Is Black & White the new Orange – A Comparison in the Spatial Activity of Two Mesocarnivores in London.

S. Mallinson[1]

1 University College London, NVTX3

Keywords

Correspondence

saulmallinson@hotmail.com

Abstract

Wildlife in urban habitats can be divided into the urban “adaptors” which are restrained to city greenspaces, and “exploiters” which can fully utilise the urban hardscapes. One of the model urban exploiters is the mesocarnivore red fox, which is spreading across numerous cities with expanding populations. The Eurasian badger is another mesocarnivroe which may be shifting towards being more of a exploiter, but would need to adapt a similar ‘Urban tameness’ to human disturbance as the red fox. I used generalised linear modelling to investigate how the spatial activity of badgers in London parks were responding to anthropogenic factors like human activity and light pollution, and compared this to the activity of red foxes. My findings were consistent with badgers as a adaptors as they avoided areas of high human activity and favoured woodland habitat, whilst foxes preferred built up areas. However, Both had a positive relationship with light, with foxes showing a interaction between light and distance to human habitation. My finding signifies that light pollution may aid fox and badger foraging, and does not act as a restriction to movement. Furthermore, Foxes may be showing a nightly migration between park dens and urban foraging. Future studies could focus on expanding human activity, refining light pollution data, and using radiotelemetry to investigate how movement patterns correspond with activity.

Introduction

The urban environment emerged into the natural world with the first cities of Ancient Mesopotamia around 6000 years ago (Oppenheim, 2013). It spread steadily over human history, before a rapid industrial urban expansion which shifted the human population from 15% to 50% Urban in the last century (Annez & Buckley, 2009) resulting in over 3 billion people living in urban cities (Riley, Cypher & Gehrt, 2010). As this urban environment expanded over the surrounding rural habitat (McKinney, 2002; Radeloff et al., 2005), many terrestrial species retreated into diminished ranges, in particular mammalian carnivores (Woodroffe & Ginsberg, 1998; Woodroffe, 2000; Cardillo et al., 2004).

However, certain populations and species of these carnivores persisted within the urban environment itself and flourished. Many were rural species which were mostly adapted to areas of the city that reflect their original environment and have been coined ‘urban adapters’, when compared to those which were fully synanthropic ‘urban exploiters’, as defined by (Mckinney, 2006).

These urban adapters were often ''edge species'' which were adapted to forest edges and the surrounding open areas (Adams, 1994). They were able to shelter from the intensive human activity and exploit some of the rich food resources provided by humans, but essentially restricted to vegetation. In contrast, the Urban exploiters can inhabit and take shelter within the urbanized 'hardscapes'' (Mackin Rogalska et al., 1988), relying on the food imported in by humans (Adams, 1994).

For mammalian carnivores, one of the clearest examples of an Urban exploiter is the Red Fox, *Vulpes vulpes*, which may be one of the most adaptable of all the wild carnivores with habitat ranges across tundra, steppe, moorland, woodland and arid desert (Macdonald, 1987; Novak, 1987); and now the heart metropolitan cities. First noted in English cities during the 1930s, the red fox has since spread to an estimated 114 cities across the globe from North America to Europe and Australia (Soulsbury et al., 2010). Within the cities, they thrive at much higher population densities than their rural counterparts with 37 individuals per km^2 recorded in Bristol (Baker et al., 2001) and $16km^2$ in Melbourne. These denser city populations also come with smaller dispersal distances and more compact home ranges (Macdonald, 1980; Adkins & Stott, 1998), and have also demonstrated altered social behaviour with typically thinly distributed populations of red foxes in Saudi Arabia becoming more tolerant of other foxes around food supplies (Macdonald et al., 1999)

On of the key factors in the overall success of the urban fox is its diet, which is broad but opportunistic and has the capability to adapt to the locality (Harris, 1981a; Reynolds & Tapper, 1999). Within cities this can be up to 60% anthropogenic scavenged food for adults, and examples in Zürich showed over 50% of adult fox stomachs containing anthropogenic food increasing with proximity to the city centre (Contesse et al., 2004). Within London, the urban foxes diet also comes with less seasonal variation compared with the rural counterparts (Harris, 1981b).

A portion of the anthropogenic aspects of this urban diet comes from the foxes being fed directly, with 29% of households surveyed in Brighton stating they would leave food out for urban mammals, with half of these doing this nightly (Roper, 2010). This food can be in the form of chicken, turkey fish or beef as shown in a California Urban park (Lewis et al., 1993). Between this direct feeding, and other anthropogenic food raided from bins or stolen pet food, human habitation provides an extremely rich resource. To exploit this resource, the urban fox appears to of undergone behavioural ontogenetic adaptions (Contesse et al., 2004) as they are considerably less shy than their rural counterparts. As a consequence the 'urban tameness' of foxes has been suggested as a one of the other major causes of their success (Hegglin, Bontadina & Deplazes, 2015).

With so much food available, the major restriction on urban fox reproduction appear to diggable areas as denning sites in order to breed (Harris & Rayner, 1986). This is likely one of the reasons why the urban fox initially emerged in British cities, as the abundant hedgerow and shrub gardens of the inter-war housing provided effective daytime cover. Despite this, foxes do retain a capacity of denning in less favourable habitat, as there are records in Harris (1981) of breeding foxes denning under the floorboards in houses both derelict and occupied. Their other restriction is mortality, which is mostly caused by anthropogenic with car collision (40%) & hunting/ euthanasia (38%) which is usually with the intent to control their populations. Regardless, urban fox still one of the model urban exploiters, setting the hall markers of Bateman & Fleming's (2012) review of a 'ideal' urban carnivore: highly adaptable diet, movement patterns and social behaviour.

Another generalist mesocarnivore that may be following in the foxes pawprints is the Eurasian Badger, *Meles meles*. In a 2018 study by Geiger et al., focusing on traffic casualty data, camera traps and citizen science has observed a growing expansion of Eurasian Badgers into urban areas. The badger has many of the same traits as the fox with a variable and adaptable diet, territorial range and dispersal pattern, as well as social structure (Bateman & Fleming, 2012). They have also been observed to take anthropogenic food (Harris, 1984) and show a capability to utilise urban greenspaces for setts (Clements, Neal & Yalden, 1988).

Despite this, badgers appeared to show a more delayed response in terms of their urban expansion. This has been attributed to their later first reproduction (Pacifici et al. 2013) and smaller fecundity (Jones et al. 2009) along with more limited dispersal because of the ties to the home sett (Kruuk, 1978) making them less capable to respond to the rapid change of the urban environment (Geiger et al., 2018). The other major restriction may also be that badgers still lack the resistance to human disturbance that comes with the foxes 'urban tameness' (Bateman & Fleming, 2012; Geiger et al., 2018).

This human disturbance can come in a number of ways, from a direct avoidance of people to an aversion for anthropogenic light, noise and air pollution. The ecological effects of light pollution in particular have been gaining increasing interest as a source of disturbance on wildlife (Longcore & Rich, 2004) from bird death on tall lit structure to disorientation of sea turtles. One of the effects of light pollution is thought to be the fragmentation of habitat (Bobkowska et al. , 2016), with the bright areas acting as a barrier to the movements some species (Bliss-Ketchum et al., 2016). For the crepuscular and nocturnal mesocarnivores that inhabit cities, this light could be repellent since both badgers and foxes generally seek cover (Reid et al., 2008).

Alternatively, another effect of light pollution is generating a “artificial full moon” by which predators can hunt by (Longcore & Rich, 2004), which could be applicable to badger and foxes who have been shown to match the diurnal activities of small mammal prey (Monterroso, Alves & Ferreras, 2013). Foxes have been known to forage in well-lit areas (Egan et al., 2019; authors personal obs), and hedgehogs have also been demonstrated to be indifferent to artificial light when there is food available there (Finch et al., 2020). How urban badgers might respond to light pollution is not clear, but it would be a major barrier to “urban tameness” if they avoid night light, and greatly limit any available urban food sources.

Overall, greater understanding how urban mesocarnivore activities respond to light could be important for predicting both their ability to colonize cities, and then their movement patterns within the urban environment. This comes at a time when fewer and fewer mammals exist outside of light pollution (Duffy et al., 2015) but a there is still a limited understanding of what effect this is having on wildlife (Longcore & Rich, 2004). These are animals with great potential as flagship species for raising interest in wildlife in an urban public that has a growing disconnection from nature (Miller, 2005), whilst also providing positive effects on ecosystem process and human welfare (Soulsbury & White, 2016). They also, however, have great potential for damage by raiding bins and allotments (Bontadina, Contesse & Gloor, 2001; Delahay et al., 2009), eating or harming pets (Harris, 1984) and bringing in disease like rabies (Distribution and density estimates for urban foxes (Vulpes vulpes) in Melbourne: implications for rabies control) or bovine tuberculosis (Meylan, 2013; Hegglin, Bontadina & Deplazes, 2015). These are species that require careful management to set their costs against their benefits, and for this an understanding of the urban factors that dictate their activity patterns is vital.

This study aims to investigate how these two mesocarnivores spatial activity patterns compare, looking at the degree to which badgers may be showing a similar “urban tameness” as foxes. My methodology builds on the work of previous student (Lovell, 2020) who investigated how habitat and human activity predicted the spatial distribution of badger activity. I expanded his models to include a new parameters, light pollution and distance from human habitation, and added a comparative model on fox responses. My prediction is that if the badger population is becoming tamer and more of an urban exploiter, then their activities patterns should have similar relationship to the urban red fox, which is my model urban exploiter.

These Urban foxes have already been shown to use more built-up areas for foraging by Wong (2019), so I predict the foxes to show positive responses to urban habitat, human activity and light pollution. If the badgers show the same patterns of preference, this would indicate that they are shifting towards a urban exploiter lifestyle similar to that of the foxes. Conversely if the badgers show a negative response to these variables it could indicate that they are more established as urban adaptors and do not generally forage in areas outside of the park's greenspace.

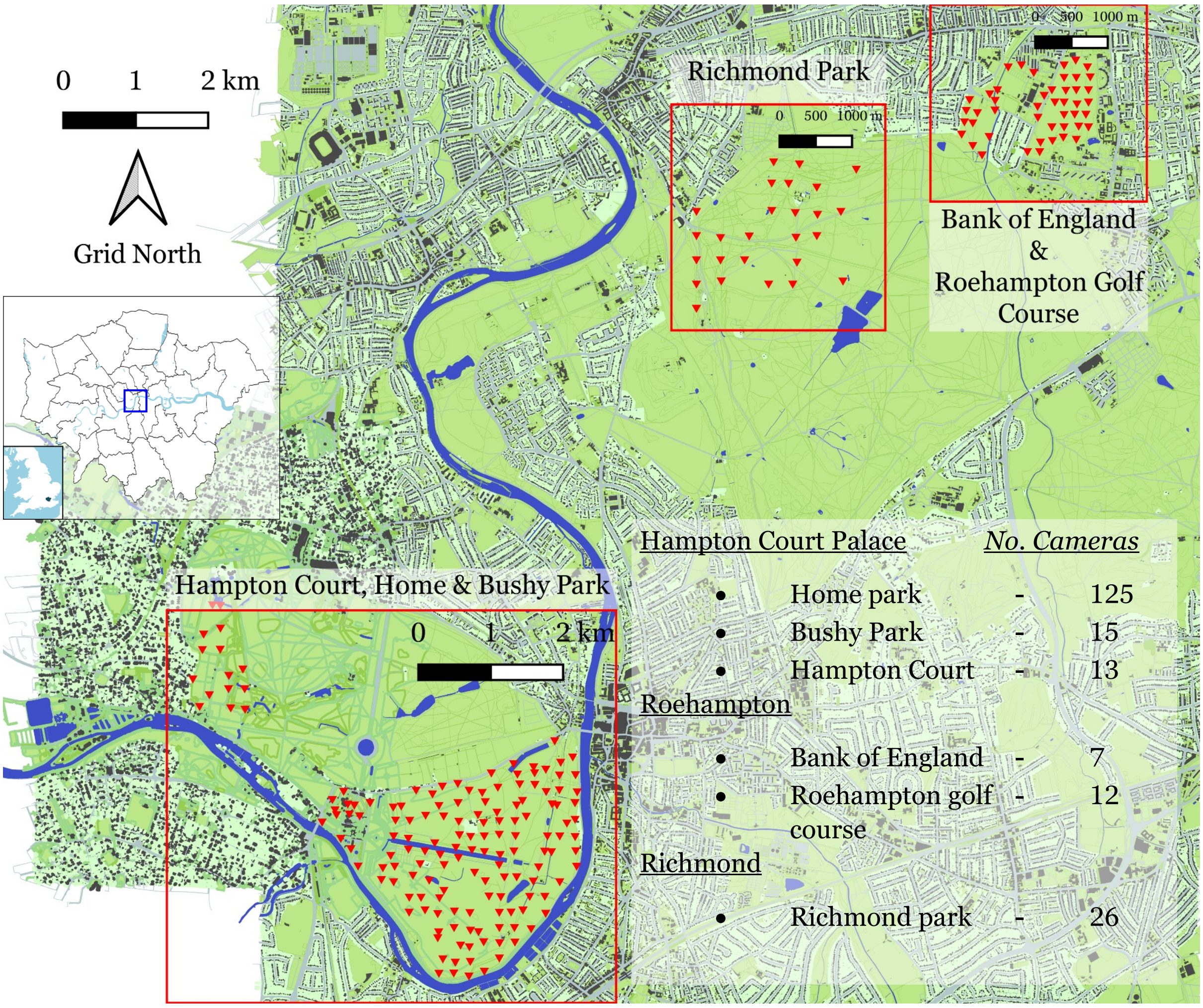

Figure 1 Study area, showing 198 camera trap sites (red triangles) from seven surveys across three locations.

Map Source: EDINA (2020)

Methods

Camera trap data

Data was used from 7 camera trap surveys (Wearn & Glover-Kepfer, 2017) collected by the Zoological Society of London (ZSL) for their 2017 to 2019 study on London's urban wildlife, laid out in Figure 1. The camera traps were positioned 20-50mm high on the nearest solid fixture to each survey coordinate, which were selected at random from a 150km^2 grid of the survey sites. Cameras were angled for best field of view and were set to capture sequences of photos in close succession to create an image batch for each contact.

Images from the camera were tagged manually by Lovell (2020), with only the first image of each batch being recorded as a contact to ensure images remained independent samples. As the target species was badgers, only images from 6:00-18:00 were analysed as the species is typically crepuscular/nocturnal.

Habitat classification

Habitat class was assigned to each camera trap site by Lovell, (2020) using google satellite/street view (Google, 2020), camera images and the Digimap habitat class data (EDINA, 2020) using the phase 1 habitat survey classification (Joint Nature Conservation Committee, 2010) – a dichotomous key on habitat classification is available their Supplementary Information One. I specifically used their habitat data sampled using a 50m buffer over the point habitat data as it generated the lower Akaike Information Criterion (AIC) in the mixed models. Habitat was additionally assigned by them as either "linear" or "non-liner" following Spellerberg and Gaywood (1993)'s definition.

Human activity

Human activity data was generated from a machine learning classifier on all (24hrs) of camera images by Li 2020, but this was only available for Home park. The human disturbance data sets from Lovell, 2020 for the whole study area (human density, walking distance and night-time accessibility) were dropped as they did not generate significant result, whereas human activity generated from the images did, and also caused issues with model convergence.

Instead, I investigated the potential for expanding machine learning classified human activity across the whole study area. This began with a pilot study on whether a classifier trained on Home Park images could create converging results with a classifier trained on Hampstead Heath images when they both analysed the same data sets. The results of this pilot study, available in figure A3 in the appendix, indicated that further work was needed to refine the classifiers, which can be used in future work.

Light Pollution

Light pollution data was acquired from the National Space Agency (NASA)/ National Oceanic and Atmospheric Administration (NOAA) 2016 Black Marble data set which is collected by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on the NASA-NOAA Suomi National Polar-orbiting Partnership (NPP) satellite (Román et al., 2018). The data was formatted at $500m^2$ resolution with the three recorded wavelengths summed together, and sampled for each camera site with a 50m mean buffer using the Raster package (Hijmans & van Etten, 2012).

I also investigated a simulated 'lightscape' data set using the methods outlined in (Bennie et al., 2014), which could have potential in future work if detailed streetlight location data can be acquired.

Proximity to human habitation

Urban proximity data was generated in QGIS (QGIS Development Team) by creating a raster of the "Urban" and "Suburban" habitats polygons in the Digimap habitat class data (EDINA, 2019) and then using this to generate a proximity distance raster. This proximity raster was then sampled at each camera location with the point sampling plugin (Jurgiel, 2019), generating distances in pixels, with a pixel size of 4.3E-5 by –1.6E-5 degrees in Coordinate Reference System (CRS)4326.

Data Manipulation

Statistical analyses were performed in R (R Core Team 2021) using dplyr (Wickham et al. 2021)and lubridate (Grolemund & Wickham, 2011), with tables and plots being produced by sjPlot (Lüdecke, 2021) and ggplot (Wickham, 2016), and map figures produced in QGIS (QGIS Development Team, 2020). Surveys that detected no badgers had been initially removed from the data to avoid issues surrounding zero-inflation (Warton, 2005).

Statistical modelling

To test the relationship of badger activity with different habitat variables, I used statistical models to investigate correlations. These were negative binomial generalised linear mixed model (nb.GLMM) to investigate the whole study area, and a negative binomial generalised linear model (nb.GLM) for Home park as the single location meant there was no need for a random effect variable. before changing the variables. The negative binomial format had been originally chosen due to overdispersion in the data, and had the natural log trapping effort (number of active days for each site) as an offset variable and camera location (Richmond/Roehampton/Hampton in Figure 1) as a random factor.

For the study-area models, my response variable was the number of badger or fox contacts. Explanatory variables were 50m habitat, habitat linearity, urban proximity and black marble light . Urban proximity and black marble were divided by 1000 so as to rescale them. An interaction was added between urban proximity and black marble, as the human habitation distance was both a major source of light but also explanatory variable in its own right. All variables used in the study-area models are spatially displayed in Figure 2.

For the home-park models, the response and explanatory variables were the same but with the addition of human activity (natural log rescaled) from classified human images, and the removal of the interaction due to non-significance. This was justified as the smaller sample size was the likely cause of the interaction raising the model AIC and causing the loss of significance of one of its components. All variables used in the home-park are spatially displayed in Figure 3.

Diagnostic cooks and qqplots were used to test that models did not violate their underlying assumptions. Explanatory variables were dropped if the variance inflation factor exceeded 3 (Zuur, Ieno and Elphick, 2010), except for interactions terms and their components which were given more leeway.

Results

Spatial distribution of activity and habitat

Figure 2 shows the distribution of the different data sets that were used in study-area' models. Badger activity ranged from no contacts to a maximum of 124 contact on one camera, with the highest densities along the eastern edge of Home park following the river as well as one of the sites in central Richmond park. Foxes meanwhile showed highest activity in the Bank of England sports centre with a maximum of 562 contacts, along with few contacts in Richmond, and continuous distribution across Hampton Court.

Habitat was majority Amenity Grassland, followed by scattered tree's and woodland with only a few scrub and built sites. Light pollution was mostly consistent with the urban areas being brightest and the centre of the parks being darkest, with a maximum value of 765 watts per square centimeter per steradian, but this was not a exact relationship with the human habitation distance data, which had a maximum of 354 pixels. Human activity had a maximum value of 26, which was the natural log of the number of human contacts per day as described in Li (2020), and was only available for Home Park, was highest in the south west corner of the park, with one high site in the north east corner.

Generalised linear models

The results for the study-area models showed that badger activity was lower in Amenity Grassland and higher in woodland (Figure 4A) and along linear habitats as outlined in Table 1. Additionally, badger activity had a positive relationship with light pollution (Figure 4A) but had no relationship with urban distance (Figure 4B/C).

Fox activity had a similar negative relationship with Amenity Grassland and positive relationship with linear habitat as outlined in Table 1. However, Fox and badger activity diverged with the foxes showing a positive relationship with urban areas, but conversely a positive relationship with distance (Figure 4F) from urban areas. Furthermore, fox activity had a positive relationship with light pollution shown in Figure 4E. This relationship with light had a interaction with urban distance shown in Figure 4H, where fox activity was higher in bright areas close urban habitat and dark areas far from urban habitat. However, this interaction has caveats as it could be due spatial autocorrelation as shown in Appendix (Figure A2).

For the home-park models, the same relationships for badger activity were seen as in Lovell (2020), with a positive relationship along woodland habitat and a negative relationship with human activity and amenity grassland, along with a loss of relationship along linear habitat, but a gain of a positive relationship with scattered tree's. The same positive relationship with light pollution was found between badgers and light pollution as the study-area model.

Fox activity also had a negative relationship with amenity grassland along with a similar positive relationship with linear habitat as the study-area model. However, I found no interaction between distance from human habitation and light pollution.

Table 1 Incidence Rate Ratio's, Confidence intervals (CI) and P-values (p) of nb.GLMM study-area models, with badger (left) and fox (right) activity as dependant variables and habitat class, linearity & distance from human habitation interacting with light pollution.

Model formula:
Badger/Fox activity ~ habitat + habitat linearity + distance from human habitation * light pollution

	badger activity			fox activity		
Predictors	*Incidence Rate Ratios*	*CI*	*p*	*Incidence Rate Ratios*	*CI*	*p*
habitat - grassland	0.00	0.00 – 0.04	**<0.001**	0.04	0.01 – 0.26	**0.001**
habitat - built up areas	1.75	0.65 – 4.75	0.271	2.38	1.24 – 4.54	**0.009**
habitat - scattered trees	1.93	0.93 – 4.00	0.079	1.55	0.95 – 2.54	0.082
habitat - scrub	1.63	0.25 – 10.41	0.607	1.09	0.28 – 4.17	0.904
habitat - woodland	5.50	2.54 – 11.93	**<0.001**	1.57	0.93 – 2.64	0.089
habitat - linear	2.39	1.34 – 4.24	**0.003**	1.97	1.36 – 2.86	**<0.001**
distance from urban habitat	2.75	0.41 – 18.38	0.297	5.37	1.44 – 19.99	**0.012**
light pollution	266.59	3.23 – 22019.60	**0.013**	83.86	3.82 – 1842.30	**0.005**
interaction: light and distance	0.15	0.00 – 6.48	0.322	0.02	0.00 – 0.31	**0.005**
Random Effects						
σ^2	1.46			0.92		
τ_{00}	1.90 $_{\text{camera\_location}}$			0.14 $_{\text{camera\_location}}$		
ICC	0.57			0.13		
N	4 $_{\text{camera\_location}}$			4 $_{\text{camera\_location}}$		
Observations	225			225		
Marginal R^2 / Conditional R^2	0.191 / 0.648			0.275 / 0.369		

Table 2 Incidence Rate Ratio's, Confidence intervals (CI) and P-values (p) of Negative Binomial Generalised Linear Model (nb.GLM) run only on Home park, with badger (left) and fox (right) activity as dependant variables and habitat class, linearity, distance from human habitation, light pollution and human activity.

Model Formula:
Badger/Fox activity ~ habitat + habitat linearity + human activity + distance from human habitation + light pollution

	badger activity			fox activity		
Predictors	*Incidence Rate Ratios*	*CI*	*p*	*Incidence Rate Ratios*	*CI*	*p*
habitat - grassland	0.03	0.00 – 0.21	**0.001**	0.08	0.02 – 0.48	**0.004**
habitat - built up areas	1.70	0.27 – 23.42	0.606	1.02	0.20 – 9.22	0.981
habitat - scattered trees	2.51	1.18 – 5.70	**0.021**	0.94	0.49 – 1.89	0.867
habitat - scrub	0.99	0.12 – 29.61	0.994	0.97	0.15 – 15.87	0.976
habitat - woodland	6.61	1.85 – 29.90	**0.003**	2.25	0.85 – 7.49	0.156
habitat - linear	1.81	0.90 – 3.61	0.079	2.16	1.21 – 3.87	**0.006**
human activity	0.85	0.73 – 0.97	**0.035**	1.03	0.97 – 1.12	0.419
light pollution	27.01	1.33 – 664.81	**0.034**	3.15	0.26 – 42.91	0.385
distance from urban habitat	0.46	0.01 – 21.00	0.719	2.27	0.06 – 92.18	0.653
Observations	125			125		
R^2 Nagelkerke	0.448			0.132		

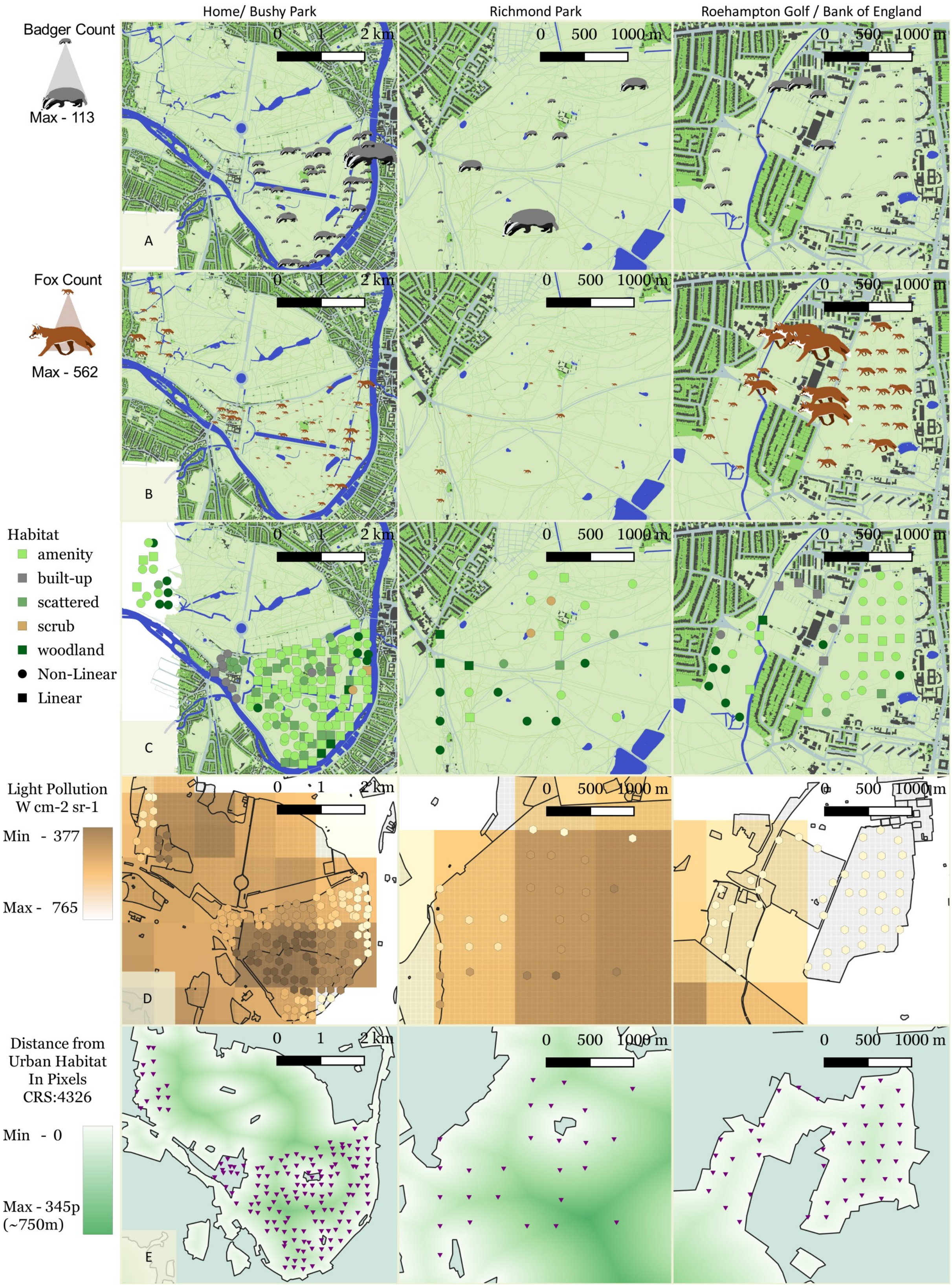

Figure 2 Data sets use in study-area models (A) Badger photographic rate (B) Fox photographic rate (C) 50m buffer Habitat class and linearity (D) Light pollution from the NASA black marble data set, 50m buffer values shown in hexagons, units are watts per square centimeter per steradian, W cm^{-2} sr^{-1} (E) Proximity from human habitation generated using the OS landcover map, in pixel values using CRS:4326

Map Source: EDINA(2020)

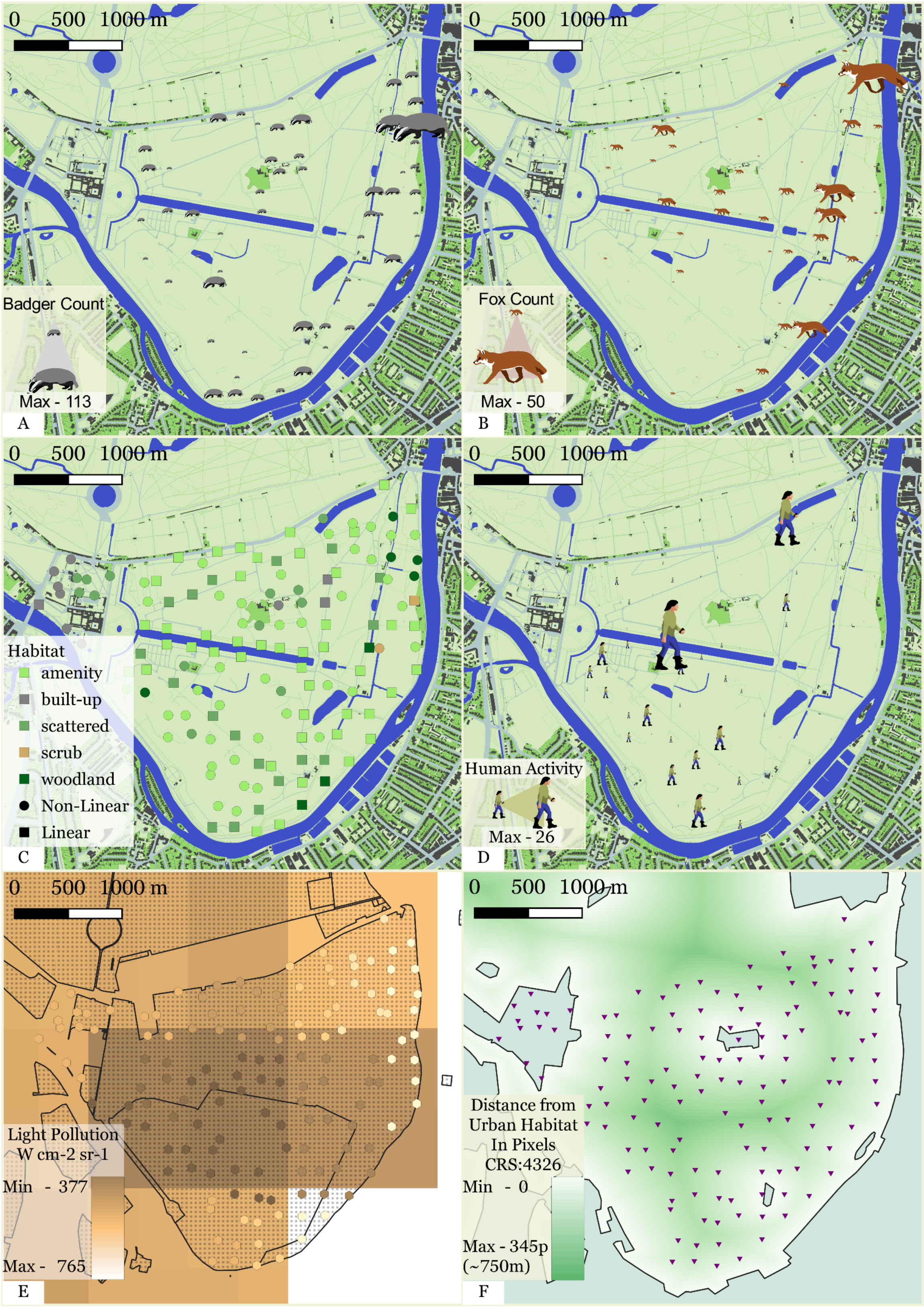

Figure 3 Data sets use in home-park models (A) Badger photographic rate (B) Fox photographic rate (C) 50m buffer Habitat class and linearity (D) Human activity (E) Light pollution from the NASA black marble data set, 50m buffer values shown in hexagons (F) Proximity from human habitation generated from OS landcover map, in pixel values using CRS:4326

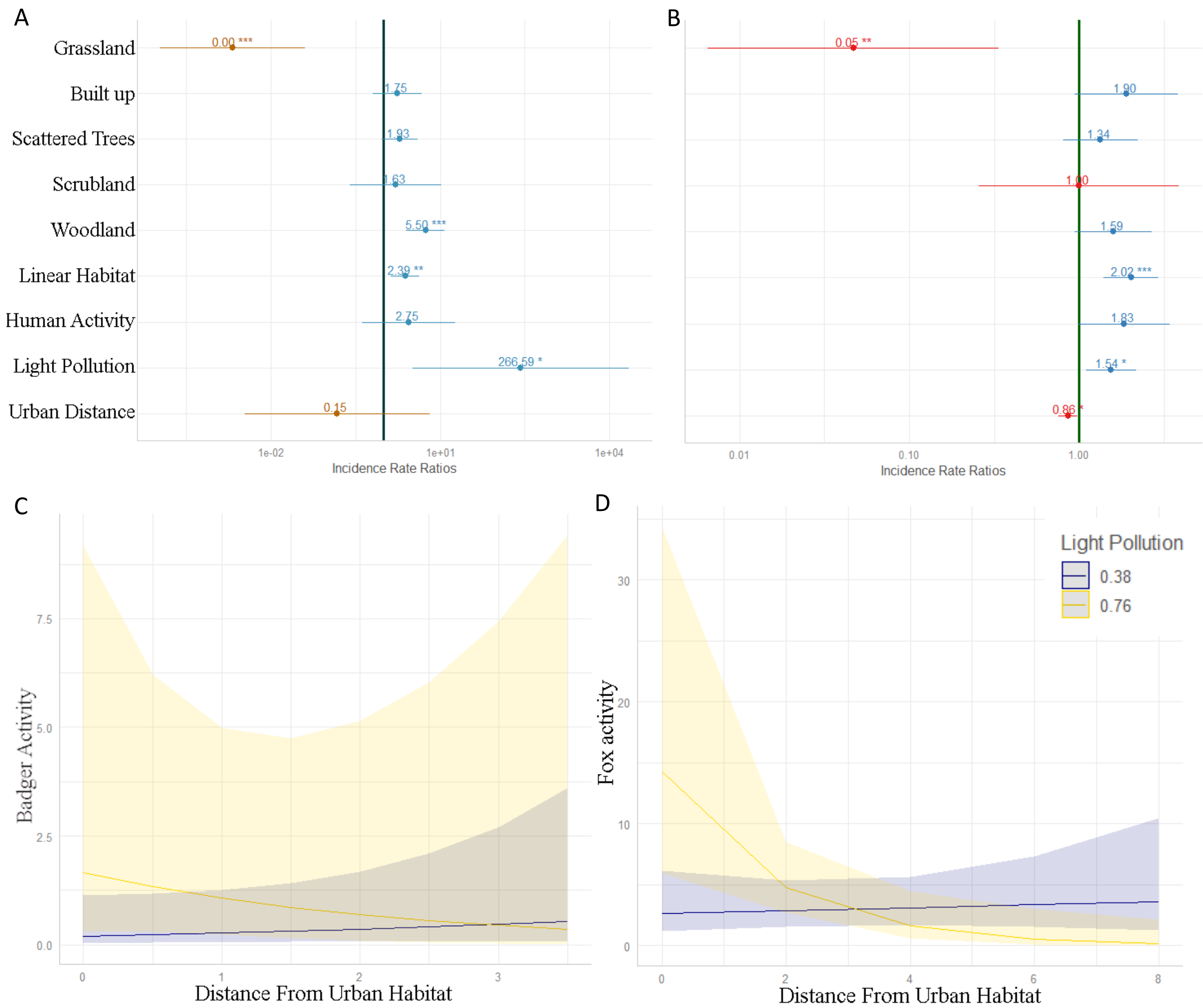

Figure 4 Incidence Rate Ratio response plots of study-area model (A) badger and (B) fox with log10 incidence ratios of habitat class, linearity, distance from human habitation, light pollution and human activity. Response plots showing interactions term between distance from human habitation and light pollution for (C) Badgers and (D) Foxes, with fox activity being higher in areas with either high light pollution close to human or poorly lit areas far from human habitation.

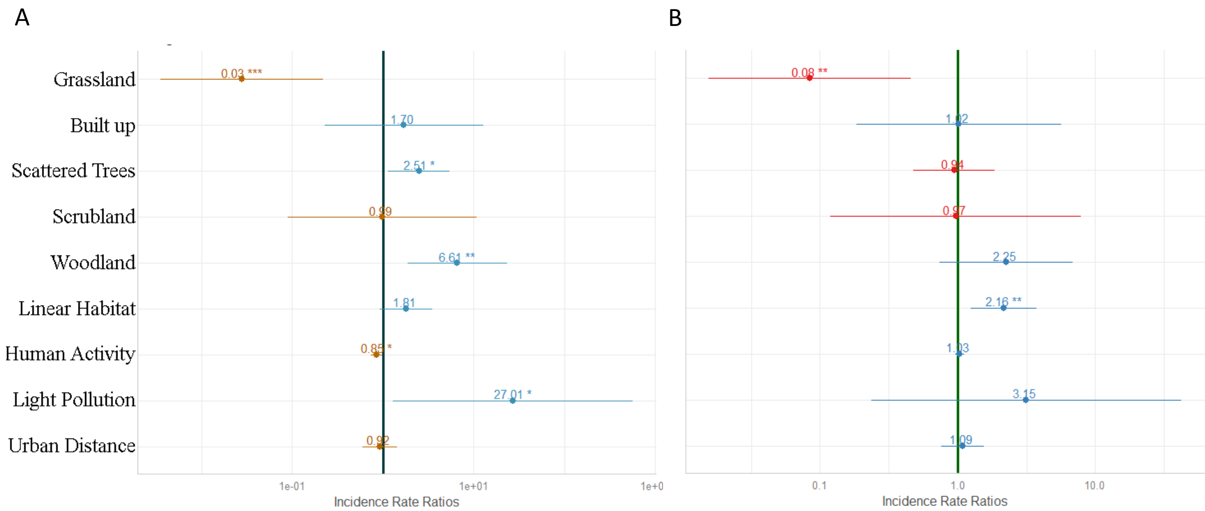

Figure 5 home park model (A) badger and (B) fox coefficient plots (above) with log10 incidence ratios of habitat class, linearity, human activity, light pollution and distance from human habitation.

Discussion

The activity of badgers appear to indicate that the species is still more of an urban adaptor over an exploiter. The foxes showed a cleara preference for built up areas (table 1), whereas the badgers showed a negative relationship with human activity (table 2 & figure 5), and had a positive relationship with woodland habitat (table 1&2). Given the red fox is our model urban exploiter, this divergence of activity patterns is indicative of them being less of a tame exploiter that forage urban areas, and instead a more shy adaptor which uses the woodlands for food.

However, my data set only contained 18/ 198 camera in build up areas which were limited to a palace and sports ground (see Figure 3). Within these, the fox's preference was exclusively for the sports ground since the home-park model showed no relationship. Many of the food sources that would make built up areas attractive, like human feeding, rubbish bins or allotments would be more associated with suburban housing (Roper, 2010) so the lack of the badger's response may be due to the lack of samples outside of parks. What is more, the highest counts for badgers at the Roehampton location were also the highest for foxes (see figure 2A & B), which could indicate that there is a anthropogenic food source for which both are taking advantage.

One variable which the badger and fox activity did converge was light pollution. Both showed a strong preference for areas with higher levels of light pollution, which supports the hypothesis of the "permenant full moon" being used by these mesocarnivores to hunt and forage by (Longcore & Rich). The exact nature of how these well-lit areas are being utilised by these mesocarnivores is unclear, but would likely be specific for each animal's habitat preferences.

For foxes, activity within bright areas in close proximity to urban areas indicate that these could be their ideal foraging areas. This 'well-lit urban' habitat acts as sources of anthropogenic food which is easily navigated under the streetlights. Foxes have been found to match the diurnal patterns of rodent prey (Monterroso, Alves & Ferreras, 2013) and many of the stomach contents of urban foxes have been found to contain rodents (Contesse et al., 2004). These rodents would likely be more abundant around urban areas and would also be more easily hunted under the artificial light. The fox activity associated with dark sites further from human habitation is consistent with Wong (2019)'s findings, that the fox activity deeper in the park revolving around natal dens and diurnal shelters. It is possible that streetlights and bins have some correlation since city councils generally place both along roads, which makes a relationship for light pollution and bins difficult to unpick.

Meanwhile badgers had no relationship with human habitation, and instead only showed a preference for woodland habitat. Their preference for light could be for the same foraging reasons as the foxes, but the badgers foraging appears still mostly restricted within the parks. This divergence in habitat foraging could also be the cause for divergence in temporal activity patterns between the badger and the fox that was observed by (Lovell, 2020) where the foxes and badgers activity rose around the same time, but the fox activity tailed off faster throughout the night. Where the foxes activity is consistent with urban foraging ground having a overabundance of food with numerous larder hoarding (Sklepkovych & Montevecchi, 1996), whereas the badgers activity may indicate that its woodland foraging ground is not as fruitful, emphasising the advantages that they could gain if they utilised the urban habitat more. The foxes have greastly benefited greatly from their urban foraging, since the Zurich population is still expanding (Contesse et al., 2004).

Regardless, the attraction to well-lit areas indicates that this is not a limiting factor for the badgers potential for greater urban exploitation. However, the badgers preferences for scattered trees, woodland and linear habitats over amenity grassland is also consistent with them retaining a strong preference for cover (Reid et al., 2008; Harris, 1981) so are more dependant on corridors of vegetation. This is also consistent with their avoidance of areas with high human activity, presumed to be due to olfactory cues (Stewart et al., 2002) and overall this points towards the badgers 'shyness' as their key restriction to foraging in urban habitats.

There are other key differences between badgers and foxes which would affect their ability to forage in the urban areas beyond the parks. Whilst both badgers and foxes vary enormously in weight, badgers average twice the weight of a fox (Delahay et al., 2006; Gortázar, Travaini & Delibes, 2000), which combined with the badgers more fossorial lifestyle makes it 5 times slower than the foxes 50km/h max speed (Garland & Jannis, 1993; Macdonald 1987). Given that death from motor cars kill 50,000 rural badgers a year, which is around 50% of all adults and post-emergent cub mortality (Harris et al., 1992, 1995), and is also the cause of death for around 40% of urban red foxes, simply being faster and more agile may be one of the key attributes for surviving as a successful urban exploiter. There is currently not enough data on the cause of mortality for urban badgers, or rural foxes, so it is difficult to know how this factor compares between the species.

This divergence in running speed may also be key in the development of the 'urban tameness', since both badgers and foxes have been persecuted for much of the UKs history (Griffiths & Thomas, 1993; Howe, 1981) the foxes greater speed of escape could be a driver for its tolerance of human activity. The mechanism by which the fox has evolved it's urban tameness may also have specific behavioural perquisites that badger lacks. In his famous experiments on silver foxes, Dmitiri Belyaev showed that a silver foxes, *Vulpes fulvus Desm*, could be bred into fully tame 'dog like' individuals within sixty years (Belyaev, Plyusnina & Trut, 1985; Dugatkin, Trut & Trut, 2017). Whether the badger has the same genetic plasticity that would allow selection to generate tame enough individuals to full exploit urban areas is not known. Another key distinction is that foxes foraging patterns appear much less restricted to their den, with home ranges up around 500 Hectares compared to badgers which average about 50 Hectares (Tsukada, 1997; Cresswell & Harris (1988); Niethammer & Krapp, 1993), which combined with a faster movement speed that may give them a edge in exploiting the urban habitat.

As an interesting side observation, the camera trap data from Barnes (just north of Roehampton) was not useable for this study due to its limited number of badgers. These badger sightings are all south of a railway line that runs through the Barnes common, which is winged by tall fences. This indicates this railway is barrier to the badger's expansion into what should be perfectly acceptable habitat. What is interesting is that there are records of Hedgehogs north of the railway line, but they are found virtually nowhere else across the rest of the study area, and this relationship is outlined in Figure 1 in the appendix. It is possible that this railway line fence is essentially 'protecting' the Barnes Hedgehogs, as Badgers will predate hedgehogs and may be driving them further into urban areas (Doncaster, 1992).

It should be noted that the interaction of light and distance for foxes was susceptible to the aforementioned lack of urban habitat amongst the camera sites. The Bank of England camera trap survey consisted of 7 cameras which had some of the highest light levels, closest proximity to human habitation and the highest number of foxes. This trend with light and urban distance could be due to a very specific aspect of the Bank of England site, and more camera surveys within urban areas is needed to confirm this as a specific trend amongst the London foxes.

There is a possibility of the results being caused by a funnelling effect of the urban environments shape making the cameras more effective (Sollmann, 2018). In principle this effect could have caused the same bias for woodland and linear habitats as well, along with negative bias against open amenity grassland. Similarly, the badger's relationship with light also has caveats, in that there was a sett located in in the top right-hand corner of Home park, and this was also one of the brightest sections as shown in Figure 3. Detailed data on the proximity of both badger setts and fox dens would be important addition for future study as both of these are likely to influence results.

Furthermore, I would also recommend expanding the human activity data set to the entire study range, but using classifier trained on the entire data set. In my initial pilot study, I found that machine learning human classifiers trained on the data from specific parks (Home park and Hampstead Heath) had diverging values when analysing the same data set (see figure A3 in appendix). The divergence appears as a skew where the 'foreign' classifier trained on a different data set assigns a greater number of human contacts, however this is in fact a artifact of how the human contact images are processed. Because a contact is classed as a human classified image that is not within 1minuet of another, this causes a bias towards false positives because the cameras record contacts as batches. Only one image in a batch needs to misclassified as human for a human contact to be added to the data, whereas a false negatives have little effect because it would take every human image in a batch to be classified as non-human for a contact to not be added to the data.

The black marble data set has been shown to be effective at investigating general light pollution, but it still lacks the resolution to show more locally specific light levels (i.e. under a street light vs down a dark alleyway). The simplest and most accurate way to record light data would be to carry out a number of light surveys at each camera, and this survey could include noise pollution to look at these anthropogenic effects in more detail.

Finally, a GPS radiotelemetry study on the badger and fox movements could give a major context on how the movement patterns of the animals reflect activity patterns. This could then utilise the Department for Environment, Food and Rural Affairs (2014) noise pollution data and simulated lightscapes shown in (Bennie et al. 2014), which can tie in specific light frequency which as been shown to be important (Dimovski & Robert, 2018). If combined with more trail camera surveys in urban areas, this could give much more exact results on how the badger and fox utilise parks and the surrounding area.

For park management, the main implication of this study is that light does not appear to be major cause of disturbance to badgers. However, it may be being used to assist hunting in which could have knock on effects on prey animals like include hedgehogs. Additionally, woodland areas, scattered trees and linear habitats all appear to still be important for badgers as cover and food, which should be taken into consideration before altering them. Foraging patterns of foxes could also become important in the incidence of tracking disease outbreaks like rabies (Aubert, 1994).

Conclusion

In this study, I indicate that the badger is more of an urban adapted or over a exploiter when put in comparison to the red fox as it actively avoids areas of high human activity, and prefers woodland habitat over built up areas for it's primary foraging. The badgers more fossorial lifestyle and restriected ranging may make it less likely to gain enough tameness to become a urban exploiter. However, it appears does have higher activity in brighter areas so may have adapted to using the "permenant full moon" of light pollution to forage which could be a first step in becoming less shy. Follow up studies could benefit from improved human activity and light data, as well as the addition of radiotelemetry.

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Appendix

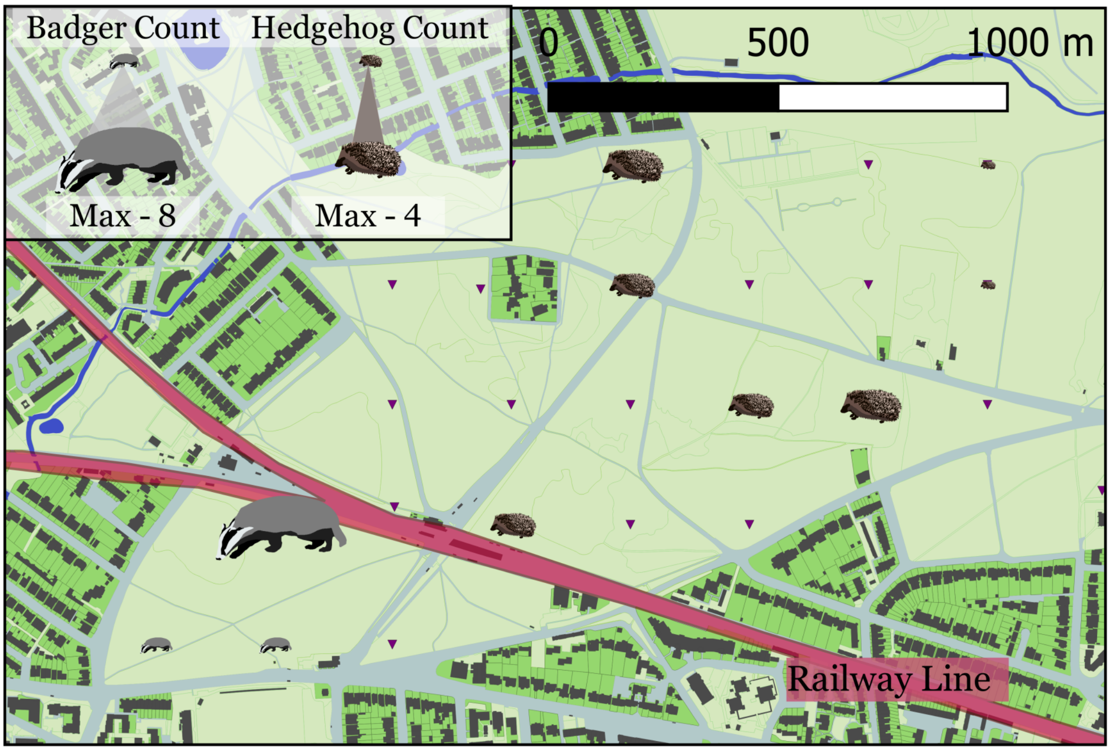

Figure A1 Potential segregation of activity between predatory badgers and hedgehogs, caused by railway line acting as physical barrier to badger colonization in northern part of Barnes common. Purple triangles indicate camera trap site. Map source: *EDINA (2020)*

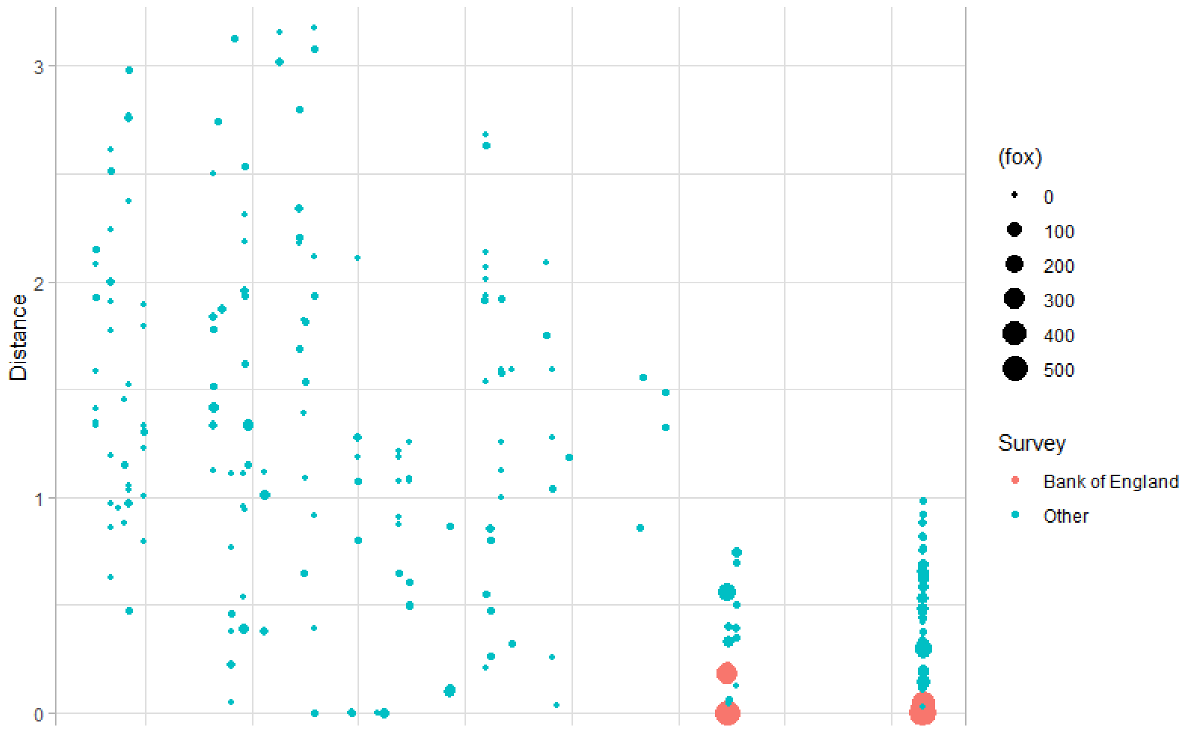

Figure A2 Scatterplot showing fox activity with distance from human habitation and light pollution. This may show a Potential issue of light/distance interaction seen in study-area' model being caused by small number of sites with very high activity, which are within close proximity to each other as shown in Figure 2B.

Appendix

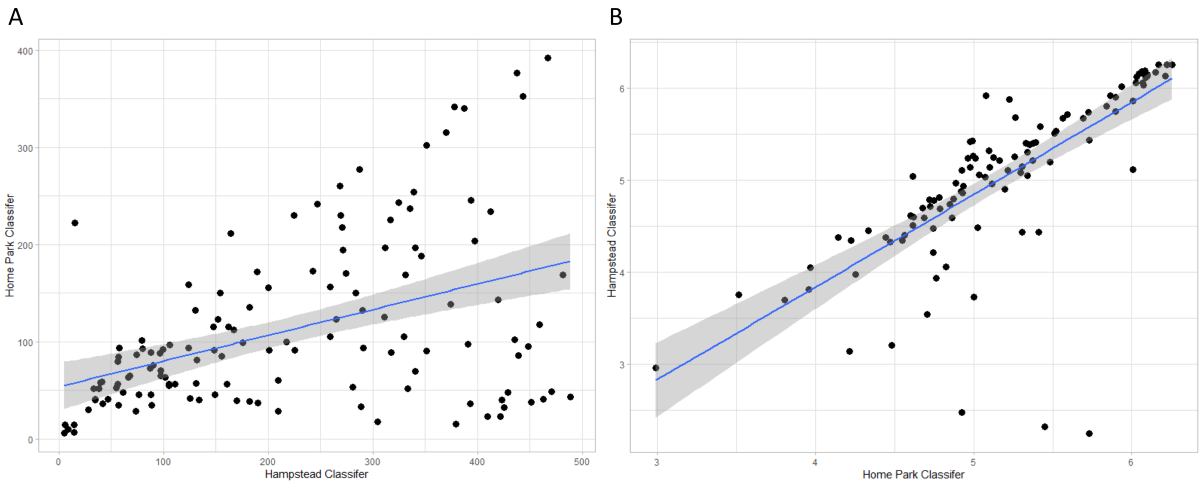

Figure A3 Scatterplots showing human activity, the number of human contacts per day that are separated by a minute or more, as generated by 2 classifiers, one trained on Home park images and one on Hampstead Heath images (A) shows results of Home Park analysis and (B) shows Hampstead Heath Analysis.

Perfect Convergence of Classifiers would be shown as a slope of x=y.

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