

Retrospective analysis of the Northern Ireland Irish hare Survey data from 2002-2010



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Retrospective analysis of the Northern Ireland Irish hare Survey data from 2002-2010

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The opinions expressed in this report do not necessarily reflect the current opinion or policy of the Northern Ireland Environment Agency.

EXECUTIVE SUMMARY

1. The Irish hare attracted major conservation concern following a population decline during the 20th century. Mean Irish hare density in Northern Ireland was estimated at 0.65 hares/km² during the mid-1990s. A Northern Ireland Species Action Plan, published in 2000, aimed to “*double [the] present population by 2010*”. To monitor hare population change, the Northern Ireland Irish hare Survey commenced in 2002 and was conducted annually from 2004 to 2010. A night-driven, spotlight, Distance-sampling survey methodology was adopted.
2. Research during 2006 and 2007 suggested that data from surveys conducted from roads violated a number of key assumptions associated with Distance-sampling resulting in biased and unrealistically precise abundance estimates.
3. The objective of the current study was to retrospectively reanalyse the Northern Ireland Irish hare Survey data from 2002 to 2010 to account for any inherent methodological biases.
4. Custom distance analysis methods were developed by the Research Unit for Wildlife Population Assessment (RUWPA) at the University of St. Andrews to incorporate potential sources of bias, including information on a) survey effort per point transect, b) consistent angular sampling bias and c) a density gradient of hares with respect to roads.
5. There was no evidence for any discernable temporal trend in hare abundance from 2002 to 2010. However, estimating absolute abundance with any degree of precision proved difficult and our best attempts yielded estimates with notably wide margins of error.
6. The mean density of hares during 2010 was estimated at 3.4 hares/km² (95%CI 1.0 - 15.1) giving a total of 40,900 hares (95%CI 12,600 - 183,800). This was 5.2 times greater than the estimate produced during the mid-1990s.
7. Taken at face value it appears that the main target of the Northern Ireland Species Action Plan was achieved. However, these results should be treated with caution as early estimates were likely to be substantially negatively biased whilst hare populations, including those of the Irish hare, are characterised by interannual and multiannual fluctuations which make determining significant change from such a short-term time-series unwise. Moreover, a paucity of data on the impact of hunting, grassland management and the efficacy of conservation strategies on hare populations make determining the drivers of any change difficult. There are no data to suggest that variance in abundance was attributable to conservation effort.
8. We make a series of explicit recommendations for how Irish hare surveys should be conducted in the future.

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INTRODUCTION

The Irish hare *Lepus timidus hibernicus* (Bell 1837) is an endemic subspecies of the mountain hare *L. timidus* (Linnaeus 1758), and is the only lagomorph native to Ireland (Fairley 2001; Hamill 2001). It attracted major conservation concern following a population decline during the late 1980s and early 1990s (Dingerkus 1997; Dingerkus & Montgomery 2002). The decline began during the early 20th century synchronous with changes in land management practices associated with agricultural intensification and landscape homogenisation (Dingerkus & Montgomery 2002; Reid *et al.* 2007a).

Mean Irish hare densities were estimated between 1994 and 1996 throughout Northern Ireland at 0.65 hares/km² (mean range 0.20-1.00) with a maximum of 1.54 hares/km² (Dingerkus 1997; Dingerkus & Montgomery, 2002). A Northern Ireland Species Action Plan (SAP) was implemented during 2000 whilst an All-Ireland SAP was implemented during 2005 (Anon, 2000; 2005). The principal objective of each SAP was to “*demonstrate a population increase by 2010*”, but the Northern Ireland SAP specified an aim to “*double [the] population by 2010*”. Consequently, a target density for 2010 was set at 1.30 hares/km² (mean range 0.40-2.00) with a maximum of 3.08 hares/km².

The Northern Ireland Irish hare survey was established during 2002 and was conducted annually between 2004 and 2010 (Tosh *et al.* 2004; Tosh *et al.* 2005; Hall-Aspland *et al.* 2006; Preston *et al.* 2006; Reid *et al.* 2007a; Reid *et al.* 2007b; Reid *et al.* 2008; Reid *et al.* 2009; Reid *et al.* 2010). Due to the nature of the SAP target, a measure of true density and abundance was necessary rather than a simple measure of change in relative abundance.

Lagomorphs have been surveyed using almost every census technique available for terrestrial mammals (Hutchings & Harris, 1993). Night-driven, spotlight surveys have become a favoured method due to their efficiency, repeatability, and lack of interference with the subject (Langbein *et al.*, 1999). Distance-sampling analysis, using the software programme Distance, enables estimates of absolute density to be modelled by relating count data to the distribution of animals relative to the observer

(Buckland, *et al.*, 2004). Consequently, a night-driven, spotlight, Distance-sampling method was adopted for the Northern Ireland Irish hare Surveys.

In principle, Distance-sampling assumes that all animals at the point of survey are detectable (i.e. 100% of animals on the survey line or point transect). The further the surveyor looks from the survey line or point, the less likely it becomes that a target animal will be detected. Thus, the probability of detection decreases with distance from the surveyor. If the survey points are located randomly with respect to animal density, it follows that if the surveyor stood anywhere else, 100% of animals would still be detected on or near the survey point. As both the number of animals observed at the point of survey can be quantified and the probability of detecting them at further distances can be estimated, the number not detected can be inferred and the total density of animals per unit area calculated. The density multiplied by the study area yields an estimate of total abundance.

Distance-sampling provides robust estimates of absolute density and abundance only when the study population and survey design conform to a number of key assumptions. However, research during the period 2002-2010 demonstrated that data from hare surveys conducted from roads violated such assumptions resulting in biased and unrealistically precise estimates (Marques & Borchers, 2006; Paxton *et al.* 2007; Marques *et al.* in press). Specifically, sampling effort was asymmetrically distributed around each survey point due to the presence of hedgerows and other obstacles which obscured the surveyors vision whilst hares themselves presented a non-uniform distribution relative to roads and/or hedgerows. Changing the survey methodology to overcome such problems would have created yet further difficulties rendering results incomparable between years.

Thus, the objective of the current study was to retrospectively analyse the Northern Ireland Irish hare Survey data from 2002 to 2010 to account for any methodological biases inherent in sampling hares from roads by incorporating additional data estimating the true distribution of hares relative to the road. The aim was to describe the temporal trend of the Irish hare population trajectory enabling the main target of the Northern Ireland Species Action Plan to be evaluated.

METHODS

Surveys were conducted during late winter and early spring (January-May) from 2002 to 2010 (excluding 2003). Eight regionally distributed 100km long meta-transects were selected to bisect a representative sample of landscape types characterised by the land classification system (Murray, McCann & Cooper, 1992) throughout Northern Ireland and were placed on minor roads (Fig. 1). Surveys used a 2×10^6 candle-power spotlight from a platform on a high clearance vehicle elevating the observer's head height >2m above ground level, i.e. above most hedgerows. The observer systematically swept the spotlight 180 degrees on both sides of the road twice, working from the area closest to the vehicle towards the horizon. For each hare detection, the location (measured to the nearest 10m using a Trimble Global Positioning System), the cluster size (i.e. number of hares), the radial distance of the cluster from the observer (measured using a laser range finder; Leica LRF 900 scan) and the bearing of the cluster from the direction of travel (measured using compass binoculars; Tasco, Offshore 54, 7x50mm) were recorded. Surveys were not conducted until one hour after sunset.

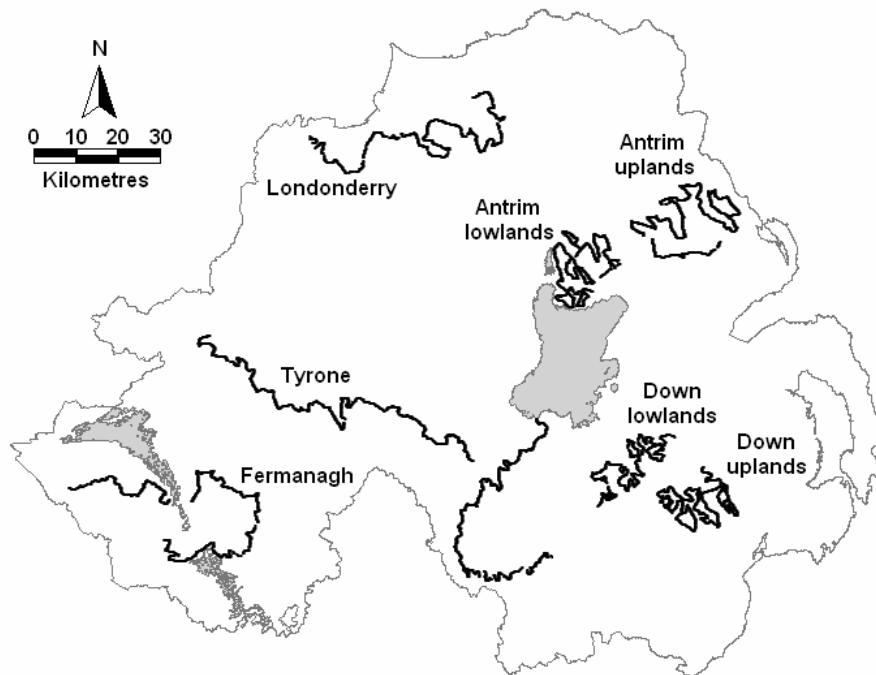


Fig. 1 Location of 8 regionally distributed 100km meta-transects used during Northern Ireland Irish hare Surveys from 2002-2010.

During 2002, each meta-transect was driven continuously at 10-15kph. No measure of survey effort was taken. During 2004, for Health & Safety reasons, individual point transects were placed approximately 200m apart on each meta-transect enabling surveys to be conducted whilst the vehicle was stationary. Total field of view (FOV) measured in degrees of a circle 250m in radius from each point transect was recorded. Subsequently, these data were transformed into the proportion of a complete circle (360°) that was visible without obstruction (ranging from 0-1). Such data were not recorded during 2004 and were missing from 4 meta-transects during 2005 but were present for the majority of points surveyed thereafter.

Conventional Distance Analysis

Each year, hare density and abundance was estimated using the software programme Distance (Thomas *et al.* 2009). During 2002, the analysis specified each meta-transect as a single line with survey effort assumed to be 1 throughout. During 2004, the analysis specified each survey point as a transect with survey effort assumed to be 1 throughout. However, from 2005 to 2010 the majority of points were associated with an individual measure of survey effort. In all cases right truncation was applied to the upper 10% of sightings. Estimates were stratified by county using three commonly used detection functions constructed at the global level, including uniform cosine, half-normal cosine and hazard-rate simple polynomial (Buckland *et al.* 2004). The parsimony of each model was evaluated using Akaike's Information Criterion (AIC) with the best model selected on the basis of the lowest AIC value (Akaike, 1973). The area of Northern Ireland used for total abundance estimation was assumed to be 14,000km². A separate report was produced each year giving an estimate of mean density \pm 95% confidence intervals and total abundance (Tosh *et al.* 2004; Tosh *et al.* 2005; Hall-Aspland *et al.* 2006; Preston *et al.* 2006; Reid *et al.* 2007a; Reid *et al.* 2007b; Reid *et al.* 2008; Reid *et al.* 2009; Reid *et al.* 2010).

Identification of bias

During 2006 and 2007, the *Hare Survey of Ireland* was commissioned by the National Parks & Wildlife Service, Department of Environment, Heritage and Local Government to estimate Irish hare density and abundance throughout the Republic

of Ireland (Reid *et al.* 2007a; Reid *et al.* 2007c). This provided an opportunity to develop new hare survey methods to account for any bias in surveying from roads and to implement an All-Ireland Survey approach running parallel with the standard Northern Ireland Irish hare Survey.

a) Spatial non-independence of meta-transects

The problem with regionally distributed 100km long meta-transects is that individual point transects spaced at 200m intervals are not spatially independent; each is more similar to the points either side of it than to points further along the meta-transect. Thus, rather than employing regional meta-transects a sampling grid was adopted using uniformly distributed 1km long meta-transects each positioned in the south-western most 1km grid square in each 10km square throughout Ireland (both north and south) giving a geographically representative sample of independent meta-transects (Fig. 2). In common with the 100km meta-transects, each 1km meta-transect had individual points transects placed approximately 200m apart with a maximum of five point transects on each. Spatial non-independence was accounted for by using each 1km meta-transect as the unit of variance.

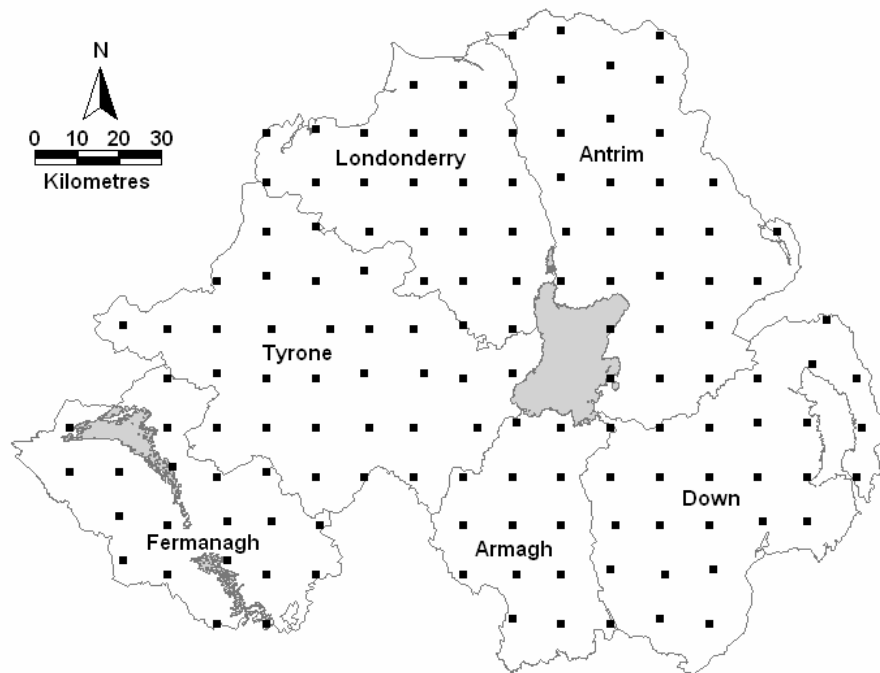


Fig. 2 Location of 140 uniformly distributed 1km meta-transects used during the Northern Ireland Irish hare Survey 2007 following the sampling methodology employed throughout the Republic of Ireland during 2006 and 2007 (Reid *et al.* 2007c).

b) Consistent angular sampling bias

Total field of view (survey effort) was recorded for the majority of point transects surveyed during standard Northern Ireland Irish hare Surveys from 2005 to 2010. However, a breakdown of the direction of such effort was not habitually collected. Therefore, the new 1km meta-transect survey method employed during 2007 provided an opportunity to augment existing data with a directional measure of sampling effort. This was achieved by dividing a circle of 250m radius around each point transect into eighteen 20° sectors (Fig. 3a) and recording whether >50% of each was visible at each point. Paxton *et al.* (2007) demonstrated that sampling effort varied significantly between sectors ($\chi^2_{df=17} = 138.8, p < 0.001$) with greatest effort perpendicular to the road i.e. around 90° and 270° than immediately in front and behind the observer i.e. around 0° and 180° (Fig. 3b). The majority of roads in Northern Ireland are bounded by hedgerows which obscure forward and backward vision whilst the observer's elevated position on the back of a pick-up truck ensured relatively unobscured vision to their left and right. Where point transects are randomly placed with respect to animal density, such bias would not be problematic *per se*, but in this case, points were located on roads which may have a substantial negative impact on density estimates due to potential avoidance behaviour.

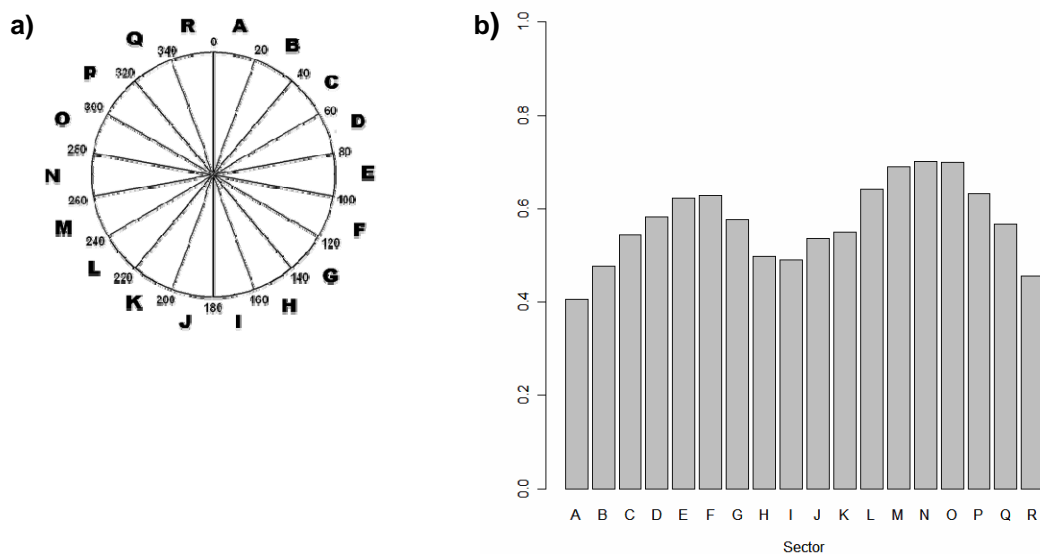


Fig. 3 a) The field of view surrounding each point transect was divided into 20° sectors, each of which was recorded as visible or obscured. b) The proportion of points transects on uniformly distributed 1km meta-transects in Northern Ireland surveyed during 2007 where each 20° sector was visible without obstruction. Letters on the x-axis correspond to labels on each sector in Fig. 3a.

c) Estimated density gradient of hares with respect to roads

Animals may not distribute themselves uniformly with respect to roads. Hares could avoid roads due to disturbance from traffic, avoid point transects due to disturbance from surveyors or avoid field boundaries to avoid predation by foxes. To minimise the former only minor roads were selected. Nevertheless, conventional distance analysis assumes that 100% of animals are detected on the transect. Clearly, if hares avoided roads for any reason this critical assumption would be violated. Previous researchers have dealt with such bias by left truncation and/or grouping animal detections into bins. Whilst this is a commonly applied technique it is totally inadequate for dealing with such major bias and may result in inaccurate estimates. Therefore, it was necessary to estimate the *true* density gradient of hares with respect to roads.

To this end, 'transfield' transects were walked perpendicular to the road at a random selection of points during 2006 and 2007 throughout Ireland (north and south). These transects extended to the first field boundary or 250m in cases where a boundary was not met. For each hare detection, the location of the observer, the cluster size, the radial distance of the cluster from the observer and the bearing of the cluster from the direction of travel was recorded. Subsequently, the perpendicular distance of the cluster from the road was calculated.

Custom Distance Analysis

Evidently, conventional distance analysis was not appropriate to estimate hare density and abundance in the Irish landscape. Therefore, a specialist custom distance analysis was written using the programming language R (CRAN, 2010) to accommodate the probable sources of bias identified above.

A modified Gaussian-based model was developed to incorporate information on a) survey effort per point transect, b) consistent angular sampling bias and c) the estimated density gradient of hares with respect to roads as determined by additional transfield transect data (Marques & Borchers, 2006; Paxton *et al.* 2007; Marques *et al.* in press). This custom analysis was employed for the 1km meta-transect data

covering the Republic of Ireland and Northern Ireland during 2006 and 2007 using country and year as output strata.

In addition to global density and abundance estimates, further estimates were produced for biologically meaningful habitat categories including i) pastoral farmland ii) mixed farmland, iii) bog, moor, heath & marsh, and iv) other marginal habitats, derived from the CORINE 2000 land cover map (EEA, 2002). Upper and lower 95% confidence limits were produced using a non-parametric bootstrapping procedure.

Comparison of estimates suggested that conventional analysis produced biased results with erroneously precise confidence intervals whilst estimating the true density gradient of hares with respect to the road was deemed to be critical (Marques & Borchers, 2006; Paxton *et al.* 2007; Marques *et al.* in press).

Retrospective analysis of the Northern Ireland Irish hare Survey data 2002-2010

The objective of the current study was to retrospectively analyse the data obtained from 100km meta-transect on standard Northern Ireland Irish hare Surveys from 2002 to 2010.

The 2002 survey was based on continuously driven line transects and, therefore, had no associated measure of survey effort which was assumed to be 1 throughout. However, the majority of point transects from 2005 to 2010 were associated with a measure of survey effort. Survey effort data were retrospectively attributed to points for which they were missing (for example, all point transects during 2004 and all point transects on 4 meta-transects during 2005) by either matching 10-figure grid references or by attributing the value for a point transect <10m distant surveyed in subsequent years.

As before, a modified Gaussian-based model was adopted incorporating a) survey effort per point transect, b) consistent angular sampling bias and c) the estimated density gradient of hares with respect to roads.

As previously discussed, a breakdown of the direction of sampling effort was not collected during standard Northern Ireland Irish hare Surveys but did exist for point transects on uniformly distributed 1km meta-transects during 2007 (Fig. 3b). There was no reason to suspect that the problem of consistent angular sampling bias did not exist throughout the Northern Ireland Irish hare Survey dataset; all surveys were conducted from roads and the majority of roads were bounded by hedgerows. Thus, the data available from 2007 were incorporated into our custom analysis for 100km meta-transects from 2004 to 2010 (excluding 2002).

Ideally, transfield transect data would have been collected each year independent of point transects located on roads. Unfortunately, the value of transfield transect data was not recognised until 2007 whilst restrictions on the survey period and available staff prevented such additional survey effort thereafter. Thus, two options were available for estimating the density function of hares with respect to the road for the Northern Ireland Irish hare Survey dataset from 2002 to 2010; i) apply the transfield transect data from 2007 (ROI and NI) or ii) apply a new transfield transect dataset collected during 2010 (NI only). The benefit of the former was that the data already existed and presented a large sample size. Unfortunately, data from 2007 were heavily skewed towards the Republic of Ireland and landscape differences with Northern Ireland may have yielded further bias. The latter presented an opportunity to collect new transfield data restricted to Northern Ireland (thus avoiding potential bias due to landscape differences).

To this end, a sample of transfield transects were walked perpendicular to the road during 2010 as in 2007. As before, these transects extended to the first field boundary or 250m in cases where a boundary was not met. Locations for transfield transects during 2007 were selected at random, but time and staffing restrictions during 2010 did not allow for the sampling effort required to amass sufficient hare detections using a random sample. Thus, transfield transects during 2010 were selected at two sites which presented the highest probability of hare detection (i.e. those with the highest density of hares). Locations with hare detections were combined from 2004 to 2009 on meta-transects in the Antrim Uplands (Larne) and Armagh. A robust fixed kernel method (Worton, 1987) using individual smoothing parameters determined by least squares cross-validation (Silverman, 1986) was

employed to obtain areas within each meta-transect that contained 50% of all detections. Transfield transects were then conducted within the selected areas. Transfield transect data from 2007 (NI only) and 2010 (NI only) were combined to provide a robust sample size.

The number of hare detections on each transfield transect was related to the length of each transect (Paxton & Borchers, 2010). Thus, the estimated density gradient of hares with respect to roads was adjusted for attenuation due to varying transfield transect lengths.

Two commonly used detection functions were used, half normal or hazard rate (Buckland *et al.* 2004) and the fit of each was evaluated using Akaike's Information Criterion (AIC) with the best model selected on the basis of the lowest AIC value (Akaike, 1973).

This density gradient was different to that produced from line or point transects alone (Paxton & Borchers, 2010). The latter assumes that hares are uniformly distributed from the road (Buckland *et al.* 2001) which was clearly not the case. Consequently, detection functions from line or point transects were combined with that from transfield transects to estimate the density gradient of hares in each year sampled.

The model predicted estimates of cluster density only. A bias in detectability associated with larger cluster sizes was tested for by regressing cluster size (log transformed) against the probability of detection. Where an inverse relationship of cluster size and detectability was discovered ($p < 0.05$) the cluster size was adjusted appropriately (Buckland *et al.* 2001).

A non-parametric bootstrapping procedure was performed to generate 95% confidence intervals for density and abundance estimates. Collections of bootstrapped estimates were used to infer confidence intervals and variances (Davison & Hinkley 1997). The unit of variance was taken as the meta-transect. Most counties were sampled using only one meta-transect (except Antrim and Down which had two each). Thus, no estimate of uncertainty could be made per county.

Therefore, estimates were produced using the same habitat categories used during 2007: namely i) pastoral farmland ii) mixed farmland, iii) bog, moor, heath & marsh, and iv) other marginal habitats, derived from the CORINE 2000 land cover map (EEA, 2002).

Finally, the area of Northern Ireland used for total abundance estimation was assumed to be 14,000km² previously. However, this was a rough approximation and did not take account of habitats unavailable or unsuitable to the Irish hare or those that could not be surveyed. Removing water bodies (unavailable), urban areas (unsuitable) and woodland (unsurveyable) the total area was adjusted to 12,165km² (Table 1). This did not alter the estimates of density but did reduce estimates of total abundance.

Table 1 A breakdown of the area of each habitat type suitable for Irish hares in Northern Ireland used for estimating total abundance.

County	Bog, moor, heath & marsh	Mixed farmland	Other marginal habitats	Pastoral farmland	TOTAL
Antrim	345	331	24	1,810	2,511
Armagh	36	234	9	896	1,175
Derry	324	322	31	1,186	1,864
Down	136	1,053	4	1,024	2,217
Fermanagh	197	110	47	1,120	1,474
Tyrone	606	330	13	1,975	2,924
TOTAL	1,644	2,381	129	8,011	12,165

Evaluating temporal trends

Three sources of data were used to evaluate the temporal trend in the Irish hare population trajectory between 2002 and 2010:

a) *Change in the total number counted*

The summed total counts per year were plotted against time. During 2002, each meta-transect was repeated (due to low numbers of detections) and the total distance driven was 2,281km. In contrast, from 2004 to 2010, each meta-transect was surveyed only once and the total distance driven was 843km. Consequently, to ensure comparability of total counts per year, the count for 2002 was calibrated using the detection rate per kilometre and the total distance driven in subsequent years (Reid *et al.* 2009; 2010). Summed total counts provided no measure of within-year variability between meta-transects.

b) *Change in an index of relative abundance*

Indices of change in the total number of hares counted were produced using the specialist software programme TRIM (TRENDS and INDICES for MONITORING data; Pannekoek & van Strien, 2001). TRIM interpolates missing observations (i.e. 2003) from changes in all other sites using a poisson general log-linear model (McCullagh & Nelder, 1989). This technique is particularly useful as it accounts for variation in the number of counts between-transects within-years. Consequently, a measure of uncertainty can be generated for each year (i.e. 95% confidence intervals) allowing the statistical significance of any change to be evaluated. Index values were standardised by cornerpoint parameterisation with the first year of the time-series equal to 1 and all subsequent years relative to the first. It should be noted that these values are meaningless in themselves; they are measures of relative abundance only.

c) *Change in density and abundance estimates from custom distance analysis*

Estimates of density and abundance produced by custom distance analysis accounting for sources of bias for each year (as described above) were plotted against time.

RESULTS

A total of 239 hares in 162 clusters were recorded on 2,281km of continuously driven line transect during 2002. A total of 1,524 hares in 1007 clusters were recorded at 28,001 point transects from 2004 to 2010 (Table 1). No European hares (*Lepus europaeus*) were detected.

The total field of view (FOV) values per point transect on 100km meta-transects during 2007 (median = 180°) differed significantly from those on 1km meta-transects during 2007 (Mann-Whitney $W_{\text{two-tailed}} = 1399938$, $p < 0.001$). Moreover, total FOV values from point transects on 100km meta-transects during 2007 and 2010 (median = 180° and 160° respectively) differed significantly (Mann-Whitney $W_{\text{two-tailed}} = 6804786$, $p < 0.001$). This implied that the sampled locations were in some sense different during 2007 and 2010. Nevertheless, a breakdown of the direction of sampling effort was available for 2007 only and, therefore, had to be incorporated into the custom analysis regardless of the differences. The consequences of this are not readily predictable. This issue was not pursued further here but should be addressed in subsequent surveys as it may introduce a bias.

Irish hare detections were not uniformly distributed with respect to point transects (Fig. 4). In the majority of years the highest density of detections occurred at approximately 50 metres perpendicular to the road (90° and 270°) and lowest densities occurred directly in front (0°) and behind (180°) the observer. This reflects the consistent angular bias in sampling effort demonstrated during 2007 (Fig. 3b).

The frequency distribution of hare detections from the road varied between years (Fig. 5).

A total of 42 hare clusters were detected on 438 transfield transects during 2006 and 2007 from throughout Ireland (ROI and NI). However, only 3 detections were made in Northern Ireland. A total of 39 hare clusters were detected on 140 transfield transects during 2010 in Northern Ireland only. We combined data from 2007 and 2010 drawn from Northern Ireland only (i.e. 42 hare clusters detected on 143 transfield transects) to prevent any bias due to differences in landscape structure between the Republic of Ireland and Northern Ireland. The frequency distribution of

detections with respect to the road varied between the two samples (Kruskal-Wallis $\chi^2_{d.f.=2} = 26.1$, $p < 0.001$, Fig. 6). Incorporation of these different distributions would yield highly divergent estimates of density (Paxton & Borchers, 2010). The difference in the distribution of the transfield transect data between both samples might also be attributed to the selection of transects in areas of high hare density only during 2010; hares may be distributed differently between areas of high and low density.

The lengths of transfield transects varied up to a maximum of 250m (Fig. 7). Therefore, the estimated density gradient of hares with respect to roads was adjusted for attenuation due to varying transfield transect length (Fig. 8). This density gradient was different to that produced from line or point transects alone (Paxton & Borchers, 2010). The latter assumes that hares are uniformly distributed from the road (Buckland *et al.* 2001) which was clearly not the case. Consequently, detection functions from line or point transects were combined with that from transfield transects to estimate the true density gradient of hares in each year sampled (Fig. 9). The mode of the hare distribution was estimated at 0 for line transects combined with transfield transects for 2002 (Fig. 9a) but not for years 2004 to 2010 which utilised point transects; in these years the mode of the distribution was estimated away from 0 (Fig. 9b-h).

The lowest estimate of mean density was during 2002 and the highest estimate during 2004 (Table 3). Estimated mean density during 2010, the final year of the time-series, was 3.4 hares/km² (95%CI 1.0 – 15.1) giving a total of 40,900 hares (95%CI 12,600 - 183,800). Density and abundance estimates were consistently higher in pastoral farmland than any other habitat type (Table 3). *Custom distance analysis yielded estimates of density and abundance not greatly different from that produced by conventional distance analysis* (Preston *et al.* 2002; Tosh *et al.* 2004; Tosh *et al.* 2005; Hall-Aspland *et al.* 2006; Reid *et al.* 2007a; Reid *et al.* 2007b; Reid *et al.* 2008; Reid *et al.* 2009; Reid *et al.* 2010) but the 95% confidence intervals were substantially wider representing a more realistic measure of uncertainty given the potential sources of bias identified.

There was no significant temporal trend in the total number of hares counted per year (Fig. 10). However, it is difficult to judge between-year changes without some measure of uncertainty for each count.

An index of the number of hares counted provided a measure of error which suggested that counts in some years (for example, 2009) were lower than other years (for example, 2004) as their 95% confidence intervals did not overlap (Fig. 11). This provides a means to evaluate significant change. Nevertheless, there was no significant temporal trend in the index of the number of hares counted per year (Fig. 11).

There was no significant temporal trend in the estimated density and abundance of hares per year produced by custom distance analysis (Fig. 12).

Table 2 Descriptive summary of Northern Ireland Irish hare Survey effort and results per habitat from 2002-2010. Note that numbers of individual hares will differ from previous reports as only those within the 250m strip adjacent to the road have been included.

Year	Habitat category	No. of point transects		% occurrence	No. of hare groups**	No. of individual hares**
		with survey effort >0	with hare detections			
2002*	n/a	n/a	n/a	n/a	162	239
2004	Pastoral farmland	4,045	191	4.7	209	293
	Mixed farmland	1,181	39	3.3	40	65
	Bog, moor, heath & marsh	239	7	2.9	8	11
	Other	110	2	1.8	2	3
	Sub-total	5,575	239	4.3	259	372
2005	Pastoral farmland	2,807	144	5.1	159	239
	Mixed farmland	1,003	22	2.2	23	36
	Bog, moor, heath & marsh	171	5	2.9	5	7
	Other	73	2	2.7	2	2
	Sub-total	4,054	173	4.3	210	284
2006	Pastoral farmland	2,340	76	3.2	94	150
	Mixed farmland	558	13	2.3	14	19
	Bog, moor, heath & marsh	131	3	2.3	3	4
	Other	69	3	4.3	9	4
	Sub-total	3,098	95	3.1	120	177
2007	Pastoral farmland	2,866	101	3.5	119	193
	Mixed farmland	789	22	2.7	27	39
	Bog, moor, heath & marsh	187	6	3.2	7	7
	Other	173	3	1.7	3	3
	Sub-total	4,015	132	3.3	156	242
2008	Pastoral farmland	2,857	92	3.2	101	154
	Mixed farmland	763	23	3.0	25	28
	Bog, moor, heath & marsh	175	1	0.6	1	3
	Other	79	2	2.5	2	1
	Sub-total	3,874	118	3.0	129	186
2009	Pastoral farmland	2,755	54	2.0	54	75
	Mixed farmland	717	9	1.3	11	12
	Bog, moor, heath & marsh	171	4	2.3	5	7
	Other	82	1	1.2	1	2
	Sub-total	3,725	68	1.8	71	96
2010	Pastoral farmland	2,657	71	2.7	85	126
	Mixed farmland	735	22	3.0	24	32
	Bog, moor, heath & marsh	181	4	2.2	3	7
	Other	87	1	1.1	1	2
	Sub-total	3,660	98	2.7	113	167
2004-10 (combined)	Pastoral farmland	20,327	729	3.6	821	1,230
	Mixed farmland	5,746	150	2.6	164	231
	Bog, moor, heath & marsh	1,255	30	2.4	32	46
	Other	673	14	2.1	20	17
	Sub-total	28,001	923	3.3	1,007	1,524

* 2002 was a continuously driven line transect not individual points transects.

** within 250 m of the road.

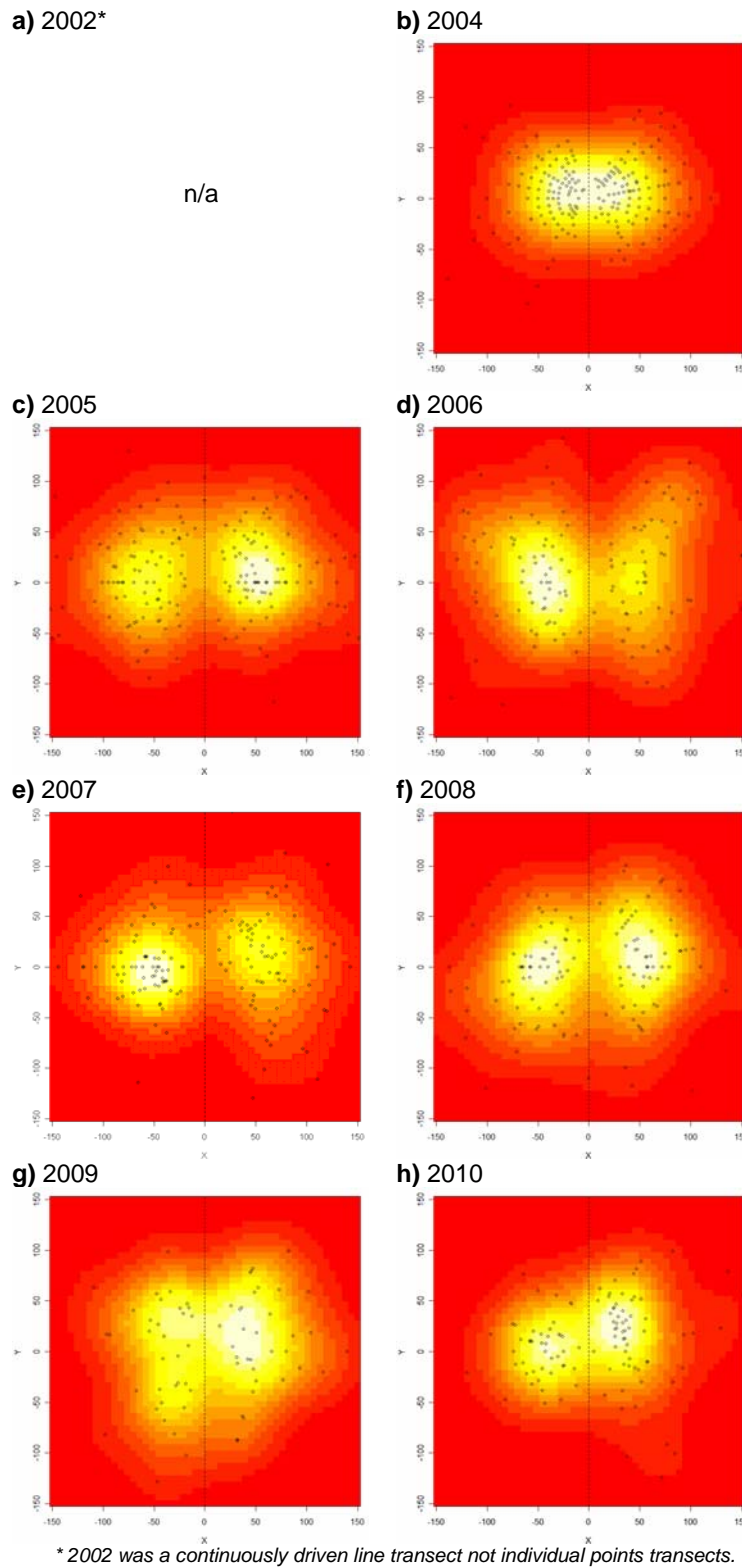


Fig. 4 Relative position of hares detected from point transects on 100km long meta-transects with respect to the road (represented as a dashed line) during **a)** 2002 **b)** 2004 **c)** 2005, **d)** 2006, **e)** 2007, **f)** 2008, **g)** 2009, **h)** 2010. The observer was located at 0,0 and colours represent a kernel density (highest relative density being white and lowest being red).

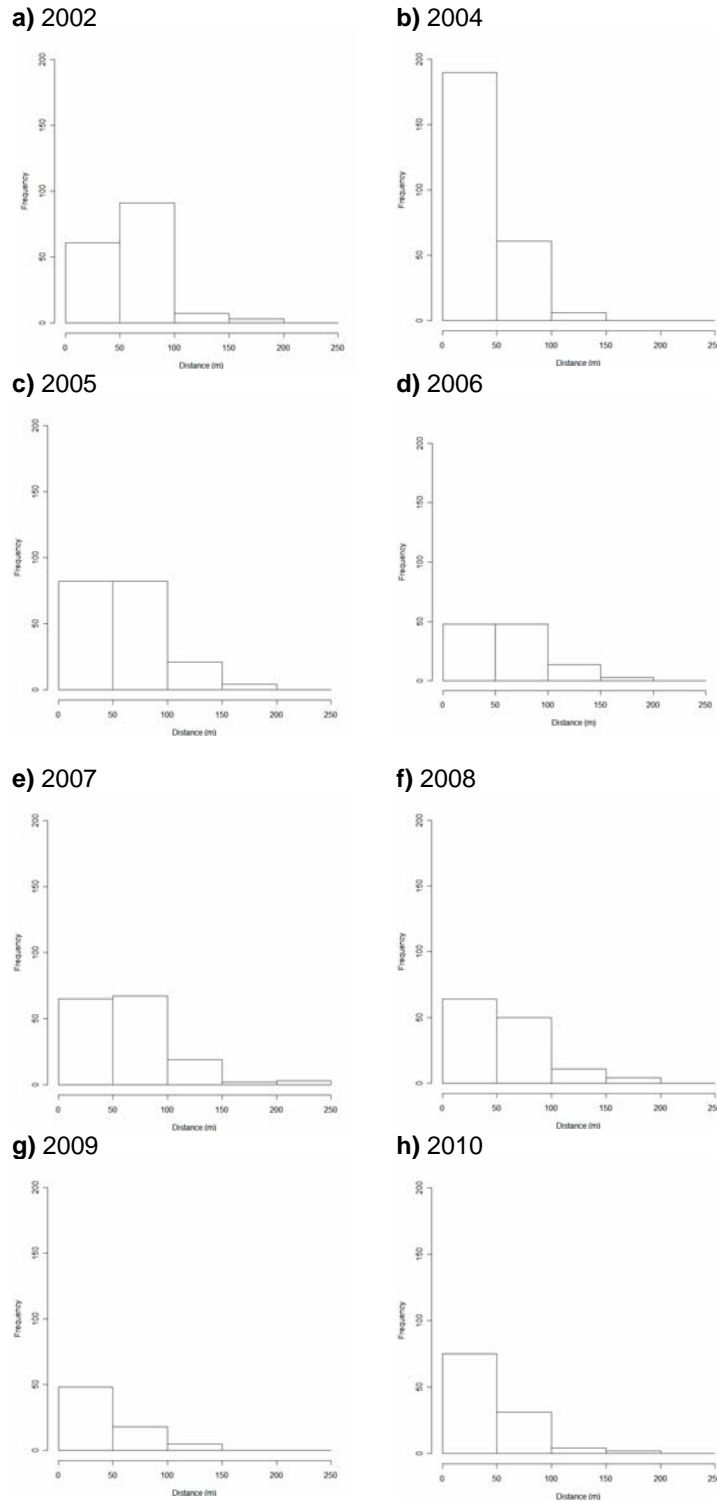


Fig. 5 Perpendicular distances of hare detections from the road (represented as the distance value 0 during **a)** 2002 **b)** 2004 **c)** 2005, **d)** 2006, **e)** 2007, **f)** 2008, **g)** 2009, **h)** 2010. From 2004-2010 positive values represent detections on the right-hand side of the road and negative values represent detections on the left-hand side of the road. Angle data were collected during 2002 so all values are represented as positive. Note that maximum values on the y-axis varies.

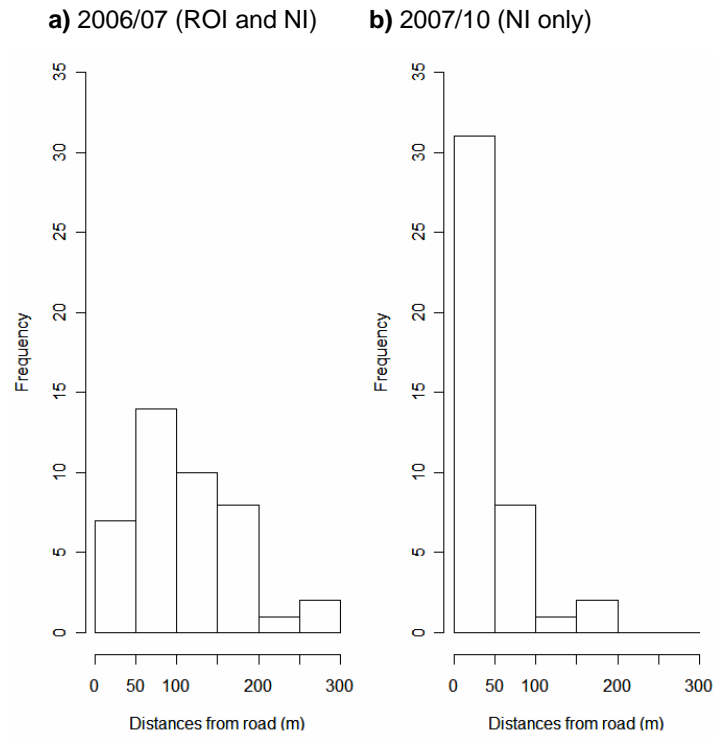


Fig. 6 Perpendicular distances of hare detections on transfield transects during **a)** 2006/07 (including ROI and NI) and **b)** 2007/10 (NI only).

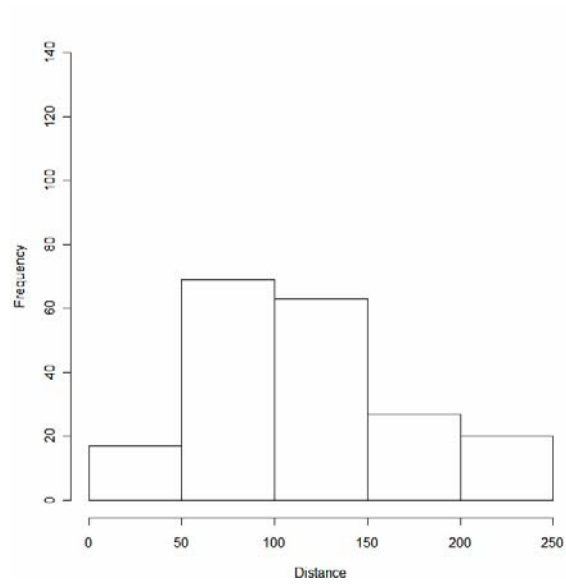


Fig. 7 Histogram of transfield transect length for 2007/10 (Northern Ireland only). Transects <250m have been truncated.

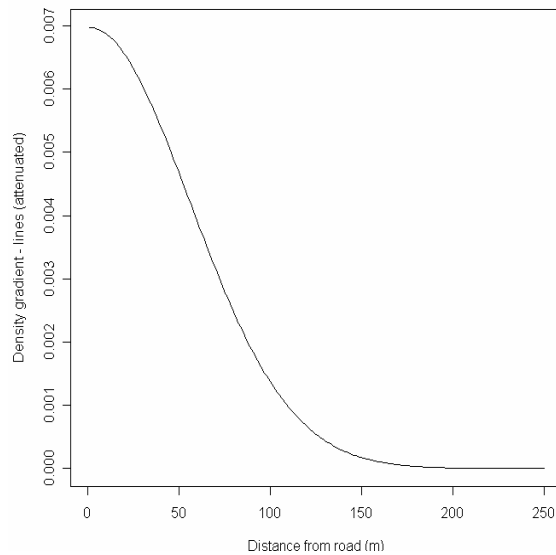
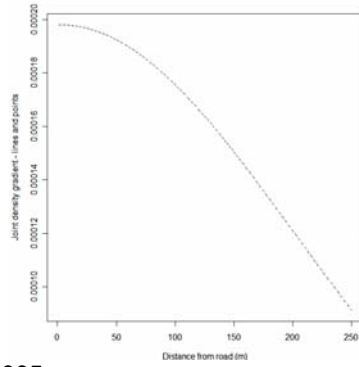
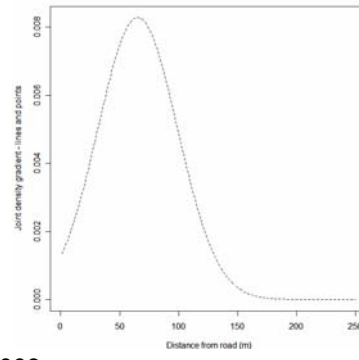


Fig. 8 Density gradient based on transfield transects (2007/10 combined) adjusted for attenuation due to varying transfield transect length (i.e. field width).

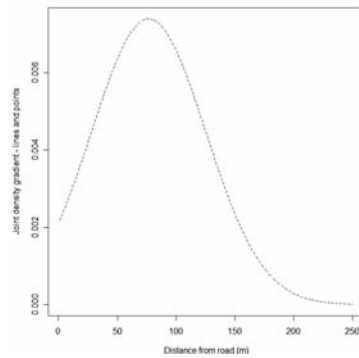
a) 2002 (excludes survey effort)



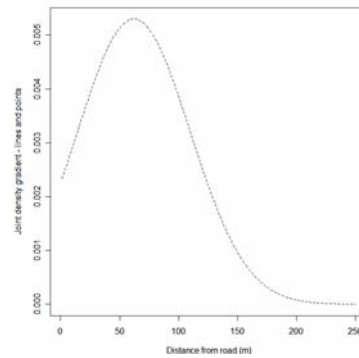
b) 2004



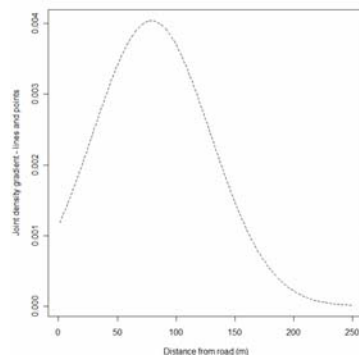
c) 2005



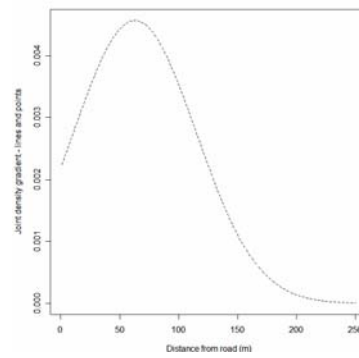
d) 2006



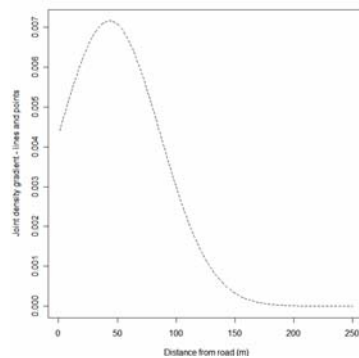
e) 2007



f) 2008



g) 2009



h) 2010

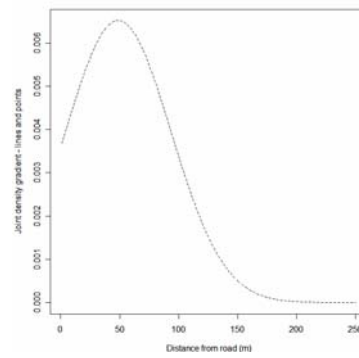


Fig. 9 Joint density gradient from transfield transects (2007/10 combined) adjusted for attenuation due to varying transfield transect length taken together with that derived from line transects during a) 2002 and point transects during b) 2004 c) 2005, d) 2006, e) 2007, f) 2008, g) 2009, h) 2010

Table 3 Estimates of mean density and total abundance of Irish hares from 2002 to 2010 stratified by habitat.

Year	Habitat category	Estimated mean density hares/km ² (95%CI)	Estimated total abundance Numbers (95%CI)
2002*	Total	1.0 (0.2 - 2.4)	6,100 (2,200 - 7,000)
2003	No survey	No survey	No survey
2004	Pastoral farmland	7.4 (5.6 - 27.0)	77,500 (44,600 - 216,800)
	Mixed farmland	5.7 (3.7 - 25.0)	13,700 (9,200 - 52,600)
	Bog, moor, heath & marsh	4.7 (1.6 - 20.6)	7,600 (2,700 - 33,800)
	Other	3.3 (1.2 - 18.9)	400 (200 - 3,200)
	Total	6.9 (5.2 - 25.0)	83,600 (63,100 - 296,900)
2005	Pastoral farmland	4.8 (3.4 - 19.1)	38,800 (27,500 - 152,900)
	Mixed farmland	2.1 (1.3 - 11.9)	5,100 (3,200 - 28,400)
	Bog, moor, heath & marsh	2.1 (0.9 - 23.6)	3,500 (1,500 - 38,800)
	Other	2.1 (1.7 - 16.1)	300 (200 - 2,100)
	Total	4.0 (2.8 - 16.1)	49,000 (34,400 - 196,500)
2006	Pastoral farmland	2.1 (1.2 - 8.3)	16,400 (9,900 - 66,500)
	Mixed farmland	0.8 (0.7 - 0.8)	3,000 (1,300 - 12,900)
	Bog, moor, heath & marsh	0.8 (0.5 - 4.1)	1,284 (800 - 6,700)
	Other	2.6 (0.8 - 13.2)	300 (100 - 1,700)
	Total	1.9 (1.1 - 7.6)	22,700 (13,700 - 92,500)
2007	Pastoral farmland	4.2 (1.4 - 15.7)	33,600 (11,500 - 125,500)
	Mixed farmland	3.4 (1.0 - 18.9)	8,200 (2,500 - 45,100)
	Bog, moor, heath & marsh	2.0 (0.7 - 5.1)	3,200 (1,200 - 8,400)
	Other	1.5 (0.4 - 6.2)	200 (50 - 800)
	Total	3.8 (1.4 - 14.3)	46,800 (17,400 - 173,600)
2008	Pastoral farmland	2.3 (1.6 - 9.4)	18,300 (12,900 - 75,500)
	Mixed farmland	1.8 (0.9 - 8.7)	4,400 (2,200 - 20,800)
	Bog, moor, heath & marsh	0.7 (0.5 - 5.0)	1,100 (800 - 8,300)
	Other	0.9 (0.7 - 12.3)	100 (90 - 1,600)
	Total	2.1 (1.5 - 8.9)	25,700 (18,400 - 108,400)
2009	Pastoral farmland	1.4 (1.1 - 6.1)	11,400 (8,700 - 48,700)
	Mixed farmland	1.0 (0.2 - 5.4)	2,300 (500 - 12,800)
	Bog, moor, heath & marsh	1.8 (0.7 - 8.2)	3,000 (1,100 - 13,400)
	Other	1.6 (1.6 - 14.9)	200 (200 - 1,900)
	Total	1.4 (1.1 - 6.1)	16,600 (12,100 - 72,500)
2010	Pastoral farmland	3.4 (1.0 - 15.8)	27,400 (7,800 - 126,500)
	Mixed farmland	3.4 (1.0 - 17.6)	8,100 (400 - 2,600)
	Bog, moor, heath & marsh	2.5 (1.9 - 13.8)	4,100 (3,100 - 22,600)
	Other	2.9 (2.7 - 20.0)	400 (400 - 2,600)
	Total	3.4 (1.0 - 15.1)	40,900 (12,600 - 183,800)

* 2002 was a continuously driven line transect, therefore, habitat breakdown was unavailable.

¹ Estimates correspond to the unverifiable assumption that density within 250m of the road is representative of the rest of the countryside.

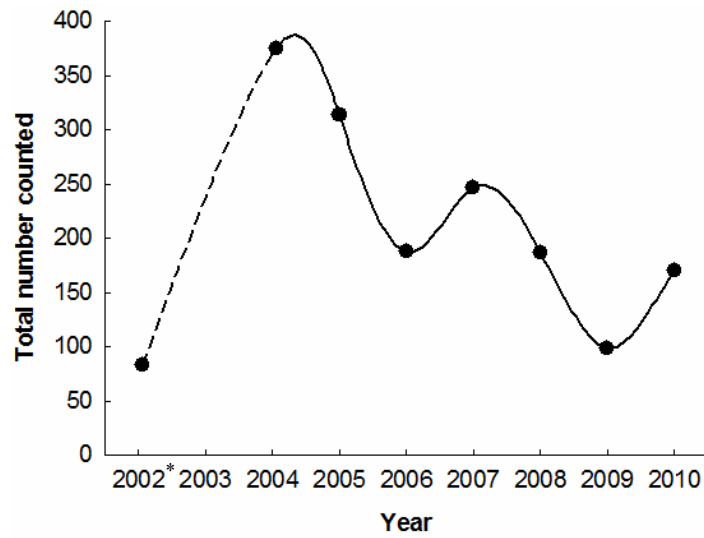


Fig. 10 Total number of Irish hares observed during Northern Ireland Irish hare surveys from 2002 to 2010. The line is a smoothed spline between the points. *Total numbers during 2002 were calibrated for the distance driven for comparability (Reid et al. 2007; 2010) and the line through 2003 was interpolated.

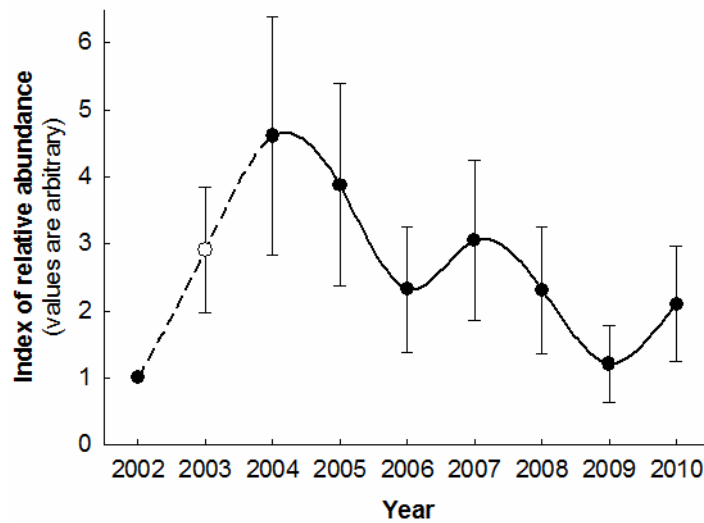


Fig. 11 Index of the total number of Irish hares observed during Northern Ireland Irish hare surveys from 2002 to 2010. The line is a smoothed spline between the points. *Total numbers during 2002 were calibrated for the distance driven for comparability (Reid et al. 2007; 2010) and the value for 2003 was interpolated using TRIM.

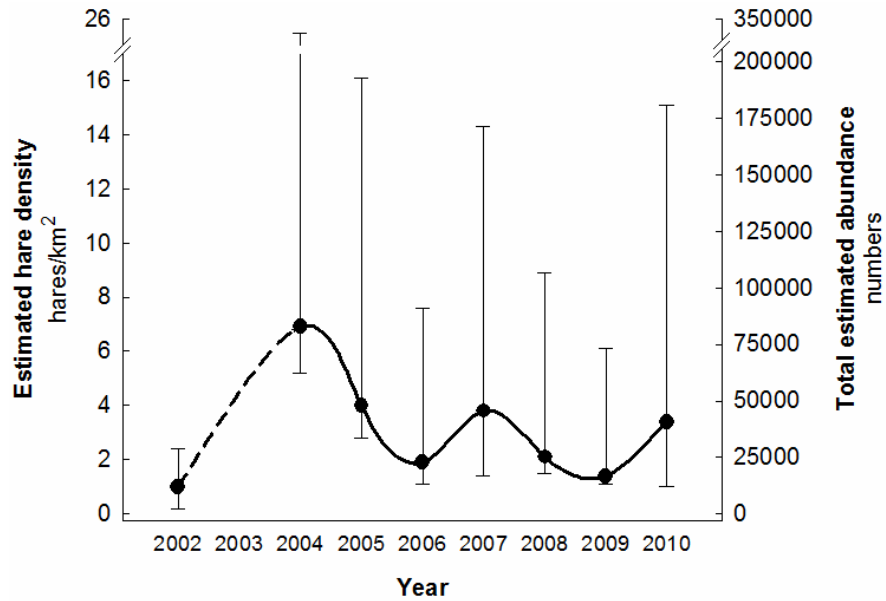


Fig. 12 *Estimated mean density and abundance of Irish hares derived from custom distance analysis of the Northern Ireland Irish hare surveys from 2002 to 2010. The line is a smoothed spline between the points and was interpolated through 2003.*

DISCUSSION

Night-driven, spotlight surveys were the only realistic method for gathering Irish hare abundance data throughout Northern Ireland. Moreover, Distance-sampling was one of few survey techniques that enabled reasonable estimates of animal density to be made (Buckland, *et al.*, 2004). However, repeated analysis of Irish hare survey data, whether from the Northern Ireland Irish hare Surveys 2002 to 2010 or the Hare Survey of Ireland 2006/07 have shown that conventional distance analyses are inappropriate for use with data collected from roads throughout the Irish landscape (Marques & Borchers, 2006; Paxton *et al.* 2007; Paxton & Borchers, 2010).

Specifically, roads may provide a biased sample of hare density as they may avoid disturbance from human activity or the act of surveying. Moreover, the Irish landscape presents significant problems in unbiased sampling due to hedgerows obscuring vision from point transects whilst hares themselves may not distribute themselves uniformly with respect to hedgerows. These technical difficulties present substantial challenges in producing unbiased estimates of density and abundance and require tailored custom Distance analyses to account for potential sources of bias.

Custom Distance analysis provides a more realistic measure of uncertainty surrounding mean estimates which greater certainty in the lower limits than upper limits. Conventional analysis may appear to provide robust estimates but many of the assumptions inherent to the collection and handling of the data are violated resulting in erroneously precise estimates.

Nevertheless, current methods also make a number of key assumptions, which if violated, may also lead to bias. For example, hares were detected only within the 250m strip of land adjacent to surveyed roads. We assume that the calculated density within this region is representative of the wider countryside (i.e. areas further than 250m from roads) and that extrapolation based on the availability of suitable habitat was justified. At least 65% of the countryside of Northern Ireland is within 250m of a road suggesting that the density estimates presented here are

representative of the majority of the country (N. Reid unpublished data). Typically, those areas not within 250m of a road are isolated upland areas of bog, moor, heath or marsh or other marginal habitats which generally had lower estimates of mean density than pastoral farmland or mixed farmland. Nevertheless, if hare density was greater further from roads due to less anthropogenic disturbance it follows that the densities and abundances presented here may be underestimated.

It is clear that transfield transect data are crucial in adjusting the detection function generated from observations made from roads. Here we assume that the distribution of hares on transfield transects during 2007/10 are representative of the distribution of each year from 2002 to 2010. If this is not the case, estimates are likely to be biased.

There was a high degree of congruence between the Northern Irish hare population trajectories regardless of whether we examine change in the total counts, an index of total counts or the custom distance estimates of density and abundance. Whilst the numbers counted and the estimated mean density and abundance fluctuated from year to year, there was no evidence for any discernable temporal trend.

It must be acknowledged that estimating absolute abundance with any degree of precision is extremely difficult and our best attempts have yielded estimates with unsatisfactorily wide margins of error. Nevertheless, the estimated mean density of hares during 2010 was 3.4 hares/km² (95%CI 1.0 - 15.1) giving a total of 40,900 hares (95%CI 12,600 - 183,800). This estimate is 5.2 times greater than the estimated density produced during the mid-1990s of 0.65 hares/km² (Dingerkus 1997; Dingerkus & Montgomery, 2002) and 2.6 times greater than the Species Action Plan target of 1.54 hares/km².

Taken at face value it appears that the main target of the Northern Ireland Species Action Plan, published in 2000, to “*double [the] present population by 2010*” has been achieved. However, there are two important caveats:

- 1) The estimate of density for the mid-1990s was derived from day-walked transects (Dingerkus, 1997; Dingerkus & Montgomery, 2002). Hares are usually inactive during daylight hours and detecting them depends on

flushing them from their diurnal lie-up site. This is often in heavy cover, such as rushes (*Juncus* spp.), and their flushing distances may vary with habitat type and local levels of anthropogenic disturbance (Hutchings & Harris, 1995). Moreover, a simple multiplicative model was used to estimate population density which did not account for variance in detectability. Therefore, it is highly likely that the estimate produced for the mid-1990s was negatively biased and should be treated as a baseline only with caution.

- 2) Hare populations elsewhere are characterised by interannual and multiannual fluctuations (Elton & Nicholson, 1942; Keith, 1963; Krebs *et al.* 1986; Keith, 1990; Ranta *et al.* 1997; Krebs *et al.* 2001). Indeed, long-term historical data from Irish hare gamebag records suggest that the species demonstrated substantial interannual and multiannual fluctuations in the past (Reid 2006; Reid *et al.* 2007). Furthermore, it has been suggested that Irish hare populations may well have inherent periodicity or cyclicity, even in recent times (Reynolds *et al.* 2006). Therefore, any changes observed from 2002 to 2010 in either the total number of hares counted or estimates of density and abundance are congruent with expected levels of variance. Interpretation of trends within short-term time-series should be avoided as data from individual years may have greater leverage on trends than within long-term time-series.
- 3) A paucity of data on the impact of hunting, grassland management and the efficacy of conservation strategies on Irish hare populations makes difficult to interpret any change in mean estimates of density or abundance. There are no data to suggest that such variance is attributable to conservation effort or is anything other than natural fluctuation.

Prior to the publication of the Northern Ireland and All-Ireland Irish hare Species Action Plans (Anon, 2000; 2005) only one estimate of hare density and abundance had been made and no work had been conducted examining best practise regarding survey methodology. The main achievement of the SAPs has been to stimulate Irish hare research.

RECOMMENDATIONS

It is relatively simple to determine temporal changes in relative abundance but it is difficult to determine absolute abundance with a satisfactory degree of accuracy or precision. Future surveys must, therefore, explicitly state their main objective.

Ideally, the best method for estimating absolute hare numbers avoiding the sources of potential bias by sampling from roads would be to conduct surveys from line transects placed randomly throughout the countryside. Notwithstanding the difficulties of doing so, we recommend that such a method be used as it may provide more reliable and unbiased estimates. The reliability of road-based surveys is questionable and such estimates rely strongly on untested assumptions. If, however, random sampling is deemed impossible for reasons of logistics or Health & Safety, we recommend road based surveys are adapted to include:

- 1) *Uniformly distributed 1km meta-transects are employed rather than regionally distributed 100km meta-transects as they provide a more geographically representative sample and have greater statistical independence.*
- 2) *A formal test of the assumption that the density of hares within 250m of the road is representative of the density in the wider countryside This can only be done reliably by conducting at least one survey with randomly placed lines.*
- 3) *Transfield transect data that are collected contemporaneously with point transects located on roads to estimate the true density of hares with respect to the road. Transfield surveys should be located at random.*
- 4) *A measure the direction of sampling effort must be collected for all point transects in addition to a measure of total survey effort (Field of View).*
- 5) *A measure of change in relative abundance should be provided for comparison with Distance-sampling results to ensure changes over time between both methods are congruent.*
- 6) *If new methods are developed they are deployed synchronously with standard hare survey methods in the first instance to allow comparison with previous estimates.*

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