

**Comparing non-invasive surveying techniques for elusive, nocturnal mammals: a case study of the West European hedgehog (*Erinaceus europaeus*)**

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1 **Comparing non-invasive surveying techniques for elusive, nocturnal**  
2 **mammals: a case study of the West European hedgehog (*Erinaceus europaeus*)**  
3  
4

5 **Lucy E. Bearman-Brown<sup>1</sup>, Louise E. Wilson<sup>2</sup>, Luke C. Evans<sup>3</sup> and Philip J. Baker<sup>3</sup>**  
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8 <sup>1</sup> Hartpury University, Gloucestershire, GL19 3BE, UK; lucy.bearman-brown@hartpury.ac.uk  
9

10 <sup>2</sup> Conservation K9 Consultancy, Wrexham, UK; louise@conservationk9consultancy.com  
11

12 <sup>3</sup> School of Biological Sciences, University of Reading, Reading, RG6 6AH, UK;  
13 p.j.baker@reading.ac.uk, L.C.Evans@pgr.reading.ac.uk  
14

15 \* Correspondence: lucy.bearman-brown@hartpury.ac.uk; Tel.: +44(0)1452 702465 (UK)  
16

17 **Abstract**

18 Monitoring changes in populations is fundamental for effective management. The West-  
19 European hedgehog (*Erinaceus europeaus*) is of conservation concern in the UK because of  
20 recent substantial declines. Surveying hedgehogs is, however, problematic because of their  
21 nocturnal, cryptic behaviour. We compared the effectiveness of three methods (infra-red thermal  
22 camera, specialist search dog, spotlight) for detecting hedgehogs in three different habitats.  
23 Significantly more hedgehogs were detected, and at greater distance, using the camera and dog  
24 than the spotlight in amenity grassland and pasture; no hedgehogs were detected in woodland.  
25 Increasing ground cover reduced detection distances, with most detections (59.6%) associated  
26 with bare soil or mown grass; the dog was the only method that detected hedgehogs in vegetation  
27 taller than the target species' height. The additional value of surveying with a detection dog is  
28 most likely to be realised in areas where badgers (*Meles meles*), an intra-guild predator, are  
29 and/or where sufficient ground cover is present; both would allow hedgehogs to forage further  
30 from refuge habitats such as hedgerows. Further consideration of the effectiveness of detection  
31 dogs for finding hedgehogs in nests, as well as developing techniques for monitoring this species  
32 in woodland, is warranted.  
33

34 **Key words:** Conservation dog; cryptic species, detection dog; infra-red camera; mammal  
35 monitoring; thermal camera  
36

37 **INTRODUCTION**

38 Wildlife management and conservation interventions are becoming increasingly important  
39 globally as extensive anthropogenic changes are made to the environment (Vitousek et al. 1997,  
40 Millennium Ecosystem Assessment (MEA) 2005, Sutherland 2013, Veach et al. 2017) and  
41 biodiversity is threatened (Butchart et al. 2010, Wagler 2013, Tittensor et al. 2014, Ceballos &  
42 Ehrlich 2018). The effective development and implementation of conservation and/or  
43 management strategies is, in part, dependent upon quantifying the distribution and abundance of  
44 populations and how they are changing spatially and/or temporally (Warren et al. 2000, Wilson  
45 & Delahay 2001, Grenyer et al. 2006, Schipper et al. 2008).

46  
47 Methods for estimating temporal and spatial variation in population size and distribution can be  
48 broadly split into direct versus indirect methods (Langbein et al. 1999, Wilson & Delahay 2001,  
49 Day et al. 2016). Direct methods are associated with counts of live animals themselves, whereas  
50 indirect counts are based on counts of “field signs” such as refugia (Waters et al. 2011, Judge et  
51 al. 2014), tracks (Alibhai et al. 2017, Williams et al. 2018b), scats (Churchfield et al. 2000, Day  
52 et al. 2016, Cortázar-Chinarro et al. 2019, Mwebi et al. 2019) and feeding signs (Redpath et al.  
53 2001, Meek et al. 2012), or e.g. counts of animals killed on roads (Baker et al. 2004, Seiler et al.  
54 2004, Bright et al. 2015) or by hunters (Aebischer et al. 2011, Aebischer 2019). These indirect  
55 approaches have tended to be used where direct methods are not possible (e.g. the focal species  
56 occupies a habitat where direct observation is not possible), or because they are cheaper (Alibhai  
57 et al. 2017). The use of indirect measures is, however, predicated on the assumption that they  
58 reflect population size per se or some relative measure of population size, but it is known that  
59 they can be associated with a range of confounding factors that make estimates uncertain and  
60 interpretation of data difficult (McDonald & Harris 1999, Bright et al. 2015). Converting counts  
61 of relative abundance to measures of absolute abundance is particularly problematic.

62  
63 In addition to counting animals for population monitoring, capturing individuals may also be an  
64 important component of scientific studies. For example, radio- and satellite-tracking have  
65 revolutionised our understanding of animal movement patterns (Craighead & Craighead 1972,  
66 Deutsch et al. 1998, Marzluff et al. 2001,) and the attachment of bio-loggers and animal-mounted  
67 video cameras enable scientists to obtain data that would otherwise be impossible to get  
68 (Yasuhiko 2004, Ropert-Coudert & Wilson 2005, Loyd et al. 2013, Volpov et al. 2015; Wilmers  
69 et al. 2015). Handling animals also enables morphological, physiological, isotopic, reproductive  
70 and parasitological data to be collected (Wassenaar & Hobson 2000, Elledge et al. 2008, Telfer  
71 et al. 2010, Wikenros et al. 2016), as well as being crucial to the application of techniques such  
72 as the use of doubly labelled water for estimating energy consumption (Lifson et al. 1955, Lifson  
73 & McClintock 1966, Nagy 2001, Pettett et al. 2017a). Typically, animals are captured using  
74 devices such as nets, traps and snares (Flowerdew et al. 2004, Hill & Greenaway 2005, Tyrrell et  
75 al. 2009): this is often expensive, time-consuming, and associated with significant animal  
76 welfare and legal issues (Putman 1995, Lane & McDonald 2010, Brown et al. 2013).  
77 Consequently, the development of novel methods for locating animals that improve welfare  
78 standards and enable the collection of robust data is important for designing successful  
79 management plans.

80  
81 The West-European hedgehog (*Erinaceus europeus*, hereafter ‘hedgehog’) is a species of  
82 increasing conservation concern in Britain (Mathews et al. 2018), and elsewhere (Haigh 2011,

83 Van de Poel et al. 2015), because of a substantial decline in recent decades (Holsbeek et al.  
84 1999, Huijser & Bergers 2000, Van de Poel et al. 2015, Hof & Bright 2016, Mathews et al. 2018,  
85 Müller 2018 Pettett et al. 2018, Williams et al. 2018a, Wilson & Wembridge 2018). This has  
86 been widely attributed to a range of factors, including: a substantial reduction in the extent and  
87 quality of hedgerows (Carey et al. 2008, Moorhouse et al. 2014); increased predation and  
88 competition pressure from badgers (*Meles meles*) (Young et al. 2006, Judge et al. 2014); direct or  
89 indirect impact of roads (Huijser & Bergers 2000, Rondinini & Doncaster 2002) and the  
90 extensive use of pesticides (Battersby 2005), which have resulted in direct poisoning (Dowding  
91 et al. 2010) or a decline in the abundance and variety of invertebrate prey (Geiger et al. 2010,  
92 Hof & Bright 2010). The magnitude of this decline is, however, equivocal because of problems  
93 associated with quantifying hedgehog density.

94  
95 To date, researchers and NGOs have generally relied upon spotlighting, footprint-tunnels,  
96 trapping and/or counts of dead animals on roads to either (i) capture hedgehogs (mainly for  
97 marking and to attach radio-tracking or GPS-tracking devices) or (ii) estimate relative abundance  
98 or hedgehog presence-absence (Young et al. 2006, Poulton & Reeve 2010, Trewby et al. 2014,  
99 Pettett et al. 2017a, b, Williams et al. 2018 a, b). However, these approaches have often varied in  
100 their efficacy and are associated with factors that may affect their robustness or usefulness. In  
101 addition, most studies have relied on a single technique, preventing comparison of the efficacies  
102 of different techniques. For example, footprint-tunnels have been used successfully in both urban  
103 and rural areas in the UK (Yarnell et al. 2014, Williams et al. 2018a, b) but have had limited  
104 success in some other studies (Haigh et al. 2012, Gurnell & Bowen 2016). Similarly, spotlight  
105 surveys were the most effective method for locating hedgehogs in Regent's Park, London  
106 (Gurnell & Bowen 2016), whereas Poulton and Reeve (2010) dismissed this method for  
107 surveying hedgehogs, as when applied, they only detected hedgehogs in 14 of 97 visits across 30  
108 sites in Britain. The latter could, however, have simply reflected low patterns of occupancy at the  
109 sites surveyed rather than a limitation of spotlighting per se; this is supported by spotlights and  
110 footprint-tunnels providing consistent results across 17 of 19 (89%), 15 of 18 (83%) and 6 of 17  
111 (94%) sites surveyed in spring, summer and autumn, respectively, by Yarnell et al. (2014:  
112 authors' unpublished data). Finally, footprint-tunnels do not provide information about hedgehog  
113 density, merely recording presence/absence (Yarnell et al. 2014, Williams et al. 2018a), whilst  
114 the number of hedgehogs killed on roads may be affected by factors other than just animal  
115 density such as road size (Rondinini & Doncaster 2002). Consequently, there is a need to  
116 consider novel survey methods that overcome the limitations associated with these current  
117 methods, but also to compare their relative efficacy by conducting standardised surveys at the  
118 same site(s).

119  
120 Two methods that could potentially be used to survey hedgehogs more efficiently are infra-red  
121 thermal cameras and detection dogs. Infra-red thermal (IRT) cameras display an image of the  
122 scene using emitted heat (infra-red radiation) rather than visible light (Cilulko et al. 2013). In the  
123 context of surveying for animals, this approach is particularly useful at night when the contrast  
124 between the heat of the animal and the surrounding vegetation is large (Sabol & Hudson 1995,  
125 Mayle et al. 1999, Butler et al. 2006, Bowen et al. 2019). This overcomes issues associated with  
126 using visible light, such as from a spotlight or torch, to detect species that are cryptically  
127 camouflaged and those, such as with hedgehogs, which "freeze" or curl up when feeling  
128 threatened (Reeve 1994, Nottingham et al. 2019). However, like spotlights, IRT cameras are not

129 as effective in dense vegetation, which blocks the heat signature (Ditchkoff et al. 2005); this is  
130 particularly problematic for small species where even short grass may obscure individuals  
131 (Boonstra et al. 1994, Karp 2020).

132  
133 Specially trained dogs have been used for conservation purposes since the 1890s when they were  
134 used to locate New Zealand kiwi (*Apreyx* spp.) and kakapo (*Strigops habroptilus*) (Helton 2009).  
135 Since these pioneering projects, dogs have been trained to detect the presence of a wide array of  
136 biological organisms and associated structures and ejecta, including: plants (Goodwin et al.  
137 2010); large mammal faeces (Vynne et al. 2011, de Oliveira et al. 2012, Arandjelovic et al.  
138 2015); reptiles (Stevenson et al. 2010, Nielsen et al. 2016); nests (Cablk & Heaton 2006,  
139 O'Connor et al. 2012); carcasses (Paula et al. 2011, Mathews et al. 2013); and owl pellets  
140 (Wasser et al. 2012). Dogs rely on detecting the focal animal/object by scent rather than sight  
141 and are able, therefore, to detect these even if they are not in direct line of sight e.g. in vegetation  
142 (Leigh & Dominick 2015, Karp 2020), at a greater distance than humans in some instances  
143 (Goodwin et al. 2010, de Oliveira et al. 2012). Furthermore, dogs trained to detect particular  
144 scents mean that they are better able to discriminate between objects/structures that challenge  
145 human observers. For example, dogs were 153% more accurate and 19 times faster at identifying  
146 koala (*Phascolarctos cinereus*) scat than experienced human surveyors (Cristescu et al. 2015).

147  
148 Both IRT cameras and dogs have previously been used to locate hedgehogs. For example, dogs  
149 were used in the search for hedgehogs on the island of North Uist in Scotland during a removal  
150 programme to protect ground-nesting birds (Scottish Natural Heritage, unpublished); overall,  
151 over 1129 searches with dogs were undertaken, although no figure of the number of hedgehogs  
152 found during that time is available. Similarly, Warwick (1987) briefly used a dog during initial  
153 surveys in North Ronaldsey (Orkney Islands, Scotland) where it effectively found hedgehogs in a  
154 familiar area but not elsewhere. Finally, Morris (1988) also mentions success in finding  
155 hedgehogs with a dog although this is not described in detail. IRT cameras have been used  
156 successfully in Regent's Park, London, UK (Bowen et al. 2019) and forest fragments in  
157 Auckland, New Zealand (Nottingham et al. 2019). Conversely, Haigh et al. (2014) concluded  
158 that the IRT camera they used was ineffective.

159  
160 The efficacy of these two techniques have not, however, been compared, nor have these  
161 techniques been applied in non-urban habitats within Britain. Therefore, in this study, we  
162 conducted a pilot project to compare the effectiveness of an IRT camera, a detection dog and  
163 spotlighting as methods for locating hedgehogs in a rural landscape. Specifically, we compared:  
164 (i) the absolute number of hedgehogs detected by each method in three different habitats  
165 (amenity grassland, pasture, woodland); (ii) the mean detection distance of each method in each  
166 habitat; and (iii) the effect of vegetative ground cover on detection distance. We then go on to:  
167 (iv) discuss our observations of using a detection dog, in controlled conditions for the first time,  
168 as a method for locating hedgehogs; and (v) consider the costs and benefits associated with each  
169 of the three methods in the context of future studies.

## 170 171 **MATERIALS AND METHODS**

172 Data were collected on the Hartpury University and College campus, Gloucestershire, UK  
173 (National Grid reference SO785237), a 360ha mixed commercial farm used for agricultural  
174 teaching and research. Previous studies had confirmed that hedgehogs were present (Bearman-

175 Brown et al. 2020). The site was surveyed on 18 separate nights during May-October 2019  
176 following a standardised transect route (approx. 6km long; but see Results) which encompassed  
177 three specific habitat types (HABITAT): amenity grassland, pasture and woodland. Surveys were  
178 conducted using three different methods (METHOD): spotlighting; infra-red thermal (IRT)  
179 camera; and a trained conservation detection dog. All three habitats were surveyed on any given  
180 night using a single method; habitats were visited in a random order. Six replicates were  
181 performed for each method giving a total of 54 surveys (3 methods \* 6 replicates \* 3 habitats).

182  
183 Surveys started approximately one hour after sunset and were conducted on nights with minimal  
184 rain and wind as these may have affected hedgehog behaviour and reduced the efficiency of one  
185 or more of the survey methods, for example strong winds can affect a dog's ability to locate the  
186 target (Jamieson 2019). Two measures of survey effort were recorded within each habitat: survey  
187 duration (TIME: maximum 40 minutes) and distance travelled (DISTANCE). Air temperature  
188 and humidity were recorded at the start and end of each survey and each time a hedgehog was  
189 located.

190  
191 **Spotlight and thermal camera surveying**  
192 Spotlight (1 million candle-power Clulite CB2 Clubman, Clulite Engineering Ltd., Petersfield,  
193 Hampshire, UK) and infra-red thermal camera (FLIR E53, FLIR Systems UK, West Malling,  
194 Kent, UK) surveys were conducted on foot by an experienced hedgehog surveyor (LBB). The  
195 surveyor was accompanied by a second person for safety reasons but who was instructed to  
196 remain silent throughout; any hedgehogs missed by the surveyor but observed by the safety  
197 person were recorded at the end of the surveying (i.e. they were not recorded as a "detection" for  
198 the purposes of the current study). The spotlight was not filtered as in some other studies (Pettett  
199 et al. 2017a,b).

200  
201 When using the spotlight or IRT, these were used intermittently with the surveyor walking ten  
202 paces then stopping to slowly scan the surrounding area whilst also listening for the sound of  
203 hedgehogs foraging or moving through undergrowth; however, no hedgehogs were detected by  
204 sound alone. This approach was adopted to minimise the risk of tripping, as the IRT camera may  
205 not indicate hazards that have equal thermal properties to the surrounding area. Batteries on both  
206 devices were changed after the second survey of the night (after approximately 1.5 hours) . The  
207 thermal camera was recently calibrated, and set up according to the following parameters  
208 (Bowen et al. 2019): emissivity setting set to a custom setting of 0.95; distance 20m; relative  
209 humidity 50%; atmospheric temperature 20°C; and window compensation off.

210  
211 **Dog-team surveying**  
212 One male rescue springer spaniel dog was trained to search for, and quietly indicate upon, the  
213 scent of hedgehog: training was conducted using hedgehog spines taken from specimens found  
214 dead on roads. The dog had previously been trained to detect a range of wildlife odours and  
215 worked in a commercial capacity for a consultancy undertaking wildlife surveys. Consequently,  
216 he was only available for the current project outside these other commitments. The alert  
217 behaviour was to sit near ( $\geq 0.5\text{m}$ ) the source of the odour and remain there quietly until called  
218 away, at which point he received the reward (tennis ball). He was handled by an experienced,  
219 trained detection dog handler (LW).

220

221 The dog and handler team were despatched on different nights to the human surveyors to ensure  
222 the dog was not following the scent of human surveyors. The dog worked on an 8m long line to  
223 ensure close control at all times. The handler followed the standardised transect route, but the  
224 dog was allowed to lead the handler when an odour was detected. Once the odour trail had been  
225 followed to ensure all areas had been covered, the dog-handler team would then return to the  
226 point at which they had departed from the transect.

227  
228 As the primary focus of this study was to determine the reliability of the dog in detecting  
229 hedgehogs in a range of habitats, the dog-handler team was followed at a distance of 15-20m by  
230 a second surveyor with the thermal camera. This allowed the area to be checked unobtrusively to  
231 determine if any hedgehogs had been missed by the dog. The handler was not informed if any  
232 hedgehogs had been missed until the surveys had been completed.

233  
234 The dog team worked for a maximum of three hours per night for welfare reasons, with 40  
235 minutes survey time followed by a 20-minute break. During the break period, the dog's harness  
236 was removed, and he was put in his kennel in a van as a clear indication that it was time to rest.  
237 Water was offered at regular intervals during surveying in accordance with environmental  
238 temperature and humidity to ensure that his mucous membranes remained moist and that he was  
239 working effectively.

#### 240 241 **Data recording**

242 To minimise disruption to surveying during the current project, a period of prior surveying was  
243 undertaken on site using the thermal camera to locate, capture and mark hedgehogs for  
244 identification purposes. By doing this, any hedgehog captured during the study could be  
245 identified and released quickly; unmarked animals, however, did need more extensive handling  
246 as these also needed to be marked for reference.

247  
248 All hedgehogs detected during the study were captured by hand under licence from Natural  
249 England, as the use of dazzling devices such as high-powered spotlights for detecting hedgehogs  
250 is restricted under Schedule 6 of the Wildlife and Countryside Act, 1981 (licence number: 2017-  
251 31042-SCI-SCI). At their initial capture, all animals were weighed, sexed, given a health check  
252 and marked using sections of numbered plastic tubing (Printasleeve Ltd, Crewkerne, Somerset,  
253 UK) glued (to five individual spines on the nape of the neck (Reeve et al. 2019). Animals caught  
254 for the first time were released at the point of capture within 15 minutes; previously marked  
255 animals that had been re-caught were typically released within  $\leq 5$  minutes. The time taken to  
256 process each animal was excluded from the 40-minute survey period.

257  
258 The capture location of each hedgehog was recorded using a handheld GPS device (Garmin GPS  
259 60). The height of vegetation in the area immediately surrounding the hedgehog was categorised  
260 as: (1) bare ground or mown grass; (2) less than the height of the back of the hedgehog (approx.  
261  $< 15\text{cm}$ ); (3)  $\leq 0.5\text{m}$  tall; (4)  $\leq 1\text{m}$  tall; or (5)  $> 1\text{m}$  tall. These categories were condensed to two  
262 levels for analysis (low: Category 1; high: Categories 2-5 combined) because of small sample  
263 sizes in the latter divisions.

264  
265 For spotlighting and the IRT camera, detection distance was approximated by pacing as the  
266 straight-line distance from the surveyor to the position of the hedgehog when it was first sighted

267 (Bowen et al. 2019). For the dog team, detection distance was taken as the straight-line distance  
268 from the dog to the hedgehog at the point the handler believed (based on extensive work  
269 undertaken by the handler with this dog and others in a professional capacity) it was clear the  
270 dog had caught the animal's scent e.g. through a noted change in direction, activity level or body  
271 position,. This would correspond to the minimum distance at which the dog detected the scent of  
272 the hedgehog, as it is not possible to define exactly the point at which the dog initially detected  
273 the scent from the target.

274

## 275 **Data analysis**

### 276 ***Survey effort***

277 As the number of hedgehogs detected by each method may vary in relation to the method itself  
278 but also the density of hedgehogs in the different habitats and survey effort, preliminary analyses  
279 were conducted to determine whether survey effort was consistent. A general linear model was  
280 used to analyse the effects of HABITAT (pasture, amenity, woodland) and METHOD (camera,  
281 spotlight, dog) on distance walked in each habitat (DISTANCE): this model included a  
282 HABITAT\*METHOD interaction term. Both predictor variables were modelled as fixed factors.  
283 Data were checked to ensure that they conformed to the underlying assumptions of the test  
284 (Grafen & Hails 2002). Data for the duration of surveying (TIME) were not normally distributed,  
285 so a Kruskal-Wallis test was used to compare median values across all nine HABITAT-  
286 METHOD subgroups.

287

288 The relationship between DISTANCE and TIME was analysed using Pearson correlation as  
289 these are likely to be inter-related, which can cause problems with multicollinearity in statistical  
290 models (Grafen & Hails 2002, Field 2017). Initially, data across all three habitats were  
291 compared. A further correlation was conducted for those data from amenity grassland and  
292 pasture but excluding woodland as the latter was excluded from the analysis comparing the  
293 survey methods since hedgehogs were not detected in woodland by any method (see Results).

294

### 295 ***Comparison of survey methods***

296 The effect of METHOD, HABITAT, TIME, DISTANCE, air TEMPERATURE and  
297 HUMIDITY on the number of hedgehogs detected was analysed using a generalised linear  
298 model (GLM) assuming a Poisson error distribution. As no hedgehogs were detected in  
299 woodland using any method, these data were both uninformative for evaluating the influence of  
300 the covariates and caused under-dispersion; they were, therefore, removed prior to analysis. An  
301 initial global model containing all covariates was fitted and then AIC based multi-model  
302 selection (Burnham & Anderson 2002) was applied using the *MuMin* package (Barton 2019) in  
303 R version 3.3.3 to find the best fitting models; models with  $\Delta\text{AICc}$  values  $<2$  were assumed to  
304 have equal support (Burnham & Anderson 2004). The assumptions of the GLM were then tested  
305 for the global model and the single best-fitting model, using a goodness-of-fit deviance test and a  
306 residual dispersion test for a Poisson error distribution through the *DHARMA* package (Hartig  
307 2017).

308

### 309 ***Factors affecting detection distance***

310 It was not possible to incorporate METHOD, HABITAT type (amenity grassland, pasture) and  
311 ground COVER (low, high) into a single analysis because of e.g. the inherent limitations of the  
312 methods themselves and how this influenced sample sizes in different categories (see



313 Supplementary Figure S1). For example, surveyors are less likely to be able to detect hedgehogs  
314 in dense cover using a spotlight or IRT camera because the animal is physically hidden from  
315 view, whereas this may not be the case for a detection dog. Therefore, we used a combination of  
316 Kruskal-Wallis and Mann-Whitney tests to compare differences in the distance over which  
317 hedgehogs were first detected in relation to (a) survey method, (b) ground cover and (c) habitat.

318  
319 General linear model, Kruskal-Wallis and Mann-Whitney analyses were conducted using  
320 Minitab version 19 and SPSS version 25. Data are presented as mean ( $\pm$ SD) or median ( $\pm$ IQR) in  
321 accordance with the statistical tests used.

322

## 323 **RESULTS**

324 Seventeen hedgehogs were found during surveys, with each hedgehog located a median of 3  
325 times (IQR = 1-3).

326

### 327 *Survey effort*

328 Survey DISTANCE was not significantly affected by METHOD (General linear model:  $F_{2,45} =$   
329  $0.05$ ,  $P = 0.952$ ) or the interaction between METHOD\*HABITAT ( $F_{4,45} = 0.99$ ,  $P = 0.424$ ) but  
330 was significantly affected by HABITAT ( $F_{2,45} = 60.74$ ,  $P < 0.001$ ). Distance walked was  
331 significantly higher in pasture ( $2.27 \pm 0.20$  km) than in amenity grassland ( $1.73 \pm 0.19$ ) and  
332 woodland ( $1.67 \pm 0.14$ ).

333

334 There was also a significant difference in the duration of surveying (TIME) across the nine  
335 HABITAT and METHOD subgroups (Kruskal-Wallis test:  $H = 20.72$ ,  $DF = 8$ ,  $P = 0.008$ ).  
336 Although there was a lot of overlap between subgroups, this difference was principally due to a  
337 longer survey time in pasture where all surveys lasted 40 minutes regardless of survey method,  
338 compared to mean survey times of 38.9 (range: 36-40) minutes for amenity grassland and 36.8  
339 (range: 32-40) minutes for woodland.

340

341 Survey duration and distance walked were significantly positively correlated when data from all  
342 three habitats were considered (Pearson correlation:  $r = 0.41$ ,  $n = 54$ ,  $P = 0.002$ ), but not when  
343 woodland was excluded ( $r = 0.31$ ,  $n = 36$ ,  $P = 0.064$ ).

344

### 345 *Comparison of survey methods*

346 Hedgehogs were detected on 47 occasions across the 54 transect surveys (mean ( $\pm$ ):  $0.87 \pm 1.20$ ;  
347 range: 0-5). There was a marked difference in the number of animals detected within each habitat  
348 (Table 1). Most notably, no hedgehogs were detected by any method in woodlands; 2.6 times as  
349 many hedgehogs were detected in amenity grassland versus pasture. On no occasion did the dog  
350 fail to detect a hedgehog that was located by the second surveyor following behind with the IRT  
351 camera.

352

353 **Table 1.** Number of hedgehogs recorded within each habitat using each survey method. Six  
 354 transect surveys were conducted in each habitat using each method.

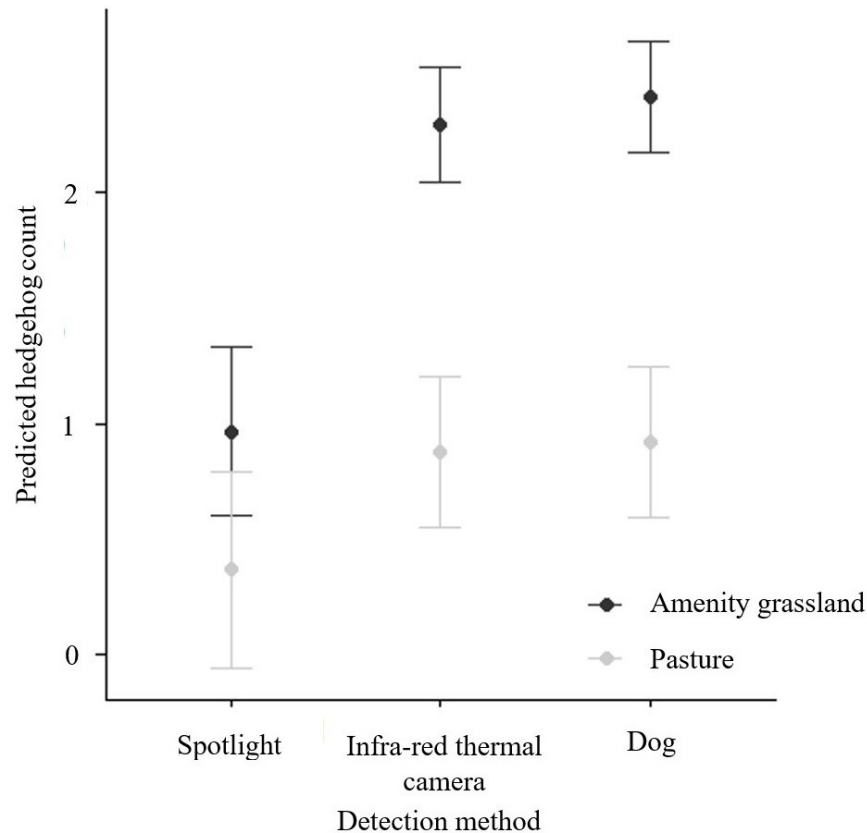
Method	Habitat			Total	Mean (±SD)	Median [Range]
	Amenity grassland	Pasture	Woodland			
Infra-red thermal camera	15	4	0	19	1.06 ± 1.55	0.0 [0-5]
Detection dog	12	8	0	20	1.11 ± 1.02	1.0 [0-3]
Spotlight	7	1	0	8	0.44 ± 0.86	0.0 [0-3]
Total	34	13	0	47	0.87 ± 1.20	0.0 [0-5]
Mean (±SD)	1.89 ± 1.32	0.72 ± 0.89	0.00	0.87 ± 1.20		
Median [Range]	2.0 [0-5]	0.5 [0-3]	0.0 [-]			

355  
 356  
 357 Across all models, there were significantly fewer hedgehogs detected in pasture than in amenity  
 358 grassland (Table 2; Figure 1). In three out of the five top-ranked models, including the best  
 359 overall model, METHOD of detection was retained, with more hedgehogs detected with the  
 360 infra-red camera and the dog compared to spotlighting (Table 2; Figure 1). DISTANCE walked  
 361 and TEMPERATURE were retained in two and one of the best models, respectively, although  
 362 neither were significant.

363  
 364 **Table 2.** Estimated regression parameters (± standard error) from the general linear model  
 365 predicting the number of hedgehogs detected. Reference level for ‘Habitat’ is amenity grassland;  
 366 reference level for ‘Method’ is spotlight. Models presented are those with ΔAICc < 2. Full and  
 367 conditional model averages are presented beneath. Asterisks denote: \* < 0.05, \*\* < 0.01, \*\*\*  
 368 < 0.001.

Intercept	Distance (km)	Habitat (Pasture)	Method (Camera)	Method (Dog)	Start temperature (°C)	df	AICc	ΔAICc
-0.04 (± 0.37)		-0.96** (± 0.33)	0.87* (± 0.42)	0.92* (± 0.42)		32	102.1	0.00
0.66 (± 0.70)		-0.89* (± 0.33)	0.97* (± 0.43)	0.87* (± 0.42)	-0.05 (± 0.04)	31	103.5	1.33
0.64*** (± 0.17)		-0.96** (± 0.32)				34	103.5	1.42
1.47 (± 1.35)	0.84 (± 0.75)	-1.39** (± 0.51)	0.83 (± 0.42)	0.86 (± 0.42)		31	103.6	1.46
-1.29 (± 1.35)	1.10 (± 0.76)	-1.56** (± 0.53)				33	103.9	1.73
-0.22 (± 1.18)	0.30 (± 0.62)	-1.11* (± 0.47)	0.61 (± 0.54)	0.61 (± 0.54)	-0.01 (± 0.03)	Full average		
-0.22 (± 1.18)	0.96 (± 0.77)	-1.10* (± 0.47)	0.88* (± 0.42)	0.89* (± 0.42)	-0.05 (± 0.04)	Conditional average		

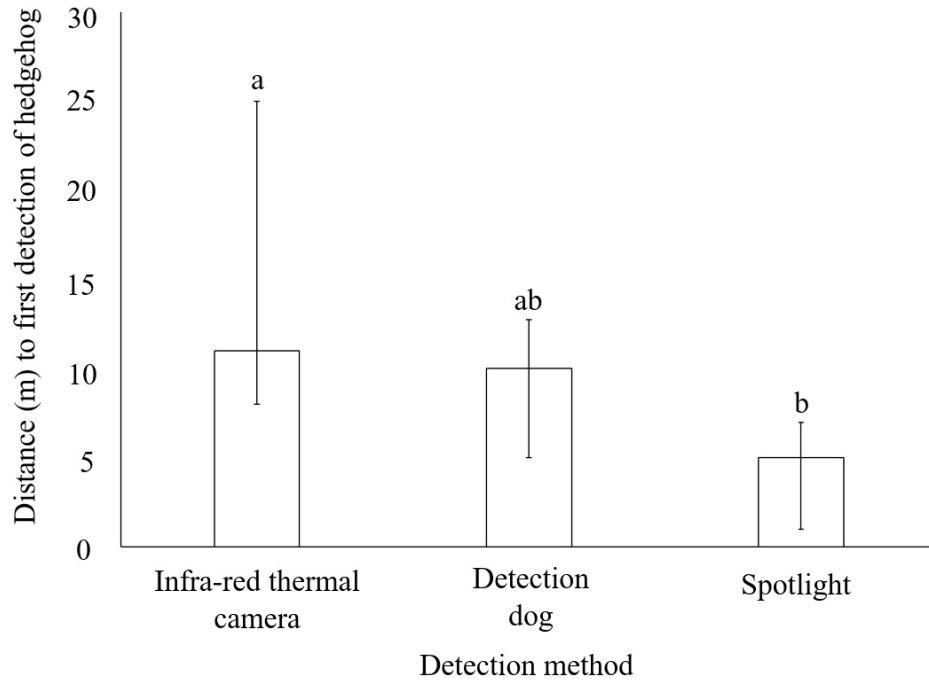
370  
 371



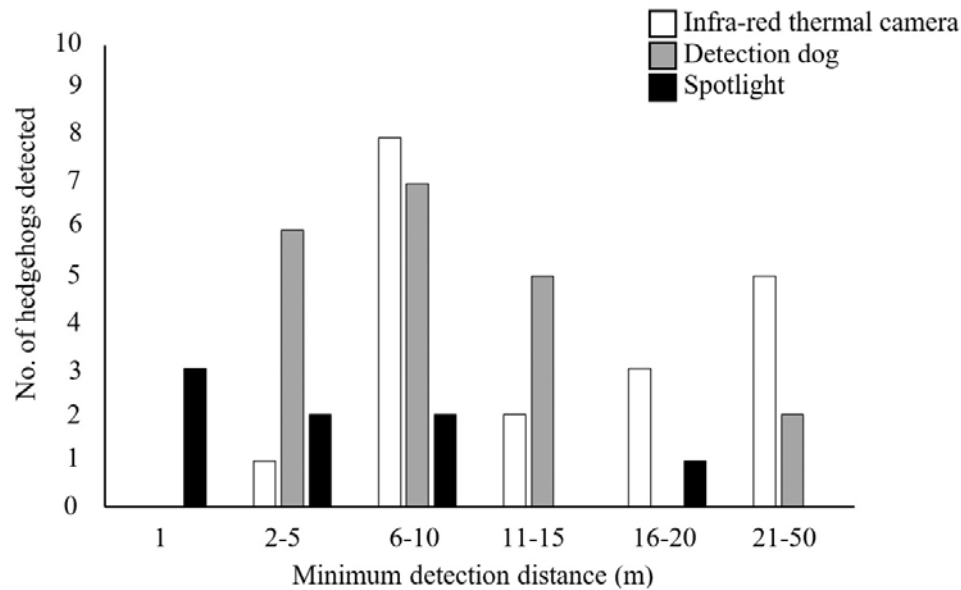
372  
 373 **Figure 1.** The predicted number ( $\pm$  SE) of hedgehogs detected per transect across HABITAT and  
 374 METHOD from the single best model (Table 2).

375  
 376 ***Factors affecting detection distance***

377 On average, the minimum detection distance was significantly greater for the IRT camera  
 378 compared to the spotlight, with the detection dog intermediate to these two methods (Kruskal-  
 379 Wallis test:  $H = 8.21$ ,  $DF = 3$ ,  $P = 0.016$ ; Figure 2). However, there was a lot of overlap in the  
 380 detection distances (Figure 3). Hedgehogs were generally detected by spotlighting at a distance  
 381 of 1-10m, although one individual was first detected at 20m. Similarly, hedgehogs tended to be  
 382 detected by the dog within 4-15m, but with two detection events at 25m and 30m; it must be  
 383 noted, however, that these values are likely to be conservative estimates as the point at which the  
 384 hedgehog was first detected was sometimes hard to estimate based upon a clear change in the  
 385 dog's behaviour. Detection distance was most variable using the IRT camera, ranging from 4-  
 386 50m; this method was associated with the majority of long-distance detections ( $>15m$ ).  
 387

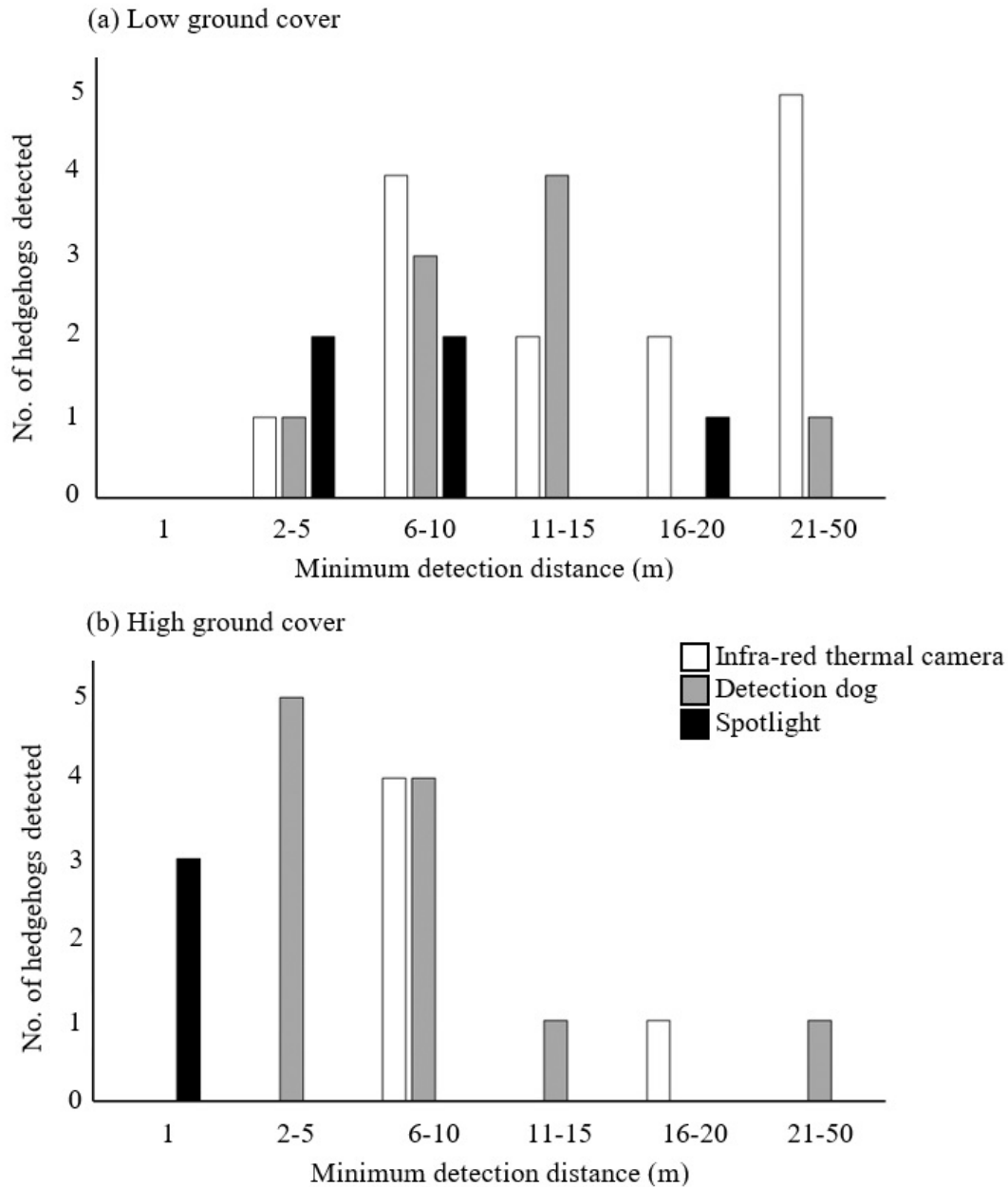


388  
 389 **Figure 2.** Median ( $\pm$ IQR) distance hedgehogs were first detected using an infra-red thermal  
 390 camera (N = 19), detection dog (N = 20) or spotlight (N = 8). Data from different habitats and  
 391 different levels of ground cover combined. Letters denote *post hoc* groupings from a Kruskal-  
 392 Wallis test.  
 393

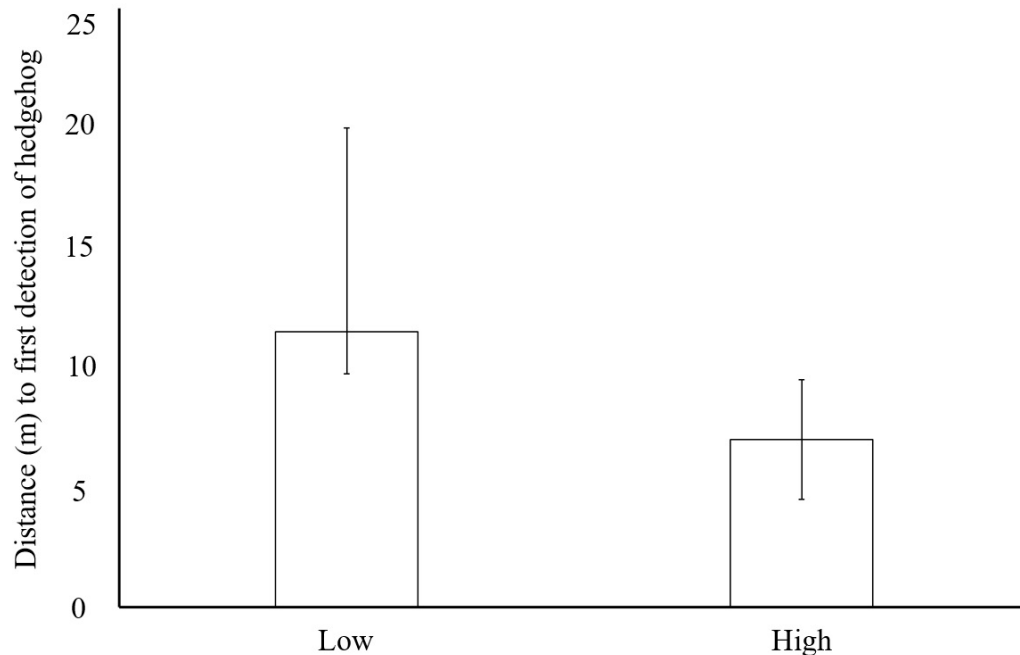


394  
 395 **Figure 3.** Pattern of minimum detection distance (m) in relation to survey method: infra-red  
 396 thermal camera (N = 19), detection dog (N = 20) and spotlight (N = 8). Data from different  
 397 habitats and different levels of ground cover combined.  
 398

399 Most detections (n = 28) were associated with low ground cover (bare ground or mown grass):  
 400 hedgehogs tended to be detected using the spotlight, dog and IRT camera at distances of 5-10m,  
 401 5-15m and 8-30m, respectively (Figure 4a). In comparison, spotlights were only able to detect  
 402 hedgehogs in higher vegetation at very short distances (1m) whereas the detection distances for  
 403 both the IRT camera and dog were much higher (6-18m and 4-25m, respectively; Figure 4b).  
 404 The dog was the only method that detected hedgehogs in vegetation greater than the height of the  
 405 hedgehog (Categories 3-5; n = 4). Given these patterns, the median detection distance was  
 406 significantly greater in low ground cover (Mann-Whitney test: U = 120.50, n = 47, P = 0.002;  
 407 Figure 5).  
 408



409  
 410 **Figure 4.** Pattern of minimum detection distance (m) in relation to survey method in (a) low (N  
 411 = 28) and (b) high (N = 19) ground cover. Data from different habitats combined.



412 **Figure 5.** Median ( $\pm$ IQR) detection distance of hedgehogs in low and high vegetation (see text  
 413 for details). Data from different methods and habitats combined.  
 414

415  
 416 **DISCUSSION**

417 This pilot study is the first to compare the efficacy of an infra-red thermal camera, a detection  
 418 dog and spotlighting as methods for locating hedgehogs in three common rural habitats in  
 419 Britain: amenity grassland, pasture and woodland. A single dog was used in this study so that we  
 420 could e.g. determine the ability of the dog to access locations where hedgehogs were likely to be  
 421 detected. In addition, the dog used in this study is part of a commercial organisation run by the  
 422 handler. As training of detection dogs is time consuming, and there are time constraints with  
 423 availability, sample sizes were relatively low but were able to identify significant differences  
 424 between the three methods used. As such, this study should be considered as a proof of concept,  
 425 but with the recommendation that further research is required.

426  
 427 To standardise survey effort, surveyors walked the same transect route in each habitat, trying to  
 428 walk at a consistent speed for a maximum of 40 minutes. In addition to affecting survey effort,  
 429 differences in walking speed in different habitats could affect the amount of noise made by  
 430 surveyors, thereby affecting the number of animals detected; this is particularly true for  
 431 hedgehogs which generally tend to freeze or curl into a ball when they feel threatened, although  
 432 some individuals will actively run away (Reeve 1994, Morris 2018).

433  
 434 However, significant differences were evident for both the distance walked and survey duration  
 435 within each of the three habitats. Distance walked during surveying was significantly higher in  
 436 pasture (mean: 2.27 km) than in both amenity grassland (1.73 km) and woodland (1.67 km),  
 437 whereas survey duration was lower in woodlands (mean: 36.8 minutes) compared to amenity  
 438 grassland (38.9 minutes) and pasture (40.0 minutes). Consequently, surveyor speed was  
 439 markedly greater in pasture ( $3.4 \text{ kmh}^{-1}$ ) than in the other habitats (amenity grassland:  $2.7 \text{ kmh}^{-1}$ ;  
 440 woodland:  $2.7 \text{ kmh}^{-1}$ ). At one level, these data indicate the need to record both measures of

441 survey effort in these sorts of studies, but also those where a single technique is used to derive an  
442 estimate of the relative abundance of hedgehogs. Standardising survey distance and time may be  
443 particularly important in large-scale surveys involving volunteers, where surveyor skill may be a  
444 particular issue for cryptic species such as the hedgehog. To date, however, survey effort has not  
445 typically been recorded in hedgehog studies in the UK and/or incorporated into the resultant  
446 statistical analyses (e.g. Young et al. 2006, Poulton & Reeve 2010, Trewby et al. 2014, Bowen et  
447 al. 2019). In this study, distance walked but not survey time was retained in two of the five best-  
448 ranked models investigating factors associated with the number of hedgehogs detected (Table 2).  
449 Hedgehogs were frequently located repeatedly throughout all survey methods, with a median of  
450 three encounters over all surveys. As is typical of hedgehog behaviour (Haigh et al. 2009, Hof &  
451 Bright 2010b), individuals were repeatedly located in the same areas, although home range was  
452 not quantified in this study as insufficient data were collected.

453  
454 Approximately twice as many hedgehogs were located, on average, using the IRT camera and  
455 detection dog than spotlighting in both amenity grassland and pasture (Figure 1). In addition, the  
456 minimum detection distance was greater for the IRT camera (median: 11m) and, to a lesser  
457 degree, the detection dog (10m) than the spotlight (5m: Figure 2). These distances for the IRT  
458 camera and spotlight are markedly lower than those reported by Bowen *et al.* (2019) from their  
459 study in Regent's Park London. In that study, the thermal camera detected hedgehogs at a mean  
460 distance of 30.0m, but with a maximum distance of 200m; comparable figures for the torch used  
461 were a mean and maximum of 12.0m and 50m, respectively.

462  
463 Drawing specific comparisons between studies is, however, difficult. For example, in addition to  
464 differences associated with the make and model of the thermal camera and torch used in different  
465 studies, and the number of surveyors applying each method at any given time (e.g. Bowen *et al.*  
466 (2019) utilised 3-4 surveyors for torch surveys compared to one person for their IRT camera), it  
467 is also necessary to consider differences in hedgehog density, habitat structure and the wider  
468 landscape. One major difference between our study and Bowen *et al.*'s (2019) study is the  
469 potential impact of the presence of badgers: these are absent from Regent's Park but are present  
470 at Hartpury. Many previous studies have documented changes in the density (Young et al. 2006,  
471 Hubert et al. 2011, Trewby et al. 2014, Van de Poel et al. 2015) and movement behaviour (Hof et  
472 al. 2012, Pettett et al. 2017b) of hedgehogs in the presence versus absence of badgers. Notably,  
473 hedgehogs tend to remain in closer proximity to areas of cover where badgers are present, which  
474 would tend to have the effect of reducing detection distances because animals would be less  
475 likely to be in open habitats a long way from protective vegetation.

476  
477 None of the three methods detected any hedgehogs in woodland. This could indicate an inability  
478 of all three methods to work effectively in very cluttered habitats, or that woods are not a  
479 favoured habitat for hedgehogs at this time of the year. Although the data are limited, there is  
480 some evidence that supports the latter hypothesis. For example, woodlands were the least  
481 selected habitat in a radio-tracking study of hedgehogs in arable landscapes (Pettett et al. 2017b)  
482 and were not identified as a factor significantly affecting patterns of hedgehog occupancy in a  
483 national survey of England and Wales (Williams et al. 2018a). As outlined above, one possible  
484 factor affecting the use of woodlands is the likelihood of encountering badgers, which favour  
485 woodlands and plantations as habitats for their setts (Wilson et al. 1997). This aspect of  
486 hedgehog ecology requires urgent attention as two previous national estimates of the total

487 number of hedgehogs in Britain (Harris et al. 1995, Mathews et al. 2018) have both relied upon  
488 an estimate of 40 hedgehogs/km<sup>2</sup> for broadleaved woodland, with this single habitat harbouring  
489 37% of the national population.

490  
491 Detection distances were, however, significantly affected by the amount of ground cover. In fact,  
492 we had to merge all categories of ground cover other than bare ground or mown grass (59.6% of  
493 all detection events) for analysis because of the small number of detections in categories where  
494 even small amounts of grass were present. Not surprisingly, therefore, the median detection  
495 distance was significantly higher (11.5m) at the lowest level of ground cover (recorded as bare  
496 ground or mown grass) compared to more vegetated areas (7.0m). In the presence of vegetative  
497 cover, the detection dog out-performed the other two methods, accounting for 11 of 19 (57.9%)  
498 detections, and was the only method where hedgehogs were detected when they were surrounded  
499 by vegetation taller than they were.

500

### 501 **Performance of the detection dog**

502 As biological organisms, detection dogs are potentially susceptible to a range of limitations not  
503 evident with other forms of survey “equipment” including fatigue, distraction and potential risk  
504 to the focal animals themselves. In this study, we therefore adapted the surveying protocol to  
505 minimise some of these issues. For example, we ensured that the dog had a 20-minute rest period  
506 after each habitat had been surveyed and did not work for more than three hours each night. In  
507 addition, as the detection of animals by scent can be affected by environmental conditions,  
508 leading to inconsistencies in detection ability (Gutzwiller 1990, Cablk et al. 2008), we only  
509 surveyed when the air temperature was above ~10°C (mean 15.4°C; range 9.3-24.1°C) and  
510 conditions were dry at the start of the night’s survey (humidity: mean 68.3%; range 39.8-99.9%).  
511 Humidity was not significant in the analysis of factors affecting the numbers of hedgehogs  
512 detected, but air temperature at the start of surveying was retained in one of the five top-ranking  
513 models: in that model, air temperature was negatively related to the number of hedgehogs  
514 located but the parameter was not significant (Table 2). This partly corroborates the observation  
515 of Pettett et al. (2017a) that hedgehogs were more likely to be further from cover in colder  
516 temperatures.

517

518 Whilst in many instances, dogs have been used to detect scats (e.g. Smith et al., 2005, Long et  
519 al., 2007, Vynne et al., 2011) or carcasses (e.g. Paula et al., 2011, Alasaad et al., 2012, Mathews  
520 et al., 2013), the use of a dog to locate and approach live (potentially) prey animals poses  
521 additional challenges. These include the potential for the dog to injure the animal, for the animal  
522 to injure itself in attempts to escape, and/or for the transmission of disease. In this context, both  
523 the selection of a dog with a low prey drive and rigorous training is critical (Karp 2020). In this  
524 study, the dog never approached a hedgehog closer than approximately 0.5m as trained, and  
525 never attempted to pursue any other animal encountered during surveying (e.g. rabbits  
526 *Oryctolagus cuniculus*). Upon approach by the dog, all hedgehogs demonstrated a freeze or curl  
527 response suggesting the risk of injury to the hedgehogs was low, as attempts to escape were not  
528 evident; all animals also demonstrated the same responses when spotlights were used, as has  
529 been previously reported (Bowen et al. 2019). However, a flee response was observed on two  
530 occasions when using the IRT camera; in both cases, the animals were already only a short  
531 distance from cover.

532



533 To further ensure the safety of the hedgehogs and the dog itself, the dog remained on a long line  
534 as recommended by Mathews et al., (2013). However, previous authors have suggested that  
535 allowing a dog to search freely allows for more natural movement and search patterns for the  
536 target (de Oliveira et al., 2012, Glen et al., 2018, Thomas et al., 2020) and dogs have been found  
537 to be more effective off-lead in controlled trials searching for scats (Cristescu et al. 2015); the  
538 use of dogs to find live, nocturnal animals at night has also been recently reported (Karp 2020).  
539 Therefore, future studies could examine whether the use of an unrestricted dog could further  
540 increase hedgehog detection rates; this could be particularly important in habitats, such as  
541 woodlands, where the presence of the surveyor may impede the dog's movement. However, it  
542 must be noted that on no occasion did the dog in this study fail to detect a hedgehog that was also  
543 detected by the second surveyor carrying the IRT camera, such that detection reliability in both  
544 amenity grassland and pasture was not negatively impacted by being restrained.

545  
546 The dog in this study was used to detect free-roaming hedgehogs. However, the ability to detect  
547 hedgehogs in their nests could offer both scientific and practical benefits. For example, they  
548 could facilitate studies investigating the use of different habitats as sites for summer nests and  
549 winter hibernacula (Morris 1973, Reeve & Morris 1985); they may be especially helpful in  
550 helping obtain data from smaller individuals that cannot be fitted with radio-tags on welfare  
551 grounds, but which may be more vulnerable to variation in food availability (sensu Rasmussen et  
552 al. 2019). Nesting hedgehogs are also vulnerable to a range of human activities including  
553 mowing, bonfires and the clearance of land for development (Reeve 1994, Reeve & Huijser  
554 1999, Rasmussen et al. 2019). In these contexts, detection dogs offer one possible means of  
555 locating nesting animals which could then be moved out of harm's way; currently no option  
556 exists to do this.

### 557 **Cost-benefit comparisons**

558 Both the IRT camera and the detection dog enabled surveyors to detect more hedgehogs and at  
559 greater distances than spotlighting, and the IRT camera detected more hedgehogs at greater  
560 distances than the dog in areas of low ground cover, but this was reversed in areas of high  
561 ground cover. As such, thermal cameras and detection dogs both offer distinct advantages over  
562 spotlighting in terms of both capturing hedgehogs and for surveying and monitoring populations,  
563 but also some disadvantages including price and practicability. For example, the IRT camera and  
564 spotlight models (including battery packs) used in this study retailed at a cost of approximately  
565 £4600 and £270, respectively. In comparison, the detection dog cost £470 a night (£350 fee, £80  
566 transport and £40 accommodation) to hire. These figures translate to a unit-cost of £242, £34 and  
567 £141 per hedgehog detected, respectively, although the cost of both the IRT camera and the  
568 spotlight are fixed, such that the financial reward of purchasing these devices would increase  
569 each time they are used; this is not the case for the detection dog.

570  
571  
572 However, the added value of the camera and the dog are the additional number of animals that  
573 would be detected per unit effort. From a scientific perspective, these extra detection events  
574 would lead to more robust data, including increased statistical power (Mayle et al. 1999).  
575 Unfortunately, quantifying the magnitude of this added value from the current study is  
576 complicated because of how the data were collected: because the focus of the study was to  
577 compare the ability of the three methods to detect live hedgehogs, and especially because the  
578 IRT camera is dependent on identifying body heat, we had to collect data on live hedgehogs in

579 real time. It was not possible to use all three methods simultaneously as having three sets of  
580 surveyors in the field in the same place would increase levels of disturbance on hedgehog  
581 behaviour and there would be difficulties in maintaining the independence of observations.  
582 Consequently, we used one technique each night, which meant that the distribution of hedgehogs  
583 was not consistent across each night of surveying. The increased detection distance associated  
584 with the camera and dog would not be of benefit if they simply detected hedgehogs that would  
585 otherwise have been detected by the spotlight in due course e.g. they were in front of the  
586 surveyor on the general trajectory of the transect and would remain stationary. The increased  
587 detection range of the camera and dog would be an advantage if hedgehogs sought cover at the  
588 sound of an approaching surveyor; there are currently no data on whether this is a problem or  
589 not, and thus the application of such techniques discussed here support future investigation.

590

591 Furthermore, data from radio-tracking studies suggest that, in areas where badgers are present,  
592 hedgehogs are typically in close proximity to refuge habitats such as hedgerows. For example,  
593 (Hof et al. 2012) recorded mean distances to cover of 8m at sites with badgers versus 28m at  
594 sites without badgers. Similarly, Pettett et al. (2017a) recorded that hedgehogs were, on average,  
595 13m and 7m closer to hedgerows and buildings, respectively, when badgers were present. In the  
596 context of, for example, a citizen-science project to estimate hedgehog abundance across a large  
597 spatial scale (sensu Williams et al. 2018b), surveyors would likely be instructed to follow  
598 hedgerows and other linear habitats because of the increased likelihood of detecting hedgehogs,  
599 but also to avoid damaging crops or disturbing livestock. In these circumstances, spotlight  
600 searches may represent a cheap and effective method for surveying hedgehogs, although  
601 surveyors would need to be licensed in accordance with the Wildlife and Countryside Act which  
602 is unlikely to be granted to novice surveyors. Conversely, a licence is not required for IRT  
603 cameras and the IRT camera provides a mechanism for detecting and following hedgehogs at a  
604 distance without the risk of the disturbance associated with the use of a spotlight, thus providing  
605 a less invasive means of surveying.

606

607 However, hedgehogs are also known to forage further from refuge habitats if badgers are absent  
608 and if other cover is available. For example, the mean distance to cover increased from 4m to  
609 42m in Hof & Bright's (2012) study, and from 12m when arable crops were less than 50cm tall,  
610 to 38m when they were >1m tall. In these circumstances, the IRT camera and dog would be  
611 advantageous, e.g. being able to locate hedgehogs much further into a pasture field even where a  
612 transect follows the field margin. A detection dog, in particular, would be able to locate  
613 hedgehogs in taller vegetation than an IRT camera or spotlight, which would help extend the  
614 amount of time surveys could be conducted throughout the year as vegetation grows; although, it  
615 is questionable whether farmers would allow surveyors to approach hedgehogs in arable fields if  
616 this was likely to damage the crop.

617

618 The current availability of just a single commercial "hedgehog dog" is a limitation for the  
619 widespread use of this approach in future studies, especially for extensive studies where multiple  
620 sites need to be surveyed within a single field-season. However, having demonstrated that dogs  
621 can be successfully trained to locate active hedgehogs, further individuals may become available  
622 in due course. It is important to acknowledge that performance can vary between dogs and  
623 handlers (Cablak & Heaton, 2006, Jamieson *et al.*, 2017, DeMatteo *et al.*, 2019), and even one

624 dog's performance may change with different handlers (Jamieson et al. 2018). As such, this  
625 dog/handler variation would need to be incorporated into the design of future studies.

626

## 627 **Conclusion**

628 Spotlights have conventionally been used to locate hedgehogs for tagging and marking and to  
629 estimate relative abundance. In this study, however, significantly more hedgehogs were detected  
630 using an infra-red thermal camera and a detection dog, and at greater distances, in amenity  
631 grassland and pasture. Nevertheless, the benefits of an IRT camera and dog for surveying  
632 hedgehog populations are likely to be dependent on the typical pattern of hedgehog foraging  
633 behaviour. One factor known to significantly affect the distance hedgehogs range from cover is  
634 the presence / absence of badgers: in the presence of badgers, IRT cameras and dogs may offer  
635 limited benefits as hedgehogs are likely to stay close to cover, within the typical detection range  
636 of a spotlight; in the absence of badgers, IRT cameras and dogs may enable hedgehogs to be  
637 detected at much greater distances from transect lines.

638

639 No hedgehogs were detected in woodland by any method. This could indicate that all three  
640 methods are not suitable for surveying in this habitat or that hedgehogs typically avoid  
641 woodlands during the summer and autumn. Future studies, therefore, need to determine whether  
642 woodlands are an important habitat for hedgehogs and, if so, identify a suitable method for  
643 surveying them. In this context, detection dogs may be suitable as they were the only method in  
644 this study to detect hedgehogs in vegetation greater than the height of a hedgehog.

645

646 This study has demonstrated that detection dogs can be trained to successfully and safely locate  
647 free-ranging hedgehogs, with a performance comparable to, or greater than, current technologies,  
648 although they are associated with markedly higher costs. Further consideration should, therefore,  
649 be given to improving this technique e.g. by comparing the effectiveness when the dog is not  
650 confined to a leash; this may be particularly true for habitats with high ground cover. Additional  
651 attention should also be focused on investigating the effectiveness of detecting hedgehogs when  
652 they are in summer and/or winter nests, as this may have applied benefits for this declining  
653 species.

654

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660 Author contributions: L. Bearman-Brown and P. Baker conceptualised the study; L. Bearman-  
661 Brown and L. Wilson collected data, L. Bearman-Brown and P. Baker analysed the data; L.  
662 Bearman-Brown and P. Baker wrote the manuscript, which all authors reviewed.

663

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