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1 **Title:** Managed parks as a refuge for the threatened red squirrel (*Sciurus vulgaris*) in light of human  
2 disturbance

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## 24 **Abstract**

25           As the invasive grey squirrel continues to spread, red squirrels are dying out. The result may  
26 be isolated populations in managed parks, where access can be controlled. However, recreation can  
27 often have a negative effect on wildlife, reducing the conservation potential of parks. Fota Wildlife  
28 Park receives over 300,000 visitors each year and is located on an island that is currently free of grey  
29 squirrels. We examined the effect of visitors on the existing red squirrel population. Sampling was  
30 conducted in the presence and absence of the public. Ten trapping sessions took place from March  
31 2013 to 2014 and faeces were collected to examine stress levels. Squirrels were observed to  
32 concentrate their activity in non-public areas and move into public areas when the park was closed.  
33 Radio tracked squirrels, from the adjacent gardens (intermediate disturbance), also used habitats in  
34 the wildlife park (high disturbance) when it was closed but returned when the park had opened. When  
35 squirrels were observed in public areas, visitors were only visible on 15% of occasions. Levels of  
36 faecal cortisol metabolites (FCM) were highest in areas where human disturbance was greatest.  
37 However, there was no correlation between visitor numbers and the stress levels of squirrels. FCM  
38 levels were however, positively correlated with density of squirrels. The fact that high numbers of  
39 squirrels continued to utilise the wildlife park demonstrates that managed parks could provide an  
40 important reserve for the maintenance of the species, as long as non-public areas are accessible.

41 **Keywords:** Glucocorticoids; invasive species; reserves; wildlife park

## 42 **Introduction**

43           The increase in tourism and recreational activities in recent times potentially adds to the  
44 already increasing pressure on endangered and vulnerable wildlife, (Lowney, 2011; Taylor and  
45 Knight, 2003). In the U.S. it is the second leading cause of the decline of federally threatened and  
46 endangered species on public lands (Losos et al., 1995). Gill (2007) commented on the potential  
47 dilemma this causes, due to the need for public access to wildlife, for educational purposes. However,  
48 wild animals often perceive humans as potential predators (Beale and Monaghan, 2004; Gill et al.,  
49 1996; Hosey, 2000), which may result in animals avoiding parts of their normal range (Gander and

50 Ingold, 1997; Hamr, 1988) and a cessation of foraging, fleeing or altered reproductive behaviour  
51 (Cole and Knight, 1991). For instance, human disturbance was found to have a significant negative  
52 effect on the nesting success of guillemots (*Uria aalge*) and kittiwakes (*Rissa tridactyla*) in Scotland  
53 (Beale and Monaghan 2003) and reindeer (*Rangifer tarandus*) densities increased in winter, when  
54 outdoor activities declined in Lapland (Helle and Särkelä, 1993).

55         However, it has been shown that while certain species may avoid human presence it may  
56 have little effect on others with some animals habituating to the predictable nature of human  
57 disturbance along trails (Knight and Cole, 1995; Whittaker and Knight, 1998). Well-managed  
58 tourism and recreational activities can even have direct benefits to certain wildlife species, as they  
59 can reduce both inter- and intraspecific conflict as well as having a disturbance effect on predators  
60 (Lowney, 2011). Other animals may not show any behavioural responses to disturbance due to high  
61 cost (Frid and Dill, 2002). Thus, Thiel et al. (2008) stated the need for a combination of methods,  
62 utilising both behavioural and a physiological measure of stress to evaluate possible responses to  
63 human disturbance. This was confirmed in their study on Capercaillie, *Tetrao urogallus* where the  
64 physiological response to winter tourism was more pronounced and obvious than the behavioural  
65 response (Thiel et al. 2008).

66         Over the past 25 years, non-invasive ways for measuring glucocorticoid metabolites in  
67 excreta have been increasingly used to evaluate stress levels in laboratory, domestic, zoo and free-  
68 ranging animals (Palme et al., 2005; Sheriff et al., 2011). The front-line hormones to overcome  
69 stressful situations are the glucocorticoids and catecholamines and these hormones are determined  
70 as a parameter of adrenal activity and thus of disturbance (Möstl and Palme, 2002). The consequences  
71 of chronic stress may be of particular importance for species inhabiting disturbed landscapes  
72 (Macbeth et al., 2010) and in areas of high levels of human activity, as has been recorded in pine  
73 martens (*Martes martes*) in North West Spain (Barja et al., 2007) and elk (*Cervus canadensis*) in  
74 South Dakota (Millsaugh, 1999).

75         Another leading threat to biodiversity (Wilcove et al., 1998) is the introduction of non-native  
76 species, which continues to cause global ecological concern (Manchester and Bullock, 2000), with

77 the monitoring of biological invasions being highlighted as a priority (Latombe et al. 2016). In the  
78 U.K. the red squirrel has disappeared from most of the areas now occupied by the grey squirrel  
79 (Reynolds, 1985) and it has been suggested that continuation at the current rate of decline will result  
80 in extinction of the red squirrel throughout the U.K. by 2023 (Tompkins et al., 2003). Following its  
81 introduction to Ireland in 1911 (Watt, 1923), the grey squirrel (*Sciurus carolinensis*) has spread and  
82 is now found in 26 of the 32 counties (Carey et al., 2007). This has resulted in a 30% contraction in  
83 the range of the native red squirrel in Ireland in the last 10 years alone (Poole and Lawton, 2009).  
84 Grey squirrels are currently absent from south Cork (Carey et al., 2007). However, Goldstein et al.  
85 (2014) confirmed that the southern frontier of the grey squirrel range has progressed in a south  
86 westerly distribution since the 2007 survey. Clearly, red squirrel populations in South Cork and Kerry  
87 are particularly at risk as it is inevitable that the grey squirrel will eventually occupy all counties.  
88 Given their inevitable decline, it is likely that red squirrel populations may become isolated to small  
89 enclosed parks, where grey squirrel access can be controlled. However, how would the more  
90 secretive of the two-species fare in these parks, especially if they are used by the public?

91 With reserves becoming established within the U.K. to conserve remaining red squirrel  
92 populations (Lowney 2011), we aimed to examine the potential of a busy wildlife park as a refuge  
93 for red squirrels in an area currently free of the invasive grey. Given the more secretive nature of the  
94 red squirrel we hypothesised that squirrels occupying the busy wildlife park may have elevated levels  
95 of FCM and may modify their behaviour to reduce human encounters. However, we hypothesised  
96 that the park may still offer the potential to sustain healthy populations of this vulnerable species.

## 97 **Materials and Methods**

### 98 **Study site**

99 The study was carried out between December 2012 and March 2014 in Fota wildlife park  
100 (51.889585° N, 8.311276° W), 16.7 km from Cork City, Ireland. The wildlife park is located on an  
101 island connected to the mainland by two road bridges and a train bridge. The 315-hectare island  
102 includes a stately home and gardens (29 hectares), an 18 hole golf course and resort (243 hectares;

103 including a scout camp) and the wildlife park (32 hectares). An additional 11 hectares of land is  
104 currently being developed to expand the wildlife park and incorporates bordering areas of car park  
105 and woodland patches between the wildlife park and gardens (Fig. 1).

106 The wildlife park has been open since 1983 and has received over 4 million visitors between  
107 1983-2004. The park is open year round with visitor peaks in the summer months. There is a total of  
108 26 tree species in the wildlife park comprised of a mixture of native and non-native species. Most  
109 trees are mature (>50 years old), some much older trees originate from the original plantings carried  
110 out in the 19<sup>th</sup> century for the Fota estate.

### 111 **Trapping**

112 As part of a larger study, thirty squirrel traps (STV076 Defenders-STV International),  
113 modified with a nest box were placed around the island in February 2013 and pre-baited for a period  
114 of two weeks before trapping commenced. Traps were placed in areas of high public disturbance  
115 (wildlife park), intermediate disturbance (gardens and surrounding area) and low levels of human  
116 disturbance (woodland within the golf course; Fig. 1). Ten trapping sessions took place between  
117 March 2013 and March 2014, resulting in 1080 trap days. On the morning of each trapping session,  
118 traps were baited with hazelnuts, whole maize and peanuts. Traps were then checked a maximum of  
119 six hours later.

120 Each trapped squirrel was flushed into a light hessian bag and then put in a wire-mesh  
121 'handling cone' to minimize stress during handling. All animals were individually marked using  
122 passive integrated transponder tags (MID Fingerprint, Bournemouth, Dorset, UK) inserted into the  
123 nape of the neck. The sex and reproductive condition were recorded. An individual was considered  
124 to be in breeding condition if the nipples were visible in females and the testes were scrotal and large  
125 in males (Wauters and Dhondt, 1993). Each animal was weighed using a Pesola spring scale balance  
126 with clip (NHBS, Devon, U.K) and the shin length taken using vernier callipers. All applicable  
127 institutional and national guidelines for the care and use of animals were followed and all procedures  
128 were carried out in accordance with current regulations. Licenses (S.23-capturing and S.32-tagging)  
129 were obtained from the Department of Environment, Heritage and Local Government.

130 **Radio-tracking**

131 As part of a larger study investigating tree preference (Haigh et al., 2015), ten individuals  
132 (5♀, 5♂) on the island were fitted with radio-collars (Holohil Systems Ltd, Carp, Ontario, Canada).  
133 Four (3♀, 1♂) of the tagged squirrels were resident in the high disturbance area. Four (1♀, 3♂)  
134 squirrels were located in the intermediate disturbance area and two (1♀, 1♂) were resident at the low  
135 disturbance area. Once tagged, fixes were obtained on two days each week for a period of six hours  
136 per day. A fix was obtained on average every hour, with each fix representing a sighting of the  
137 animal. Sampling took place over two time periods, between morning to midday and midday to late  
138 afternoon with equal sampling times being conducted in each time segment to examine movement  
139 in and out of the wildlife park (high disturbance area). Of the 10 squirrels that were radio-tagged, a  
140 mean of 99 ( $\pm 16$ ) fixes per individual (range 48-183) were obtained, over a mean of 7 ( $\pm 0.17$ ) months  
141 (range 4-12). When located, the behaviour of the animal was recorded for a minimum of ten minutes  
142 or until the squirrel was no longer visible. The number of visitors (if any) visible by the observer  
143 from that location was also recorded. In addition, daily visitor numbers were obtained from park  
144 staff.

145 **Sampling/Locating squirrels**

146 The 32 ha park (high disturbance) consists of non-public areas (8 ha) and areas accessible to  
147 the public (24 ha). Two 1 km routes were selected, one encompassing areas in the public domain and  
148 the other, covering areas that were not accessible to the public (Fig. 2). The park is open from 10 am-  
149 5 pm daily during the summer, closing at 4 pm in the winter, with staff arriving around 8 am. For the  
150 purpose of this study the park was accessible to the authors 24 hours a day. These two transects were  
151 walked at a steady pace at times when the park was closed and again when it was open and all squirrel  
152 encounters were recorded. When a squirrel was observed, its GPS (Garmin) location was recorded,  
153 where possible its behaviour (Table 1), and the number (if any) of visitors that were visible to the  
154 observer from that location. Temperatures ( $^{\circ}\text{C}$ ) were obtained from MET Eireann ([www.met.ie](http://www.met.ie)).

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157 **Faecal cortisol metabolites (FCM)**

158 At the time of capture, faeces from individual squirrels were collected from all 30 traps on  
159 the island. This was to investigate variations in stress levels between the different areas of the island  
160 and whether elevated stress levels were correlated with the greater public disturbance in the high  
161 disturbance area in comparison to areas of low public disturbance. When faecal matter was present,  
162 it was removed using forceps and placed in vials and labelled with the P.I.T tag identification code  
163 of that squirrel. Faeces were only collected if that squirrel had not previously been caught in that  
164 trapping session, to eliminate recording elevated stress levels due to trapping. Samples were placed  
165 in freezer bags and frozen at -20 °C a maximum of four hours later. At the end of trapping in March  
166 2014, samples were sent on dry ice to the University of Veterinary Medicine, Vienna and extracted  
167 as previously described in detail (Touma et al., 2003; Dantzer et al., 2010; Dantzer et al., 2011; Palme  
168 et al., 2013). FCM were analysed with a 5 $\alpha$ -pregnane-3 $\beta$ ,11 $\beta$ ,21-triol-20-one enzyme immunoassay  
169 (EIA) which measures glucocorticoid metabolites with 5 $\alpha$ -3 $\beta$ ,11 $\beta$ -diol structure (Touma *et al.* 2003).  
170 This EIA has been successfully validated in different squirrel species (Bosson et al., 2009, 2013;  
171 Dantzer et al., 2010) including the European red squirrels, *Sciurus vulgaris* (Dantzer et al., 2016).

172 **Data analysis**

173 Means are provided with standard errors unless otherwise stated. All analysis was performed  
174 on IBM SPSS statistics 22 (IBM, NY). Chi Square tests were used to compare the observed number  
175 of squirrel fixes with what would be expected along transects and whether the park was opened or  
176 closed to the public. These tests were also used to examine whether there was a significant  
177 relationship between the number of squirrel fixes in public and non-public areas. To investigate a  
178 number of potential factors that could influence FCM levels, a general linear model (GLM) was  
179 performed. Factors tested included season, sex, breeding condition, weight, temperature, visitor  
180 numbers and whether the area experienced low, intermediate or high public disturbance. Residuals  
181 were checked for normality using the Kolmogorov Smirnov test ( $P > 0.05$ ). Due to the low sample  
182 size for some months, the year was divided into four seasons (December-February; March-May;  
183 June-August and September-November). The mean temperature was  $10 \pm 4$  (SD) °C and the number



184 of visitors per day  $428 \pm 666$  (5 (min)-2467 (max)). All assumptions were met, with for example the  
185 data showing independence of residuals (Durbin-Watson-1.729) (Durbin and Watson, 1951,  
186 Hocking, 2013), no evidence of multicollinearity (as assessed by tolerance values of  $>0.1$ ) and a  
187 maximum Cooks distance score of 0.168. Stepwise model selection was performed by eliminating  
188 parameters with p values  $>0.05$ . To investigate whether there was an effect of the number of  
189 individual squirrels caught per area and the FCM levels, a spearman rank correlation was performed.

## 190 **Results**

### 191 **Distribution of radio-tagged squirrels**

192 A total of 481 fixes were collected from four (3♀, 1♂) squirrels in the high disturbance area  
193 from March 2013 to March 2014. Significantly more fixes were obtained in non-public (n=397) than  
194 public (n=84) areas ( $\chi^2=87.68$ , df=18,  $p<0.001$ ; Fig. 3). The non-public areas were dominated by  
195 areas of yew (*Taxus baccata*) and squirrels were found to select this tree species at all times of the  
196 year (Haigh *et al.* 2015). An exception to this was a yew rich area which was situated in the public  
197 area at the entrance of the park. There was significantly more radio-fixes obtained in public areas  
198 when the park was closed as opposed to when it was open to the public ( $\chi^2=33.00$ , df=17,  $p<0.01$ ).  
199 For instance, in one public area bordering a non-public zone, up to six squirrels were seen foraging  
200 on the ground beneath a stand of yew just prior to the park's opening. However, as soon as the park  
201 opened they either left the park or retreated to non-public areas (pers. obs.). Four (1♀, 3♂) of the  
202 squirrels first trapped in the intermediate disturbance area also entered the high disturbance area,  
203 particularly the aforementioned stand of yews (public area). They were observed to utilise this area  
204 significantly more at times when the park was closed and occupy the intermediate area when it was  
205 open ( $\chi^2=10.15$ , df=2,  $p<0.01$ ). The other squirrels (1♀, 1♂) were resident in the low disturbance  
206 area and were never recorded in the area of high disturbance.

### 207 **All other sightings**

208 Non-radio-tagged squirrel sightings were recorded over 80 days (twice a week) from March  
209 2013 to March 2014, resulting in a total of 299 observations. There was a significantly higher number  
210 of observations ( $\chi^2=24.49$ , df=15,  $p<0.05$ ) in non-public areas (n=200) than public areas (n=99) but

211 there was no significant difference in the number of observations along the transects, when the park  
212 was open or closed to the public ( $\chi^2=17.3$ ,  $df=15$ ,  $p>0.05$ ). However, activity was concentrated in  
213 non-public areas with more incidences of them being in public areas when the park was closed (46  
214 vs. 32 observations) and in non-public areas when the park was open (168 vs. 53). When squirrels  
215 were observed in public areas during open times, visitors were observed on only 15% of occasions.

## 216 **Behaviour**

217 In the majority of observations squirrels were either foraging (54 (public) and 33 (non-  
218 public) %) or jumping and climbing (20 and 35%). There was little difference in the behaviour of  
219 squirrels in the public and non-public areas and depending on whether visitors were present or not  
220 (Table 2). Notably, there was no difference in vigilance behaviour when people were present or  
221 absent (Table 2).

## 222 **FCM levels**

223 Over the ten trapping sessions, 52 faecal samples were collected from 34 separate individuals  
224 (16♀, 18♂). A mean of  $1.6 \pm 0.03$  (SE; range 1-5) samples were collected per individual. The mean  
225 ( $\pm$  SD) weight of squirrels was  $358 \pm 26$  g. The general linear model revealed two factors (area and  
226 breeding condition) that significantly affected the squirrels FCM levels ( $R^2 = 0.494$ ,  $F_{2, 49}=7.917$ ,  
227  $p=0.001$ ;  $F_{1, 50}=6.185$ ,  $p=0.016$ ; Table 3). Mean FCM levels were higher (mean  $14.3 \pm 2.64$ ) in the  
228 high disturbance area than in the low disturbance area (mean  $6.35 \pm 3.34$ ). Mean FCM levels ( $\mu\text{g/g}$   
229 faeces) of squirrels were almost double when they were not in breeding condition ( $14.8 \pm 2.68$ ), as  
230 opposed to when they were ( $7.08 \pm 1.58$ ). This pattern was apparent in both males and females. There  
231 was no significant relationship between the stress levels of squirrels and the number of visitors in the  
232 park ( $p=0.370$ ) and this was therefore excluded from the model. For instance, the lowest FCM levels  
233 were found in June-August when the park was at its busiest (Fig. 4) and highest in September-  
234 November when the park was quietest. Instead the density of other squirrels had an effect with a  
235 significant correlation ( $r_s=0.813$ ,  $p<0.01$ , Spearman's rank) between FCM levels and the number of  
236 different individuals that were caught in that trap over the study period, suggesting that squirrels in

237 areas where there was a higher number of captures/squirrel density, also had elevated stress levels  
238 (Fig. 5).

## 239 **Discussion**

240 This study hypothesised that red squirrel densities would be lower in areas exhibiting the  
241 highest levels of human disturbance and that squirrels would avoid human encounters, as has been  
242 found in previous studies on red squirrels (Lowney 2011), mountain hares *Lepus timidus*; (Rehnus  
243 et al., 2014) and black grouse, *Tetrao tetrix*; (Arlettaz et al., 2007; Formenti et al., 2015). In contrast  
244 to what was hypothesised, squirrel densities in the current study were higher in the areas with the  
245 highest levels of human disturbance. However, while densities were higher in these areas, squirrels  
246 did show avoidance behaviour. For instance, when squirrels were observed in public areas during  
247 open times, they were always near non-public areas and the public were only visible on 15% of  
248 occasions. Similarly, Thiel et al. (2008) stated that capercaillie probably use skiing areas only when  
249 undisturbed refuges are also available within their home ranges.

250 In accordance with the hypothesis, there was also evidence that squirrels altered their activity  
251 to avoid human encounters and may have habituated to the opening hours of the park. Blanc et al.  
252 (2006) recorded how habituation can occur frequently among species, if as Conomy et al. (1998)  
253 stated animals experience a regular and predictable stimulus which does not represent a lethal threat.  
254 In the same manner, the red squirrels in the high disturbance area, may have adapted to the routine  
255 of visitor times, something which is suggested by their movement into public areas during times  
256 when the park was closed. Furthermore, squirrels that inhabited adjacent areas of the park were also  
257 observed to enter the park during closed periods.

258 The immediate response of many animals to disturbance is a change in behaviour, which can  
259 result in a trade-off between avoiding perceived risk and other fitness enhancing activities such as  
260 feeding, parental care and mating (Frid and Dill, 2002). Some animals may compensate for energy  
261 losses by increasing their food intake after the disturbance event (Blanc et al. 2006; Arlettaz et al.  
262 2014). Experimental disturbance of black grouse resulted in an extension of feeding duration during  
263 the following evening foraging bout, confirming the prediction that black grouse must compensate

264 for the extra energy expenditure elicited by human disturbance (Arlettaz et al., 2014). However, the  
265 fact that squirrels did not change behaviours such as foraging and vigilance in public and non-public  
266 areas and at times when the park was open and closed, suggests that the squirrels were displaying  
267 habituation rather than compensatory strategies.

268 In the current study, we hypothesized that squirrels occupying areas of the highest visitor  
269 numbers would have associated elevated FCM levels, as for instance has been observed in  
270 capercaillie who showed markedly increased stress hormone levels closer to locations with winter  
271 recreation activity (Thiel et al. 2008, 2011). However, while FCM levels of squirrels were higher in  
272 the high disturbance areas, than in the intermediate and low disturbance areas, there was no  
273 correlation between visitor numbers and stress levels. Visitor numbers were highest in June-August  
274 and at this time FCM levels were low amongst the squirrels in the park. Martin and Reale (2008)  
275 observed that human frequentation did not affect cortisol levels in chipmunks suggesting that it was  
276 not the main factor responsible for their stress reaction. Instead they stated that other factors such as  
277 intraspecific aggression and predation might play a role in cortisol secretion. A higher number of  
278 individuals were caught in traps in the high disturbance areas and higher FCM levels were observed  
279 in those animals. Dantzer et al. (2013) observed that experimental elevation of actual and perceived  
280 density induced higher maternal glucocorticoid levels. Squirrel densities were higher in the high  
281 disturbance area (mean of  $0.35 (\pm 0.03)$  (S.E) per ha) than in the intermediate ( $0.17 \pm 0.03$  per ha)  
282 and low disturbance areas ( $0.009 \pm 0.007$  per ha; Haigh et al. submitted) and this could potentially  
283 result in an increased competition for resources from conspecifics and a subsequent increase in stress  
284 levels. FCM levels in the current study were observed to be highest in September-November and  
285 when the squirrels of both sexes were not in breeding condition. This is in accordance with some of  
286 the findings of Dantzer et al. (2016) who described that the lowest FCM levels were present in  
287 pregnant females. Wauters and Dhondt (1993) observed that after the breeding season, adult females  
288 started to forage more intensively over the whole home range. This consequently results in more  
289 frequent interactions with transients, and potential elevated stress levels through competition, which  
290 may result in a 'stress of subordination' (Blanchard et al., 1993). Dantzer et al. (2016) also observed

291 elevated FCM levels in the autumn/winter period, something they attributed to more frequent  
292 intraspecific interactions linked to dispersal, higher predation risk when foraging on the ground and  
293 reduced food quality and/or more extreme weather conditions in winter. This pattern was also  
294 observed in alpine chamois, *Rupicapra rupicapra* (Corlatti et al. 2014).

295 From a conservation perspective, human disturbance of wildlife is important only if it affects  
296 survival or fecundity and hence causes a population to decline (Gill et al., 2001). Rehnus et al. (2014)  
297 observed that female hares failed to reproduce following stress experiments and that higher FCM  
298 levels observed as a result of tourism could negatively affect the reproduction of wild mountain hares  
299 in the subsequent breeding season. This can have long term impacts with lower body masses and  
300 lipid reserves as observed in disturbed chamois (Schnidrig-Petrig et al., 1998). However, in the  
301 current study all squirrels caught exhibited weights that were in line with what was defined as healthy  
302 in other studies (Wauters & Dhondt, 1989). In addition, no differences were observed between the  
303 body or breeding condition of squirrels in disturbed versus undisturbed areas of the island (Haigh et  
304 al. submitted) or in the vigilance of squirrels in public/non-public areas and in the presence of the  
305 public.

## 306 **Conclusions**

307 In Ireland, the range expansion of the grey squirrel has been up to 13.4 km/year (Teangana  
308 et al., 2000). Similarly, in Italy, following introductions from 1948 to 2000 the grey squirrel has  
309 colonised at a mean rate of 17.2 km<sup>2</sup> per year and it is estimated that it could reach France in 2026-  
310 2031 and Switzerland in 2031-2041 (Bertolino et al., 2008). With this rapid spread of the grey,  
311 managed parks will take on a greater importance for the maintenance of red squirrel populations.  
312 While Southern (1964) commented how the red squirrel favours seclusion, Tittensor (1970) observed  
313 that in city parks in Stockholm, red squirrels were as tame as grey squirrels in British cities. Similarly,  
314 Rezouki et al. (2014) observed that an urban park near Paris, successfully maintained a viable  
315 population of red squirrels and provided an important potential refuge for the species. In the case of  
316 mountain hares, Rehnus et al. (2014) asserted that there should be regulations in areas where  
317 mountain hare habitats overlap with human winter recreational activities, with tourists being confined

318 to marked trails. Likewise, the results of this study would suggest that red squirrels can habituate to  
319 human disturbance, as long as non-public areas are also available. Forest patches that are inaccessible  
320 to humans might provide a visual and acoustic shield from recreation activities in adjacent areas  
321 (Thiel et al. 2008). It is therefore essential that management strategies are implemented to provide  
322 these undisturbed areas for the maintenance of red squirrel populations in parks. Not only could these  
323 parks provide important refuges for the maintenance and conservation of this endangered species but  
324 these reserves could also provide important source populations for the recolonisation of other areas,  
325 ensuring the long term survival of this species in the wild.

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### 331 **References**

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474 **Figure titles**

475 **Figure 1:** The 315 ha of Fota Island displaying the main recreational areas of the island.

476 **Figure 2:** Public and non-public transects walked through the wildlife park.

477 **Figure 3:** Radio tracking fixes (n=481) from March 2013-March 2014, showing the squirrels  
478 locations during visitor times and when the park was closed.

479 **Figure 4:** Mean ( $\pm$ SD) number of visitors to Fota Wildlife Park per month and mean ( $\pm$ SD) FCM  
480 levels ( $\mu$ g/g faeces) of squirrels during the same period.

481 **Figure 5:** Mean FCM levels ( $\mu$ g/g faeces) per trap and the trapping density over nine trapping  
482 sessions.

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496 **Table 1:** Ethogram of behaviours displayed by the squirrels.

Recorded behaviour	Description
Foraging/Eating	This includes eating, digging at the ground, manipulating branches with forelimbs, and engagement in searching for food.
Vigilant	The animal is frozen, flat on the branch, staring downwards
Climbing/jumping	The squirrel is moving through the branches or between the trees without stopping to forage.
Other	This includes grooming, courtship behaviour, running, walking, vocalisations or when the squirrel was stationary

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513 Table 2: The percentage of time that squirrels were observed engaged in each of the recorded  
 514 behaviours in non-public and public areas and in the presence and absence of the public.

	<b>Public areas (n=252)</b>	<b>Non-public areas (n=145)</b>	<b>Public</b>	
			<b>People present (n=16)</b>	<b>No people present (n=402)</b>
<b>Foraging/Eating</b>	54	33	63	40
<b>Vigilant</b>	3	9	6	6
<b>Climbing/jumping</b>	20	35	25	28
<b>Other</b>	23	23	6	26

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530 Table 3: The results of the general linear model, showing the factors significantly impacting on the  
 531 FCM levels of squirrels (B=unstandardised regression co-efficient, SE= standard error of the co-  
 532 efficient;  $\beta$ =standardised co-efficient).

	<b>B</b>	<b>SE<sub>B</sub></b>	<b><math>\beta</math></b>	<b>P value</b>
Intercept	9.596	6.121		
Area	8.596	2.707	.401	0.003
Breeding condition	9.660	3.275	.373	0.005

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