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When does the cat roam: Temporal patterns of pet cat (*Felis catus*) roaming in Norway

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Preface

This study was conducted at the Faculty of Environmental Sciences and Natural Resource Management at the Norwegian University of Life Sciences (NMBU). First of all, I would like to express my sincere gratitude to my supervisors Torbjørn Haugaasen and Richard Bischof and for making this project happen and for all the work they did related to the experimental setup. I would like to thank senior adviser Cathrine Glosli for establishing and maintaining the webpage for project and questionnaires. I would also like to thank the staff at IT service centre at NMBU that helped us to set up access to large file storage on NMBU's server.

Torbjørn Haugaasen deserves special thanks for all the help and guidance during this project. Thank you for your intensive work in such a short period to help me, a procrastinator. And for all the help with the statistical analysis as well as valuable comments on the manuscript. Many thanks to for his invaluable knowledge of statistics, for helping me build models and analyse the data, valuable tips about handling position data in R, as well as helpful comments on the manuscript. I would also like to thank group member Bettina Bachmann, Filip Sarfi, Gina Sande Leikanger and countless cat owners together with their cats for the brilliant cooperation we had in this project.

Last, but not least I would like to thank my parents and my lovely cats for always supporting and comforting me when I'm stressed out.

Ås, 17.08.2020

………………………………………………

Fan Wu

Appendix 1

Questionnaire for cat owners to nominate themselves to the cat tracking project

Kattesporet: Regitration

Cats are popular pet animals, but much of their life remains mysterious for us. In this project, we want to discover more about cats when they are released outdoors by using a GPS logger, and install camera trap in the cat owner's yard. The project is also aimed to motivate children's curiosity in science and scientific research.

Notice: We recruit only cats that were used to roam around.

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experiment will last for one week from the day you received the equipment and mounted it. Your task as cat owner is to make sure that the PGS is turned on every time the cat leaves and off when it comes back.

- If there is a mismatch with your schedule, you can still fill out the form. We can contact you next round.
- If this fits you, you can start filling out the form below.

Contact information

Name of the parent *

Family name Surname

Email *

Tel *

Address *

Post code*

Post region *

Du you have a yard?

- ☐ Yes
- ☐ No

About the child

One of the purposes of this project is to motivate kids' interest in science, thereby we recruit only families with school kids.

Age of your child

About the cat

How often does the cat travel outside? On average *

- ○ Less than onve a day
- ○ One a day
- ○ Twice a day
- ○ Three times a day or more

When your cat stay outside, how long it stay? On average *

- ○ Less than 5 hours
- ○ 5-10 hours
- ○ 11-20 hours
- ○ More than 20 hours

A camera trap can use movement sensor to detect and film movements in its vision field. Are you interested in mounting a camera trap in your yard and film your cats movement and possiblely other animals?

- ☐ Yes
- ☐ No
- ☐

Informasjon

Ved å trykke på "Submit" godtar du at NMBU lagrer disse dataene, og kontakter deg per e-post eller telefon.

Submit

Appendix 2

Collecting information of the cat

Kattesporet: Information of your cat

Thank you for participating this research project. Vi would like to collect more information on your cat befor tracking it.

Name of the owner *

Family name Surname

Email *

About the cat

Name

Upload a picture of the cat. Notice, the picture should be without human. By uploading this picture, you authorized NMBU to use this picture on any case that is related to this project..

Upload a File

Select Files

Age (year) *

Gender*

- ○ Male
- ○ Female

Is it sterilized/castrated *

- ○ Jes
- ○ No

If it is intact female cat, is it taking birth control pill?

- ○ yes
- ○ No

weight (kg) *

Breed *

Personality *

- ◯ Explorative
- ◯ Careful

Cat health

Is it vaccinated? *

- ◯ Yes
- ◯ No

Does it have any form of illness? *

- ◯ No
- ◯ Yes

If yes, what it is?

____

Habits and rutines

How is the cat fed? *

- ◯ Ad libitium
- ◯ Portional

Is the cat used to wear collar? *

- ◯ Yes
- ◯ No

Access to the outside

Which type of residence you live?

- ◯ Rural
- ◯ Suburban
- ◯ Urban

At what time of a day is you rcat outdoors*

- ☐ Morning
- ☐ Daytime
- ☐ evening
- ☐ Night

How you release the cat? *

- ◯ Cat flap
- ◯ Owner controlled cat flap
- ◯ Owner release it in and out

How often your cat brings prey hoem? *

- ◯ Daily/almost daily
- ◯ Weekly
- ◯ Monthly
- ◯ Seldom/never

How many other cats are there in the neighborhood? *

- ◯ 0-5
- ◯ 6-10
- ◯ 11 or more

Other relevant information you would like to tell us. (For example pregnancy, post-natal, newly had operation, under medicine treatment etc.)?

Informasjon

Submit

Abstract

The domestic cats (*felis catus*) are popular pet animals, and their population is growing worldwide. As a natural predator, cats roaming outside raise conservation concerns. It is thereby important to know when and where cats interact with wildlife, especially endangered species. This study GPS tracked 111 free-roaming pet cats in Oslo, Viken, Vestfold and Telemark counties in Norway. Each cat was tracked 7 days while spending time outside. The result demonstrated apparent differences between cats living in urban areas and suburban/rural areas. Urban cats spent less time roaming ($p = 0.009$) and roamed mainly during the day. Suburban and rural cats roamed both day and night. The residence context is the factor most associated with all roaming patterns. Gender is moderately associated with circadian patterns. Age and how cats accessed the outdoors do not affect circadian patterns. The result suggest that urban cats have a circadian pattern more synchronized with human activity, while suburban and rural cats roam in a manner like feral cats. To protect endangered species sharing their habitat with pet cats, restricting the cats' access to outdoor roaming and motivate cat owner for more interaction with their cat at home can be a solution. In the region where this experiment was conducted, free roaming cats will not threaten endangered bird species, because they occupy different temporal niches.

Sammendrag

Huskatter (*Felis catus*) er populære kjæledyr, og deres populasjonsstørrelse stiger over hele verden. Som et naturlig rovdyr, katter som vandre rundt løfter bevaringsproblemer. Det er derav viktig å vite når og hvor samhandler kattene med dyrelivet, spesielt den truede arten. Dette studiet sporet 111 katter ved bruk av GPS I Oslo, Viken og Vestfold og Telemark fylke in Norge. Hver katt var sporet på 7 dager når de er utendørs. Resultatet viste tydelig forskjeller mellom katter som bor i urbane områder og forsteder / landlige områder. Urbane katter brukte mindre tid på å vandre omkring ($p = 0{,}009$) og vandret hovedsakelig på dagtid. Katter i forstaden og bygda vandret både dag og natt. Boligkonteksten er den faktoren som er mest knyttet til alle vandremønstre. Kjønn er i moderat tilknytning til døgnmønstre. Alder, hvordan katter får tilgang utendørs, påvirker ikke døgnmønstre. Resultatet antydet at urbane katter har et døgnmønster som er mer synkronisert med menneskelig aktivitet, mens forstads- og bygdekatter streifer på en måte som ildkatter. Domestasjonsnivået er forskjellig mellom bostedssammenhenger. For å beskytte truede arter i samme leveområde med katter, kan det være en løsning å begrense kattens tilgang utendørs og forbedre de katt-menneskelige sosiale båndene. I regionen der dette eksperimentet ble utført, vil huskatter vandring ikke har stor påvirkning om truede fuglearter, fordi de okkuperer forskjellige tidsmessige nisjer.

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1. Introduction

The domestic cat (*Felis catus*) is the most popular pet animal worldwide. It is by far the most numerous of all the cat family, the Felidae (Macdonald and Loveridge, 2010), with an estimated 600 million globally (Kays et al., 2019). Cat domestication started in Egypt around 4000 years ago and the current domestic cat is believed to derive from one or both of two closely related wild species, the European wild cat, *Felis silvestris*, and the African wild cat *Felis lybica* (Bradshaw, 2012).

According to varying degrees of association with humans, domestic cats can be divided into several types. Feral cats form self-sustaining populations with no direct reliance on humans, whereas semi-feral cats (also termed stray cats) are partially provisioned. Pet cats live in close association with a household but wander largely at will, while housebound cats are confined entirely within their owners' premises (Baker et al., 2010, Calver et al., 2011). Bradshaw et al. (1999) further separate feral cats into feral and pseudo-wild cats, of which feral cats receive food resources accidentally from humans, while pseudo-wild cats are true feral cats that maintain little connection with human. The transition between types can be easy, such as a pet cat becoming semi-feral or feral, and *vice versa*.

Roaming is essential for feral, semi-feral, and pseudo-wild cats since it plays an important role in mating, predation, and territorial defence. Outdoor activities are also important for pet cats, as the outdoor environment provides lots of stimuli and allows more natural behaviors. However, with their rapid increase in numbers, these free-roaming cats raise many concerns worldwide. Much discussed are their impacts on public health (Gerhold and Jessup, 2013) and conservation. A review by Loss and Marra (2017) revealed that free foaming cats have contributed to at least 63 vertebrate extinctions, pose a major hazard to threatened vertebrates worldwide, and transmit multiple zoonotic diseases. Predation by cats is the main cause of the reduction in small vertebrate populations worldwide, but cats also affect vertebrate populations through disease and fear-related effects. The consequence of free-roaming cats has been especially dire on small islands where native prey species are most vulnerable to novel predators, resulting in at least 33 extinctions (Medina et al., 2011).

To suppress the effect of owned cats on wildlife, several management methods have been tested and implemented. For example, wearable devices have been developed and tested. Bell mounted collars have been extensively used, but have produced ambiguous results; Barratt

(1998) found no effect of the bell collars on predation rates, while Ruxton et al. (2002) and Nelson et al. (2005) found reduced predation rates of both mammals and birds. Woods et al. (2003) observed that the bell only reduced predation rates of mammals, not birds. The Birdsbesafe® collar is another gadget that has been found to efficiently reduced cat predation success on birds (Hall et al., 2015, Willson et al., 2015). The electronic sonic warning device is also found to be an effective device of reducing wildlife kill rates by domestic cats (Nelson et al., 2005).

Another solution is to limit the possibility of free-roaming cats in a region to interact with wildlife, particularly in regions containing endangered species. Many studies have therefore focused on defining 'buffer zones' around natural areas with important wildlife populations (Lilith et al., 2008, Thomas et al., 2014) based on the estimation of the cat's home range size. To this end, researchers have collected movement data of both feral and pet cats using Global Positioning System (GPS) and radio-telemetry to investigate cat movements, home-range size (Kays and DeWan, 2004, Kitts-Morgan et al., 2015, Hanmer et al., 2017), and to evaluate the spatial extent of potential encounters with wildlife (Woods et al., 2003, Baker et al., 2008, van Heezik et al., 2010, Bengsen et al., 2012). However, most of these studies are limited in sample size and study area, so results may be less representative at a larger scale.

In recent years, the development of inexpensive GPS loggers (e.g. iGotU GPS Travel Logger) have motivated more large-scale studies of pet cat movement. Kays et al. (2019) provide an analysis of movements by 925 cats from 6 countries to determine home range size and habitat selection. The study found much smaller habitat use of pet cats than feral ones and provide a comprehensive overview of pet cat outdoor movements.

However, when using radio-telemetry or satellite-based systems to investigate the cat's outdoor behaviors, most studies focused on home range size, travel distance, and habitat selection. The value of temporal information in such trajectory data has been largely ignored. Horn et al. (2011) found pet cats been most active between 0430 – 0800 and 1600–2100, while unowned cats had both higher levels and more prolonged periods of nocturnal activity, with their greatest activity between 1700 and 0600 hours. The size of outdoor area also influences the cat's roaming behavior. A small outdoor area is associated with a higher level of diurnal activity, while a large outdoor area is associated with a higher nocturnal activity and higher activity level in general (Piccione et al., 2013). Barratt (1995) suggested that night-time curfews would be needed to protect mammals and day-time curfews to protect birds from cats. Circadian activity patterns of cats may provide significant input for conservation actions, as cats may interact with different wildlife at different times of day.

In Norway, there are an estimated 770 000 pet cats in 400 000 households (Braastad, 2019). The animal protection organization 'Dyrebeskyttelsen Norge' handled 6069 homeless animals in 2019, of which 90% were cats. The feral cat population size remains unknown, but the organization believes that there is a large number of cats and cat colonies that remain undiscovered (DyrebeskytelsenNorge, 2020). In Norway, it is not obligatory to chip-mark pet animals, and chip marking is less common in cats than dogs. This intensifies the difficulty of controlling feral cats, since it is difficult to tease apart what cat is and is not owned.

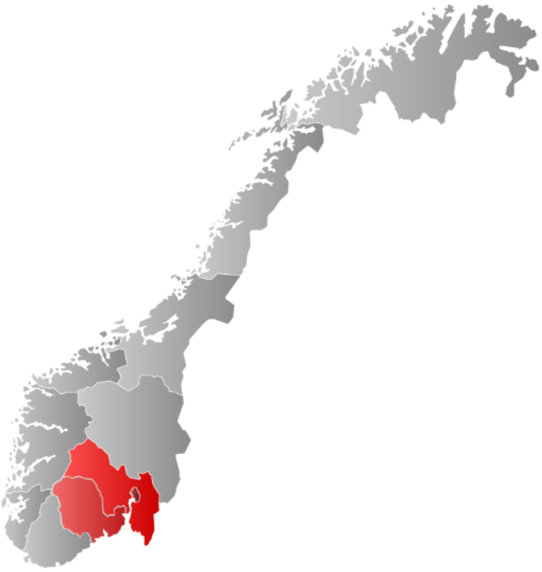
Many cat owners in Norway let their cat go outside, as to increase the cat's welfare. On the other hand, the Norwegian ornithology Union estimated that 7 million birds predated by cats each year in Norway and consider this a big threat to wild bird populations, especially during hatching season (Shimmings and Heggøy, 2019). To date, no study has described the home range or movement pattern of cats in Norway. Since only 1.7% of land in Norway is built-up area and 3.5% is agricultural land (SSB, 2020b), pet cats in this country may have easier access to natural habitat than those in other more populated countries. How pet cats behave outdoors in this unique landscape is therefore an interesting question.

To assess roaming behavior in Norwegian pet cats, a citizen science project – where members of the public were directly involved GPS tracking their cats – was established. The current study investigates temporal patterns in roaming behavior. Pet cats receive food, shelter, and grooming from their owners. This builds strong social bonds between pet cats and their owner. I hypothesized that free-roaming pet cats would have their roaming activity pattern synchronized with their owner. In other words, they would be more active during daytime when their owners are away from home, and less active in the evening, night, and morning when the owners are at home.

2. Methods

2.1 Study area

Data collection was conducted between August and December 2019 in south-eastern Norway (Figure 1a), including Oslo, Viken, Vestfold and Telemark counties, in Akershus, Asker, Bærum, Drammen, Drøbak, Eidsvoll, Fredrikstad, Horten , Lier, Lillestrøm, Moss, Nittedal, Nesodden, Nordre Follo, Oslo, Rælingen, Ullensaker, Vestby, Våler and Ås municipalities. House locations of the participants were pinned in Figure 1b.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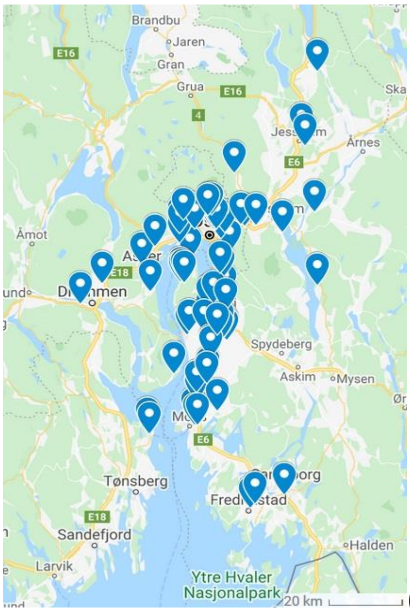


(b)

Figure 1. (a) Map of Norway, where the red regions are experiment region in this study. (b) House location of participants in this study (N = 89).

Oslo is the capital city of Norway and constitutes both a county and a municipality. There are approximately 693 000 inhabitants(SSB, 2020). Oslo's area is distributed between 62.6% productive forest, 3.9% unproductive forest, 1.8% fully cultivated land and 22.9% developed areas(NIBIO, 2020, SSB, 2020b). The average temperature in experimental period varied from a maximum of 16.8 °C in summer to a minimum of 0.4 °C in winter (Blindern, Oslo) (NKS, 2020).

Viken county has the largest number of inhabitants of the Norwegian counties, with a total of approximately 1.2 million people(SSB, 2020). 50.8% of the total area is productive forest, while 10.8% is unproductive forest. 8.8% is fully cultivated land and 2.5% is developed areas (NIBIO, 2020, SSB, 2020b). The average temperature in our experimental period varied from a maximum of +16.2 °C in summer to a minimum of 0°C in winter. (NKS, 2020).

Vestfold and Telemark county has approximately 419 0000 inhabitants (SSB, 2020). Productive forest stands for 41.5% of the total area, while unproductive forest occupies 16.8%. This county has 4.1% fully cultivated land and 1.6% developed areas, less than the other two counties (NIBIO, 2020, SSB, 2020b). Since this county is represented only by Horten municipal in this study, I chose to look at the temperature for Horten specifically. The average temperature in experimental period varied from a maximum of 16.1 °C in summer to a minimum of 0.2 °C in winter (Horten) (NKS, 2020).

The most dominating tree species in these counties are Norway Spurce (*Picea abies*), Scots Pine (*Pinus Sylvestris*) and Birch (*Betula pubescens ssp. pubescens*) (NIBIO, 2020b). The participating cats lived mostly in urban areas, but some also lived in suburban and rural areas.

2.2 Data collection

We recruited cat owners by sharing the project webpage with a registration link on social media. The registration link was a questionnaire collecting general information of cat owners including name, address, and contact information (Appendix 1). 307 cat owners nominated themselves (and their cats) to participate. 131 were rejected as the applicants were located outside the project area. 176 participants received an invitation email with further information regarding the participation and a second questionnaire collecting more information about their cat (Appendix 2). Not all participants were able to be accommodated during the project's timeframe. In the end, 110 household and 136 cats received a GPS tracking device kit.

The kit included an i-gotU GT-120 GPS Travel Logger (44.5 x 28.5 x 13 mm, Mobile Action Technology, Inc.) with a silicon case, mounted on a cat collar (figure 2), a USB charging cable, and an instruction manual showing how to use and charge the GPS device. A sheet for the cat owners to fill out the date and time they started and ended each tracking was also provided. The cat owners were requested to register all trips of their cat for 7 consecutive days. The GPS device was pre-set with a fix schedule of one fix every 10 seconds. This setting results in a battery time of approximately 10 hours. It was therefore important that the owners regularly removed the GPS from their cat to charge it. However, the fix rate provides high precision in analysing movement patterns, such as the time spent roaming, the number of times they crossed roads, and habitat preference. Owners were requested to turn on the GPS device every time the cat left the house and turn it off when the cat came back. In the circumstance that the cat left the house unsupervised (e.g. via a cat flap), the owners were asked to turn on the device before they left the cat alone. When the 7-day tracking was completed, the owners shipped the device back to the Norwegian University of Life Science for data processing.

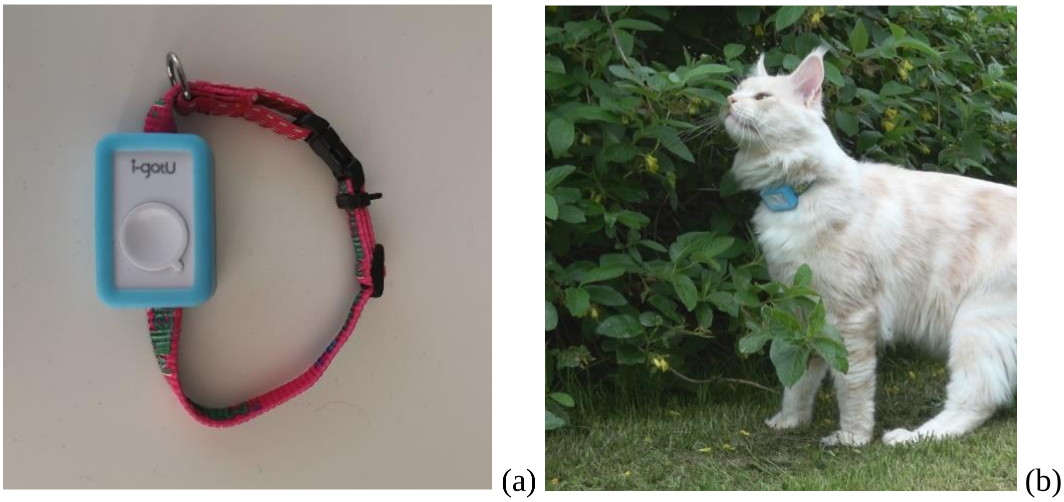


Figure 2. (a) GPS device and collar used in this experiment. There is a short elastic band attached to the collar buckles, to ensure easy release if the cat gets stuck. Photo: Bettina Bachmann. (b) Demonstration of cat wearing the GPS device. Photo: Ronny Steen

2.3 Data processing

Position data of the cat were extracted from the GPS using the software @trip PC. It generates one datasheet of comma-separated values (csv) for each cat, with position data for the entire tracking period. The file includes 18 parameters, but only 5 parameters (date, time, latitude, longitude, and speed (maximum speed of way point, meter/hour) was used to conduct the data analysis in this study.

First, a keyhole markup language (KML) file from each csv file was created, to visually inspect the movement pattern in Google Earth Pro. The original data include some positions that do not reflect a cat’s movement, including driving tracks with high speed, single points several kilometres away from the original track due to technical glitches, and some portraying the wrong date. These records were discarded manually from the csv file.

Data files were then handled by RStudio (Version 1.2.5033). To assess outdoor activity, I identified changing points between roaming and stationary via change point analysis (Edelhoff et al., 2016). This analysis uses a net squared displacement (NSD) parameter as the model input and a sweep window moving along the time axis to detect NSD changes. I also removed points that were within 20 meters of the cat’s home coordinates, using the R packages *sp*, *regos,* and *raster*. This was done for two reasons. First, the GPS device performed well when outdoors, but collected some imprecise locations indoors, resulting in a cloud of points within 30 m of the house when cats were inside or under the roof (Kays et al., 2019). This resulted in a false active status when the cat was stationary. Second, these points may represent a situation where the cat is locked outdoors, but is within their own home or yard environment, waiting for their owner to let it in. The *tidyverse* was then used to extract time information and calculate time patterns.

To detect possible temporal pattern associated with human activity, I divided the 24-hour time scale into four sections morning, day, evening, and night based on cat owner's activity (Table 1).

Table 1: Time division of a day for analysing circadian pattern associated with human activities.

	Time section	Cat owner's activity status
Morning	06:00-08:59	Active at home
Day	09:00-16:59	Not at home
Evening	17:00-21:59	Active at home
Night	22:00-05:59	Resting at home

2.4 Statistical analysis

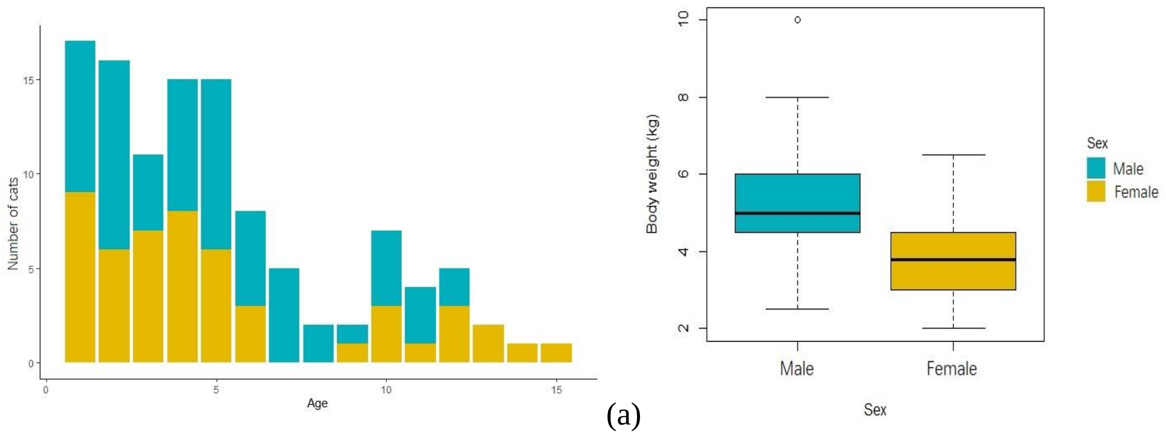
I used R Commander plugin .NMBU V1.8.11 (Liland and Sæbø, 2019) for statistical analysis. Q-Q plot and Shapiro-Wilk normality test were used to explore normality of the variables daily outdoor time, roaming time and age. Plots revealed normal distribution of these three parameters. ANOVA model was used to detect the effect of independent variables on outdoor time and roaming time cats spent each day. Independent variables include age, gender, and residence as fixed effects. Tukey test was used for post-hoc analysis on parameters gender, residence, and release method. Pearson's product-moment correlation was used to describe correlation between time spent outdoors and time spent roaming. Paired t-test was used to compare proportional roaming time in the morning, day, evening, and night section for each gender-residence combination.

3. Results

3.1 Cat information

Movement data were received from 111 of the 136 participating pet cats. Twenty-five cats did not provide data. This was due to cats not accepting the collar, the collar/device got lost when cats were released outside, participants changed their mind, or the GPS device caused malfunction of the electronic cat flap due to the interference.

Of the 111 successfully tracked cats, 60 were males aged from 1 to 12 years old, were and 51 females aged from 1 to 15 years old (Figure 3a). Mean male body weight was 5.29kg (n=59) and mean female body weight was 3.89kg (n=50), Two owners didn't report the bodyweight of their cat. The male cats were on average heavier than female cats ($p < 0.05$) (Figure 3b). All cats were castrated/spayed except 2 female cats. One of these two was taking birth-control pills, while the other was not under any birth control. Most of the cats were non-pedigree (n=83), while 17 are pedigree cats including Norwegian forest cat (n=6), Siberian (n=5), Maine Coon (n=2), Bengal cat (n=2), Birman (n=1), and British Longhair (n=1). The remaining cats (n=11) were hybrids between two or more breed.



(a) (b)

Figure 3. Information on cats participated this study. (a) Age distribution of cats divided by sex. (b) The bodyweight distribution of cats divided by gender.

Most cats lived in suburban areas (n=84, 76%) while 6 cats (5%) living in the urban areas and 21 cats (19%) in rural areas (Table 2). Sixty-five (59%) of cats were released by their owner, 38 (34%) cats used a cat flap with free access to the outside, and 8 (7%) cats also used a cat flap, but was contained by their owner with a set routine.

Table 2. The number of cats in each releasing method category and residence category, grouped by gender.

		Male (N = 60)	Female (N = 51)	Sum (N = 111)
Type of outdoor access	By the owner	36	29	65
	By cat flap	22	16	38
	By cat flap (supervised)	2	6	8
Type of residence	Urban	1	5	6
	Suburban	42	42	84
	Rural	17	4	21

3.2 Activity patterns

The cats were tracked 7 ± 0.22 days. On average, male cats spent 550.36 min ± 31.69 outside each day, while female cats spent 478.3 min ± 29.37 minutes, but the difference was not significant ($p = 0.1$). Male cats spent more time outside in all three kinds of residence (urban, suburban, rural) contexts, but the gender difference was not significant either (Suburban: $p = 0.64$, rural: $p = 0.49$). Urban cats were not tested for gender differences because the sample size is too small. (Table 3). Cats living in urban areas spent the least amount of time outdoors (307.67 min ± 62.34). In rural area, cats stayed outdoors 637.33 min ± 55.94, significantly higher than urban cats ($p = 0.0006$). Suburban cats were intermediate (501.30 min ± 23.86). The cats utilizing cat flap spent 590.84 min ± 42.04 outside each day, higher than cats released by their owners (468.78 min ± 26.99, $p = 0.028$). Cats using temporary closed cat flap were intermediate (561.50 min ± 10.71). ANOVA analysis indicated that residence type and how cats are released outdoors had a significant effect on the time cats spent outside (Table 4).

Of the total time cats stayed outdoors each day, roaming accounted for 37%, while cats remained stationary 63% of the time. This proportion did not differ significantly between gender and residences. Cats living in urban area roamed less (119.52 min ± 35.74) than rural cats (246.50 min ± 25.37, $p = 0.009$). Suburban cats were intermediate (183.33 min ± 11.74 minute) (Table 3). In both urban and rural areas, female cats spent longer time roaming than males, while suburban female cats roamed shorter time than male cats. None of these differences were significant (Suburban: $p = 0.331$, rural: $p = 0.533$). Urban cats were not tested for gender difference because the sample size is too small. There were no significant differences among cat groups that used different outdoor access ($p = 0.542$). ANOVA analysis indicated that only residence type had a significant effect on the time cats spent roaming outside (Table 4).

Table 3. Mean time (in minutes) spent outdoors and roaming every day ± standard errors. Grouped by gender and residence type.

Gender	Residence	Sample size	Daily time spent outdoor (Shimmings and Heggøy)	Daily time spent roaming (Shimmings and Heggøy)
Male	Urban	1	299.00	76.80
	Suburban	42	513.30 ± 34.72	194.82 ± 19.21
	Rural	17	656.71 ± 65.49	238.56 ± 24.19
Female	Urban	5	309.40 ± 76.32	128.06 ± 42.50
	Suburban	42	491.10 ± 32.29	171.84 ± 13.52
	Rural	4	555.00 ± 97.50	280.25 ± 93.78

Table 4. Model coefficients for ANOVA model on the time cat spent outdoors and roaming each day. Independent variables refer to age/gender/residence/ type of outdoor access as fixed effect.

	Variables	Sum Sq	Df	F value	Pr(>F)
Time spent outdoors	Gender	355	1	0.0080	0.9291
	Residence	519715	2	5.8267	**0.0042**
	Age	824856	14	1.3211	0.2107
	Type of outdoor access	394443	2	4.4222	**0.0147**
Time spent roaming	Gender	1070	1	0,0888	0.7664
	Residence	75506	2	3.1343	**0.0483**
	Age	148524	14	0.8808	0.5816
	Type of outdoor access	28519	2	1.1839	0.3108

There is a relatively strong positive correlation (correlation coefficient = 0.69) between the time that the cats spent outside and roaming. The plotting of roaming time against outdoor time indicated this positive correlation with large individual variation (Figure 4). There is also a possible plateau of roaming activity with increased time the cats spent outdoors.

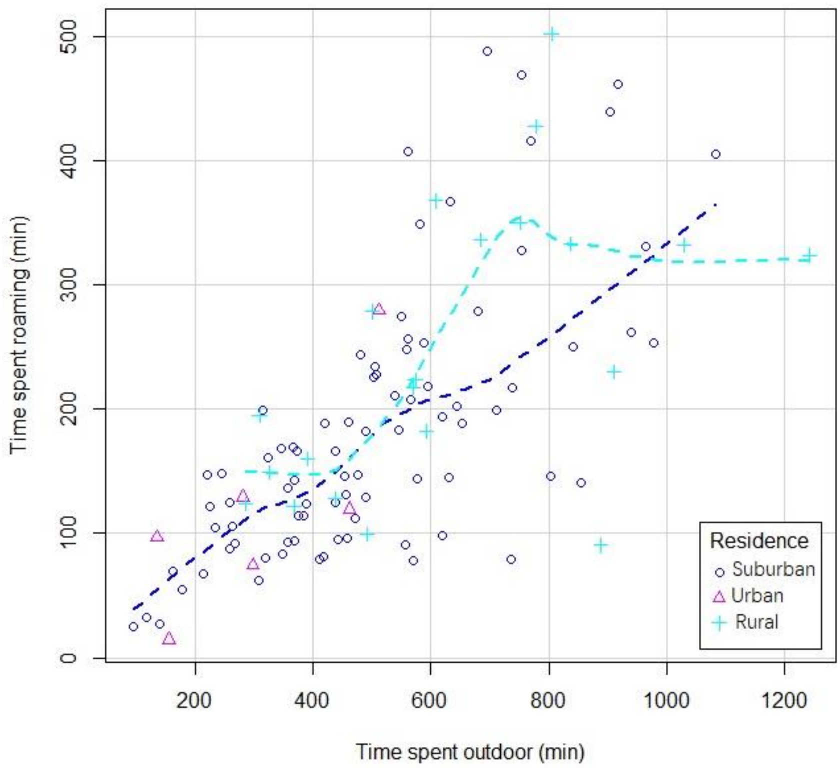
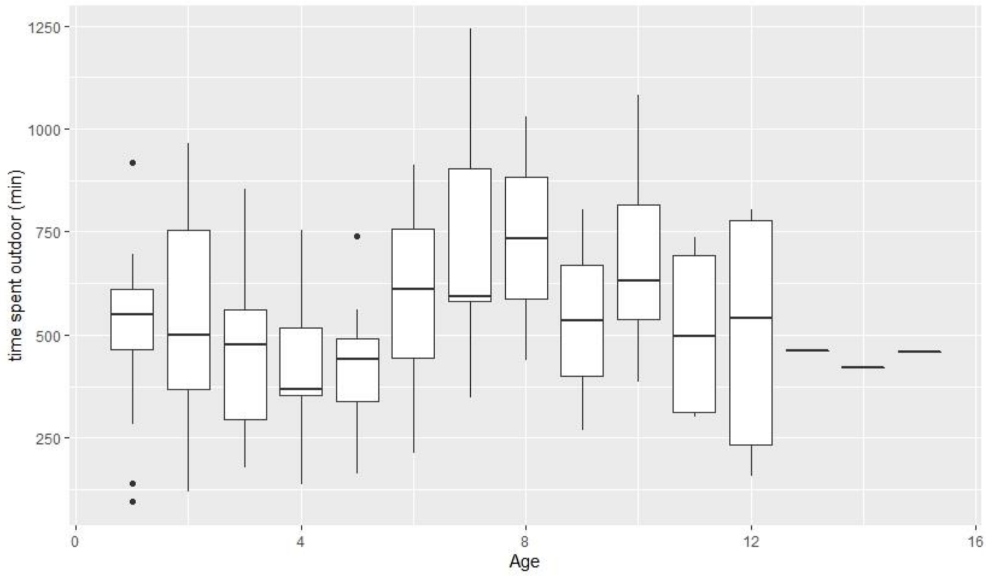
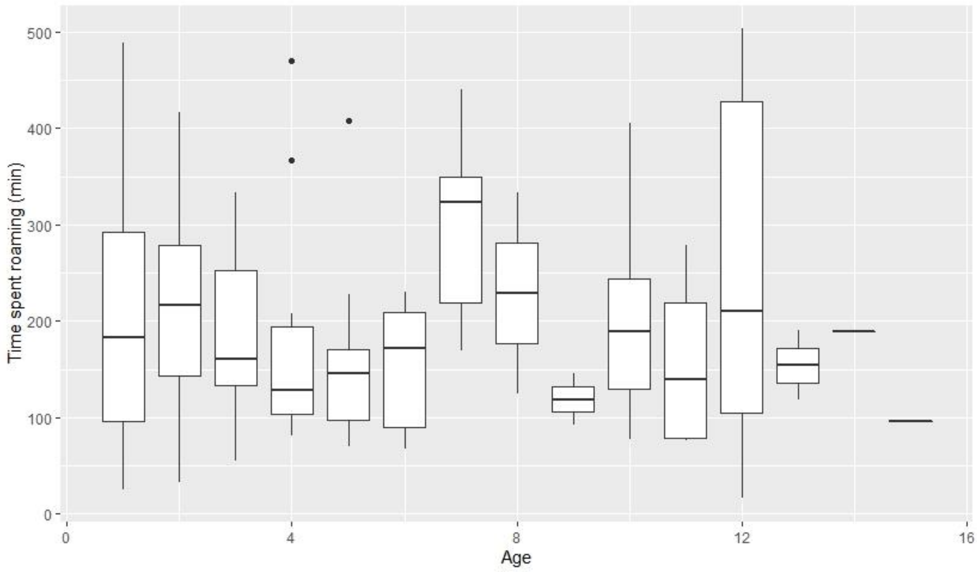


Figure 4. Correlation between the time cats spent outdoors and roaming. Correlation coefficient = 0.69.

One-way ANOVA revealed no age differences on outdoor activity (p = 0.26) and roaming activity level (p = 0.55). But certain traits can be observed (Figure 5); young cats (age 1-2) and mature cats (age 7-10) tended to be more active staying outdoor and roaming, while prime cats (age 3-6) were less active in outdoor behavior. Senior cats (age 11 and above) reduced their time spent outdoors, but activity level fluctuated within this age group. Lacking a clear trend in this age group may be due to the small sample size and large intra-group variation.



(a)



(b)

Figure 5. Cat outdoor and roaming behavior at different ages. (a) The time cats spent outside. (b) The time cats spent roaming.

3.3 Circadian roaming patterns

The roaming time is summed by hour unit to investigate circadian pattern. Plotting of smoothed conditional means at each hour unit indicated that circadian patterns differ between gender and residence contexts (Figure 6).

Suburban male cats were most active at midnight (00:00) and most sedentary at 10:00, there is a clear decline of roaming behavior from midnight to the bottom point and then increase smoothly until the end of the day. Suburban female cats are less active than male cats at midnight ($p = 0.209$) but maintained a similar activity level until 08:00 and dropped slightly afterward until the end of the day (Figure 6a).

Rural female cats had a higher level of roaming activity than male cats during the entire time scale (e.g. p = 0.45 at 15:00 where the largest gender difference occurred), but circadian patterns are quite similar. They kept a high level of roaming activity in the evening and at night with a peak at 20:00. The activity level declined continually from midnight to midday and reached the bottom at 10:00 for female cats and 12:00 for male cats (Figure 6b).

Urban cats (mainly female cats) had an opposite circadian roaming pattern to suburban males. They had an increased level of roaming activity from midnight to the daytime, reached peak activity level at 14:00, and then dropped to almost sedentary at midnight (Figure 6c).

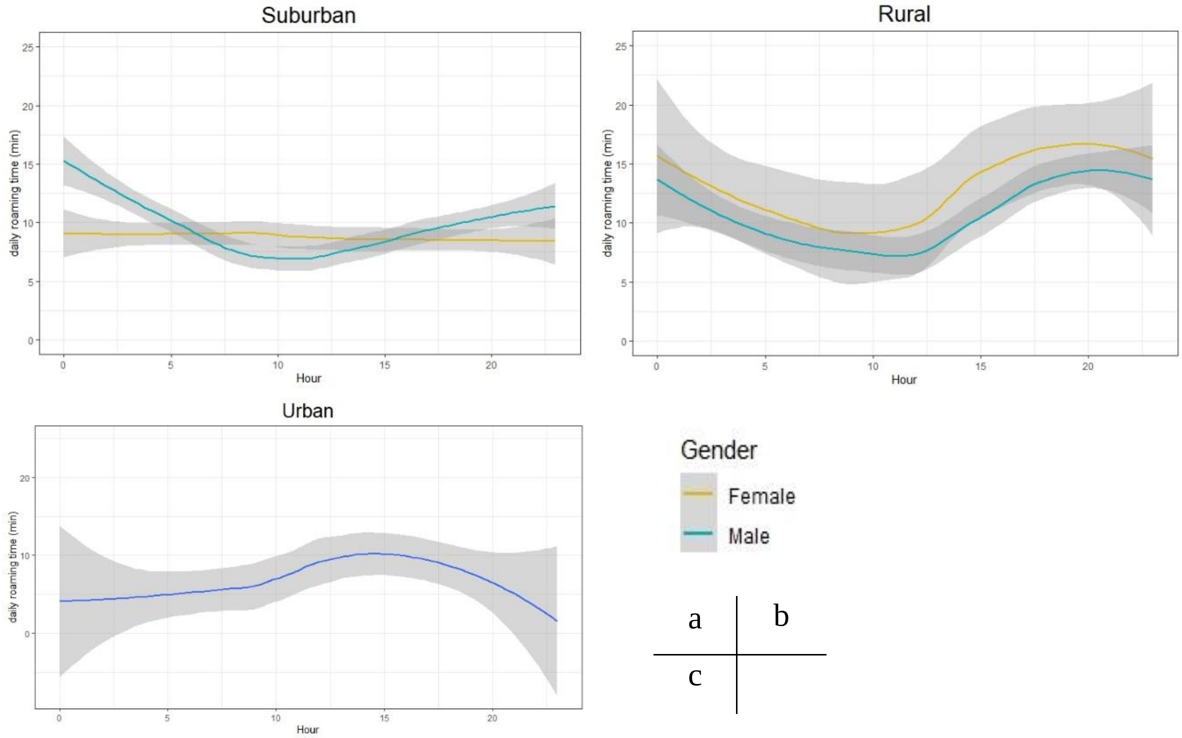


Figure 6. Circadian roaming patterns of the cats in three different residence contexts, grouped by gender. (a)Suburban cats (n = 84), male cats roamed more at night and kept stationary during the daytime, while females showed less time preference. (b) Rural cats (n = 21), both male and female cats performed more roaming activity during evening and night, and peaks in the evening. Female cats more active than male cats all the time. (c) Urban cats (n = 6), less active in general than the other two resident contexts. Roaming activity level peaks in the afternoon. Plotting is not distinguished by gender in this group, because there is only one male in this group, the comparison between gender is not representative.

To present how the cats distribute their activity budget in the time sections, the time cats spent roaming within each time section was converted to proportions of the total roaming minutes (Figure 7). Age and type of outdoor access showed a low correlation to the circadian roaming patterns and were therefore excluded from regression analysis in this part. A set of paired t-Test was conducted for each gender-residence combination to detect differences among the four time sections (Table 5). The p values indicated that all cats were most sedentary in the morning, regardless of gender and residence contexts. Rural female cats roamed less in the evening than day and night, but insignificant. Suburban female cats roamed most during the day section, significantly higher than evening (p = 0.0020), but did not differ from the night. Rural and suburban male cats increased their roaming activity level from day to night and reached the peak at night, but insignificant. Urban cats roamed most in the day section and kept low roaming activity levels in the morning evening and night.

Table 5. Paired t-Test of proportional roaming activities in different time sections, grouped by gender and residence combination.

	morning	Day	evening	night
Rural-Female	0.0584	0.2052	0.2645	0.4720
Rural-Male	0.0890	0.2687	0.3041	0.3382
Suburban-Female	0.1405	0.3810	0.2162	0.2622
Suburban-Male	0.1103	0.2858	0.2545	0.3490
Urban-Mix	0.1394	0.5483	0.2110	0.1013

(a) Mean value of proportional roaming activity in the time sections.

	morning -day	morning -evening	morning -night	Day-evening	Day-night	evening -night
Rural-Female	**0.0284**	0.1077	**0.0485**	0.6505	0.1831	0.3039
Rural-Male	**1.1E-06**	**2.6E-06**	**0.0003**	0.3762	0.3215	0.5620
Suburban-Female	**2.28E-08**	**0.0464**	**0.0032**	**0.0020**	0.0612	0.3463
Suburban-Male	**1.08E-06**	**0.0001**	**3.58E-06**	0.4843	0.3060	0.0544
Urban-Mix	**0.0002**	0.2727	0.6622	**0.0109**	**0.0132**	0.1270

(b) P value from a set of paired t-test. Text in bold indicating $p < 0.05$.

ANOVA type II test and Post-hoc Tukey test indicated that proportional roaming patterns in the morning and afternoon sections were not affected by gender or residence. In the day and night sections, residence type had an impact on roaming patterns (p = 0.029 and 0.08, respectively). Urban cats were more active in the day section and sedentary in the night section than the suburban and rural cats. Female cats performed more active roaming in these two sections than males (p = 0.0925 and 0.0672, respectively). Urban cats were the only group in compliance with my prediction.

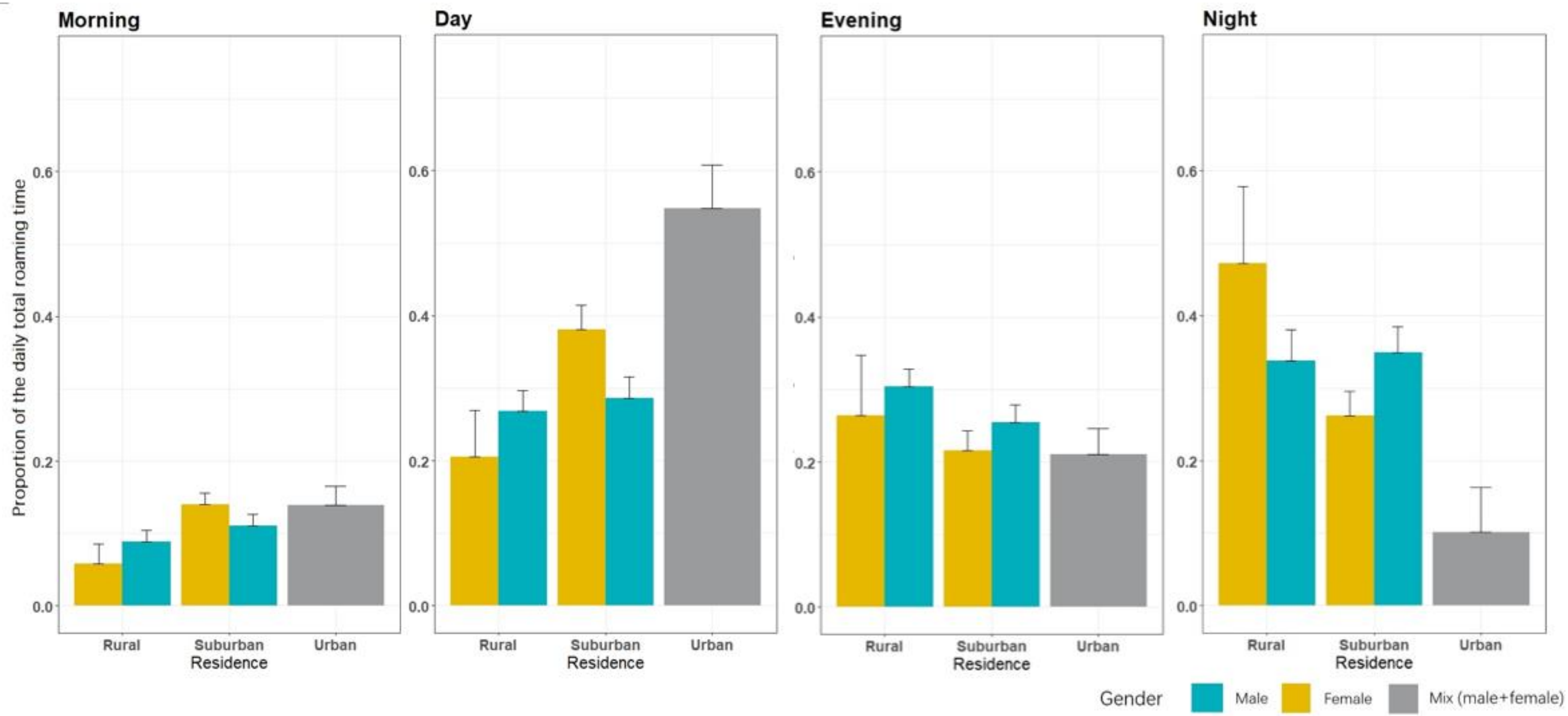


Figure 7. Proportion of daily roaming activity (min/min) in the four sections of a day, grouped by residence and gender. Time distribution in urban areas presented as mixed gender, because this group has a small sample size (n =6), and with only one male cat. Rural cats were most sedentary in the morning and increased their roaming activity from day to night. Suburban cats were also most sedentary in the morning. But female cats reached their peak roaming activity during the day while male cats at night. Rural cats performed most roaming activity during the day and less active rest of the day.

4. Discussion

The primary aim of this study was to establish temporal roaming patterns of pet cats and to find out possible factors associated with such patterns, e.g., gender, residential area, and human activity. I found that temporal patterns were most associated with residence contexts, while gender has a moderate effect.

4.1 Total roaming time

In this study, the cats’ roaming time accounted for 37% of the total time they spent outside, while stationary status accounted for 63%. Similarly, rural pet cats in Australia were observed resting or sitting under vegetation in their yard and sometimes crouching in tall grass, which accounted for 68% of the time they spent outdoors (Lilith et al., 2008). Urban cats roamed least while rural cats roamed most. Such patterns reflect the home range differences. Roaming plays an essential role in seeking resources, predation, mating, and territorial defense, while for owned pet cats, in our case, most castrated, the essential meaning of roaming becomes territory patrolling. Many studies revealed a smaller roaming range in urban cats than suburban and rural ones (Barratt, 1997a, Horn et al., 2011, Meek, 2003, Morgan et al., 2009), and patrolling time reduces together with their home range. More roaming time spent by young-aged cats may reveal more playful behavior outdoors, when exposed to abundant stimuli.

4.2 Circadian pattern

Suburban and rural cats in this study roamed both day and night, while slightly more active at night than during the day. A previous study also found suburban been active roaming both day and night but largely nocturnal (22-6), and to a lesser extent crepuscular (Barratt, 1997b). Such circadian patterns were also found with unowned feral cats living in a mountain area with little human disturbance. They maximized movement rates during the periods 15–21 and 21–03 hours (Recio et al., 2010). Social bonds with humans seemed to be weak for cats in these residence contexts. The similarity between suburban, rural, and feral cats indicates that cats are instinctive nocturnal. It also suggests an easy transition between these types, as Bradshaw et al. (1999) described.

Urban cats in this study roamed mainly during the day, and night-time was least preferred for roaming. Urban cats in New Zealand showed the same trend of been least active between the hours of 1701 and 2400 (Morgan et al., 2009). A smaller housing condition also resulted in more diurnal activity than the cats housed with a large outdoor area (Piccione et al., 2013). The synchronized roaming pattern of urban cats with human activity can result from conditioned learning and/or a strong social bond between cat and owner. All six cats in this group had their access controlled by their owner. To roam at night can be associated with a lack of food, water, and shelter. Previous results indicate that the friendly symbiosis with humans is a factor that influences both food intake and circadian rhythm of activity in cats (Randall et al., 1985).

Why urban cats developed strong social bonds, but not suburban and feral cats can be explained by their solitary lifestyle. Cats are mainly solitary, especially adult males. Natural group living occurs in colonies of related females, while the other type is semi-feral colonies, which involves a localized concentration of food, deliberately or accidentally from human activities (Bradshaw, 2012). In the case of suburban and rural cats, they were neither kin of other cats around, nor restricted by the food supply. A communal lifestyle is not essential for them. As solitary animals, cats do not defend their territory; instead, they scent mark throughout a looser home range (Feldman, 1994). They tend to minimize home range overlap, either spatial or temporal (Barratt, 1997b). Therefore, cats spent much time roaming to patrol these loose home ranges and reinforce the scent marks without directly encountering other individuals.

On the other hand, the urban cat lives in a higher population density, and avoiding other individuals may be more challenging. It results in the reduced home range mention previously and less time required by the cats to patrol these areas. The shorter patrolling time, the longer resting time that cats spend at home, under vegetations either in their own homes or in adjacent properties (Lilith et al., 2008). Long-time stay at home introduces a higher chance to socialize with their owner, which reinforces the social bond between cat and owner and thereby more synchronized with their owner’s activity pattern.

4.3 Implication for conservation

The activity pattern of urban cats is mainly diurnal. It indicates that urban cats roaming outside introduce more threats to birds and reptiles because these species are mostly diurnal (Barratt 1998). The night-time curfews in Australia are ineffective for the protection of birds and reptiles, but reduce the cat’s ability to control rodents. For suburban and rural cats that are active throughout the day with increased activity at night, nocturnal species are potentially at higher risk of predation. Necessary confinement should reduce the utilization of natural habitat by suburban and rural cats.

There is a trend that modern cat shifts to more diurnal activities. It may be an effect of domestication and/or an adaptation to life with diurnal humans (Turner et al., 2000). Instead of forced confinement, advising the cat owners generating more interaction with their cat may also be a solution to achieve conservation.

In the study area in Norway, there are two amphibian species, 9 nine mammal species, and 40 bird species that are on the red list (Artsdatabanken, 2018). Of all these species, amphibians and mammals are threatened by habitat loss and human disturbances, while two bird species black guillemot (*Cepphus grille*) and common eider (*Somateria mollissima*) out of 40 are threatened by invasive species predation. According to the cats' predatory preference that most birds in the morning, most reptiles in the afternoon, and most mammals in the evening and night (Turner et al., 2000), the threatened bird species will not be primarily affected by free-roaming pet cats, since they are least active in the morning in all residence contexts. Cat owners releasing their cats outdoors should not trigger strong conservational concerns in this region.

4.4 Limitations of this study

4.4.1 GPS and collar affecting roaming behavior

The GPS device used in this experiment was not specifically designed for cats, but rather a commercial product for human sports activities. However, it is widely adopted in cat tracking studies (Coughlin and van Heezik, 2015, Kikillus et al., 2017, Roetman et al., 2017, Kays et al., 2019). The GPS device weighs 20g and 35 g together with the silicone case and collar. It constitutes 0.35-1.75% of the cats' body weight (the lightest cat weighed 2kg and the heaviest 10kg) in this experiment. The weight is far below the widely applied rule of thumb that instrumentation weights should not exceed 3–5% of an animal's body weight (Casper, 2009, Gursky, 1998). I also suggested the cat owners terminate tracking if the cat performed a strong reaction towards the GPS mounted collar, such as continuously rubbing the collar or shaking their head. So, I assumed that the cats' outdoor behavior is not affected by this GPS mounted collar. However, Brooks et al. (2008) suggested that small animals (<5kg) should not carry a collar that weighs>1% of their body mass. The same GPS device as I used in this experiment was tested on cats with modified weights (constituted 0.86%-3.11% of the cat's body weight) and found a decline of home-range size and travel distance when collar weight increase, and no evidence for progressive acclimation to wearing an instrument (Coughlin and van Heezik, 2015). Bruholt (2018) studied farm foxes and discovered behavioral changes and body weight loss, even the collar constituted only 1-2% of the fox's body weight. However, foxes show an acclimation to the collars over time. In my study, 78 cats (70%) do not wear a collar regularly. Whether the device-mounted collar altered behavior and influenced the movement, and when the cats acclimated to the collar remains unknown. Undetected behavioral changes may underlie the temporal patterns I observed.

4.4.2 Bias caused by cat owners

There was a clear bias caused by the cat owners. Several owners mentioned that they want to participate project because their cats were active and spent long hours outside. Besides, we sent only one GPS device per household, even though they had multiple cats at home. It was considered to avoid swap of the devices accidentally on cats during the tracking period. In this case, cat owners would like to track the most active one because they think this provides impressive track results. Cats less active in the same household were excluded from data collection by their owner. It is a clear violation of the random sampling rule. This selection towards active individuals will result in an overestimation of cats' activity level on average. This may also explain the relatively high level of roaming activity for cats seven years old and above. The selection caused bias was compensated by a large sample size for young cats, but when the sample size reduced with increased age, the bias became more obvious.

4.4.3 Data process

In this study, I was unable to characterize more behaviors than roaming and stationary. As the device is pre-set with one fix every 10 seconds, instantaneous behaviors were embedded in behavior status, and impossible to be detected. For example, predation is one of the behaviors most likely to occur during roaming. Typical predation consists of stalking run, watching, possibly second stalk run, springing, and pounce. Except for the first stalking run that can be a few meters of walking, rest of these instantaneous behaviors happen in a short distance. The position points registered during this set of behaviors will thereby form a cluster, the same as when cats were stationary. That means the highly active behavior – hunting will be processed as stationary for further analysis. This led to an underestimation of the activity level when cats were outside. Therefore, radio or GPS tracking is often combined with a camera trap, observational studies, or an accelerometry to identify more behavioral traits (Andrews et al., 2015, Lilith et al., 2008).

5. Conclusion

The results clearly demonstrated the temporal patterns of the cat's roaming behavior. The patterns distinguish in residence contexts, but a less degree of gender and other factors. It also underlines an adaptation of lifestyle when cats live in close relationships with humans. Finding support the theory that domestication changes cats' circadian rhythms closer to humans. However, the effect requires a high level of interaction with humans, meanwhile less access to the outdoors. Further research could cover the weak points found in this study to describe the cats' outdoor behavior with more behavioral categories and increased accuracy.

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