# Testing the effects of recreational disturbance on two upland breeding waders

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Previous work has shown that Golden Plovers *Pluvialis apricaria* guarding chicks utilize heavily disturbed habitat at a lower rate than surrounding areas, but that such rates of avoidance are reduced when the movement of people is restricted to a surfaced footpath. However, there remained some unanswered questions, which are addressed in this paper. First, we examine to what extent habitat avoidance is dependent upon visitor numbers, and find no evidence that Golden Plovers avoided disturbed areas at a site where visitor pressure was half that previously studied. Secondly, we examine whether these relationships between habitat occupancy and disturbance apply to other upland waders and find that Dunlin *Calidris alpina* habitat utilization in disturbed areas showed a non-significant increase of approximately 50% following the provision of a surfaced footpath, in a manner similar to that observed for Golden Plover. Thirdly, we examine whether the large numbers of visitors (120 per weekend day) using the surfaced footpath impact on Golden Plover breeding success, despite the lack of habitat avoidance. There was no evidence that nest location, clutch survival or chick growth rates were reduced close to the footpath. Together, these results suggest that high levels of disturbance can impact upon habitat usage by upland waders, but only in limited circumstances where visitor pressure is very high (greater than at least 30 visitors per weekend day). However, access to such areas can be permitted for large numbers of visitors without impacting upon wader reproductive performance through the provision of a well-surfaced route.

The extent to which human disturbance detrimentally impacts on wild bird populations has been a long-standing conservation issue (e.g. Hockin *et al.* 1992). Effects can vary, from the avoidance of favoured areas or habitats (Gill *et al.* 1996) to reduced levels of breeding success and increased mortality rates (West *et al.* 2002, Murison *et al.* 2007, Stillman *et al.* 2007). Ground-nesting birds such as waders (Charadriidae) are regarded as being particularly susceptible to human disturbance. Disturbance of incubating birds can expose eggs to increased risk of chilling or predation (Strauss & Dane 1989, Novick 1996), whilst the survival rates of precocial chicks

may also be limited through reduced foraging opportunities and increased predation rates (Dowling & Weston 1999, Ruhlen *et al.* 2003).

In England and Wales, concern regarding the detrimental impacts of human disturbance on ground-nesting birds has increased following the introduction of the Countryside and Rights of Way (CRoW) Act 2000 (Bathe 2007). The Act creates a statutory right of pedestrian access for open-air recreation to mountains, moors, heaths, downs and registered common land. Increased access rights to upland areas are of particular concern owing to the high numbers of visitors such areas attract (e.g. Peak Park Joint Planning Board 1988). Given the internationally important breeding bird assemblage in many such upland areas, of which the wader community is an

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important component (Thompson *et al.* 1995), there is the potential for conflict between rights of access and nature conservation.

One of the best-studied upland waders is the Golden Plover *Pluvialis apricaria*, which is found at particularly high densities on some UK upland sites (Ratcliffe 1976), and is listed under Annex 1 of the EU Wild Birds Directive (79/409/EEC). It has been long-studied at Snake Summit in the Peak District National Park, traversed by the Pennine Way long-distance footpath, which is heavily used by walkers (Pearce-Higgins & Yalden 1997). This work has shown that, although relatively insensitive to disturbance during incubation, Golden Plovers exhibit a strong behavioural response to disturbance when guarding chicks, when the adults alarm call in response to human intrusions within 200 m (Yalden & Yalden 1989a, 1990). Consequently, pairs with chicks utilized suitable habitat within 200 m of the Pennine Way at a lower rate than surrounding areas (Finney *et al.* 2005). However, this avoidance was dependent upon human behaviour, being maximized when the footpath was eroded and the movement of people widespread and unpredictable, but was reduced to 50-m avoidance following resurfacing of the Pennine Way with flagstones, after which over 96% of walkers remained on the path (Pearce-Higgins & Yalden 1997, Finney *et al.* 2005). Thus, although high levels of disturbance can negatively impact upon habitat utilization by upland waders, it is possible to mitigate such detrimental effects where they occur through appropriate footpath management.

However, this work still leaves some unanswered questions. First, to what extent was the initial 200-m avoidance of the footpath dependent upon the high number of visitors at Snake Summit? Secondly, are these relationships between habitat occupancy and disturbance found in other upland waders? Thirdly, although there was little avoidance of the Pennine Way following resurfacing, did the high levels of disturbance close to the path during this time (120 visitors per weekend day; Pearce-Higgins & Yalden 1997) have a negative impact on breeding success?

We address each of these questions in turn in this paper. Additional data on Golden Plover habitat use from a second location along the Pennine Way in the Peak District with fewer visitors than at Snake Summit are analysed using the methods of Finney *et al.* (2005) to assess whether habitat use is similarly reduced in proximity to the footpath. The same approach is used to analyse data on Dunlin *Calidris alpina* distribution at Snake Summit from 1987 to 1998, to see whether this species shows a similar pattern of habitat use in relation to the Pennine Way as Golden Plovers at the same location (Finney *et al.* 2005). Finally, detailed data on the location and survival of Golden Plover nesting attempts (Pearce-Higgins & Yalden 2003), and growth and survival of radiotagged chicks (Pearce-Higgins & Yalden 2002, 2004) are analysed from the period following footpath resurfacing at Snake Summit, to see whether breeding success is negatively affected by high disturbance levels.

## METHODS

### Study sites

Data were collected from two locations in the Peak District. Snake Summit (53°26′N, 1°52′W) encompasses 6 km² of blanket bog between 450 and 550 m altitude, whilst Saddleworth Moors (53°33′N, 1°53′W) covers 6.5 km² of similar habitats between 420 and 530 m. Both sites are dominated by large areas of Hare's-tail Cotton-grass *Eriophorum vaginatum* (49 and 62% cover, respectively), with mosaics of Crowberry *Empetrum nigrum* and Bilberry *Vaccinium myrtillus* (32 and 31%, respectively), and heather on the lower slopes at Snake Summit (13 and 0%, respectively). The Pennine Way long-distance footpath transects both study sites from south to north (Pearce-Higgins & Yalden 1997). Both sites have open-access agreements, allowing visitors access across the site, subject to certain conditions, reflecting the situation which will be applied to most upland areas under the CRoW Act. Between April and July, Snake Summit received approximately 60 visitors per day at weekends and 20 during the week during the 1980s (people departing the study area and then returning were counted twice), numbers that doubled following footpath surfacing (Yalden & Yalden 1988, Pearce-Higgins & Yalden 1997). During the 1980s, Saddleworth Moors was visited by 30 visitors per day at weekends and 15 visitors during the week, with similar proportions of visitors remaining on the Pennine Way in both locations (Yalden & Yalden 1988). Distance to the footpath therefore provides a close surrogate to measuring levels of human disturbance at both locations, although the relationship between distance and disturbance varies between sites and years.

## Bird surveys

Breeding Golden Plovers were mapped at Saddleworth Moors from 1986 to 1988 using the methods described in Finney *et al.* (2005). Weekly surveys were conducted at weekends between 09:00 and 18:00 h during suitable weather, and all areas approached to within 200 m. The locations of birds were recorded to 100-m resolution, along with behavioural codes. The same methods were used to survey Dunlin during the chick-rearing period (June and July) at Snake Summit in 1987–88 and 1996–98, but with visits undertaken every 2–8 days. In addition to the two intensive survey periods, an annual survey of Dunlin distribution was undertaken from 1987 to 1998 during the spring bank holiday weekend at the end of May, allowing temporal changes in Dunlin distribution to be examined in relation to the timing of footpath resurfacing (as already conducted for Golden Plover; Finney *et al.* 2005).

## Nest location and clutch survival

Searches for Golden Plover nests were undertaken once or twice per week between mid-March and the beginning of June (described in Pearce-Higgins & Yalden 2003). The location of all nests was recorded to the nearest 100 m. The survival of clutches was then determined by repeated visits approximately every 4–6 days. The date of clutch initiation (hereafter laying date) was either back-calculated from the hatching date, assuming a 30-day incubation period, or for nests found during laying, back-calculated from the number of eggs in the nest when first discovered, assuming a 48-h laying interval between eggs (Ratcliffe 1976, Parr 1980). Where nests failed before hatching, hatching dates were estimated from an egg density index, and laying dates determined by back-calculation as described above (Yalden & Yalden 1989b).

After hatching or clutch loss, various nest-site characteristics were recorded: (1) vegetation height, based on the mean of four measurements taken along the four cardinal compass bearings 15 cm from the nest-cup; (2) the height of the edge of the nest-cup above the ground; and (3) the percentage cover of bare peat, heather, Hare's-tail Cotton-grass, Bilberry and Crowberry within a 0.1-m$^2$ quadrat centred on the nest-cup; other vegetation types were recorded but the sample sizes were too small to include in the analysis (Pearce-Higgins 1999). Similar measurements (except nest-cup height) were also recorded for 50 randomly selected points across the study area.

## Chick growth rate

Radiotelemetry was used to collect data on habitat use, growth rates and survival of 22 Golden Plover chicks from 12 broods (see Pearce-Higgins & Yalden 2002). The presence of a radiotag has the potential to alter the behaviour of the individual to which it is attached, but previous studies of Golden Plovers have found no significant difference between tagged and untagged chicks in the distance moved per day, the length of the fledging period or the probability of survival to fledging (Whittingham *et al.* 1999, Pearce-Higgins & Yalden 2002). We therefore assume that the data collected from the radiotagged chicks during this study were representative of the wider population.

At intervals of 1–5 days, chicks were relocated and biometrics taken. Mass was measured to the nearest 0.1 g initially and then to the nearest 0.5 g for chicks greater than 50 g. Total head plus bill length was measured to the nearest 0.1 mm. The time of day that the measurements were taken and the location of chicks to the nearest 100 m were also recorded.

## Habitat information

Habitat information was derived from aerial photographs taken in 1998 for Snake Summit, and in 2001 for Saddleworth Moors. These were scanned onto a computer, achieving a resolution of approximately 66 cm, and geo-referenced to the British National Grid in MapInfo Professional 6 (MapInfo Corporation 2000). A 100-m grid was overlaid, and the percentage composition of grass (*Deschampsia flexuosa*, *Nardus stricta* and *Juncus effusus*), Crowberry, Bilberry, heather and cotton grass *Eriophorum* spp. was estimated within each grid cell to the nearest 5% by eye, whilst viewing at a scale of approximately 1 : 1000. It was not possible to separate Crowberry and Bilberry with certainty from the photographs of Saddleworth Moors, so the cover of the two species was combined and termed non-heather dwarf shrub cover for that site. Areas of bare peat were digitized in MapInfo, allowing the percentage cover in each grid cell to be calculated to the nearest 0.1% (this precision could not be used for vegetation cover because of the fine-scale mosaics of different species and gradual gradations in cover). The average gradient and altitude in each grid square were calculated from a 50-m digital terrain model (Panorama, Ordnance Survey, UK). All bird survey data and the position of nests and chicks were located on the same grid, allowing easy cross-referencing of bird and habitat data.

## Statistical analysis

### Golden Plover distribution at Saddleworth Moors

Each grid square was given a value of 1 if a Golden Plover in attendance of a brood had been recorded in that square, and a value of 0 if no birds had been seen. These data were then analysed in relation to a range of explanatory variables using logistic regression. Data were summarized separately for each of the three years of the study, specifying a repeated-measures model design with an unstructured covariance matrix (Genmod Repeated procedure, SAS Institute Inc. 1997), thus accounting for the repeated measures from each year in the analysis. Fixed effects included in the initial model were year, distance from the footpath, gradient, altitude, and the percentage cover of bare peat, grass, cotton grass and non-heather dwarf shrub. An autocovariate term was also included in the initial model to minimize the potential confounding effects of spatial autocorrelation (Finney *et al.* 2005).

### Dunlin distribution at Snake Summit

The impact of human disturbance on the distribution and reproductive performance of Dunlin was analysed using data from the intensive surveys undertaken during the years 1987–88, when the Pennine Way was unsurfaced, and 1996–98, after the footpath had been resurfaced. Insufficient data were available to distinguish adults with chicks from failed or non-breeding birds, and therefore the locations of all adult Dunlin recorded in the study area during the chick-rearing period were included in the analysis. Each of the 100-m grid squares was given a value of 1 if a Dunlin was recorded in that square during the chick-rearing period and a value of 0 if no birds had been seen. This was carried out separately for each of the five years of the study, using a logistic regression, with a repeated-measures design, as above. Distance to the Pennine Way, gradient, altitude, distance from the forestry plantation and the percentage cover of the six habitat variables (bare peat, heather, cotton grass, Bilberry, Crowberry and grass) were each included in the initial model. Year was specified as a nested effect (nested within 'footpath condition', i.e. two years before the footpath was resurfaced and three years following resurfacing work). The interaction between distance from the footpath and footpath condition was also included to determine whether the relationship between Dunlin distribution and distance from the footpath differed before and after the footpath was resurfaced. To avoid the possible confounding effects of spatial autocorrelation, an autocovariate term was also included (see above).

### Golden Plover breeding success at Snake Summit

To examine the effect of recreational disturbance on nest-site selection, the characteristics of 42 known Golden Plover nests were compared with those of the 50 randomly selected sites using a logistic regression. The dependent variable had a value of 1 if it was a Golden Plover nest and a value of 0 if it was a randomly selected site. Explanatory variables included in the initial model were distance from the footpath, distance from the forestry plantation, height of the vegetation surrounding the nest-cup, vegetation cover and the gradient of the 100-m grid square in which the nest was located. Vegetation cover included the percentage cover of bare peat, heather, Crowberry, Bilberry and cotton grass, both within the 100-m square containing the nest and within the 0.1 m$^2$ immediately surrounding the nest cup.

Clutch survival was expressed as the number of days since laying that the clutch survived, divided by the total number of days between laying and hatching. Clutches that failed were assumed to have done so half way between successive visits and the period between laying and hatching was assumed to be 35 days (see above). This method was used as it allowed the length of time that a clutch survived to be included in the analysis. These data were then analysed in relation to a range of explanatory variables using a generalized linear model with a binomial error distribution (SAS Institute Inc. 1997). Explanatory variables included in the initial model were year, laying date and the habitat variables included in the nest location analysis. To test for potential biases in the data caused by finding nests at different stages of the breeding cycle (i.e. clutches found later during the incubation period are more likely to survive to hatching), the number of days from laying to discovery of the nest was also included in the initial model. Furthermore, as the frequency of visits differed between nests, the mean number of days between successive visits was also included in the initial model.

Growth rate was expressed as the change in mass (g/h) between successive measurements. As data from individual chicks within a brood were non-independent, mean growth rate for each brood was calculated from measurements of individual chicks within the brood. Golden Plover chicks lost mass between hatching and 1 day of age; data used

in the analysis were therefore limited to chicks older than 1 day. The relationship between growth rate and recreational disturbance was analysed in a linear mixed model using REML (Restricted Maximum Likelihood; Patterson & Thompson 1971, SAS Institute Inc. 1997). This technique allowed repeated measurements from each brood through time to be accounted for in the analysis by including 'brood' as a random effect (Pearce-Higgins & Yalden 2004).

Fixed effects included in the initial model were year, date, brood age and the mean distance of the brood from the footpath (assuming broods moved in a straight line between recorded locations). The percentage cover of the habitat variables (bare peat, heather, cotton grass, Bilberry, Crowberry and grass) were also included. These were the mean values from all 100-m grid squares through which the chicks would have passed between recorded locations, again assuming broods moved in a straight line. Temperature has been shown to affect the growth rate of chicks (Pearce-Higgins & Yalden 2002); the minimum recorded temperature between successive measurements was therefore included as a fixed effect. As any potential response to recreational disturbance is likely to be most evident at weekends, when levels of human activity are greatest, the proportion of time between successive measurements that fell on a weekend was included as a fixed effect in the initial model. Quadratic terms were included to test for non-linear relationships between growth rate and brood age, date and distance from the footpath. The interaction between distance from the footpath and the proportion of time between successive measurements that fell on a weekend was also included in the initial model.

*General principles*

In all analyses, the maximal model was fitted and then simplified by deletion of the least significant term. The significance of any interaction terms was assessed prior to the main effects. This was repeated until the minimum adequate model was attained (i.e. all remaining terms were significant at the $P < 0.05$ level). Any quadratic terms were retained if the square of the variable concerned was significant, or if the effect of the variable and its square were significant when tested together. The success of the logistic regression models was assessed using receiver operating characteristics (ROC) plots, with the area under the curve (AUC) presented for each model (Swets 1988).

# RESULTS

## Golden Plover distribution at Saddleworth Moors

The population size of Golden Plovers varied from 23 to 27 breeding pairs during the course of the study. Having accounted for the significant spatial autocorrelation in the data, as assessed by the autocovariate measure, the probability of grid square occupancy was negatively correlated with both percentage cover of grass and slope (Table 1). Probability of occupancy was not correlated with distance to the footpath ($\chi_1^2 = 1.4$, $P = 0.23$; Fig. 1), and thus Golden Plovers did not appear to avoid disturbed areas close to the footpath at Saddleworth Moors. The

**Table 1.** Output from logistic regression showing the variables found to have a significant effect on Golden Plover distribution at Saddleworth Moors.

| Variable | | Estimate | SE | chi-squared | df | *P* |
|---|---|---|---|---|---|---|
| Intercept | | −2.802 | 0.252 | | | |
| Autocovariate | | 3.057 | 0.511 | 22.8 | 1 | < 0.001 |
| Year | 1986 | 0.839 | 0.235 | 20.1 | 2 | < 0.001 |
| | 1987 | 0.882 | 0.218 | | | |
| | 1988 | 0.000 | 0.000 | | | |
| Grass (% cover) | | −0.749 | 0.203 | 34.0 | 1 | < 0.001 |
| Gradient | | −0.045 | 0.025 | 4.0 | 1 | 0.046 |
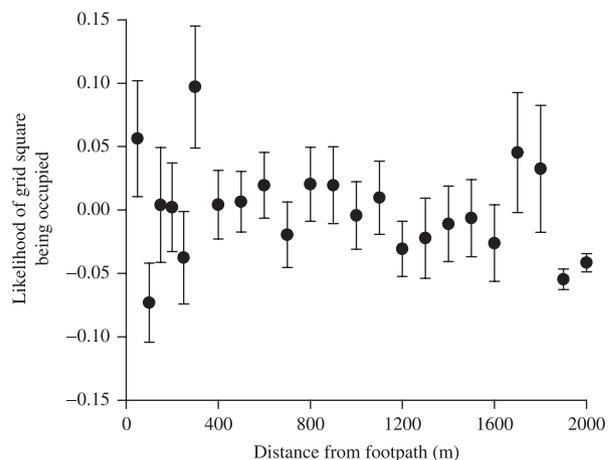


**Figure 1.** Likelihood of a grid square being occupied by a Golden Plover at Saddleworth Moors in relation to its distance from the Pennine Way footpath. Raw residuals from a generalized linear model, having controlled for the significant effects of habitat type and topography, are shown. Mean (± se) residuals at intervals of 50 m (< 300 m from path) and 100 m (> 300 m from path) are given.

AUC value of the final model was 0.75, indicating a good fit between the predicted and observed distribution.

## Dunlin distribution at Snake Summit

The number of Dunlin seen during the surveys ranged from zero to nine individuals (mean ± sd 2.7 ± 0.2 individuals). The autocovariate measure was highly significant (Table 2), indicating significant spatial autocorrelation in the data. Having controlled for this in the analysis, there was a significant positive relationship between grid square occupancy and altitude, and negative correlations between occupancy and both slope and heather cover (Table 2). There was an additional significant negative relationship between the probability of a grid square being occupied and its distance from the footpath (Table 2); Dunlin were more likely to occupy grid squares close to the Pennine Way. The slope of the relationship tended to differ before and after the footpath was resurfaced ($\chi_1^2 = 3.1$, $P = 0.078$), as the proportion of occupied grid squares that were within 200 m of the footpath increased by approximately 50% following the resurfacing work (Fig. 2). The AUC value of the final model was 0.84, indicating a good fit between the observed and expected distribution.

Data from the annual May bank holiday surveys of Dunlin distribution show that Dunlin tended to be found close to the Pennine Way following footpath resurfacing (Fig. 3), with the greatest reduction in distance occurring immediately following the resurfacing work, although this tendency was not statistically significant (generalized linear model, $\chi_1^2 = 2.2$, $P = 0.14$).

## Golden Plover breeding success at Snake Summit

Golden Plover nest-sites differed significantly from the 50 random sites in the percentage cover of

**Table 2.** Results of logistic regression showing the variables found to have a significant effect on the distribution of Dunlin during the chick-rearing period at Snake Summit

| Variable | Estimate | SE | chi-squared | df | P |
|---|---|---|---|---|---|
| Intercept | −11.96 | 4.329 | | | |
| Autocovariate | 5.637 | 0.736 | 4.9 | 1 | < 0.001 |
| Heather (% cover) | −0.111 | 0.066 | 3.9 | 1 | 0.049 |
| Gradient | −8.009 | 4.202 | 5.5 | 1 | 0.019 |
| Altitude | 0.019 | 0.008 | 4.9 | 1 | 0.027 |
| Distance from footpath | −0.039 | 0.013 | 8.2 | 1 | 0.004 |
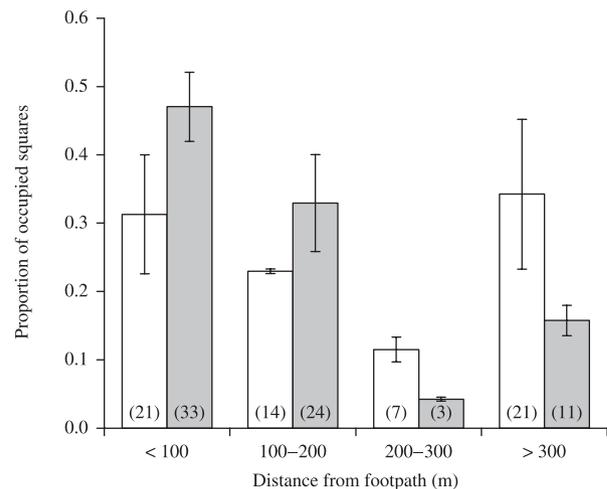


**Figure 2.** Distribution of adult Dunlin in relation to the Pennine Way footpath at Snake Summit. The proportion of grid squares occupied by Dunlin during the chick-rearing period that were within 100-m intervals of the Pennine Way before the footpath was resurfaced (white bars) and following the resurfacing work (grey bars) are shown. The total numbers of individuals seen are given in parentheses.
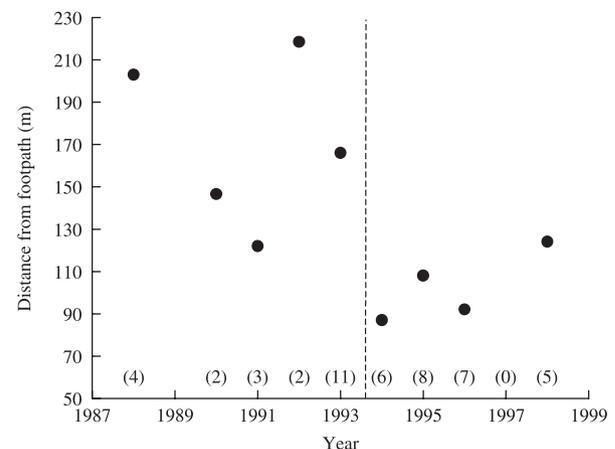


**Figure 3.** Median distance of Dunlin from the Pennine Way footpath at Snake Summit. Dashed line indicates the time when the footpath was resurfaced. The numbers of Dunlin seen during each annual survey are given in parentheses. Medians are presented as the data did not conform to a normal distribution.

heather and Bilberry within the surrounding 0.1 m² (Table 3); Golden Plovers avoided areas of both when selecting locations for their nests. The nests found during this study were located between 29 and 1074 m from the Pennine Way (median distance 228 m), and there was no evidence that nesting Golden Plovers avoided areas of high disturbance adjacent to the footpath ($\chi_1^2 = 1.3$, $P = 0.26$; Fig. 4a).

**Table 3.** Model outputs showing the variables found to have a significant effect on (a) nest location, (b) clutch survival and (c) chick growth rate in Golden Plovers at Snake Summit.

| Variable | Estimate | SE | df | (a,b) chi-squared (c) $F$ | $P$ | Variation explained by final model (%) |
|---|---|---|---|---|---|---|
| **(a) Nest location** | | | | | | |
| Intercept | 0.592 | 0.275 | | | | |
| Percentage cover of Heather | −0.170 | 0.126 | 1 | 9.6 | 0.002 | |
| Percentage cover of Bilberry | −0.146 | 0.055 | 1 | 20.3 | < 0.001 | 22 |
| **(b) Clutch survival** | | | | | | |
| Intercept | −0.438 | | | | | |
| Days since laying that the nest was first located | 0.144 | 0.048 | 1 | 13.7 | < 0.001 | |
| Percentage cover of Crowberry | 0.036 | 0.018 | 1 | 4.4 | 0.037 | 35 |
| **(c) Growth rate** | | | | | | |
| Intercept | −0.213 | | | | | |
| Age (days) | 0.148 | 0.051 | 1,90 | 8.6 | 0.004 | |
| Age$^2$ | −0.020 | 0.007 | 1,90 | 7.1 | 0.009 | |
| Minimum temperature (°C) | 0.011 | 0.006 | 1,90 | 4.2 | 0.044 | 9 |

Of the 42 nests located, 17 failed during laying or incubation and 25 successfully hatched one or more young. Six of the failed nests were omitted from the analysis of clutch survival as the eggs had already been predated or abandoned when first discovered. As expected, there was a significant positive relationship between the number of days after clutch initiation that the nest was first discovered and clutch survival (Table 3); clutches found later during the incubation period were more likely to survive to hatching. Having controlled for this in the analysis, there was a significant positive relationship between clutch survival and the percentage cover of Crowberry. There was no significant relationship between clutch survival and the distance of the nest from the footpath ($\chi^2_1 = 0.6$, $df = 1$, $P = 0.45$; Fig. 4b).

Of the 22 chicks from which growth rate data were collected, 13 died and six fledged successfully; radio-transmitters on the remaining three chicks failed before fledging. The mean rate of mass change was 0.15 g/h or 3.5 g/day (range 5.5–12.0 g/day). Beyond the known effects of age and temperature on chick growth (Table 3; Pearce-Higgins & Yalden 2002), there was no significant relationship between growth rate and any of the other explanatory variables. Specifically, there was no evidence of a relationship between change in mass and distance from the footpath ($F_{1,87} = 0.13$, $P = 0.72$; Fig. 4c) either during the week or at weekends (interaction between the proportion of time between successive measurements that fell on a weekend and distance from the footpath, $F_{1,85} = 1.33$, $P = 0.25$).

## DISCUSSION

### The effects of disturbance on habitat occupancy

Golden Plovers at Snake Summit tend to avoid areas close to the Pennine Way footpath during the chick-rearing period. When the footpath was unsurfaced, visitor numbers were approximately 60 per weekend day, 32% of whom strayed from the path (Yalden & Yalden 1988), and habitat avoidance was apparent up to 200 m from the footpath (Finney *et al.* 2005). Following footpath surfacing, despite a doubling of visitor numbers (Pearce-Higgins & Yalden 1997), levels of avoidance fell to less than 50 m, probably as a result of the more predictable movement of people along the path (Finney *et al.* 2005). This pattern of Golden Plover distribution in relation to the Pennine Way was not replicated at Saddleworth Moors during the 1980s, when the Pennine Way received only 30 visitors per weekend day and Golden Plovers did not appear to avoid the path. This suggests that the response of Golden Plovers to the location of footpaths is heavily dependent upon the visitor usage that a particular footpath receives, as found for seabirds (Beale & Monaghan 2004, Beale 2007). Our confidence in this conclusion is increased by the fact that the two sites were otherwise similar in terms of habitat composition (see methods), breeding density (3.5 pairs and 3.9 pairs/km$^2$ at Snake Summit and Saddleworth Moors, respectively; D.W. Yalden unpubl. data), footpath visibility (Yalden & Yalden 1989a)
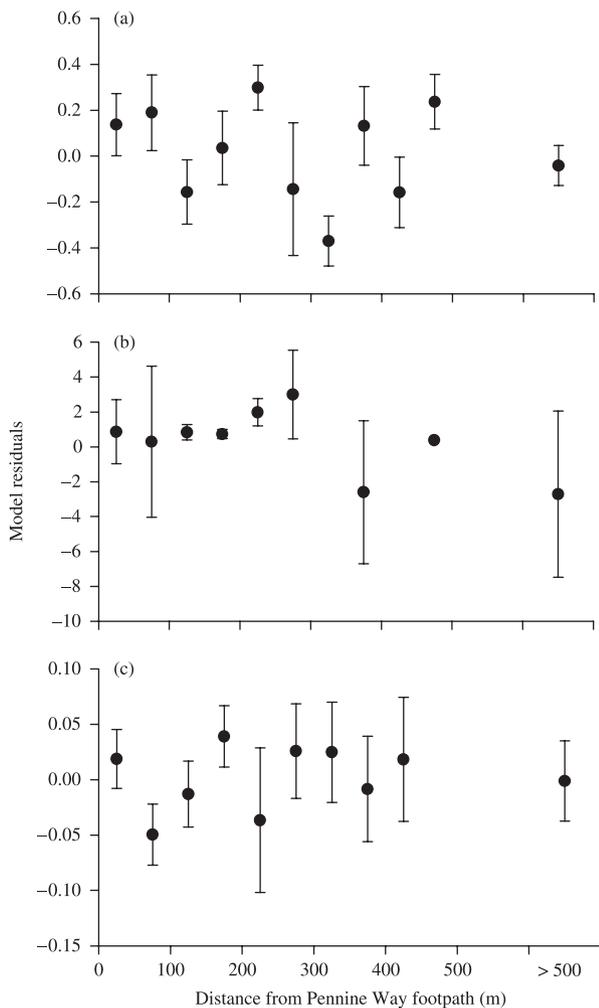
**Figure 4.** (a) The likelihood of finding a Golden Plover nest in relation to distance from the footpath at Snake Summit compared with randomly selected sites. Raw residuals from a logistic regression, having controlled for the significant effects of habitat type, are shown. If the occurrence of nests close to the footpath was lower than that expected by chance, the graph would show a trend running from bottom left to top right (see text for details of the analysis). (b) Clutch survival in relation to the distance of the nest from the footpath. Raw residuals from a generalized linear model, having controlled for the significant effects of habitat type and the stage the nest was found, are shown. (c) Growth rate of Golden Plover chicks in relation to the distance of the brood from the footpath. Raw residuals from a general linear mixed model, having controlled for the significant effects of chick age and ambient temperature, are shown. In all graphs, mean (± se) residuals at 50-m intervals are given.

and proportion of visitors retained by the footpath (Yalden & Yalden 1988).

In contrast to Golden Plover, the distribution of Dunlin at Snake Summit was negatively correlated with distance to the Pennine Way; habitat occupancy was greatest close to the footpath. This is probably a function of the Pennine Way crossing good Dunlin habitat, being located along a ridge dominated by cotton grass (cf. Haworth & Thompson 1990, Stillman & Brown 1994), rather than an active preference for disturbed habitats. However, there was a weak tendency for Dunlin to show a similar response to the changed levels of disturbance following resurfacing as that of Golden Plover, with an increase in occupancy of areas within 200 m of the footpath by 50% following resurfacing. Given the relatively high magnitude of this effect, the lack of significance ($P = 0.08$) is probably attributable to the relatively low power of the data, given the small Dunlin population and hence sample size, compared with Golden Plovers (Finney *et al.* 2005).

## The effects of disturbance upon breeding success

Despite the very high levels of disturbance close to the Pennine Way during the 1990s, with 120 visitors per weekend day, and areas of moorland adjacent to the footpath being disturbed for up to 60% of the day (09:00–18:00 h; Pearce-Higgins & Yalden 1997), there was no evidence that recreational disturbance had a significant impact on nest-site selection, or an adverse impact on Golden Plover reproductive performance.

Ground-nesting birds often flush from nests when approached by humans (Nesbit 2000, Lord *et al.* 2001). Recreational disturbance might therefore be expected to reduce clutch survival as unattended eggs are exposed to chilling or predation (Liley 1999, Bolduc & Guillemette 2003), but we found no evidence that clutch survival was lower among Golden Plovers breeding closest to the footpath. Our results are, however, consistent with those from a previous study, which found that adult birds were relatively tolerant of human disturbance during incubation compared with other stages of the breeding cycle (Yalden & Yalden 1990). During the present study, Golden Plovers nested from 29 m to over a kilometre from the Pennine Way (average distance 228 m) and it is therefore likely that most incubating birds remained on the nest when people passed on the footpath. In line with these results, we found no evidence that Golden Plovers avoided areas of high disturbance adjacent to the footpath when selecting nest locations.

During the chick-rearing period, adult Golden Plovers alarm-call loudly when people approach to

within 200 m (Yalden & Yalden 1989a); chicks hide in response to their parents' alarm-call and therefore cannot either feed or be brooded (Yalden & Yalden 1990). Repeated interruption of feeding as a result of recreational disturbance could therefore reduce the growth rate of chicks, and their probability of survival. However, although recreational disturbance along the Pennine Way is very high, particularly at weekends, we found no evidence that the growth rate of chicks was reduced when broods were foraging in close proximity to the path. Importantly, this was in a situation where 60% of observations were of broods within 200 m of the path, and therefore subject to behavioural effects of disturbance (Yalden & Yalden 1989a, 1990). This finding is in contrast to several previous studies of waders, which show that human interruption of foraging can have a significant impact on the growth and survival of chicks (Lord *et al.* 1997, Verhulst *et al.* 2001). However, these studies were of species that breed in coastal habitats and forage predominantly in the intertidal zone. This is a narrow linear habitat, usually with unpredictable patterns of disturbance across much of the available habitat, making it difficult for birds to move away from disturbed areas. Furthermore, the birds have a restricted time in which to feed and there is limited opportunity for chicks to compensate for foraging time lost as a result of human disturbance. By contrast, Golden Plovers breed in upland habitats and chicks feed on invertebrates found in the vegetation and on the soil surface (Whittingham *et al.* 2001, Pearce-Higgins & Yalden 2004). During the breeding season recreational disturbance is generally limited to the period between 09:00 and 18:00 h (Pearce-Higgins & Yalden 1997) whereas it gets light at 04:00 h and does not usually become dark until after 22:00 h. This leaves approximately 9 h when the moor is undisturbed and there is sufficient light for foraging, which may be enough for chicks to compensate for feeding time lost during the day. Furthermore, there is some evidence to suggest that Golden Plover chicks are able to feed at night (Whittingham *et al.* 2000), which would further extend the time available for foraging.

## Implications of these findings for conservation management

The strong avoidance of habitat close to the unsurfaced Pennine Way in the 1980s by Golden Plover at Snake Summit indicates that in some situations, high levels of disturbance can impact upon habitat use by

upland waders (Finney *et al.* 2005). However, the lack of an equivalent response at Saddleworth Moors, where visitor pressure was lower, and weak evidence for an equivalent negative impact of disturbance on Dunlin distribution (this study), suggests that the circumstances where upland waders will be negatively affected by visitor pressure are likely to be relatively few. For such responses to be regarded as of biological importance, they must be shown to have a population-level impact (cf. Gill *et al.* 1996), or to affect the favourable conservation status of a protected site for nature conservation. There are two possible hypotheses to account for the observed spatial and temporal variation in Golden Plover distribution in relation to footpath distance. The first is that the observed avoidance of areas close to the Pennine Way at Snake Summit observed during the 1980s was purely a result of habitat preference, and as the population has increased following recent mild winters (Yalden & Pearce-Higgins 1997), these more disturbed areas have become increasingly occupied, producing the shift in distribution with footpath resurfacing detected by Finney *et al.* (2005). Alternatively, the avoidance of the unsurfaced Pennine Way at Snake Summit reduced the ability of Golden Plover broods to exploit the disturbed moorland habitat, and hence limited breeding success. Following resurfacing, which reduced the levels of disturbance on adjacent moorland (Pearce-Higgins & Yalden 1997), the utility of areas close to the path increased, contributing to the observed population increase. Given the lack of a correlation between population size and median distance of Golden Plovers to the Pennine Way (Finney *et al.* 2005), necessary for hypothesis one to be supported, and the large areas of moorland required by Golden Plover chicks to access a sufficient range of invertebrate prey (Pearce-Higgins & Yalden 2004) that provides a mechanism for density dependence to impact upon breeding success (Yalden & Pearce-Higgins 1997), the balance of evidence currently supports the second hypothesis.

The Pennine Way resurfacing work appears to have successfully resolved the conflict between human visitor pressure and upland wader conservation interest at Snake Summit. Reassuringly, although the provision of a flagstone footpath has doubled the number of walkers along the Pennine Way (Pearce-Higgins & Yalden 1997), the detailed analyses of clutch survival and chick growth rates presented in this paper provide no evidence of an adverse impact of recreational disturbance on Golden Plover

breeding success at the site. It remains to be established whether more wary species (notably Curlew *Numenius arquata* and Redshank *Tringa totanus*) would be equally tolerant.

To conclude, there appear to be situations where high levels of visitor pressure will negatively impact upon upland wader populations, but that those situations are likely to be very rare, and restricted to the most heavily used sites with a network of poor-quality paths. However, because disturbance to birds can be significantly reduced if walkers remain on a linear route, the simple provision of clear waymarked paths with an easy surface on which to walk should reduce the conflict between visitor access and wader conservation interest in most situations where it arises. This approach works even where there are few access restrictions, as with both sites studied in this paper, and can therefore be applied to land designated as open access under the CRoW Act. More widely, these findings suggest that in situations where recreational disturbance is regarded as being of conservation concern, management to restrict the spatial extent of disturbance can successfully reduce any population-level consequences. The prescriptions associated with such management are likely to have to be most restrictive (i.e. exclusion zones) where bird distributions are limited to narrow or fragmented habitats with widespread patterns of disturbance, such as shorelines and beaches (Burger *et al.* 1995, Leseberg *et al.* 2000). By contrast, this work shows that on environs with extensive areas of habitat, particularly where footpaths increase the ease of access due to terrain or vegetation which is difficult to traverse, the provision of such access routes (albeit potentially costly, depending upon the materials used) may be all that is required to manage visitors successfully.

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