

Detecting the elusive Scottish wildcat *Felis silvestris silvestris* using camera trapping

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Abstract Population monitoring is important for conservation management but difficult to achieve for rare, cryptic species. Reliable information about the Critically Endangered Scottish wildcat *Felis silvestris silvestris* is lacking because of difficulties in morphological and genetic identification, resulting from extensive hybridization with feral domestic cats *Felis catus*. We carried out camera-trap surveys in the Cairngorms National Park, UK, to examine the feasibility of camera trapping, combined with a pelage identification method, to monitor Scottish wildcats. Camera trapping detected individually identifiable wildcats. Of 13 individual wild-living cats, four scored as wildcats based on pelage characters and the rest were wildcat × domestic cat hybrids. Spatially explicit capture–recapture density estimation methods generated a density of wild-living cats (wildcats and hybrids) of $68.17 \pm SE 9.47$ per 100 km². The impact of reducing trapping-grid size, camera-trap numbers and survey length on density estimates was investigated using spatially explicit capture–recapture models. Our findings indicate camera trapping is more effective for monitoring wildcats than other methods currently used and capture success could be increased by using bait, placing camera stations ≤ 1.5 km apart, increasing the number of camera stations, and surveying for 60–70 days. This study shows that camera trapping is effective for confirming the presence of the wildcat in potential target areas for conservation management.

Keywords Camera trapping, *Felis silvestris silvestris*, monitoring, Scotland, Scottish wildcat, spatially explicit capture–recapture

Introduction

Monitoring wildlife populations is important for conservation management but is often difficult to achieve effectively, particularly for rare and cryptic species

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(e.g. Gese, 2001). Monitoring carnivores is challenging because they are often threatened and exist at low densities and in fragmented populations (Gese, 2001). Carnivores suffer from many, mostly anthropogenic, threats, including direct persecution, habitat loss and competition with humans for prey. Lack of information on the current status of many carnivores may be hindering effective conservation action (Gittleman et al., 2001).

The Scottish wildcat is a subpopulation of the European wildcat *Felis silvestris silvestris* and is Britain's only surviving native felid (Macdonald et al., 2004). Although widely distributed (Africa, Asia, Europe) and categorized as Least Concern (Driscoll & Nowell, 2009), this species is subject to several threats globally, resulting in local extinctions and population fragmentation, especially in Europe (Nowell & Jackson, 1996). Recent estimates, from the proportion of cats with wildcat pelage from a 1990s sample, indicate the Scottish population may be Critically Endangered, with < 400 genetically pure individuals remaining (Kitchener et al., 2005; Driscoll & Nowell, 2009). Once widespread across Britain, habitat loss (Nowell & Jackson, 1996), persecution (Langley & Yalden, 1977; Tapper, 1992; Kitchener, 1995) and hybridization with feral domestic cats *Felis catus* (McOrist et al., 1991; Hubbard et al., 1992; Beaumont et al., 2001; Daniels et al., 2001) have now restricted wildcats to northern Scotland (Balharry & Daniels, 1998; Daniels et al., 1998; Davies & Gray, 2010).

Hybridization is currently considered the greatest threat to this species (Nowell & Jackson, 1996; Macdonald et al., 2004, 2010). Documented since the 18th century (Berwick, 1920), hybridization has potentially occurred since domestic cats arrived in Britain 2,000–3,000 years ago (Clutton-Brock, 1987; Serpell, 2000). Extensive introgressive hybridization has led to difficulties in distinguishing Scottish wildcats from some wildcat × feral cat hybrids, complicating enforcement of protective legislation, hindering monitoring and making management potentially ineffective (Macdonald et al., 2004, 2010). Kitchener et al. (2005) identified seven principal and eight subsidiary pelage characters to distinguish Scottish wildcats from hybrids and feral domestic cats, providing an objective method for identifying wild-living cats in the field. Monitoring methods for wildcats to date include road traffic accident surveys, live trapping, interviews and questionnaires, or combinations of these (Easterbee et al., 1991; Balharry & Daniels, 1998; Daniels et al., 1998; Davies & Gray, 2010). Although these methods generate useful data, each has limitations. For

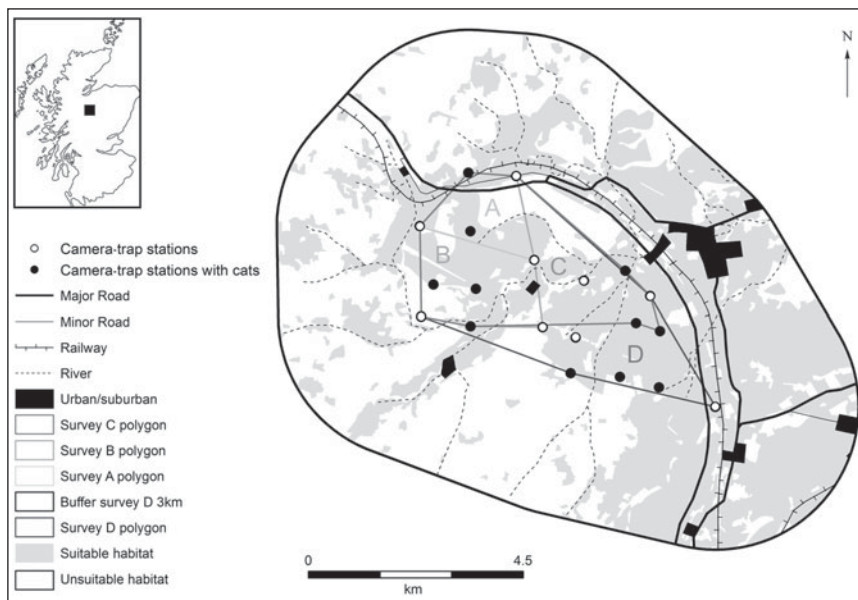


FIG. 1 The study site at the Seafield and Strathspey Estates, showing the locations of the camera-trap stations and their associated habitat: suitable (woodland, scrub and pasture/grassland) and unsuitable (arable, urban/suburban, heather moorland, bog and montane). The rectangle on the inset indicates the location of the main figure in north-east Scotland. A, B, C and D refer to the subsets of camera traps used in the spatially explicit capture–recapture analysis examining how a reduction in survey area affects density estimates.

example, road traffic accident surveys may be biased towards hybrids and feral cats, which scavenge more frequently on roads as a result of competition with larger wildcats (A. Kitchener, unpubl. data). Live trapping is time consuming, and requires experience and licensing under British law. Information from questionnaires and interviews depends on respondent experience and this method is liable to observer error (Davies & Gray, 2010). Also, except for the survey of Davies & Gray (2010), most data on Scottish wildcats were collected before the development of the current pelage identification method. Given the limitations and biases of existing methods, exploring other survey methodologies, such as camera trapping, is desirable.

Camera trapping can provide much useful data (e.g. Karanth & Nichols, 1998, 2002; Carbone et al., 2001), including population-density estimates for monitoring studies (Yoccoz et al., 2001; Martin et al., 2007). Presence and abundance of European wildcats have been determined from camera trapping, which has also allowed individual identification (Monterroso et al., 2005; Anile et al., 2009; Sarmiento et al., 2009). This study aimed to (1) determine the feasibility of camera trapping for surveying and monitoring Scottish wildcats, (2) compare the success of baited, scented and unbaited camera traps, and (3) develop a camera trapping protocol for future surveys. Population-density estimates under different models were generated using spatially explicit capture–recapture analysis.

Study area

The study was carried out on Seafield and Strathspey Estates in north-east Scotland (Fig. 1), partly within the Cairngorms National Park, of which 57.6 km² is designated a Site of

Special Scientific Interest. Comprising a mixture of heather moorland, Scots pine *Pinus sylvestris* plantations, birch woodland (*Betula* sp.) and rough grazing, the site supports diverse wildlife, including Scottish wildcats. Traditionally used for red grouse *Lagopus lagopus scotica* shooting and deer stalking, predator control was important for estate management. Although the estate is now primarily used for tourism and deer stalking, predator control continues, mainly to protect capercaillie *Tetrao urogallus* leks (Seafield & Strathspey Estates, 2001). The estate was selected because putative wildcats had been seen by gamekeepers and wild-living cats were present regularly (Estate manager, pers. comm., 2009).

Methods

Twenty camera trap stations were placed in a 4 × 5 grid. Based on the minimum home range of female Scottish wildcats (Corbett, 1979; Daniels et al., 2001), stations were located 0.8–1.5 km apart so that individuals with the smallest recorded home range had a probability of > 0 of encountering a station (Karanth & Nichols, 1998). Two Cuddleback Capture 3.0 (Cuddleback Digital, Green Bay, USA) camera traps were used per station. The first station was located where a cat with wildcat-type pelage had recently been trapped alive and released following standard estate predator control practices. The remaining 19 stations were arranged around this site. Stations were located where either wild-living cat signs (footprints, scats, dens, scrape marks) were present or where there were signs of pine martens *Martes martes* (which have similar habitat and prey requirements to the Scottish wildcat; Balharry, 1993; Birks et al., 2005) or rabbits *Oryctolagus cuniculus* (e.g. burrows, sightings, footprints, latrines). Camera traps were set across

obvious animal trails 2.1–10.8 m apart, facing each other (but slightly staggered, to avoid flashes interfering with photographs from opposite cameras), to ensure both sides of wildcats were photographed for individual identification. Some camera traps were angled or moved slightly to face baits or lures in surveys using these attractors. Camera traps were attached to suitable trees or fence posts 20–150 cm above ground level, to achieve the best angle for photographing pelage characteristics.

There were three successive camera trap surveys. Survey 1 during February–March 2010 (900 trap nights) did not use bait or lures. Survey 2 during March–April 2010 (560 trap nights) used pheasant/partridge bait, which was attached to trees or posts at heights of 60–80 cm to encourage cats to stretch up and expose the dorsal, neck and shoulder regions for pelage assessments. Survey 3 during April–May 2010 (500 trap nights) used valerian tincture as a scent lure. Following studies on European wildcats (e.g. Weber, 2008), lures comprised rough-surfaced wooden stakes (c. 60 cm length) in the ground between the camera traps. The upper 1/3 of the stake was coated with undiluted valerian tincture (AVogel/Holland & Barrett), extracted from dried roots of valerian *Valeriana officinalis*; it is believed to have a similar effect on cats as catnip *Nepeta cataria*.

Wild-living cats caught on camera were identified as wildcat, hybrid or domestic/feral cat based on seven key pelage characters, following Kitchener et al. (2005). Scoring was 1 (domestic), 2 (hybrid) and 3 (wildcat) for each pelage character. Any individual with a total score of ≥ 14 and no scores of 1 for any character was considered a wildcat unless other data conflicted with this (e.g. white paws, white patches on flanks or back; Kitchener et al., 2005). Hybrids could score 3, 2 or 1 for any of the characters and domestic cats had no scores of 3 for any characters.

Camera-trapping density estimates were compared to similar data collected during road traffic accident surveys and from sightings by estate staff. Roads and estate tracks surrounding and crossing the survey area were checked for cat carcasses every 10–14 days, while camera traps were checked. Estate staff were regularly questioned about cat sightings during and after surveys.

Data analysis

Data were managed using Camera Base (Tobler, 2010), displayed in ArcGIS v. 9.3 (ESRI, Redlands, USA) and analysed using SPSS v. 21.0 (SPSS, Chicago, USA). The Kolmogorov-Smirnov non-parametric test was used if residuals were not distributed normally. SPACECAP v. 1.0.6 (Singh et al., 2010), with R v. 2.15.2 (R Development Core Team, 2012), was used to generate estimates of population density.

Trap nights were calculated as the total number of 24-hour periods that all stations were active (Table 1). Capture

TABLE 1 No. of capture events, individuals caught and no. of trap stations at which the Scottish wildcat *Felis silvestris silvestris* was captured at the Seafield and Strathspey Estates in north-east Scotland (Fig. 1).

	Survey 1	Survey 2	Surveys 1 & 2 combined
No. of trap nights	900	560	1,460
No. of different individuals	6	8	13
No. of individual wildcats	2	2	4
No. of individual hybrids	4	6	9*
No. of different stations at which cats were captured	6	7	11
Total captures & recaptures	8	13	21
Total capture rate per 100 trap nights	0.9	2.3	1.4
No. of wildcat capture events	3	5	8
Wildcat capture rate per 100 trap nights	0.3	0.9	0.5
No. of hybrid capture events	5	8	13
Hybrid capture rate per 100 trap nights	0.6	1.4	0.9

*One hybrid was caught in both Survey 1 and Survey 2.

events were the capture of an individual at a trap station within a 24-hour period. If the same individual was re-photographed within the 24-hour period this was considered one capture event. If cats were not individually identifiable, or were difficult to identify, and re-captured within a short time period (an arbitrary 30-minute interval), we assumed these were the same individuals and recorded them as single capture events. Capture rates for wildcats, hybrids and feral cats were calculated as number of capture events per 100 trap nights.

SPACECAP is designed to estimate animal population densities using photographic data and closed capture–recapture models in a Bayesian Framework. SPACECAP takes into account capture locations of individuals, thus incorporating spatially explicit capture heterogeneity into analyses to achieve more precise and accurate estimates (Royle et al., 2009). This method has advantages over traditional mark–recapture methods (e.g. CAPTURE; Otis et al., 1978) because it avoids having to convert abundance estimates into population-density estimates using effective sampling area approaches, which may inaccurately represent distances moved by individuals, often resulting in violation of the closure assumption (Royle et al., 2009). SPACECAP also recognizes that individual trap encounter histories are the outcome of two processes: distribution of individuals and an encounter process that describes whether or not individuals are encountered by traps as a function of their location (Singh et al., 2010). The programme also deals with problems posed by individual heterogeneity

TABLE 2 The variation in the parameters generated by SPACECAP when the data were modelled over survey lengths of 10–80 days, with number of cats captured, the Bayesian P-value (which indicates the accuracy of each model: adequate models have P close to 0.5 and inaccurate models have P closer to 0 or 1), mean movement parameter (σ), mean encounter frequency (λ_0), mean number of individuals (n), and mean density of wild-living cats per 100 km².

	Survey length (days)							
	10	20	30	40	50	60	70	80
No. of cats captured	4	5	5	5	7	10	13	13
Bayesian P-value	0.5	0.6	0.5	0.6	0.5	0.4	0.3	0.5
Mean $\sigma \pm$ SD		0.38 \pm 0.16	0.34 \pm 0.12	0.39 \pm 0.16	0.53 \pm 0.30	0.37 \pm 0.13	0.34 \pm 0.078	
Mean $\lambda_0 \pm$ SD		0.05 \pm 0.03	0.06 \pm 0.03	0.03 \pm 0.01	0.02 \pm 0.02	0.022 \pm 0.011	0.03 \pm 0.011	
Mean $n \pm$ SD		53.63 \pm 24.44	49.49 \pm 23.56	52.66 \pm 24.12	65.26 \pm 23.84	79.06 \pm 20.10	61.52 \pm 8.54	
Mean density \pm SD (95% CI)		59.43 \pm 27.08 (14.40–109.70)	54.84 \pm 26.11 (14.40–107.48)	58.35 \pm 26.72 (15.51–109.70)	72.31 \pm 26.41 (28.81–118.56)	87.60 \pm 22.27 (47.65–121.88)	68.17 \pm 9.47 (49.86–79.78)	

in capture probabilities and offers non-asymptotic inferences, which are more appropriate for small samples of capture data typical of photo-capture studies (Singh et al., 2010).

In *SPACECAP* the surveyed area contains camera traps and an extended area around it called the 'space state'. The space state is defined in *ArcGIS* as a fine mesh of equally spaced points (here, 500 \times 500 m), representing all possible home-range centres of all animals in the survey area (Singh et al., 2010). It should be large enough to ensure that it contains all individuals potentially caught by the camera traps. In this case a 3 km buffer was added to a rectangle encompassing the outermost camera traps. Where these points fell on suitable habitat they scored 1, and for unsuitable habitat (water, urban/suburban areas, roads) they scored 0.

SPACECAP was initially run using the spatial capture–recapture model with no trap response and a bivariate normal model, for 50,000 iterations with a burn-in period of 1,000. The thinning rate = 1 (default value) and the data augmentation value = 100 under the basic model (c. 8 times the total number of individuals captured). The model was also run with the trap response present, which implements a trap-specific behavioural response under which the encounter probability (p_2) in that trap increases or decreases after initial capture at that trap (p_1). Spatially explicit capture–recapture models were run to examine how population-density estimates varied under different scenarios. The accuracy of the models was assessed using Bayesian P-values (adequate models with P close to 0.5, and inaccurate models with P closer to 0 or 1).

Post-hoc power analysis was carried out in *G*Power v. 3.1.7* (Faul et al., 2007) to examine whether camera trapping could detect changes in population density over an arbitrary four survey periods. Statistical power of 0.8 was considered sufficient. Power at increases and decreases in population density of 75, 50, 25 and 10% and the effect of decreasing the posterior standard deviation of means to 75, 50, 25 and 10% of original values were modelled to

determine their impacts on whether camera trapping could detect changes in population density.

Population-density estimates for different camera-trap array sizes were also modelled. The trapping grid was divided into four subsets of camera traps; A, B, C and D, running sequentially from the north to south of each survey site (Fig. 1). Each consecutive subset encompassed the cameras contained within the previous one plus an additional five camera-trap stations. The effective areas covered by each subset's space state (outer rectangle plus 3 km buffer) were A (68 km²), B (80.75 km²), C (104.5 km²) and D (138 km²). The percentage of home-range centres falling on unsuitable habitat was comparable: A (4.5%), B (3.3%), C (4.3%) and D (3.8%; $t = 0.629$, $P = 0.59$, $df = 3$). The percentage of suitable land cover (mixture of woodland, scrub and grassland) in each subset did not differ significantly: A (85.95%), B (80.58%), C (80.89%) and D (76.25%; $t = 3.719$, $P = 0.07$, $df = 3$). Coniferous woodland (recently felled coniferous woodland, young plantation, mature) comprised 45–60% of habitat in each subset. The effect of survey length on population-density estimates was also modelled, using sampling periods of 80, 70, 60, 50, 40, 30, 20 and 10 days (Table 2).

To examine whether camera-trap spacing was sufficient, a measure of home-range radius was calculated. Under the bivariate normal model for animal movement, the movement parameter σ from *SPACECAP* can be converted into an estimate of home-range radius. This estimate provides a useful check on the validity of camera-trap spacing by converting it into a measure of the diameter of the home range (e.g. Karanth & Nichols, 2002).

Results

Cameras were active for a total of 1,954 trap nights, and successfully detected wildcats in an area where they were thought to occur. No cats were captured using valerian lures,

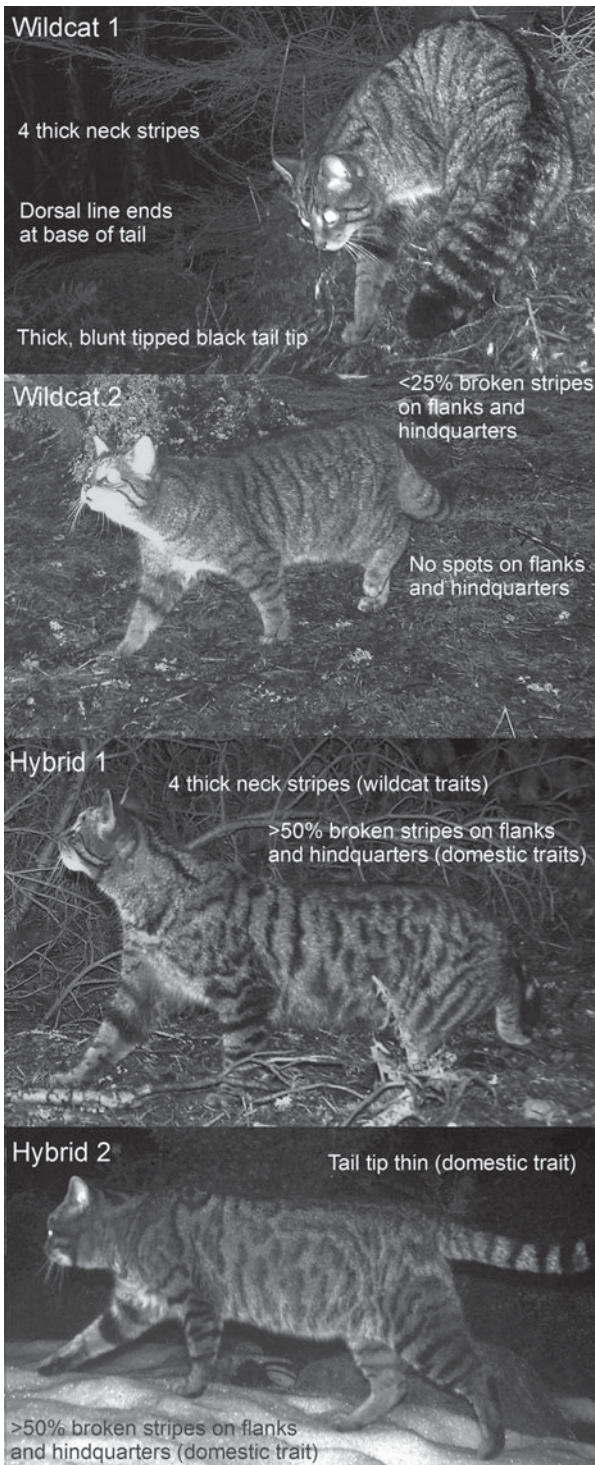


PLATE 1 Wild-living cats (two wildcats and two hybrids) photo-trapped, showing some of the pelage characteristics and pelage variation.

and therefore Survey 3 was excluded from the analysis. No photographs of cats were obtained during periods of heavy snowfall, despite other species being photographed. No cat carcasses were found along the roads surveyed during the study, and gamekeepers did not see any cats during the surveys.

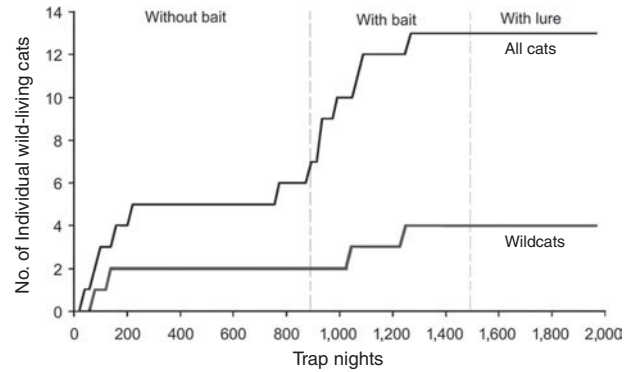


FIG. 2 Cumulative number of individual wild-living cats *Felis silvestris silvestris* photo-trapped across the three surveys.

Thirty photographs of wild-living cats were obtained and cats were detected at 11 of the 20 trap stations. A minimum of 13 different individual wild-living cats were captured at least once during Surveys 1 and 2 (Table 1). From pelage characters (Plate 1) four were classified as wildcats, nine as hybrids and none as feral cats. Although not all characters were visible in all photographs cats classified as hybrids (total pelage characteristic scores ≤ 14) had scores of 1, 2 or 3 for one or more of the seven pelage characteristics and had a mean total score of $9 \pm \text{SD } 4$. The four wildcats (total scores > 14) did not score 1 for any visible characters and had a mean total score of $16.5 \pm \text{SD } 3$.

The mean time to first photo-capture was $624 \pm \text{SD } 457$ trap nights for all wild-living cats and $629 \pm \text{SD } 605$ trap nights for wildcats only (Fig. 2). Capture rate per 100 trap nights increased with bait, but not significantly (Mann Whitney *U* test: $Z = 0.000$, $P = 1.0$; $Z = 0.408$, $P = 0.67$; $Z = 0.152$, $P = 0.91$ for all cats, wildcats and hybrids, respectively; Table 1). In most cases use of bait also increased the number of photographs of individuals, making identification easier: 1 photograph per capture event without bait compared to a mean of $1.75 \pm \text{SD } 2$ photographs per capture event with bait ($n = 21$; range 1–5). In only three capture events were photographs obtained from both of the camera pair.

The initial model using Surveys 1 and 2 combined over the complete survey length of 80 days generated an unrealistically high movement parameter (σ). Therefore no further results are shown for this survey length. At a survey length of 70 days population density was estimated to be $68.17 \pm \text{SD } 9.47$ individual wild-living cats per 100 km², with a 95% posterior interval of 49–79 individuals per 100 km² and an encounter probability (λ_0) of 0.026, $\sigma = 0.34$ km, giving a 95% home-range radius of 0.84 km and estimated home range of 2.44 km². The posterior mean population density per 0.25 km² (home range centre) is shown in Fig. 3. Population density was greatest adjacent to a large rabbit population and on the edges of grassland/ woodland habitat.

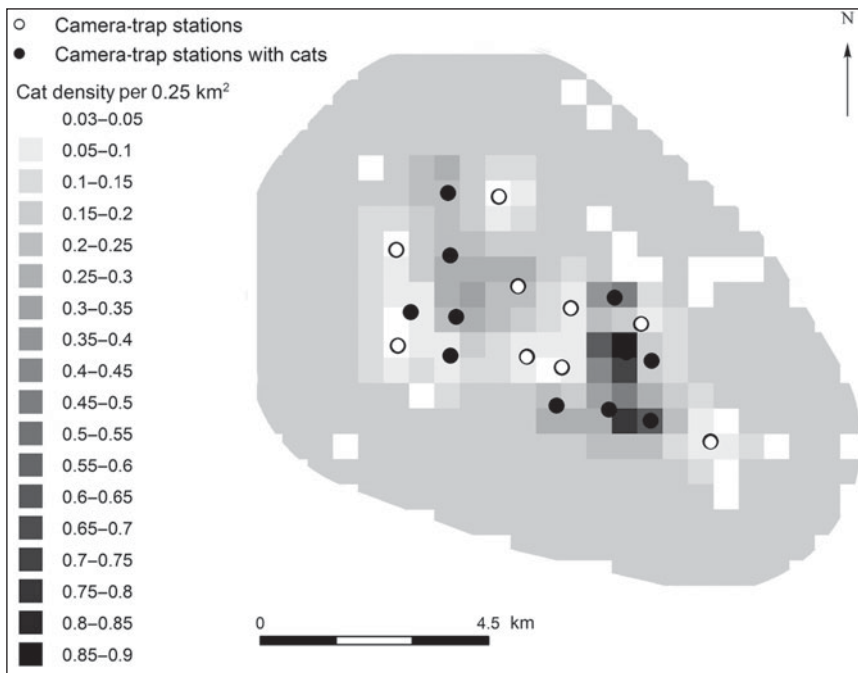


FIG. 3 Posterior mean cat density per 0.25 km² across the space state (see text for details). Home range centres are centred in each square. Circles indicate camera trap stations.

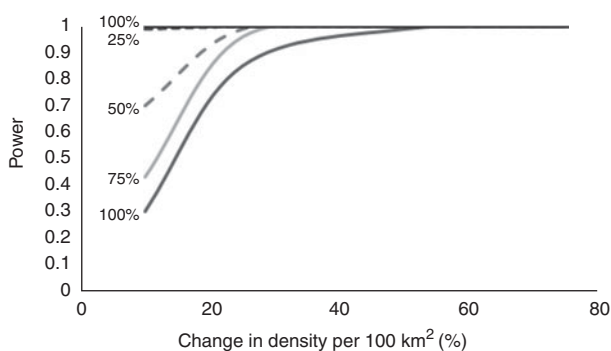


FIG. 4 Power analysis graph showing how the power of camera trapping to detect an increase or decrease in mean density of individual cats per 100 km² over four surveys increases as the SD decreases from 100 to 10% of the original value.

Power analysis (Fig. 4) shows this level of confidence of the mean density ($SD = \pm 9.47$) is sufficient to detect $\geq 25\%$ increase or decrease in mean population density with statistical power > 0.8 . Modelling a reduction in posterior standard deviation of mean population density to $\leq 25\%$ of the original value increases power sufficiently (≥ 0.8) to detect a 10% change in population size.

Running the trap response model increased the population density estimate to $98.7 \pm SD 19.22$ individuals per 100 km², with posterior intervals of 62–124 individuals per 100 km². The encounter probability also increased ($\lambda_0 = 0.01$), with a positive trap response observed ($p_1 = 0.01$, $p_2 = 0.33$), $\sigma = 0.45$ km, giving a 95% home-range radius of 1.1 km and home-range size of 3.8 km². Bayesian P-value = 0.3, indicating the trap response model is less accurate than the original model without a trap response.

Population density estimates were robust to changes in survey length, with no significant difference in population densities for surveys lengths of 20–70 days ($t = -0.866$, $P = 0.426$, $df = 6$) although 95% confidence intervals were significantly higher ($t = 11.523$, $P < 0.01$, $df = 6$) and lower ($t = -4.657$, $P = 0.06$, $df = 6$) for shorter survey lengths (Table 2). The encounter probability λ_0 was 0.02–0.05 and the movement parameter σ 0.3–0.5 km at different survey lengths. A 10-day survey length resulted in an unrealistically large estimate for σ , as did reducing the survey area, even by 25%.

Discussion

Camera trapping detected wildcats and wild-living cats when none were recorded in road traffic accident surveys or observed by estate staff. Furthermore, with camera trapping cats could be individually identified and classified from pelage characters, facilitating estimation of population densities.

There are few estimates of the population density of Scottish wildcats: 0.1 individuals per 10 km² from radio-tracking in west Scotland (Scott et al., 1993) and 3 per 10 km² using radioactive scat surveys in the east (Corbett, 1979). In both studies it is unknown whether the estimates included mixtures of wildcats and hybrids, although this is probable given that both occurred before Kitchener et al. (2005) proposed the use of pelage criteria. Population density in our study was estimated to be 6.8 individuals per 10 km². This estimate is based on all wild-living cats from Surveys 1 and 2 combined and therefore may be an underestimate

as the use of bait produced higher capture rates during survey 2. The use of bait across the whole survey period may therefore have resulted in an increased number of captures overall and a corresponding greater population density estimate.

Running the spatially explicit capture–recapture model with a trap response resulted in a positive trap-specific behavioural response, with a greater encounter frequency resulting in a larger population density estimate, indicating baited cameras were revisited by individuals. Also, although not significant, baiting increased capture rate and overall numbers of capture events. Occasionally, baiting resulted in multiple photographs of the same individual, leading to more accurate identification. In particular, placing bait so cats had to stretch up to reach them, with one camera facing the bait, enabled several pelage characteristics to be seen more clearly, including neck stripes, shoulder stripes and dorsal line. Without bait these characters were often difficult to see. Using two cameras per station thus aids identification of individuals, facilitating more accurate estimates of population density (Jackson et al., 2005).

Valerian lures did not appear to attract any cats, despite their successful use in some studies of European wildcats (Hintermann & Weber, 2008; Weber, 2008), although not in all (Anile et al., 2009). Hintermann & Weber (2008) suggested using hair-lure surveys during November–April for optimum results. Outside this period, valerian did not seem to attract cats. Survey 3 occurred during April–May, which may thus not have been optimal for using valerian lures. Studies have shown that a felid's response to catnip is genetically determined (Bradshaw, 1992); if a response to valerian is also genetic, all individuals in the study area, or Scottish wildcats (and possibly hybrids) in general, may be unable to detect it. However, even if valerian failed to attract cats some would be expected at camera traps by chance (as cats were photo-trapped in Survey 1 without lures). Lack of detection of cats in Survey 3 could be because (1) Survey 3 occurred when wildcats were giving birth, and thus female cats recorded in the previous two surveys may have had more restricted activity and ranges, whilst kittens were young, (2) male cats may have changed their ranges (Daniels, 1997) following changes in resource availability, (3) valerian may have deterred cats in the area. Further research could identify an effective scent lure.

Population density estimates were generally robust to reduced survey lengths, except for short (10 days) and long (80 days) periods, which both produced unrealistically high movement parameter estimates. A 10-day survey may be unsuitable because of the resulting small sample size and an 80-day survey because populations may not be closed over a longer period. Generally, upper and lower 95% confidence intervals were significantly greater when < 13 individuals were captured. Although cats were photo-captured after only 40 trap nights (within 2 nights of all stations being

active), the effort required to detect sufficient individuals for reliable population estimates using *SPACECAP* (10–13; A. Golpanswany, pers. comm., 2012) was considerably greater, with at least 990 trap nights required for the minimum of 10 individuals. Generally, spatially explicit capture–recapture methods need ≥ 20 recaptures for precise estimates of population density (Efford et al., 2009), which was only achieved by combining Surveys 1 and 2. The overall capture rate of wildcats per 100 trap nights (0.5) is similar to that of European wildcats in Portugal (0.51; Sarmiento et al., 2009).

Reducing survey area size by even 25% generated unrealistically large values for the movement parameter. This suggests reducing survey area and/or using < 20 camera stations for wildcats may not produce accurate population density estimates using spatially explicit capture–recapture. For monitoring, detecting changes in population trends is achievable if population density estimates are sufficiently accurate. Although both posterior standard deviations and posterior 95% confidence intervals decreased with increased survey lengths, even the population estimate from combining Surveys 1 and 2 still had a large confidence interval (49–79) and posterior standard deviation (9.47), which will not detect with confidence changes of $\leq 10\%$ in population density unless the posterior standard deviation is reduced. Further surveys should therefore attempt to reduce the standard deviation and confidence interval to maximize monitoring success. To estimate population density most effectively, camera-trap surveys using a minimum of 20 stations should operate for 60–70 days.

The estimated 95% home range radius was 0.84 km², giving a home range of c. 2.44 km². Under the trap response, the estimate of home range was c. 3.8 km². Both estimates were higher than expected based on previous studies (e.g. Corbett, 1979; Daniels et al., 2001) indicating that, in this study area at least, wildcat home ranges could be greater than expected. To take these larger home ranges into account, camera traps should be placed slightly further apart (c. 1.5 km), or more camera traps used, to increase the survey area and increase the number of individuals likely to be detected during the survey period, thereby improving density estimates.

Future studies using this method for wildcats should aim to increase capture probabilities, to improve robustness of population density estimates. Capture probabilities can be improved by using bait, increasing the number of camera traps to cover larger survey areas, using two cameras at each station to increase probability of photographing wildcats, and placing cameras ≤ 1.5 km apart to maximize the capture probability of individuals. Increasing survey length is not recommended, because population closure cannot be ensured (Silver, 2004). Also, different camera trap models have different capabilities, resulting in different detection abilities. Therefore, using higher specification camera traps

(e.g. faster trigger speeds, greater detection distances, improved battery life) may increase capture probabilities. It is noteworthy that we did not photo-trap cats when snow was > 100 mm deep, even though other species were captured. Studies have shown that locomotion through deep snow is often difficult for European wildcats (Mermod & Liberek, 2002), influencing what habitat they use during periods of heavy snowfall, and Scottish wildcats are probably affected similarly. Camera trapping wildcats in heavy snow will not therefore yield reliable results.

To summarize, our study demonstrates that camera trapping is effective for detecting Scottish wildcats and could be used for other wildcat populations, particularly where hybridization is less extensive and differences in pelage patterns between wildcats and domestic cats are more pronounced (Ragni & Possenti, 1996). Camera trapping may prove particularly useful for identifying areas where wildcats, hybrids and domestic/feral cats co-exist, facilitating effective targeted management of wildcat populations. However, long-term monitoring requires increased capture success to detect changes in population trends with confidence.

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