Fawn bedsite selection by a large ungulate living in a peri-urban area

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Abstract

Human-wildlife conflict in expanding peri-urban and urban areas is of increasing concern, as a result of growing human populations along with the associated anthropogenic footprint on wildlife habitats. Empirical data from wildlife research carried out within human dominated landscapes are key to understanding the effects of human pressures on wildlife ecology and behaviour, exploring wildlife behavioural flexibility (or phenotypic plasticity), and informing wildlife management decisions. Here, we explored how female fallow deer (*Dama dama*) responded to human and dog presence during the birthing period in the largest walled urban park in Europe. We collected data on 477 bedsites utilised by 283 neonate fawns across three consecutive fawning seasons, gathered fine-scale data on humans and dogs space use, and built Resource Selection Functions at multiple spatial scales. We found that, when choosing bedsites to give birth and leave fawns unattended, fallow deer mothers significantly avoided hotspots of park visitors on foot (and their dogs) along the hiking trail routes. Bedsites were also unlikely to be in close proximity of paved roads used by vehicle traffic. Additionally, fallow deer mothers were found to select for dense understory vegetation for bedsites, providing low visibility to conceal their offspring. Our results provide detailed insights into bedsite spatial and habitat selection by a large herbivore in response to human activities, and we provide clear indications to wildlife managers to preserve established fawning sites and alleviate human-wildlife conflict during a critical period of the deer annual biological cycle.

Keywords: human-wildlife conflict, deer, urban wildlife, Resource Selection Functions, bedsite selection.

Introduction

We are currently in the Anthropocene, defined by extensive human impact on our planet's ecology and geology (Morelli et al., 2020). It is estimated that more than 50% of the human population will be concentrated in cities by 2030 (Lowry et al., 2013, Shochat et al., 2006), with these cities presently expanding at an unprecedented rate worldwide (Wolff et al., 2018). This process leads to increased synurbanisation, i.e. wildlife increasingly living in and adapting to urban environments, with a concurrent increase in encounters between humans and wildlife (Barber et al., 2010, Gallo et al., 2019, Huijbers et al., 2013, Tucker et al., 2018). Several concerns have been raised about the potential for artificial selection processes to occur as a result of human-wildlife interactions (i.e., certain morphological and/or behavioural traits favoured over others) within urban settings (Griffin et al., 2022, Lowry et al., 2013).

Empirical research has repeatedly shown that human presence can affect wildlife behaviour significantly (Gander and Ingold, 1997, Hebblewhite et al., 2005, Recarte et al., 1998, Shen-Jin et al., 2007, Whittington et al., 2004). Wildlife species may increase flight response in locations with high human presence (Recarte et al., 1998), as well as increase selection of safer habitats and reduced movement (Gander and Ingold, 1997, Hebblewhite et al., 2005, Recarte et al., 1998, Shen-Jin et al., 2007, Whittington et al., 2004). Within urban settings, however, wildlife species need to adapt their anti-predator strategies (e.g., reduced flight distance) as fleeing any time that they encounter humans would be energetically expensive. This highlights how behavioural flexibility (or phenotypic plasticity) may be an important characteristic for succeeding in urban environments (Lowry et al., 2013).

Dog owners within urban areas need to walk their dogs and make any possible use of green areas and urban parks, potentially leading to high encounter rate between dogs and wildlife inhabiting urban areas. Dog presence has been shown to alter wildlife behaviour, though responses vary depending on the wildlife species (Manor and Saltz, 2004, Martinetto and Cugnasse, 2001, Miller et al., 2001). Both domestic and feral dog presence increases alert and escape distances in many ungulate species, and has been associated with a reduction in offspring:female ratios (Manor and Saltz, 2004, Martinetto and Cugnasse, 2001, Miller et al., 2001). These decreases in offspring production could be caused by associated increases in vigilance in mothers, decreased breeding behaviour, or a combination of both (St. Clair and Forrest, 2009). Due to the importance of successful breeding seasons in keeping wild animal populations healthy, changes in breeding behaviours during this sensitive period can lead to indirect effects, with potential long-term consequences for the composition (i.e., age ratios) of wild populations and natural selection processes (Lowry et al., 2013). As humans and their dogs are both likely to come into more regular contact with wild animals within increasingly human dominated environments, studies assessing the consequences of human and dog presence on wildlife are increasingly important.

Ungulates exhibit various strategies to increase offspring survival during their first weeks of life; this constitutes a continuum ranging from “hider” to “follower” species (Walther, 1961a). As a “hider” species, fallow deer (*Dama dama*) mothers hide their offspring in dense vegetation, where they remain separated for several hours at a time (Chapman and Chapman, 1997). Selection of these “bedsites” after parturition plays a major role in increasing offspring survival (Gerlach and Vaughan, 1991, Tull et al., 2001, Van Moorter et al., 2009, Monestier et al.,

65 2015). During this vulnerable time for offspring, fallow deer mothers decrease their home-range
66 sizes and select for denser vegetation to increase concealment and decrease predators' ability to
67 detect fawns (Ciuti et al., 2006). However, research to date has focused almost exclusively on
68 rural areas, with little understanding of bedsite selection in peri-urban landscapes (Smith and
69 Lecount, 1979, Long et al., 1998, Piccolo et al., 2010). This highlights the need for an empirical
70 quantification of the impact of people and their dogs on deer behaviour during fawning to
71 manage wildlife populations within urban settings.

72 Here, we gathered data on 477 bedsites used by 283 individual fallow deer fawns
73 across 3 consecutive fawning seasons in the largest walled urban park in Europe, Phoenix Park,
74 located at the heart of Dublin, Ireland. This is the largest dataset ever compiled on bedsite
75 selection in a large ungulate in an urban parkland. We explored bedsite selection by fallow deer
76 mothers that have adapted to live in a peri-urban area under high human pressure. Phoenix Park
77 is an ideal model for this study as boasts a substantial herd of wild fallow deer, it receives 10
78 million annual visitors, typically on foot with many walking their dogs, and large amounts of
79 vehicular traffic (which includes commuters to and from Dublin city centre) at the edge of a
80 capital city. Also, because of the walled nature of the park and the peri-urban environment, it is
81 extremely hard for the deer to leave and find suitable habitat outside the park.

82 We made 3 main predictions related to our hypothesis that fallow deer mothers would
83 select for the most suitable bedsite features while attempting to minimise human disturbance,
84 where possible, in such a restricted space: (i) mothers would select bedsites characterized by
85 denser vegetation and lower visibility, when compared to random available sites, to reduce fawn
86 detectability by terrestrial predators (including humans); (ii) bedsites would be located outside

87 and at greater distances from hotspots of human and dog presence along hiking trails; and (iii)
88 mothers would avoid roads with vehicle traffic when selecting fawns' bedsites. Our study site,
89 Phoenix park, is dominated by park visitors during the day; as a consequence, fallow deer
90 mothers are expected to find the best balance between selecting suitable vegetation and an
91 appropriate distance from humans for their fawns' bedsites, giving us the opportunity to describe
92 deer plasticity and adaptation to extreme conditions in terms of human presence. To better
93 disentangle such behavioural response, we analysed our data looking at two spatial scales: large
94 scale (study-site-level), to depict general avoidance of human presence hotspots; and a small
95 scale (bedsite-level), to understand specific decisions made by mothers when selecting for
96 bedsite characteristics and visibility. Our work has important management implications because
97 our analytical approach allows to estimate threshold distances (distance to roads and hiking
98 trails) and vegetation characteristics (vegetation density and related visibility) that may be used
99 by park managers to create buffer zones and strictly protected core areas for wild deer during
100 this important stage of their annual biological cycle.
101

102 **Materials and methods**

103 Study site

104 The study was conducted in Phoenix Park, a 709ha urban park located in Dublin,
105 Ireland (53°22'N, -6°21'W, Fig. 1), which receives an estimated 10 million visitors annually (Office
106 of Public Works, OPW, official data). The vegetation is mainly grassland (56%) and woodland
107 (31%), with 7% of the park covered by roads and buildings (OPW, 2020). The Park management
108 (OPW) maintains a fallow deer population of around 600 individuals (end of summer population

109 estimate, which includes newborn fawns, OPW official data), and this number is kept constant
110 by yearly culls. The only natural predator in the park is the red fox, which seldomly predates
111 newborn fawns. Over the years, however, we have made several direct observations of
112 unleashed dogs chasing fawns, in many cases resulting in the injury or death of fawns.
113

114 Data collection

115 *Fawn captures and bedsite characteristics*

116 Fawns have routinely been captured in June (from June 5th to June 28th) and ear-tagged
117 with unique numbered plastic tags (Allflex medium; Mullinahone Co-op, Ireland) since the early
118 1970s as part of the monitoring and management of the fallow deer herd (Hayden et al., 1992,
119 Amin et al., 2021). We split the geographical area typically used by females as fawning sites
120 (displayed in both Fig 1 and Fig. 2a) into seven sectors. These were patrolled routinely, visiting 2-
121 3 sectors daily, with each sector visited at least once every 2-3 days. Approximately 10-15 trained
122 team members supervised by a certified wildlife biologist captured fawns using circular fishing
123 nets (1–1.5m of diameter) manoeuvred by long handles (1.5m long). The capture team usually
124 worked between 9:00 to 16:00 hrs daily, 7 days a week for more than three consecutive weeks,
125 with the goal of tagging most of the newborn fawns within this population (~85%).

126 The capture team collected data on fawns and their associated bedsites following a
127 well-defined protocol; see Amin et al. (2021) for a full description of the information collected on
128 fawns. For this study, we used the following data: fawn identity (ear tag code) and sex; fawn
129 weight (i.e. an objective proxy for age *sensu* Amin et al. (2021), determined by placing the fawn
130 into a 100-litre bag, which was weighed using a digital scale – resolution: 0.01 kg, Dario

Markenartikelvertrieb); GPS coordinates of the bedsite (using a Garmin etrex 30 hand-held unit); and bedsite visibility (see below for full description). Fawns were routinely recaptured to monitor body growth (Griffin et al., 2023), allowing us to collect bedsite characteristics in older fawns. Our final database consisted of fawn capture data collected in 2018 (n = 102 individual fawns), 2019 (n = 81), and 2020 (n = 100). Note that we also had data on 4 additional bedsites outside the capture sectors which we excluded due to the lack of random available points. Because of recaptures, we gathered data on a total of 477 bedsites (n = 163 in 2018, n = 152 in 2019, and n = 162 in 2020, Fig. 3). Note that the bedsite location of recaptured fawns could be different from the one of the first capture, either because the mother moved the fawn, the fawn – once old enough to move independently (1-2 weeks old) – decided to relocate elsewhere, or because of our disturbance. Nevertheless, we were interested in capturing the behavioural process behind the selection of bedsites in an area heavily used and disturbed by humans, and therefore keen to learn from multiple recaptures of the same individual, with the *a priori* assumption that when a bedsite was disturbed, the next one would be selected to minimise human disturbance. Concurrent research in the same park (Faull et al. 2024) has showed that bedsite selection is dictated by the mother when the fawns are neonates (first few days of life). Older (heavier) fawns, however, tend to be more mobile and may have a role in selecting the exact place where to settle down when moving from one bedsite to another (Faull et al. 2024).

We assessed the average visibility of the fawn bedsite – ranging from 0 (no visibility) to 1 (full visibility) (*sensu* Bongi et al., 2008) – as follows: from a distance of 10m along the four cardinal directions we recorded the proportion of visually unobstructed triangles on a cardboard shape the size of a standing fawn (height: 45cm, width: 36cm), with the bedsite set as the

153 centroid. We observed the cardboard shape from an eye height of 70cm, which approximately
154 corresponds to the eye height of a red fox or a medium-sized dog. The study protocol and all
155 research procedures were approved by the UCD Animal Research Ethics Committee for the
156 duration of 5 years (2018-2023), under the permit AREC-E-18-28.

157 *Presence-available study design*

158 We used a presence-availability design to depict bedsite selection using Resource
159 Selection Functions (RSFs) (Thurfjell et al., 2014, Ciuti et al., 2018). RSFs allowed us to estimate
160 the relative probability of selection by comparing environmental features of used sites (a.k.a.
161 presence data from sites where fawns were found and captured) to those of sites selected at
162 random, defining environmental characteristics available in the study site. Random available
163 points were selected in R 3.6.3 (R Core Team, 2020) within the capture areas with the rule that
164 they each had to be at least 20m apart to avoid overlap (and therefore dependency) of visibility
165 measurements taken at each bedsite. Random points were visited during the fawning season,
166 and, for each location, we recorded the visibility following the same protocol adopted for the
167 true fawn bedsites (Fig. 3).

168 *Spatially-explicit data collection on park visitors and their dogs during the fawning* season

169 We collected data on park visitors and their dogs during the fawning season of 2019
170 (7th-28th of June, Fig. 2b) to build a spatially-explicit model of human abundance. Hiking trails
171 were the same in 2018, 2019, 2020, and our goal was not to estimate the variation in human
172 abundance across years, but rather understand which hiking trails were commonly used by park
173 visitors. We walked at a constant pace (5km/hr) along all hiking trails following a strict systematic
174 stratification, to survey each trail equally as a function of time of the day and day of the week.

We used a GPS handheld unit to record the position of human and dog presence on paths or trails. If people or dogs were outside the path or trail (see Fig. 2b) – which occurred seldomly – their GPS location was estimated by combining data from the GPS hand-held unit (Garmin etrex 30), a rangefinder (Hawke Endurance), and a compass. For each observation, we counted the number of visitors and dogs.

Data Analysis

All analyses were carried out in R 3.6.3 (R Core Team, 2020). Using the human and dog presence observations, we created probability maps of park visitors and dogs in the fawning area. We first overlaid a grid of 50x50m cells on the fawning area and added the observation counts to each cell, once for humans and once for dogs, and separately for weekdays and the weekend, resulting in four observation maps. Since the observations of dogs were considerably lower than the observations of humans, dog presence was converted into a binomial value (presence-absence). We then fitted two spatial Generalized Additive Models (GAMs; Wood, 2017) for humans and dogs as a function of the fawning area location (east coordinate, north coordinate) and day of the week (categorical, 2 levels: Mon-Fri weekday, and Sat-Sun weekend), specified in R as follows: (i) Human abundance model: *gam*(human abundance ~ s(east coordinate, north coordinate, k=29) + day of the week, family = Poisson (quasi-Poisson corrected)); (ii) Dog presence model: *gam*(dog presence ~ s(east coordinate, north coordinate, k=29) + day of the week, family = binomial). We used a quasi-Poisson-corrected Poisson error distribution for the human abundance model to account for a mild overdispersion (Zuur et al., 2009). For both models, the spline knots were manually set to 29 to avoid overfitting the data following the indications from the *gam.check* function (Wood, 2017). Both models were used to

197 predict human abundance (number of visitors) and dog presence at the 50x50m resolution using the
198 *predict* function in *mgcv* (Wood, 2017).

199 For each used and available point we assigned land cover type (Ordinance Survey
200 Ireland, official data – 10m resolution) using the o*ver* function from the *sp* package (i.e.
201 categorical variable with two levels: forest, and open habitat – corresponding to grassland), as
202 well as predicted (either weekday or weekend) human abundance and dog presence, and
203 distance to the nearest paved road (where vehicular traffic was allowed, in meters) using the
204 function *gDistance* from the *sp* package (Pebesma and Bivand, 2005, Bivand et al., 2013). We
205 created buffers of 250m and 2500m around all bedsites to assign the random available points at
206 the two spatial scales (bedsite-level and study-site-level). The small size diameter was chosen
207 since it was the smallest buffer that allowed for all bedsites to be compared with enough
208 available points at this resolution (used:available ratio 1:6). The large scale corresponded to the
209 distance between the two most distant vertices of the polygon defining the fawning area,
210 therefore in this instance availability was defined at the population level (Manly et al. 2007).
211 Buffer zones were created using the *gBuffer* function from the *sp* package in R. Our sampling
212 design did not match presence data with available points in the close proximity only, which
213 should have been analysed using a conditional logistic regression able to stratify on matching
214 pairs where each stratum would have its own intercept (*sensu* Thurfjell et al. 2014). We were
215 interested instead in building multiple scale resource selection functions, meaning that given a
216 spatial scale – e.g. 250m – the environmental characteristics of used points were compared to
217 those of the random available points occurring within the 250 meters of all used points. This
218 allowed us to understand the decisions taken by mothers when selecting for fawn bedsites at

219 different spatial scales: when looking at 250m scale, for instance, we were investigating the
220 selection of environmental characteristics on a small scale, but unable to understand the effect
221 of larger scale patterns (e.g. the avoidance of human hotspots at a greater distance than 250
222 meters) that could be depicted instead by the large scale analysis.

223 We screened all variables described above, to include in the RSF, for collinearity
224 (Dormann et al., 2013), and found that the spatially-explicit predictions of number of park visitors
225 were highly collinear with dog presence (see Supporting information). We therefore retained the
226 number of park visitors since it was continuous data and able to give a better picture of different
227 levels of disturbances when compared to the binomial probability of dog presence.

228 Resource Selection Functions, built assuming an exponential form, require normally
229 distributed continuous predictors (Thurfjell et al., 2014). Therefore, we transformed both human
230 abundance and road distance data to meet model assumptions. We succeeded with the
231 transformation of human abundance data using a box-cox transformation, a family of power
232 transformations which selects the best mathematical function for the data transformation to
233 achieve data normality (i.e., achieved using a log-likelihood procedure to find lambda and
234 transform the non-normally distributed variable, see Supporting information) using the *MASS*
235 package (Venables and Ripley, 2002). We were not able to improve the extremely skewed
236 distribution of road distance; this variable was therefore converted into a two-level categorical
237 predictor (close vs far) using a threshold point of 50m. The threshold point was selected by
238 running a sensitivity analysis with preliminary resource selection functions fitted with different
239 threshold values, and the best model was the one with the lowest Akaike Information Criterion,
240 AIC (see Supporting information).

241 To estimate the coefficients for the small and large scale RSFs, we fitted Generalized
242 Mixed-effect Models (GLMM, *glmer* function from package *lme4* - Bates et al., 2015) with a
243 binomial distribution of errors (response variable: used points, 1s; and random available points,
244 0s) and fawn identity as random intercept. The *a priori* model structure – fitted for both spatial
245 scales - is reported in Table 1. We scaled numerical predictors to improve model convergence
246 and included quadratic terms to account for non-linear effects. We defined our model structure
247 *a priori* by considering the predictors that we hypothesized to be ecologically relevant in driving
248 habitat selection in this population living in a peri-urban area. We therefore intentionally did not
249 attempt to simplify the model structure, but rather opted for interpreting the full model structure
250 (Dorman et al. 2018). The inclusion of quadratic effects was motivated by the fact that we did
251 not expect bedsite visibility, distance to roads, nor human abundance to have a straight linear
252 effect but rather a plateau effect (e.g. flat after a certain value of the predictor variable) or fully
253 quadratic effect. Note that sex, weight of the fawn (proxy for age), and year of study were
254 included in the model as confounding predictors to specify the dependency structure of the data
255 (see Table 1 for full details) but no ecological inference will be made because their significant
256 levels would simply predict that e.g. more used locations have been collected in a year compared
257 to the next one. Sex and year could have been included as random intercepts in the GLMM but
258 this was avoided due to reduced degrees of freedom.
259 Parameters estimated by the GLMM were extracted and plugged into the RSF taking
260 the exponential form (Thurfjell et al., 2014, Fechter et al., 2019, Brivio et al., 2019). RSF
261 scenarios estimating relative probabilities of selection (Thurfjell et al., 2014) were built by
262 varying the predictor of interest (e.g., visibility) while keeping all the other variables to median

263 values (for numerical variables) or to a fixed level (for categorical variables: Year = 2018, Sex = f,
264 Land cover type = open).
265

266 Results

267 We depicted human abundance and dog presence probability maps (50x50m resolution)
268 of the fawning area in Phoenix Park as predicted by the Generalized Additive Models in Fig. 4 (see
269 Supporting Information for full details). In terms of bedsite use, the n = 477 bedsites were
270 characterised by a mean visibility of 0.06 (min-max: 0-1); 21% of them were at a distance lower
271 than 50m from roads (average distance from roads 119m; min-max: 4-338m); mean human
272 abundance predicted at bedsites was 1.22 people per 50x50m pixels(min-max: 0.0009-5.81), and
273 70% of the besites were found in forest habitat.

274 We reported the parameter estimates of the two GLMMs (small and large scale,
275 respectively) in Table 2. Year, sex, and weight were included in the model to specify the
276 dependency structure of the data, but no inference was made because not included as
277 interaction terms *a priori*. Areas with higher human abundance were avoided at the large spatial
278 scale (Table 2), with bedsites clustered and located outside human hotspots (Fig. 4), whereas
279 human abundance was not significant at the small spatial scale, where both used and available
280 points were far from the areas with higher human abundance. We found bedsite visibility to be
281 a key driver of selection at both spatial scales, with bedsites characterised by significantly lower
282 visibility (denser vegetation) than random available points (Table 2). Bedsites were more likely to
283 be located at distance greater than 50m from roads with vehicle traffic. Finally, bedsite locations
284 were more likely to be selected within forest habitat than open areas (Table 2). We depicted the

key scenarios which described bedsite visibility and avoidance of human hotspots and roads in Fig. 5 and Fig. 6. In Fig.5, we showed the highly significant avoidance of human hotspots at the large spatial scale, with bedsites more likely to be located in an area with less than 5 people/ha and at a distance greater than 50m from paved roads. In Fig. 6, we can see for both spatial scales how bedsites were selected in areas with horizontal visibility close to zero and – again – at distance from paved roads greater than 50 meters.

Discussion

We found that, when selecting bedsites, fallow deer mothers significantly avoided hotspots of humans on foot (which was also associated with dog presence) along the hiking trail network. Bedsites were located away from paved roads used by vehicular traffic (rarely being located within 50m from a road), mostly within forest habitat, and in dense understory vegetation with low horizontal visibility (nearly zero, from a distance of 10m). For the first time, through the combination of bedsite data and observations of human abundance and dog presence, we described bedsite selection at a high spatial resolution, gathering empirical evidence on the features of bedsites selected by mothers to successfully give birth and protect their fawns during their first weeks of life in a peri-urban setting. This data can be used by urban wildlife managers to identify and protect fawning sites and alleviate human-wildlife conflict during this critical period of the deer annual biological cycle. This is fundamental for maintaining high welfare standards for urban wildlife through the implementation of good management practices and improve human-wildlife coexistence.

306 Despite both humans on foot and vehicular traffic being highly predictable in the park
307 – cars never leave paved roads and humans on foot rarely leave walking trails – our study showed
308 higher disturbance from humans on foot compared to roads used by vehicular traffic. The first
309 50m from the nearest paved road was avoided, but bedsites were located at a much higher
310 distance from human hotspots. This may be because vehicles on the road follow a strictly
311 predictable course (vehicles are not allowed off road) compared to people walking/running in
312 the park who could leave the trails (even if they rarely do so) and are often in the company of
313 unleashed dogs. Several studies have shown that wildlife disturbance is highly dependent on the
314 type of human activity (Stankowich, 2008, Naylor et al., 2009, Ciuti et al., 2012). For example,
315 Ciuti et al. (2012) showed that large herbivore behaviour is impacted more by humans on foot
316 than bicycles and horses on trails and roads. Further studies on ungulates have shown human
317 avoidance and behavioural changes when close to locations with high human disturbance levels
318 (Shen-Jin et al., 2007, Whittington et al., 2004, Manor and Saltz, 2004). Mountain Gazelles
319 (*Gazella gazelle*), for example, not only actively avoid humans, but they have also been shown to
320 alter their flight distance when close to hotspots of human presence (Manor and Saltz, 2004).
321 Similar results were found in a study by Shen-Jin et al. (2007); fallow deer were observed to
322 increase vigilance rates when close to locations with higher human density, whereas they
323 increased resting time when further away from humans. Our study adds new empirical evidence
324 on the effects of human presence and activity on ungulate behaviour by reporting novel effects
325 on bedsite selection in a peri-urban setting.

326 Vehicular disturbance has also been widely documented to impact wildlife behaviour.
327 Noise disturbance created by busy roads, for example, creates a phenomenon called "noise

328 masking". Noise masking impacts communication between individuals in a wide range of taxa.
329 Many studies have shown severe effects on reproductive success, density and community
330 structure as well as anti-predator and foraging behaviour (Barber et al., 2010, Pelletier, 2014,
331 Papouchis et al., 2001, Bonnot et al., 2013). Most ungulates avoid being close to roads, especially
332 when high-traffic levels are present (Pelletier, 2014, Papouchis et al., 2001). For example, a study
333 by Bonnot et al. (2013) showed that roe deer avoid roads even if it compromises their access to
334 important feeding sites. Similar avoidance behaviour has been shown in our study, although we
335 found that, at this limited spatial scale, fallow deer mothers had to balance a trade-off between
336 finding suitable bedsites and keeping a safe distance from roads, which resulted in avoidance of
337 roads being limited to 50m.

338 Concealment and safety from predators are the top priorities for ungulate mothers
339 when selecting a bedsite to hide their newborns (Barbknecht et al., 2011). This anti-predator
340 strategy manifests in this study through the selection for low visibility habitats for fawns'
341 bedsites. Bongi et al. (2008) showed that lactating roe deer females select for habitats with
342 reduced visibility. Likewise, Ciuti et al. (2006) revealed a preference for dense vegetation and low
343 visibility by fallow deer mothers to hide their fawns from predators. We found that this anti-
344 predator behaviour remains intact even within urban areas. Our study demonstrates consistency
345 in the selection for low visibility when choosing fawns' bedsites at both spatial scales after
346 accounting for the presence of humans on foot (and their dogs) and vehicles on roads. Our
347 findings can therefore inform management decisions when it comes to reducing human pressure
348 on fawning sites within these urban and peri-urban areas. During the fawning season, for
349 instance, hiking trails closer than ~200m to established fawning sites should be temporarily

closed to minimise disturbance, and policies regarding keeping dogs on a leash should be enforced. Understory vegetation within forest habitats as well as grasslands should not be cut (which may be a practice in several urban parks to improve human access): in Phoenix Park, for instance, hiking trails are the only linear features where the grassland is managed, therefore promoting use by park visitors, and making it less likely that they will walk in the high grass closer to fawning areas. Knowing the impact that humans are having on wildlife populations living in urban areas is fundamental to avoid detrimental effects on wildlife welfare and health. The impacts that we have on wildlife can be minimised by understanding the issues present and creating management plans to mitigate them. In this case, wildlife managers working within urban parks and green spaces can incorporate our findings into management plans in order to promote human-deer coexistence during the birthing season.

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Availability of data and materials

The datasets generated and/or analysed during the current study as well as the R markdown script/HTML showing the statistical analysis of this study are available in the '*Fawn bedsite*

selection by a large ungulate living in a peri-urban area' repository, https://doi.org/10.5281/zenodo.10886373.

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Table 1: Structure of the GLMM models (binomial distribution of errors) fitted to estimate the parameters for the Resource Selection Functions at two spatial scales (250 and 2500m, respectively) and explaining fawn bedsite selection in the fallow deer population of Phoenix Park, Dublin, Ireland.

Variable type	**Variable name**	***A priori* rationale for including the variable in the model**
Response variable	Used, available (1,0)	Response variable.
Explanatory (inclusive of quadratic term)	Bedsite visibility (ranging from 0 to 1)	Bedsites were expected to be characterised by lower visibility. Relationship was expected to be non-linear *a priori*.
Explanatory variable	Road distance (lower or equal to 50m, greater than 50m)	Bedsites were expected to be less likely located close to roads.
Explanatory variable (inclusive of quadratic term)	Human abundance (predicted number of people per 50x50m pixel)	Bedsites were expected to be selected in areas with reduced probability of encountering humans and their dogs (being dogs presence highly correlated with human abundance). Relationship was expected to be non-linear *a priori*.
Explanatory variable	Land cover type (2 levels: forest, open)	Bedsites were expected to be selected in habitats with greater cover, i.e. forest.
Confounding variable	Year (3 levels: 2018, 2019, 2020)	To specify to the model the dependency structure of the data, with data collected either in 2018, 2019, or 2020. Note that this was not included as random effect due to low degrees of freedom. This variable is included in the model as a confounding but should not be interpreted ecologically.
Confounding variable (inclusive of quadratic term)	Fawn weight (in kg)	To account for age of the fawn (older fawns = heavier) and specify to the model the dependency structure of the data. This variable is included in the model as a confounding but should not be interpreted ecologically because not included as interaction term.
Confounding variable	Sex of fawn (male, female)	To account for sex of the and specify to the model the dependency structure of the data Note that this was not included as random effect due to low degrees of freedom. This variable is included in the model as a confounding but should not be interpreted ecologically.
Random effect	Ear-Tag (identification code of the fawn)	To account for repeated observations of multiple besites belonging to the same fawn.

Table 2: Parameters estimated by the GLMMs fitted at two spatial scales (small: 250m; large: 2500m) explaining the relative probability of bedsite selection by fallow deer in the Phoenix Park, Dublin. Significance abbreviations: *** p<0.001, ** p<0.01, * p<0.05, · p<0.1, ns p>0.1, with p < 0.05 corresponding to 95% CI not overlapping zero.

Scale	Variables	Estimate	Std. Error	Z value	Pr(>|z|)	Significance
250m	(Intercept)	-3.39045	0.16137	-21.011	<2e-16	***
	Visibility	-2.30137	0.21582	-10.663	<2e-16	***
	Visibility^2	1.29053	0.25683	5.025	5.04e-07	***
	Road distance [>50]	0.30066	0.12802	2.349	0.0188	*
	Human abundance	-0.05440	0.05392	-1.009	0.3130	ns
	Human abundance^2	-0.01307	0.05243	-0.249	0.8031	ns
	Year2019	-0.97618	0.12207	-7.997	1.28e-15	***
	Year2020	-1.33774	0.12380	-10.805	<2e-16	***
	Sex (male)	0.02158	0.10011	0.216	0.8293	ns
	Weight	0.08826	0.31559	0.280	0.7797	ns
	Weight^2	-0.11144	0.31421	-0.355	0.7228	ns
	Land cover type (open)	0.19751	0.11180	1.767	0.0773	.
2500m	(Intercept)	-5.77268	0.16877	-34.204	<2e-16	***
	Visibility	-2.37996	0.22760	-10.457	<2e-16	***
	Visibility^2	1.29965	0.28195	4.610	4.04e-06	***
	Road distance [>50]	0.26029	0.12131	2.146	0.0319	*
	Human abundance	-0.11213	0.06320	-1.774	0.0760	.
	Human abundance^2	-0.32845	0.07786	-4.219	2.46e-05	***
	Year2019	-0.70036	0.11676	-5.998	1.99e-09	***
	Year2020	-0.98314	0.11871	-8.282	<2e-16	***
	Sex (male)	0.03313	0.09717	0.341	0.7331	ns
	Weight	0.08524	0.31048	0.275	0.7837	ns
	Weight^2	-0.09228	0.30750	-0.300	0.7641	ns
	Land cover type (open)	-0.22119	0.10763	-2.055	0.0399	*

515

Figure Legends

Fig. 1: Map of the Dublin metropolitan area, with the study site location, Phoenix Park, clearly visible as the largest green space in the top left of the map. The highlighted polygon (in green) in the western side of Phoenix Park represents the fallow deer fawning area, with the 7 sectors clearly defined.

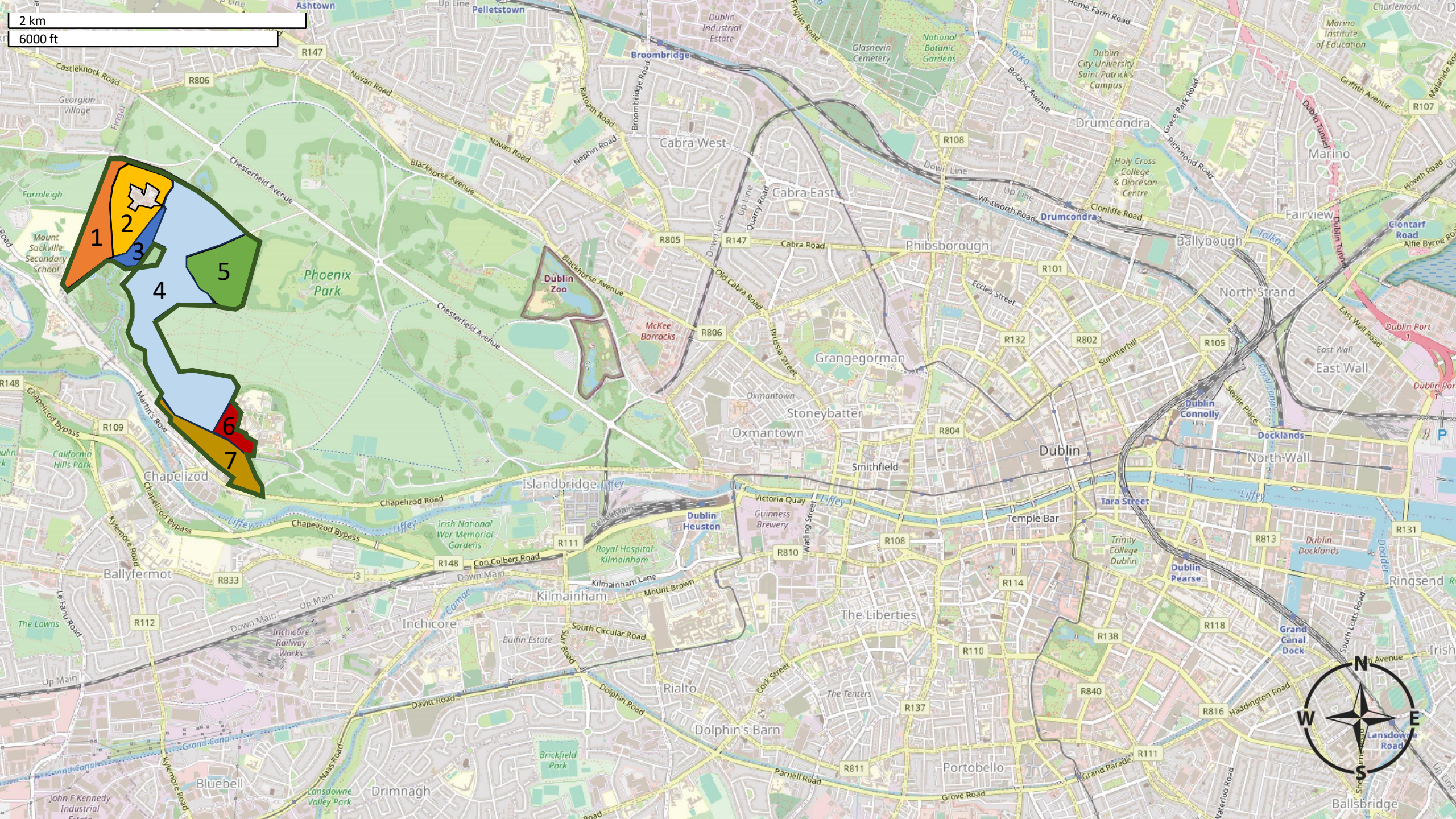
Fig. 2: Map of the Phoenix Park, Dublin (a) including land cover types (open, forest), roads (black linear features. Within the fawning area, (b) hiking trails (grey lines) were systematically walked during the fawning season to locate park visitors and their dogs (blue triangles). The fallow deer fawning area, which has been patrolled by the team during ear-tagging procedures, is indicated by the pink polygon in both plots.

Fig. 3: Locations of fallow deer fawn bedsites (blue circle) and random available points (purple triangle) across the 3 years of the study (2018-2020) within the traditional fawning area (pink area) of the Phoenix Park, Dublin.

Fig. 4: Predicted maps depicting human abundance (a: greater abundance indicated by lighter colours, see legend indicating predicted human abundance) and dog presence (b: greater probability indicated by lighter colours, see legend indicating predicted human presence) in the fawning area of Phoenix Park. Both maps include bedsite locations (triangle) and random available points (circle). X-axis (corresponding to longitude) and Y-axis (corresponding to latitude) are expressed in meters. Note how the location of the fawn bedsites are outside the hotspots of people and dog occurrence.

Fig. 5: Predicted effect of the number of people per hectare (x-axis, 100x100m) on the relative probability of bedsite selection (y-axis, RSF score [w(x)]) when the distance to the closest road is between 0 and 50 meters from the road (light blue line) or greater than 50 meters from the road (dark blue line). Note the stronger selection for bedsites far from roads, particularly when the number of people per hectare is lower. Also note avoidance of humans was remarkable at the large spatial scale (2500m), and weaker at the small spatial scale (250m), where both bedsites and random available points are both far from human hotspots.

Fig. 6: Predicted effect of the bedside visibility (x-axis, ranging from 0% to 100% of a standing fawn visible from 10 meters and eye height of 70cm) on the relative probability of bedsite selection (y-axis, RSF score [w(x)]) when the distance to the closest road is between 0 and 50 meters from the road (light blue line) or greater than 50 meters from the road (dark blue line). Note the stronger selection for bedsites with low visibility and more distant from roads when compared to random available points at both spatial scale.


2 km
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6
7
Phoenix Park
Dublin Zoo
Farmleigh
Mount Sackville Secondary School
Chesterfield Avenue
Blackhorse Avenue
Navan Road
Castleknock Road
Ashtown
Pelletstown
Broombridge
Cabra West
Cabra East
Cabra Road
Old Cabra Road
Quarry Road
Nephin Road
Ratoath Road
Broombridge Road
McKee Barracks
Dublin Industrial Estate
Glasnevin Cemetery
National Botanic Gardens
Botanic Avenue
Drumcondra
Dublin City University Saint Patrick's Campus
Holy Cross College & Diocesan Centre
Whitworth Road
Clonliffe Road
Grace Park Road
Richmond Road
Phibsborough
Ballybough
Fairview
Marino
Marino Institute of Education
Griffith Avenue
Howth Road
Clontarf Road
Dublin Port
East Wall
North Strand
Grangegorman
Oxmantown
Stoneybatter
Prussia Street
Eccles Street
Summerhill
Dublin Connolly
Docklands
North Wall
Dublin
Smithfield
Victoria Quay
Guinness Brewery
Waterling Street
Tara Street
Temple Bar
Trinity College Dublin
Dublin Pearse
Dublin Docklands
Ringsend
Grand Canal Dock
Lansdowne Road
Ballsbridge
Portobello
Grand Parade
Haddington Road
Parnell Road
Grove Road
The Liberties
The Tenters
Cork Street
Rialto
Dolphin's Barn
Dolphin Road
Brickfield Park
Drimnagh
Lansdowne Valley Park
Bluebell
John F Kennedy Industrial Estate
Naas Road
Davitt Road
Grand Canal
Inchicore
Inchicore Railway Works
Bulfin Estate
South Circular Road
Kilmainham
Kilmainham Lane
Mount Brown
Con Colbert Road
Royal Hospital Kilmainham
Irish National War Memorial Gardens
Dublin Heuston
Islandbridge
Liffey
Chapelizod
Chapelizod Road
Chapelizod Bypass
Martin's Row
California Hills Park
Ballyfermot
Kylemore Road
Le Fanu Road
The Lawns
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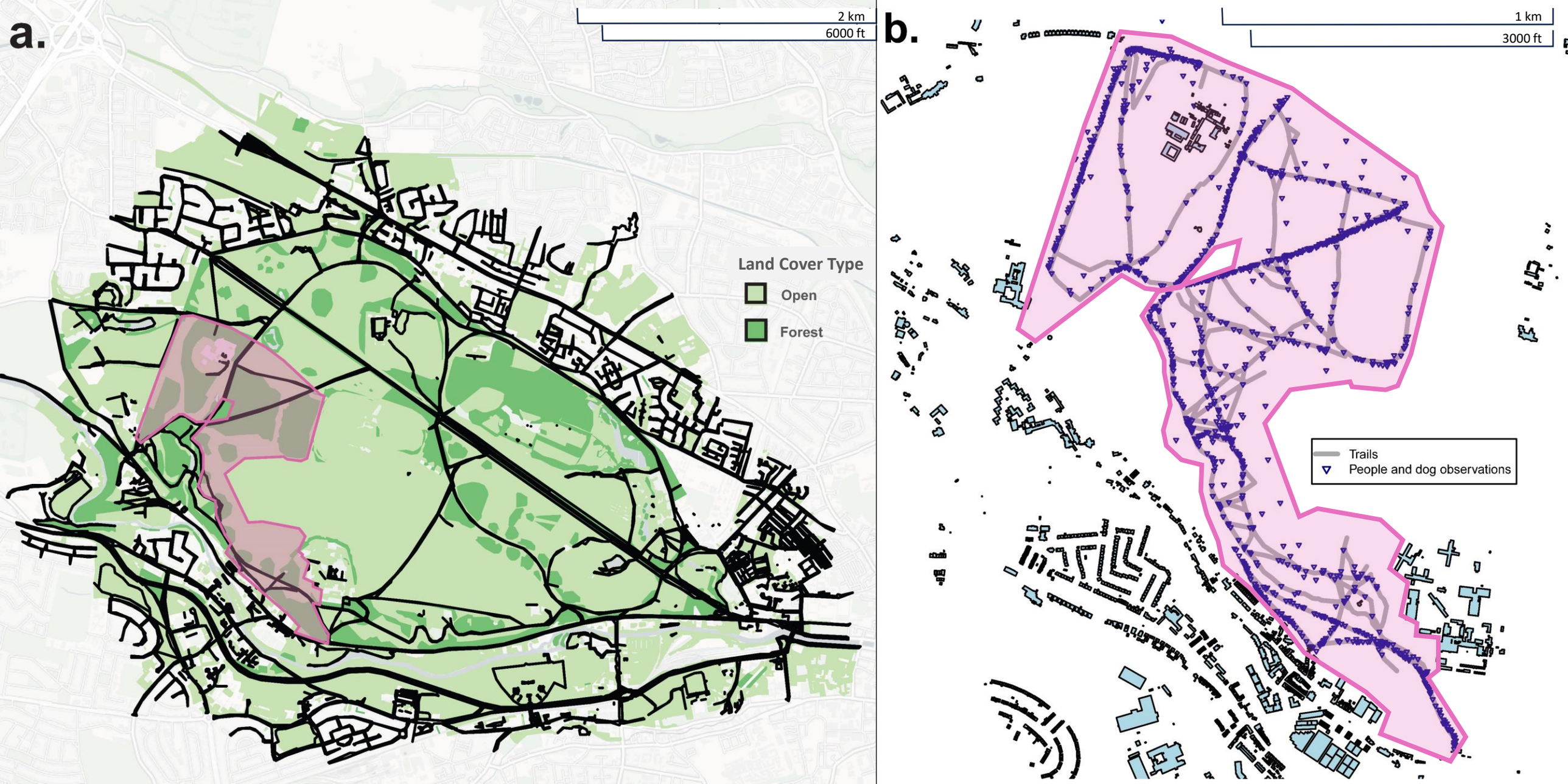
a.
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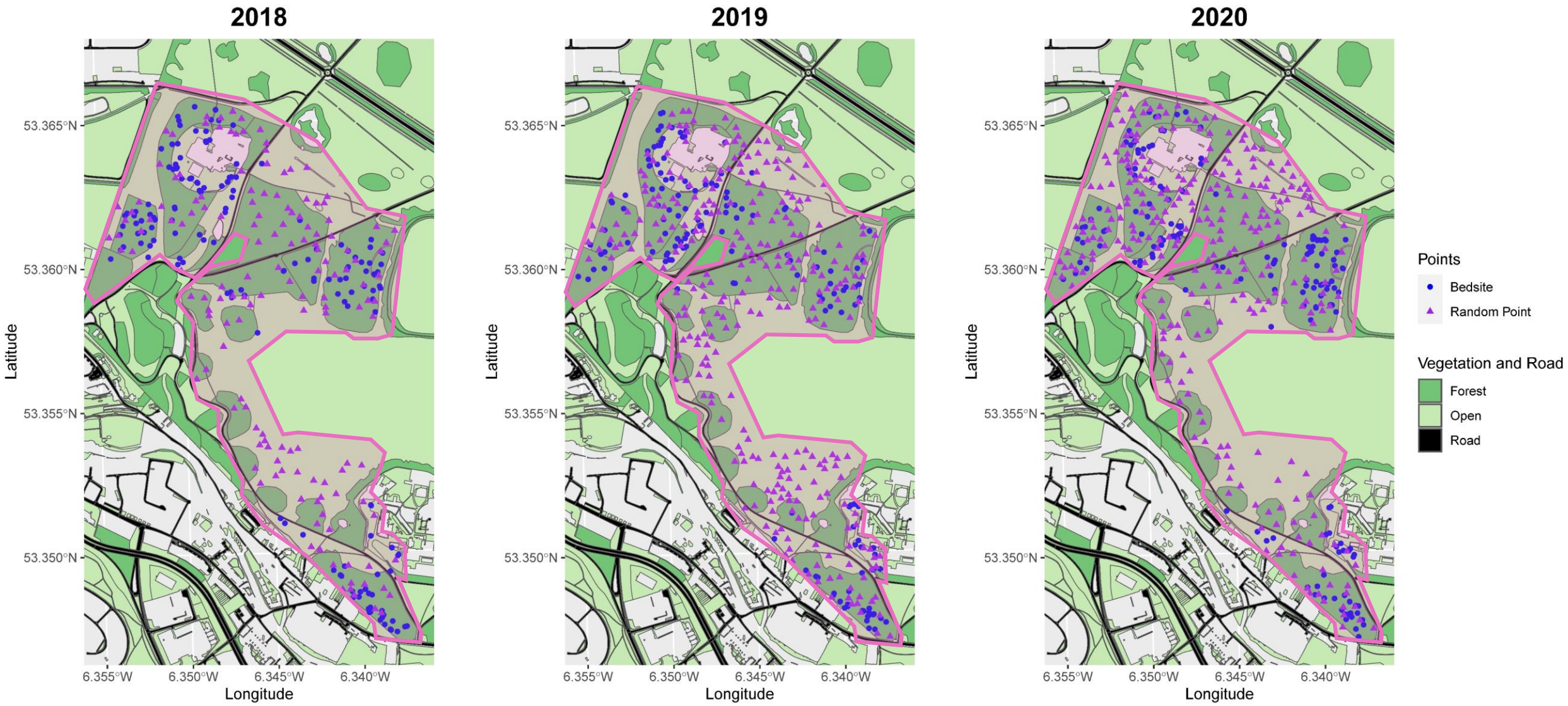
Land Cover Type
Open
Forest
b.
1 km
3000 ft
Trails
People and dog observations


2018
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53.365°N
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Latitude
6.355°W
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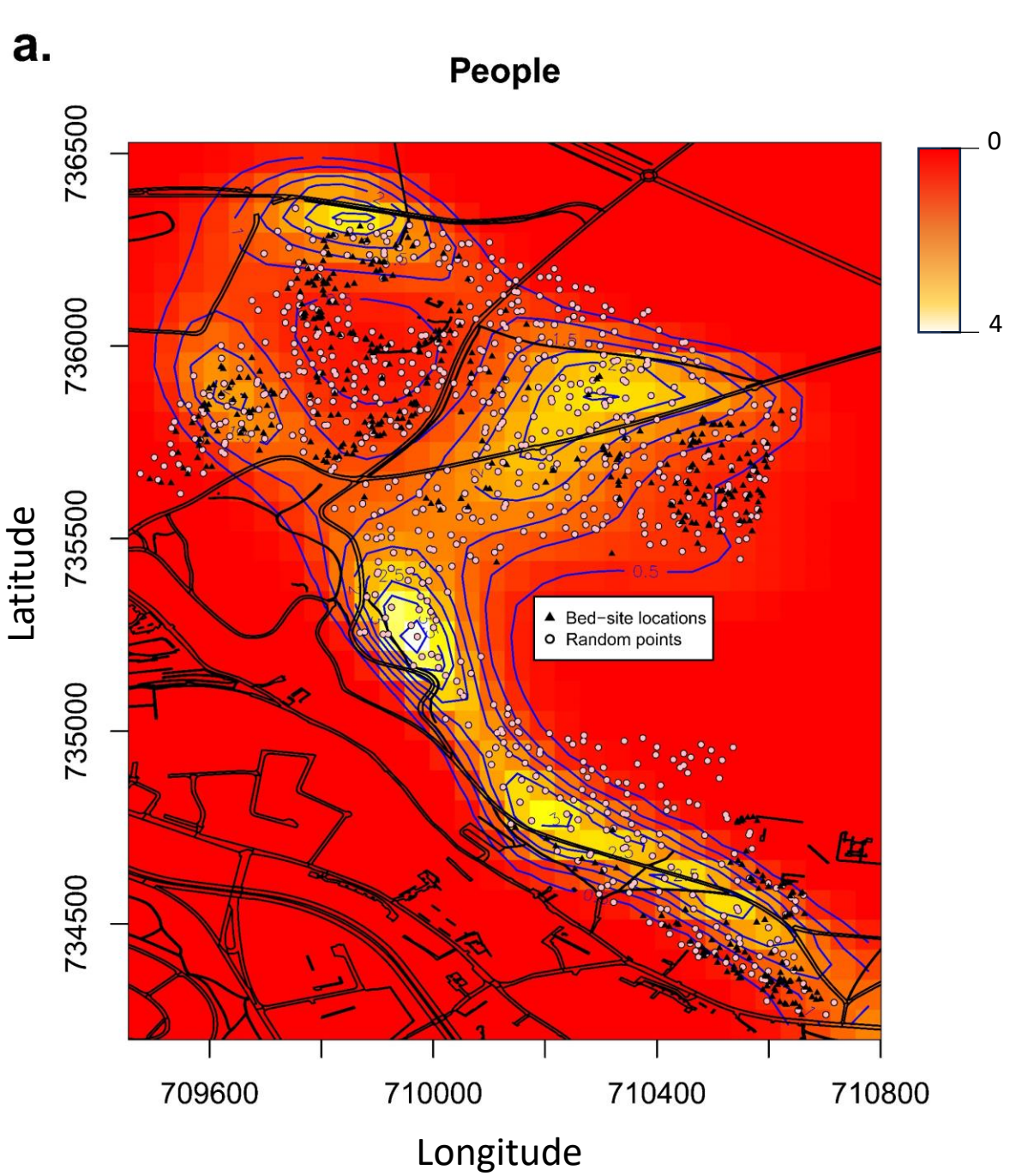
Forest
Open
Road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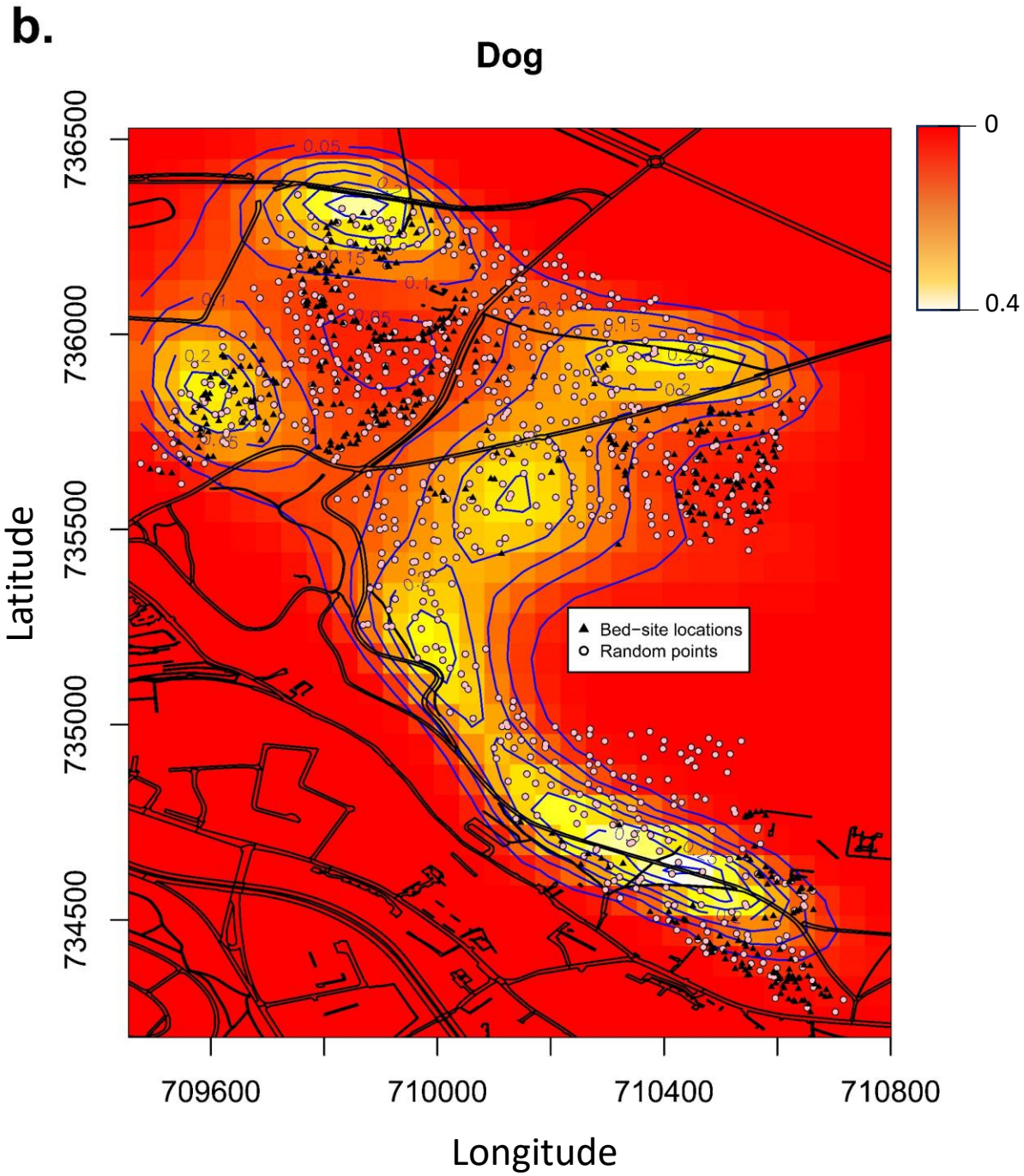
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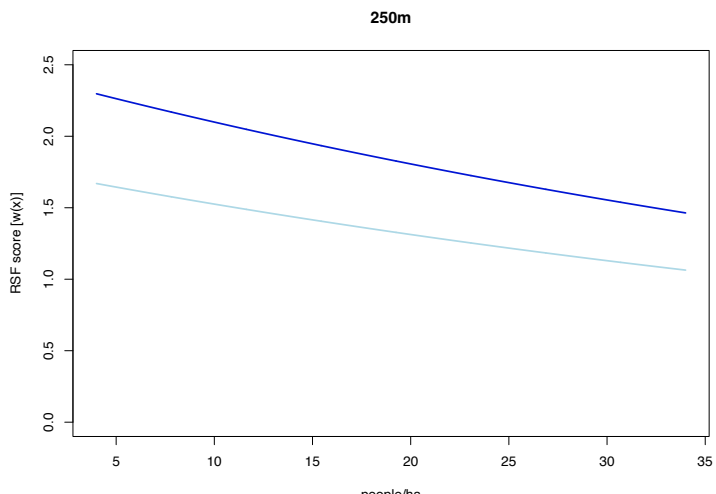
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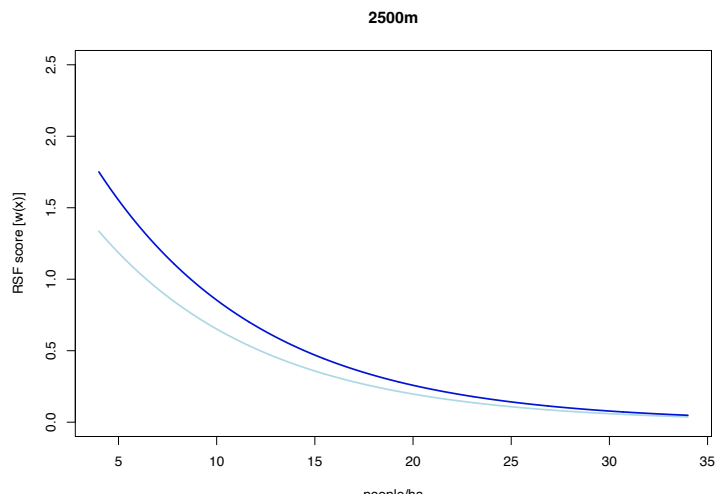
35
people/ha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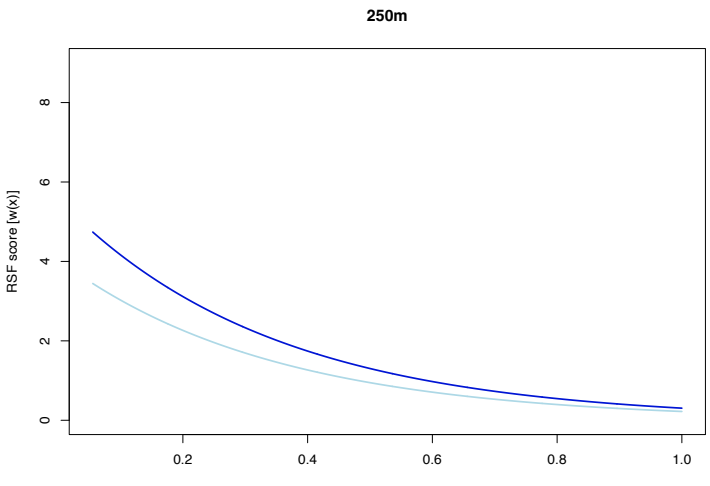
250m
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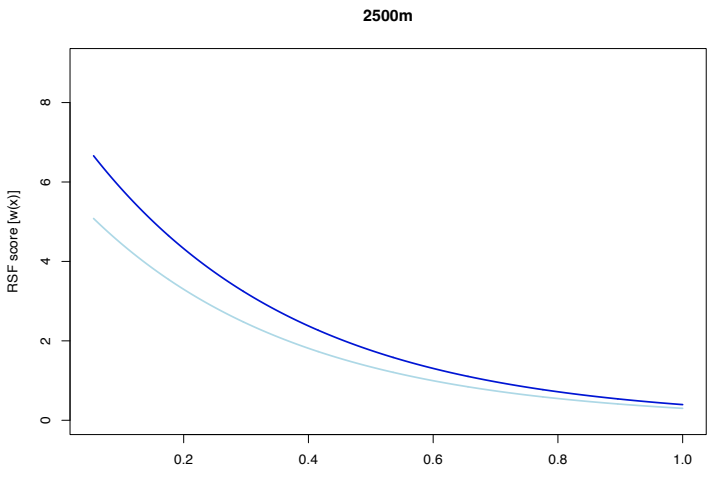
visibility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