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ABSTRACT

A recent Game and Wildlife Conservation Trust (GWCT) report (Hesford & MacLeod 2022) suggested densities of mountain hares (*Lepus timidus*) may reach 52 - 125/km^2 in parts of the Peak District, England. These are notably higher than previous and current estimates of 5 - 33 hares/km^2 (Matthews et al. 2018; Bedson et al. 2022). We review Hesford & MacLeod (2022) who based their methods on those used in a review of mountain hare survey methods in Scotland (Newey et al. 2018). This review demonstrated a weak, non-significant relationship between hare encounter rates using spotlight surveys of walked transects at night and estimated densities derived from spatial capture-recapture (SCR) methods on managed heather moorland (p=0.08). Newey et al. (2018) recommended that this relationship should not be used to estimate hare densities. We reproduce the Newey et al. (2018) linear model and confirm its poor predictive ability and show that removal of one outlier reduces an already marginal relationship to a near flat line (p=0.80). Hesford & MacLeod (2022), nonetheless, used this relationship to estimate hare densities along non-randomly placed transects. We conclude that reportedly high mountain hare densities estimated by Hesford & MacLeod (2022) are biased and based on a model with little predictive power; more recent Distance Sampling estimates are from 37 - 96% lower (Bedson et al. 2022). It is important that wildlife monitoring methods robustly account for survey bias and error, detection probability and variation between habitats, especially if results are to inform potential population management interventions.

INTRODUCTION

The mountain hare (*Lepus timidus*) is a Northern hemisphere circumpolar mammal occupying a range of habitats and elevations (Angerbjorn & Flux 1995). Some of the highest densities in Europe occur in northeast Scotland, where shooting estates rotationally burn heather (*Calluna* and *Erica* spp.) providing ideal habitat for red grouse (*Lagopus lagopus*) with collateral benefit to mountain hares which benefit from regenerating young heather shoots. Over recent decades, controversy has surrounded the practice of hare culling on some shooting estates to mitigate perceived transmission of tick-borne disease from hares to red grouse (Mathews et al. 2018). Only 1% of the mountain hare population present in the 1950s remains on some grouse shooting estates in Scotland (Watson & Wilson 2018). Mountain hare conservation status is presently "unfavourable-inadequate" and “deteriorating” (JNCC 2019).

There have been few estimates of mountain hare density in the Peak District, which supports England’s only population reintroduced from Scotland. In 2022, the Game and Wildlife Conservation Trust (GWCT) published a report which concluded that "data on the number of

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Key words: Density estimation; encounter rate; Game and Wildlife Conservation Trust; GWCT; lamping survey; *Lepus timidus*; linear model; spatial capture-recapture.

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hares recorded by gamekeepers in the Peak District National Park may be equivalent to a population density of between 52 - 125 mountain hares /km^2... in the environs of those managed moorland count sites" (Hesford & MacLeod 2022). This estimate is notably high relative to a previous estimate of *ca*. 10 hares/km^2 (Matthews et al. 2018) and current mean estimates of 5 - 33 hares/km^2 throughout the Peak District with highest densities on ecologically restored peat bog with 25 - 42 hares/km^2 and notably lower densities on land managed for grouse shooting where grouse moorland bog had 9 - 16 hares/km^2 and grouse moorland heath had 6 - 17 hares/km^2 (Bedson et al. 2022).

The results in Hesford & MacLeod (2022) were based on night-time lamping surveys. This method was trialled by Newey et al. (2018) among tests of methods for estimating mountain hare density and has become one of several approaches now used in Scotland. Mountain hares are primarily nocturnal and counts at night using spotlights or thermal imaging are expected to detect more hares than daytime surveys (Newey et al. 2018). For the GWCT Peak District survey (Hesford & MacLeod 2022), gamekeepers were trained in the lamping survey methodology used at 12 survey sites identified according to guidelines in Newey et al (2018). Their survey transects totalled 108 km. The number of hares seen was divided by transect length to generate encounter rates of hares/km walked. Hesford & MacLeod (2022) derived absolute abundance estimates by predicting spatial capture-recapture density estimates from encounter rates using the weak, non-significant linear relationship reported by Newey et al. (2018). Hesford & MacLeod (2022) state: "as outlined in Newey et al. 2018, simple counts of the number of hares seen were divided by the length of the transects covered to give an encounter rate. This can be used to provide an index of animal abundance. Report 1022 (Newey et al. 2018) calibrated encounter rates against Spatial Capture Recapture (SCR) methods with a view to interpreting density estimates without need for furthermore complex *Distance* Analysis." However, Newey et al. (2018) state in bold print: "**The relationship between SCR density and indices is not currently suitable to be used to infer exact density with sufficient confidence.**" In a subsequent monitoring report, Newey et al. (2020) also state: "Night-time lamping surveys as described by Newey et al. (2018) do not generate absolute abundance or density estimates, only indices of population density. Night-time lamping combined with the survey design outlined here are intended to provide indices of mountain hare density that can be used to assess long-term trends in mountain hare numbers... methods assessed and developed by Newey et al. (2018) are not applicable to areas of non-moorland, and arguably non-managed moorland... [and are] unlikely to be effective where visibility is obstructed by tall shrubs, trees, or terrain, and where population density is low."

The conservation charities People's Trust for Endangered Species (PTES), Hare Preservation Trust (HPT) and the Derbyshire Wildlife Trust (DWT) invited us to assess the purported linear model used by Hesford &MacLeod (2022) to evaluate their claims about hare populations and grouse moorland management in the Peak District.

METHODS

We reviewed the methods and results of Hesford & Macleod (2022). They recorded night lamping count data of hares / km walked (mean=7.8, range: 3.5 - 13.6) and used the inferred linear relationship of SCR density estimates (Newey et al. 2018) to predict densities of 52 - 125 hares/km^2. To consider this linear relationship, Newey et al. (2018) themselves reported data from eight study sites. We extracted these data from Newey et al. (2018: tables 6 & 8). We replicated the linear relationship for the eight sites using the function [lm] in the package "stats" for R (R Core Team 2021). We tested for outliers using functions in the "stats" package. We also tested for outliers using function [check outliers] in the package "performance" in R which determines a composite outlier score via the joint application of multiple detection algorithms (Ludecke et al. 2021). Site 5 was identified as an outlier strongly leveraging the model. We refitted the linear regression without Site 5 and reported the results of the analysis both with and without Site 5.

RESULTS

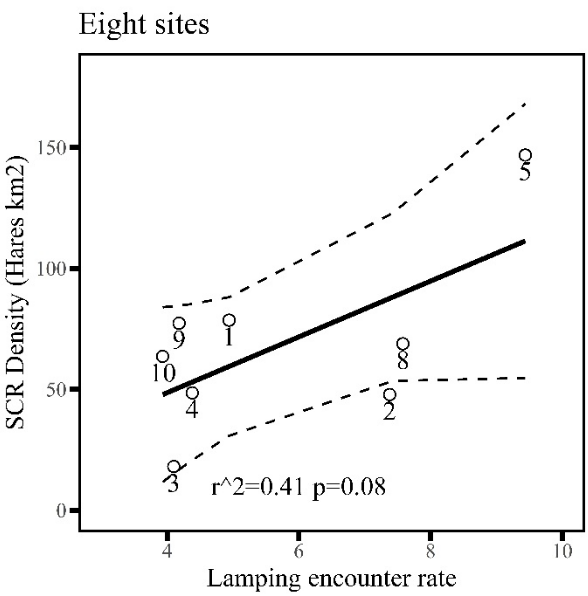
With the inclusion of the data from Site 5, estimated hare density from Spatial Capture Recapture (SCR) methods was not significantly (p<0.05) related to spotlight encounter rates (Intercept = 2.51, $F_{df=1,6}$= 4.34, β = 11.53 ± 5.53, p=0.082, r^2=0.41; Fig. 1a). This weak relationship suggested a trend between density estimates ranging from *ca*. 50 - 120 hares/km^2 and encounter rates ranging from *ca*. 4-10 hares/km with wide confidence intervals (Fig. 1a). Tests for outliers in the linear model reported Site 5 had a mean standardised residual = 1.76, studentised residual = 2.33, Cook's distance = 2.0 and leverage = 0.57, all exceeding thresholds for influence (Field et al. 2012). Thus, Site 5 was deemed an outlier (Table 1, Fig. 1b). Given the small sample size (n=8) an outlier can have a large effect (Field et al. 2012). After excluding Site 5 as an outlier, the non-significant relationship between hare density and spotlight encounter rate became even weaker with r^2 declining from 0.41 to a negligible 0.01 (Intercept = 49.51, $F_{df=1,5}$= 1.54, β = 1.54 ± 5.99, p=0.807, r^2=0.01; Fig. 1c). With Site 5 excluded, this relationship suggested a near constant density of *ca*. 50 hares/km^2 regardless of the encounter rate, driven entirely by the value of the intercept, and no relationship between the dependent variable (hare density) and the predictor variable (encounter rate). The predictive value of the model was almost zero.

Table 1 Mountain hare density estimates obtained from Spatial Capture Recapture (SCR) studies and night spotlight encounter rates at eight sites in Scotland as reported in Newey et al. (2018). Test results for outliers based on linear regression obtained using "stats" package in R (R Core Team 2021).

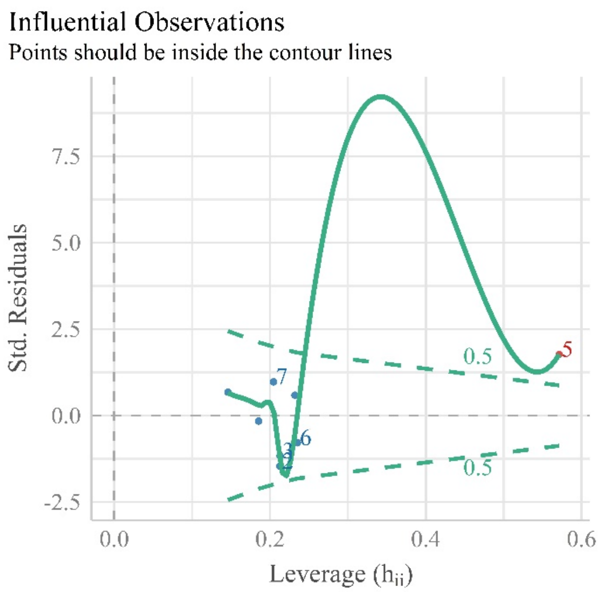
Study Data (Newey et al. 2018)			Test results for outliers			
Site	SCR density (hares/km^{-2})	Spotlight encounter rate (hares/km)	Standardised residuals	Studentised residuals	Cook's distance	Leverage
1	78.62	4.94	0.676	0.642	0.039	0.146
2	47.87	7.38	-1.462	-1.664	0.289	0.213
3	18.08	4.10	-1.167	-1.211	0.184	0.213
4	48.56	4.38	-0.162	-0.148	0.003	0.185
5	146.87	9.44	1.769	2.334	2.084	0.571
8	68.85	7.58	-0.787	-0.758	0.095	0.235
9	77.33	4.18	0.974	0.968	0.122	0.205
10	63.64	3.93	0.588	0.553	0.052	0.232

Fig. 1 a) The linear relationship between hare encounter rate and density reported in Newey et al. (2018) with n=8 (see Table 1). b) Plot of potential outliers, assessed with "performance" package in R (the solid line should be within the dotted lines. Site 5 is an outlier). c) Regression excluding Site 5 with n=7.

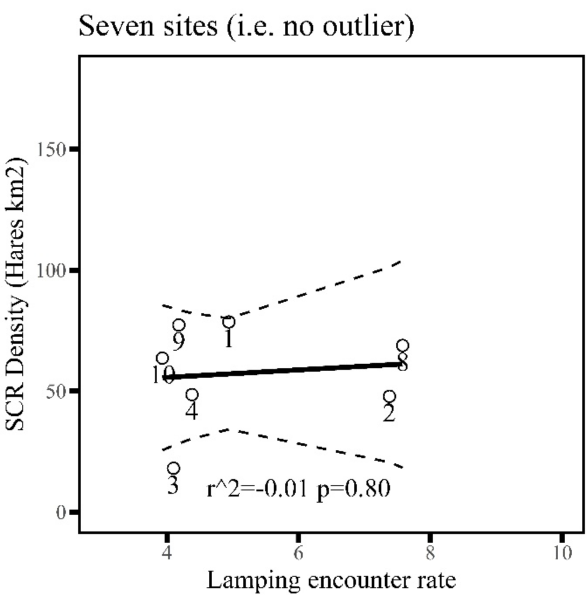
a)



b)



c)



DISCUSSION

We reproduced the model from Newey et al. (2018), the basis of the mountain hare density estimates for the Peak District from Hesford & MacLeod (2022). Whilst there was a positive trend between encounter rates and Spatial Capture Recapture (SCR) density estimates using eight sites from Newey et al. (2018), removal of Site 5 as a clearly identified outlier rendered the relationship into a near flat line with near zero predictive ability. We support the assessment by Newey et al. (2018) that the relationship, whilst worthy of original investigation and reporting, should not be used to estimate absolute mountain hare abundance. In so doing, the Game and Wildlife Conservation Trust's (GWCT) population estimates of 52 - 125 hares/km (Hesford & MacLeod 2022) for the Peak District are likely biased and in error. More recent estimates using Distance Sampling of randomly placed daylight transects suggest densities of 5 – 33 hares/km^2 in the Peak District (Bedson et al. 2022); much lower than those reported by (Hesford & MacLeod 2022). Comparing survey methods (daylight visual surveys, night-time thermal imaging and camera traps) for estimating mountain hare density in the Peak District suggests daylight surveys (where animals exhibiting their winter white pelage are conspicuous against a brown landscape) with Distance Sampling, is as effective a method as those used at night (Bedson et al. 2021). Count data for animal population estimation are vulnerable to survey bias (e.g. detection probability) and error (e.g. extrapolation from non-randomly placed transects) affecting both accuracy and precision (Milner-Gulland & Rowcliffe 2007). Particular caution is warranted if population estimates are to inform population management interventions or landscape management practices.

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