The effect of recreational disturbance on an upland breeding bird, the golden plover *Pluvialis apricaria*

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Abstract

The use of the countryside for recreation has increased dramatically in recent years. This has led to concern amongst conservationists about the effects increased human disturbance may have on important wild animal populations. In the UK, recent legislation has widened the level of access to upland habitats, which support internationally important breeding bird populations. Determining the extent to which recreational disturbance affects upland breeding birds is therefore a conservation priority. We used data collected over 13 years to investigate the impact of recreational disturbance on the distribution and reproductive performance of golden plovers breeding in close proximity to the Pennine Way, an intensively used long-distance footpath. Importantly, the Pennine Way was resurfaced in 1994 to prevent further erosion of the surrounding vegetation. We were therefore able to examine if the response of golden plovers to recreational disturbance was influenced by changes in the intensity and extent of human activity resulting from the resurfacing work. Before the Pennine Way was resurfaced, golden plovers avoided areas within 200 m of the footpath during the chick-rearing period. At this time over 30% of people strayed from the footpath and the movement of people across the moorland was therefore widespread and unpredictable. Following resurfacing, over 96% of walkers remained on the Pennine Way, which significantly reduced the impact of recreational disturbance on golden plover distribution; golden plovers only avoided areas within 50 m of the footpath at this time. Despite the clear behavioural responses of golden plovers to the presence of visitors, there was no detectable impact of disturbance on reproductive performance. In many countries, a conflict arises between the use of the countryside for recreational purposes and the protection of habitats or species of high conservation value. However, this study suggests that the implementation of simple measures to influence visitor behaviour can dramatically reduce the impact of recreational disturbance on wild animal populations.

1. Introduction

The extent to which the increasing use of the countryside for recreation may have adverse effects on wildlife is a growing conservation issue (Gill et al., 2001b; Papouchis et al., 2001). Animals often respond to humans as they would to potential predators (Frid and Dill, 2002) and responses to human intrusions are well documented for a range of species. These include elevated heart rate (Weimerskirch et al., 2002), increased alarming or defensive behaviours (Andersen et al., 1996; Reby et al., 1999) and ultimately the avoidance of high-risk areas, either completely or by using them for limited periods only (Gill et al., 1996). Disturbance by people can also increase the risk of predation (Anderson, 1988). Consequently, in areas where levels of human activity are high, repeated disturbance by visitors can lead to a reduction in the survival or reproductive success of individuals (Goodrich and Berger, 1994; Burger et al., 1995).

Ground-nesting birds, such as waders (*Charadriidae* spp.), are thought to be particularly at risk from human disturbance. When approached, birds often flush from

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nests, leaving eggs and chicks exposed to possible chilling or predation and imposing an energetic cost on the adults (Nudds and Bryant, 2000; Bolduc and Guillemette, 2003). For example, human disturbance is thought to significantly reduce the chick-rearing ability of African black oystercatchers *Haematopus moquini*, which breed on the coasts of South Africa at the height of the summer tourist season; breeding success outside protected areas was approximately one third of that on reserves (Leseberg et al., 2000). Similarly, human disturbance was found to interrupt incubation and reduce chick foraging time in New Zealand dotterels *Charadrius obscurus* (Lord et al., 1997, 2001). However, other studies have found no evidence of an adverse effect of human disturbance on bird populations (Gill et al., 2001b; Verboven et al., 2001).

In England and Wales, concern regarding the possible detrimental impact of recreational activity on ground-nesting birds has increased following the introduction of the Countryside and Rights of Way (CRoW) Act 2000. The Act creates a statutory right of access on foot for open-air recreation to mountains, moors, heaths, downs and registered common land. Increased access rights are of potential concern in upland areas due to the high numbers of visitors these areas attract (e.g. Peak Park Joint Planning Board, 1988). These upland habitats support internationally important breeding bird populations, including a unique assemblage of breeding waders (Ratcliffe, 1991; Thompson et al., 1995). Under the provisions of the CRoW Act, restrictions can be put in place in areas where new access is likely to jeopardise important breeding bird populations. However, to date, few studies have investigated the impact of recreational activity on upland birds (see Yalden and Yalden, 1989, 1990a) and further research is urgently required to provide reliable information on which to base management decisions.

We investigated the effects of recreational disturbance on the breeding distribution and reproductive performance of golden plovers *Pluvialis apricaria*. Some of the highest recorded breeding densities of golden plover occur on moorlands in Britain (Byrkjedal and Thompson, 1998) and the golden plover is listed under Annex 1 of the EU Wild Birds Directive (79/409/EEC), giving it full legal protection and making this species a priority for conservation. This study was carried out in the Peak District National Park, northern England. The study area is traversed by the Pennine Way long-distance footpath and receives approximately 5000 visitors between April and July (Pearce-Higgins and Yalden, 1997). As a direct result of this intense use, considerable damage had been sustained to sections of the path and the surrounding vegetation (Porter, 1989). In an effort to improve the amenity of the route and to reduce further damage, a 4 km section of the Pennine Way was paved with flagstones during the winter of 1993/1994; access

points were also restricted by the erection of a fence along the edge of the road. This had a significant effect on the behaviour of hikers; over 30% of people strayed from the footpath prior to the resurfacing work compared to just 4% after the flagstones were laid (Pearce-Higgins and Yalden, 1997). This area therefore provided an ideal situation in which to investigate the impact of recreational disturbance on breeding golden plovers, as the amount of human activity varied both spatially and temporally. We tested the hypothesis that golden plovers avoid areas of high disturbance along the footpath and that this is most evident when disturbance levels are highest, at weekends. We also tested the hypothesis that high levels of human disturbance along the Pennine Way result in a lower reproductive performance by pairs with territories nearest to the path. Furthermore, the resurfacing of the footpath, and the associated change in visitor behaviour, enabled us to investigate how different access management options could influence any impact of visitor activity on breeding golden plovers. This study concentrated on the chick-rearing period, as previous research has shown that golden plovers are particularly sensitive to human disturbance at this time (Yalden and Yalden, 1989, 1990a).

2. Methods

2.1. Study site

Data were collected from the Peak District National Park, northern England, between 1986 and 1998. The study site is a 6 km^2 area of blanket bog to the south of Snake Summit (UK Ordnance Survey Grid Ref: SK088929; Fig. 1), dominated by cotton grass *Eriophorum vaginatum*, with bilberry *Vaccinium myrtillus* and crowberry *Empetrum nigrum* in the drier areas and heather *Calluna vulgaris* on lower slopes. The altitude of the site ranges from 450 to 554 m. As the study site is owned by The National Trust, a UK conservation charity, the land has been designated as "open access" since 1951. Walkers are therefore not restricted to footpaths, although they are encouraged to keep dogs on a lead and to avoid disturbing sheep and ground-nesting birds.

2.2. Survey methodology

Surveys of breeding golden plovers were carried out during the years 1986–1988 and 1996–1998. These were undertaken every 2–8 days during the chick-rearing period (May–July) between 09:00 and 18:00, avoiding days with heavy rain, high winds or poor visibility. A surveyor walked at a steady pace and approached all areas of the study site to within 200 m (Yalden and Yalden, 1990b). The route walked varied between surveys to avoid potential biases in the data by visiting a given area
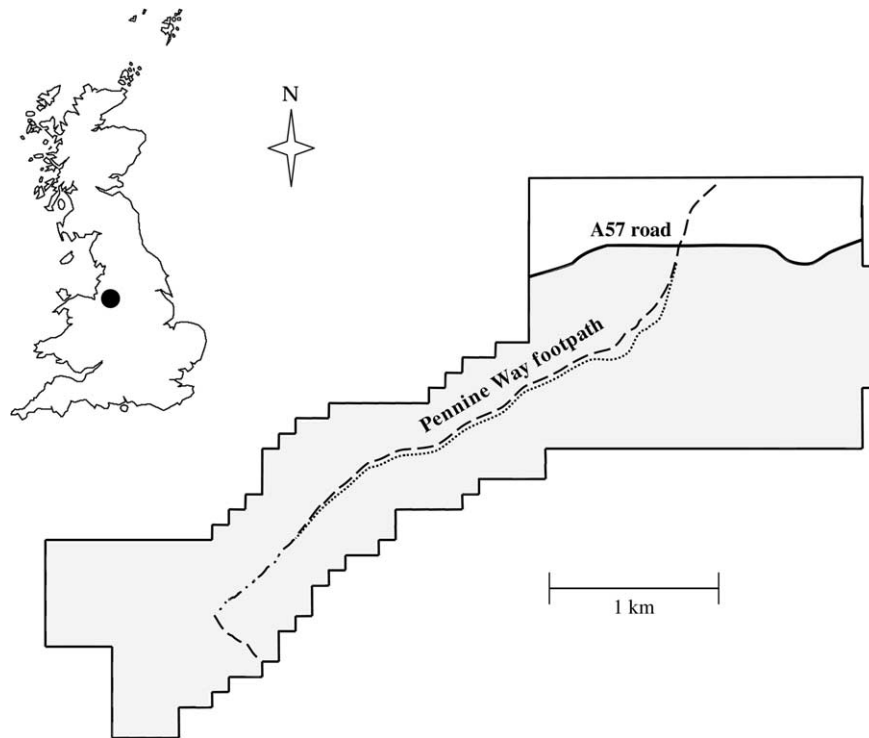
Fig. 1. Snake Summit study site (shaded area) showing the original route of the Pennine Way (dashed line), the route of the resurfaced footpath (dotted line) and the A57 trunk road (solid line).

of the study site at the same time of day on each occasion. The locations of all birds seen were recorded to the nearest 100 m grid square, which is a resolution that is likely to encompass chick locations in those cases where the adults had broods (Whittingham et al., 1999). To assess breeding status, detailed observations of the bird's behaviour (e.g., territorial display, alarm-calling, loafing) or the presence of a nest or chicks were also recorded. Where possible, observations were attributed to a particular pair based on either unique colour-ring combinations or on individual characteristics such as the amount of black ventral colouration (Yalden and Yalden, 1990b, Appendix A). Attributing behavioural observations to particular pairs enabled the survival of individual broods to be monitored (see below).

Only data from birds with chicks were used in the analyses of golden plover distribution and reproductive performance. Adults were classified as having chicks if they showed a characteristic alarm response (Yalden and Yalden, 1990b). Hatching date was taken as the date when adults were first observed showing the alarm response. The minimum fledging age recorded for golden plover chicks at this site is 34 days (Pearce-Higgins and Yalden, 2002). Given the frequency of surveys, all pairs observed alarm-calling for 30 days or more were considered to have successfully fledged young. To avoid potential misclassification, pairs were only considered to have failed if they were observed alarm-calling for 22 days or less. The remaining 9% of

pairs that could not be classified in this way were omitted from the analysis of reproductive performance. This is a reliable method for assessing brood survival as adult attendance is estimated at 93% during the chick-rearing period; pairs with chicks were therefore unlikely to have been missed during the surveys (Yalden and Yalden, 1990b). Furthermore, the study site encompasses a discrete area of suitable breeding habitat and, as such, pairs that disappeared before their chicks had reached fledging age (and were thus assumed to have failed) could not simply have moved their broods away from the study site.

In addition to the two intensive study periods, a survey of golden plover distribution was undertaken annually between 1986 and 1998 during the spring bank holiday weekend at the end of May. This allowed changes in golden plover distribution through time to be examined, specifically with respect to the timing of the footpath resurfacing work. The methodology was as described above with the exception that the same route around the study site was followed each year (Yalden, 2003). Any disturbance caused during the surveys was uniform across the study site and is therefore unlikely to have influenced the results of this study.

2.3. Habitat information

To assess the impact of recreational disturbance on breeding golden plovers accurately, it was first necessary

to control for the potential confounding influence of habitat type and topography. Habitat data were obtained from aerial photographs of the study site taken in 1983 and 1998 at a scale of approximately 1:12,000. The photographs were scanned onto computer, achieving a resolution of approximately 66 cm^2 per pixel. The scanned images were geo-referenced to the British National Grid (MapInfo Corporation, 2000) and a 100 m grid was overlaid. To test for changes in vegetation cover through time, habitat data from 25, 100 m grid squares, were compared between the two periods. Grid squares were selected randomly but selection was stratified with distance from the footpath to include a representative sample of habitats. For each 100 m grid square, the percentage cover of dwarf shrub and cotton grass were estimated by eye to the nearest 5%. Areas of bare peat were digitised, allowing percentage cover to be estimated to the nearest 0.1%. There was no significant difference between 1983 and 1998 in the percentage cover of dwarf shrub ($r = 0.95$, Paired t test: $T = 1.33$, $P = 0.20$), cotton grass ($r = 0.95$, $T = 0.89$, $P = 0.39$) or bare peat ($r = 0.97$, $T = 1.76$, $P = 0.09$), estimates of which were highly correlated between the two time periods. Habitat data for the analyses of golden plover distribution and reproductive performance were therefore obtained from the 1998 photographs only, as these were of higher quality, allowing the "dwarf shrub" category to be split into heather, bilberry and crowberry and allowing the percentage cover of grass (*Deschampsia flexuosa* and *Nardus stricta*) to be estimated. A mature conifer plantation bordered the eastern side of the study site; distance from the edge of the plantation was also calculated for each grid square. The average gradient and altitude in each grid square was estimated using a 1:25,000 Ordnance Survey map of the study site; the gradient measurement was based on the number of contour lines crossed within the 100 m square.

2.4. Statistical analysis

Most (>85%) people crossing the Snake Summit study site stayed on, or within 200 m of, the Pennine Way footpath (Yalden and Yalden, 1988; Pearce-Higgins and Yalden, 1997). Distance from the footpath was therefore used as an index of human disturbance. When the Pennine Way was resurfaced in 1994, the flagstones were laid up to 100 m to the east of the original route (Fig. 1). As a result, the distance of a given 100 m grid square from the footpath differed slightly before and after 1994. The impact of human disturbance on the distribution and reproductive performance of golden plovers was analysed using data from the intensive surveys undertaken during the years 1986–1988, when the Pennine Way was unsurfaced, and 1996–1998, after the footpath had been resurfaced. Each of the 100 m grid squares (590 squares in total)

was given a value of 1 if a golden plover (considered to be in attendance of a brood) had been 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 weekends and weekdays in each of the 6 years of the study. These data were then analysed in relation to a range of explanatory variables using logistic regression.

With such an analysis, there is potential for a Type I error as a single pair could be recorded in more than one grid square. However, although pairs were recorded in a mean of 4.7 ± 0.19 grid squares during the chick-rearing period, there was no significant relationship between the number of grid squares in which a pair was recorded and the distance of the territory from the footpath (generalised linear model with year as a fixed effect: $F_{1213} = 2.57$, $P = 0.11$). Furthermore, when the model was re-run using the number of pairs recorded in each grid cell as the dependent variable (rather than simply presence/absence of golden plovers), the explanatory variables found to have a significant effect on golden plover distribution were the same as in the original analysis. Together with the inclusion of an autologistic term in the model (see below), the use of presence/absence data as described above was therefore considered a robust measure of golden plover distribution.

To allow repeated measurements within grid squares through time to be accounted for in the analysis, the model had a repeated measures design and an unstructured covariance matrix (Genmod Repeated procedure, [SAS Institute Inc., 1997). Fixed effects included in the initial model were distance from the footpath, day of the week (i.e., weekend or a weekday; bank holidays were categorised as weekends), footpath condition (surfaced or unsurfaced), gradient, altitude, distance from the plantation and the percentage cover of the six habitat variables (bare peat, heather, cotton grass, bilberry, crowberry and grass). Year was included as a nested effect (nested within "footpath condition", i.e., 3 years before the footpath was resurfaced and 3 years following resurfacing work). First order interactions between distance from the footpath, day of the week and footpath condition were also included; the inclusion of interaction terms allowed us to determine if any relationship between golden plover distribution and distance from the footpath differed between weekends and weekdays, and before and after the footpath was resurfaced.

To avoid the possible confounding effects of spatial autocorrelation, we adopted the approach of Augustin, Mugglestone and Buckland (1996) by incorporating an autologistic term in the model. The autocovariate was calculated using the equation

$$\text{autocovariate}_i = \frac{\sum_{j=1}^{K_i} W_{ij}Y_j}{\sum_{j=1}^{K_i} W_{ij}}. \tag{1}$$

This is a weighted average of the number of occupied grid squares amongst a set of K_i neighbours of grid square I (the surrounding eight grid squares were used to calculate the autocovariate in our analysis). The weight given to square j is $Wij = 1/hij$ where hij is the straight-line distance between the centres of squares i and j. The response variable Y was 1 if golden plover were present and 0 if they were absent. As above, the autocovariate was calculated separately for weekends and weekdays in each of the 6 years of the study.

The impact of human disturbance on the reproductive success of golden plovers was analysed using logistic regression. Pairs that had hatched chicks were classified as being either successful or unsuccessful in producing fledged young. To control for seasonal changes in reproductive performance, estimated hatching date was included as a fixed effect in the initial model. The mean of the values for the six habitat variables from each of the 100 m grid squares in which the pair was recorded during the chick-rearing period were also included as a measure of habitat use. Footpath condition (surfaced or unsurfaced) and territory location (calculated as the mean distance of the pair from the footpath during the chick-rearing period) were included as fixed effects and year as a nested effect. The mean distance of the pair from the forest plantation and the interaction between footpath condition and territory location were also included in the initial model.

In both analyses, the maximal model was fitted and then simplified by step-wise deletion of the least significant term. This was repeated until the minimum adequate model was attained (i.e., all remaining terms were significant at the $P < 0.05$ level). The significance of interaction terms were assessed first and then main effects. The success of the minimum adequate model was assessed using receiver operating characteristics (ROC) plots (Osborne et al., 2001). This is considered a more robust approach than simply judging models as successful if predicted probabilities >0.5 correspond to occurrences and values <0.5 with absences, because this dichotomy is arbitrary and lacks any ecological basis. The ROC curve is constructed by varying the cutpoint that determines which predicted probabilities are assumed to be associated with a positive event. A ROC plot depicts on the y-axis sensitivity, i.e., $a/(a + c)$ in a 2×2 confusion matrix (Kohavi and Provost, 1998) of the model prediction against the observation. This is plotted against 1 – specificity, i.e., $1 - (d/(b + d))$ from the same confusion matrix. If the model was no better than chance at correctly predicting positive events, the plot would show a line following the positive diagonal, whereas models that are better than chance will follow a curve lying in the upper left half. The area under the ROC curve (AUC) is a measure of overall fit and varies from 0.5 (for a model with predicted values that are no better than chance) to 1.0 for a perfect fit.

3. Results

3.1. Golden plover distribution

The population size of golden plovers breeding within the Snake Summit study area increased twofold during the course of this study from an estimated 15 breeding pairs in the late 1980s to 30 breeding pairs in the mid 1990s (Yalden and Pearce-Higgins, 1997 and data from this study). Habitat type and topography had a significant influence on the distribution of golden plovers within the study area (Table 1(a)). Grid squares were more likely to be occupied by golden plovers during the chick-rearing period if they contained a high percentage cover of bare peat or crowberry. However, there was evidence that birds avoided grid squares containing a high percentage cover of heather or grass, and those in close proximity to the forest plantation. Golden plovers were also less likely to occupy grid squares on sloping ground or those at lower altitude. There was no evidence of spatial autocorrelation in golden plover distribution using the autocovariate measure ($\chi^2 = 0.8$, df $= 1$, $P = 0.37$).

3.2. Impact of human disturbance on golden plover distribution

After accounting for the effects of habitat, topography and year, there was a significant relationship between the probability of a grid square being occupied and its distance from the footpath (Fig. 2). However, the relationship differed significantly before and after the footpath was resurfaced (Table 1(a)). At weekends, prior to the footpath being resurfaced (1986–1988), the probability of a grid square being occupied decreased significantly within approximately 200 m of the footpath (Fig. 2(a)). During the week, there was a more gradual decline in the probability of a grid square being occupied with decreasing distance to the footpath (Fig. 2(b)). However, the difference between weekends and weekdays was not statistically significant ($\chi^2 = 1.9$, df $= 1$, $P = 0.17$). After the Pennine Way had been resurfaced (1996–1998), the probability of a grid square being occupied decreased within 50 m of the footpath at weekends (Fig. 2(c)) but there was no evidence that golden plovers avoided areas close to the footpath on weekdays (Fig. 2(d)).

The AUC value of the final model was 0.78, indicating a good fit between the predicted and observed distribution of golden plovers (Swets, 1988; Fig. 3(a)).

3.3. Long-term trends in distribution

Data from 1986, 1987 and 1989 were omitted from the investigation of long-term trends in golden plover distribution as bad weather had prevented surveys from

Table 1
Output from logistic regression showing the variables found to have a significant effect on golden plover (a) distribution and (b) reproductive performance

Variable	Estimate	SE	χ^2	df	P
(a) Golden plover distribution					
Intercept	−12.301	1.949			
Bare peat	0.135	0.048	6.1	1	0.014
Crowberry	0.072	0.022	9.9	1	0.002
Grass	−0.188	0.048	15.7	1	<0.001
Heather	−0.122	0.022	23.7	1	<0.001
Distance from forest plantation (m)	0.325	0.036	45.2	1	<0.001
Gradient	−7.426	1.403	22.6	1	<0.001
Altitude (m)	0.019	0.004	26.9	1	<0.001
Distance from footpath (m)	−0.001	0.008	8.7	1	0.003
Day of the week	0.720	0.082	5.3	1	0.021
Year (footpath condition)			51.8	4	<0.001
Footpath condition	−1.460	0.220	82.0	1	<0.001
Distance from footpath×footpath condition	0.043	0.009	19.6	1	<0.001
Day of the week×footpath condition	−0.985	0.161	22.9	1	<0.001
(b) Golden plover reproductive performance					
Intercept	2.859	2.076			
Date (Julian day)	−0.030	0.013	5.9	1	0.015
Crowberry	0.038	0.012	10.7	1	0.001
Year (Footpath condition)			8.3	4	0.080
Footpath condition	1.097	0.597	9.7	1	0.002
Distance from forest plantation (m)	0.231	0.112	4.4	1	0.037

Habitat variables refer to percentage cover. The parameter estimates for the nested variable "year" are not presented.
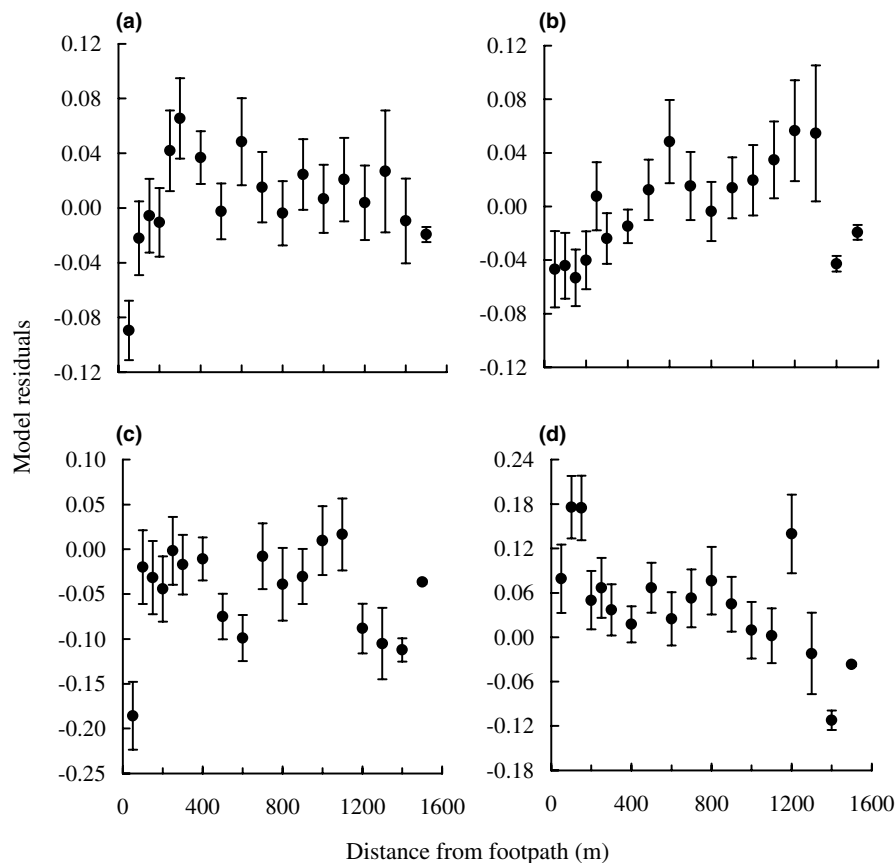

Fig. 2. The likelihood of a grid square being occupied by a golden plover in relation to its distance from the Pennine Way footpath. Raw residuals from a generalised linear model, having controlled for the significant effects of habitat type and topography, are plotted for (a) weekends and (b) weekdays before the footpath was resurfaced and (c) weekends and (d) weekdays after the footpath was resurfaced. Mean (±SE) residuals at 50 m (<300 m from path) and 100 m (>300 m from path) intervals are given.
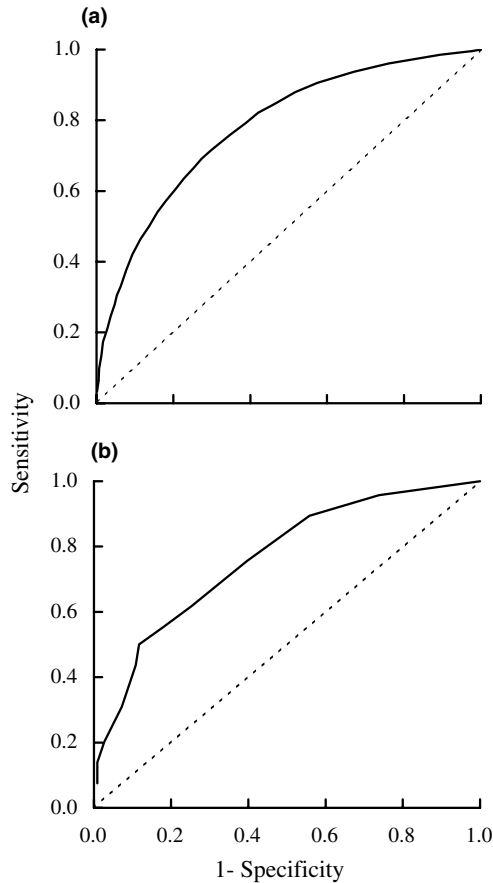
Fig. 3. Receiver operating characteristics (ROC) plots used to assess the fit of the logistic regression models describing (a) distribution and (b) reproductive performance of golden plovers (solid lines). The dashed lines indicate the outcome that would be expected if the model were no better than chance at correctly predicting a positive event.
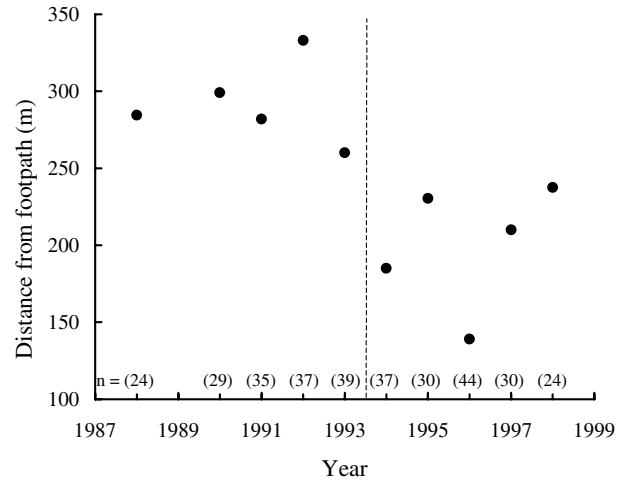

Fig. 4. Median distance of golden plovers from the Pennine Way footpath between 1988 and 1998. The total number of birds seen during each survey is given in parentheses. The dashed line indicates the time when the footpath was resurfaced. Median distances are presented as the data did not conform to a normal distribution.

3.4. Impact of disturbance on reproductive performance

There was a significant negative relationship between hatching date and reproductive performance; pairs with chicks that hatched late in the season were less likely to fledge young successfully (Table 1(b)). Pairs were more likely to have a successful breeding attempt if they were recorded in grid squares with a high percentage cover of crowberry. There was a significant positive relationship between reproductive performance and distance from the forest plantation; pairs with territories closest to the plantation were less likely to fledge young (Table 1(b)).
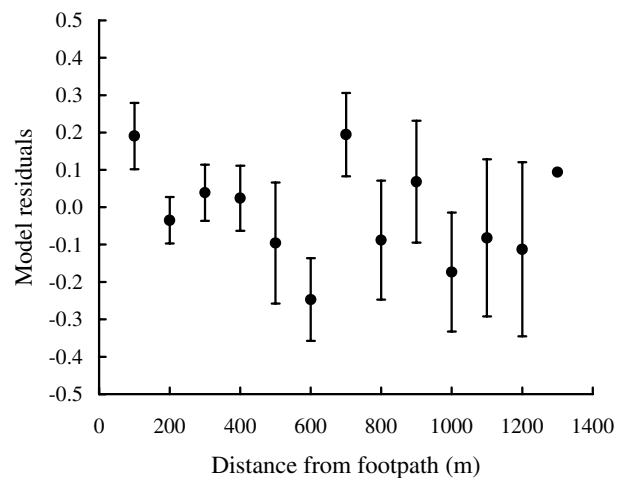

Fig. 5. Reproductive performance (brood survival) of golden plovers in relation to the distance of their territory from the Pennine Way footpath. Raw residuals from a logistic regression, having controlled for the significant effects of habitat type and date, are plotted. Mean ($\pm$SE) residuals at 100 m intervals are given.

being carried out during the holiday weekend at the end of May. Results from the remaining 10 years accorded well with those obtained from the two intensive survey periods. There was a significant decrease in the average distance of golden plovers from the Pennine Way in 1994, which coincided with the footpath being resurfaced (Generalised Linear Model; $\chi^2 = 5.8$, df $= 1$, $P = 0.016$; Fig. 4). The median distance of golden plovers from the footpath during the 5 years (for which data were available) before the footpath was resurfaced was 277 m compared to 191 m during the 5 years immediately following the resurfacing work. The possible confounding influence of changes in population size through time were accounted for by including an estimate of the number of breeding territories in the initial model (Yalden and Yalden, 1990b; Yalden and Pearce-Higgins, 1997). However, there was no significant relationship between the number of breeding territories and the median distance of golden plovers from the Pennine Way ($\chi^2 = 2.0$, df $= 1$, $P = 0.16$).

The reproductive performance of golden plovers differed significantly between the two study periods being 68% for the period 1986–1988 and 46% for 1996–1998. However, there was no evidence of a relationship between reproductive performance and the distance of the territory from the footpath ($\chi^2 = 0.1$, df = 1, $P = 0.78$, Fig. 5) and no significant interaction between the distance of the territory from the footpath and footpath condition ($\chi^2 = 1.3$, df = 1, $P = 0.26$). The AUC value of the final model was 0.77, indicating a good fit between observed and predicted reproductive performance (Swets, 1988; Fig. 3(b)).

4. Discussion

4.1. Influence of habitat on distribution and reproductive performance

Habitat type had a significant influence on the distribution of breeding golden plovers at the study site. During the chick-rearing period, golden plovers were predominantly found in areas with a high percentage cover of bare peat and crowberry but avoided areas of heather or grass. This pattern of habitat use reflects the distribution of tipulid larvae, caterpillars and beetles, which are the main prey items in the diet of golden plover chicks (Whittingham et al., 2001; Pearce-Higgins and Yalden, 2004). The higher reproductive performance amongst pairs found in areas with a high percentage cover of crowberry may also reflect the value of this habitat as a food source for chicks. There was evidence golden plovers avoided grid squares in close proximity to the forest plantation, a response that has been recorded previously, both in this species (Buchanan and Pearce-Higgins, 2002) and in other upland waders (Stroud et al., 1990). This may be due to an increased predation risk close to the forest edge (Stroud et al., 1990; Warren, 2000), as pairs breeding closer to the plantation had lower brood survival.

4.2. Influence of recreational disturbance on distribution and reproductive performance

In the 1980s, before the Pennine Way was resurfaced, the Snake Summit study site received approximately 60 visitors per day at weekends and 20 visitors per day during the week; areas of moorland adjacent to the Pennine Way footpath were disturbed for up to 33% of the day (0900–1800, Yalden and Yalden, 1988). Additionally, 32% of walkers strayed from the footpath in an effort to avoid the most severely eroded sections (Yalden and Yalden, 1988). Movement of people across the study site was therefore widespread and unpredictable. This study demonstrates that this level of recreational disturbance had a significant effect on golden plover

distribution during the breeding season. Golden plovers tended to avoid areas within 200 m of the footpath during the chick-rearing period. At weekends, when disturbance levels were highest, golden plovers were 54% less likely to occupy areas within 200 m of the footpath and 62% less likely to occupy areas within 50 m of the footpath. Furthermore, golden plovers did not appear to move closer to the footpath on weekdays, when levels of disturbance were lower. As the study site had open access, the situation during the 1980s will be similar to that on many moorlands mapped as open access land under the CRoW Act, but with a heavily-used footpath running through it. Although open access moorland without footpaths crossing them are likely to remain relatively quiet (Yalden and Yalden, 1988), access mapping may result in increased disturbance close to access points, between access points and areas of interest, and along existing footpaths. In such situations, the results from our study suggest that there would be a zone of approximately 400 m in width along any well-used, unsurfaced footpaths where golden plover occupancy would be reduced. However, how the magnitude of this effect varies with different levels of footpath use requires further research.

These findings are consistent with those from an earlier study (Yalden and Yalden, 1989), which used the alarm-calling behaviour of adult birds to estimate the sensitivity of golden plovers to visitor disturbance. They found that the average distance at which adult birds began alarm-calling in response to an approaching human was approximately 200 m during the chick-rearing period. This suggests that for breeding waders, similar behavioural studies could be used to indicate the distances from sources of disturbance over which habitat occupancy is likely to be reduced. For example, response distances include 75 m for common sandpipers *Actitis hypoleucos* (Yalden, 1992), 100 m for New Zealand dotterels (Lord et al., 2001), and in excess of 1 km for both curlew *Numenius arquata* and redshank *Tringa totanus* (Yalden and Yalden, 1989). These figures suggest that the impact of increased recreational activity on breeding waders will vary depending on the sensitivity of the particular species concerned. For golden plovers, the avoidance of areas within 200 m of a footpath is unlikely to be a serious threat in places where a single footpath crosses a large area of suitable habitat. However, human disturbance may become a problem in areas where there is a network of footpaths, particularly if paths are spaced less than 400 m apart, as this may exclude golden plovers from otherwise suitable habitat.

Despite the clear behavioural responses of golden plovers to the presence of visitors, there was no detectable impact of disturbance on brood survival. Disturbance has the potential to affect brood survival as chicks often hide in response to their parents alarm calls and therefore cannot either feed or be brooded; this may be a

particular problem if disturbance occurs during periods of bad weather (Yalden and Yalden, 1990a). Furthermore, human disturbance may lead to an increase in aggressive interactions as birds displaced from an area are forced into neighbouring territories (Yalden and Yalden, 1990a) and chicks may also be at greater risk of predation while the parents are distracted (Anderson, 1988; Liley, 1999). Our findings are however consistent with several previous studies, which have shown that a strong behavioural response to human disturbance does not necessarily lead to reduced reproductive performance (Mueller and Glass, 1988; Gill et al., 2001a). However, it must be remembered that reproductive performance in our study was measured in terms of whether entire broods survived or failed. Differences in hatching success or the number of fledglings produced would therefore not have been detected. Further, the study site has relatively few predators (Pearce-Higgins and Yalden, 2003) and we cannot rule out the possibility that disturbance may increase the probability of eggs or chicks being predated in other situations (e.g. Liley, 1999).

The area around the Pennine Way that was avoided by breeding golden plovers fell from 200 m before the footpath was resurfaced to just 50 m following the resurfacing work. Golden plovers were 24% less likely to occupy areas within 50 m of the footpath at weekends, but did not appear to avoid areas close to the footpath on weekdays. These changes occurred despite a twofold increase in the number of people visiting the Snake Summit study site over the same period (Pearce-Higgins and Yalden, 1997). We found no evidence that the increase in the population size of golden plovers at Snake Summit during the course of this study, thought to be linked to a series of mild winters (Yalden and Pearce-Higgins, 1997), influenced the distribution of golden plovers in relation to the Pennine Way footpath. The reduction in the area avoided by golden plovers was therefore most likely due to the change in visitor behaviour following the resurfacing work (Pearce-Higgins and Yalden, 1997). After the Pennine Way was resurfaced, over 96% of walkers stayed on the newly laid flagstones and it is possible that birds were able to exploit habitat closer to the footpath as people followed a narrower and more predictable route across the study site. This is further supported by evidence from the long-term study of golden plovers at this site. Annual surveys during the breeding season showed a steep decline in the average distance of golden plovers from the Pennine Way in 1994, which coincided with the footpath being resurfaced. In line with these results, there was no detectable impact of recreational disturbance on reproductive performance following the resurfacing work.

When the Countryside and Rights of Way Act is fully implemented in 2005 (Countryside Agency, 2002), people will have the right to access any areas mapped as open access land under the Act. The results from our study suggest that an increase in recreational activity could have an adverse impact on breeding golden plovers, and potentially other upland waders, by reducing the availability of suitable chick-rearing habitat, but that this is most likely to occur in extreme situations, such as at Snake Summit, where there is very high visitor pressure. From a conservation perspective, such reduction in habitat use is only important if it impacts on the breeding density or reproductive performance of the species concerned and hence causes the population to decline (Gill et al., 1996). Given the mean home-range size of broods at Snake Summit of 41 ha (Pearce-Higgins and Yalden, 2004), it is likely that the 54% drop in occupancy within 400 m of the Pennine Way (an area equivalent to 29% of the study site), was sufficient to reduce breeding density at Snake Summit during the 1980s. This contention is supported by use of the model to predict abundance across the study area in the absence of the footpath. In situations where recreational disturbance has an adverse impact on breeding density or performance, our findings show that such impacts can be significantly reduced by providing defined access points, a clear route and an easy surface on which to walk, thereby encouraging visitors to remain on a linear route. In this way, landowners who are concerned about increasing recreational activity on their land as a result of the open access legislation could use waymarked paths to direct people away from sensitive areas. However, paths need to be well maintained and should be located far enough apart so as not to prohibit birds using the intervening habitat. In the absence of further research on other species, we suggest the use of alarm-calling distances (cf. Yalden and Yalden, 1989) and home-range sizes as a guide, with the spacing of paths sufficient to allow territories to exist undisturbed between paths.

The provision of waymarked, surfaced paths may also be effective in other situations where recreational disturbance is a problem for wildlife, particularly endangered breeding waders for which the results from this study are most directly applicable. Such an approach is most likely to be effective where footpaths significantly improve the ease of walking compared to the surrounding terrain, and can be routed to encompass sufficient areas of interest that will satisfy most visitors. In many situations, this is likely to be a more publicly acceptable option than the use of formal access restrictions or closure as a measure to protect important wildlife sites. Where disturbance is located along narrow linear habitats, such as shorelines that some waders use for breeding (e.g. Yalden, 1992; Liley, 1999), then alternative management options such as sanctuaries may be required, particularly where there are demonstrable population level impacts arising from disturbance (Liley, 1999).

Appendix A

The reliability of using individual differences in ventral colouration to attribute behavioural observations to particular pairs was assessed by comparing the results obtained using this method with those obtained from 21 pairs where at least one bird had been uniquely colour-ringed. This analysis was based on data collected during 1996–1998, when birds were first colour-ringed at this site (Yalden and Pearce-Higgins, 2002). There was no significant difference between ringed and unringed pairs in the number of days recorded alarm-calling (generalised linear model: $F_{1181} = 2.49$, $P = 0.12$), the distance moved between successive surveys (generalised linear mixed model, including "brood" as a random effect: $F_{1559} = 2.52$, $P = 0.11$) or the outcome of the breeding attempt (Logistic regression: $\chi^2 = 3.35$, df $= 2$, $P = 0.19$). The use of variable plumage colouration to attribute behavioural observations to particular pairs was therefore considered a reliable method for monitoring brood survival.

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