIS and these procedures were repeated 10 times (Gonser et al. 2009). Nearest-neighbour analysis was performed on these sets of points and the values of the ratio Observed Mean Distance/Expected Mean Distance and the Z-scores of the deer harvest locations of sika deer and fallow deer were compared with those of the ten sets of generated random points using the one-sample t-test in SPSS.

Kernel density analysis

Kernel density estimation (KDE) techniques can be applied, as part of a geospatial analysis, to point datasets with spatially extensive attributes (Nakaya and Yano 2010). In this study, the distribution patterns of the harvest locations were explored with the Spatial Analyst extension in ArcGIS, and the expectation was that harvest locations formed clusters (known as "hotspots") in some areas. The objective was to find all hotspots and to use them for further analysis.

Nearest feature analysis

Based on the assumption that there are interactions between the occurrence of harvest events and landscape types, the distance from each harvest location to the nearest landscape features was considered. In ArcGIS, the Near Tool determines the distances from each selected features (i.e. the input features) to one or more nearby features (i.e. the near features), within the search radius (Kulikowski and Bejleri 2006). In this study, the boundaries between forest stands and agricultural fields were deployed as the near features to measure the shortest distance from each harvest location (the input features) to them.

Buffering analysis

For each harvest location, a series of concentric circular buffers were constructed, with radii of 50, 100, 150 and 200 m, using ArcGIS 10, and all geographic information system (GIS) layers were then clipped to these buffers (Ross et al. 2005). Subsequently, the areas of different land uses and forest types and age classes in each buffer were calculated, which were classified into four different categories according to a deer-habitat suitability model developed by Barrett et al. (2005) (Table 2). By comparing the land use and forest characteristics in all circular buffers for each deer species, the species' preference for particular site characteristics was investigated, and the role that scale (i.e. buffer width) may have in characterising the harvest locations was assessed.

In the same way, a range of concentric buffers was created along the main roads (black lines in Figure 1), which were considered the main source of human disturbance in the study area. The same series of buffer widths were used, and all the culling locations were then spatially joined with these buffers. On finishing the spatial joining process, the culling events falling into each buffer were determined and the distribution patterns were examined for both species.

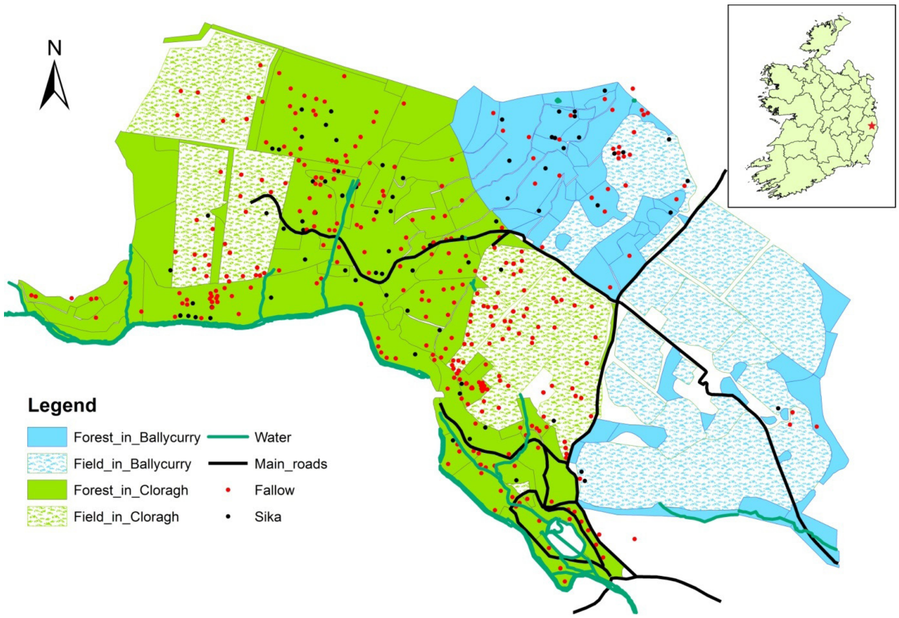

Figure 1: *Map of the study area in County Wicklow, Ireland, including the location of each culling event. The map in the upper right corner shows the location of the study area in Ireland.*

Table 2: *Deer habitat suitability of different forest types with age classes (adapted from Barrett et al. 2005).*

Age range	Broadleaf				Conifer			
	Neutral	**Cover**	**Forage**	**Both**	**Neutral**	**Cover**	**Forage**	**Both**
0-5			+				+	
6-10			+			+		
11-30				+		+		
31-40				+	+			
41-45	+					+		
46-70	+							+
71-100				+				+
100-200				+				+

Results

From 2000 to 2012, 102 sika deer and 420 fallow deer were harvested. The harvests occurred mainly in the period from mid November to late February, and fewer were shot during the calving season (Table 3). No clear trends were found in harvest number proportions for male and female deer over the annual seasons. The numbers of harvest occurrences in different land-use types (forest stands by forest type and 5-year age classes, and agricultural fields), over the 12 years, were compared for both deer species (Figure 2).

It was noted that fallow deer culling was concentrated in fields, stands aged 36-40 (82% CHF and 18% MHF) and 1-5 years (93% CHF and 7% MHF), and the culling of sika deer mainly occurred in forest stands over 40 years of age (68% CHF and 32% BHF).

Distribution patterns

After geo-coding all harvest locations, the distribution patterns were explored via nearest neighbour analysis. The null hypothesis for the t-test was that there were no differences in the distributions of harvest locations for both sika and fallow deer and of the generated random points. The comparison of the random points with harvest locations for sika and fallow deer seperately, indicated that there was less than 5% chance that the distribution of harvest locations for both species were the results of random chance.

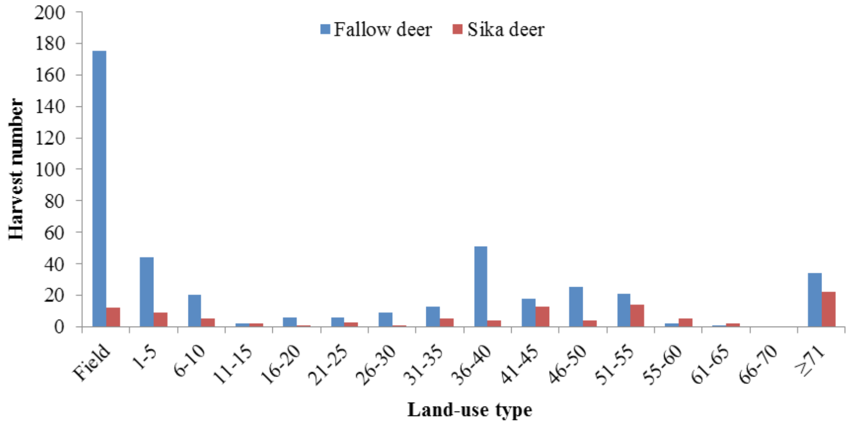

Figure 2: *Total deer harvest numbers for each species in different land-use types (field and forest age classes), for the period 2000 to 2012.*

Table 3: *Total hunting numbers, by age classification and sex (M = male; F = female), in each annual season, for both deer species.*

	Breeding season						Calving season						Remaining season					
Age	**Calf**		**Yearling**		**Mature**		**Calf**		**Yearling**		**Mature**		**Calf**		**Yearling**		**Mature**	
Sex	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Fallow	21	20	50	13	33	30	2	4	3	5	3	10	62	34	48	26	21	93
Sika	7	2	13	2	25	6	0	0	0	1	0	0	6	7	7	6	7	25

The t-test ($t(9) = 52.744$, $p < 0.05$) revealed a significant difference between the mean Z-Score of 10 sets of the random points and the Z-Score of the 420 harvest locations for fallow deer ($M = 0.90$, $s = 1.05$). Similarly, a significant difference ($t(9) = 12.139$, $p < 0.05$) was found between the mean Z-Score of 10 sets of the random points and the Z-Score of the 102 harvest locations for sika deer ($M = 0.64$, $s = 1.65$).

In the same way, in terms of the comparison of the mean ratios of Observed Mean Distance/Expected Mean Distance for random points and harvest locations, significant differences were found between the ratios for fallow deer ($t(9) = 52.745$, $p < 0.05$) and for 10 sets of 420 random points ($M = 1.02$, $s = 0.03$), and between the ratios for sika deer ($t(9) = 12.129$, $p < 0.05$) and for 10 sets of 102 random points ($M = 1.03$, $s = 0.85$).

Based on the results of the four sets of t-tests, the harvest locations for both sika and fallow deer were found to be non-randomly distributed. The distribution patterns were further examined using the kernel density analysis. A minimum kernel value of 1,000 culls per hectare (based on the total culls per grid cell divided by the grid cell area) was set as the cut-off value for hotspots. Several hotspot-areas can be observed in the output (Figure 3); seven hotspots (deep blue and purple) for fallow deer harvest locations and one hotspot for sika deer harvest location were found, with one hotspot-area shared by both species (i.e. the area in a 142-year-old oak forest at the south-western end of Cloragh Estate). In the seven fallow deer hotspots, three were in agricultural fields (one was at the upper north corner of Ballycurry Estate, another one was in Cloragh Estate close to borders with Ballycurry Estate and the third one was at the south-western corner of the pasture in the south-eastern part of Cloragh Estate), and two were in forest stands adjoined to fields (one a 142-year-old oak forest and the other was an 11-year-old Sitka spruce *(Picea sitchensis* (Bong.) Carr.) forest). The remaining two (within 13-year-old and 8-year-old Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) forest) were located far removed from agricultural fields.

Forest-field boundaries and harvest locations

The Near Tool in ArcGIS facilitated the measurement of the distance from each harvest location to the nearest edge between forest stands and agricultural fields (Table 4). A set of random points (with the same number as fallow deer harvests) was created for comparison and the distances from these points to the nearest edge were also calculated. For both species, most culling events occurred within 150 m of the edges between forest stands and agricultural fields. For fallow deer, 252 were shot in forest stands, among which 144 (57%) were shot within 150 m of the edges with agricultural fields. An approximately exponential relationship was observed when fallow numbers culled in the forest were regressed against the distance from the edge of an agricultural field (Figure 4a). A logarithmic relationship best explained the trend in the numbers of fallow deer shot in agricultural fields with distance to a forest edge (Figure 4b). Comparing

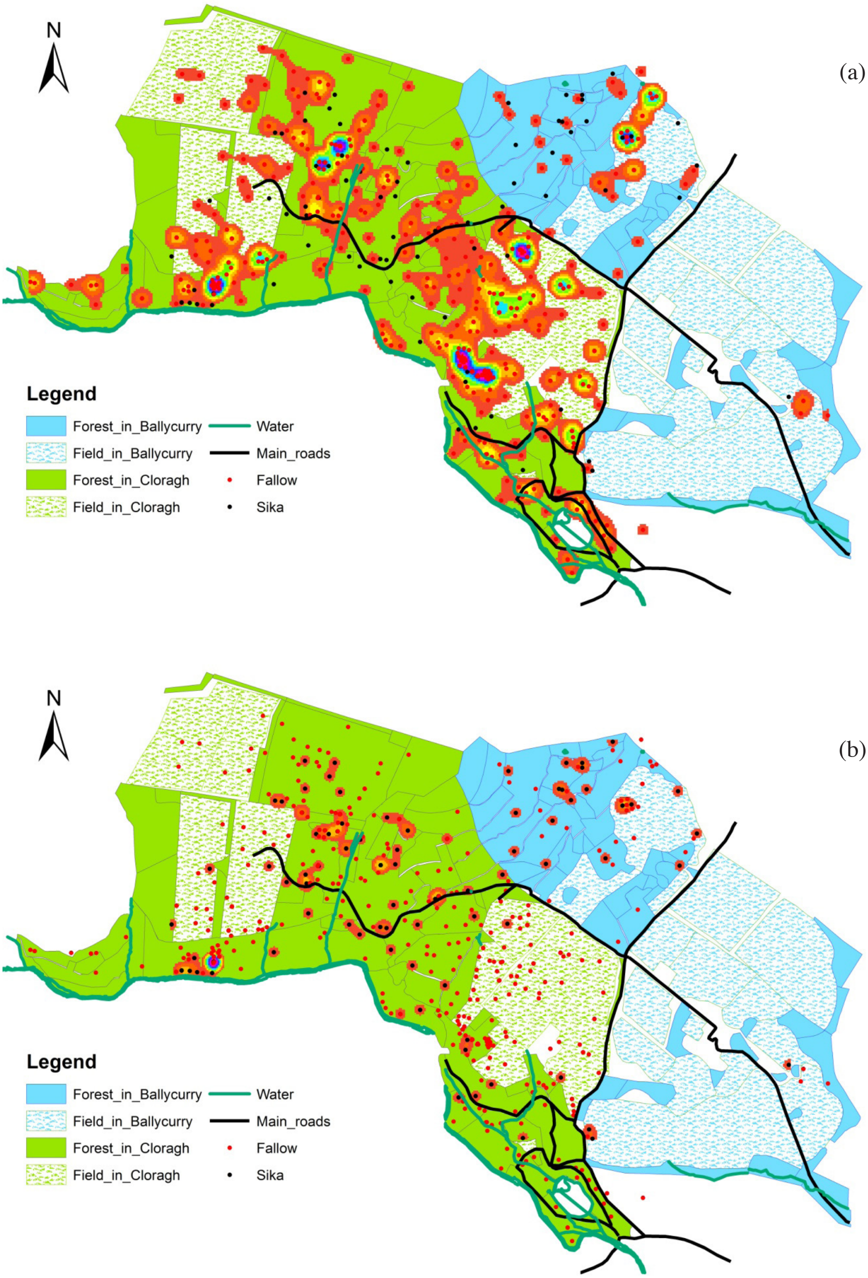

Figure 3: *Kernel density analysis for fallow deer (a) and sika deer (b) for the period 2000 to 2012*.

Table 4: *Deer numbers for both species culled in each land-use type, in comparison with random points, by distance classes to the nearest edges of forest stands and agricultural fields.*

Deer species and location	Distance classes (m)													
	0 to 50	**50 to 100**	**100 to 150**	**150 to 200**	**200 to 250**	**250 to 300**	**300 to 350**	**350 to 400**	**400 to 450**	**450 to 500**	**500 to 550**	**550 to 600**	**600 to 650**	**650 to 700**
Fallow forest	62	48	34	27	22	14	11	16	9	4	1	1	2	1
Fallow field	74	44	25	15	8	2	0	0	0	0	0	0	0	0
Sika forest	10	5	26	9	14	6	2	3	8	5	2	0	0	0
Sika field	6	5	1	0	0	0	0	0	0	0	0	0	0	0
Random forest	65	47	27	15	21	16	14	11	7	13	9	4	6	2
Random field	101	69	48	25	12	6	4	0	0	0	0	0	0	0

the patterns of fallow deer harvests and random points in forest stands and agricultural fields separately, half of the random points that fell in forest stands were within 150 m of the edges, and 87% of the random points in field areas were within 150 m of the edges, indicating that the patterns of fallow deer culling followed the same trend as the random points. Fallow deer were therefore randomly distributed when considering the distances from culling points to forest-field boundaries.

The situation for sika deer was very different and no obvious distribution patterns could be found for those culled in both forest stands and agricultural lands (Figure 4c). Only 12 sika deer were shot in agricultural fields, and all were shot within 150 m to a forest edge.

Effects of surrounding habitat

By applying multi-ring buffer analysis, the influences of the habitat at the harvest location and in the surrounding area were determined and the effect of scale was examined. First, an analysis was done of culling locations of both species against four land-use type categories defined by cover and forage suitability. The proportions of each habitat category were relatively constant with increasing circular width for fallow deer, but a clear trend was found for sika deer, where habitat that provided both forage and cover was much more prevalent in the circular buffer than in the study area, especially for small buffer widths. For fallow deer, there was a constant weak preference for forage habitat, independent of buffer width, compared to the proportion present in the study area (Figure 5).

A detailed analysis of the areas of each specific land-use type also was carried out. The highest proportion of harvest locations for fallow deer occurred in agricultural fields (0 label in Figure 6), while for sika deer the greatest proportion occurred in mature forest stands, over 70-years old in the 50 m buffer zones (95% BHF, 4.4% CHF and 0.6% MHF), with a significant proportion also in agricultural fields. Very

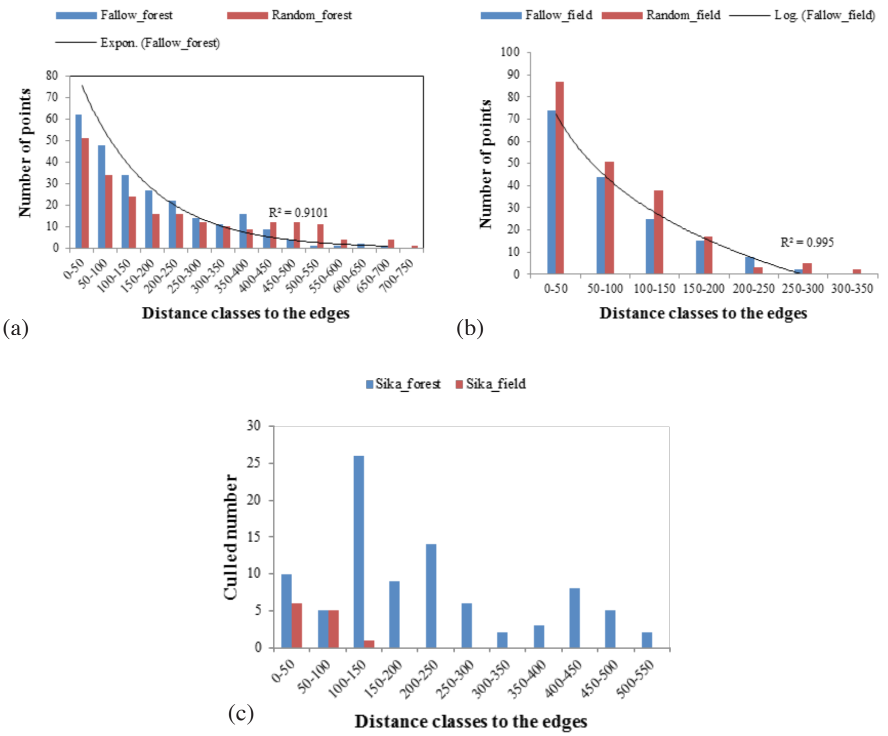

Figure 4: *a) fallow numbers culled and random points in forest stands, by distance classes (in m) to the nearest edge of an agricultural field; b) fallow numbers culled and random points in agricultural fields, by distance classes (in m) to the nearest edge of a forest stand; c) sika numbers culled in forest stands and agricultural fields, by distance classes (in m) to the nearest edge between forest stands and agricultural fields.*

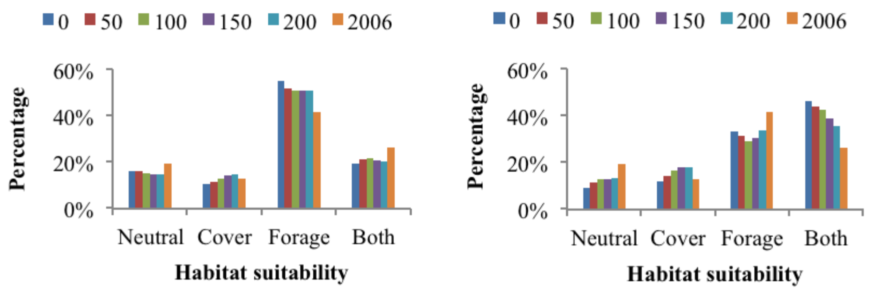

Figure 5: *Proportions of culling locations (0), circular buffers (50, 100, 150 and 200 m) and the study area (2006) categorised by forage and cover suitability, for fallow deer (left) and sika deer (right).*

few deer, either fallow or sika, were shot in or near forest stands aged 11 to 30 years; taking the circular buffer zone of 200 m around the culling venues as an example, these forest stands occupied only 8.2% of the area for fallow deer and 9.2% for sika deer, and for both species these stands were of the CHF type.

Compared with the habitat characteristics of the whole study area in 2006, the values for four land use and forest types were under-represented in the harvest location data for fallow deer, based on a 200 m buffer (Figure 6): forests aged 6 to 10 years (0.5% BHF, 97% CHF and 2.5% MHF), forests aged 31 to 35 years (98% CHF and 2% MHF), forests aged 46 to 50 years (3% BHF, 86% CHF and 11% MHF) and forests aged over 71 years (90% BHF, 8% CHF and 2% MHF). It is interesting to note that in fields and in forests aged 1 to 5 years (97% CHF and 3% MHF), the proportions of harvest locations were over-represented.

Different patterns were found for sika deer than for the other species, with the proportions for the following four land-use types under-represented in the harvest location data, based on a 200 m buffer (Figure 7): agricultural fields, forest aged 6 to 10 years (100% CHF), forest aged 36 to 40 years (96% CHF and 4% MHF), and forest aged 46 to 50 years (90% CHF and 10% MHF). For most of the remaining land-use categories the proportions for each harvest location were over-represented compared with those for the entire study area.

The most obvious difference between sika and fallow deer occurred in the proportion of culls in fields compared to the proportion of the estate in fields, with the proportion for fallow deer higher (Figure 6) and the proportion for sika much lower (Figure 7) than the proportion of fields for the study area.

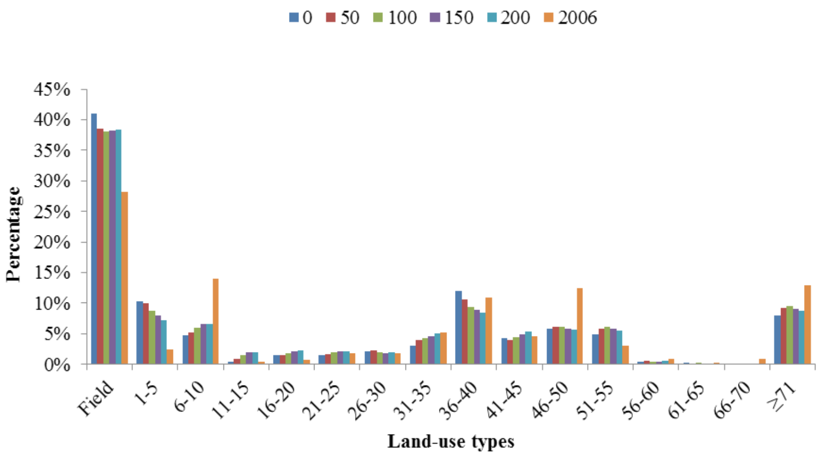

Figure 6: *Proportion of different land-use types (field and forest age classes) for the study area (2006) and in circular buffers (of 0, 50, 100, 150 and 200 m radius) surrounding harvest locations of fallow deer.*

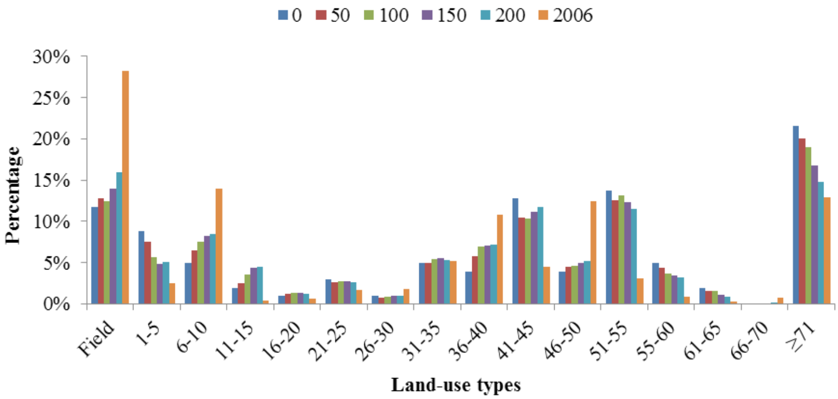

Figure 7: *Proportion of different land-use types (field and forest age classes) for the study area (2006) and in circular buffers (of 0, 50, 100, 150 and 200 m radius) surrounding harvest locations of sika deer.*

Hunting effort and public disturbance

By adding the time used for each cull for each deer species in the same hunting season, the seasonal hunting effort was calculated (Table 5). Since the data lacked hunting times for many culling events, only 188 fallow deer and 46 sika deer were included in this analysis. Although a significant difference in terms of culling numbers existed, the average hunting effort times for both species were similar (3.43 and 3.47 hours for fallow and sika, respectively).

The public disturbance study focused on the main roads in the study area; a multi-ring buffer was created around the main roads and then the culling locations were analysed against each buffer (Table 6). Culling locations for both fallow and sika deer generally followed the pattern of random points, except those for sika more than 150 m from the main roads.

Discussion

The data used in this study do not automatically reflect the distribution of both deer species over the study area, as an important factor that determines the locations of the culling events is the hunter's behaviour and his choice of hunting locations. Detailed discussions with the hunter revealed that he selected hunting locations arbitrarily, covering the whole study area. Of the seven hotspots for fallow and the one for sika deer, the hunter has identified all of these as locations he visited more frequently, at intervals, because deer were present in large numbers, either resting in or moving through these areas. He felt that the increasing sika deer population had originated from plantations to the north of Ballycurry and Cloragh estates and had settled in inaccessible areas of lodgepole pine (*Pinus contorta* Douglas). The fact that most of

Table 5: *Hunting effort (hours per deer) by hunting season and species, for the period 2000 to 2012.*

		Hunting season											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Hunting time (hr)	Fallow	19.50	62.25	75.75	84.50	59.25	64.95	59.35	79.30	56.65	58.50	7.00	25.50
	Sika	0.00	2.00	17.50	10.00	3.25	3.00	12.50	26.25	16.50	48.00	7.00	19.50
Hunting number	Fallow	6.00	19.00	21.00	21.00	16.00	18.00	17.00	23.00	16.00	20.00	2.00	9.00
	Sika	0.00	1.00	5.00	2.00	1.00	1.00	3.00	7.00	6.00	12.00	2.00	6.00
Effort (hrs per deer)	Fallow	3.25	3.28	3.61	4.02	3.70	3.61	3.49	3.45	3.54	2.93	3.50	2.83
	Sika	0.00	2.00	3.50	5.00	3.25	3.00	4.17	3.75	2.75	4.00	3.50	3.25

Table 6: *Deer numbers and proportions culled for both fallow and sika deer, within distance classes to main roads, in comparison with those for random points (represents fallow and sika deer separately).*

Species	Distance to main roads									
	50 m		**100 m**		**150 m**		**200 m**		**>200 m**	
	Number	***Proportion (%)***	**Number**	***Proportion (%)***	**Number**	***Proportion (%)***	**Number**	***Proportion (%)***	**Number**	***Proportion (%)***
Fallow	62	*14.76*	38	*9.05*	48	*11.43*	32	*7.62*	240	*57.14*
Random (fallow)	67	*12.84*	59	*11.30*	60	*11.49*	40	*7.66*	296	*56.70*
Sika	14	*13.73*	10	*9.80*	10	*9.80*	4	*3.92*	64	*62.75*
Random (sika)	13	*12.75*	11	*10.78*	13	*12.75*	8	*7.84*	57	*55.88*

the harvest locations were within 150 m from field-forest boundaries was, according to the hunter, based on the high incidence of deer activity in these areas, and not on the hunter's behaviour. Based on this analysis of the hunter's behaviour, the culling location data can be considered, to a very large extent, to reflect the habitat preferences of the deer species, so the focus of this discussion reflects this conclusion.

Three groups of random points were applied as control groups for three different analyses in this study. The results for these three analyses to determine if the distributions of fallow and sika deer were random provided contradictory information. The reference objects differed between the three approaches, which may explain this result. The results for the nearest-neighbour analysis showed that the culling locations of both fallow and sika deer were not randomly distributed, which was then cross-verified using kernel density analysis, resulting in the identification of the hotspots. The distance to the nearest boundary between forests and agricultural fields and the distance to the main roads were the reference objects used in the other two analysis methods. These two analyses indicated that the distributions for both species were random relative to the distances to nearest edges and main roads. Fallow deer followed the general rule: the greater the distance from the nearest edges between fields and forests, the smaller the population there (Borkowski and Pudelko 2007). For sika deer the result was quite different, indicating that sika deer were more forest-based and stayed away from the edges, as the highest cull numbers were recorded for the 100-150 m distance class in the forest. This result concurs with those obtained by Takatsuki (1989), who found that the number of faecal pellets deposited by sika deer, representing the population abundance, was mainly concentrated in the forest and in the "adjacent zone" (up to 150 m out from the forest) and decreased suddenly more than 150 m from forest. The pattern of sika culled in fields in this study (all the sika deer were culled in or within 150 m from the forest) also agreed with the findings by Mysterud and Østbye (1999) that deer, especially smaller species, often used the 200 m zone closest to the forest edge for feeding. Similarly, in the analysis of distance to the main roads, the relatively high proportion of sika in the areas further than 200 m from the main roads, compared with the random points, indicated that sika deer were more sensitive to the public disturbance than fallow deer and tended to avoid the area near the main roads (<200 m).

The clustered areas (hotspots) for fallow deer were mostly distributed along the boundaries of forest stands and agricultural fields, or in fields near to forest stands. The two exceptions (hotspots within 13-year-old and 8-year-old Douglas fir stands) were far removed from the boundaries, but they both neighboured a Douglas fir stand established in 1955, which was regarded as providing both forage and cover habitat by the habitat-suitability-model. Therefore, both shelter and forage resources were provided in the fallow deer hotspots or their adjoining areas. Mysterud and Østbye

(1999) summarised that ungulates often experience a trade-off between food and cover, and use edges more often than interior areas.

In this study, fallow deer were found in agricultural fields or in forests with easy access to grassland. This finding is consistent with part of the conclusions by Borkowski and Pudelko (2007) that the most often used habitats were thickets (13-35 year-old forest stands) and meadows. They also concluded that mature forests (>50 years) and young plantations (1-5 years) were least used, but, in contrast, our study found that forests aged 1-5 years and over 50 years attracted large numbers of deer. This contrary finding may be the result of differences in the landscape structures between the two studies, and may also be caused by the favourable understorey conditions in stands in these age classes in our study, in contrast to the relatively poor understorey conditions in these types of stands in their research. In the same way, Mertzanidou and Legakis (2004) utilized point sampling technique to correlate deer presence with habitat types in the southern part of Rhodes Island, and concluded that the main habitat type occuring in the fallow deer range is the forestland (48.99%), which is in line with our results.

Sika deer were generally dispersed over the study area, and only one hotspot was found. The hotspot area was an old oak forest aged 142 years, which was classified as providing both forage and cover habitat. Overall, it is clear that sika deer were more forest-based compared with fallow deer. Uzal et al. (2013) indicated that safe access to pastures was the key criterion in the habitat selection and distribution of sika deer. This agrees with our finding that sika deer were frequently found 100-250 m from the nearest field boundary.

The habitat suitability analysis further demonstrated that sika deer considered cover as a key habitat factor to their distribution, while fallow deer seemed to regard forage conditions more important. The width of the buffer zones had little effect on the outcome of the habitat analysis for fallow deer, but for sika there were clear trends. With an increase of the buffer width, the proportion of habitats providing both cover and forage in the buffer zones went down, while those offering only cover went up, reflecting the role of cover in the habitat selection of sika deer. The analysis of the buffers around the harvest locations also identified a preference of both deer species for habitat that contained both fields and forests; however, fallow deer clearly showed more preference for agricultural fields than did sika. In addition, forest stands aged between 1 and 10 years (95% CHF and 5% MHF for fallow deer, and 100% CHF for sika deer), and especially those between 1 and 5 years (93% CHF and 7% MHF for fallow deer, and 100% CHF for sika deer), attracted relatively high numbers of deer, reflecting the opportunities for both cover and forage that these young stands provide, with large amounts of ground vegetation covering the space between the planted trees, especially in coniferous plantations. Although though a certain amount of browsing damage to these young trees has been found throughout the study area, this has not been excessive, and no need for fencing of conifer reforestation areas has been identified. It is assumed that easy access to agricultural fields throughout the study area reduced the browsing pressure on the young trees. In other areas in Wicklow, where forests cover is very high, serious damage to young conifer plantations has been observed.

Sika deer numbers in this study were relatively low across the whole period. Therefore, conclusions drawn about habitat selection by this species in the study need to be validated based on additional data over more hunting seasons.

At the final stages of the study, feedback from the hunter was obtained and he made available the harvest results for hunting season 13 and part of 14 (from 1st September 2013 to 17th January 2014). It should be noted that new hunting strategies and personnel had been introduced in season 13, with a greater focus on the culling of sika deer. In season 13, 113 deer (60 fallow and 53 sika) were shot, and in the first part of season 14, 56 deer were shot (26 fallow and 30 sika). In total, 67 out of 86 fallow deer and 24 out of 83 sika deer were shot in field areas. This re-enforces the findings that sika deer are more forest based compared with fallow deer, but also illustrates the fact that large deer populations are still present on the estates, even after the removal of considerable numbers during the 12 seasons investigated in this study. The influx of deer from neighbouring areas will make the further reduction of deer numbers on the estates a difficult and continuous process that would greatly benefit from a deer management strategy on a regional or national level.

Results of this study may have implications for the management of forests that contain large deer populations. In particular, this study shows the importance of cover for sika deer and forage for fallow deer and the preference of both species for edge and mixed habitat, containing both forests and fields. Both species also showed preference for forest aged 1-10 years (mainly coniferous plantations), and continued monitoring is needed to ensure no excess damage is done, by either species, to the young trees in these stands. However, the extent to which the criteria identified in this study as important determinants of habitat selection by sika and fallow deer can be extrapolated to other landscapes of similar scale, or even to regional scales, requires similar studies over a wider geographical range.

In conclusion, this study has identified different patterns of spatial distribution for both fallow and sika deer in the study area. These results appeared to be driven by the distribution of forage and cover resources and by the potential risks associated with using the open agricultural grasslands and with public disturbance, which is caused by the main roads in the study area. They revealed different considerations for habitat selections by the two deer species, and the modification of landscape features (e.g. further afforestation of traditionally agricultural landscapes, changes in availability of cover or/and forage resources through forest management, and increased public disturbance) may lead to changes in deer population distributions. This information is therefore of value when designing integrated deer-management strategies for these two species, which clearly must be species and site specific.

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