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Extensive monitoring of Rock Ptarmigan *Lagopus mutus* in Scotland: a pilot to test the efficacy of using volunteer surveyors for monitoring arctic-alpine birds

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Abstract – A pilot study to examine the efficacy of using volunteers for the extensive monitoring of Rock Ptarmigan *Lagopus mutus* in Scotland attracted 140 volunteer surveyors, many of whom were not specialist birdwatchers. A total of 3,212 km of transects (all self-selected by the volunteers) were surveyed for birds and signs of their presence (faecal piles) between April and August 2006.
Encounter rates reported by volunteers were low (means of 0.25 birds and 0.34 'sites' per km - 'sites' being an encounter rate that included groups of faecal piles) but they did not differ significantly from those achieved concurrently by experienced professional ornithologists (means of 0.16 birds and 0.57 'sites' per km) undertaking monthly repeated surveys of transects for calibration purposes. Reports of no birds were made significantly less frequently by volunteers (54% of all survey returns) than by professional fieldworkers (77% of transects), potentially indicating that a proportion of surveys where no birds were seen were not reported and that the encounter rates reported by volunteers may be artificially high. The encounter rates of 'sites' by volunteers were highest in April and inversely related to the proportions of the transects covered by snow. No such relationships were apparent in their detection rates of birds, nor for either birds or 'sites' in the systematically repeated transect surveys. The differences between the volunteer surveys and the repeated transects are likely to be the result of biases associated with both surveyors and birds selecting snow-free patches.
This project indicated interest and enthusiasm by volunteers to participate in the monitoring of Rock Ptarmigan in the mountains of Scotland. For the development of a long-term extensive monitoring programme, issues of reporting nil returns and an enhanced systematic approach to surveying should be explored. Any modifications of the survey methods need to be acceptable to the volunteers to retain their enthusiasm however.

INTRODUCTION

The Rock Ptarmigan *Lagopus mutus* is a specialist bird of arctic-alpine habitats with a circumpolar distribution across northern Eurasia and North America. In Europe, there are isolated southern populations in the mountain ranges of the Pyrenees and the Alps and also in Scotland (Cramp and Simmons 1983). The insular population in Scotland is represented by the endemic subspecies *L. m. millaisi* (McGowan *et al.* 2003); this is a widespread resident across the Highlands, and some islands, where combinations of altitude and exposure maintain arctic-alpine habitats suitable for the species (Gibbons *et al.* 1993, Thompson *et al.* 2003).

The monitoring of trends in populations of widespread birds in Britain is primarily undertaken by volunteer birdwatchers but upland areas, including the entire range of the Rock Ptarmigan, have been severely under-represented (e.g. Raven and Noble 2006). Although a long-term study of Rock Ptarmigan populations has been made within some core areas of its distribution in Scotland (the Cairngorms and the Mounth; e.g. Watson 1965, Watson *et al.* 1998, Watson *et al.* 2000), there is little information on population levels, or trends from the majority of its range within Scotland and notably none from the southern peripheral parts of its range (e.g. Bryant *et al.* 1993).

Over recent decades, some population declines and range contractions of Rock Ptarmigan in Scotland have been associated with higher grazing intensities by domestic and wild herbivores, leading to the loss of ericaceous food plants (Watson and Rae 1993), and to human disturbance and an associated increase in predation (Watson and Moss 2004). Climate and weather patterns are predicted to change as a result of anthropogenic influences (e.g. Hulme *et al.* 2001) leading to changes in bird distribution, demography and phenology (e.g. Winkler *et al.* 2002, Crick 2004, Sæther *et al.* 2004). Population level responses to variation in climate have been shown for the ecologically similar White-tailed Ptarmigan *Lagopus leucurus* in Colorado (Wang *et al.* 2002) and weather has been shown to be a likely contributory factor influencing the population dynamics of Rock Ptarmigan populations in restricted study areas in Scotland (Watson *et al.* 1998). With changes in climate, weather patterns and grazing regimes predicted or likely, we suggest that populations of Rock Ptarmigan would be an appropriate indicator for the condition of arctic-alpine environments in Scotland.

This paper reports on a pilot study to test the efficacy of using volunteers such as recreational hill walkers, who were not necessarily specialist birdwatchers, to monitor Rock Ptarmigan in Scotland. With the current lack of extensive bird monitoring data from upland areas of Britain, the ultimate aim of the work reported here is to develop a cost-effective long-term monitoring programme for Rock Ptarmigan, and potentially other species, in the arctic-alpine areas of Scotland (Calladine and Wernham 2007).

METHODS

Following discussions with hill walkers (the most numerous potential volunteers for any fieldwork monitoring Rock Ptarmigan) and an initial pilot study to assess field methods in 2006 (Calladine 2005), it was decided to survey Rock Ptarmigan using linear transects. Alternative approaches such as random selection of survey sites and block surveys (e.g. searches of 1-km squares) were deemed unattractive by potential volunteers and incompatible with their principal aims (to climb mountains). In the months leading up to the survey period (April to August inclusive, 2007), articles were written for mountaineering magazines, club newsletters and websites and for the more general press to publicise the project with the aim of recruiting potential volunteers. Information sheets were supplied to volunteers that described transect selection and recording protocols, how to identify Rock Ptarmigan and their faecal piles and also background information about Rock Ptarmigan and the aims of the project. They were also given information on how to differentiate Red Grouse (*Lagopus lagopus scoticus*), the only potential confusion species.

Transect selection and recording

Survey routes were self-selected by the volunteers from within the known range of Rock Ptarmigan in Scotland (after Gibbons *et al.* 1993) and surveyed between April and August 2006, inclusive. Following the guidelines that were provided, these mostly started higher than 750 metres above mean sea level, the lower altitude for Rock Ptarmigan over much of their range in Scotland (Watson and Rae 1993). In the event that any Rock Ptarmigan were encountered at lower altitudes of the route taken, surveyors were asked to start their recording transects at that point. Such a design accommodated some areas (e.g. in the north-west highlands) where exposure permits Rock Ptarmigan to inhabit considerably lower altitudes. Surveyors were asked to supply eight-figure grid references (giving locational precision to within 100 m) for the start point and end points of their recording transects and also of any major turning points on their route. The overall length of transect surveyed was also recorded, and a random sample of these was compared against the given grid references to assess accuracy of details supplied. Also recorded were: the date of each survey; the start and end times for the walk along the survey route; the proportion of the survey transect that was covered with snow (five categories: none; <5%; 5-20%; 20-40%; >40%); and an indication of whether the surveyor thought that weather conditions were sufficiently adverse to affect their ability to detect birds (two categories: yes or no). In addition, details of other species recorded were also requested in an attempt to gauge the broader ornithological skill levels of participants and also to encourage data submission even when no Rock Ptarmigan were recorded (Calladine and Wernham 2007).

Recording of Rock Ptarmigan and their signs

The total number of individual Rock Ptarmigan that were seen along survey transects of known length and location was recorded. In addition, faecal piles were also recorded as an indicator of the presence of Rock Ptarmigan. Analyses considered both the numbers of Rock Ptarmigan actually seen on each survey transect and also the number of 'ptarmigan sites' encountered. 'Ptarmigan sites' were defined as spatial clusters of birds and/or their faecal piles. A single faecal pile or a cluster of piles represented a single site. Similarly, a single ptarmigan or a flock represented just one site as did bird(s) seen in the same area as pile(s). Based on the distribution of birds and faecal piles found during the initial assessment of field methods in 2005 (Calladine 2005), a minimum separating distance of 20 m between birds or faecal piles was assigned to identify separate 'sites'. In the event that such 'sites' extended for more than 20 m, surveyors were asked to call each 20 m section a separate 'ptarmigan site'. We are not aware that the latter was ever required, however.

The faeces of Rock Ptarmigan are inseparable in the field from those of Red Grouse and the two species occur close together in some areas of Scotland. Surveyors were asked to record the number of Red Grouse seen along their survey transects and the ratios of Rock Ptarmigan to red grouse counted were used to assign the proportion of faecal piles to species for cases when the birds themselves were not seen.

Systematic calibration transects

Concurrent with the volunteer based survey, a series of transects were surveyed by experienced professional ornithologists. The aim was to repeat a series of 35 transects, each between 2-4 km in length (total combined length 78.8 km), that were clustered at 10 sites in the Scottish Highlands (Fig.1), in each of the five months April to August inclusive. The calibration transects were self-selected in the same way as the extensive survey transects and included routes that generally headed towards mountain summits so as to be as comparable as possible to the extensive survey transects. A spread of sites of differing longitude was also chosen for the practical and logistical reasons of increasing the chances of appropriate weather for surveying within the suite of sites. The recording of birds and signs of their presence was identical to that undertaken by volunteer surveyors (above). The aims of these transects were: to try and quantify any seasonal variation in the detection rates of Rock Ptarmigan; and to compare detection rates between volunteer (often inexperienced) surveyors and those of experienced professional ornithologists.

Analyses

Scotland is divided into 21 Natural Heritage Zones (NHZs) or biogeographic regions, based on topography, geology and land use (Scottish Natural Heritage undated). The known breeding distribution of Rock Ptarmigan includes 11 of these NHZs (Fig. 1) and it is possible that a number of ptarmigan persist, or recolonisation is conceivable, in a twelfth (Rae 2007). Within each NHZ, the total number of Rock Ptarmigan seen by volunteers was expressed as a proportion of the combined total number of Rock Ptarmigan and Red Grouse that were seen. These proportions were used to estimate the number of faecal piles that could be assigned to Rock Ptarmigan. For the repeated calibration transects, the proportions of faecal piles that were attributed to Rock Ptarmigan were similarly estimated but using the sum totals of Rock Ptarmigan and Red Grouse seen at each of the ten sites through the 5 month survey season.

Generalised linear models (GLMs) were used to assess the influences of geographical region, season (month, $N = 5$), snow cover ($N = 5$ classes) and poor weather ($N =$

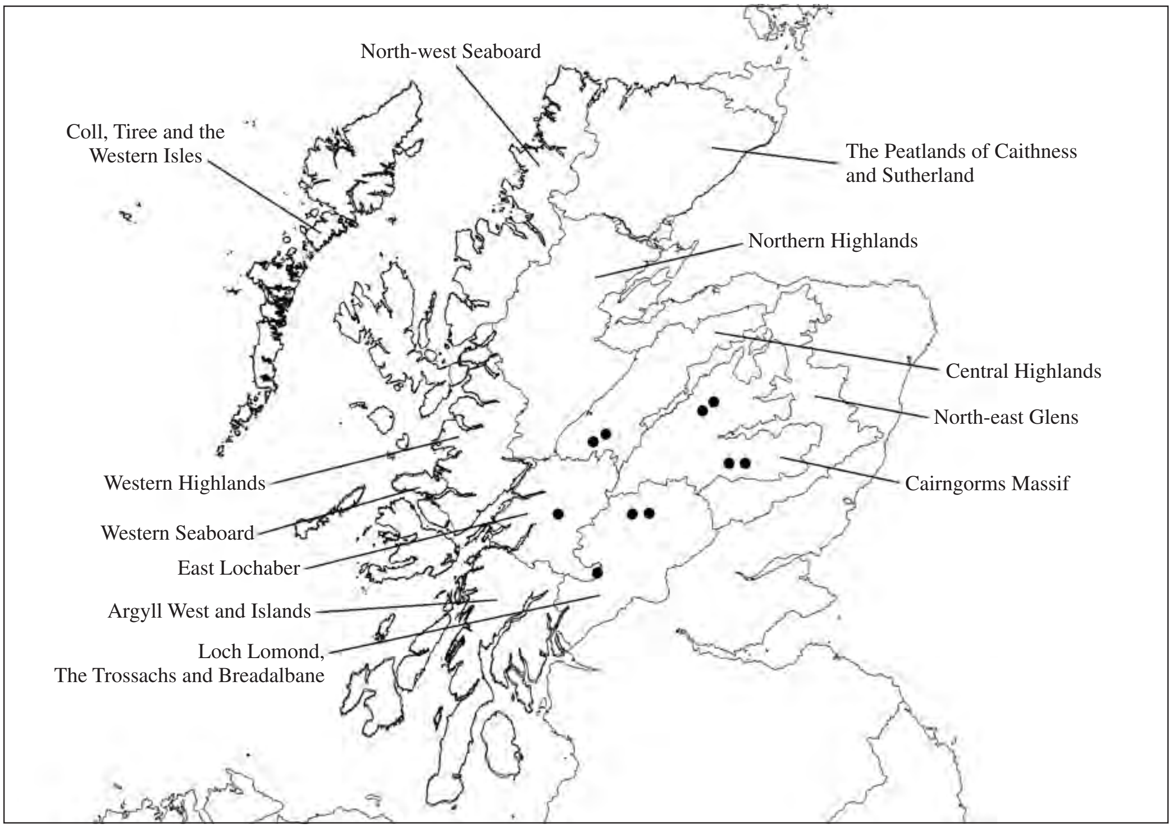

Figure 1. The locations of 10 calibration transects surveyed systematically in each of five months (April-August) by experienced professional ornithologists and the boundaries of Natural Heritage Zones in which Rock Ptarmigan are known to occur in Scotland.

2 classes) on encounter rates by volunteer surveyors as follows:

Count = Region + Month + Snow Cover + Poor Weather + constant

Two separate models were run, where 'count' was either the number of actual birds seen or the number of 'ptarmigan sites' encountered on a transect, the latter after the number of faecal piles had been corrected for the estimated proportions attributable to Rock Ptarmigan. The logarithm of the lengths of transect surveyed (in km) was introduced into the model as an offset and the models assumed a negative binomial distribution and a Log link function. In order to achieve model convergence, it was necessary to combine some neighbouring NHZs with sparse data to form eight biogeographic regions (Tab. 1). Similarly models that included the individual surveyor as an influencing factor on detection rates did not converge. Although most volunteers (78%) supplied survey data from just one region, there were at least 20 individuals (maximum 73) providing data from any one region. Therefore, we suggest that any biases associated with the detection rates of individual surveyors were likely to have been minimal and would have resulted in additional noise rather than any systematic bias. For the repeated calibration transects, the influences of season (Month, $N = 5$) and snow cover ($N = 5$ classes) were examined using the GLM:

Count = Month + Snow Cover + constant

Transect ($N = 35$) was included as a repeated measure and the logarithm of the lengths of the transect (km) was introduced as an offset. The models again assumed a negative binomial distribution and a Log link function. Note that the calibration surveys were not undertaken in conditions when poor weather was considered to have hindered the ability of the surveyors to detect birds.

Mean encounter rates, and their precision (standard error and confidence intervals), were estimated by back transformation of the adjusted (least squares) means from the above models.

RESULTS

Volunteer surveys

A total of 614 transect surveys were completed by 140 individual volunteers during the period April to August 2006, inclusive (Tab. 1, Fig. 2). A total of 3,212 km of transects were surveyed (mean 24.9 km per person, range 1-156 km per person) and a total of 1,027 Rock Ptarmigan and 1,672 'ptarmigan sites' were reported, the latter after correcting for the proportions of faecal piles that were likely to have been attributable to Red Grouse. Encounter rates of 'sites' tended to be greater than for birds (Fig. 3) and encounter rates differed significantly between some

Table 1. The number of transects surveyed by volunteers (and the sum length of transect surveyed (km) in parentheses) in each Natural Heritage Zone (NHZ) in each month, April to August inclusive, 2006.

	April	**May**	**July**	**August**	**TOTAL**
Argyll	0	1 (3)	0	0	4 (23)
Cairngorms	29 (181)	37 (246)	39 (285)	20 (156)	174 (1168)
Central Highlands	6 (20)	11 (57)	5 (25)	3 (6)	35 (144)
East Lochaber	16 (69)	23 (79)	21 (117)	11 (44)	102 (473)
North-west Seaboard	7 (35)	15 (53)	12 (39)	2 (2)	42 (193)
North-east Glens	5 (9)	0	0	0	5 (9)
Northern Highlands	19 (78)	20 (186)	19 (132)	6 (19)	87 (542)
Peatlands of Sutherland	1 (1)	2 (5.5)	4 (145)	0	11 (28)
Trossachs and Breadalbane	17 (112)	6 (32)	15 (64)	16 (68)	72 (330)
Western Highlands	4 (15)	15 (54)	22 (55)	11 (45)	66 (264)
Western Seaboard	2 (5)	5 (9)	1 (3)	1 (3)	13 (26)
Western Isles	0	0	2 (5)	1 (8)	3 (13)
TOTAL	106 (523)	135 (724)	140 (739)	71 (350)	614 (3212)

Note. To permit analytical models to converge, the following NHZs were combined:
Argyll with Trossachs and Breadalbane;
Cairngorms with North-east Glens;
North-west Seaboard with Peatlands of Sutherland;
Western Seaboard with western Isles.

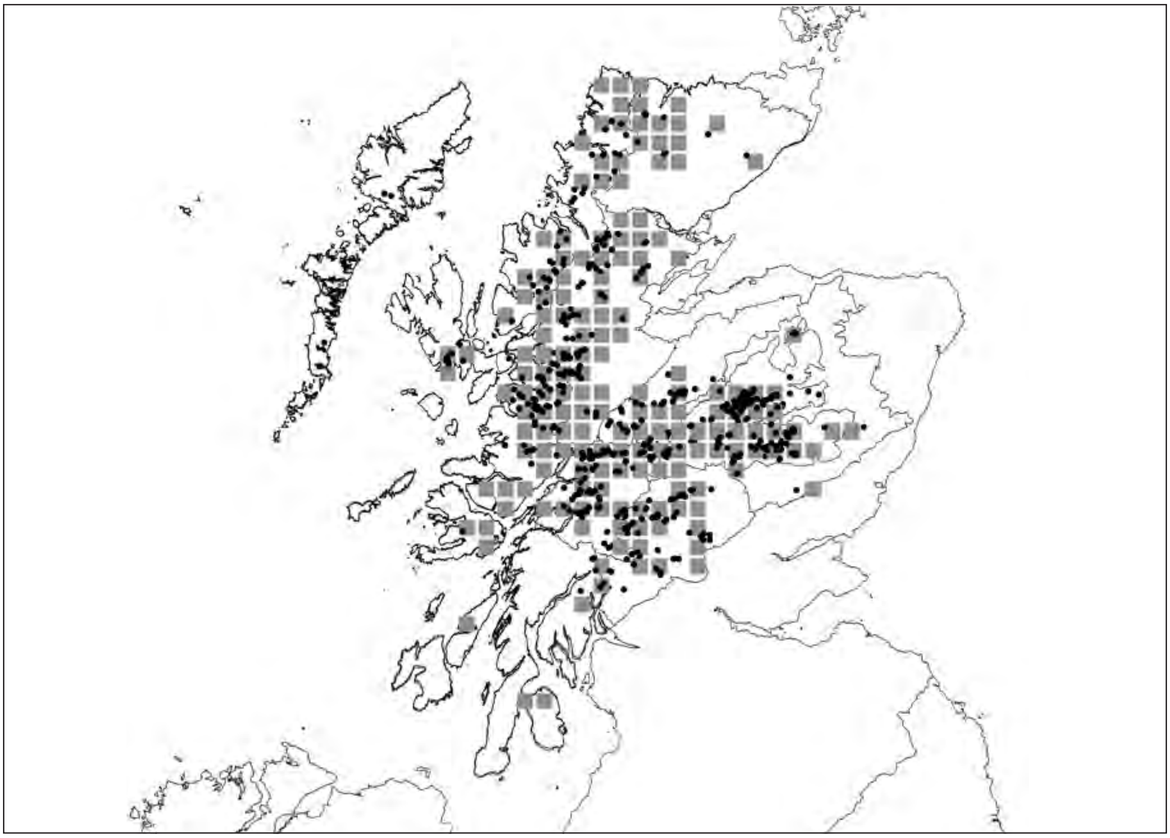

Figure 2. The distribution of survey returns from volunteers (black dots representing the central points of survey transects) and the distribution of Rock Ptarmigan in Scotland as reported during a national atlas of breeding birds in 1988-91 (grey squares representing the 10-km squares in Rock Ptarmigan were recorded; after Gibbons *et al.* 1993).

regions (Tab. 2, Fig. 3). The highest encounter rates (of both birds and 'sites') were in the Cairngorms (95% confidence intervals: for birds, 0.34-0.55 per km; for 'sites' 0.49-0.94 per km), and the lowest in the combined area of Argyll, the Trossachs and Breadalbane (95% confidence intervals: for birds, 0.05-0.14 per km; for 'sites' 0.09-0.22 per km) and the Western Isles and Western Seaboard (none) (Fig. 3).

Table 2. The relationships from generalised linear models assessing the influences of region, season, snow cover and poor weather on the detection rates of Rock Ptarmigan and 'ptarmigan sites' (a measure of abundance that includes faecal piles) by volunteer surveyors in Scotland, April to August 2007.

	BIRDS			SITES		
	χ^2	df	P	χ^2	df	P
Region	34.5	6	<0.001	59.0	6	<0.001
Month	2.1	4	0.72	19.1	4	0.001
Snow cover	3.7	4	0.46	12.3	4	0.02
Poor weather	0.1	1	0.75	0.02	1	0.90

Although having no effect on the detection rate of birds, there were significant influences of both season and snow cover on the detection of 'sites' (Tab. 2). Encounter rates of 'ptarmigan sites' were inversely related to the proportion of the survey transect that was covered by snow (Fig. 4) and were also greatest in April, although there was little variation between the other four months of the survey (May, June, July and August; Fig. 5). Although poor weather was reported by the volunteers as likely have affected 24% of the surveys completed, no statistically significant influence was detected (Tab. 2).

Systematic surveys

Complete coverage of all the 35 systematic calibration transects (totalling 78.8 km) was achieved only in August. Poor weather prevented completion in each of the other four months with 23 transect sections (51.6 km) surveyed in April, 33 (73.4 km) in May, 27 (56.8 km) in June and 32

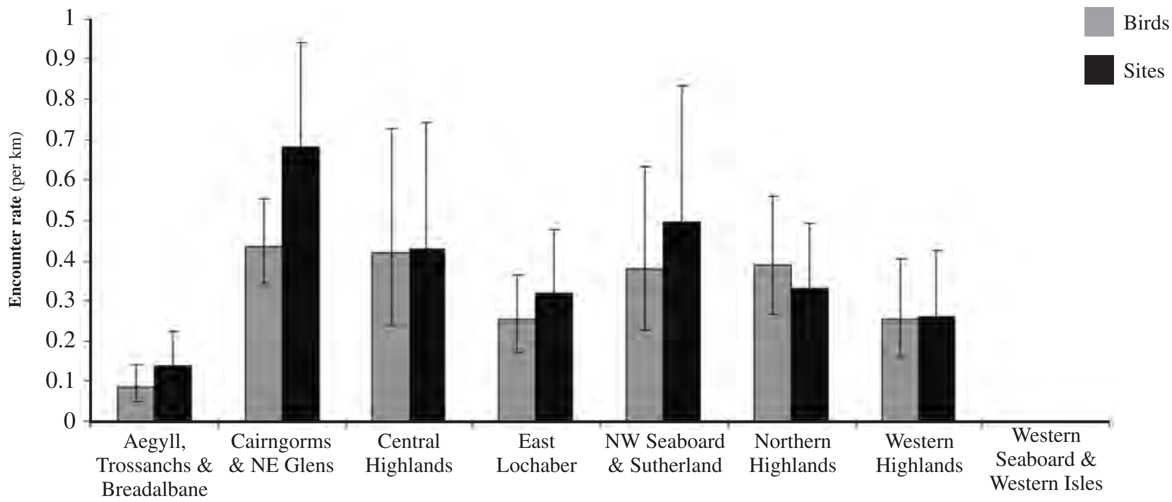

Figure 3. Encounter rates (means ± 95% confidence limits) by volunteer surveyors of Rock Ptarmigan and 'ptarmigan sites' by volunteer surveyors within eight regions of Scotland during April to August 2007.

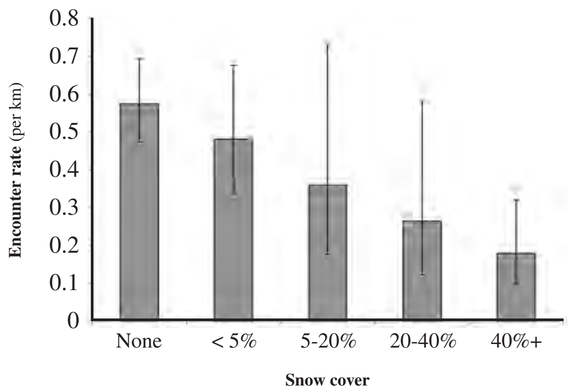

Figure 4. The encounter rates (mean ± 95% confidence limits) of 'ptarmigan sites' by volunteer surveyors with different proportions of snow cover on the survey transects.

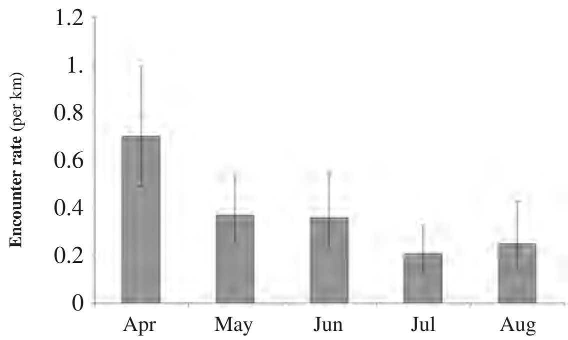

Figure 5. The encounter (mean ± 95% confidence limits) rates of 'ptarmigan sites' by volunteer surveyors in each of the five months, April to August, 2007.

(67.8 km) in July. In common with the surveys undertaken by volunteers, no statistically significant influences of season or snow cover were apparent on the detection rates of Rock Ptarmigan ($\chi^2_4 = 4.6$, $P = 0.33$ for Month; $\chi^2_3 = 1.8$, $P = 0.62$ for Snow cover). In contrast to the data collected by volunteers, however, no statistically significant influences of snow cover along each transect or of season on the encounter rates of 'sites' were detected ($\chi^2_4 = 4.0$, $P = 0.26$ for Month; $\chi^2_3 = 4.0$, $P = 0.26$ for Snow cover).

Comparison of detection rates between volunteer and systematic surveys

Systematic calibration surveys were undertaken in just four of the 12 NHZs in which surveys were also made by volunteers. The influences of region, season, snow cover and poor weather on the encounter rates of both birds and sites within a sub-sample of the volunteer data from those four NHZs only were very similar to those for the full volunteer data set, however. Similarly, the detection rates of birds (mean 0.28 km^{-1}; 95% confidence limits 0.18-0.43) and encounter rates of sites (mean 0.37 km^{-1}, 95% confidence limits 0.25-0.54) by volunteer surveyors within those four regions did not differ significantly from the complete data set (see below). In the absence of any differences, comparisons of systematic repeated surveys are made with the full data set submitted by volunteers.

The mean detection rate of birds by volunteer surveyors (0.25 km^{-1}; 95% confidence limits 0.18-0.36) was

56% greater than by professionals undertaking systematic repeated surveys (mean 0.16 km^{-1}; 95% confidence limits 0.08-0.33), while in contrast, the mean encounter rate of 'sites' by volunteers was 40% less (mean 0.34 km^{-1}, 95% confidence limits 0.25-0.46 compared to 0.57 km^{-1}, 95% confidence limits 0.36-0.91); the differences were not statistically significant, however. Amongst the volunteer surveys, 54% ($N = 615$) of the survey returns reported no birds, significantly less than the 77% ($N = 149$) of the systematic professionally surveyed transects ($\chi^2_1 = 6.41$, $P = 0.03$). There was no significant difference in the proportions of nil returns for 'sites' reported by volunteers (36%, $N = 550$) and by professionals (40%, $N = 149$) ($\chi^2_1 = 0.42$, $P = 0.95$), but note that 65 volunteer survey returns (11%) did not include details of any counts that included faeces piles, nil or otherwise.

DISCUSSION

This project demonstrated a keen interest in the voluntary monitoring of birds in the mountain areas of Scotland by hill walkers, many of whom are not specialist birdwatchers. Furthermore, the differences in the relative abundance of ptarmigan detected by the volunteers between regions indicate a level of reliability in the quantitative data collected: the highest densities (of birds and signs) were recorded in the Cairngorms, the region of Scotland with the most extensive continuous areas of habitat suitable for Rock Ptarmigan (Shaw *et al.* 2006), and the lowest densities were recorded in the south of their range, where arctic-alpine habitats are highly fragmented and where anecdotal reports suggest that ptarmigan densities are low.

In general the detection rates of ptarmigan by volunteers were low, leading to low statistical power to detect spatial or temporal differences in abundance. Based on the detection rates and their variation reported by volunteers in 2006, a pair-wise difference of less than 60% might not be reliably detected (assuming a t-test to detect differences between pairs of transect data). Encounter rates were greater if faecal piles were also recorded and a similar test of the power to detect pair-wise differences suggested that a 40% difference could be detected reliably. Whilst a time series of data (e.g. data collected annually) could give enhanced power to detect significant trends, greater statistical power would be expected if data on faecal piles are collected in addition to sightings of birds.

No influence of season or of snow cover on encounter rates was apparent in the systematic repeated surveys undertaken by experienced ornithologists. For encounter rates of faecal piles (but not for sightings of birds) this contrasted with the data collected by volunteers, which indicated a higher encounter rate in April and an inverse relationship with snow cover on the transects; there was no suggestion of a similar relationship from the repeated transects surveyed by professionals. It is most likely that this difference resulted from the processes used to select routes by volunteers compared to professionals. The transects by professionals were surveyed principally to investigate seasonal differences in detection rates, so that the data collected by volunteers could be corrected for these if necessary. The protocol adopted by the professionals required that the same transect routes were surveyed regardless of snow conditions on the ground. If conditions were impassable, then that transect (or section of it) was omitted. To ensure that the volunteer surveys were compatible with the aim of hill walkers to climb mountains and with no requirement for repeat surveys, the volunteers were able select their own transects routes. This meant that they could choose to avoid areas covered with snow. Similarly, Rock Ptarmigan probably select snow free areas in which to feed, hence their faeces piles might be concentrated in these areas. Therefore the high encounter rates of faecal piles by volunteers in April (the month in which the greatest snow cover was recorded) could potentially be an artefact of both the birds and surveyors being concentrated within snow-free areas.

Given this potential problem with using the quantitative data provided by volunteer surveyors, an alternative approach might be to use simple presence and absence data from defined areas (e.g. mountain groups) to measure temporal changes in distribution and abundance. The detection rates of birds and sites were similar between volunteer and experienced professional surveyors but there was a difference in the proportion of survey returns reporting no birds, with volunteers providing a lower proportion of nil returns. Although the survey instructions, recording forms and other materials associated with the project all emphasised the importance of reporting an absence (as well as a presence) of ptarmigan and the encouragement to record other species, it appears that some volunteers who completed surveys but did not see any birds failed to submit their records. This tendency would clearly limit any intention to monitor the species using simple presence and absence data, and also suggests that the detection rate of birds reported by volunteers might be artificially high.

The inability of the professional surveyors to complete all of the calibration transect surveys demonstrated the practical problems of monitoring birds in arctic-alpine habitats of Scotland. Even when resources (man-power and time) were available, poor weather prevented nearly 20% of the survey transects from being completed within the five month study period. Extensive long-term monitoring of Rock Ptarmigan, and potentially other mountain birds, is likely therefore to rely on a major contribution by volunteer surveyors. Further development of a monitoring programme for Rock Ptarmigan in Scotland would benefit from a more systematic approach by volunteer surveyors, however. This would aim to reduce the potential biases associated with observer (and bird) distribution and snow cover and also to increase the reliability with which surveyors report having seen no birds. These refined survey approaches need to be developed in conjunction with the volunteers themselves, however, to ensure that they remain both enjoyable and compatible with their main purposes for being in the mountains.

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REFERENCES

Bryant DM, Bell MV, Henty CJ, Newton SF 1993. Birds. In: Corbett L, Dix NJ, Bryant DM, McLusky DS, Elliot BJ, Tranter NL (eds). Central Scotland: Land - Wildlife - People. Forth Naturalist and Historian, Stirling pp. 57-76.

Calladine J 2005. A pilot study to test the efficacy of field methods for widescale monitoring of Ptarmigan in Scotland. BTO Research Report Number 423, BTO, Stirling.

Calladine J, Wernham C 2007. Extensive monitoring of Arctic alpine birds in Scotland: a pilot survey to test the potential of using volunteer surveyors. BTO Research Report No. 473. BTO Scotland, Stirling.

Cramp S, Simmons KEL 1983 (eds). Birds of the Western Palearctic. Vol. 2. Oxford University Press, Oxford.

Crick HQP 2004. The impact of climate change on birds. Ibis 146 (suppl.): 48-56.

Gibbons DW, Reid JB, Chapman RA 1993 (eds). The New Atlas of Breeding Birds in Britain and Ireland: 1988-91. T and AD Poyser, London pp. 128-129.

Hulme M, Crossley J, Lu X 2001. An exploration of regional climate change scenarios for Scotland. Scottish executive, Edinburgh.

McGowan RY, Clugston DL, Forrester RW 2003. Scotland's endemic subspecies. Scottish Birds 24: 18-34.

Rae, S 2007. Rock Ptarmigan. In: Forrester RW, Andrews IJ, McInerny CJ, Murray RD, McGowan RY, Zonfrillo B, Betts MW, Jardine DC & Grundy DS (eds) *The Birds of Scotland*. The Scottish Ornithologists' Club, Aberlady. Pp 296-299.

Raven MJ, Noble DG 2006. The Breeding Bird Survey 2005. BTO Research Report Number 439, BTO, Thetford.

Sæther BE, Sutherland WJ, Engen S 2004. Climate influences on avian population dynamics. Advances in Ecological Research 35: 185-209.

Scottish Natural Heritage Undated. Natural Heritage Zones: A National Assessment of Scotland's Landscapes. http://www.snh.org.uk/futures/Data/pdfdocs/LANDSCAPES.pdf (accessed 9 May 2007).

Shaw P, Thompson DBA, Duncan K, Buxton N 2006 Birds. In: Shaw P, Thompson D (Eds) The nature of the Cairngorms: Diversity in a changing environment. TSO, Edinburgh pp 293-338.

Thompson DBA, Whitfield DP, Galbraith H, Duncan K, Smith RD, Murray S, Holt S 2003. Breeding bird assemblages and habitat use of alpine areas in Scotland. Ecological Studies 167: 327-338.

Wang GM, Hobbs NT, Galbraith H, Ojima DS Braun CE 2002. Relationships between climate and population dynamics pf white-tailed ptarmigan *Lagopus leucurus* in Rocky Mountains National Park, Colorado, USA. Climate research 23: 81-87.

Watson A 1965. A population study of Ptarmigan (*Lagopus mutus*) in Scotland. Journal of Animal ecology 34: 135-172.

Watson A, Moss R 2004. Impacts of ski-development on ptarmigan (*Lagopus mutus*) at Cairngorm, Scotland. Biological Conservation 116: 267-275.

Watson A, Moss R, Rae S 1998. Population dynamics of Scottish Rock Ptarmigan cycles. Ecology 79: 1174-1192.

Watson A, Moss R, Rothery P 2000. Weather and synchrony in 10-year population cycles of Rock Ptarmigan and Red grouse in Scotland. Ecology 81: 2126-2136.

Watson A, Rae R 1993. Ptarmigan. In: Gibbons DW, Reid JB, Chapman RA (eds). The New Atlas of Breeding Birds in Britain and Ireland: 1988-91. T and AD Poyser, London pp. 128-129.

Winkler DW, Dunn PO, McCulloch CE 2002. Predicting the effects of climate change on avian life-history traits. Proceedings of the Natuional Acadamy of Sciences, USA 99: 13595-13599.