Lesser Horseshoe Bat:

Population, Trends and Threats 1986 to 2012

Final Report, November 2012

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INTRODUCTION

Counts at lesser horseshoe (*Rhinolophus hipposideros)* winter and summer roosts have been undertaken principally by staff of the National Parks and Wildlife Staff (NPWS) and the Vincent Wildlife Trust (VWT) at lesser horseshoe sites across the main counties of its known Irish distribution Mayo, Galway, Clare, Limerick, Kerry and Cork.

Data is collected and stored by the NPWS on a yearly basis, and data cleaning and processing has been carried out regularly. However, to-date there had been no review of overall population trends or comprehensive data trawling to determine more fully the pressures or activities that may be impacting lesser horseshoe bats across their range in Ireland.

Bat Conservation Ireland (BCIreland) in 2012 is compiling a book on the State and Distribution of Irish Bats and requested to be permitted to carry out analyses of the lesser horseshoe data in order to inform the chapter on this species for the publication. Since this also dovetailed with the need to review the status of the lesser horseshoe bat for EU Article 17 reporting in spring 2013, the NPWS and BCIreland co-operated in carrying out the present project.

In June 2012 Bat Conservation Ireland received the lesser horseshoe bat dataset from NPWS (MS Excel format) that comprised of 3194 records for multiple sites dated from the 1970s to 2012. The majority of records were collected from 1990 onwards, however.

As part of the project the following points were addressed:

- Index of counts for summer and winter sites and GLM/GAM modelling to determine population trends.
- TRIM analysis in order to facilitate integration in the European Bats as Indicators project.
- Power Analysis
- Activities and threats at roosts

METHODS

Monitoring of lesser horseshoe sites in Ireland has been carried out for several decades, although sample sizes were small initially. Wintering sites were counted from December to February, although in 2006 the range of suitable dates for winter counts was restricted to January and February. There was also a shift in dates when summer counts were carried out. Prior to 2001 counts were spread across the active season for bats, including August. From 2001 to 2005 counts were not, for the most part, carried out in the month of August. From 2006 onwards, two counts were required to be carried out between May 23rd and July 7th. Counts in summer are usually carried out with a tally counter and bat detector while winter counts entail visual estimation of torpid bats using torchlight.

Data collected during the lesser horseshoe monitoring scheme is entered onto a tailor-made MS Excel spreadsheet and data from this is, in turn, entered into a centrally held MS Access database. For the purposes of the present review a spreadsheet with 3194 records from 835 discrete sites were provided to BCIreland. Some data cleaning was carried out in order to facilitate statistical analysis. This included:

- Deletion of records of other bat species (28 records).
- Amendment of dates – where month and year was specified this was modified to 15th of each month, one count listed as 30/02/1994 was amended to 20/02/1994 (96 records).
- Deletion of records where no date, just year or range of years given (271 records).
- Amendment of count values where text and number are listed (e.g. c20, 30-40 or 40+) to the minimum value (i.e. 20, 30 and 40, respectively) (41 records).
- Deletion of records where other textual information was provided instead of counts (31 records).
- For assessment of activities and population estimation, counts of 100 bats for site codes 653 and 654 in 2008 were replaced with zero since they were found to be erroneous.

Therefore, 2,864 records were available for statistical and other data analysis. The earliest record on the cleaned database is from 1978, although data was first collected and recorded systematically for sites in Clare in 1983.

STATISTICAL ANALYSIS

The statistical software, Genstat, was used to carry out trend, power and simulation analyses. TRIM (Trends and Indices in Monitoring Data, Statistics Netherland) was used for comparative trend analysis. Data mining and ancillary analyses were carried out using R (Development Core Team, 2008).

SUMMER COUNTS

Counts between May and August inclusive were used, from 1997 onward; before 1997 comparatively few valid counts were made. A Poisson Generalised Linear Mixed Model (GLMM) was used to model numbers in the May to August period, primarily in order to explore the trend over the season and hence investigate the potential for including records outside the official survey period (May23rd to July 7th).

Generalised Additive Model (GAM) smoothing was applied to yearly estimates from the GLMM to estimate significant trend changes and direction.

Winter Counts

A Poisson Generalised Linear Model was used to model numbers, primarily to check for seasonal patterns which might impact on trend estimates.

TRIM vs GAM

The winter and summer count datasets were entered into TRIM (Trends and Indices for Monitoring Data, Statistics Netherlands) for a comparison of trend analysis using the TRIM and GAM methods. The automatic (all changepoints) method was selected in TRIM.

In addition, simulations were carried out using variances based on National Bat Monitoring Programme (Bat Conservation Trust, UK) lesser horseshoe counts. Three different simulation methods were used:

- Using a Poisson distribution based on variances from a GLMM of lesser horseshoe counts, but without any over-dispersion. This gives a perfect Poisson distribution and is far less skewed than real bat data.
- As above, but with a single extreme outlier added to each simulated dataset by replacing the maximum value with a zero. This reveals the impact of an extreme outlier on the analyses.
- Based on a log-normal distribution using variances from a log-normal REML analysis of the lesser horseshoe counts. This produces a skew distribution similar to the real distribution of counts.

Each simulation produces values for 100 sites in 15 years. The 'unsmoothed' models were fitted; i.e. annual GLM estimates with bootstrapping at the site level for the 'GAM', and a TRIM model with all possible changepoints. The TRIM model estimated over-dispersion and serial correlation. Simulations were run with and without a linear trend, but results below are for the situation without any added trend.

Power Analysis

Simulations are based on the variance components from a Residual Maximum Likelihood (REML) model of bat counts per survey, transformed using normal scores (see for example Armitage and Berry, 1987) and estimating variances for sites, sites within years and replicate surveys within sites within years. Data are simulated using these variance estimates and back-transformed to the original scale after adding suitable year effects in order to produce the required long-term trend. Uncertainty in the estimates of variances can lead to erroneous estimates of power (Sims *et al*. 2006) and so each simulated dataset is based on variance estimates taken from a bootstrapped version of the original dataset, thus ensuring that the power results are effectively averaged over a range of plausible values of the variance estimates.

GAM models are then fitted to the simulated data, using bootstrapping to produce a one-tailed test for a decline at $P = 0.05$ (equivalent to $P = 0.1$ for a two sided test). Calculations are based on a GAM analysis of trend over time (rather than REML), although a REML model is used as the basis for the simulations. In order to find the number of years required to achieve 80% power for each number of sites, a sequential method (based on a modified up-and-down method, Morgan, 1992) is used to determine the number of years of data to include in each simulated dataset, ensuring that precise estimates are obtained with the minimum number of simulated datasets. The final estimate of power is then taken from a logistic regression of the probability of obtaining a significant decline against the number of years of data included in the simulation.

All GAM curves used the default degrees of freedom (0.3*nyears). Because GAM trends are estimated with less precision in the first and last years of a series, the second year is used as the base year in the simulations, and the trend is estimated up to the penultimate year.

Results

Summer Count Trends

Counts between May and August inclusive were used, from 1997 onward; before 1997 comparatively few valid counts were made. There were a large number of roosts visited only once, usually with no bats recorded. After excluding sites where lesser horseshoes were never seen, and those only visited in a single year, 171 sites remained to contribute information on trends. Many of these sites were only recorded in two or three years, with only about a quarter counted in more than six years (Table 1).

Table 1: Numbers of years of data from each lesser horseshoe roost visited in two or more years.

Number of years	Number of sites	% of total	Cumulative %
2	42	24.6	24.6
3	32	18.7	43.3
4	30	17.5	60.8
5	10	5.8	66.7
6	14	8.2	74.9
7	21	12.3	87.1
8	5	2.9	90.1
9	5	2.9	93.0
10	4	2.3	95.3
11	3	1.8	97.1
12	4	2.3	99.4
13	1	0.6	100.0

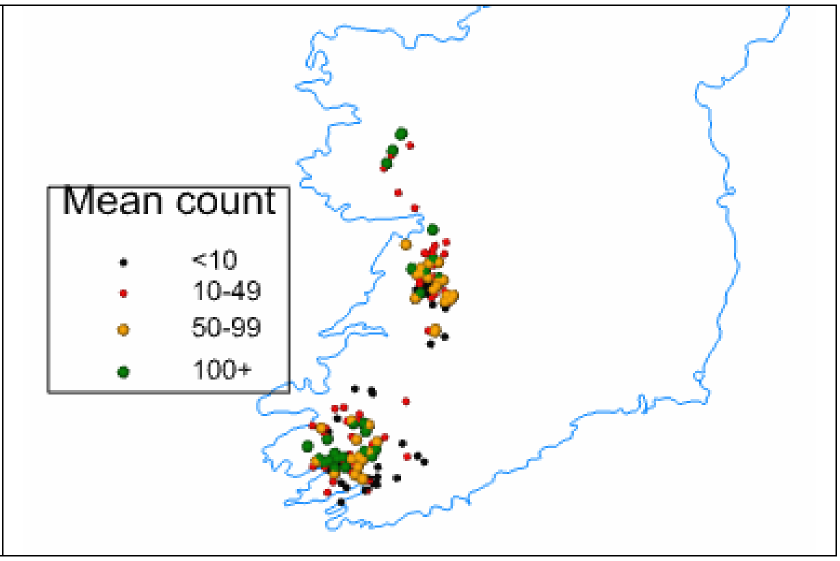
Notes: based on counts for May-August 1997 to present. Excludes sites where lesser horseshoes were not recorded in this period, and those only surveyed in a single year.

GLMM on summer counts

There was a significant increase in bat numbers during each year (May to August). This could be fitted as a linear effect of day number in year, but for presentation purposes month is fitted as an explanatory variable (Table 2a). The mean count is lowest in May, rises to a similar level in June and July, before rising again in August.

There were also significant differences between counties, with the highest counts tending to be in County Mayo and the lowest in Cork (Table 2b). This pattern is explored further in Figure 1. The high mean for Mayo is because it has six roosts with counts in two or more years, three of which are large. In view of this comparatively small sample size, not too much should be made of this and, in any case, it could be due to the selection of observed roosts (e.g. if some areas with few volunteers only counted the biggest roosts), rather than a genuine difference between counties.

Figure 1: Mean summer counts from Lesser Horseshoe roosts 1997-present.



The final term in Table 2 picks out roosts where the words 'derelict', 'disused' or 'ruin' occurred in the building type field. These buildings have significantly higher average counts.

Table 2: Effects of factors from the GLMM model. Counts of bats are shown with standard errors, as well as predicted values on the log scale, after adjusting for the effects of other factors in the model. The absolute value of the adjusted means is not informative due to the averaging over other terms, but the relative sizes indicate where the differences lie; standard errors are applicable to the log values, but back-transformed values are easier to interpret.

(a) Month ($F = 3.32$ with 3 and 449 d.f., $P=0.020$)

		Raw data		**Adjusted for other variables**		
Group	**surveys**	**mean**	**s.e.**	**log**	**s.e.**	**back-trans**
May	62	78.4	11.18	1.66	0.074	45.8
Jun	549	80.9	3.81	1.78	0.059	59.6
Jul	264	71.2	4.70	1.77	0.061	59.0
Aug	104	92.9	9.03	1.84	0.066	68.7

(b) County ($F = 5.39$ with 5 and 167 d.f., $P<0.001$)

		Raw data		**Adjusted for other variables**		
Group	**surveys**	**mean**	**s.e.**	**log**	**s.e.**	**back-trans**
Clare	249	73.6	4.50	1.83	0.080	67.7
Cork	170	34.5	3.13	1.36	0.099	23.0
Galway	63	56.2	5.36	1.79	0.160	61.6
Kerry	394	88.2	4.72	1.78	0.056	60.7
Limerick	32	51.6	8.00	1.55	0.163	35.7
Mayo	71	191.4	12.65	2.25	0.184	176.6

(c) Disused buildings ($F = 4.77$ with 1 and 165 d.f., $P=0.030$)

		Raw data		**Adjusted for other variables**		
Group	**surveys**	**mean**	**s.e.**	**log**	**s.e.**	**back-trans**
disused, derelict or in disrepair	288	104.7	6.10	1.86	0.088	72.1
Others	691	68.8	2.88	1.66	0.057	46.2

GAM MODELS FOR SUMMER TREND

In terms of a trend model, the effects revealed by the GLMM for disused buildings and for counties are of no consequence, since they do not vary within a site (although the former could do so in theory) and so cannot directly affect the trend estimate. By contrast, the within season temporal effect, fitted in the GLMM model by month, has the potential to influence trend estimates. This is a particular problem in this case because, as the box plot in Figure 2 shows, there has been a change in when summer counts have been carried out over time; up to 2000 the median time was around day number 200 (around 19th July). It then moved forward by ten days or so up to 2006, when a further shift took the median to around 175 (around 24th June). This will inevitably have an impact on the observed trend, since the counts would be liable to fall as counting dates were, on average, brought forward. The precise impact of this on the trend is difficult to quantify; whilst fitting month suggested a period of stability in June-July (Table 2a), an alternative linear model is not inconsistent with the data, and this would give a greater impact.

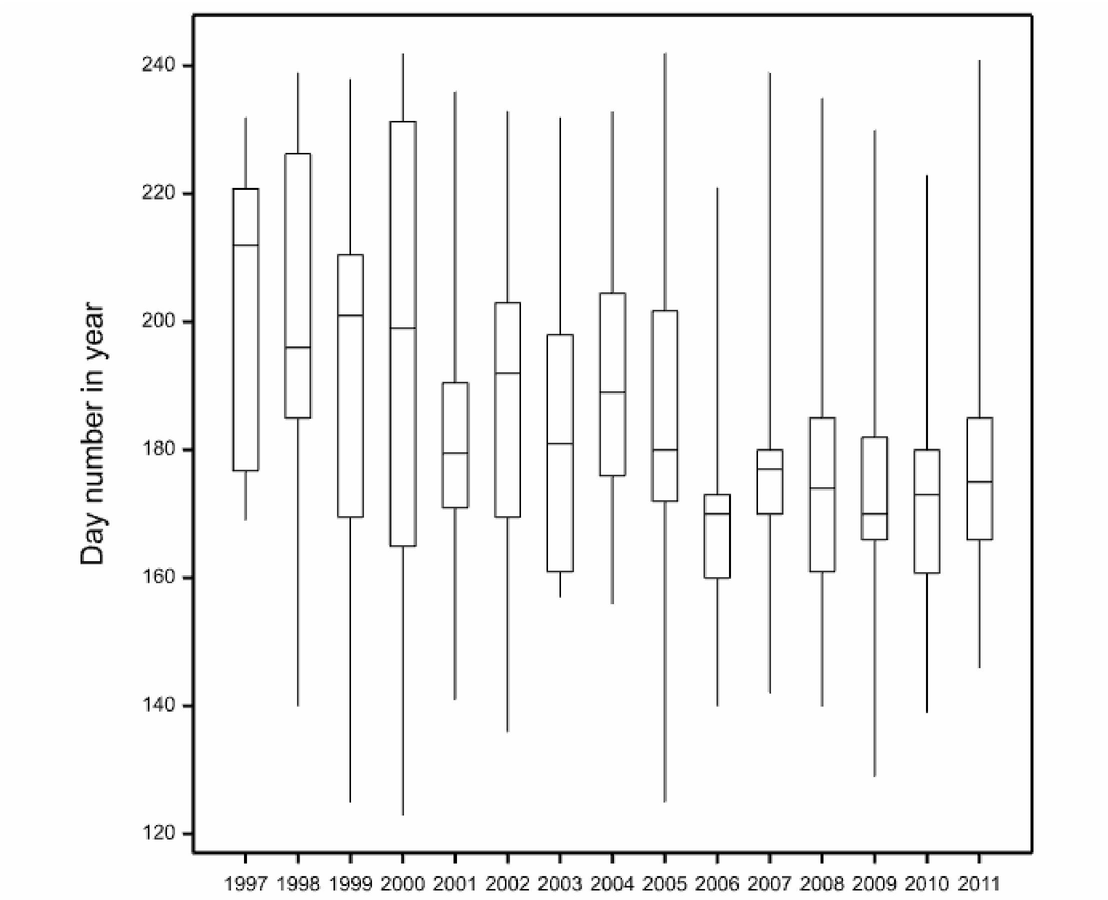


Figure 2: boxplot of day number in year for summer (May-August) counts from 1997-2011. The whisker shows the full range of dates and the box shows the range from the lower to upper quartile. The median is the line across the box.

One way to reduce the impact of the changing count period is to only include counts in, or close to the current survey period. Figure 3 and Table 3 show results based on surveys between days 137 (16/17th May) and 194 (12/13th July), which gives around a week either side of the specified dates. Whilst the 95% confidence limits always enclose 100, indicating that index values in earlier years are never significantly less than the 2009 value, there is a significant upward trend in 2003, 2004 and 2005. Results with day number as a covariate are not given as they are very similar to results without covariates in Table 3.

One point to note is that 2009 is used as the base year for these results. It is more common to use a base year at the start of the time series however, with this dataset, numbers of sites are much lower in the early years, and it is important to have good precision for the base year. 2009 has a very large sample size and also is not too near the end of the series; using the final year can give unreliable results, particularly if this is an outlier.

Table 3: GAM results with 95% confidence limits (138 sites contribute to the trend). Results for surveys between day 137 and 194 (where 1st Jan is day 1), without covariates.

					Index 2009 = 100					
					smoothed		**95% conf limits**		**unsmoothed**	
year	**counts**	**Sites**	**Mean**	**s.e.**	**estimate**	**s.e.**	**lower**	**upper**	**Estimate**	**s.e.**
1997	8	8	98.0	27.3	80.3	12.9	57.5	107.4	74.4	14.7
1998	8	7	75.4	28.5	80.8	11.8	60.8	107.3	90.2	22.7
1999	29	27	54.5	11.9	80.8	11.0	63.4	106.2	91.6	21.1
2000	7	6	77.7	31.1	80.4	10.3	64.5	104.4	76.0	22.0
2001	40	26	93.5	11.5	80.8	9.9	65.8	103.8	79.1	12.8
2002	21	18	86.2	15.5	83.2	9.4	68.9	105.0	73.2	12.3
2003	23	15	72.5	17.6	87.8	9.0	74.1	108.7	94.1	17.0
2004	34	27	63.3	10.4	92.9	8.5	79.5	112.4	97.3	12.0
2005	18	12	61.8	7.3	97.1	7.5	84.7	114.0	111.2	17.0
2006	111	105	70.3	7.8	99.6	5.9	89.8	112.7	99.3	7.5
2007	42	40	66.2	11.6	100.8	3.8	94.3	109.0	107.1	12.9
2008	73	57	112.8	11.6	100.7	1.6	97.8	104.1	100.8	7.1
2009	131	107	81.3	8.2	100.0	0.0	100.0	100.0	100.0	0.0
2010	56	43	115.8	15.3	99.1	1.5	96.1	102.1	102.8	5.7
2011	113	90	87.0	8.3	97.7	3.6	90.9	105.0	97.9	5.4

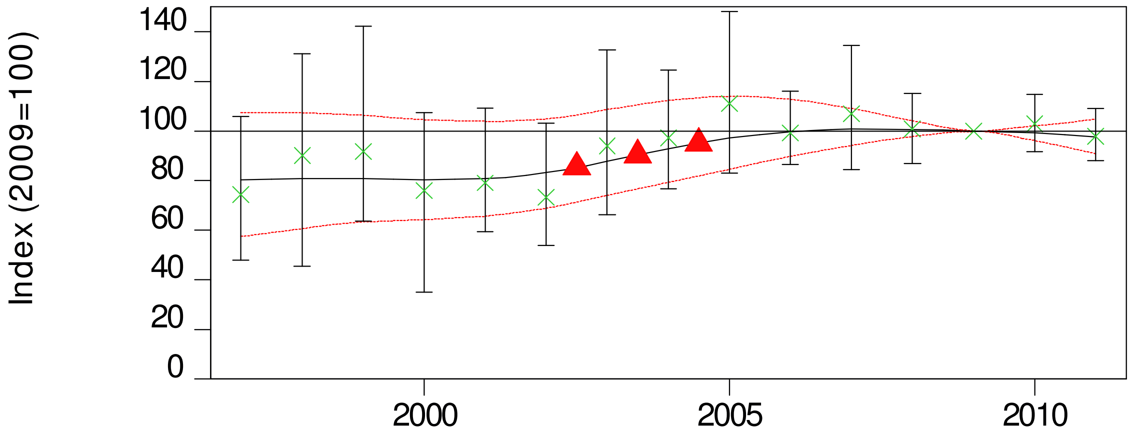


Figure 3: GAM results with 95% confidence limits (including days 137-194 only). Green points are estimated annual means and are shown to illustrate the variation about the fitted line. Red stars indicate significant (P<0.05) change points, where the slope of the smoothed trend line changes. Red triangles indicate that the upward or downward trend is significant between years.

Whilst these results are encouraging from the perspective of the ability of the monitoring system to detect changes, sample sizes are smaller than is desirable in the earlier years. Figure 4 and Table 4 therefore displays results for the whole May-August period, with and without a covariate for day number in year. Including the covariate does make a difference. The results with the covariate results similar to those in Figure 3 in terms of the significant increases in 2003 to 2005, whereas these increases are not significant without it, perhaps due to the distortion created by the change of median survey day (Figure 2). With the covariate, index values for 2001 and earlier are significantly different from 2009, as can be seen from the fact that the upper 95% limit on the smoothed trend is below 100.

The other benefit of increasing the count period is that numbers of sites are much greater in the earlier years, and this has made it possible to extend the series back to 1992, albeit with very small numbers of sites before 1997. These results suggest that there were significant increases in the period 1993-95, although this result should be treated with caution, given the less than ideal number of sites surveyed.

Figures 3 and 4 show the full information from the GAM analysis, including tests for changes between successive years, and 'change points' where the trend changes (there are none of the latter significant with this data).

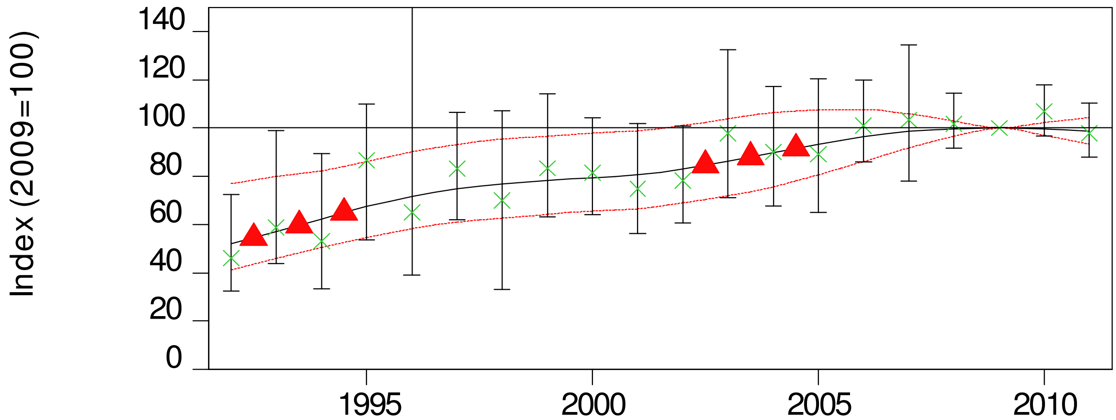


Figure 4a: GAM results with 95% confidence limits (all summer data May-Aug), with day number as covariate. Green points are estimated annual means and are shown to illustrate the variation about the fitted line. Red stars indicate significant (P<0.05) change points, where the slope of the smoothed trend line changes. Red triangles indicate that the upward or downward trend is significant between years.

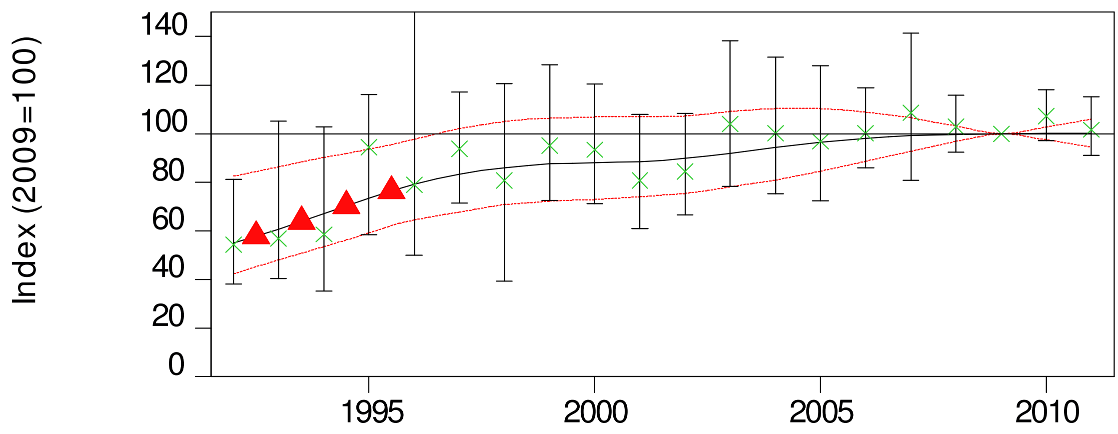


Figure 4b: GAM results with 95% confidence limits (all summer data May-Aug), no covariates.

Table 4: GAM results with 95% confidence limits (177 sites contribute to the trend). Results for all surveys between 1st May and 31st August.

With covariate for day number.

					Index 2009 = 100					
					smoothed		**95% conf limits**		**unsmoothed**	
year	**counts**	**Sites**	**Mean**	**s.e.**	**estimate**	**s.e.**	**lower**	**upper**	**estimate**	**s.e.**
1992	16	12	75.5	18.5	51.9	9.3	41.4	77.2	46.0	10.2
1993	23	10	80.3	14.1	57.0	8.6	46.1	80.0	58.8	13.8
1994	12	9	87.4	19.8	62.3	8.2	50.7	82.4	53.1	14.7
1995	17	13	95.2	24.0	67.4	8.0	54.7	86.2	86.8	13.8
1996	3	3	73.3	23.3	71.7	8.0	58.4	90.3	65.1	93.9
1997	30	22	96.1	15.4	74.8	8.2	61.1	93.3	83.3	11.3
1998	25	19	58.3	17.1	76.9	8.3	62.8	95.6	69.9	19.4
1999	80	60	56.4	7.6	78.3	8.3	64.4	96.8	83.4	13.1
2000	45	38	86.2	11.5	79.3	8.3	65.8	98.0	81.4	10.2
2001	48	28	92.5	10.4	80.7	8.3	66.6	99.1	74.7	11.6
2002	41	37	80.3	11.7	83.0	8.3	69.1	101.1	78.3	10.3
2003	34	22	73.6	13.1	86.2	8.2	72.0	103.9	97.9	15.2
2004	55	44	72.7	11.0	89.8	7.8	75.8	106.5	90.2	13.0
2005	29	22	52.8	7.0	93.3	6.8	80.7	107.6	89.2	13.7
2006	123	117	65.3	7.3	96.5	5.4	86.2	107.6	101.1	9.0
2007	49	44	70.6	12.3	98.6	3.5	91.9	105.8	103.4	14.5
2008	84	66	106.4	10.5	99.7	1.6	96.7	102.7	101.6	5.9
2009	151	119	77.2	7.6	100.0	0.0	100.0	100.0	100.0	0.0
2010	66	46	105.4	14.1	99.7	1.4	96.9	102.5	107.0	5.3
2011	125	98	81.8	7.7	98.7	2.9	93.2	104.5	97.9	5.7

Without covariate for day number.

					Index 2009 = 100					
					smoothed		**95% conf limits**		**unsmoothed**	
year	**counts**	**Sites**	**Mean**	**s.e.**	**estimate**	**s.e.**	**lower**	**upper**	**estimate**	**s.e.**
1992	16	12	75.5	18.5	54.9	10.3	42.6	82.6	54.4	11.1
1993	23	10	80.3	14.1	60.8	9.6	48.2	86.4	56.9	16.9
1994	12	9	87.4	19.8	67.2	9.0	53.6	90.4	58.6	18.1
1995	17	13	95.2	24.0	73.5	8.7	59.3	93.7	94.5	14.5
1996	3	3	73.3	23.3	79.1	8.5	64.7	97.8	78.9	96.9
1997	30	22	96.1	15.4	83.4	8.7	67.7	102.3	93.7	11.8
1998	25	19	58.3	17.1	86.1	8.8	71.0	105.1	80.8	21.3
1999	80	60	56.4	7.6	87.5	8.8	72.3	106.6	95.2	14.4
2000	45	38	86.2	11.5	88.1	8.7	73.1	106.9	93.4	12.7
2001	48	28	92.5	10.4	88.5	8.5	74.2	107.0	80.7	12.1
2002	41	37	80.3	11.7	89.9	8.2	75.6	107.5	84.4	10.8
2003	34	22	73.6	13.1	92.1	8.0	78.2	109.2	104.0	14.8
2004	55	44	72.7	11.0	94.4	7.5	81.1	110.4	100.1	14.1
2005	29	22	52.8	7.0	96.4	6.6	84.7	110.2	96.9	14.1
2006	123	117	65.3	7.3	98.1	5.2	88.7	108.8	100.1	8.5
2007	49	44	70.6	12.3	99.3	3.5	92.9	106.4	108.7	16.5
2008	84	66	106.4	10.5	99.8	1.6	96.9	103.0	102.9	5.9
2009	151	119	77.2	7.6	100.0	0.0	100.0	100.0	100.0	0.0
2010	66	46	105.4	14.1	100.1	1.4	97.4	103.0	107.2	5.4
2011	125	98	81.8	7.7	100.1	2.9	94.3	106.2	101.6	6.1

Regional differences in summer trend

Trends were tested for a difference between the sites in Cork and Kerry and those elsewhere in the country. The two trends are shown in Figure 5; a randomisation test for the difference between them is nowhere near significant (P=0.630).

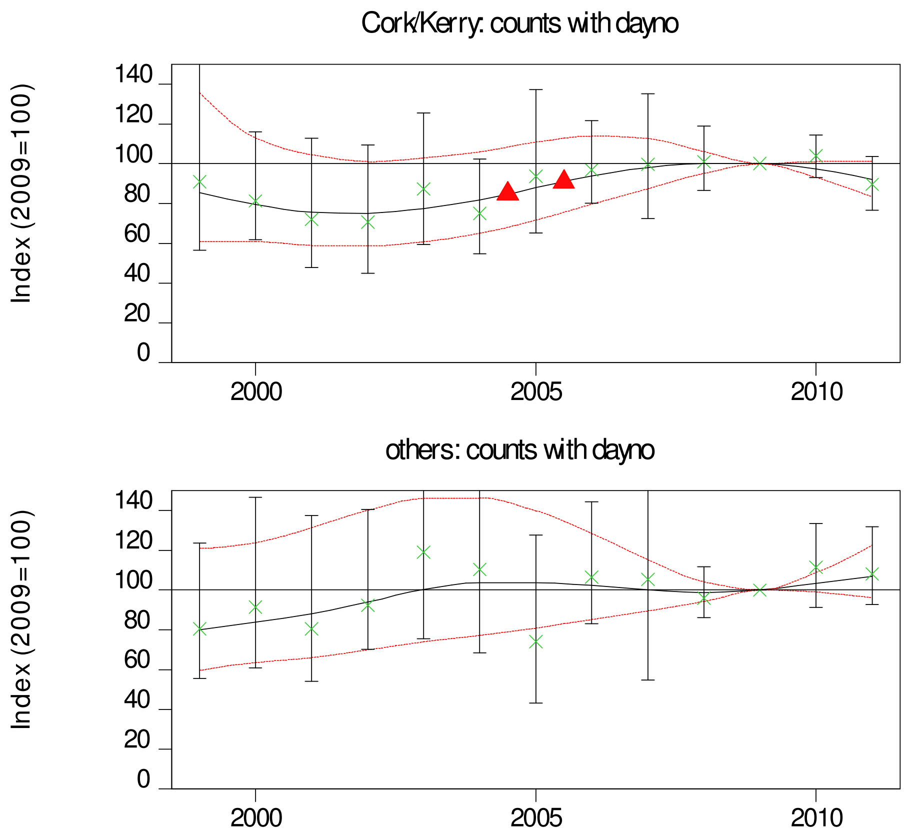


Figure 5: Regional GAM trend lines with day number as a covariate

Linear trends were also mapped, separately for 1999 to 2006 and 2006 to 2011, to see whether there was any sign of a spatial pattern. In the most recent period there seem to be a few more green spots in the Clare/Galway area, but not in sufficient numbers to convince.

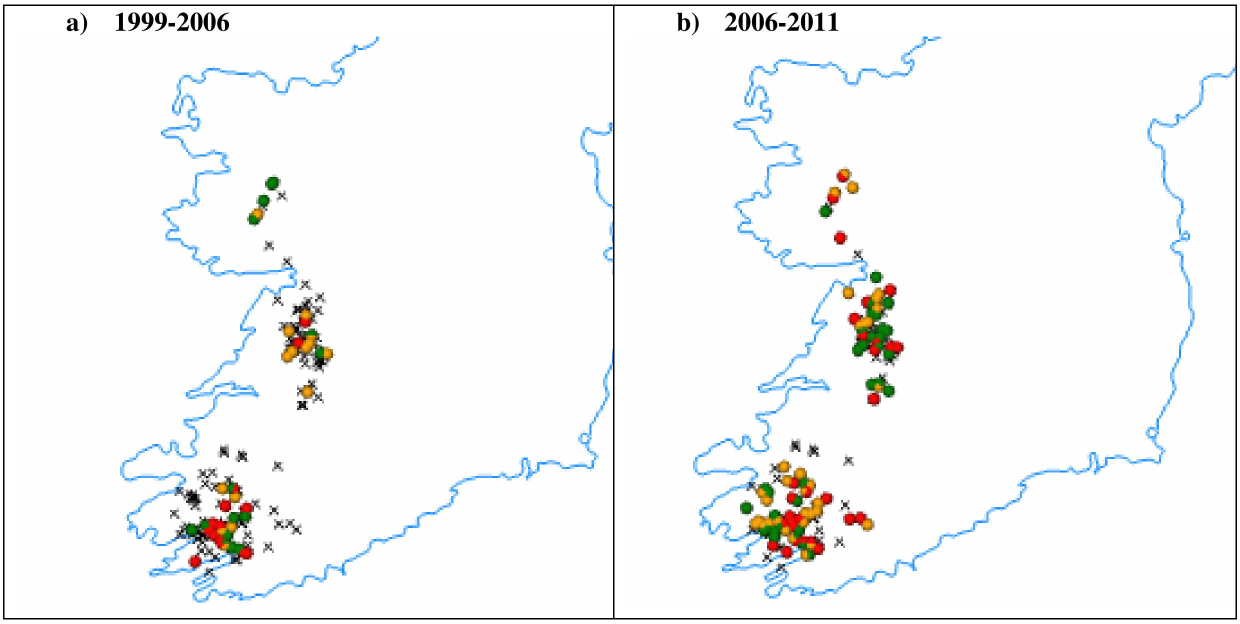


Figure 6: Spatial pattern of linear trends on log scale. Sites are divided into thirds on the basis of the linear trend for each site; red points are the most negative trends, amber the middle third, and green points the sites with the most positive trends in the appropriate period. Black crosses are sites with less than 3 years data in the period.

WINTER COUNT TRENDS

Data was handled as for the summer counts, except that only data between 26th December and 7th March (i.e. approximately a week either side of the official survey period) was used. Numbers of years from each site are shown in Table 5.

Table 5: Numbers of years of data from each winter site.

Number of years	Number of sites	% of total	Cumulative %
2	18	15.0	15.0
3	13	10.8	25.8
4	17	14.2	40.0
5	13	10.8	50.8
6	18	15.0	65.8
7	12	10.0	75.8
8	10	8.3	84.2
9	7	5.8	90.0
10	2	1.7	91.7
11	3	2.5	94.2
12	2	1.7	95.8
14	1	0.8	96.7
15	1	0.8	97.5
17	2	1.7	99.2
18	1	0.8	100.0

Notes: based on counts for 25th December to 7th March, 1986 to present. Excludes sites where lesser horseshoes were not recorded in this period, and those only surveyed in a single year.

GLMM ON WINTER COUNTS

Results of the Poisson GLMM are shown in Table 6; there is a significant seasonal pattern (represented by 10 day blocks through the period), with average numbers falling off towards the spring.

Two other factors show signs of being significant. There are differences between counties, although not with the most obvious spatial pattern (Table 6b). Clare and Kerry tend to have higher average counts. Cork also has a high predicted value, although the simple mean is less strong. Finally the number of storeys in the structure is of borderline significance, with higher counts in the taller structures (Table 6c). This variable was deduced from the 'building type' column in the spreadsheet; where it is not directly specified it is deduced (e.g. mansions have two or more storeys). The unknown category mainly consists of underground structures (caves, tunnels and icehouses etc.), but also includes others where the number of storeys was not immediately obvious or relevant (barns and stables etc.).

Table 6: Effects of factors from the GLMM model. Counts of bats are shown with standard errors, as well as predicted values on the log scale, after adjusting for the effects of other factors in the model. The absolute value of the adjusted means is not informative due to the averaging over other terms, but the relative sizes indicate where the differences lie; standard errors are applicable to the log values, but back-transformed values are easier to interpret.

(a) Period (F = 2.61 with 6 and 624 d.f., P=0.017)

		Raw data		**Adjusted for other variables**		
Ten day period	**surveys**	**mean**	**s.e.**	**Log**	**s.e.**	**back-trans**
1	50	98.4	17.66	1.69	0.135	49.4
2	206	70.4	6.94	1.59	0.125	39.3
3	136	71.1	8.16	1.54	0.127	34.9
4	153	60.2	7.97	1.54	0.125	34.7
5	146	55.8	6.18	1.45	0.126	28.3
6	55	39.7	7.41	1.49	0.137	30.8
7	20	44.3	13.38	1.39	0.158	24.5

(b) County (F = 6.33 with 5 and 119 d.f., P<0.001)

		Raw data		**Adjusted for other variables**		
Group	**surveys**	**mean**	**s.e.**	**Log**	**s.e.**	**back-trans**
Clare	205	99.5	7.93	1.91	0.161	81.1
Cork	87	50.6	7.49	1.84	0.193	69.3
Galway	141	21.4	2.29	1.27	0.180	18.4
Kerry	204	87.6	7.33	1.82	0.123	66.1
Limerick	46	15.4	4.52	0.99	0.233	9.8
Mayo	83	37.5	8.02	1.35	0.195	22.2

(c) Storeys (F = 2.82 with 3 and 104 d.f., P=0.043)

		Raw data		**Adjusted for other variables**		
Group	**surveys**	**mean**	**s.e.**	**Log**	**s.e.**	**back-trans**
Unknown	553	54.5	3.43	1.42	0.074	26.2
One	34	51.8	9.96	1.32	0.255	21.0
one & half	21	72.4	13.12	1.57	0.347	36.8
two or more	158	101.8	10.25	1.81	0.120	64.4

GAM MODELS FOR WINTER TREND

Various covariate models were used to represent the seasonal pattern, but all show essentially the same results. Table 7 and Figure 7 show results using the linear effect of day number in year (with negative values for the few surveys in late December). There is a fairly consistent increase between 1993 and 2003, and probably before that, but sample sizes are small. The increase then levels off, with a significant change point in 2008.

This pattern is reasonably similar to that revealed by the summer counts (see Figure 8), which is encouraging. The slope of the hibernation line is perhaps both rather steeper and rather smoother than the summer one, but not too much should be made of this, given the smaller sample sizes in the earlier years.

Table 7: GAM results with 95% confidence limits (119 hibernation sites contribute to the trend). Using day number as a covariate.

					Index 2009 = 100					
					Smoothed		**95% conf limits**		**unsmoothed**	
Year	**counts**	**Sites**	**Mean**	**s.e.**	**estimate**	**s.e.**	**lower**	**upper**	**estimate**	**s.e.**
1986	17	16	48.7	14.8	30.1	9.7	19.0	55.5	36.9	12.0
1987	15	11	51.6	10.4	32.0	8.6	21.4	54.9	25.5	7.3
1988	16	15	61.6	12.3	34.2	7.8	24.2	54.1	32.7	7.7
1989	3	3	77.7	31.2	36.8	7.1	27.3	54.7	41.1	6.3
1990	7	5	137.9	32.3	39.8	6.8	29.8	55.9	41.8	15.6
1991	7	5	126.3	14.5	43.2	6.5	32.8	57.7	38.4	8.3
1992	12	9	104.8	22.5	47.0	6.5	35.5	60.8	48.8	9.5
1993	15	13	57.8	22.1	51.0	6.7	38.7	64.6	43.0	11.5
1994	38	34	41.0	13.3	54.9	6.7	42.6	68.7	73.9	13.1
1995	16	12	48.4	16.3	58.3	6.4	46.4	71.3	49.5	8.0
1996	15	15	59.3	22.5	61.5	6.0	50.1	73.9	58.3	8.4
1997	21	20	72.1	19.1	64.9	5.9	53.4	77.5	62.8	6.7
1998	6	6	175.2	43.7	68.7	6.2	57.2	81.7	70.6	12.1
1999	13	12	80.4	22.2	73.0	6.7	60.9	87.0	61.6	11.0
2000	12	12	58.8	28.0	77.8	7.3	64.7	93.0	79.7	9.5
2001	28	27	63.4	16.0	82.8	8.0	68.0	99.2	86.2	9.4
2002	8	8	131.1	51.3	87.1	8.9	70.3	105.1	97.9	36.0
2003	9	8	88.8	42.6	90.3	9.5	71.9	108.8	101.6	19.3
2004	12	9	101.7	44.3	92.5	9.5	73.9	110.8	105.8	32.2
2005	20	11	107.9	19.0	94.3	8.6	77.7	110.9	83.9	13.7
2006	83	82	51.4	9.7	96.6	7.1	82.6	110.2	85.1	9.9
2007	16	16	98.6	29.6	99.5	5.1	89.3	109.4	122.1	14.8
2008	19	18	70.9	16.1	101.0	2.7	95.6	106.0	124.2	27.8
2009	99	89	65.7	10.5	100.0	0.0	100.0	100.0	100.0	0.0
2010	89	82	65.2	11.8	96.6	3.1	91.0	103.6	103.5	11.7
2011	99	87	57.8	9.4	91.6	6.6	79.9	106.2	86.4	13.9
2012	71	64	41.7	8.0	86.5	10.3	69.5	109.0	86.0	16.4

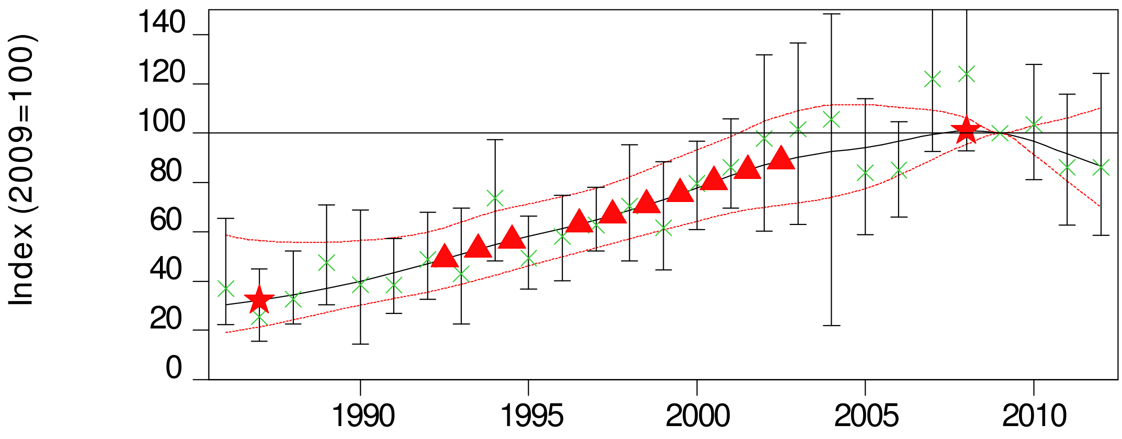


Figure 7: GAM results with 95% confidence limits, using day number as covariate. Green points are estimated annual means and are shown to illustrate the variation about the fitted line. Red stars indicate significant (P<0.05) change points, where the slope of the smoothed trend line changes. Red triangles indicate that the upward or downward trend is significant between years.

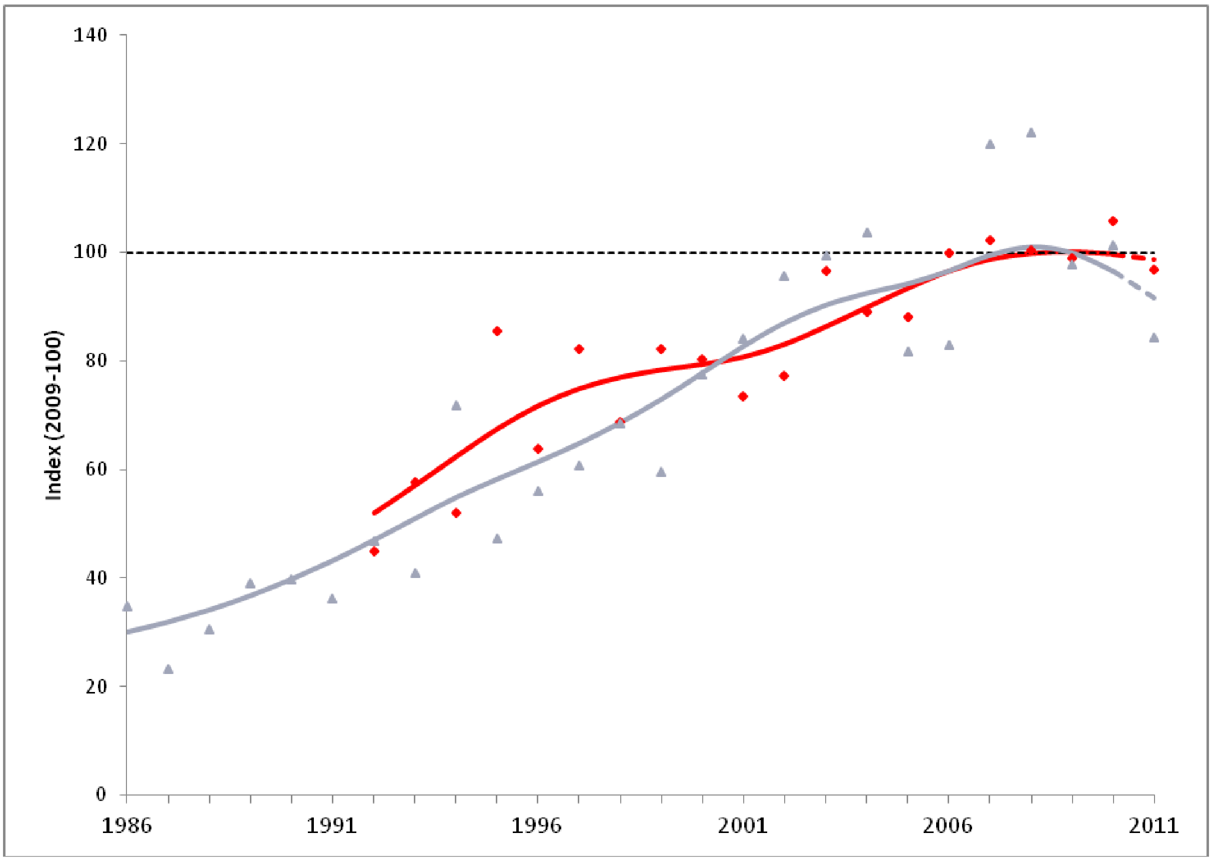


Figure 8: GAM results for winter counts (grey) and summer counts (red), using day number as covariate, without confidence limits displayed. Points are estimated annual means and are shown to illustrate the variation about the fitted line. Dual plotting of both season counts shows that trends for both are very similar.

Comparison between TRIM and GLMM/GAM

Summer counts

Figure 9 shows the results for the summer counts using both models. For comparison purposes data from the full summer period was used without a covariate for day number, since continuous covariates cannot be used in TRIM. This time GAM confidence limits for the unsmoothed estimates are consistently wider, but particularly so in 1998. The GAM confidence limits for the smoothed trend are also much wider than those for the stepwise TRIM model.

Before considering these results further it is useful to look at how the two analysis methods perform with simulated data (see below)

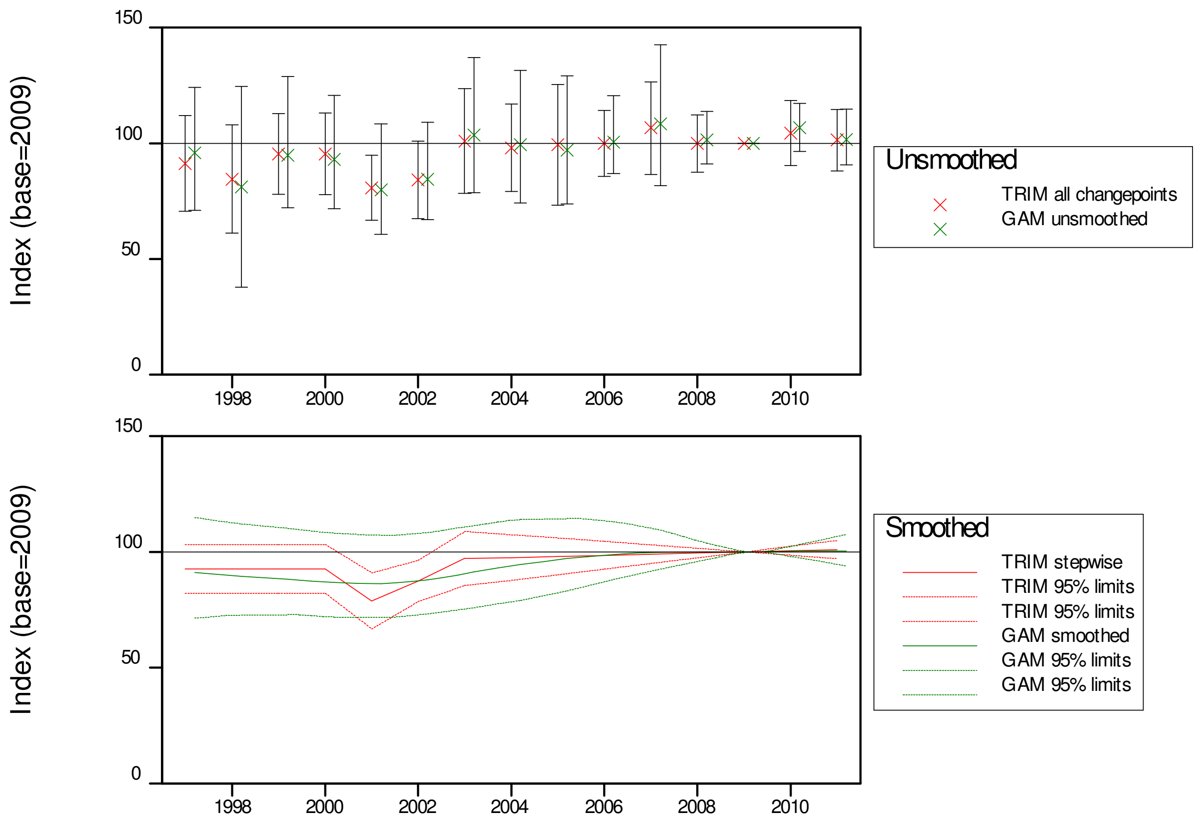


Figure 9: comparison between TRIM and GAM results for summer counts. The graph above show unsmoothed estimates; the red points are from TRIM using a linear model with all possible changepoints, whilst the 'GAM' result is from a GLM model with estimates from each year and standard errors based on bootstrapping at the site level. The graphs below compare a linear TRIM model, using the default stepwise method of selecting changepoints, with a GAM curve with 2 d.f.

Winter counts

Figure 10 compares TRIM results with those from the GAM analysis reported previously. Looking first at the unsmoothed results in the top graph, the annual estimates from the two methods are very similar. This is expected as the basic methodology of the two methods is very similar. The width of the confidence limits is similar for most years, but GAM confidence limits are wider in others; this is because TRIM uses a common estimate of variance over all years, whereas the GAM bootstrapping limits represent the varying uncertainties in different years.

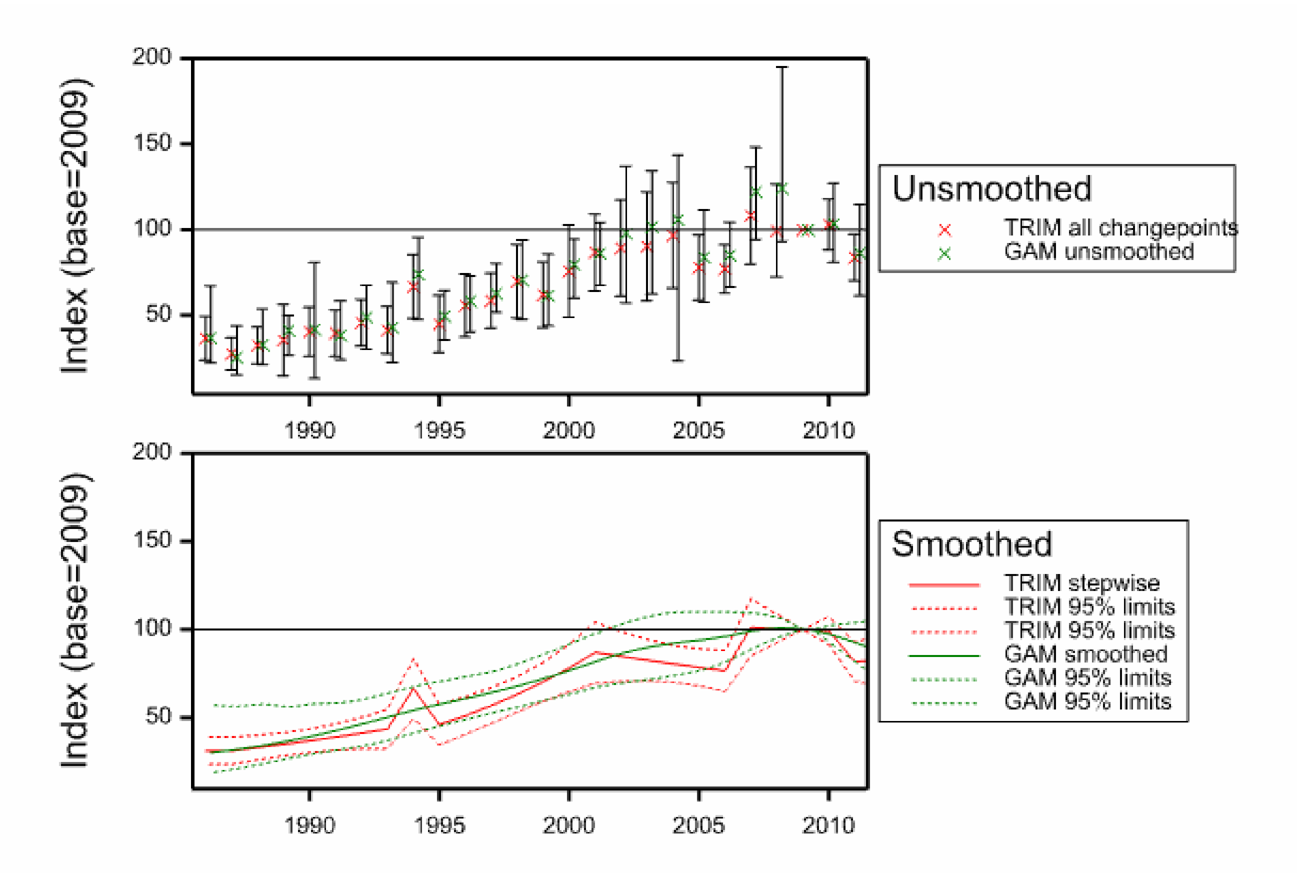


Figure 10: Comparison between TRIM and GAM results for winter counts. The graphs above show unsmoothed estimates; the red points are from TRIM using a linear model with all possible changepoints, whilst the 'GAM' result is from a GLM model with estimates from each year and standard errors based on bootstrapping at the site level. The graphs below compare a linear TRIM model, using the default stepwise method of selecting changepoints, with a GAM curve with 2 d.f.

The smoothed GAM trend and the TRIM stepwise model are very similar. The only clear difference is that TRIM deviates to allow for the 1994 data whereas the smoothed GAM model is designed to pick out the long-term trend and is not substantially influenced by a single outlying year, no matter how extreme.

Simulations

Results of simulations are shown below.

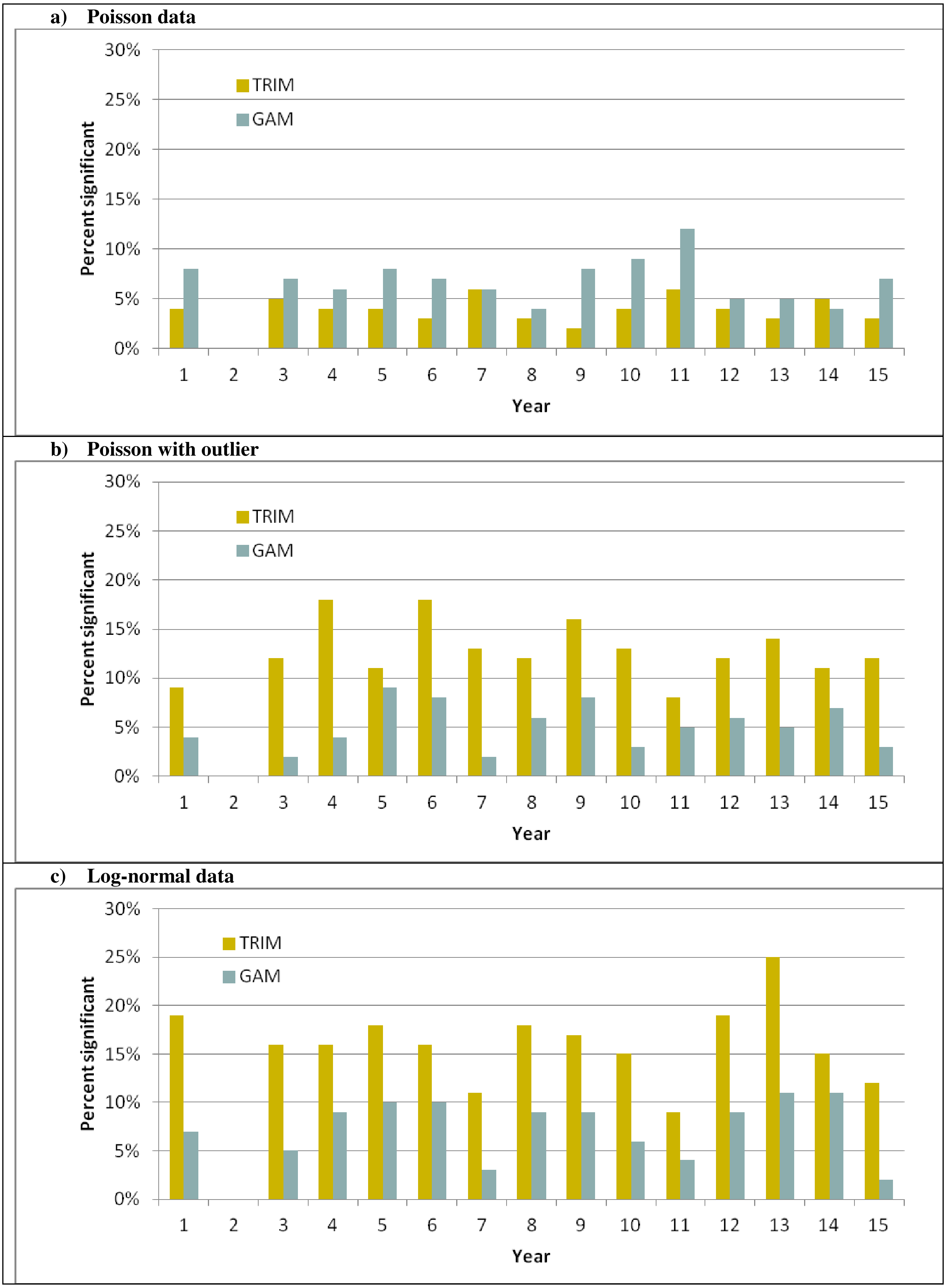


Figure 11: Results of simulations with no added trend. The vertical axes shows the percentage of simulations that were significantly different from the base year (year 2) at a nominal 5% significance level when no trend

or year effect was present. The 'GAM' results are for a GLM with a term for each year, with significance tests based on bootstrapping at the site level.

Results are shown in Figure 11 in the form of histograms showing the percentage of simulations that were significantly different to the base year (year 2). Since there is no simulated trend and no simulated year effects, approximately 5% of simulations should be statistically significant at the 5% level, although there will be random variation around this value as only 100 simulations were run. Looking at the Poisson data in Figure 11a, results are close to this 5% level, although the GAM method tends to give slightly too many significant values; this is not unexpected since tests are based on a simple bootstrap procedure.

When an extreme outlier is added, TRIM gives too many significant results (Figure 11b), with over 10% significant in most years. Results are even more striking with over-dispersed data (Figure 11c), with TRIM giving more than 15% significant in most years, despite using the TRIM option for over-dispersion.

These results are important in interpreting the results of Figure 10 for the summer counts. TRIM gave consistently narrower confidence limits, which would usually be interpreted as implying that this was the more precise method. However, these simulation results suggest that with heavily over-dispersed data TRIM confidence limits may be artificially small, and that it may be better to use the GAM method which produces more reliable confidence limits.

Power Analysis

Results should be treated with caution as they are dependent on many assumptions, some of which will only be approximately correct. In particular, the simulations assume that the same trend applies across all habitats, and more sites will be needed in the situation where the extent of the decline varies geographically or between different habitats. It is also assumed that all surveys are successfully completed; missing surveys will increase the number of sites needed to achieve the specified level of power.

Winter counts

Results for winter counts are shown in Table 8; these are based on the variances of counts between 26th December and 7th March. Since most roosts in this dataset are only counted once each year during this period, power estimates are produced for both one count per site per year, and for two counts. Interestingly, doing two counts gives very little improvement in the time taken to detect trends.

Table 8: number of years (including the extra years needed at either end of the GAM curve) to achieve 80% power for lesser horseshoe winter roost counts. Whilst the number of years must be an integer in reality results are shown here with one decimal place to aid comparisons. Simulations used a maximum of 28 years and '>28' indicates that 80% power was not achieved in this period.

a) One count per site per year

	Years for 80% power					
	Red alert (50% decline over 25 yrs)		**Amber alert (25% decline over 25 yrs)**		**50% increase over 25 yrs**	
Sites	**Estimate**	**s.e.**	**Estimate**	**s.e.**	**Estimate**	**s.e.**
20	19.1	1.1	>28		>28	*
30	16.2	1.1	>28		26.9	1.5
40	13.4	0.6	26.1	1.6	22.2	1.1
50	12.7	0.7	27.4	1.6	19.8	1.2
75	11.3	0.4	22.8	1.2	16.3	0.6
100	10.7	0.4	21.3	1.6	14.6	0.7
125	9.8	0.5	18.2	1.0	13.1	0.7
150	9.0	0.4	17.1	1.0	12.1	0.5

b) Two counts per site per year

	Years for 80% power					
	Red alert (50% decline over 25 yrs)		Amber alert (25% decline over 25 yrs)		50% increase over 25 yrs	
Sites	**Estimate**	**s.e.**	**Estimate**	**s.e.**	**Estimate**	**s.e.**
20	17.8	0.9	<28		<28	
30	15.0	0.9	<28		24.7	1.2
40	13.1	0.6	26.2	1.9	21.1	1.0
50	12.5	0.6	23.7	1.4	19.3	1.4
75	10.1	0.3	20.7	1.0	15.5	0.7
100	9.8	0.5	18.6	1.3	13.4	0.6
125	9.6	0.3	16.4	0.9	13.0	0.7
150	8.6	0.4	15.8	0.7	11.6	0.5

Summer counts

Results for summer counts are shown in Table 9; these are based on the shorter summer period (days 137 to 194) in order to minimise the variances. Power estimates are shown for both one count per site per year, and for two counts. Again, doing two counts gives very little improvement in the time taken to detect trends, although, looking at the results in more detail, it is apparent that only doing one count can have a greater impact on the width of the confidence limits in the final year of the survey. This is particularly apparent with low numbers of sites, when an outlier in the most recent year can result in high levels of uncertainty.

Table 9: number of years (including the extra years needed at either end of the GAM curve) to achieve 80% power for lesser horseshoe summer roost counts. Whilst the number of years must be an integer in reality results are shown here with one decimal place to aid comparisons. Simulations used a maximum of 28 years and '>28' indicates that 80% power was not achieved in this period.

a) **One count per site per year**

	Years for 80% power					
	Red alert (50% decline over 25 yrs)		Amber alert (25% decline over 25 yrs)		50% increase over 25 yrs	
Sites	**Estimate**	**s.e.**	**Estimate**	**s.e.**	**Estimate**	**s.e.**
20	14.7	0.6	<28		23.4	1.0
30	12.4	0.5	25.3	1.9	18.8	0.6
40	11.8	0.7	18.0	0.7	16.2	0.6
50	9.8	0.4	19.9	1.5	14.8	0.7
75	9.3	0.5	16.3	0.9	12.8	0.5
100	8.1	0.3	15.0	0.9	10.8	0.4
125	7.5	0.4	13.3	0.4	10.3	0.4
150	7.5	0.4	13.8	0.8	10.3	0.4

b) **Two counts per site per year**

	Years for 80% power					
	Red alert (50% decline over 25 yrs)		Amber alert (25% decline over 25 yrs)		50% increase over 25 yrs	
Sites	**Estimate**	**s.e.**	**Estimate**	**s.e.**	**Estimate**	**s.e.**
20	13.6	0.7	27.6	2.5	19.9	1.7
30	10.6	0.4	22.5	1.2	17.1	0.8
40	10.8	0.7	17.9	0.8	14.7	0.8
50	9.6	0.5	16.2	0.9	13.2	0.6
75	8.6	0.3	15.0	0.8	11.4	0.4
100	7.8	0.3	13.2	0.5	10.2	0.5
125	7.3	0.3	12.1	0.4	9.8	0.5
150	7.0	0.4	11.5	0.5	9.5	0.6

Roost Sizes and Structures

Figures below show the relative abundance of roosts of differing sizes in summer and winter. While the histograms appear to show that roosts of 21 to 50 bats are more frequent in summer than small roosts with 1-5 individuals, this may simply be indicative of the fact that larger roosts are more likely to be regularly counted. Both Figures 12 and 13 suggest a proportionate increase in larger roost sizes in the most recent time series, which tallies with the increasing trend shown from GLMM/GAM modelling.

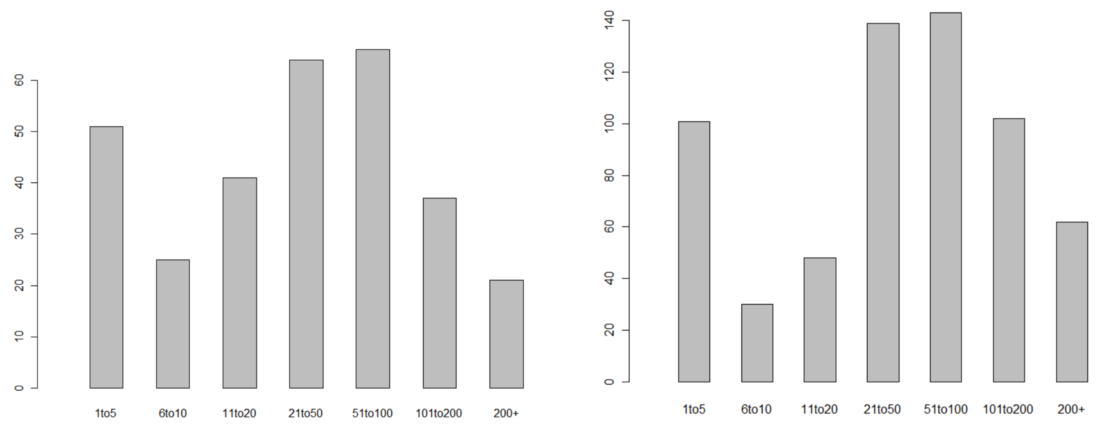


Figure 12 (a) and (b). Number of bats per summer roost 1984-1999 (left, a); Number of bats per summer roost 2000-2009 (right, b). Includes data from all days in June, July and August. NPWS dataset.

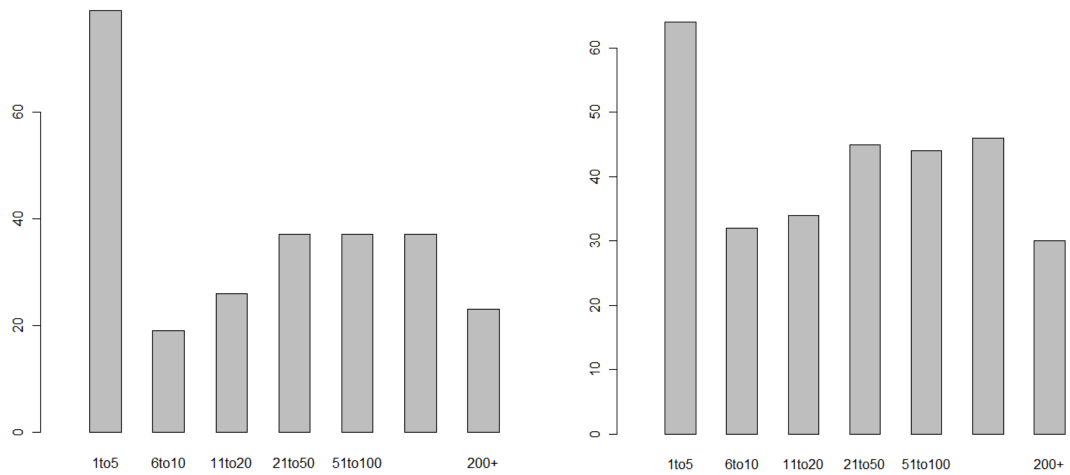


Figure 13 (a) and (b). Number of bats per winter roost 1984-1999 (left, a); Number of bats per winter roost 2000-2009 (right, b). Includes data from all days in December, January and February of each year. NPWS dataset.

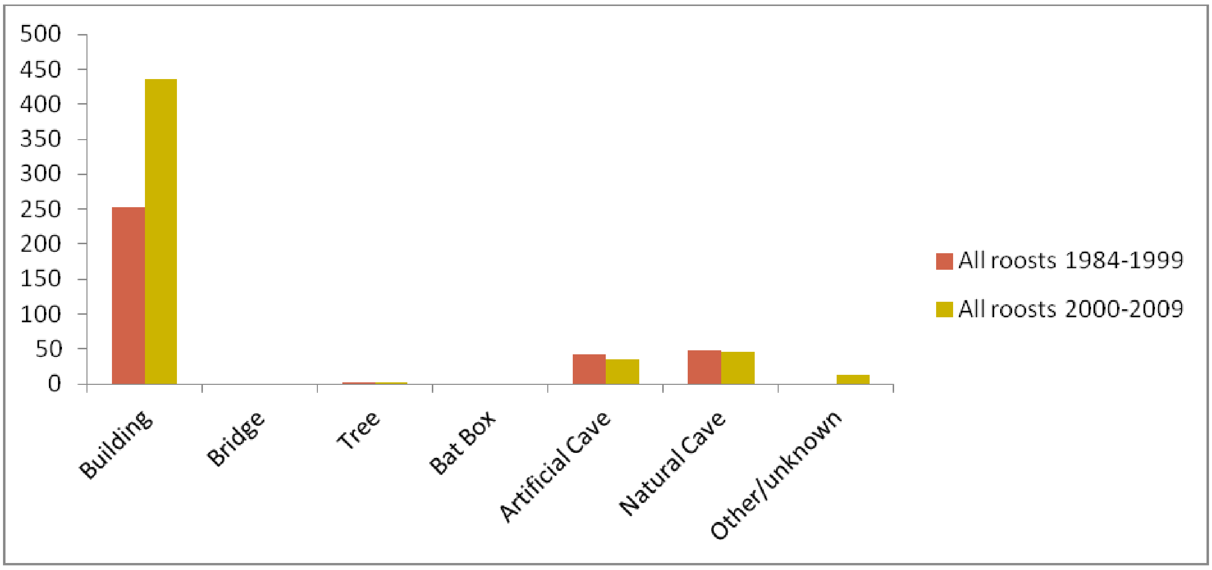


Figure 14: Bar chart indicating categories of roost structure used by lesser horseshoe bats. Note that one tree roost is listed in the dataset in 1996 whilst another tree roost was recorded to the BCIreland database in 2003.

As may be expected for the lesser horseshoe bat, the vast majority of roosts are situated in buildings, or underground in natural and artificial caves. There was a slight change in proportions of roost types observed from the early part of the time series (1984-1999) when more artificial and natural caves were recorded in proportion to building roosts, while from 2000-2009 there has been a proportionate increase in the number of building roosts. This may simply be the result of increased survey effort for roosts in buildings. Tree roosts have been recorded but are extremely rare for the species in Ireland. The species has never been recorded in a bat box or roosting under bridges.

Population Estimates

2000-2006 Reporting

The following steps were taken to estimate the population of lesser horseshoe bats for 2000-2006 Article 17 reporting (NPWS, 2007). A detailed inventory of at least all the major roosts had been prepared and a database of all roost types and bat counts developed (Kelleher, 2004). The first concentrated effort to count lesser horseshoe bats at all 153 identified major maternity roosts in the country was undertaken in June 2006. The maternity roost counts taken during the intensive survey in 2006 were used to extrapolate the population of lesser horseshoe bats in Ireland at the present time. The following method was used in 2007:

- 153 known major lesser horseshoe maternity roosts were visited in summer 2006 and counts taken at each (total 7565 bats).
- 183 maternity roosts are identified in the NPWS database (Kelleher, 2004).
- Peak counts from all roosts in the NPWS database were used to calculate the average number of bats per roost as 20.
- This average number per roost was assigned to the 30 unsurveyed maternity roosts identified from the NPWS database to give a figure of 600 bats for these 30 sites.
- Thus the total number of bats in identified maternity roosts in the country was 7565 (summer 2006 at 153 roosts) + 600 (estimated at 30 unmonitored maternity roosts) to give a total of 8165 bats in maternity roosts.
- It is understood that males represent about 25% of a maternity roost's population (Schofield, *pers. comm*.2006, Knight, *pers. comm*., 2006). Thus 25% (2040) of the total maternity roost number (8165) was subtracted to give an estimated total female number for maternity roosts (6125).
- A population estimate of 12,250 was therefore derived.

2007-2012 Reporting

Using the same methodology as above, and maximum counts for monitored sites for 2011, a population estimate of 13,450 is derived. This implies that there has been an increase of 9.8% since 2006.

However, since a longer monitoring time series is now available it may be pertinent to use information from this to impute missing counts with greater accuracy.

A number of monitoring sites were found to have no valid count data for any of the years 2000-2011 and were therefore omitted from the list of monitored sites. 142 monitoring sites had valid counts for this time period.

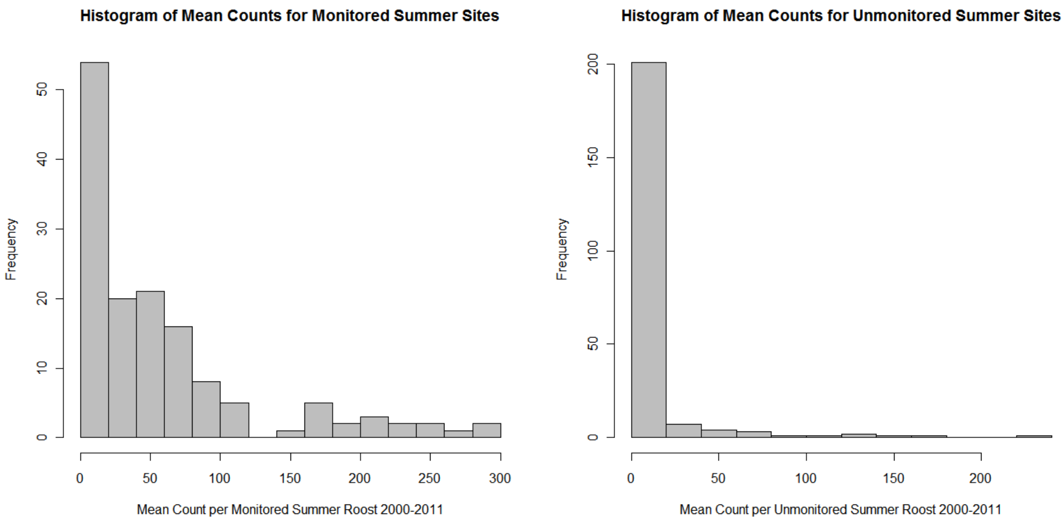


Figure 15: Histograms of frequency of mean counts for both monitored (a) and unmonitored (b) summer sites. A larger proportion of unmonitored sites have very low number of bats present.

Mean counts were calculated, to determine whether monitored sites have a higher mean than non-monitored sites. A plot of the frequency of mean counts (Figure 15) for unmonitored and monitored summer sites shows that a far greater proportion of unmonitored sites have very low roost numbers. The mean count (May-July, mean of the average for each site) for sites that are included in the monitoring scheme (either on a one year or three yearly basis) from 2000-2011 is 57.57 (N=142, standard error=±5.7). The mean count (May-July, mean of the average for each site) for sites that are not included in the monitoring scheme for 2000-2011 is much lower at 8.67 (N=222, standard error=±1.89). This implies that the number of bats assumed to be present in unmonitored sites may have been overestimated for the previous reporting round.

A revised population estimate was therefore derived for 2006 and 2011 separately and for two, two year ranges, 2005-2006 and 2010-2011, whereby:

- The maximum count for all monitored sites in a particular year, or range of years, is used.
- A mean count (all data from May, June and July) was calculated for each of the 142 monitoring roosts visited in summer, from 2000-2011.
- A mean count for May, June and July for all non-monitored sites was calculated for 2000-2011 as 8.67.
- 183 maternity roosts were identified in the NPWS database (Kelleher, 2004). This figure has been retained for the present estimation in the absence of complete maternity roost status information for current sites.
- For any given monitored site for which count data is unavailable in a particular year, or range of years, a count is imputed from the mean for that site.
- Maximum counts and imputed counts (for monitoring sites where no count is available) are summed. This gives a total figure for 142 monitoring sites.
- To bring the total to 183 summer sites, 8.67 x 41 is added, in the assumption that the average count for unmonitored roosts is lower than that of monitored sites.
- It is understood that males represent about 25% of a maternity roost's population (Schofield, *pers. comm*.2006, Knight, *pers. comm*., 2006, cited in NPWS (2007)). Thus the total count (max + imputed + unmonitored) is multiplied first by 0.75 and then by 2 to give an estimate for the total population, male and female, assuming a male: female population ratio of 1:1.

Table 10: Estimated population based on either Article 17 (2007) reporting method or revised using imputed data and a mean of 8.67 for sites not included in the monitoring scheme.

Year	Article 17 (2007) method	Number of monitored sites with max count data	Max + Imputed + (41 x 8.67 (unmonitored)), adjusted for male:female ratio
2006	12,250	111	13,438
2011	13,452	90	13,369
Range of Years			
2005-2006		111	13,740
2010-2011		104	14,009

Using the Article 17 (2007) calculation method for 2011 indicates that there is a current population of approximately 13,450 bats. However, calculations using maximum and imputed counts indicate that there has been little real increase between 2006 and 2011. Instead, the population in 2006 may have been underestimated by approximately 1,000 individuals.

Since roosts are sometimes counted sporadically or not at all, using a range of two years for calculating the population may be sensible for this and future estimates. Counts could, therefore, be used for a site from the previous year if none is available for the current one. Using the year ranges 2005-2006 and 2010-2011, the population estimate is 13,740 for 2006 and 14,010 for 2011. Again, this indicates that the population may have been a little underestimated in 2007 but that change has been negligible since that time.

Activities at Roosts

Negative Activities

The majority of records for 2000-2009 (1,206, 85.6%) had no activities recorded. The most frequently recorded negative activity was ‘Urbanisation’, which was recorded as having a negative impact on 24 sites (see Table 11).

For sites with activities that are listed as potentially damaging, or having a negative impact, a total of 1,202 individual bats were counted in winter and 1,734 in summer using the most recent counts available for each site from 2006 to 2009 (see Table 12).

Despite the potentially damaging activities described, however, winter counts at the same sites showed increased numbers from 2010-2012 when 1,447 individuals were counted at these locations (an increase of approx. 20%, see Table 13). In addition, fewer damaging activities were recorded at these sites during the 2010-2012 three year count period although flooding, building deterioration and cave closures were still listed at 12 of the 22.

For the same summer sites in the 2010-2011 period (2012 data were not available) 1,475 bats were counted, although counts were not available for all of the same sites. When sites for which there is no duplicate count have been removed it appears that overall numbers remained relatively stable (1,412 2006-2009; 1,475 2010-2011, 27 sites). Nonetheless, activities with a potentially negative impact, such as deteriorating buildings and light pollution, were still recorded for more than half of these summer sites.

Table 11: Breakdown of activities at roosts listed for 2000-2009.

No of records	No of Sites	Code	Meaning	+ve	=	-ve	Impact not recorded or unknown
645		None					
561		0					
9	9	100	Cultivation	3	3		3
44	34	140	Grazing	1	33		10
1	1	141	Lack of grazing				1
2	2	150	Restructuring agriculture	1		1	
4	4	152	Removal of scrub		2	1	1
9	8	160	General Forestry	5	3		1
1	1	164	Forest clearance			1	
2	1	165	Forest undergrowth removed			2	
2	2	168	Felling native or mixed woodld			1	1
8	6	190	Agr & Forest activities, other		2	4	2
1	1	330	Mines				1
1	1	332	Underground mining		1		
1	1	390	Mining activities, other		1		
39	36	400	Urbanisation	1	5	24	8
2	2	401	Continuous urbanisation			2	
2	1	403	Dispersed habitation	1		1	
1	1	404	?				1
1	1	410	Industrial or commercial		1		
4	4	421	Disposal of household waste			3	1
1	1	430	Agricultural structures	1			
4	3	440	Storage of materials	1			3
1	1	530	Improved access to site	1			
3	2	601	Golf course		1	2	
1	1	610	Interpretative centres			1	
3	3	624	Mountaineering, rockclimbing, speleology				3
2	2	690	Leisure & tourist, other				2
4	3	710	Noise pollution		1	3	
7	5	740	Vandalism			5	2
2	2	780	?		1	1	
21	19	790	Other pollution, human activities	3	3	14	1
2	1	800	Landfill, reclamation				2
3	3	840	Flooding modifications			2	1
1	1	900	Erosion			1	
1	1	941	Inundation (natural)			1	
2	2	943	Landslide, underground collapse		2		
1	1	960	Interspecific faunal relations			1	
2	2	965	Predation			1	1
8	8	990	Reduced fecundity/inbreeding or Other natural processes??	1		5	2
1409	**177**			**19**	**59**	**77**	**46**

Table 12. Total number of sites and bats with negative activities listed. Total individuals are calculated from the most recent available count.

	2006-2009	2010-2012	% Change
Total number of winter sites	24	16	-33%
Number of bats	1202	911	-24%
Total number of summer sites	35	39 (2012 data not available)	+11%
Number of bats	1734	1505	-13%

Table 13. Sites with negative activities listed from 2006-2009 compared with same sites 2010-2011. Sites included if count data was available for both time periods. Total individuals are calculated from the most recent available count.

	2006-2009	2010-2012	% Change
Number of winter sites	22	22	n/a
Number of bats	1202	1447	+20%
Number of summer sites	27	27 (2012 data not available)	n/a
Number of bats	1412	1475	+4%

Looking at the 2010-2012 dataset separately, in total, 52 sites (82 records) were listed with potentially negative/damaging activities (compared to 177 from 2000-2009). At these sites 1,505 individual bats were counted at 39 sites in summer, while 911 bats were counted at 16 sites in winter.

There appears, therefore, to have been a decrease in negative activities occurring at wintering sites, with a considerable decline in the number of sites and individual bats impacted. This suggests that for at least some sites where negative activities had previously been recorded, the activities had since ceased or had been caused to cease, perhaps by local NPWS staff, but exact changes may not have been documented.

In contrast, there was an increase in the number of summer sites with negative activities listed in the later time series but an overall decline in the number of bats affected.

'Deterioration of buildings' was recorded from 22 sites impacting at least 761 individual bats in summer (most recent counts from 2010 and 2011). Equivalent data was available for 20 of these sites for the preceding decade. An average of summer counts for each site was calculated (the number of counts from 2000-2009 varied between 1 and 16, depending on the site) and the total mean number of bats in these sites in the preceding decade totalled 923 individuals. By comparison, 751 individuals were recorded at the same 20 sites in 2010 and 2011 representing a *possible* decline of up to 19%. Declines from the mean in 2000-2009 to 2010-2011 were particularly evident in sites 27 (Kilkishen House, Clare), 295 (Tomies East, Kerry) and 734 (Carrignahihilan, Kerry) where between 30 and 94 fewer individuals were recorded from each site. Nonetheless, increases from 2000-2009 and 2010-2011 have also been recorded from some sites, e.g. site 131 Ballycullinane, Clare and site 193 Derrycreha House, Glengarriff, where activities such as deterioration of roost are recorded as having a negative impact. This suggests that there is a period whereby bats will continue to use a favoured site despite deterioration evident to surveyors. In fact, deterioration in its initial stages may coincide with an increase numbers using a roost, perhaps because of generally decreased human disturbance. Note that buildings noted as 'disused', 'derelict' and in 'disrepair' are likely to house significantly more bats than those that are not listed as such (see analysis of summer roost counts above).

Derrycreha House provides a good example of the dynamic state of lesser horseshoe roosts, in 2008 remedial work on the site was reported as having a positive impact and numbers increased from a low of 20 in 2006, to 120 in 2008. The roost was again listed as deteriorating in 2011 although numbers remained high in that year.

POSITIVE ACTIVITIES

Positive activities were not recorded on the database prior to 2006. There are 41 records at 32 sites with associated positive activities recorded on the database. Positive activities include general forest management, roost renovation and closure of caves or galleries. Positive activities were recorded at 19 sites from 2006 to 2009 where 1,707 bats were present (using most recent counts available during this period) see Table 14.

Table 14. Total number of sites and bats with positive activities listed. Total individuals are calculated from the most recent available count.

	2006-2009	2010-2012	% Change
Total number of winter sites	4	10	+150%
Number of bats	992	1321	+33%
Total number of summer sites	15	7 (2012 data not available)	-50%
Number of bats	717	606	-15%

Table 15. Sites with positive activities listed from 2006-2009 compared with same sites 2010-2011. Sites included if count data was available for both time periods. Total individuals are calculated from the most recent available count.

	2006-2009	2010-2012	% Change
Total number of winter sites	4	4	n/a
Number of bats	992	632	-36%
Total number of summer sites	14	14 (2012 data not available)	n/a
Number of bats	713	694	-3%

From 2010 to 2011 positive activities were recorded at 18 sites where 1,927 bats were present. At most sites where positive impacts were recorded, bat numbers remained relatively stable from 2006-2009 to 2010-2011. However, at Kilgarvan Ice House (site code 431), general forestry was described as having a positive impact on bats in 2009 and 2010. Over 400 bats were counted at that site during winter of those years. No activities were recorded in 2011 or 2012 as having a positive (or negative impact) but numbers counted dropped from 121 in 2011 to zero in 2012. This was the first time that no bats had been recorded in winter in Kilgarvan Ice House since records were first collected there in 1986. No cause has been documented but unfavourable weather conditions are suspected (T. Burkitt and K. McAney *pers. comm.*). As a result of the zero count at Kilgarvan in 2012, the number of bats impacted by positive activities at winter sites has undergone a counter-intuitive decline (see Table 15).

Reconstruction or renovation was documented at seven sites where 418 bats were present.

DISCUSSION

TRENDS

Trend analysis suggests that lesser horseshoe summer roosts counts increased for much of the period studied, with significant increases from 2003-2005 and a levelling-off or slight decline since 2008. The magnitude of increases in the population is considerably less than the very high rates seen in Britain (e.g. Anon 2011), and the increase seems less consistent over time, although this may be partially due to the smaller sample size. It is of interest that numbers seem fairly constant over the last five years or so, despite the larger sample sizes which should aid detection of any trend present.

Some caution is needed in interpreting these results however, due to the changes in the period in the year when most counts were made. As a result, estimation of the trend in the May-August dataset is dependent on the use of a covariate for day number in year, and it is difficult to be certain of the precise form of this relationship. There is a case for seeking to count some roosts later in the season in the coming years, in addition to the counts in the main survey period. Doing this for a few years, ideally with roosts that had been monitored since the 1990s, would help improve the estimation of the relationship with day number, and hence strengthen the interpretation of the analyses with covariates.

No evidence was found for differences in summer trends between regions (Cork/Kerry vs other areas) although graphical presentation of linear trends per roost may show slightly more sites with increasing numbers in Clare. There is some difference in average summer roost numbers between counties, with particularly high numbers in Mayo. This county, however, has relatively few roost sites and three of the six have very high numbers, thus skewing the mean. Clare has the second largest average summer roost size, while lowest average summer roost numbers are found in Cork. Counts at summer roosts tend to be lowest in May, stabilise in June and July and then rise in August. As part of the modelling exercise the terms 'disused' 'derelict' and 'disrepair' were picked out from the dataset and roosts with these descriptive terms were found to house significantly higher numbers of bats.

Trend analysis for a longer time series is possible with winter counts since data for a number of sites extend back to the mid-1980s. Results suggest that an increasing trend has been apparent since that time, although a low number of sites in the early years means that trends must be interpreted with caution. More recently, since 2008, numbers in winter have declined somewhat.

Encouragingly, trends in summer and winter sites show a large degree of overlap.

Within winter sites some patterns were picked up by the models. In the first instance, average numbers fall off towards spring, which may be expected. Secondly, some differences in average counts were found between counties, with Clare showing highest counts, Kerry the second highest and Limerick the lowest numbers. In addition to this, highest average winter counts are recorded in buildings with more than two storeys. This may reflect ideal conditions for a colony when summer and winter roosts are available in the same location, or a wider range of potential hibernating (and summer roosting) conditions thus facilitating larger numbers of bats.

The number of sites counted has been much higher in recent years, and this will help to achieve good precision in trend analysis. Numbers have fluctuated from year to year in this period, with the largest sample sizes in 2006, 2009 and 2011; this fluctuating pattern is not, in itself, a big problem for trend estimation. Indeed, counting sites every second or third year can be reasonably efficient.

POWER ANALYSIS

Power analysis results show that reasonably high power can be achieved with annual counts; dual counts add little improvement to the power of the data to detect declines or increases in either winter or summer. For summer roosts, counts at just 50 sites will achieve sufficient power to detect red alert declines within 10 years. However, 100 summer sites need to be counted every year in order to detect an amber decline within 15 years. At present, surveillance tends to be carried out at 90-110 summer sites per annum.

For winter hibernacula, a greater number of sites need to be counted annually in order to achieve the same power. 125 sites counted once per annum in winter, achieves similar power to 50 sites counted once in summer. However, to detect red alert declines within 13 years and amber alerts within 27 years, counts only need to be carried out at 50 sites. Nonetheless, winter site counts, even if not carried out in sufficient numbers to achieve as high power as their summer equivalent, are still very useful in that they facilitate a cross validation of trends between seasons. Winter surveillance also ensures that these essential sites are checked out on a regular basis and that any conservation issues arising are highlighted.

TRIM VS GAM

TRIM does not cope well with either high levels of over-dispersion or with extreme outliers, both of which are common problems in bat survey data. By contrast, the GAM bootstrapping approach, whilst slightly non-conservative, produces reasonably reliable significance tests regardless of the distribution of the simulated data. This is perhaps not surprising since TRIM was developed for bird count data, which tend to be closer to the theoretical Poisson distribution. The underlying GEE (Generalised Estimating Equations) methodology used in TRIM is not necessarily unsuitable for bat data, but it needs the use of a more appropriate distribution (e.g. negative binomial) and at present TRIM only allows a Poisson distribution.

These results are important in comparing the results of TRIM vs GAM smoothing. TRIM gave consistently narrower confidence limits, which would usually be interpreted as implying that this was the more precise method. However, these simulation results suggest that with heavily over-dispersed data TRIM confidence limits may be artificially small, and that it may be better to use the GAM method which produces more reliable confidence limits.

This is not the only limitation of TRIM for bat data. TRIM only allows for covariates in the context of fitting different trends to different habitats. It cannot fit more complex covariate models, such as the ones we use to adjust for factors like temperature, day number or bat detector type. This is an important issue given the importance of covariates in some analyses.

These results have been highlighted to the Statistics Netherlands team.

POPULATION ESTIMATION

Population estimation based on the same methodology as that used for the previous reporting round was repeated for summer 2011 data and came to 13,450, thus implying an increase of over 1,000 bats since 2006 (from 12,250, an increase of 9.8%). However, since a longer time series of monitoring data is now available, a slightly modified estimation method using maximum counts where available, imputed counts where no recent count was known, and a revised mean for unmonitored sites, suggests that, while the total population may have been slightly underestimated in 2006 (by approximately 1,000), it has remained relatively stable since that time. The estimated population of lesser horseshoe bats in Ireland in 2010-2011 is 14,010. For the next reporting round it is suggested that the figure given by Kelleher (2004) for 183 maternity sites be re-examined to see if any changes need to be made to this.

Activities at Roosts

A thorough examination of activities at lesser horseshoe bat sites is limited by inconsistent recording to the database. From the available data it appears that negative activities impacting on winter roosts can sometimes be simpler to rectify (grilling of a cave, for example) and can quickly result in confirmed increases in numbers of wintering bats. Sites with negative activities recorded in the 2006-2009 period saw a 20% increase in bat numbers in the 2010-2012 period, presumably at least partly as a result of positive conservation efforts.

On the other hand, the myriad of issues that impact on summer roosting sites, for example regarding building structure and possibly surrounding land may involve more resources (time, staff input, negotiating, building materials etc.) over a greater period in order to see equivalent increases in bat numbers. Nonetheless the number of bats impacted by negative activities has declined in both winter and summer roosts over the five years for which data is available.

The issue of building deterioration is a complex one and dynamic one. While on the one hand, lesser horseshoe bats clearly favour buildings that are not used by humans and roost in significantly higher numbers in these than at other sites, excessive deterioration usually leads to roost loss. There have been considerable reductions in mean counts at some sites where this activity has been recorded.

It is worth noting that the most regularly recorded negative activity is ‘Urbanisation’, the impacts of which include decreased habitat availability, loss of connectivity, increased street lighting and increased human disturbance, all of which are likely to threaten the integrity of lesser horseshoe bat colonies. However, there is no evidence from the past six years that sites where urbanisation is noted have undergone significant declines.

The dynamic state of disused buildings, surrounding landscapes and weather conditions, means that bat numbers can fluctuate greatly from year to year for little apparent reason. Consistent recording of activities to the database, of even minor building repairs, can facilitate easier interpretation of trends in single roosts, over time.

A fairly simple programme that runs through the annual surveillance returns and notes significant declines from the mean count (for a site) may be useful in flagging sites where immediate intervention is necessary or warranted.

Conclusions

The lesser horseshoe bat population is well-recorded and appears to be, at present, in a healthy state in Ireland. The population underwent increases before and just after the turn of the 21st Century, although there are recent signs of levelling out. Although population estimates vary depending on the methodology used, the number of individuals in Ireland is probably roughly 14,010 at present but it is not likely to have increased significantly since the previous reporting round. A number of activities around roosts such as increased urbanisation or inappropriate forest management may be considered a future threat, although current negative activities are often related to deterioration of buildings which benefit from human intervention, or climatic factors that are outside the control of conservation bodies.

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