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Space use by pet cats living near an urban nature reserve

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Master of Science in Nature Management

Preface

This thesis was carried out at the Faculty of Environmental Sciences and Natural Research Management (MINA) at the Norwegian University of Life Sciences (NMBU).

I would like to express my sincere gratitude to my supervisor Richard Bischof for always finding time to guide me and for the valuable feedback on both data analysis in R and my writing of this thesis. I would also like to give a big thanks to Torbjørn Haugaasen for valuable feedback on the writing of this thesis. A thank you to Nina Rosita Hansen for helping with all the preparatory work with the GPS units and for being a big help during the tracking period.

This research would not have been possible without participating cat owners. The study was funded by the Research Council of Norway.

Further, I would like to thank my fellow master students Martine and Julie for many trips to Østensjøvannet nature reserve. Lastly, I would like to thank my classmates for giving me two memorable years at NMBU.

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Abstract

Domestic cats (*Felis catus*) with outdoor access pose a significant threat to local wildlife worldwide, and a thorough understanding of their space use is needed to mitigate their ecological impact. Although knowledge about the spatial behavior of individual domestic cats is growing, we still know little about their habitat selection among the non-built-up areas in an urban environment.

Using a citizen science approach, we GPS-tagged and tracked the movement of 57 domestic cats with outdoor access living in an urban area surrounding Østensjøvannet nature reserve, a protected wetland area (0.53 km^2) in southeastern Norway. The nature reserve consists of a lake (Østensjøvannet) surrounded by wetlands and other vegetation. The objective of this reserve is to preserve the important wetland areas with vegetation, birdlife and other wildlife from the increasing development pressure. The outdoor movement of the GPS-tagged cats was tracked for about 4 weeks during spring 2022. The resulting position data were analyzed using resource selection functions to investigate habitat selection outside of built-up areas by cats. In addition, I identify the proportion of the population actively using the nature reserve within the urban study area, as well as the duration and timing of their activity within the reserve.

My results reveal substantial variation in the selection of habitat in non-built-up areas. One or more cats significantly selected forest, open firm ground, bog and agricultural land. Only nine (15.9%) cats had registered positions within the reserve, and among them, only five cats had parts of their 95% BBMM home range within the reserve. The best predictor of reserve use by cats was the distance between a cat's home and the boundary of the reserve.

Results presented here suggest that establishing a buffer zone will be an effective measure to safeguard wildlife within protected areas. However, a buffer is not always applicable, and thus I suggest that each cat owner evaluates their own cats' roaming behavior and take preventative actions, such as neutering, limiting outdoor time or access. Further, more studies are needed to investigate space use with the aim of identifying effective management strategies to lower the encounter rates between domestic cats and wildlife.

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1. Introduction

Domestic cats (*Felis catus*) with outdoor access pose a significant threat to wildlife as they are opportunistic predators that prey on a wide range of fauna (Trouwborst et al., 2020). Domestic cats have been involved in the endangerment of 377 species of birds, mammals and reptiles, and in the extinction of another 63 species (40 bird, 21 mammal, and 2 reptile species) (Doherty et al., 2016). In Norway, it is estimated that cats kill 6.95 million birds annually (Heggøy & Shimmings, 2018) and in the United States alone it is estimated that cats kill 1.3-4 billion birds, 6.3-22.3 billion mammals, 258-822 million reptiles and 95-299 million amphibians each year (Loss et al., 2013).

The presence of cats or their cues such as feces, urine or fur (Apfelbach et al., 2015) creates a 'landscape of fear', defined as areas of greater or lesser risk of predation (Laundré et al., 2010), and may result in prey stress responses such as adjustments of prey foraging habits (Fardell et al., 2020). Beckerman et al. (2007) and Bonnington et al. (2013) found the effect of fear negatively impacts the reproductive success of prey species. Other concerns cats pose is the transmission of zoonotic diseases (e.g., *Toxoplasma gondii*) to both wildlife and humans (Hollings et al., 2013; Lepczyk et al., 2015) and that pet cats contribute to increase the population of unowned feral cats by not returning home, via breeding, or kitten abandonment (Fardell et al., 2021).

Overall, the ecological impact of domestic cats is due to their large number. Pet cats are popular companion animals with an estimated 600 million worldwide (Kays et al., 2020). This makes them one of the most numerous carnivores globally (Bischof et al., 2022). Since domestic cats are food subsidized they are not regulated by the quantity of prey and are therefore able to live at densities much higher than natural predators (Kays et al., 2020; Sims et al., 2008). For a 5kg wild carnivore the theoretical maximum density is estimated to be 15.7 individuals/km^2 (Kays et al., 2020), while in comparison, there are between 132-1580 cats/km^2 in the UK (Sims et al., 2008) and above 200 cats/km^2 in the US (Lepczyk et al., 2004).

Pet cat roaming activity varies greatly (Hall et al., 2016b), and areas more exposed to predation and other negative effects from pet cats can be mapped by estimating home ranges. Home range can be defined as the area an animal conducts its regular activities (Powell, 2000). Most studies indicate that pet cats spend most of their time close to their house and have relatively small home ranges (Bischof et al., 2022; Kays et al., 2020; Kays & DeWan, 2004; López-Jara et al., 2021). However, home range size depends on the individual cat, and some cats roam much further than others (Bischof et al., 2022; Kays et al., 2020; López-Jara et al., 2021; Pirie et al., 2022). Plausible sources for variation of home range

size may be age, as older cats (>8 years) have been found to have smaller home ranges than younger cats (Hall et al., 2016b), and sex as males have been found to have bigger home ranges than females (Braastad, 2012). However, as male home ranges are largely determined by access to females (Braastad, 2012), castration have been found to reduce home range size (Ferreira et al., 2020; Kays et al., 2020). Nonetheless, Hall et al. (2016b) found no difference in home range size between castrated and uncastrated cats. Home range size is also affected by landscape context and population density, as cats in an urban environment have smaller home ranges than suburban cats (Hall et al., 2016b; Hanmer et al., 2017).

While several studies have investigated home range size among domestic cats (Bachmann, 2020; Hanmer et al., 2017; Kays et al., 2020) their space use within the home range is not well known (Roshier & Carter, 2021). Cats' roaming behavior can help elucidate their impact on local wildlife, because there may be specific habitats that cats use more than the rest of the home range. Therefore, it is crucial to comprehend how cats use their home ranges. To date, studies that have investigated habitat use by cats often track a small subset of the population, for example, Fardell et al. (2021) and Pillay et al. (2018) with 6 and 11 cats, respectively. This study uses high-frequency GPS data (fine temporal scale), and a bigger sample size than most other studies.

In this study, I use cat owners as citizen scientists to mount GPS collars on their cat(s) to track the cat's space use when outdoors. The goal was to investigate whether they prefer any non-built-up habitats, and how many tracked cats used a nature reserve. More specifically, I investigated:

1) What non-built-up habitats do the cats select for? I predict cats will select agricultural fields and open areas rather than forested areas since previous studies indicate cats select against forest (Gehrt et al., 2013; Kays & DeWan, 2004; van Heezik et al., 2010).

2) What proportion of the GPS-tagged cats used the nature reserve and what is the duration and timing of activity inside the reserve? I predict that few cats use the reserve because most cats stay close to home (Bischof et al., 2022; Kays et al., 2020).

3) What determines the probability of using the reserve? I predict that cats living close to the reserve boundary has a higher probability of using the reserve than cats that live further away, as cats typically spend most of their time within 50 or 100 meters of their home (Bischof et al., 2022; Kays et al., 2020). Given the known effect of sex on home range size and ranging behavior, I also predict that males are more likely to use the nature reserve (Braastad, 2012).

2. Methods

2.1 Study area

The study area (3.37 km^2) is located in Østensjø district (50 838 inhabitants; 12,2 km^2) in Oslo municipality, south-eastern Norway. The study area includes a protected area, Østensjøvannet nature reserve, and surrounding residential area (primarily single and multi-family homes and some farms; Figure 1). Østensjøvannet nature reserve has been protected since 1992 and has a total area of 0.53 km^2, where 0.2 km^2 is mainland and 0.33 km^2 is water. The reserve has high ecological importance related to wetlands, other important nature types, avifauna, and other wildlife. However, the reserve is mostly known for its particularly species-rich avifauna, as it is both an important nesting site and migration stop (Oslo Bymiljøetaten, n.d.). As of 2019, a total number of 232 bird species have been registered (Oslo Bymiljøetaten, n.d.).

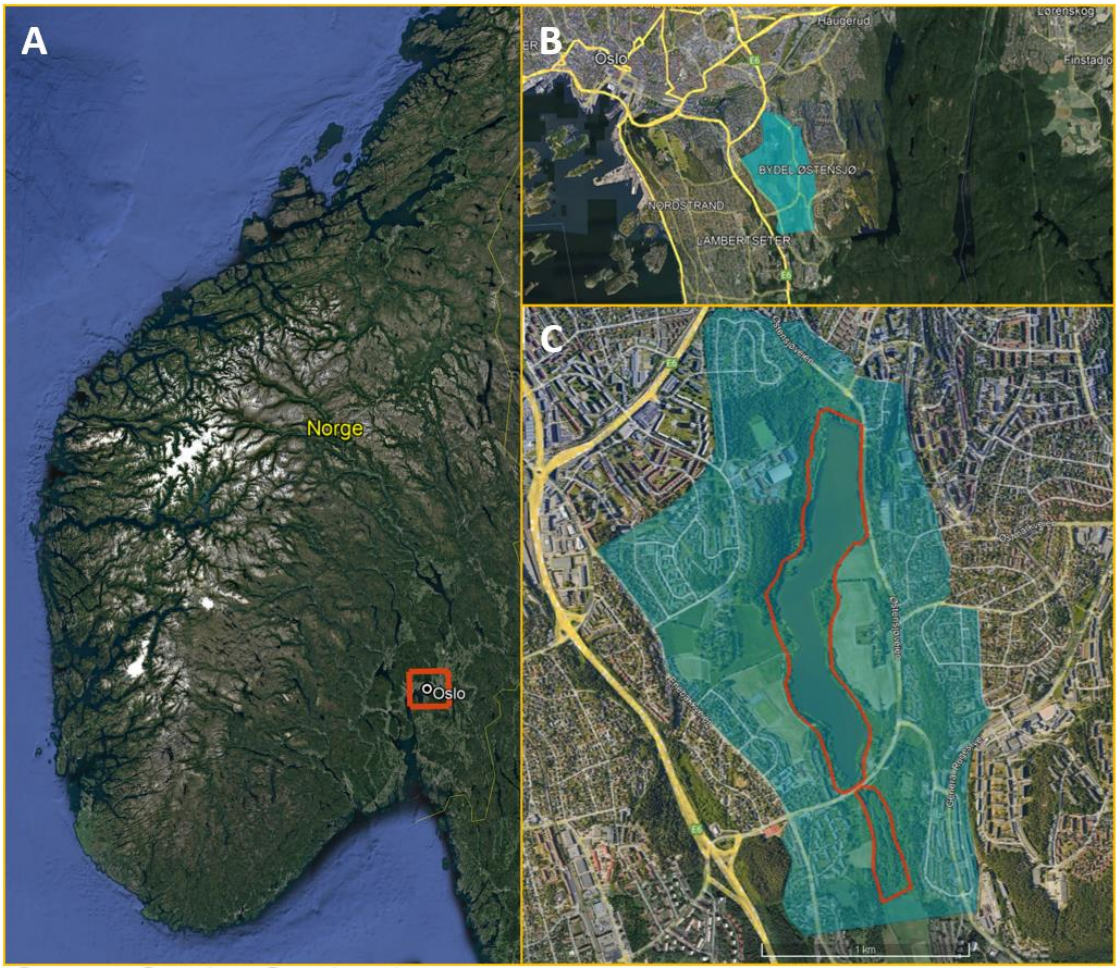

Figure 1. *A) Map of the study area location in south-eastern Norway. B) The study area in relation to Oslo to the north-west and Østmarka to the east. C) The study area (green shaded polygon) with Østensjøvannet nature reserve indicated by the red line. Google Earth, earth.google.com/web.*

The landscape within the study area is dominated by built-up areas (43%), which primarily consists of residential buildings and backyards. However, the landscape surrounded by the built-up areas is a mosaic of forests (17.8%), agricultural land (8.3%), pasture (1.3%), open firm ground (9.9%), bog (2.5%) and water (11.3%; Figure 2). The different land cover types are described in more detail in Table 1.

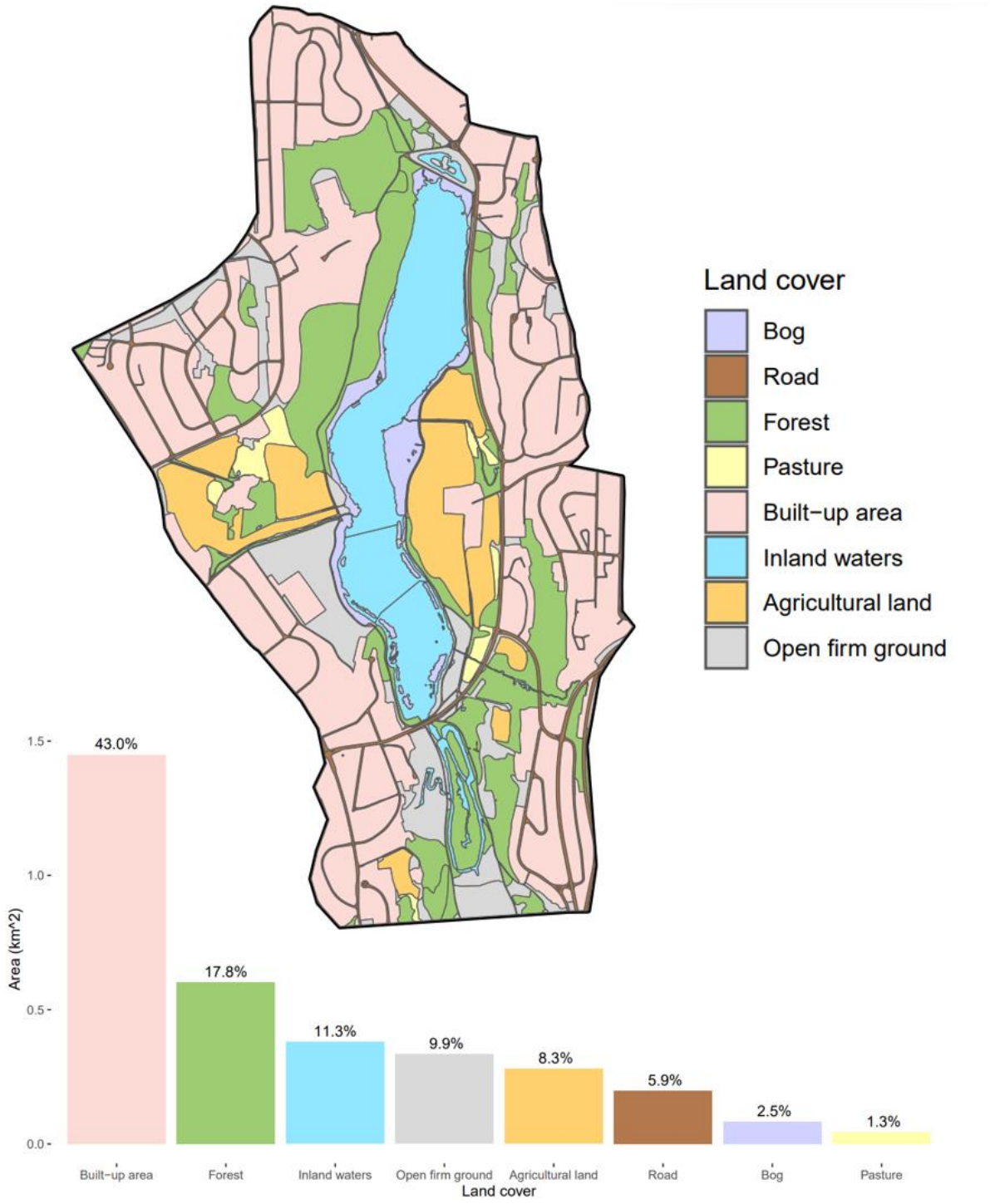

Figure 2. *Area (km^2) and percent of each land cover within the study area.*

Table 1. *The standard land cover types in the AR5 classification system (NIBIO, 2019) within the study area.*

Land cover	Description
Built-up areas	Area that has been developed or significantly improved, as well as adjacent area that is functionally closely linked to the buildings
Road	Roads and railway
Inland waters	Lake, river, and stream
Bog	Area with bog vegetation and > 30 cm peat layer
Forest	Area with minimum 6 trees per hectare which are or can be 5 meters high, and which are evenly distributed over the area
Open firm ground	Area that is not bog, agricultural, forest, built-up or traffic (e.g. lawn)
Pasture	Agricultural land that can be used as pasture but cannot be harvested mechanically. At least 50% of the area must be covered with cultivated grass and grazing-resistant herbs
Agricultural land	Area with standard plowing depth

2.2 Recruiting cat owners

With the intention of recruiting as many of the resident cats as possible, we advertised on two local social-media groups and distributed flyers in every residential mailbox in the study area. Participants could register through an online registration form. Those cat owners who registered their participation were then prompted to fill out a second online form collecting detailed information about each cat (e.g., sex, age, release method).

2.3 GPS unit description

The GPS units used in this study was i-gotU GT-120 GPS (Mobile Action Technology, Inc.), which is the same model used in several previous studies involving pet cats due to its light weight, low cost, and ease of use (Bischof et al., 2022; Coughlin & van Heezik, 2015; Forin-Wiart et al., 2015; Hanmer et al., 2017; Hervías et al., 2014; Kays et al., 2020; Morris & Conner, 2017; Thomas et al., 2014). Each unit weighs 26 g with a silicone cover (4 g) and measures 2.4 x 2.7 x 1.3 cm in size (Figure 3). The fix rate was set to 1 minute, and with this fix rate the GPS unit is estimated to have a battery time of at least 10 hours (Hansen, 2022). Data needs to be downloaded manually.

Figure 3. *Pet cat wearing an i-gotU GT-120 GPS unit. Foto: Ronny Steen.*

2.4 Data collection

The GPS tracking period lasted from 6th of May to 6th of June 2022. Each owner received a package containing a GPS unit, a collar, and a charger in their mailbox. The owners that participated with multiple cats received collars with different colors to tell them apart, thereby each cat had their own designated GPS unit. The participants' main task was to charge the unit when the cats were inside to avoid unnecessary gaps in the data collection due to a dead battery. If needed, technical assistance or new gear (e.g., due to fault with the charger) were provided on request throughout the tracking period. To assure that all GPS units were functioning properly, data from the units were collected midway through the tracking period. At the end of the study period, the equipment was retrieved from each participant and all the data downloaded from the GPS units using the accompanying software @Trip PC (Mobile Action Technology, Inc).

2.5 Data pre-processing

The GPS data were pre-processed following methods outlined in Bischof et al. (2022) partially based on recommendations by Gupte et al. (2022) and Morris and Conner (2017) to remove positions that were considered unreliable. In short, GPS positions were removed if they 1) had an elevation outside the range of 0-300 m, or 2) had an estimated horizontal position error (EHPE) ≥ 5000, or 3) were obtained during the first two days of tracking or on days where the GPS units was picked up for data download. In addition, delineation of outdoor activity was conducted to ensure that positions used during the analysis can be considered arising from the cat's outdoor activity. This was done by

removing all the GPS positions associated with clusters with centroids that fell within the participants homes. Additional details on delineation of outdoor activity are outlined in Bischof et al. (2022).

2.6 Data analysis

All data processing and data analyses were done using R version 4.2.2 (R Core Team, 2021). To estimate home ranges for each cat, the 95% Brownian Bridge movement models (BBMM) were constructed using the R package *BBMM* (Nielson et al., 2013). To process spatial data, the R package *sf* was used (Pebesma, 2018). To estimate the proportion of home ranges that fell within the nature reserve, cell values in each cat's utilization distribution (UD), a probability distribution that indicates the likelihood of an animal using a specific location in space, were rescaled to sum to 1. The scaled UD was then intersected with the polygon of the nature reserve obtained from the Norwegian Mapping Authority (www.geonorge.no). The sum of the UD cells within the nature reserve represents the proportion of the cat's activity (probabilistic space use) inside the nature reserve.

To assess how many cats that had registered positions within the reserve, I intersected GPS positions with the polygon of the protected area. To determine the effect of different cat-specific attributes (e.g., sex, age, home range size) or cat maintenance (e.g., release method) on the probability of space use within the reserve, *a-priori* candidate models were created using generalized linear regression models (GLMs) with a logit link (i.e., logistic regression). The response was whether a cat had one or more GPS positions within the reserve (1) or zero GPS positions inside the reserve (0). The different predictor variables tested was age, sex, 95% BBMM home range size, distance between a cats' house and the reserve, release method and total time tracked. The candidate models were then tested using the Akaike Information Criterion (AICc) to select the model that best explains the data using the *AICcmodavg* package (Mazerolle, 2023). For each cat, the total time spent outdoors, and the proportion of outdoor time spent inside the reserve were calculated. Gaps longer than 10 minutes were excluded from the calculations of proportion of time spent inside the reserve.

Since urban pet cats spend most of their time in urban habitats (Bischof et al., 2022; Hanmer et al., 2017; Kays et al., 2020; López-Jara et al., 2021), I rather investigate what non-built-up habitats cats prefer. I used resource selection functions (RSF) to estimate habitat selection by cats to see whether they favor any non-built-up habitats over others. RSF depends upon a used-available design, where locations used by GPS-collared cats are compared to locations not used but considered as available ("null model"). For each used GPS position, I randomly sampled 60 available positions (excluding inland waters, built-up areas, and roads). In order to associate the GPS-locations to different habitats, I used spatial data obtained from a land cover map (AR5, 1:1000) (NIBIO, 2019). Home ranges for this analysis

were estimated with the kernel home-range function *kernelUD* and *getverticeshr* from the *adehabitatHR* package in R with 95% isopleths (Calenge & Fortmann-Roe, 2020). To be included in the RSF, each cat had to have locations in more than one non-built-up habitat type, and the remaining area had to be larger than 250 m^2. I then fitted a generalized linear model to obtain RSFs using the *glm* function on each cat individually. The response was whether a location was used (1) or available (0), and the predictor variable was habitat type (i.e., forest, bog, pasture, open firm ground and agricultural land).

3. Results

3.1 Participating cats

In total, 57 cats participated from 49 households; 8 households had 2 participant cats. Owners did not provide demographic and maintenance details for 6 cats. The sex ratio of GPS-tagged cats was close to even (54.9% male; 45.1% female), with the same median age for both sexes (4yrs). All except one cat (cat ID 14) were reported sterilized or castrated. Most cats (70%) were manually released by their owner to get outdoor access, while the remainder had free or partially free outdoor access via a pet door (also called "cat flap"). The majority of cats (84.3%) were given unlimited access to food. Reportedly, 64.7% rarely or never brought prey home, while 17.6% brought prey home on a weekly or monthly basis.

Home range size estimates (95% BBMM) during the tracking period ranged from 0.3 to 12.4 ha (mean: 2.1; Table 2). The overall average distance of outdoor positions from the home was 34 m (range: 7-385). Distance between a cat's home and the reserve border varied greatly, with a mean distance of 374 meters (range: 31-1037 meters). The average duration a cat was tracked during the tracking period was 274 hours, which is about 11 days (Table 2).

Table 2. *Summary statistics of explanatory variables for all the cats tracked in the current study.*

	Mean	Median	SD	Min	Max
Home range (ha)	2.09	1.28	2.39	0.34	12.37
Maximum distance from house (m)	268.04	217.74	180.63	80.49	862.27
Mean distance from house (m)	34.45	21.45	51.61	7.57	384.97
Distance of home from the reserve	373.54	339.88	237.22	30.91	1036.82
Total time tracked (minutes)	16 495.8	16 409.9	7 418.82	203.2	33 254.3
Total time tracked (hours)	274.93	273.49	123.67	3.39	554.24

3.2 Habitat selection

Only 17 cats met the requirements for inclusion in the RSF (Figure 4), which means 40 cats did not include any or only one non-built-up habitat in their home range, or the combined area of multiple non-built-up habitats was smaller than 250 km^2. Two cats (cat ID 38 and 48) had all five habitat types within their home range, but the majority had three types of habitat within their home range (Table 3). Among these 17 cats, 11 had a significant preference or avoidance for one or more of the non-built-up habitats (Figure 5). Bog, forest, agricultural land and open firm ground were significantly selected for by one or more cats (Figure 5). Among the seven cats with bog inside their home range (Table3), only two significantly selected it. Open firm ground was within the home range of 15 cats, but only significantly selected by four cats (Figure 5). All of the 17 cats, except for one (cat ID 1), had forest inside their home range (Table 3); four cats exhibited significant selection for forest habitat. Only one cat (cat ID 14) significantly selected agricultural land and none significantly selected pasture (Figure 5). The two cats with access to all the habitat types (cat ID 38 and 48) significantly selected bog and open firm land and bog and forest, respectively.

One or more cats also significantly avoided each habitat (Figure 5). Open firm ground, pasture and agricultural land are the three habitats more cats significantly avoided than selected. Five cats significantly avoided open firm ground, three cats avoided pasture while five cats avoided agricultural land. Four cats significantly avoided forest, which is the same number that also significantly selected the habitat. Lastly, only one cat significantly avoided bog (cat ID 19).

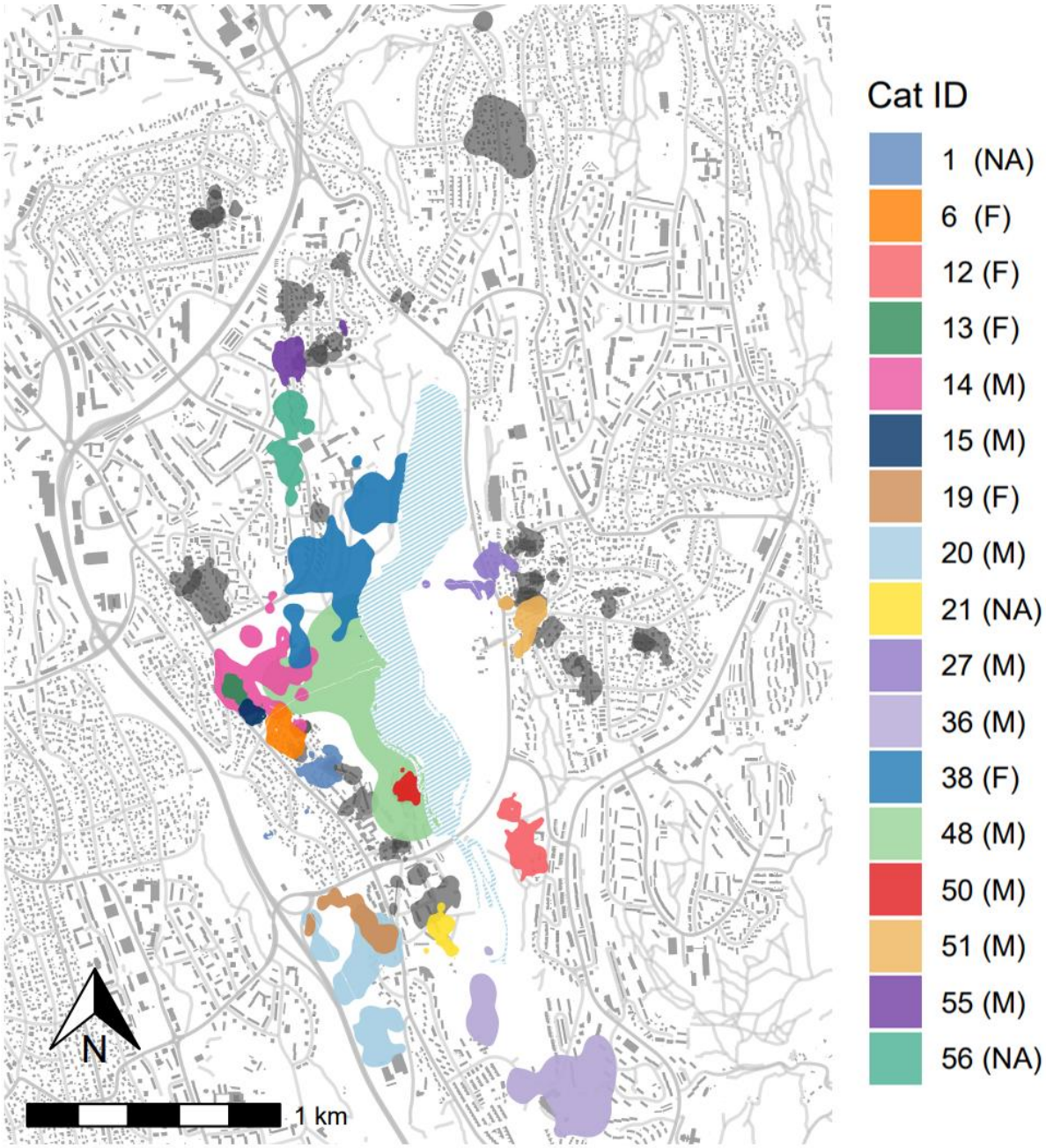

Figure 4. *Home ranges of the 17 cats included in the RSF-analysis highlighted with colored polygons (95% kernel home range). Home ranges of the 40 cats not included in the RSF-analysis are shown as dark-grey polygons. The light-grey polygons and linear features represent buildings and roads in OpenStreetmap (OSM). The lake (Østensjøvannet) is shown as polygon with blue hashing. M = male; F = female; NA = unknown.*

Table 3. *Overview of habitats each cat included in the RSF-analysis (see Figure 4) had within their 95% Kernel home range.*

Cat ID	Sex[1]	Age (years)	Habitats	Number of habitats
1	NA	NA	Open firm ground, bog	2
15	M	10	Forest, agricultural land	
36	M	4	Forest, open firm ground	
55	M	4	Forest, open firm ground	
56	NA	NA	Forest, open firm ground	
19	F	3	Forest, open firm ground, bog	3
20	M	1	Forest, open firm ground, bog	
50	M	2	Forest, open firm ground, bog	
6	F	3	Forest, open firm ground, agricultural land	
12	F	2	Forest, open firm ground, agricultural land	
13	F	3	Forest, open firm ground, agricultural land	
21	NA	NA	Forest, open firm ground, agricultural land	
51	M	3	Forest, open firm ground, agricultural land	
27	M	4	Forest, agricultural land, pasture, bog	4
14	M	2	Forest, open firm ground, agricultural land, pasture	
38	F	2	Forest, open firm ground, agricultural land, pasture, bog	5
48	M	4	Forest, open firm ground, agricultural land, pasture, bog	

[1] M = male; F = female; NA = unknown

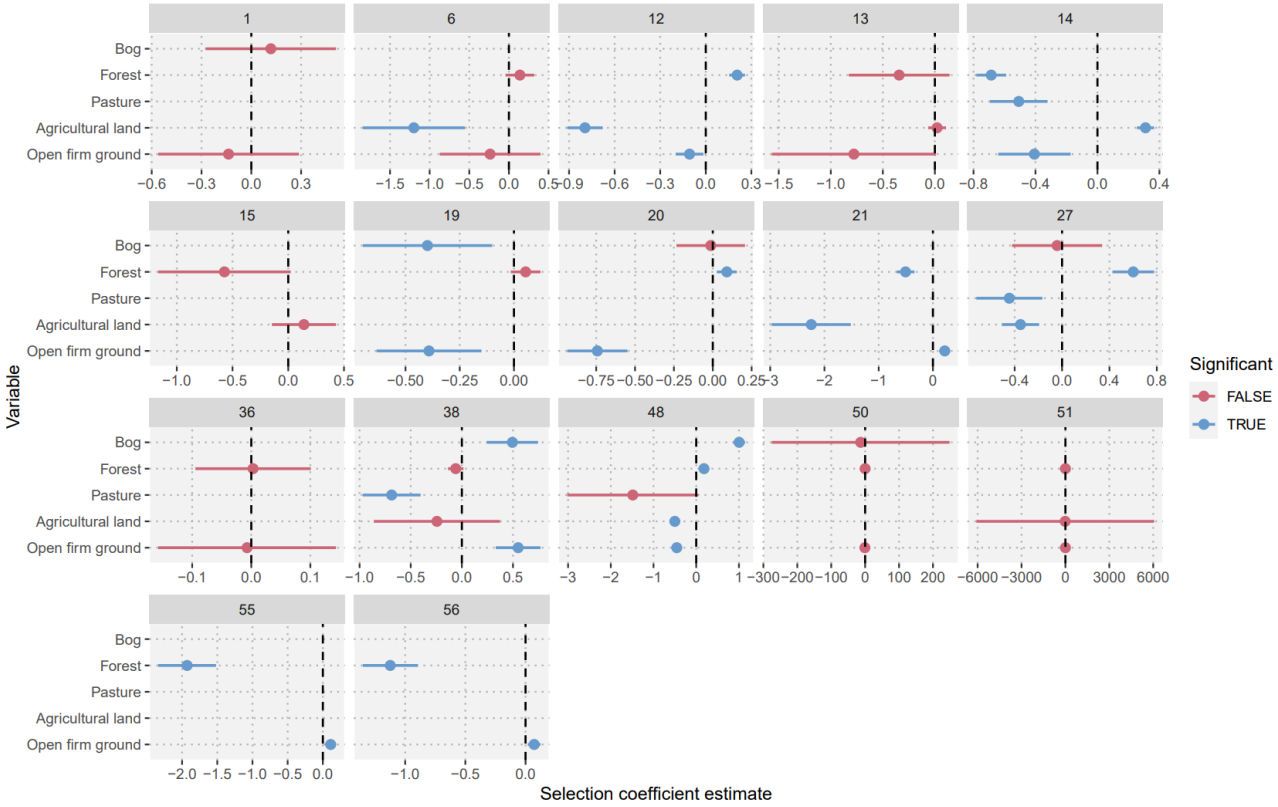

Figure 5. *Selection coefficient estimates for habitat variables for each cat included in the RSF-analysis. Each panel represent one cat ID. Point estimates and 95% confidence intervals are based on the standard errors for the RSF model. All significant points are significant at the alpha level of 0.05. Positive and negative selection coefficients indicate selection for and against a given habitat type, respectively.*

3.3 Activity within the nature reserve

Nine of the 57 participating cats had registered locations within the reserve. Of these, two were females and seven were males, and males were older than the females (median = 2 and 4 years for females and males, respectively). Five cats were manually released by their owner to get outdoor access, while three cats had an unlimited cat flap and one cat had a limited cat flap. All nine cats that entered the reserve were reported sterilized. Five cats reportedly never or rarely brought prey home, three cats brought home prey each month, and one cat brought prey home weekly.

Among the nine cats that entered the reserve, the BBMM (95%) home range size ranged from 0.6 to 12.4 ha (mean: 4.4 ha, Table 4). Four cats had <10 fixes within the reserve, and because the home range estimate for each cat includes 95% of the fixes, only five cats had part of their home range within the reserve, with a mean area of 0.13 hectares of their total home range size (Table 4). The nine cats have an overall average distance of 150 meters between their home and the reserve, with a minimum distance of 31 meters and a maximum distance of 503 meters. Three individuals spent > 18 hours inside

the reserve, which is significantly more than the other cats (< 2 hours; Figure 6b). Based on the number of GPS locations within the reserve, cats spent most time inside the reserve early in the morning (6-8 am) and in the evening (20-21 pm; Figure 7).

Table 4. *Summary statistics of explanatory variables for the cats that enter the reserve.*

	Mean	Median	SD	Min	Max
Home range (ha)	4.38	3.25	4.33	0.66	12.37
Home range within the reserve (ha)[1]	0.07	0.03	0.09	0	0.24
Home range within the reserve (ha)[2]	0.13	0.16	0.09	0.03	0.24
Maximum distance from house (m)	418.9	299.9	280.87	169.0	862.27
Mean distance from house (m)	77.46	29.87	119.19	13.30	384.97
Distance of home from the reserve	150.45	140.89	141.99	30.91	502.72
Total time tracked (minutes)	16 626	14 707	6 833.4	5 372	26 294
Total time tracked (hours)	277.10	245.11	113.89	89.53	438.23

[1] summary for all the nine cats that enter the reserve
[2] summary for the five cats with 95% BBMM home range within the reserve

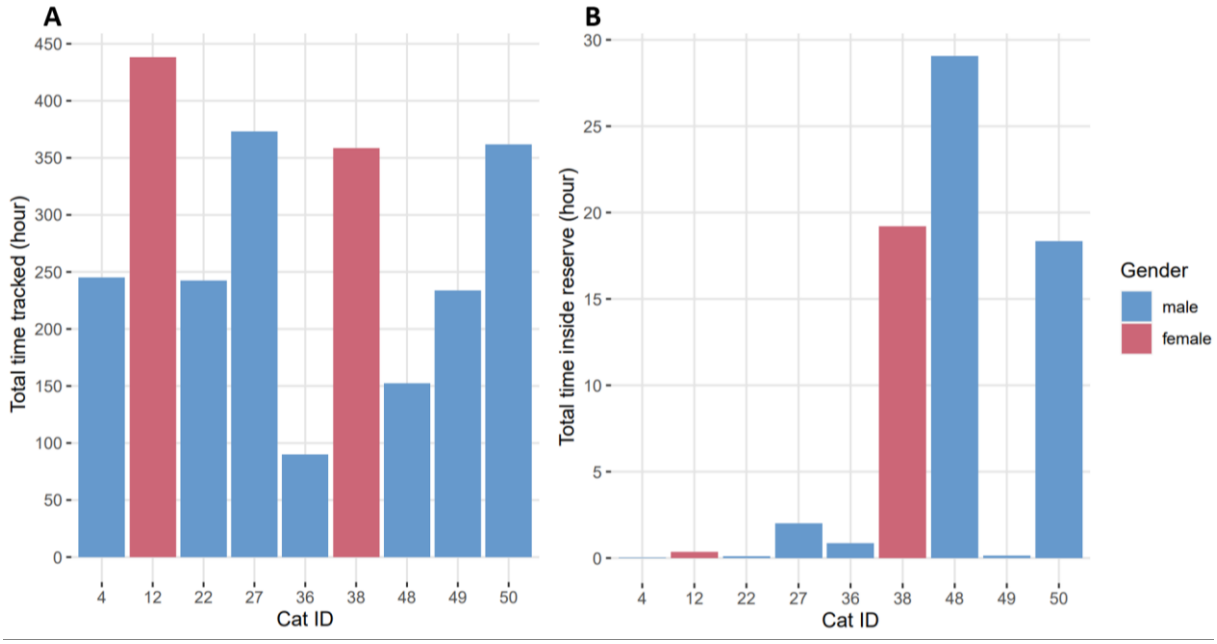

Figure 6. *Total time tracked (a) and total time tracked inside the reserve (b) for all the 9 cats that entered the reserve. Note the difference in scale on the x-axes.*

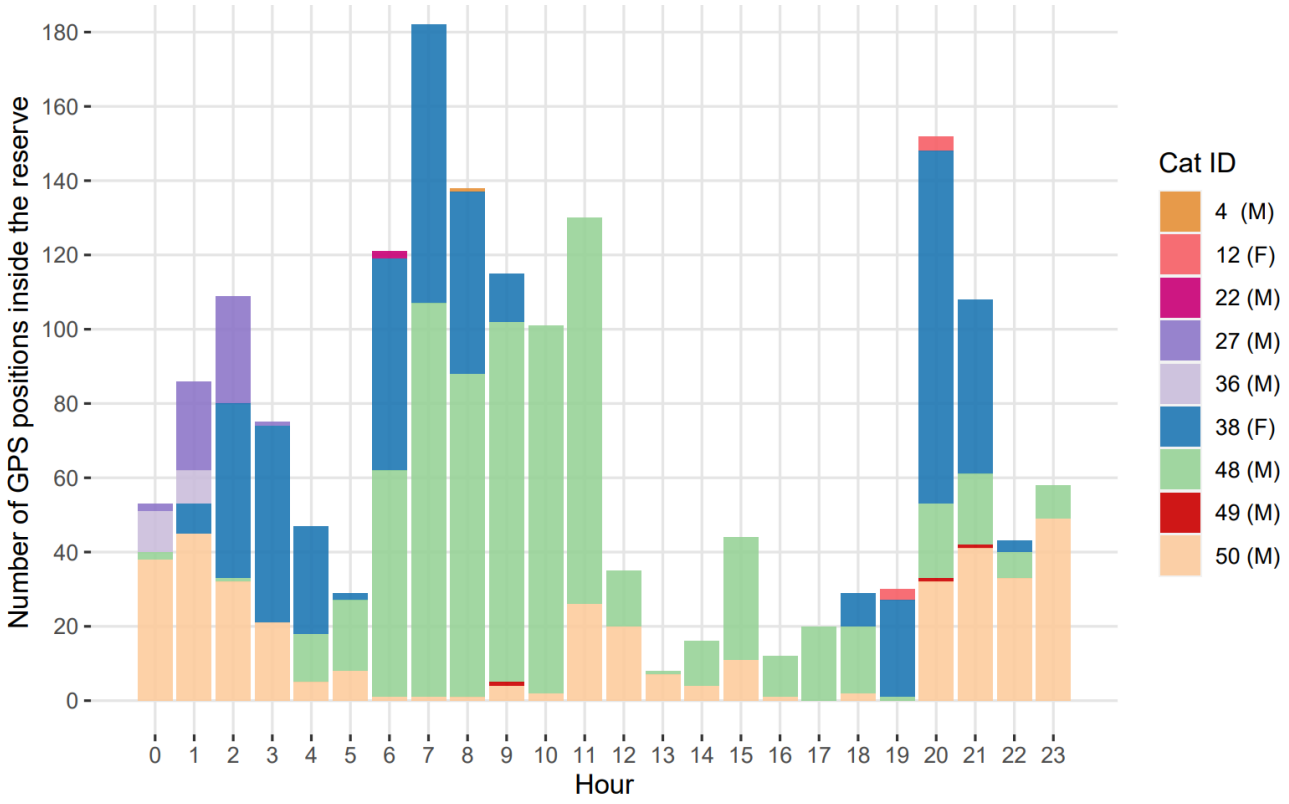

Figure 7. *Number of GPS positions for each cat (identified with different colors) inside the reserve throughout the day. Zero indicates midnight. M = male; F = female; NA = unknown.*

3.4 Determinants of cat use of the nature reserve

Cat use within the nature reserve strongly decreased the further away a cat lived. The model that best explained use of the reserve by local cats included 95% home range and distance from home to nature reserve boundary with an interacting relationship (Table 5). However, the other competing model (ΔAICc < 2) also included the same determinants but with an additive relationship. Only home distance from the nature reserve significantly influenced use of the reserve ($p < 0.05$; Table 6).

Table 5. *Eight different a-priori candidate models for the response variable "enter reserve". The response could either be that the cat entered the reserve = TRUE (1) or that the cat did not enter the reserve = FALSE (0).*

Model	Model specification	K	LL	AICc	ΔAICc	AICcWt
2	home.distance.from.nr[1] * HRsize95[2]	4	-9.86	28.58	0.00	0.48
3	home.distance.from.nr[1] + HRsize95[2]	3	-11.07	28.64	0.06	0.47
4	home.distance.from.nr[1] + cat.gender	3	-14.51	35.52	6.94	0.02
8	home.distance.from.nr[1] + cat.age + cat.gender + HRsize95[2] + hom.released[3] + total.time.tracked[4]	8	-8.56	36.55	7.97	0.01
5	home.distance.from.nr[1] + cat.age	3	-15.13	36.76	8.18	0.01
6	home.distance.from.nr[1] + how.released[3]	4	-14.00	36.87	8.29	0.01
7	home.distance.from.nr[1] + total.time.tracked[4]	3	-15.33	37.17	8.59	0.01
1	~ 1[5]	1	-23.77	49.61	21.03	0.00

[1] "home.distance.from.nr" = distance (m) between a cats' home and the nature reserve
[2] "HRsize95" = home range size with 95% isopleths
[3] "how.released" = method used to give the cats outdoor access (i.e., manually, limited cat door or unlimited cat door)
[4] "total.time.tracked" = total amount of time tracked outdoors
[5] "~1" = intercept-only model

Table 6. *Results of the model with the lowest AICc value (model 2 from Table 5) with response variable "enter reserve" and predictor variable "home distance from nature reserve" and "95% home range size" with an interacting relationship. Significant values (<0.05) are marked with "*".*

With enter.reserve	Estimate	Std.Error	Z value	P(>|z|)
(intercept)	3.345644	2.145111	1.560	0.1188
home.distance.from.nr	-0.029843	0.013419	-2.224	0.0261*
HRsize95	-0.081482	0.452128	-0.180	0.8570
home.distance.from.nr:HRsize95	0.003089	0.002056	1.503	0.1329

4. Discussion

4.1 Habitat selection among non-built-up habitats

The study revealed substantial variation in resident cats' selection of non-built-up habitat. However, the highest number of cats significantly selected forest and open firm ground, followed by bog and agricultural land. However, one or more cats also significantly avoided each habitat. Due to the variation of habitat available in each cat's home range, it is challenging to compare all cats to each other.

The same number of cats both significantly selected and avoided forest. In fact, previous studies show similarly divergent findings; several studies indicate that cats select against forests (Gehrt et al., 2013; Kays & DeWan, 2004; van Heezik et al., 2010), while other studies have found that cats show a weak or no selection against forest (López-Jara et al., 2021; Pirie et al., 2022; Thomas et al., 2014). Multiple studies have looked at how far into forests cats go (Gehrt et al., 2013; Kays & DeWan, 2004; López-Jara et al., 2021; Marks & Duncan, 2009; Pirie et al., 2022; Thomas et al., 2014; van Heezik et al., 2010), and even though this is beyond the scope of the current study it sheds light on an interesting phenomenon. Most of the evidence thus far suggests that cats prefer forest edges over forest interior (Gehrt et al., 2013; Kays & DeWan, 2004; van Heezik et al., 2010). Kays and DeWan (2004) found that domestic cats spent most of their time in forest edges except when they were in built-up habitats. In contrast, López-Jara et al. (2021) found that even cats venturing relatively far from home (average maximum distance 738 meters), cats that lived further than 200 meters from the forest hardly entered it. These findings suggest that forests are likely not a preferred habitat for pet cats and that they rather stay close to the forest edge. This may also be the case in the current study, as the study area contains mostly small fragments of forest, which means cats are never far from the edge.

Contrary to my prediction that cats would select agricultural fields and open areas rather than forested areas, results show that the majority of the cats with respective habitats in their home range significantly avoided agricultural land and pasture. However, four cats significantly selected open firm ground. Open firm ground is a land cover type used as an umbrella-term for both natural and culturally affected areas, and can contain scattered buildings such as cabins or houses (Bjørkelo et al., 2013). This may be the reason why cats select open firm ground more than pasture and agricultural land. A plausible explanation to why cats did not significantly select pasture and agricultural land may be because there is no shelter to ambush potential prey or to hide from potential predators and thus, they rather move on areas with different kinds of shelter. These results build on existing evidence that cats avoid open habitats, and rather select vegetation buffers or edges when roaming (Genovesi &

Toso, 1995; Sarfi, 20202). It was beyond the scope of this study to investigate movement and use of linear features such as edges within each habitat, but this may be a plausible explanation as to why cats avoided agricultural land and pasture.

Two cats significantly selected bog, while one cat significantly avoided it. These results may contradict common knowledge that, in general, domestic cats will avoid getting wet and thus avoid wetlands such as bog. However, the two cats who significantly selected bog, cat ID 38 and 48, had their bog habitat within the nature reserve, while the one cat that significantly avoided bog (cat ID 19) did not have it within the nature reserve. As the nature reserve is known for its diverse fauna and especially birds, prey availability may be a plausible explanation for why just the two cats with bog habitat within the nature reserve significantly selected it. Østensjøvannet nature reserve with associated bog habitat is one of the most important nesting areas for water birds in Oslo and Akershus municipality (Oslo Bymiljøetaten, n.d.). Even though just two cats significantly select for the habitat, their presence may result in different prey stress responses such as reduced reproductive success and changes in prey feeding habits (Beckerman et al., 2007; Bonnington et al., 2013; Fardell et al., 2020).

4.2 Activity in the nature reserve

Only a small proportion of the tracked cats entered the reserve (n=9). Four cats had <10 fixes within the reserve and clearly portray limited use of this area. It is also possible that the fixes are location errors that led to habitat misclassification, a trade-off from using more affordable GPS devices (Forin-Wiart et al., 2015). The remaining five cats had parts of their 95% BBMM-estimated home range within the reserve. This is fewer than expected, however, one possible explanation can be that the cats avoid overlapping their home range with other cats (Barratt, 1997; Hansen, 2022). Overlapping home ranges are more common between males and males and females than between females (Barratt, 1997; Guttilla & Stapp, 2010). Related cats or cats from the same residence are more likely to overlap their home ranges (Barratt, 1997). Regular encounters with neighbors may reinforce exclusive home ranges, even if it results in smaller home ranges (Hansen, 2022), which is particularly likely to occur in urban settings with high cat densities. This intraspecific avoidance and already limited land area within the reserve (0.2 km^2) might restrict other cats from also entering the reserve.

Only three individuals (cat ID 38, 48 and 50) spent more than 18 hours inside the reserve during the tracking period. The cats roamed within the reserve largely in the early morning and late evening. This pattern can be the result of cats being inside during the day or that the cats are drawn to the reserve when the crepuscular fauna is active. This might explain the sudden drop in GPS positions within the

reserve around mid-day. Cat owners and their chosen release method affect when the cat(s) are outdoors. Cat 48 and 50 both access the outdoors via an unlimited cat flap, while cat 38 is released manually. This may explain why cats 48 and 50 are inside the reserve practically continuously throughout the day.

4.3 What determined space use within the nature reserve

Distance between the reserve and the cat's home was the strongest determinant of whether cats were present in the reserve. In other words, cats were more likely to be present within the reserve if they lived closer to it. Among the cats that entered the reserve, the furthest distance between a cat's home and the reserve was 503 meters. Previous studies show that domestic cats rarely roam further than a few hundred meters (Bischof et al., 2022; Kays et al., 2020; López-Jara et al., 2021). However, there is a large individual variation in roaming distance, with some individuals roaming much further. This is consistent with several previous studies reporting distance as a strong determinant of cats being a specific place (e.g., forest, national park or wetland reserve; Nyheim (2022), López-Jara et al. (2021), Wierzbowska et al. (2012), Morgan et al. (2009)).

The top model from the *a-priori* candidate models also included 95% home range size in addition to distance between a cat's home and the reserve. However, the effect of home range was not significant; but I observed a pattern. The cat that lived furthest away also had the smallest proportion of its home range (< 0.03 ha) within the reserve. Only one cat (cat ID 48) had part of their core home range (50% BBMM) within the reserve and this cat lived very close to the reserve boundary (34 meters). Male cats have been found to have a significantly larger home range than females (Hall et al., 2016b; Kays et al., 2020) however, I found no proof for my prediction that males are more likely to use the nature reserve than females. The reason I found no support for my prediction could be the small sample size of cats that enter the reserve (nine cats). Even though the *a-priori* model (model 4; Table 5) with cat sex as a predictor variable were not a competing model (ΔAICc > 2), the majority of cats using the nature reserve are males.

4.4 Implications for management

Due to the massive expansion of human settlements, urban environments have become increasingly important for conserving biodiversity (Lepczyk et al., 2017), and even small patches of green spaces

are proven areas of environmental and biodiversity significance (Soanes et al., 2019). Surveys establish that there is awareness among cat owners as well as non-owners of the ecological threats free-roaming cats inflict (Crowley et al., 2019; Hall et al., 2016a). Despite the awareness of the ecological impacts cats cause, there is a lack of public support for implementing pet cat restrictions (Fardell et al., 2021). However, it should be in people's and governments interest to reduce the impact pet cats have on wildlife because urban biodiversity improve the public health of human populations (Wolch et al., 2014; World Health Organization, 2016). Non-owners are more likely than owners to agree that pet cats killing wildlife is a problem (Hall et al., 2016a) and that cat owners are reluctant to impose restrictions on their pet cat roaming behavior in order to protect wildlife (Crowley et al., 2019; Grayson et al., 2002). Few owners are in favor of cat management beyond neutering (McDonald et al., 2015), and although neutering has been observed to decrease cat home ranges, it may not have that effect for all cats (Hall et al., 2016b). However, investigating the potential effect of neutering is still an important research priority (López-Jara et al., 2021).

This study supports previous findings that cats living close to a protected area are more likely to use it than others living further away. Even when cats are not hunting, their presence can negatively affect wildlife by creating a landscape of fear (Loss & Marra, 2017; Preisser et al., 2005) and can for instance prevent birds from feeding and rearing their young. In this study, the nature reserve has an irregular shape that is long and narrow, and with a lake as the "interior". Therefore, the wildlife within the strip of protected habitat around the lake is likely disturbed by visiting cats. Several studies have recommended constructing a buffer zone around vulnerable habitats to lessen the impacts of cats, often suggesting buffers of 300-400 meters (Lilith et al., 2008; Thomas et al., 2014). This study supports the creation of a buffer zone around protected areas, either cat-free residential areas or resident-free buffer zones, to lessen the probability of a cat entering. However, this study indicates that a buffer would need to be >500 meters wide. A no-building buffer zone would therefore clearly be impractical in a heavily urbanized setting. In such an area, any restrictions on cat roaming would rely heavily on cat owners, but this may be challenging because there is no official public management of domestic cats.

Other management measures would be to restrict a cat's outdoor access, as well as limit their time outdoors. There are households that keep their cats indoors at all times. While this is beneficial for local wildlife, some argue that cats get better stimulation and exercise from being outdoors, and it would reduce the cat's quality of life to be kept inside at all times. As a compromise, different devices with the aim of reducing predation (e.g., clown-collars, bibs and specialized collars with a small bell) have been tested. Pirie et al. (2022) unexpectedly found that bell-wearing was associated with

increased overall predation, however, this needs further testing. In addition to limited success, measures like this are also limited to domestic-owned cats.

While the population of unowned domestic and feral cats in Norway is moderate (Heggøy & Shimmings, 2018), there are substantially greater populations of feral cats elsewhere in the world. To mitigate the impact of unowned cats, stronger legislation to prevent abandonment and a more restrictive breeding licensing could help prevent an increase in the feral cat population (Loss & Marra, 2017).

5. Conclusion

The aim of this study was to investigate what non-built-up habitats domestic cats select in a patchy, urban environment, and how large a proportion of the GPS-tagged cats used a protected nature reserve. In addition, I also studied what attributes of cat or cat maintenance were determinants of use of the nature reserve by cats. I found that there was substantial variation between cats in the selection of non-built-up habitats, and surprisingly little use of the nature reserve - both in terms of a low number of cats and time spent inside the reserve. The strongest determinant of cat use within the reserve proved to be the distance between a cat's house and the reserve. Together, these findings are useful to assess what management strategies may be most effective to reduce encounter rates of roaming domestic cats with wildlife. Ideally, to reduce the impact of domestic cats with outdoor access, cats would live in low densities and with restricted outdoor access both in terms of quantity and area. However, the likelihood of such restrictions being implemented is small. A feasible solution to lessen the impact of pet cats is for each owner to observe their roaming behavior and make some adjustments if they have a cat that travels far, especially into vulnerable wildlife areas. One adjustment could be neutering to potentially reduce the home range size. Another adjustment is to limit outdoor access by changing from unlimited cat-flap to manual release, and thus have more control on when the cat is outdoors. In addition, another adjustment could be to keep the cat indoors in periods where typical prey species are more vulnerable, for instance during the bird nesting season. However, more knowledge on habitat selection, interactions and hunting habits is needed to know the extent of their threat to local wildlife. This will in turn enable us to understand how to best mitigate their impacts.

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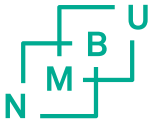

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