Potential Disturbance Effects, Nesting Success and Territory Placement in Stone Curlews at Porton Down 2010-2012.

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EXECUTIVE SUMMARY

1. Since 2004, a relatively stable population trend on one sub-site of Porton Down (Battery Hill) has contrasted with a strongly declining population trend on a second sub-site (Easton Down) for Stone Curlews. To explain the patterns of declines, the potentially limiting effects of disturbance were investigated and compared to trends in settlement patterns, coupled with new detailed observations of nest behaviour and nest survival rates, using nest cameras, carried out between 2010 and 2012.

2. Statistically significant effects were detected for two behavioural variables, 'Time off the nest' and 'Total alarm rate'. Both variables were negatively correlated with nest proximity to internal access roads. No significant effect was detected in relation to the public road (Winterslow Road) although the relationship was weakly negative. No effect was detected for daily nest survival rates relative to their proximity to potential disturbance agents.

3. Analysis of pair densities revealed a negative effect of the internal access roads, woodlands and denser scrub (though interactions with shrubs warrant closer investigation). However, on Easton Down, birds nested closer to these features over time, while abandoning seemingly more suitable ground. Also on Battery Hill, birds nested closer to the public (Winterslow) road over time, implying habituation (supported by video data). There were no clear effects of the testing bund on nesting pairs but there was a strong negative effect of low organic soil, consistent with the population decline on Easton Down. Possibly, the abandonment of soils of lower organic content or more suitable swards elsewhere, have led to birds nesting closer than expected to roads and woodlands.

4. The lower density of Stone Curlew breeding attempts on Easton Down was not consistent with disturbance from roads or buildings since the birds' abandoned seemingly better placed areas relative to these features. Also, the abandonment of central Easton Down had begun before nest survival rates began to decline after 2006. Stone Curlew pair nest attempts tend to be within relatively close proximity to one another thus, the implication is that settlement decisions made early in the season (preceding nest-predation events) are paramount for determining settlement patterns. For already settled birds, the proximate cause of nest mortality was nocturnal predation (mainly by badgers). Neither spatial nor temporal variation in the activity patterns of predators could be measured in this study, but such an investigation would help determine the mechanism behind increasing predation rates.

5. Contrasting settlement patterns between Battery Hill and Easton Down suggest that interactions between sward condition, soil type and declining key invertebrate populations, may explain the observed changes in settlement patterns (c.f Environmental Change Network monitoring). Analysis of such interactions alongside the monitoring of settlement patterns and nest success during the current phase of rabbit decline (rabbits may exacerbate effects on sward structure in very dry conditions) would be timely and instructive.

6. Recommendations are made that complex interactions between light shrub cover (where nests were located in recent years), soil moisture, swards and invertebrate biomass would benefit from further investigation. The potential for shrub cover to buffer against excessive drying or support higher invertebrate biomass would be an important finding in the light of scrub clearance programmes: areas where very few birds have nested in recent years. More frequent recording of nest occupancy would improve the precision of daily nest survival rates, and provide a more accurate and standardised performance monitoring of nest outcomes across the site and between years, to assist management decisions.

1.   BACKGROUND

The Stone Curlew *Burhinus oedicnemus* is a rare breeding species in Britain. The current UK population is estimated at around 350 pairs (RSPB, unpublished data). The species is largely restricted to open country with sparse vegetation, on free-draining, stony soils. In Europe, this species is listed as 'Vulnerable' on Annex I of the EC Birds Directive and Appendix II of the Bern Convention.   In the UK it is protected under Schedule 1 of the Wildlife and Countryside Act 1981, and its status has improved from being of 'most concern' to 'moderate concern' due to huge conservation intervention over the last twenty or more years to protect nests and habitats (Eaton *et al.,* 2009).

Due to their high conservation status, Stone Curlews have become the subject of considerable research interest regarding their potential sensitivity to disturbance (Day 2003, Green *et al*. 2000, Taylor *et al*., 2007, Sharpe *et al*. 2008). As a ground nesting bird with a long incubation period Stone Curlews are vulnerable to nest losses caused by farm operations, fast growing crops and predation. Stone Curlews, use nest-crypsis as a major means of nest defence. The incubating parent will vacate the nest readily and inconspicuously to leave well-camouflaged eggs exposed to the elements or possible discovery by predators. This behaviour is triggered by perceived threats from humans or mammalian predators that approach the nest, and the parent returns to the nest briskly and stealthily after the threat has receded (Cramp and Simmons, 1983). The Stone Curlew's nest-defence strategy is adapted for incidental levels of disturbance but excessively frequent disturbance may exacerbate problems of nest exposure. The chicks disperse from the nest within two or three days of hatching (Cramp and Simmons, 1983), therefore nest disturbance mainly affects the incubation period, and may influence the settlement decisions of prospecting birds (Taylor 2006)

In earlier studies of nest behaviour and densities, Taylor *et al*. (2007) found that 'alert' responses in incubating birds, such as head-raising and standing, were especially prevalent with dogs present at <500m, and then to a lesser extent by walkers and then slow-moving vehicles. It is not clear what affect if any such an increase in the alert response of incubating adults had on nest-productivity but the densities of breeding birds were potentially negatively affected by regular human disturbance at visible distances up to and exceeding 500m. Green *et al*. (2000) had earlier also reported higher breeding densities on farmland beyond 3.6 km from major roads leading to a calculated, negative influence on carrying capacity equivalent to a 47% decline in the population, especially within 1.4 km of roads (Taylor 2006).

In the UK, one of the major breeding areas for Stone Curlews is the South Downs in southern England. Here, Porton Down lies as an extensive area of grassland, scrub and woodland.   Porton Down constitutes one of the largest uninterrupted tracts of semi-natural chalk grassland in Britain, and is an important stronghold for breeding Stone Curlew with approximately 10% of the British population nesting on the site. Porton Down is therefore designated as a Special Protection Area (SPA) under the Birds Directive, 1979 for supporting around 18-25 pairs of Stone Curlews annually. In recent years, despite management intervention, the breeding densities of Stone Curlews on some areas of Porton Down have declined sharply.   Explanations for this decline include a possible local re-distribution of pairs, reduced prey availability/habitat quality, increased predation pressure and effects of anthropogenic disturbance itself. Regarding habitat condition, between 1987 and 1994, annual surveys of Stone Curlews at Porton Down revealed a strong positive correlation for short June swards (Green and Taylor 1995). Further analysis of their distribution and breeding success revealed positive correlations with rabbit *Oryctolagus cuniculus* densities (short swards) and drier May conditions (Bealy *et al*. 1999). However, since 2007, soil drying has become a major issue for Porton Down, associated with measurable declines in the invertebrate fauna, including key prey species in the diet of Stone Curlews at this site (Corbett & Atkinson 2012). Relative changes in prey

availability may be one explanation for relative changes in Stone Curlew breeding densities at Porton Down. Alternatively, on-site service-roads, a public road and occasional detonation noise may potentially contribute a source of disturbance.

Since 2004, a relatively stable population trend on one sub-site of Porton Down, known as Battery Hill, has contrasted with a declining population trend on a second sub-site, known as Easton Down. To help explain the Stone Curlew decline on Easton Down in relation to potentially limiting effects of disturbance on settlement patterns and nest success, the two sub-sites were compared for historical trends in settlement patterns, coupled new observations on nest behavioural and nest survival rates, made between 2010 and 2012. The study takes into account rabbit abundance (Bealy *et al.* 1999), topographical and habitat features (scrub, woodland and soil type), with implications for downland management for this species.

2 METHODS

2.1 Study Site and Set Up

Porton Down (51.13402°N 1.70159°W) SPA occupies 1237 ha of calcareous grassland and farmland. Two adjacent dowland study sites, Easton Down (149 ha) and Battery Hill (127 ha; Fig. 1) have traditionally held around eight to 10 pairs of Stone Curlews per annum, collectively. Both are areas of rolling, open downland with areas of scattered small bushes at varying densities. Easton Down in particular was the subject of extensive scrub clearance between 2001 and 2005 (Fig. 1) to benefit the chalk grassland, Stone Curlew, Marsh Fritillary butterfly *Euphydryas aurinia* and Juniper *Juniperus communis*.

Since 2004, all nest locations on both sub-sites were plotted so that locations could be analysed in relation to habitat features or human artefacts. In 2010, a new energetics-testing facility (a bund for testing explosions) was being built by Easton Down (Fig. 1) while an upgraded public road (known as 'Winterslow Road' (Fig. 1) was now carrying up to 5000 vehicle movements per day. This road ran adjacent to the Battery Hill, and between the Battery Hill and Easton Down study sites. The buildings, internal roads, woodlands, broad areas of varying soil type (identified by Corbett and Atkinson (2012) as being of higher, medium and lower organic content according to soil colour sampled from exposed soil in mole hills) and all bushes were also digitised (Arc map 10) so that the proximity of nesting attempts or pairs to these features could be compared over time and to randomly generated 'null' points of distribution. A standardised count of rabbit droppings based on a transect method employed at Porton Down since 2000 was used in the analyses as an assumed but nevertheless, relative and systematic proxy of rabbit abundance

A very considerable amount of work has been devoted towards Stone Curlews at Porton Down in the past, with supporting data extending back to 1987 (Bealy *et al*. 1999), which adds context to the present work conducted between 2010 and 2012.

2.2 Study Species

Stone Curlews have a protracted breeding season at Porton Down, with most eggs occurring between April and early August. Pairs arrive from March to early April and make two or three nest attempts with most first attempts occurring between 10 April and 10 May (Green *et al.* 2000). The incubation period is approximately 25 days and is shared by both parents who swap duties regularly through the day and night. Foraging activity away from the nest is mainly crepuscular or nocturnal and typically within 1 km of the nest location or chicks (Green *et al.* 2000). Stone Curlews at Porton Down use free-draining, short swards, with stone exposed (Bealy *et al.* 1999; Green *et al*. 2000). However, on such downland in southern England, nest-area faecal analyses have revealed three prominent prey groups in the diet: Amadillids (woodlice: 31.5%), Lumbricids (earthworms: 27%) and Coloepotera (beetles: 25%) by biomass (Green *et al*. 2000). The first two species groups in particular have declined since 2007 on parts of Porton Down, along with drying soils (Corbett & Atkinson 2012).

2.3 Measuring Nest Site Behaviour

Between 2010 and 2012, a sample of nests was monitored to measure variations in adult behavioural activities at the nest. The main purpose was to quantify evidence of *diurnal* disturbance on Stone Curlews caused by potential disturbance agents such as road traffic and other activities, but infra-red cameras were installed in 2011 & 2012 to provide additional data on nocturnal nest activities and sources of predation. The measured actions of Stone Curlews were similar to those

identified by Taylor *et al*. (2007), and represented both settled birds (categories: 'incubate', 'egg shift', 'body shift' and pair 'switch-over') and those indicative of disturbed birds (*alert responses*: 'crouch', 'head raise', 'stand' and 'walk-off' and; *alarm responses*: 'run-off' and 'fly off'). 'Time off the nest' (where no parent was present) was also measured, excluding short duration events, such as a pair-switching, egg-shifting or preening.

All nests were visited under licence (Schedule 1 Disturbance Permit). Nest visits were conducted by experienced personnel who took time to understand the bird's method of dealing with nest-disturbance before visiting nests, to minimise disturbance and desertion risk. Nests were approached in clear view, from a distance, to avoid surprising the attendant birds. Nest visits that involved camera installation were completed within 20 minutes and were never conducted in heavy or persistent rain. Follow-up visits to change batteries were completed within 10 mins., at intervals of 4 or 5 days. In total, 75 nest-visits were made between 2010 and 2012. On *every* occasion the parent resumed incubation, and normally within 20 mins of the observer leaving the nest-area. For two nest-visits the parent's return was just under one hour later.

At each nest, egg dimensions and weight were measured to help predict egg age and hatching date. Where a camera was installed, a battery/video recorder pack was located 10 m away from each nest with a surface cable leading to a 40cm-tall mini-camera stalk placed 1 m from the nest. The pack was preferentially lowered into a rabbit scrape or positioned by a shrub and covered with military camouflage netting to reduce its profile (digging is not permitted at Porton Down). The infra-red, motion sensitive camera's largest dimension was 3cm x 3cm in profile. The camera stalk was the only physical change made to the nest area. No stones or prominent vegetation was moved or damaged and care was taken to avoid leaving lasting depressions around the nest area.

To control for the presence of the nest cameras and to reduce nest visit frequencies, *Maxim* iButtons (16 mm dia., temperature loggers) were added to most nests in 2012. Temperature was recorded at 30 min intervals so that the end point of a nest could be detected due to a relatively abrupt change in temperature when compared to an ambient iButton value taken from 1 m away. At nests, each iButton was inserted into the nest scrape with precision so as to be invisible to the birds. The iButton was thus placed into a shallow finger depression beneath the surface of the nest scrape, and back-covered with a fine layer of soil, followed by the single layer of three or four of the tiny stones often added by the birds to help camouflage their eggs. These stones were returned according to their exact original arrangement.

2.4   Analysis

The focus of the analysis was to detect effects of disturbance on patterns of breeding abundance, distribution and nest-phase productivity, relative to the effects of other habitat-related features. Analysis was largely based on General Linear Models (GLM) regression (SAS Incorporated 1996) with a site-area (ha) offset variable included as necessary to convert count data to relative densities. All response and explanatory variables were tested for their frequency distribution and the distribution of the response variable determined the error-terms used (for the best model fit). Tests for co-linearity between explanatory variables meant variables correlated at $r = 0.7$ or above were not entered into the same model statement, as such effects can cause the signs of the regression coefficients to be counter-intuitive (Christensen 1990). Behavioural activities were analysed as frequencies relative to the total observation time per nest. 'Time off the nest' was calculated as a proportion of the total observation time.

As null 'expected 'values', in each year 2004 to 2012, random points were plotted from 10 iterations of the same number of random points per year as nests found (or pairs - depending on the subject

level begin analysed). Thus, four nests found in year 1 meant 10 iterations of four random points from which mean inter-point distances and mean proximities to habitat features could be calculated (with confidence intervals). Differences between Battery Hill and Easton Down operated as further temporally-linked analytical 'controls'.

Nest outcomes were calculated as percentage probabilities calculated as daily nest survival rates extrapolated to the 25 days incubation period of the bird. The nest survival rates were calculated for the *egg phase* only, for consistent comparison between years and sites while controlling for nest visit effort (nest 'exposure time', eg., Mayfield 1975).

3   RESULTS

3.1   Patterns of Settlement

Figure 3 illustrates temporal change: a) in the proportion of pairs breeding on Battery Hill and Easton Down respectively, between 2004 and 2012 relative to the whole SPA, and b) the change in pair densities. The densities of pairs on both sites declined ($F_{1, 7}$ = 3.75, P = 0.05) and on Easton Down, the decline coincided with a shift in distribution away from area 'b', with significantly lower (log) inter-pair nearest neighbour distances between the periods "early phase" ('2004 to 2007') and "late phase" ('2008 to 2012'; $F_{1, 20}$ = 4.04, P = 0.05). This change was only partially compensated for by an increase in the frequency of nesting on area 'a' ($F_{1, 4}$ = 1.26, ns, p/df =1.12). While not quite statistically significant ($F_{1, 16}$ = 3.45; P = 0.08, NS) the proportion of pairs breeding on Easton Down (relative to the whole SPA) declined but was relatively stable on Battery Hill, bar 2009. Overall, inter-pair spacing (using the mid-point between nest attempts) was significantly less (304.1m, SD = 166, N = 36 and ED = 395.5m, SD = 195.6, N = 22) than random (mean 725.4 m, SD = 374, n = 580; $F_{1, 579}$ = 12.8, P < 0.0001) relative to ten iterations of randomly selected points equal to the number of nest pairs settled per sub-site per year. The data imply a non-random distribution and an influence of either habitat or anthropogenic features or a degree of social cohesion between settling pairs. Despite the clumped distribution, inter-pair distances increased over time. The inter nest distance between attempts for pairs on downland was on average around 250 m. Thus the majority of birds that settled for their first attempt (typically in April) remained close-by for their subsequent attempts and almost always re-nested on the same area of downland (46/51 = 90.2% of occasions).

3.2   Spatial Determinants of Nest Sites: Univariate Tests Against Random Locations

Using random points as the null expected distribution, the mean distance from individual nest locations to site features and from randomly generated points to site features is shown in Fig. 4. Across all years, there were significant differences between the random and real locations of nests for three variables. First, the distance to the nearest public road of birds nesting on Battery Hill was significantly greater than randomly generated points (F = P < 0.02; mean distance of 661 m, 95% CI = 34.4). Second, the distance to the nearest internal, metalled road for birds nesting on Easton Down was significantly greater than randomly generated points (P < 0.02; mean distance of 820 m, 95% CI = 54.5 m). Third, birds nesting on Easton Down were located at a significantly greater distance from woodland compared to random points, where the average proximity to woodland of random points was only 156 m. On Battery Hill, there was no detectable effect of woodland on the nest locations but the average distance to woodland for random points was, in any case, large at 462 m. Compared to random locations, there was no significant 'preferences' for birds nesting by shrubs, but on average, birds were nesting approximately 10m closer than randomly generated points.

3.3   Determinants of Pair Densities: Multivariate Regression Models

The General Linear Models of pair density are summarised in Table 1. The best model fits were achieved with normal/identity error terms and structured as: pairs = explanatory variables + offset variable (site area) and with a scale deviance (Pearson chi-square/d.f.) between 0.8 and 1.4). These models included combined controls for the potential effects of plateaux or valleys, of the proximity to buildings, woodlands and internal service roads, and the public road (Winterslow Road). To help explain settlement criteria, the models also included the estimate of soil-organic content: low ('lo'), medium ('me') and high ('hi') (see Corbett and Atkinson 20012). In some models, the proximity to shrubs of nests (log-mean of the 10 nearest shrubs) was included also.

Internal road and public road: generally a negative effect but on Easton Down birds nested closer to the internal ('Ridge') road over time, during the later phase. On Battery Hill birds nested further from the internal road but closer to the public (Winterslow) road over time, i.e., during the late phase.

Bund: no clear effects of the bund on nesting pairs though there was a negative effect on densities on Easton Down during the early phase 1 (2004-2007).

Soil organic content: a strong negative effect of low organic soil in late phase 2 on Easton Down was consistent with the temporal decline in pair densities there.

Overall, the mean minimum distance to shrubs was greater for higher densities of pairs but over time this distance was reduced (though it was not quite a significantly difference).

The association with the rabbit index was generally negative in multivariate models in phase 2, especially on Easton Down.

The influence of the woodland blocks was negative generally but in the late phase (phase 2) on Easton Down, higher pair densities were associated with a closer proximity to woodland blocks.

Overall, the two main determinants of early phase nest densities on Easton Down, included a positive association with soil of lower organic content and a negative effect of the internal road. However, during the late phase both relationships were reversed (especially on Easton Down) due to birds abandoning previously occupied areas of lower organic downland. On Battery Hill, where the soil is classed as of relatively high or medium organic content the response was different, with the change in distribution of birds being less evident and with effects being significant and positive for the higher organic content soils during both phases; there was no significant difference during the late phase between high and medium soils.

The implications are that abandonment is correlated especially with soils of lower organic content, on Easton Down, with birds settling closer to roads, woodland and shrubs as a consequence and against expectation.

3.4   Behavioural Responses

In total, for 21 nests and 17 pairs nesting on downland, approximately 1544 hours of diurnal footage and 610 hours of nocturnal footage were recorded (equivalent to an average of 5 days and 4.5 nights per nest). The best model fits were again achieved with normal/identity error terms and structured as: nests (too few pairs in the sample) = explanatory variables (no offset variable required) with a scale deviance (Pearson chi-square/d.f.) between 0.78 and 0.95. Statistically significant effects were detected for two variables only, (log) 'Time off the nest' and (log) 'Total alarm rate' (a sum of all the alarm actions combined). Both variables were negatively correlated with proximity to the internal road ($F_{1, 15} = 6.23$, $P < 0.03$; $F_{1, 15} = 5.79$, $P < 0.04$, respectively; Fig. 5). For night-time, the relationship with 'Time off the nest' and the internal road was similar but not significant at $\alpha = 0.05$. No significant effect was detected in relation to nest proximity to Winterslow Road, including no detectable change in the alarm or alert patterns of incubating birds during the 'rush-hour' period (0700 h to 0800 h) when slow and queuing traffic was present.

3.5 Nest Losses and Nest Survival Rates

Nest survival rate (NSR, controlling for nest 'exposure' days and reporting effort) estimates were calculated for several phases and locations on Porton Down between 2004 and 2012 (Fig. 6). These calculations are compared to values calculated in previous studies for the period 1987 to 1996 for the whole of Porton Down (Bealy *et al.* 1999). In spite of a relative recovery in 2011, the egg-stage mean daily nest survival probability for Battery Hill and Easton Down combined between 2010 and 2012 was 14.2% and lower than the period 1994 to 1996 (NSR = 19.1%) which was itself very low relative to the value of 54.3% recorded for the period 1987 to 1993 (Bealy *et al.* 1999). This value of 14.2% is comparable to the egg-stage survival rates of nests on other parts of Porton Down SPA between 2010 and 2012 (also 14.7%; Fig. 6) meaning that generally egg-stage mortality of nests was high across the whole SPA. However, the mean NSR for Easton Down (mean ED) between 2010 and 2012 was close to half (8%) of the value of Battery Hill (mean BH: 15%), or other areas of the SPA (14.9%), though the differences were not statistically different due to a small sample of nests available for the analysis.

Overall, egg-stage nest mortality appears to have increased over time across the SPA as a whole, and was especially high during this study on Easton Down between 2010 and 2012. It is consistent with this general trend that the proportion of nests failing at the egg stage ('apparent' mortality) increased on Battery Hill and Easton Down combined especially between 2008 and 2012 (Fig. 7). However, NSR was not associated with a higher alarm response rate of incubating birds (variables, 'Time off the nest' and 'Total alarm rate'; $F_{1, 105}$ = 0.42, ns, scale deviance =0.78; $F_{1, 15}$ = 3.1, ns, scale deviance =0.95, respectively). In other words there was no evidence that diurnal 'disturbance' was leading to higher nest mortality – not least because all nest losses were nocturnal. Of 21 failed nests monitored between 2010 and 2012 on downland, all were lost to night-time predation, with badgers being responsible for 80% of observed events (eight nests) and foxes 20% of losses (two nests). Diurnal species, Common Buzzards, gulls and corvids, were all common on the site but were not responsible for any nest failures between 2010 and 2012. Always, the Stone Curlew parents were seen alive after their nests were lost. The probability of egg-stage success was higher for second attempts than for the first attempts (Chi-squared; 12.5, df = 1, P < 0.01).

There was no significant relationship detected between NSR and nest proximity to internal access roads, the public road (Winterslow Road), the bund or buildings, though with only 24 nests available, the analytical power to detect such effects was limited.

There was no indication that nest camera installation or camera presence caused or increased the probability of nest failures. Failure rates on Battery Hill and the rest of the SPA, where no cameras were installed, were comparable (Fig. 6). The NSR for nests with a camera installed and for nests where a camera was not installed (16.3% survival rate) were comparable.

Predation does not explain the change in settlement patterns on Easton Down. Between 2006 and 2007, apparent nest failure rates (Fig. 7) were at their lowest value, despite the 'abandonment' of Easton Down having already begun. Stone Curlew nest attempts also tended to be within relatively close proximity to one another implying that settlement decisions are made early in the season (preceding predation events). Instead, higher nest losses may be a result of birds on Easton Down, especially, nesting in closer proximity of woodland habitats in more recent years, having abandoned previously occupied and more remote areas of the downland (Fig. 2; Table 1) for other reasons.

General Linear Models	Easton Down			Battery Hill		
a)Univariate effects	All years	Phase 1 (2004-2007)	Phase 2 (2008-2012)	All years	Phase 1 (2004-2007)	Phase 2 (2008-2012)
	Z (P <)	Z (P <)	Z (P <)	Z (P <)	Z (P <)	Z (P <)
Internal road	-1.53 ns	-3.6***	44.0***		3.2*	-2.5*
Bund		-2.1*				
Public (Winterslow) Road						
Soil organic content	2.5* (+low)		-13.2**(-low)	1.8* (+hi)		
Valley floor	-2.2*	-5.1**				-6.8**
Rabbit index		2.5 *	-13.6**			-2.3*
Woodland	-1.7*		6.3**			
Mean distance to shrubs		3.2*	-52.0 ***			
b) Type 3 multi-variate effects						
	χ2 (P <)	χ2 (P <)	χ2 (P <)	χ2 (P <)	χ2 (P <)	χ2 (P <)
Internal road	-1.3 ns		3.8*	3.7*	3.8*	
Bund						
Public (Winterslow) Road					-3.8*	+3.9*
Soil organic content			-3.4* (-low)	1.8* (+hi)		
Valley floor	-4.3*					
Rabbit index			-2.6*/ns			-3.4*
Woodland	-5.04**		3.2 ns			
Mean distance to shrubs						-4.7*

The effect of shrub proximity on Easton Down birds was confounded by soil organic type. When included in the models, mean shrub proximity is strongly negative (birds nesting at higher densities were therefore nesting further away from shrubs, on average but this was reversed during phase 2 due to birds nesting closer to shrubs over time). Low soil organic content and mean shrub proximity are correlated (Chi-squared = 4.31, $P < 0.05$, n = 32). However, during the late phase, the effect of soil type is overriding and a negative effect of rabbit numbers also becomes more pronounced.

c) Temporal effects on nest locations: change between 2004 and 2012 (F values)		
Internal road	12.7**	Birds nesting closer to the internal road over time on Easton Down
Winterslow Road	variable	Weakly negative but birds on Battery Hill nested closer over time
Soil organic content	14.6*** (- low)	Bird nested less on low organic soils less so over time.
Bushes	+1.6 (ns/*)	Birds on Easton Down moving slightly closer to bushes over time.

d) Daily nest survival rates 2010 to 2012	
Nest survival probability was approximately 8% for Easton Down and 15% for Battery Hill, almost twice as high. However, due to the small sample size, the difference was not statistically significant (Fig. 6).	
Internal Road	Ns
Bund	Ns
Woodland	Ns

4.   DISCUSSION

The alarm response of incubating Stone Curlews was detected in relation to nests being in closer proximity to the internal access roads. The pattern of response was consistent with previous studies of potential disturbance effects on the birds' nest-site behaviour (Taylor *et al* 2007). However, there was no clear indication of subsequent effects on nest failure and settling birds in more recent years nested closer to potential disturbance agents rather than further away, contrary to expectations. Birds nesting on Easton Down moved away from more remote areas of the downland (with respect to the average distances to woodlands and human artefacts) to nest at lower density but in closer proximity to these features. Meanwhile, birds nesting on Battery Hill also nested on average, in closer proximity to the adjacent public road – over time, against expectations and with no detectable effects on their behaviour. The traffic on the public road is kept moving, by law, and habituation by the birds to moving traffic would also be consistent with the findings of Taylor *et al* (2007). Disturbance and avoidance of roads, buildings or woodlands does not explain the changing patterns of nesting distribution over time or the reduced carrying capacity of Easton Down.

The failure rates, of nests, on Porton Down have increased over time, with nocturnal mammalian predators being the main source effect. The impacts of predation are difficult to assess (cause or consequence) since nest failure may be a consequence of birds nesting in sub-optimal areas of downland, for example in closer proximity to woodland. Increased predation is not an intuitive explanation for why birds should have ceased nesting in more remote locations (where predation rates were lower) or where the probability of opportunistic predation was unlikely to be higher than for nests located closer to woodland features for example. Also, between 2006 and 2007, apparent nest failure rates were at their lowest value, despite the 'abandonment' of Easton Down having already begun. Interestingly, the probability of egg-stage success was higher for second attempts than for the first attempts, which may be due to predators having a wider choice of alternative sources of food later in the season? Unfortunately, no mammal density or movements data are available on which to test these speculations at this point in time.

Other lines of circumstantial evidence suggest that sward condition or invertebrate availability may influence on the decision of settling birds. First, settlement patterns were established early in the season, in April and the majority of birds continue their nest attempts well within 400m of this initial decision. Though occasionally flying much further, typically, birds stay within close proximity of the nest when not incubating (<1-km; Green *et al.* 2000), to share duties of nest defence, incubations and vigilance. The implications are that early settlement decisions are based on the availability of suitable nesting locations and foraging conditions, broadly within the vicinity of the nest. Second, the most dramatic change in pair settlement patterns was associated with abandonment of soils of a lower organic content. At Porton Down the summer soil moisture content was declining between 2008 and 2011 (Corbett pers comm.). In principle, this should favour Stone Curlews, along with the high rabbit densities (Bealy *et al.* 1999). However, a drying substrate can reduce earthworm availability. Earthworms may enter diapause below a 25%-30% moisture threshold and may die below 20% soil moisture (Edwards and Lofty 1972). In the drought year of 2009, the soil moisture deficit on the low organic soils on the downland was as low as 23% in May and June, and down to 21% in July, with earthworm populations being lower the following spring on SPA downland than on adjacent arable farmland (Corbett pers com.). The trade-off between habitat suitability for nesting and for foraging may be a significant influence on the settlement patterns of Stone Curlews that breed here, on the northern edge of their western European range. Possibly drying, when exacerbated by the actions of 'exceptionally' high rabbit densities, may shift conditions away from those that favour critical food species for Stone Curlews at Porton Down, such as earthworms, woodlice and beetles (Corbett and Atkinson 2012).

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Interestingly, birds tended to nest closer to shrubs over time. Shrub removal has been a conspicuous conservation activity on Eaton Down up until 2005, for creating more open habitat for Stone Curlews amongst other species. However, since 2007 the areas of downland subject to extensive shrub removal have tended *not* to support Stone Curlew nest attempts. While it is unlikely that the shrubs themselves attract the birds, since generally higher pair densities were associated with a lower average proximity to shrub, there is some anecdotal evidence to suggest that sward condition associated with scattered shrub cover is less affected by rabbits that prefer creating burrows out in the open downland (Corbett pers com.). The relationship between shrubs, rabbits, sward condition, soil type and invertebrate populations is worthy of closer inspection in case light shrub cover may, in patches, buffer some of the extreme drying effects witnessed on the open downland. Having increased for several years the rabbit population on Porton Down was beginning to show signs of a decline in 2012, with the potential for swards and invertebrates populations to recover, and perhaps for Stone Curlews to re-colonised abandoned areas of downland in the year ahead. If the invertebrate populations are important to settling Stone Curlews then a decline phase among rabbit will present an opportunity to predict and track the interactions between the birds and the environmental variables, to help inform future management decisions.

5.   SUMMARY AND RECOMMENDATIONS

Although the distribution of Stone Curlew breeding attempts was not random, their decline on Easton Down was not related to disturbance effects or the proximity of the nests to roads or buildings, although effects on the birds' behaviour were detected. Analysis of pair densities revealed a negative effect of the internal access roads, woodlands and denser scrub (though complex interactions with shrubs warrants closer investigation). However, on Easton Down, birds nested closer to these features over time, while abandoning seemingly more suitable ground. Also on Battery Hill, birds nested closer to the public (Winterslow) road over time, implying habituation (supported by video data). There were no clear effects of the testing bund on nesting pairs.

Nest predation has increased in the last nine or ten years and birds may from that point of view, be nesting, in recent years, in sub-optimal locations compared to their distribution between 2004 and 2006 when breeding densities were at a peak. Contrasting patterns of settlement between Battery Hill and Easton Down suggest that interactions between sward condition, soil type and invertebrate populations may have stimulated the abandonment of previously occupied areas of Easton Down, (supported by Environmental Change Network monitoring), depending on how the birds assess habitat suitability. There was a strong negative effect of low organic soil, consistent with the population decline on Easton Down. The implications are that abandonment of soils of lower organic content may have led to birds settling closer than expected, and at lower densities, to roads and woodlands. There is evidence to suggest that excessive drying was problematic between 2008 and 2011, affecting soil invertebrate populations, particularly on soils of lower organic content where abandonment by Stone Curlews has been most acute. Further analysis of these interactions with the monitoring of settlement patterns and nest success during the current new phase of rabbit decline (rabbits may exacerbate effects on sward structure) would be timely and instructive. Recommendations are made that interesting and complex interactions between light shrub cover (where nests were located in recent years), soil moisture, swards and invertebrate populations would benefit from further detailed investigation, as potential drivers of the settlement patterns of Stone Curlews on Porton Down. The potential for shrub cover to buffer against excessive drying and support more abundant invertebrate populations would be an important finding in the light of scrub clearance programmes, where very few birds have nested in recent years. More frequent recording of nest occupancy would improve measures of nest survival rates, for a more accurate and standardised performance monitoring of nests across the site and between years, to assist management decisions.

For already settled birds, the proximate cause of nest mortality was nocturnal predation (mainly by badgers). Neither spatial nor temporal variation in the activity patterns of predators could be measured in this study, but such an investigation would help determine the mechanism behind increasing predation rates and the probability of their discovering Stone Curlew nests.

Acknowledgements

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Figure 1   Maps showing the extent of the Porton Down range and SPA boundary (bold perimeter line map 'a') and the location of the two BTO study sites, Easton Down and Battery Hill. On map (b) the locations of nesting attempts between 2010 and 2012 are shown.
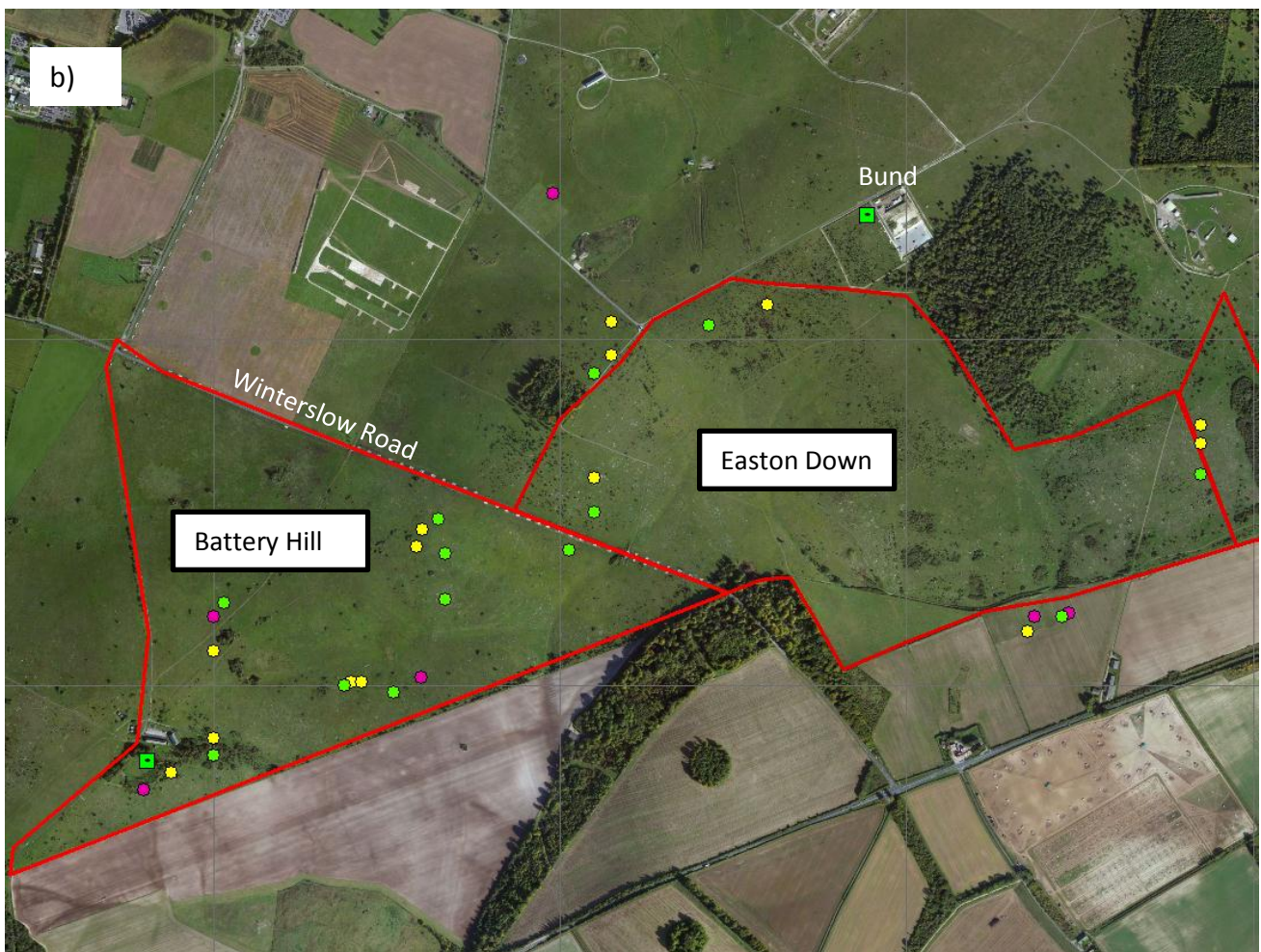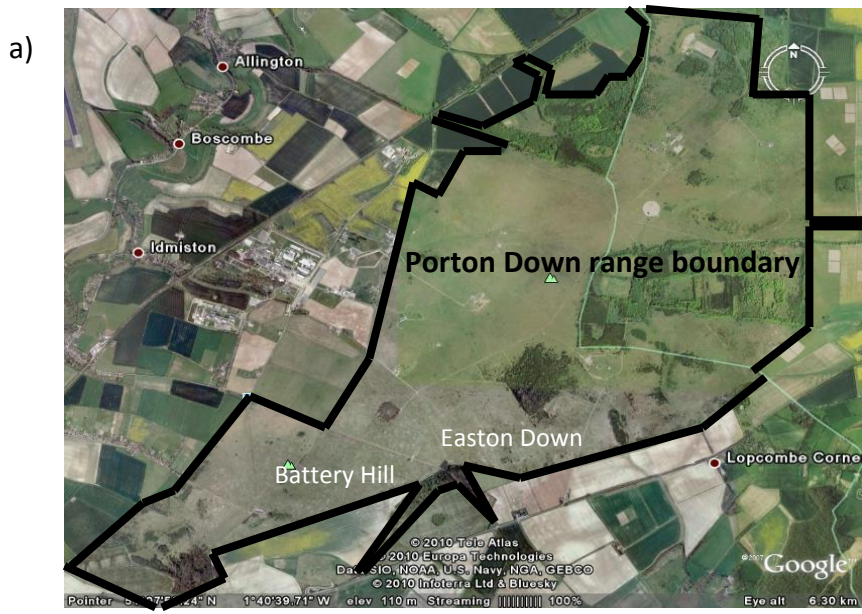
Figure 2 The distribution of nest attempts in years 2004 to 2007 illustrating occupation of Easton Down (cf. Fig. 1, map 'b' for the period 2010-2012)**.**
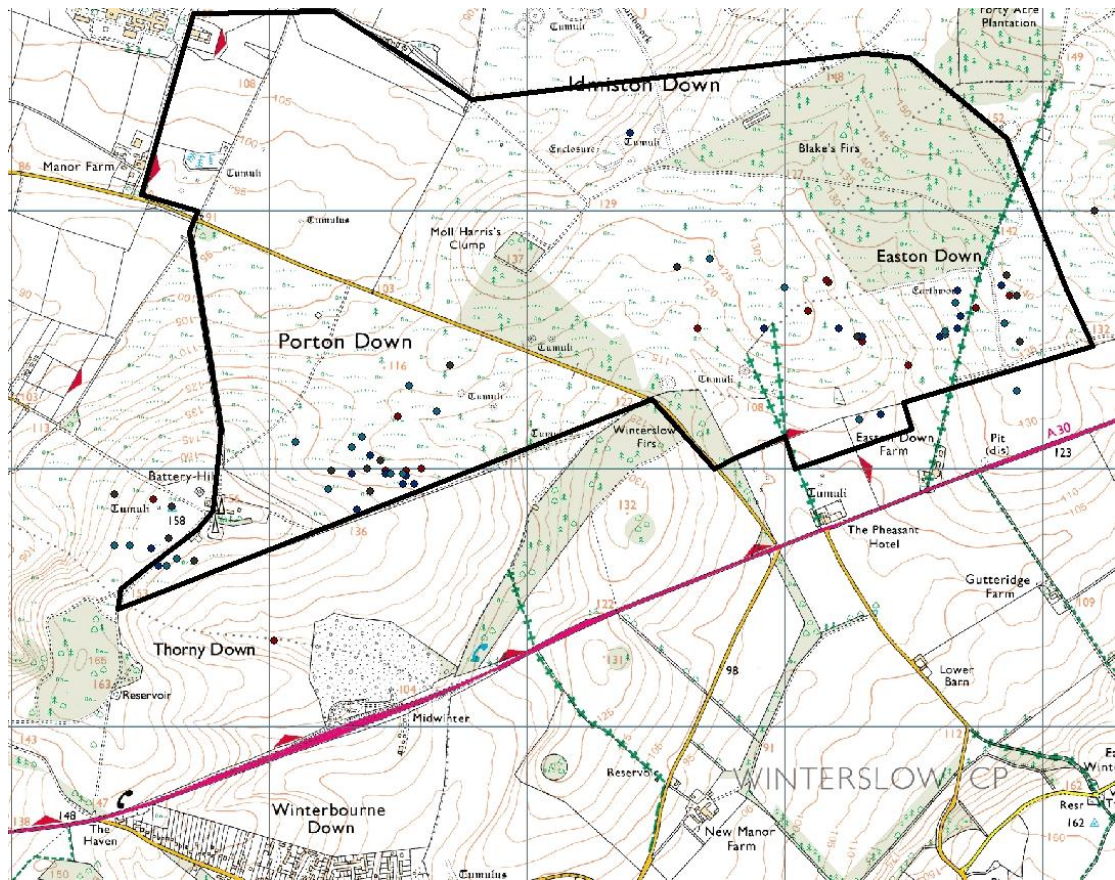
Figure 3 Change in the annual proportion of all (a) nest attempts and (b) pair densities on Easton Down and Battery Hill between 2004 to 2012, relative to all nest attempts and pairs across the whole of Porton Down (the latter estimated at 18 for 2011). The proportion of pairs attempting to nest on Easton Down especially has declined since 2004.

a) Proportion of pairs settling on Easton Down and Battery Hill

b) Pair density
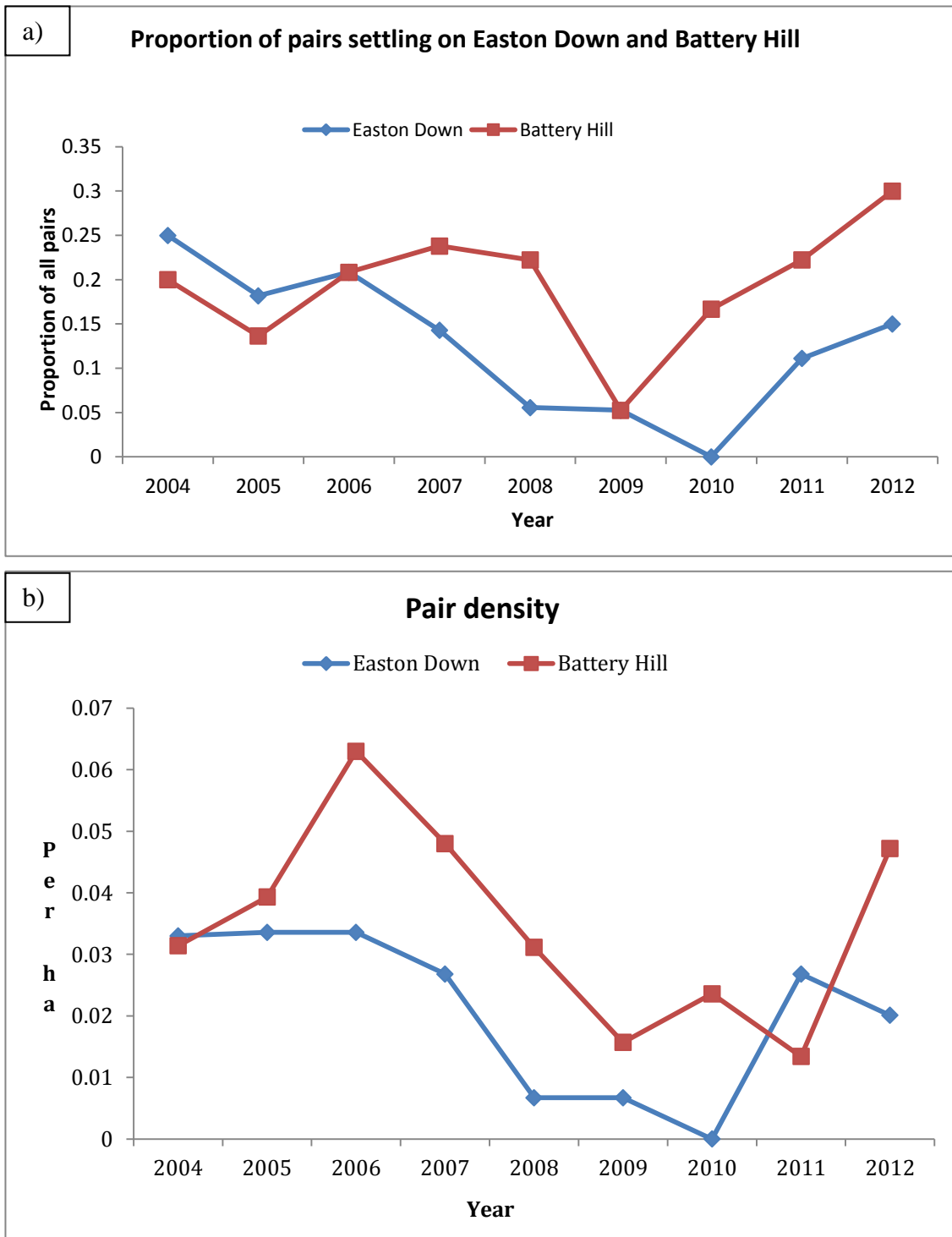
Figure 4 Comparing the proximity of nest sites to site features compared to random locations generated as a null hypothesis for the complete period 2004 to 2012 combined.
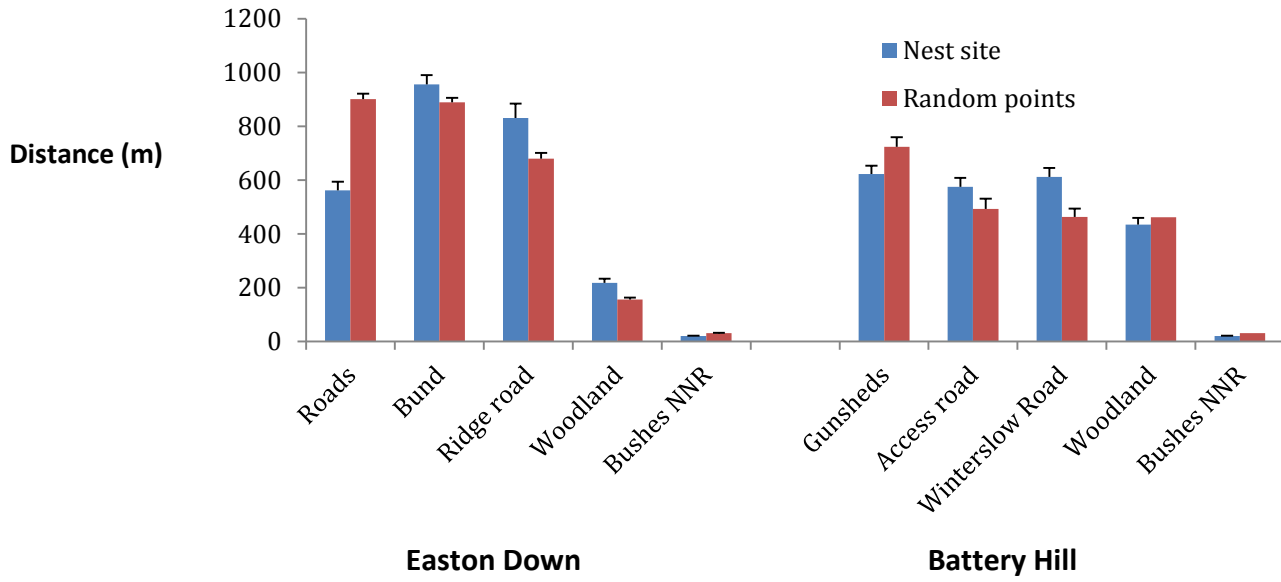
Figure 5 Showing a negative relationship between the diurnal alarm response rate of incubating birds (y-axis: per minute) and nest proximity to internal roads (x-axis metres) at Porton Down.
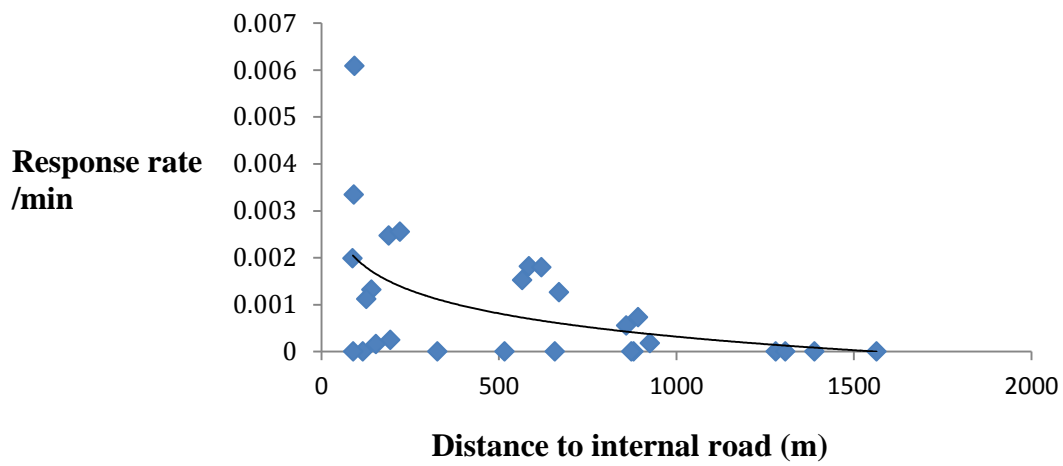
Figure 6 Nest survival rate (NSR) estimates are shown relative to the whole of Porton Down between 1987 and 2012. In spite of a relative recovery in 2011 the mean rate of daily nest survival for 2001-20012 was 14.2% and lower than the period 1994 to 1996 (NSR = 19.1%) which was itself very low relative to the value of 54.3% for the period 1987 to 1993. In (b) the mean NSR for Easton Down (mean ED) between 2010 and 2012 was close to half of the value of Battery Hill (mean BH), though the two were not statistically different due to the small sample size of nests. The 'rest of Porton Down' refers to egg-stage NSR for nests monitored elsewhere on the SPA.
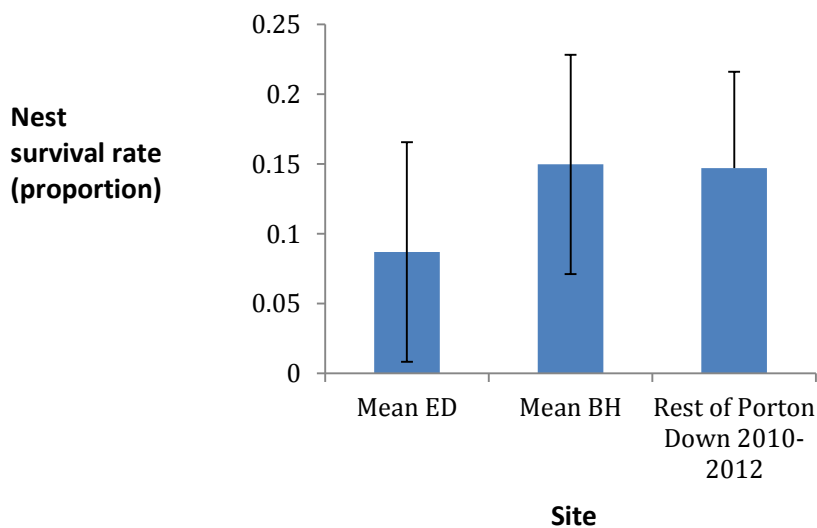

Egg-stage nest survival probability
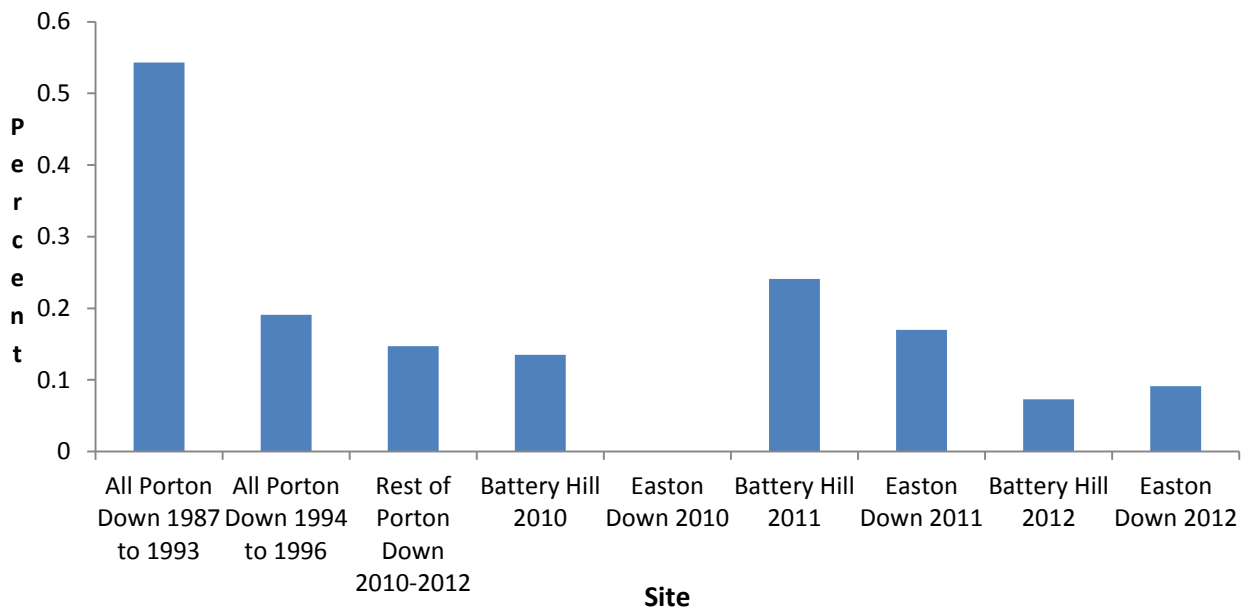
a)

Mean NSR 2010-2012

b)

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Figure 7 The proportion of nests ('apparent' failure), of known outcome, failing at the egg stage (Battery Hill & Easton Down combined). These values are difficult to verify with precision because the outcome of many nests is not always known or nests are eventually found but relatively late during the incubation phase, which over-estimates survival (i.e., does take account of nests lost early, and before detection). Nevertheless, egg stage failure appears to have increased especially from 2008 to 2012.