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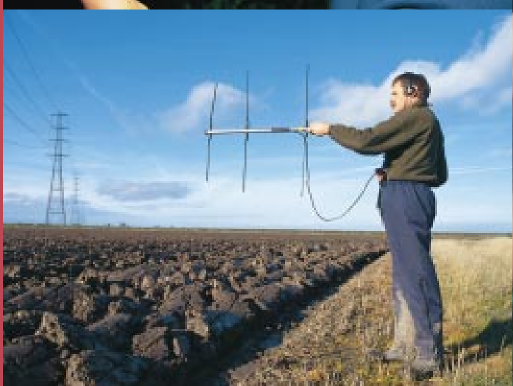
English Nature Research Reports



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The impact of human disturbance on the breeding success of nightjar *Caprimulgus europaeus* on heathlands in south Dorset, England

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Contents

Abstract....7
Introduction....9
Methods....11
- Study area and sites....11
- Mapping nightjar territories and nest searching....12
- Nest monitoring....13
- Nest site characteristics....13
- Disturbance characteristics relative to territory location and territory success....14
- Disturbance characteristics relating to nest location and nest success....14
- Data and Statistical Analysis....14
- Disturbance analysis relative to territory location and success....15
- Analysis of breeding success....15
- Disturbance analysis relative to nest location and nest success....16

Results....17
- General....17
- Territory location....18
- Territory success....19
- Nest site location....20
- Nest success and site difference....22
- Nest site and disturbance characteristics....25

Discussion....34
Further work....36
Site/access management....37
References....38
Acknowledgments....41

Abbreviations

RSPB	Royal Society for the Protection of Birds
CEH	Centre for Ecology and Hydrology
HCT	Herpetological Conservation Trust

Abstract

The effects on birds of human disturbance through recreation is an issue of conservation concern. With the passage of the Countryside and Rights of Way Act (2000) access patterns to heathland sites are likely to change. Yet, very few studies have been published on the effects of access on heathland bird species.

The nightjar is one of the key breeding bird species associated with lowland heathland in the British Isles. The breeding success of nightjars was compared on several sites in Dorset with varying levels of public access. Sites with no public access showed significantly higher breeding success than sites with open access. On sites with public access, territory centres and nest sites occurred considerably further away from urban development. In addition, nests that did succeed were located significantly further away from paths.

The probability of nest survival was 12%. The key cause of nest loss was predation (60% of all nests failed, 93% due to predation). The evidence from nest remains, post predation, suggested that 63% of failed nests were predated by corvids. The results therefore suggest that predation and disturbance may be linked, the possible mechanism being that birds nesting close to paths are flushed from the nest more often, betraying the nest site to predators. Anecdotal evidence suggests that dogs off leads may be a particular cause for concern.

The results have been presented with recommendations for site management and further work.

Introduction

The European nightjar *Caprimulgus europaeus* declined in number and range throughout Britain during the 20^{th} century (Stafford 1962; Sharrock 1976). By 1981, the population had dropped to just 2100 males (Gribble 1983). Since then, there has been partial recovery in geographical range and numbers, to around 3400 males, as indicated by the national nightjar survey, which took place in 1992 (Morris *et al* 1994). The nightjar has been identified as a Species of European Conservation Concern (SPEC2), whose global population is concentrated in Europe, but which has an unfavourable conservation status in Europe (Tucker & Heath 1994; Annex 1 of the Birds Directive). It is a priority species under the UK Biodiversity Action Plan (HMSO 1998) and a Red listed species (Gibbons *et al* 1996; Gregory *et al* 2002), marking it as a species of high conservation importance.

Nightjar breeding activity is concentrated mainly within southern and eastern England: Dorset, southern Hampshire, Norfolk and eastern Suffolk account for nearly half the national population (1,590 males counted in the 1992 survey, Cresswell 1996). Breeding nightjars prefer well-drained, open ground habitat with dry vegetation types, such as young conifer woodlands, clearings in coniferous/ mixed woodland, heather moors or glades and exposed woodland margins (Berry 1979; Tate 1987). In Britain, the nightjar is one of the key breeding species associated with lowland heathland.

Nightjars are ground nesting species, their nests consisting of little more than scrapes on bare ground in small clearings in vegetation (Cresswell 1996). The nests are generally uncovered and unprotected, and are frequently located near open land or clearings (Cramp & Simmonds 1985; De Hoyo *et al* (eds.) 1999).

Very few studies have been done on nightjar reproductive success. Berry & Bibby (1981) and Berry (1979) identified human disturbance as a potentially negative factor on the breeding success of nightjars. This is most likely because they nest on the ground in clearings, often near paths.

The Dorset heathlands provide an ideal study area for investigation into the impacts of human disturbance on nightjars. Dorset holds 7373ha of heathland, split into 151 different fragments (Rose *et al* 2000), which have been mapped and the areas of heathland vegetation determined for each fragment (Chapman *et al* 1989, Rose *et al* 2000). These heathland fragments occur both adjacent to and within the large urban centres of Bournemouth and Poole, while heathland sites to the west of Poole are less managed for people, have fewer open spaces and grassy clearings within woodland and heath, and are often far from any development. The county is also a stronghold for nightjars, holding 12.8% of the national population at the last census in 1992 (EU Directive on the conservation of wild birds 79/409/EEC).

A study on Dorset heathlands by Liley and Clarke showed a strong negative relationship between the degree of urban development adjacent to heathland sites and the density of nightjars on the heathland, regardless of the extent of the heathland habitat (Liley & Clarke 2002, Liley & Clarke *in preparation*). They suggest that the identified trend could be at least partly due to human presence on heathland sites.

With the passage of the Countryside and Rights of Way Act in November 2000, the potential increase in recreational disturbance on heathland sites, particularly on those with no previous public access, may have a negative effect on the nesting success of key heathland breeding species like the European nightjar.

The aim of this study is to determine the impact of human disturbance on nightjar breeding success. By comparing breeding success on a range of sites with different levels of human access, it was hoped to determine the extent to which breeding success is influenced by disturbance and to suggest any recommendations by which such effects could be prevented or minimised.

Methods

Study area and sites

The fieldwork was undertaken at ten sites in south Dorset. Liley and Clarke (2002) calculated the amount of developed land, within a 500m zone, around all heathland patches greater than 10ha in Dorset. The numbers of houses, offices and industrial sites were counted within this area, giving a surrogate measure of the effects of urban development impacting directly on the heaths. Sites were chosen from this range of different disturbance levels, using the measure of urban development. Eight sites were actively searched for nightjar territories (Table 1). Two sites allowed no public access (Arne West Track & Holton Heath) and served as control sites for the project. All sites had been surveyed repeatedly in the past and had recent or historical records of nightjars holding territories.

Data were collected during 29 May - 31 August, which approximates to the peak nightjar-breeding season (Berry 1979; Berry & Bibby 1981).

Table 1: The ten heathland sites on which nightjar territories and nests were recorded

Site	*Grid reference*	*Area (ha)*	*Access*	*Agency responsible for nature conservation management*	*Nightjar territories 2002*	*Nightjar nests 2002*
Arne (West Track)	SY970887	55	Area closed	RSPB	5	4
Holton	SY952913	96.7	Area closed	English Nature	9	6
Winfrith	SY805870	114.1	Open access, rural heath	Dorset Wildlife Trust	5	4
Great Ovens	SY923900	82.1	Open access	HCT/ Drax Estate	5	1
Canford	SZ036961	380	Open access, urban heath	Poole Borough Council	12	9
West Parley	SZ091988	116.9	Open access, urban heath	HCT	4	9
Avon Heath	SU123031	227.2	Country park, open access, with visitor centre	RSPB/ Dorset County Council	5	6
Town Common	SZ144965	187.6	Open access, urban heath.		4	5
Stoborough	SY925850	110	Open access, rural heath	RSPB	Not surveyed	1
Bovington	SY835900	157	Military site, restricted access	MOD	Not surveyed	2
Totals:					**49**	**47**

Mapping nightjar territories and nest searching

Between three and five evening visits were made to eight sites. The movement and song post locations of each ‘churring’ male nightjar were noted on aerial photographs. The flight paths were used to define individual territories as set out by standard CBC type methodology (Bibby *et al* 1992). Territories were plotted on MapInfo (Version 6 for Windows).

Each nightjar territory was then walked systematically during daylight hours within a few days of the evening visits. When more than one person was walking, individuals were no more than 2m apart while holding a straight line at right angles to the direction of travel. By this means, the ground was covered systematically, in a series of small blocks. The number of nests found was linearly related to the number of hours spent searching, with more hours producing more nests. In general, it was found that the more people searching at any one time, the greater the chance of finding a nest (Figure 1).

Later in the study period, after extended observation of nightjar breeding behaviour, evening visits targeted individual birds, in order to evoke a response from the adult pair. This consisted of defensive display behaviour, if birds had a nest nearby, including diving and circling overhead accompanied by loud ‘quipping’. The area of heath covered during such a defensive display would then be walked in search of a nest.

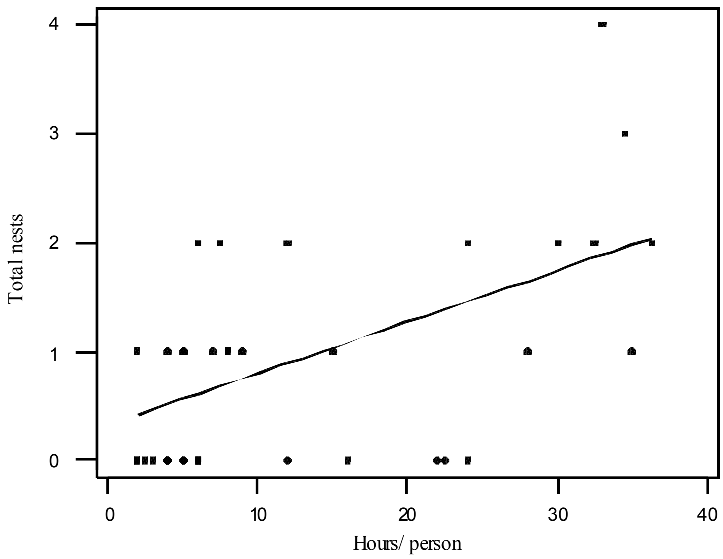

Figure 1: Measure of effort in nightjar nest searches (S=0.856, F=15.478, $p<0.0001$)
A total of 571.25 person hours were spent nest searching = 13.28 hours/nest (n=43 nests)

Nest monitoring

Nests were not marked to avoid the possibility of attracting predators (Angelstam 1986) or passers-by to the nest site. Instead, notes were made highlighting the prominent natural features near to the nest, to aid in relocation. Nests were visited at approximately 5-day intervals, the large gap in visits marking an attempt to minimise visitor-related disturbance and to lessen the chances of leading predators to the nest site. Characteristics of failed nests were recorded, and nest remains carefully checked and described to allow identification of predators where possible.

Nest site characteristics

Table 2 lists the habitat variables measured at each nest site. Vegetation variables were measured at 43 nests at the end of the breeding season, to avoid disturbance to breeding adults or young.

Table 2: Nest vegetation variables measured at 43 nests

Characteristic	*Variable measured*
Vegetation composition	% grass spp. % heather spp. % gorse spp. % bracken % saplings
Ground cover composition	% bare ground % moss/lichen % debris
Vegetation height	% vegetation < 5cm % vegetation 5-15 cm % vegetation 16 – 30 cm % vegetation > 30 cm
Clearing size	l x b (m)
Nest cover/ shading	% shaded

Heights of vegetation were measured using a marked cane. Two heights were recorded using the sward stick method (Sutherland 2000) for all four sides of the vegetation clearing (north, south, east, west). Nest cover (horizontal vegetation density) was approximated using a method similar to the Secchi disc. A red card ($30cm^2$) was placed in the centre of the nest clearing. Nest sites were then circled at a distance of 3m (the average distance at which a nightjar flushed from eggs when disturbed by a person on foot), the percentage of card hidden was averaged for each side of the nest (north, south, east, west), and the average total gave an approximate percentage of nest shading at each nest site. Clearly, this measure would vary between observers of differing height, so the same researcher performed all necessary observations. The size of the nest clearing (not the nest scrape) was measured using a marked cane. The percentage ground cover of the main plant groups and other features within the nest clearing was estimated. Debris was defined as pine needles, pine cones, dead bracken, fallen branches and dead wood.

Disturbance characteristics relative to territory location and territory success

Areas of heathland sites and territories were obtained in hectares using MapInfo. Postal code data was used to approximate the overall urban development immediately adjacent to heathland sites, by counting the total number of houses/buildings/offices within 500m of the site. This technique has been used before (Liley and Clarke 2002).

Nightjar territory centres were plotted, using MapInfo, on aerial photographs. Within each site, random points were plotted, using the same number of random points as the number of territories for each site. For each point (territory centres and random points), the distance to the nearest edge of the site, the distance to the nearest postal code data point (nearest building/s) and the distance to the nearest road were calculated. Aerial photographs were used to delineate the major paths, and to identify the primary access points and roads for each site. Paths were rated as high, medium and low use paths across all sites. The sum of the lengths of paths of each type (low, medium, high-use and roads), within each territory, was also measured using MapInfo SQL.

Disturbance characteristics relating to nest location and nest success

Using 0-75m, 75-150m and 150-225m bands from paths, the density of nightjars within each band was calculated and nesting success determined for each category.

Nest disturbance characteristics were also measured on MapInfo. From each nest site, the distance to the nearest path, the nearest low use path, the nearest medium use path, the nearest high use path, and the nearest road and access point were measured. The total lengths of each type of path, within three sets of circular zones (50m, 100m and 500m radii) drawn around each nest site, were also calculated (Table 3).

Data and Statistical Analysis

Data were analysed using Minitab statistical software, Version 13.1 for Windows and Microsoft Excel 1997.

Table 3: Nest disturbance characteristics measured on MapInfo for 43 nests

Characteristic		*Variable measured*
Path distance (metres)		Distance to nearest path
		Distance to nearest low use path
		Distance to nearest medium use path
		Distance to nearest high use path
		Distance to nearest road
		Distance to nearest access point
		Distance to nearest house/ building
Sum of path lengths in zones around each nest site (metres)	50m zone	All paths
		Low use paths
		Medium use paths
		High use paths
		Roads
	100m zone	All paths
		Low use paths
		Medium use paths
		High use paths
		Roads
	500m zone	All paths
		Low use paths
		Medium use paths
		High use paths
		Roads

Disturbance analysis relative to territory location and success

Nightjar density was calculated as the number of adult breeding birds divided by the area of heathland (hectares). Density figures were then compared with the percentage of urban development in a 500m zone around the site using regression analysis. Nightjar territory centres were compared with random points, visually, by combining all sites and using Box and Whisker plots and then statistically, by comparing the two data sets using a non-parametric technique (Mann Whitney U tests).

Analysis of breeding success

The breeding results from all nests were pooled in order to calculate overall breeding success. Mayfield's method of calculating nest success (Mayfield 1975), by estimating the probability of daily survival for each egg and nest, was used. To assess site differences, Johnson's Z test (Johnson 1979) was used on sites with sufficient nest numbers to make comparison viable.

Disturbance analysis relative to nest location and nest success

Nightjar nests were compared with random points, using the techniques previously described for territory location.

Relationships between nest success/failure and nest vegetation characteristics were investigated using Principal Components Analysis (PCA), which reduced the interrelated habitat variables into a smaller set of independent compound variables. Differences in the vegetation and disturbance variables for successful and failed nests were then established, using non-parametric univariate tests (Mann Whitney U tests), as data were non-normal (all data were tested for normality, using the Kolmogorov Smirnov test). The closed access sites of Arne West Track and Holton Heath were excluded from these calculations.

Where significant differences in the nest variables of failed and successful nests were found, the proportion of failed nests was compared to different categories of nest vegetation and disturbance characteristics.

The relationship between nest outcome and nest variables was explored further using binary logistic regression. Binary logistic regression was appropriate because the dependent variable was dichotomous (i.e. successful/failed). In an attempt to create a predictive model of the probability of nest failure, using nest parameters significantly different for successful/failed nests, logistic regression with Somers' D and Goodman-Kruskal Gamma's tests of concordant and discordant pairs, was used with PCA vegetation scores and nest disturbance characteristics as predictor variables.

Results

General

Overall, eight sites were surveyed in the evenings, culminating in 48 mapped territories (Figure 2). Of these, only 20 were successfully searched for nests. The remaining nest sites were located outside known territory boundaries or on additional un-surveyed sites. A total of 47 nests was located (Figure 2), 36 with eggs, eight with chicks, and a further three with immature birds, only one of which was linked back to its original nest site.

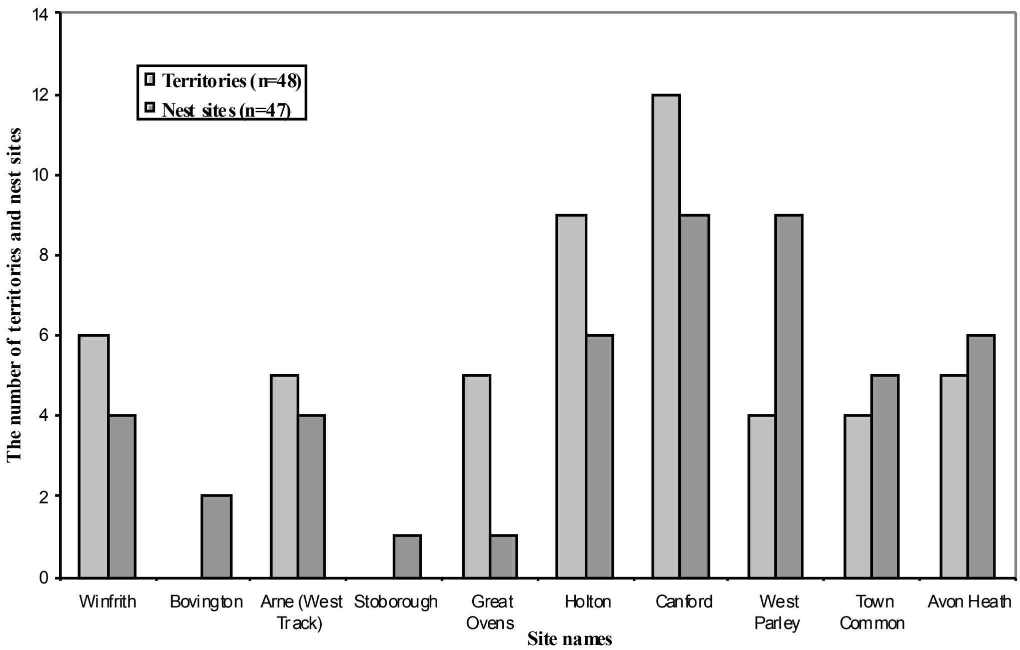

Figure 2: The number of territories and nest sites found on each site. Bovington and Stoborough were not surveyed for territories.

Territory location

There was a negative relationship between nightjar density and the degree of urban development (total number of buildings) within a 500m zone around the heathland site, estimated from postal code data (Figure 3), but this was not significant (S=0.026, F=4.09, p<0.09).

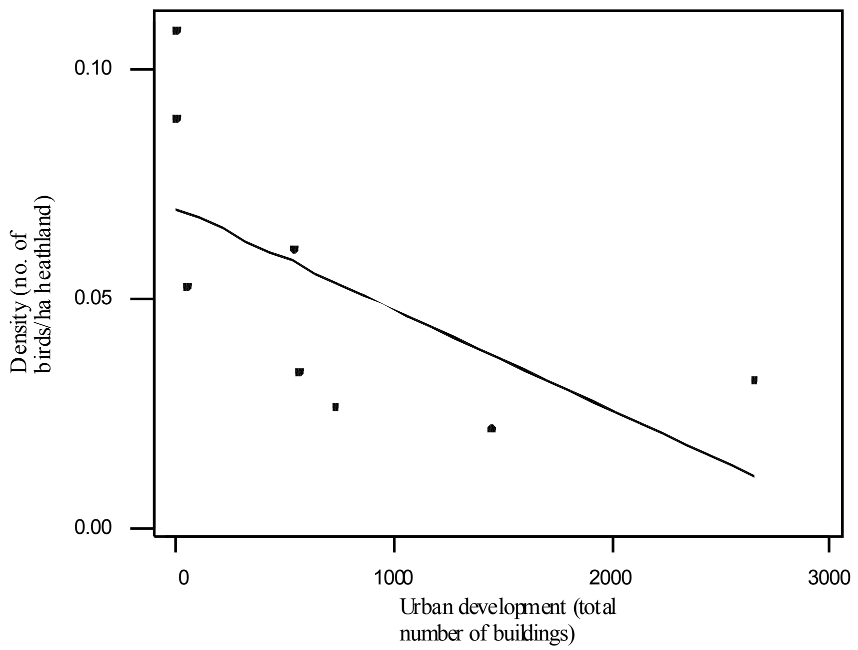

Figure 3: Relationship between nightjar density (birds/ha heathland) and urban development (total number of buildings within 500m of heathland site) (S=0.026, F=4.09, p<0.09, n=8)

Nightjar territory centres were compared with random points (Figure 4). With points for all sites combined, there was no significant difference in the distance (m) between nightjar territory centres and random points, to the nearest edge of the site, or to the nearest road (p=0.2611 and p=0.0592, respectively). Nightjar territory centres were however located significantly further away from postal code points (the nearest built up area) than random points (p=0.0009).

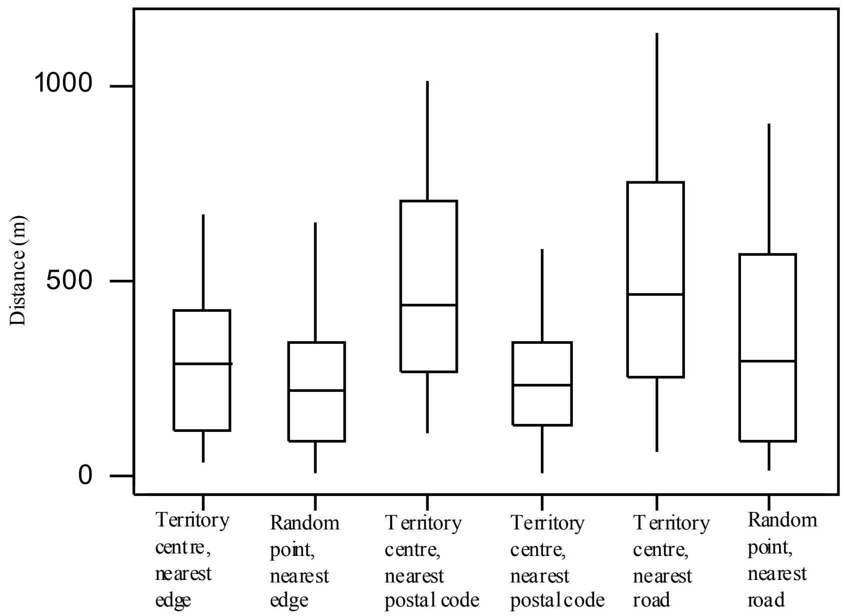

Figure 4: Box plots summarising the location of nightjar territory centres compared to random points. Box = interquartile range (25-75%), middle horizontal line = median, vertical lines = remaining data range. The difference is significant only for distance to nearest house (Mann Whitney U statistics: W=749.0, p=0.0009). Distance to edge of site and distance to nearest road are not significant (W=643.0, p=0.2611, W=680.0, p=0.0592).

Territory success

A territory was considered successful if it contained a successful nest. Territory success was compared with path disturbance data. The sum of path lengths for each path category and for all paths was tested against territory success. Although there was a negative relationship in all cases, the results were not significant (Table 4).

Table 4: Length of paths and roads within a territory compared with territory success (ie: a territory is successful if it contains a successful nest).

Disturbance variable (metres)	*Regression co-efficient*	*G*	*p*
Sum of low use path lengths within a territory	-0.00068	0.355	0.552
Sum of medium use path lengths within a territory	-0.00023	0.403	0.526
Sum of high use path lengths within a territory	-0.0010	3.021	0.082
Sum of road lengths within a territory	-0.00085	0.831	0.362
Sum of all path and road lengths within a territory	-0.00053	2.793	0.095

Nest site location

Nest locations were compared with random points (Figure 5). For all sites combined, there was no significant difference in the distance (m) between nightjar nest locations and random points, to the nearest edge of the site. However, nightjar nests were located significantly further away from postal code points and from roads than random points (p=0.0006 and p=0.0118 respectively), with distance from the nest to the nearest postal code showing the greatest overall difference. Similarly, nightjar nests were compared with random points, with respect to the distance to the nearest path. For all sites combined, there was no significant difference between nightjar nest locations and random points to the nearest paths (Figure 6). Nightjar densities were comparable within 75m and 75 to 150m from a path, decreasing at distances of further than 150m (Figure 7).

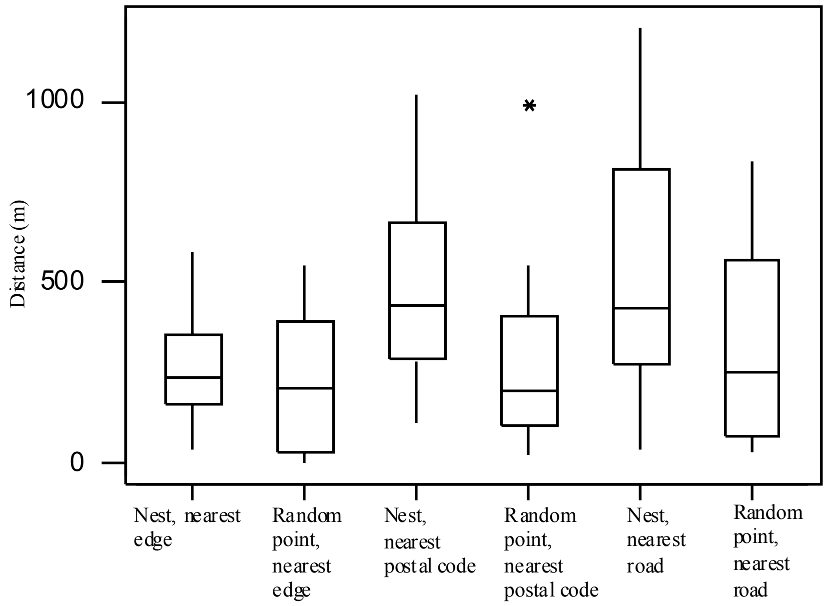

Figure 5: Box plots summarising the location of nest sites compared to random points. Box = interquartile range (25-75%), middle horizontal line = median, vertical lines = remaining range of data points, * denote outlying points. The difference is significant for distance to nearest postal code point and nearest road (Mann Whitney U tests: W =942.0, p = 0.0006, W=888.5, p=0.0118, respectively). The difference was not significant for distance to nearest edge (W=806.0, p=0.2757).

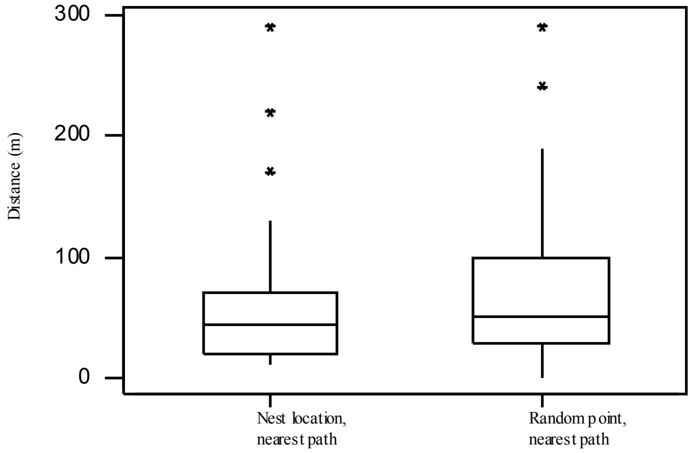

Figure 6: Box plots summarising the location of nest sites compared to random points. Box = interquartile range (25-75%), middle horizontal line = median, vertical lines = remaining range of data points, * denote outlying points. The difference is not significant for distance to the nearest path (Mann Whitney U tests: W=1687.5, p=0.3833)

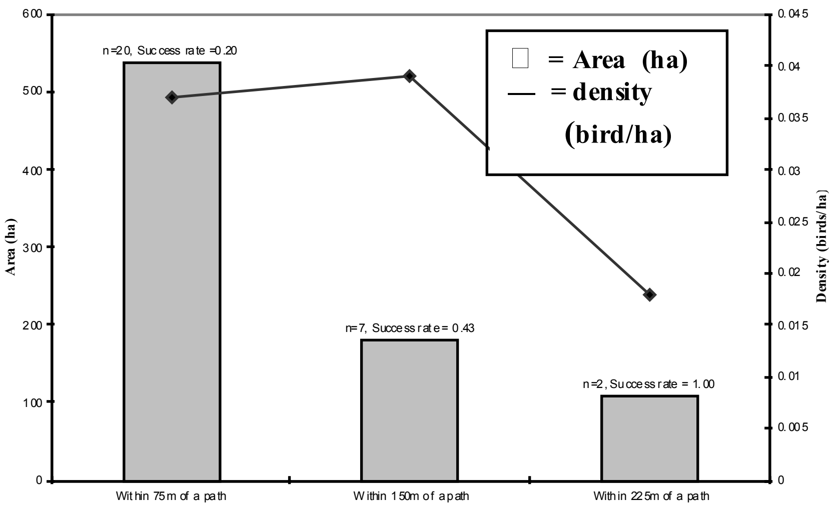

Figure 7: The area of heathland within 75m, 150m and 225m of paths and the relative densities of nightjars and success rates for each, for the disturbed heathland sites of Canford, Avon Heath, Town Common and West Parley. On undisturbed sites, all nests were found within less than 75m of a path (n=14, Area within 75m of a path = 136.23 ha, density = 0.103 birds/ha, Success rate =0.71)

Nest success and site difference

Of the 47 nests found across ten sites in this study, 40 % (19 nests) were successful. Failure or predation of one egg in a nest resulted in failure of the whole clutch, as adult pairs abandoned nest sites after partial failure. Daily survival rates of individual eggs and nests thus could be taken as the same measure of success, and therefore only one set of Mayfield analysis was necessary.

Nest success was divided into 3 stages: the first, incubation success, defined as the probability of an egg surviving to hatch (incubation period = 19 days), the second hatching success, the probability of an egg hatching successfully and the third, fledgling success, the probability of a chick surviving to reach flight capability (fledgling period = 18 days). Mayfield estimates for each were as follows:

incubation success (0.145, S.D. =0.0184/nest day)
hatching success (0.880, S.D. =0.00161)
fledgling success (0.855, S.D.=0.00497/nest day)

Therefore, the probability that an egg, at the start of incubation, would produce a fledgling was 0.12 (S.D. = 0.0085/nest day).

Twenty-nine young were reared overall. The average number of young reared per pair was 0.63 for 46 pairs, and per successful pair, 1.53 young for 19 pairs. Twenty-four nests failed as eggs and only three as young birds.

Nest success (the proportion of successful nests per site) and nightjar density were significantly correlated (Pearson's correlation coefficient = 0.773, p=0.042).

Fifty-five percent of all nests were predated during the study. Of the 28 failed nests, 26 were predated (93%), one abandoned and one trampled by a horse (Table 5). Where possible, nest remains after predation were attributed to a predator type according to the nest remains, as described in Table 5. There was a great deal of variation in nest success between sites. The proportion of successful nests at each site is illustrated in Figure 8.

Table 5: Description of nest remains, presumed cause of nest failure and the number of nests found in each category

Nest Remains	*Reasons for Failure*	*No. Found*
Eggs whole but cold, no recent evidence of bird occupation	Nest abandoned	1
All eggs/chicks/fledglings eaten, scrape untouched	Predation, mammalian	4
All eggs eaten, scrape and nest area trampled/ ground disturbed	Predation, mammalian	3
All eggs eaten, scrape and nest area trampled/ ground disturbed. Small fragments of shell scattered around nest site or buried	Predation, mammalian	1
Part of clutch missing. A few small shell fragments left in scrape, nest abandoned	Predation, mammalian	1
Predated egg remaining in scrape with large hole in top	Predation, avian	17
Fragments of shell, with yolk found scattered around nest scrape, ground disturbed	Nest trampled	1
Total		**28**

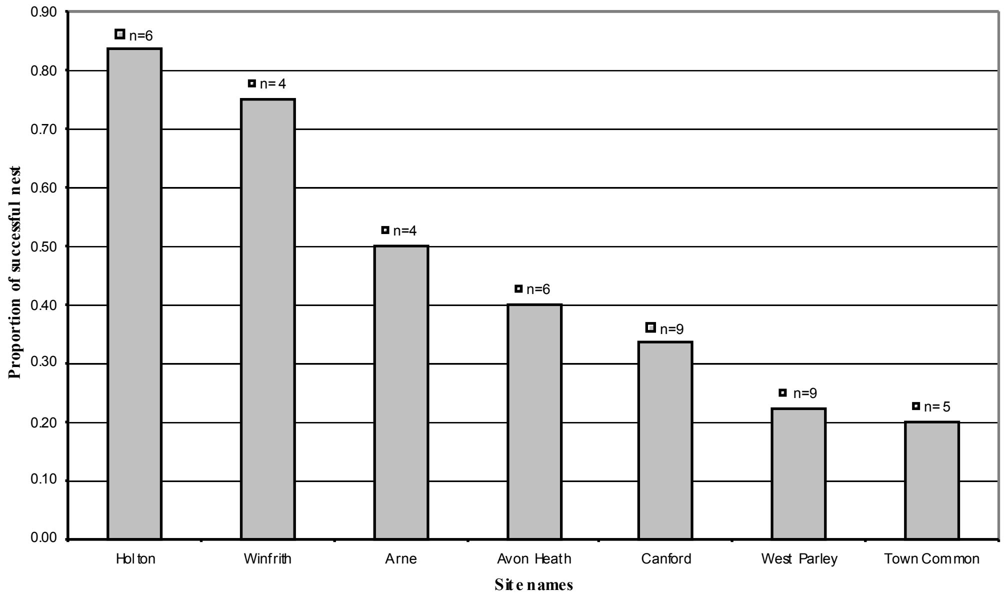

Figure 8: The proportion of successful nightjar nests at each site

Town Common, with 20% nest success (n=5) was the least successful site, followed closely by West Parley (22% nest success, n=9). The most successful sites were Holton Heath, with 83% nest success (n=6) and Winfrith, 75% nest success (n=4). There was a negative relationship between the proportion of successful nests for each site and urban development surrounding the site, calculated from postal code data (Figure 9: S=0.214, F=3.030, p=0.142).

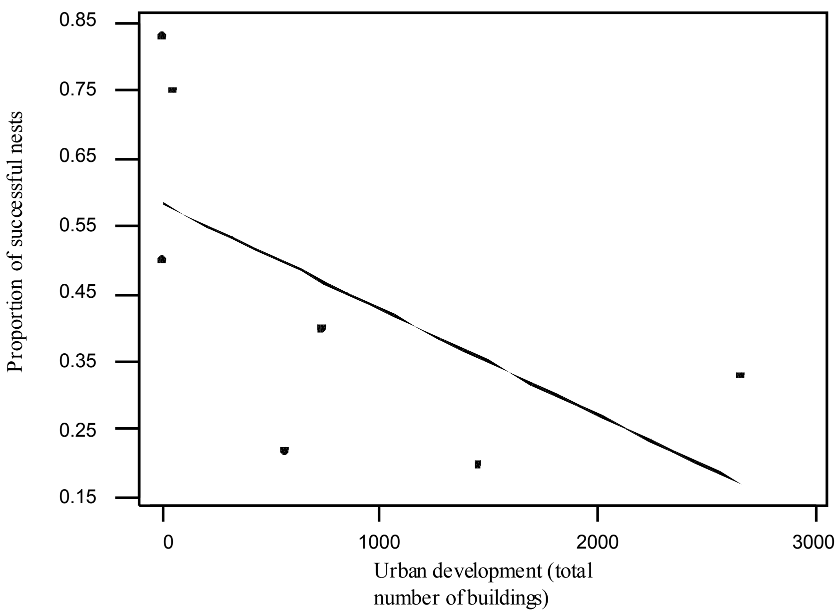

Figure 9: Relationship between the proportion of successful nests for each site and urban development (total number of buildings within 500m of heathland site) (S=0.214, F=3.030, p=0.142)

The percentage of predated nests on each site is shown in Figure 10 and the number of avian and mammalian predations in Figure 11. The proportion of avian versus mammalian predated nests ranged from sites where all the predation was by avian predators (Winfrith, Holton and Avon Heaths) to Canford Heath where 80% of predated nests were predated by mammalian predators.

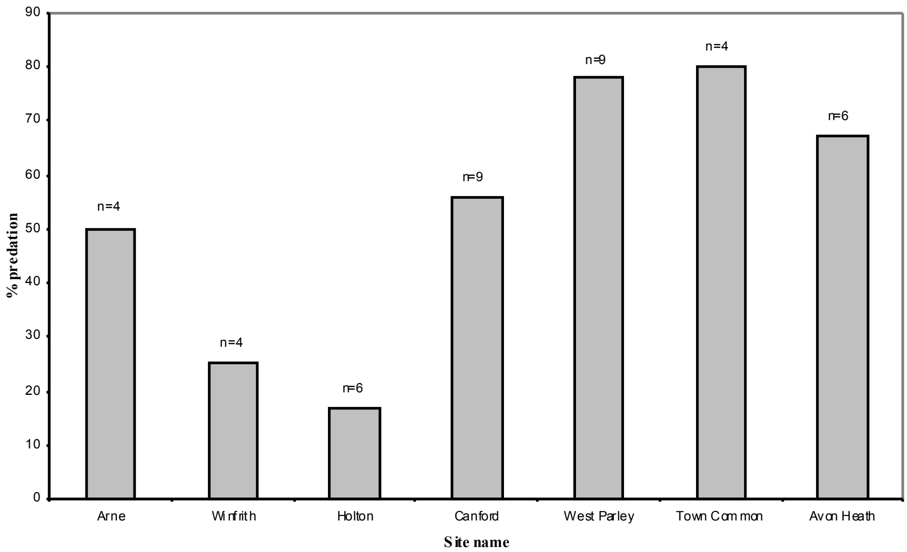

Figure 10: The total number of nests predated on each site (Mean value of 55% of all nests)

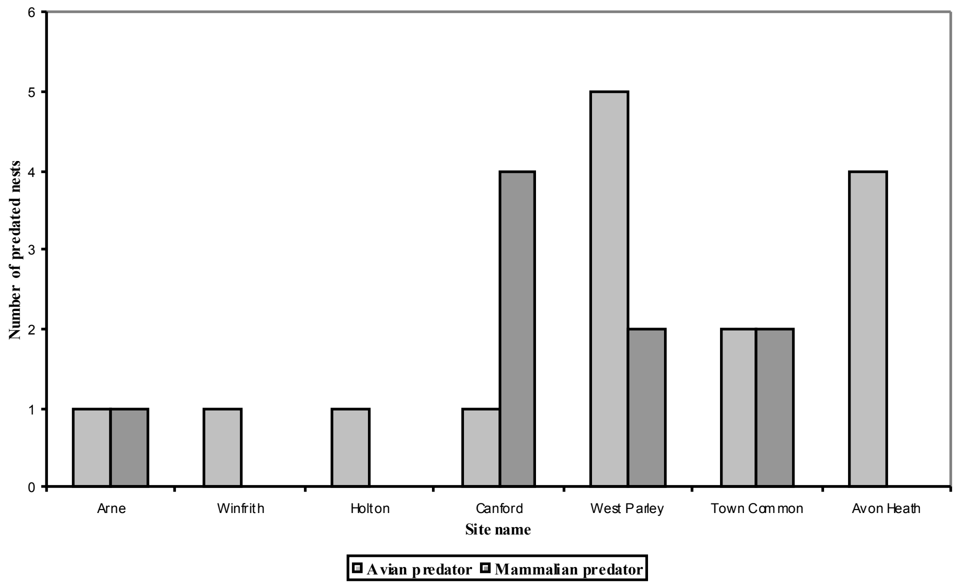

Figure 11: The total number of avian and mammalian predated nests on each site

To assess differences in nest success between sites, Johnson's Z test was used on the Mayfield estimates for sites with sufficient nest numbers to make comparison viable. Daily nest success at Canford Heath and West Parley was compared with that at Holton Heath (Table 6). The measures of nest success between sites proved significantly different, with both Canford and West Parley exhibiting much lower daily nest survival rates than Holton Heath (z=2.13 and z=2.54, respectively).

Table 6: Johnson's Z test results comparing overall Mayfield nest survival estimates between different heathland sites

Site name	*Daily nest survival rate*	*SD / nest day*	*Comparison of sites' Mayfield nest survival rates with those of Holton (>=1.96 is significant)*
Canford	0.958	0.0166	**2.13**
West Parley	0.923	0.0279	**2.54**
Holton	0.995	0.0051	-

Nest site and disturbance characteristics

The principle components derived for the PCA analysis are shown in Table 7a. The first four are of primary importance as they account for 85% of the total variability in the data.

Table 7a: Principal components selected from original nest site variables, with eigenvalues and percentage variance explained by each component. Those highlighted in bold type cumulatively explain the majority of the variance.

Component	*Eigenvalues*		
	Total	%Variance	Cumulative variance
1	**4011.5**	**43.8**	**43.8**
2	**1945.6**	**21.3**	**65.1**
3	**1099.1**	**12.0**	**77.1**
4	**720.0**	**7.9**	**85.0**
5	374.6	4.1	89.1
6	324.5	3.5	92.6
7	254.1	2.8	95.4
8	215.0	2.3	97.8
9	128.3	1.4	99.2
10	66.3	0.7	99.9
11	9.9	0.1	100

Table 7b shows the composition of the first four principal components. The percentage of variance explained by each PC is shown in parenthesis and the strength of the correlation between the PCs and the original variables are given. PC1 contrasts well shaded, debris–strewn, heather-based nests, with nests in high vegetation (>30cm), consisting mainly of gorse. PC2 contrasts shaded nests in high (>30cm) heather, with nests in very low vegetation cover (<5cm) with debris for ground cover. PC3 contrasts nests in heather and debris-strewn ground cover, with nests in grass and with no ground cover. PC4 contrasts nests in low vegetation cover (<5cm), with moderately protected nests (nests with vegetation heights between 16 and 30cm).

Table 7b: Principal components explained using original nest site variables in the first four principal components

PC1 (43.8%)	*PC2 (21.3%)*	*PC3 (12.0%)*	*PC4 (7.9%)*
% heather height (0.411)	% heather height (-0.473)	% heather height (-0.477)	vegetation height <5cm (-0.533)
% gorse height (-0.304)	% vegetation height <5cm (0.352)	% grass height (0.339)	vegetation height 16-30cm (0.743)
vegetation height >30cm (-0.427)	vegetation height >30cm (-0.506)	% bare ground (0.599)	
% debris (-0.412)	% debris (0.370)	% debris (-0.442)	
% shading (-0.467)	% shading (-0.335)		

There were a number of differences in nest site vegetation and disturbance characteristics between successful and failed nests (Table 8). Of the nest vegetation characteristics, only the second PCA variable, PC2, contrasting well-shaded nests surrounded by high vegetation and nests of low vegetation cover, proved significantly different for failed and successful nests (Figure 12, W =693.0, p=0.0028). Plotting PC1 and PC2 scores against one another showed a division between successful and failed nests on the PC2 axis. Failed nest sites were characterised by much shorter surrounding vegetation, and overall lower vegetation cover, relying instead on ground debris to provide shelter. These predated nests were therefore linked with shorter vegetation and associated reduced cover.

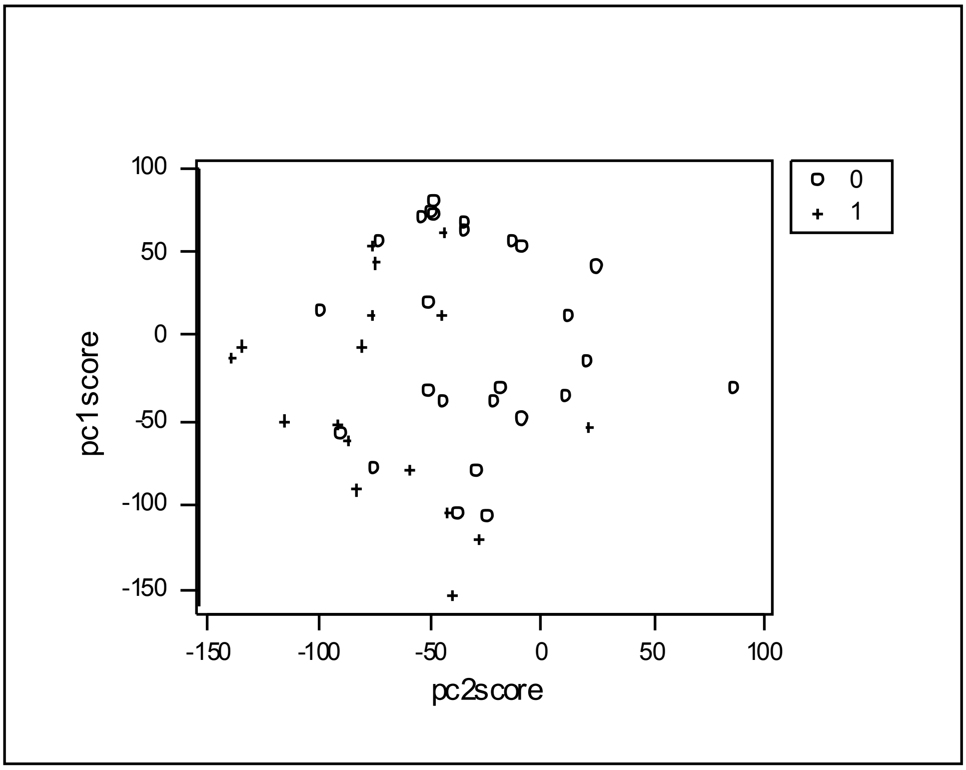

Figure 12: The PC1 component plotted against the PC2 component for successful (1) and failed (0) nests. Failed nests are grouped to the right of the PC2 axis, indicating nests of low surrounding vegetation height. The difference in PC2 for successful and failed nests is significant (Mann Whitney U tests: W=693.0, p=0.0028).

Significant differences were also found between successful and failed nests and path disturbance characteristics (Table 8). Holton Heath and Arne West Track were excluded from these calculations, as they are both closed access sites. All nests at these two sites (Holton Heath and Arne) were within 75m of a path. Applying the path disturbance characteristic: 'distance to the nearest path'; predated nests were found significantly closer to paths than non-predated nests (W= 1178.0, p=0.0121). In addition, nests surrounded by greater total path length (in 50m, 100m and 500m zones around the nest site), were associated with higher nest predation (W=686.0, p=0.0054; W=688.0, p=0.0121; W=691.0, p=0.0109, respectively). The greater lengths of medium and high use paths within 500m of the nest site also had a significantly negative effect on nest success (W=678.5, p=0.0219; W=683.0, p=0.0169, respectively). Similarly, higher numbers of medium and high use paths within 100m had a negative effect on nest success, but this was not significant (W=654.0, p=0.0528; W=650.0, p=0.0682, respectively).

Table 8: Differences in nest site characteristics for failed and successful nests showing results from Mann Whitney U tests. Significantly different variables are highlighted in bold type.

Variable		*W*	*p*
PC1			
PC2		**693.0**	**0.0028**
PC3			
PC4			
Distance to nearest path		**1178.0**	**0.0121**
Distance to nearest low use path		103.5	0.6693
Distance to nearest medium use path		310.0	0.1513
Distance to nearest high use path		300.5	0.4921
Distance to nearest road		598.5	0.2372
Distance to nearest access point		397.5	0.3793
Distance to nearest house		637.5	0.2143
50 m zone around nest	Total lengths of medium use paths	626.0	0.1290
	Total lengths of high use paths	626.0	0.1701
	Total lengths of all paths	**686.0**	**0.0054**
100 m zone around nest	Total lengths of low use paths	612.0	0.3468
	Total lengths of medium use paths	654.0	0.0528
	Total lengths of high use paths	650.0	0.0682
	Total lengths of road	577.0	0.7196
	Total lengths of all paths	**688.0**	**0.0121**
500 m zone around nest	Total lengths of low use paths	621.5	0.3404
	Total lengths of medium use paths	**678.5**	**0.0219**
	Total lengths of high use paths	**683.0**	**0.0169**
	Total lengths of roads	574.0	0.7711
	Total lengths of all paths	**691.0**	**0.0109**
	Residential housing	1756.0	0.6556
	All housing	578.0	0.8722

Arne and Holton Heath (the sites with closed access) were analysed separately, comparing nest success to the path disturbance variable 'distance to the nearest path'. All nests were found within 75m of a path (n=10). Three of the four nests located less than 25m from a path, failed.

The categorical plots of proportion nest failure versus increasing path disturbance showed a strongly negative relationship between nest proximity to path, overall path length and intensity of path use (Figures 13a-f). The most striking visual patterns were firstly, with regard to path use, between the total lengths of high intensity use paths within 500m of the nest, increasing total length of high use paths having a negative affect on nest success (figure 13e). Increasing total path length, particularly in the 100m and 500m zones, also showed a strongly negative relationship with nest success (Figure 13f), suggesting the possibly detrimental affects of greater overall recreational activity on nightjar breeding success. Possibly the most significant influence was the extreme negative relationship between nests and their distance to the nearest path, nest success decreasing rapidly with higher path proximity (Figure 13a).

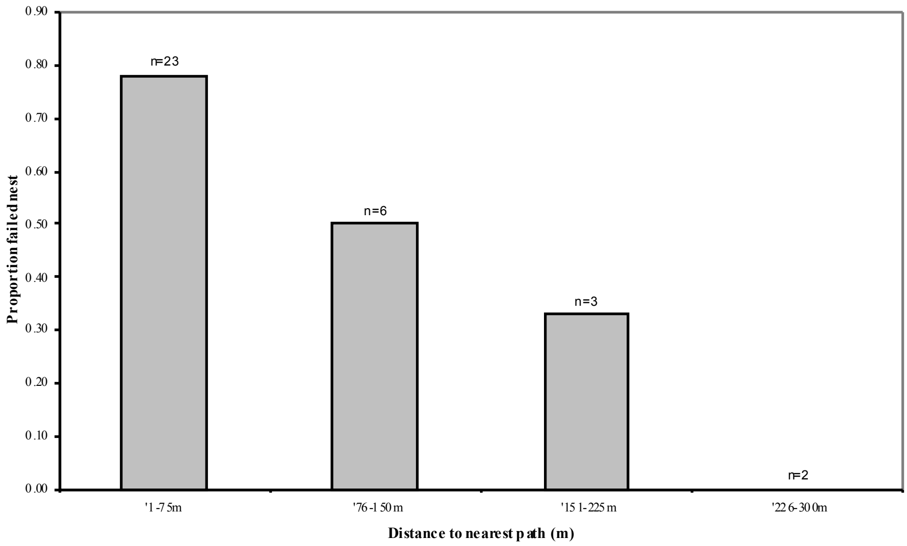

Figure 13a: Proportion of failed nests at different distances (metres) to the nearest path. (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation.)

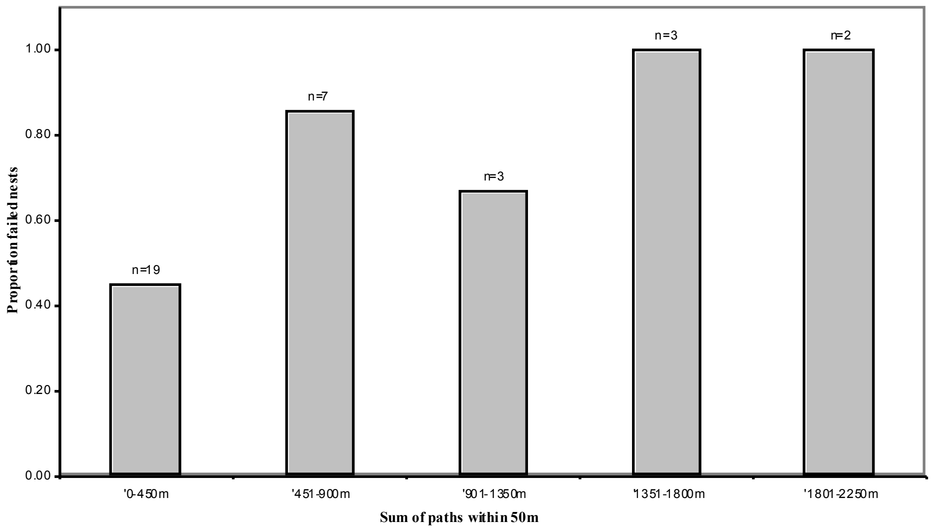

Figure 13b: Proportion of failed nests with increasing total lengths of paths (metres) within 50m around the nest sites (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation).

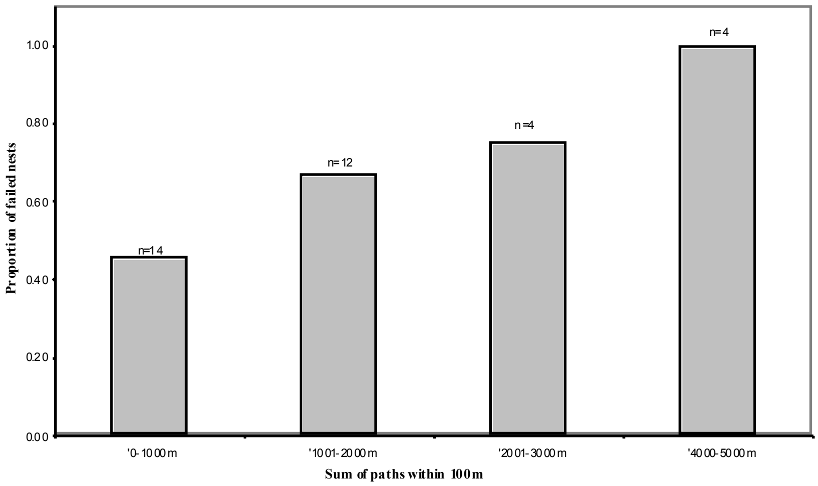

Figure 13c: Proportion of failed nests with increasing total lengths of paths (metres) within 100m of the nest sites (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation).

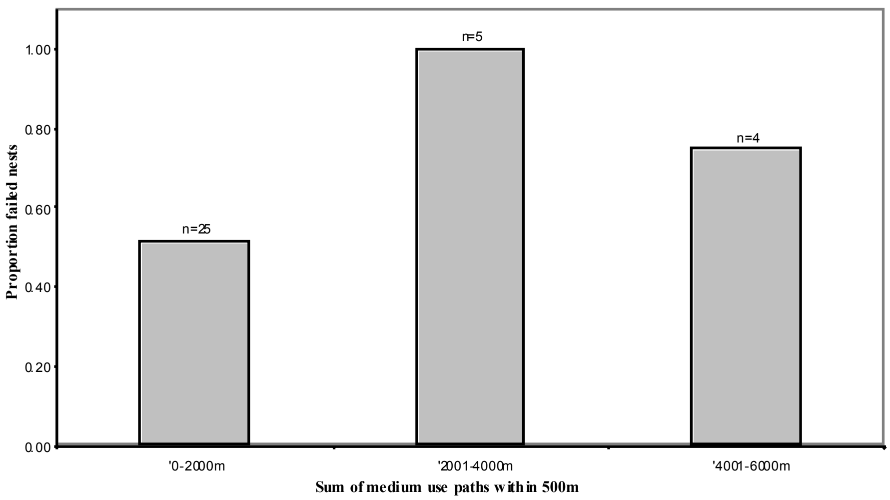

Figure 13d: Proportion of failed nests with increasing total lengths of medium use paths (metres) within 500m of the nest sites (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation).

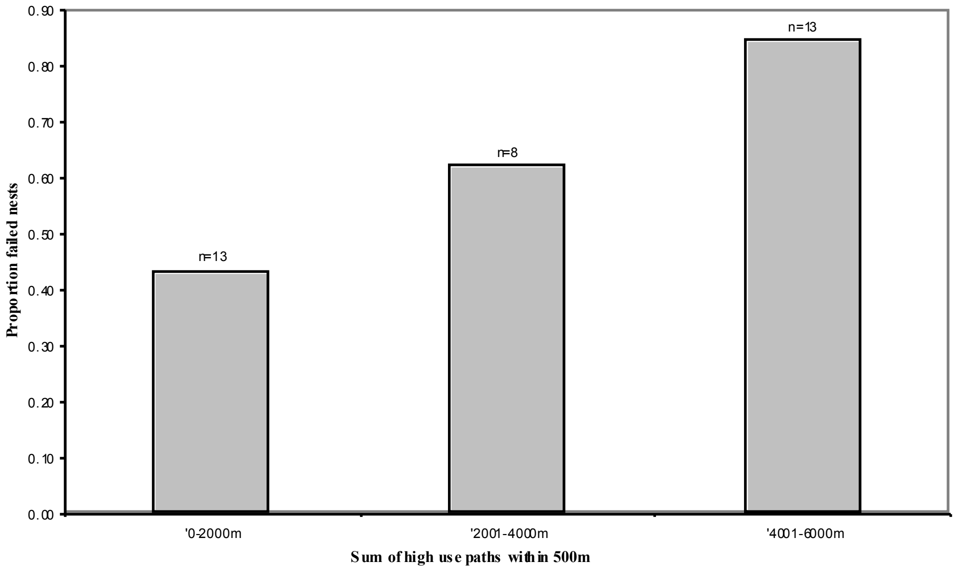

Figure 13e: Proportion of failed nests with increasing total lengths of high use paths (metres) within 500m of the nest site (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation).

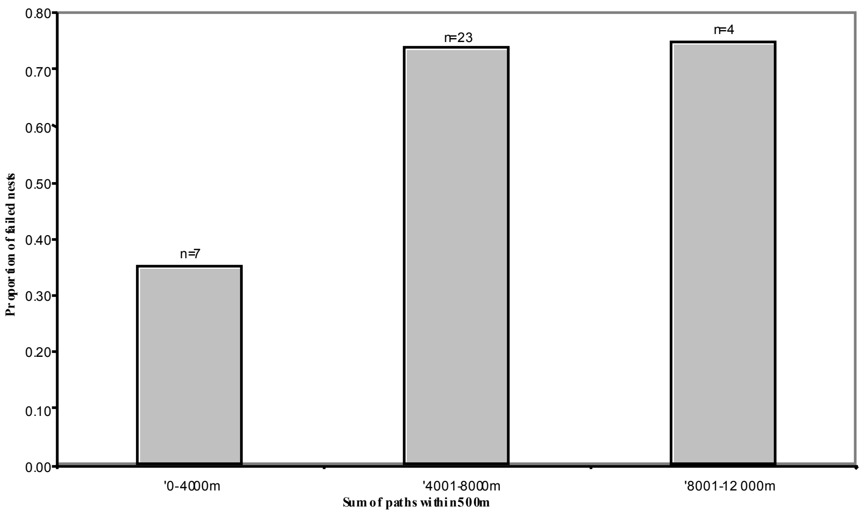

Figure 13f: Proportion of failed nests with increasing total lengths of paths (metres) within 500 of the nest sites. (The closed access sites of Holton Heath and Arne West Track were omitted from this calculation.)

There were no significant differences between the nest characteristics of those nests predated by mammalian predators and those nests predated by avian predators (Table 9).

Table 9: Differences in nest site characteristics for avian-predated (n=15) and mammalian predated (n=9) nests showing results from Mann Whitney U tests.

Variable	*Median for avian-predated nests*	*Median for mammalian-predated nests*	*W*	*p*
PC1	54.29	-31.71	216	0.1
PC2	-37.53	-22.06	180	0.68
PC3	-13.51	-21.16	186	0.95
PC4	2.67	-12.77	199	0.51
Distance to nearest low-use path	120	165	64	0.91
Distance to nearest medium-use path	100	50	147	0.1
Distance to nearest high-use path	140	50	143	0.19
Distance to nearest road	380	460	179	0.63
Distance to nearest access point	500	490	146	0.83
Distance to nearest house	420	560	159	0.094
Total length of all paths within 50m	0	606.7	167	0.216
Total length of all paths within 100m	1203.9	1583	172	0.38
Total length of all paths within 150m	4969	7772.5	156	0.07

The use of binary logistic regression to build a predictive model of nest predation based on the variables measured at each nest site was used as a test of whether the probability of nest failure could be predicted on the basis of nest vegetation and disturbance characteristics alone.

Firstly, univariate analysis was used within binary logistic regression for each of the nest site disturbance characteristics that proved significantly different for failed and successful nests, and the vegetation characteristic, PC2. The significance values of the G test were used to identify variables with $p>0.05$ (Table 10). These were considered to be of less importance in predicting the dependent variable. This step excluded the path disturbance characteristics: total length of paths within the 50m zone and total lengths of medium use paths in within 500m from use in a high quality predictive model. Goodness-of-Fit tests were applied to assess the reasonableness of using the data in a logistic regression model ($p>0.05$ indicated an adequate fit of the data to the model). All characteristics tested showed a good fit to the logistic regression model. Finally, Somers' D and Goodman-Kruskal Gamma tests were used to test the predictive quality of the model.

The distance of the nest site to the nearest path proved the most significantly related to nest success. Somers' D and the Goodman-Kruskal Gamma test to investigate the model's predictive qualities showed that 83.5% of the data was concordant with the model's prediction for those data (Table 11). Thus, a nest's proximity to paths may be considered a significant predictor of nest success.

Table 10: Results of the univariate binary logistic regression analysis on 46 nests to determine which variables were significantly related to nest success/failure and, subsequently which variables proved significant predictors of nest failure. Significant results ($p<0.05$) are highlighted in bold type.

Variables					*Log-likelihood test.*		*Goodness of Fit tests (p>0.05 – adequate fit)*						*Predictive quality of model*	
							Pearson		Deviance		Hosmer-Lemeshow		Somers' D	Goodman-Kruskal Gamma
	Coefficient	z	p		G	p	χ^2	p	χ^2	p	χ^2	p		
PC2	0.034	2.75	**0.0006**	***S***	10.193	**0.001**	40.861	0.477	4.520	0.224	7.867	0.447	0.52	0.52
Distance to nearest Path	**0.016**	**2.59**	**0.01**	***S***	**15.121**	**<0.0001**	**16.442**	**0.562**	**18.912**	**0.397**	**4.406**	**0.819**	**0.70**	**0.72**
Total lengths of paths within 50m	-0.00072	- 1.48	0.140	***Ns***	2.412	0.120	21.022	0.458	25.777	0.215	1.394	0.845		
Total lengths of paths within 100m	-0.00083	- 2.24	**0.025**	***S***	7.612	**0.006**	23.176	0.509	26.933	0.308	1.716	0.887	0.44	0.51
Total lengths of paths within 500m	-0.00025	- 2.39	**0.017**	***S***	6.414	**0.011**	27.441	0.440	31.429	0.254	6.385	0.381	0.46	0.50
Total lengths of medium use paths within 500m	-0.00049	- 1.84	0.065	***(s)***	4.409	**0.036**	13.578	0.697	17.123	0.446	3.719	0.445		
Total lengths of high use paths within 500m	-0.00043	- 2.25	**0.024**	***S***	5.852	**0.016**	17.567	0.417	20.237	0.262	1.328	0.857	0.42	0.49

Table11: Classification of probability for Predictor variable: Distance to nearest path, showing high predictive ability = 0.72 (Goodman-Kruskal Gamma test)

Classification	*Model prediction*
Concordant (nests that succeed have high probability of success)	**83.5%**
Discordant (nests that succeed have low probability of success)	13.7%
Ties	2.8
Total	100%

Discussion

The results of this study clearly demonstrate that nightjar breeding success differs between heavily visited sites and those with little or no public access. Breeding success is shown to correlate with density, with the lower densities on sites with the poorest breeding success. Breeding success is influenced by both the nest-site habitat and by the proximity of paths. Path effects on disturbed sites correlate strongly with nest failure up to 225m from the path edge. The causal link between nest predation events and human disturbance from path use is at present anecdotal for nightjars. However, a number of other studies have offered direct evidence as to the relationship between nest predation and human disturbance.

Ground nesting birds are particularly vulnerable to disturbance, especially from trampling and dogs. Birds tend to flush more readily in response to the presence of dogs than people, dogs causing greater disruption to the incubation of eggs and chicks, than humans on foot. (Yalden & Yalden 1990; Lord *et al.* 2001). Evidence that dogs do predate eggs and chicks was found in studies on Killdeer (Nol & Brooks 1982) and Ringed Plovers (Pienkowski 1984a, 1984b). Adult birds are also flushed from the nest site by human intruders, leaving their eggs to be predated while they are away (Schauer & Murphy 1996). Unguarded eggs and chicks are vulnerable to predators, which may be attracted to the nest site by the calls and defensive displays of disturbed adults.

In this study, most of the disturbance on sites with public access was through dog walkers. A report of a dog predating a nightjar nest on Lion's Hill (pers. comm.) and the consequent finding of a dead chick that had been mauled by springer spaniels demonstrates the threat posed by dogs (off lead) to breeding nightjars. At Canford, dogs were also seen flushing an adult nightjar from eggs and trampling the nest site (pers. obs). The high percentage of nests predated by avian (corvid) predators at the egg stage, suggests that the exposed nightjar eggs, being mostly white, may be highly visible to these predators (De Hoyo *et al* (eds.) 1999). Any disturbance resulting in the subsequent exposure of eggs (ie adults leaving the nest when flushed by dogs or humans) will therefore leave the nest highly vulnerable to predation, particularly by avian predators. On a number of occasions during this study, nightjars were watched to assess the time taken by adults to return to the nest site once flushed. Several birds took up to 15 minutes to return to eggs, although some birds did return almost immediately to chicks. The potential for predation in this interim period is great. Nightjars demonstrate noisy, defensive behaviour when flushed, including injury-feigning flight display, accompanied by wing-claps and short calls, which may alert predators to the presence of a nest site. This anecdotal evidence suggests the mechanism by which human disturbance, mainly attributed to dog walkers on paths, is causing nightjar nest failure.

This study also showed clear differences in breeding success between high-level disturbance sites and closed access and rural sites. Taylor (2002) found that corvid abundance was positively correlated to counts of people on heathland sites in Dorset, both within and between sites. The high proportion of avian predated nightjar nests on disturbed sites in this study indicates the strong link between increased site disturbance, higher predator numbers on disturbed sites, and the subsequent high predation rates of nightjar nests. Sample sizes were too small to identify any differences between nests predated by corvids and those predated by mammalian predators, however it might be expected that certain features of heathland sites, such as the availability of high perches such as telegraph wires or lone trees in the nest vicinity, may be different were sample sizes larger.

Nightjars avoided establishing territories or nesting close by to any large-scale urban development. Nightjar densities were lower on the more disturbed sites, low densities in turn being closely linked to low overall breeding success.

In order to assess the impact of disturbance on population size, it remains necessary to assess how changes in behaviour, in response to disturbance, relate to demographic parameters such as survival. In addition, an understanding of the density-dependence within the heathland system is essential (Gill *et al* 2001; West *et al* 2002). Such data would be difficult to collect for a species as difficult as the nightjar, yet it seems likely that recreational access is influencing the population size of nightjars on the Dorset heaths.

Further work

A number of areas for further study are clear from the results presented here.

- Further investigation into the mechanism of breeding failure and the link between disturbance and nest predation. Placement of cameras at nest sites could record actual predation incidents as well as giving an indication of the amount of time adults spend away from the nest, when flushed by human or dog intruders.

- The relationship between corvid density / predation pressure and site characteristics warrants further study.

- Improved quantification of disturbance is also required. Counts of people walking past a known nest site would give a more accurate assessment of the actual disturbance levels and types of disturbance that may be important; especially in a comparison between disturbance created by dogs on and off leads.

- Building on work done in this study, nest and disturbance sample sizes (in particular path disturbance data) could be increased, potentially providing further insights into the relationship between disturbance and nightjar breeding success. Increased sample size could also mean a potential increase in the number of predictor variables used in a model investigating nest outcome, to include variables such as the frequency of path use and nest cover.

- Further work on nest location relative to territory boundaries and path proximity could provide answers to questions such as: Do nightjars prefer to nest near paths, or is their apparent proximity to paths on urban heaths merely a result of the high numbers of paths present or the lack of suitable habitat away from paths? Paths tend to avoid areas of unfavourable habitat, such as wet heath, as do breeding nightjars. Settlement patterns and observations of territorial disputes at the time of the male nightjars' arrival in May could give an indication of the most sought after territories on urban sites. Investigation into nightjar nest locations on sites without paths and with adequate suitable habitat could also provide further insight into their choice of nesting sites on heathland.

- Quantifying the effects of disturbance, by measuring the trade-off between resource use (heathland habitat available for breeding) and risk of disturbance (Gill *et al.* 1996), would allow exploration into the potential consequences of changes in disturbance on the size of populations. Whether nightjars prefer to nest near paths or not, on site disturbance remains a crucial problem.

Site/access management

The results presented here suggest that the following options deserve consideration as possible mechanisms that may reduce disturbance and predation effects. However, it is recommended that further research into visitor activities and differential responses to techniques geared towards eliciting suitable behaviour amongst countryside users is undertaken.

- Overall review and where appropriate re-design of path distribution, density and alignment, steering people away from sensitive sites.
- Seasonal or permanent path deflection techniques, or re-alignment of routes traversing important nesting areas.
- Techniques to manage heathland habitats so as to reduce predation, for example reducing the number of trees on open sites to decrease the numbers of perching posts available to corvids.
- Techniques to encourage or ensure that the great majority of visitors stay on paths at sites where nightjar disturbance is a concern.
- Educational and interpretive campaigns to ensure visitors, especially those with dogs, are aware of the implications of their actions
- Techniques to ensure dogs are on leads or excluded between May and August at key sites, or are under close control (on rights of way) perhaps focussed on routes with known territories and nest sites adjacent to paths.

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