Norwegian University of Life Sciences

**Master's Thesis 20202 60 ECTS**

Faculty of Environmental Sciences and Natural Resource Management

# Home ranges of domestic cats (*Felis catus*) in south-eastern Norway.

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Masters in biology

# Forewords

As a cat breeder and enthusiast, I could not resist this thesis when my supervisor Cathrine Strømø sent me the information about the citizen science project that would eventually be called Kattesporet. I would like to give a big thanks to my supervisors: Torbjørn Haugaasen and Richard Bischof. I would also like to thank Ronny Steen for his help with the project. We worked on this project as a group of students as well, and I would like to give a big thanks to all of them! Filip Sarfi, Fan Wu and Gina Sande Leikander. I would also like to thank my friends who helped to test the GPSs trackers on their cats in the beginning of the project: Charlotte Ejsten Pedersen, Sølvi Ann Karlsen and Matias Lakso.

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# Abstract

Small GPS units were used to track pet cats in south-eastern Norway from august 2019 to November 2019, in order to obtain home range size estimates. In total, 111 (51 females and 60 males) cats were tracked using their owners as citizen scientists. Of these, 104 cats provided data that could be included in the analysis. I used two different methods to estimate home range size – Minimum Convex Polygon (MCP) and Kernel Density Estimation (KDE). Results show that mean home range size was 3.6 ha with MCP 95% and 4.7 ha with KDE 95%. On average, male cats have larger home range sizes than females, thus only significantly larger with MCP 95%. In addition, older cats tended to have smaller home ranges than younger cats. Cats in rural areas had larger home ranges, but larger home ranges were not related to an increase in hunting behaviour. Home range size estimates provided here are larger than those for pet cats in other countries where similar work has been conducted. A larger buffer zone around important wildlife areas is suggested than in other countries, to protect local wildlife in south-eastern Norway.

# Content

## 1.1 Introduction

The domestic cat (*Felis catus)* is one of the most common pets in Europe and in the US (Braastad 2012; Willson et al. 2015) and has been kept by humans for more than 10.000 years (Serpell 1988). Cats are found in high numbers in many countries and there are possibly as many as 600 million owned cats (domestic) globally (Kays et al. 2020). In the US alone, the number is estimated to be somewhere between 84 – 95,6 million domestic cats, with an almost equal number of feral cats (domestic cats without an owner). The UK has an estimated 10 million domestic cats and more than 800 000 feral cats (Hanmer et al. 2017), whereas there are approximately 8,5 million domestic cats in Canada (Hanmer et al. 2017; Willson et al. 2015). By 2016, it was estimated to be around 770 000 domestic cats in Norway (Braastad 2019).

Cats are generalist consumers and are assumed to have a big impact on bird and small mammal populations, as well as populations of invertebrates, reptiles and amphibians (McDonald et al. 2015; van Heezik et al. 2009; Willson et al. 2015). Cats are regarded as an invasive species by some (Loss et al. 2018) and are assumed to have driven several species to extinction or significant decline (Tschanz et al. 2011). For example, cats are assumed to depredate approximately 2,4 billion birds and 12,3 billion small mammals each year in the US alone (Willson et al. 2015). The high number of cats and the high number of assumed kills lead to severe conservation challenges in several countries (Loyd et al. 2013; McDonald et al. 2015; Willson et al. 2015; Walker et al. 2017). Some even consider cats the largest anthropogenic threat to wildlife (Willson et al. 2015). Cats are major predators of native wildlife worldwide (Hanmer et al. 2017; Loyd et al. 2013; Pillay et al. 2018). They occur at artificially high densities as they are fed by their owners (Thomas et al. 2014) and thus present an overabundant predator in human-dominated areas (Pillay et al. 2018; Kays et al. 2020). However, several factors may influence predator rates. For example, cat age and predation success rates appear to be negatively correlated (Loyd et al. 2013) and cat personality may also play a role (Tschanz et al. 2011). The area where the cat lives, as well as outdoor access, will also likely affect predation rates (Lloyd et al. 2013; McDonald et al. 2015; Tschanz et al. 2011). Unlike home range size, which vary between the genders and between gonadectomized cats and intact cats, predation rates do not seem to vary between males and females. Gonadectomy does not seem to alter the predation rate either (Lloyd et al. 2013; McDonald et

al. 2015; Tschanz et al. 2011). However, the difference in hunting activity by urban and rural dwelling cats in Norway has not yet been tested.

Most domestic cats spend time outdoors, but little is known of what they do when they are outside. One method to learn more about their outdoor activities is to observe the cats' home range size and movements. Home range can be defined as the area where the animal does its day-to-day movements and activities (Baillo & Cachon, 2018; Powell 2000). In other words, the home range is the area where the animal searches for food, raises young and finds shelter. Home range size must not be confused with territory, which has another definition. A territory is an area that is defended by the animal from animals of the same sex or both sexes. It can be the same area as the home range entirely, or parts of it, and often contains the core of the home range (Powell 2000).

The size and geographical site of the home range will change over time and it is therefore important to consider the length of time that the home range size is observed (Gregory 2017). The animal may for example use different areas at different times of year, depending on resource availability or other factors (Gregory 2017; Powell, 2000). Domestic cats view the house as a part of its home range and will spend a lot of time there (Braastad 2012; Thomas et al. 2014). Cats that live in the same house often share much of their home range. However, cats that share a home might just tolerate, not like, each other and can keep distance from each other (Braastad 2012).

The landscape context may also significantly influence home range size and use. Access to large rural areas will likely allow larger home ranges than in more urban settings, as the density of cats are often higher in urban areas (Braastad 2012; Thomas et al. 2014). High density seems to constrain the home range size for domestic cats (van Heezik et al. 2009). In addition, cats that live in areas with high density will often share the same areas but use them at different times. These areas can be a common food source, like a garbage dump (Braastad 2012; Horn et al. 2011). If density is not very high, the overlap of area usage will be small or none (Braastad 2012). Some prey species are also more abundant in urban areas than in rural areas (Kays et al. 2020). The cat has higher self-confidence the closer it is to the centre of its home range, and social rank is thought to influence the home range size as well (Braastad 2012; Hall et al. 2016).

Feral- and domestic cats normally have different home range sizes based on gender. Intact (not neutered) males, both feral and domestic, usually have the largest areas that may include the home range of several females, as their home range size is based on their need to search out females (Bengsen et al. 2015; Braastad 2012; Hall et al. 2016). Neutered males no longer have the motivation to look for females, nor the same need of a large home range (Braastad 2012; Hall et al. 2016; Thomas et al. 2014). However, most domestic cats in Norway that spend time outdoors are gonadectomized (neutered and spayed) (Braastad 2012) making it difficult to study these differences. Although several studies from other countries, such as Australia (McGregor et al. 2015; Keys et al. 2020), Japan (Kim et al. 2019), Korea (Kim et al. 2020), US (Horn et al. 2011) and the UK (Hanmer et al. 2017; Thomas et al. 2014) have quantified home range size in domestic cats, no large-scale study to date has investigated home range size in Norwegian domestic cats in relation to their gender.

Home range size is also liked to territoriality. Only females have territories among cats, according to Braastad (2012), while the males do not. The males have too large areas to defend. Females keep territories that they defend from other female and from males, expect from when they are in heat, or from other females that they are closely related to. Females can live in family groups, often with a female and her daughters, raising the young together. Neutered males will also keep territories and will defend them (Braastad, 2012; Hall et al. 2016).

To better understand the ecological impact of domestic cats, we need to investigate what they do outdoors and how their behaviour is shaped by intrinsic and extrinsic factors. This study used citizen scientists to collect data from GPS-tagged domestic cats across rural and urban areas in south-eastern Norway to estimate home range size and hunting activity by domestic cats in the region. It is the largest study on cat home ranges conducted in Norway to date. More specifically I examined: 1) How large are the cat home ranges? 2) Does home range size depend on sex, cat age and landscape context (rural vs urban)? 3) Does home range size predict predation rates? 4) Does landscape context influence predation rates? I predict that P1) Males and females will have equal home range sizes. Most cats in this study are gonadectomized and should have similar home ranges. P2) There will be a correlation between age and home range size. Older cats should have smaller home ranges according to previous studies. P3) Home range size and predation rate will have a correlation. Results are discussed in relation to previous studies and conservation implications.

## 2.1 Methods

### 2.1.1 Study Area

Participants mostly lived in proximity to the Oslofjord, in the counties of Viken, Oslo, and Vestfold and Telemark at elevations 0–178 m.a.s.l (hoydedata.no). The landscape surrounding the urban centres is highly influenced by forestry and agriculture, creating a fragmented mosaic of fields and pastures (17.5%), forests (59.1%), developed areas (18.2%) and transportation networks (2.8%) (NIBIO, 2020b).

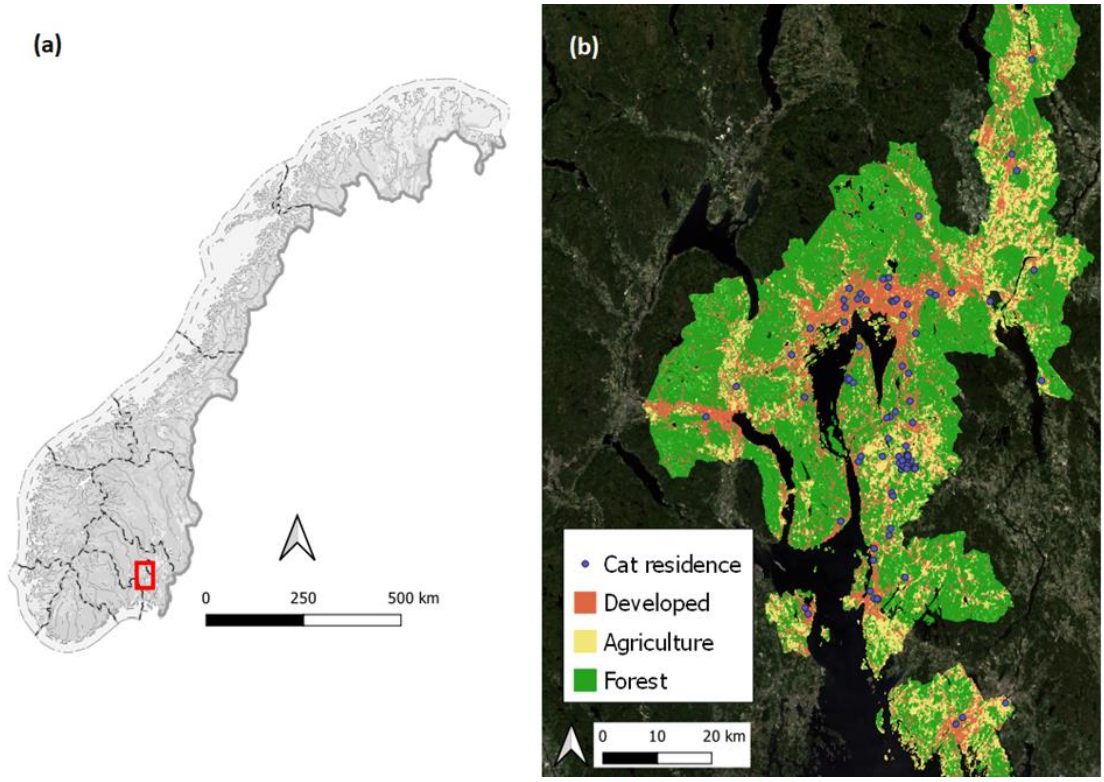


**Figure 1.** *Map of the study area in southern Norway (a) and the location of the participating pet owners (b).*

The study was carried out in the so-called "Oslo region" in southern Norway, contained by a rectangle drawn by the coordinates 59.07 - 60.28 N, 10.05 - 11.27 E (Figure 1). The study area is situated in the boreonemoral vegetation zone (Lillethun and Moen 1998) and has a warm humid continental climate (Kottek et al. 2006), with maximum and minimum temperatures of 34.1 °C and -20.6 °C respectively (NKS 2020). The average temperature in the area during the study period was 14.5 °C. The dominating tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula spp*), rowan (*Sorbus aucuparia*) and *Salix spp* (NIBIO 2020). Common prey species for cats include small rodents and birds, such as the field vole (*Microtus agrestis*), brown rat (*Rattus Norvegicus*), house sparrow (*Passer domesticus*) and dunnock (*Prunella modularis*) (Artsdatabanken 2020).

### 2.1.2 Participants

Project participants (cat owners) were recruited through the Facebook page of NMBU. A video was created for advertisement and published on the Facebook page, in addition to written information about how to sign up. The participants would then get access to the first survey. The survey gave us information about where in Norway they lived, contact information and whether they had a child in the family. We chose participants that who lived in the south-eastern Norway, and that had a child in the family, as the child was supposed to take part in the data collection

**Figure 2.** *The cat SC*UA Bluesmaine Edelweiss, a Maine Coon male, fitted with a GPS unit. Photo by Ronny Steen.*

The selected participants would then get access to a second survey. The data we received from the second survey was put in a table with the categories: "**Age**", "**Weight**", "**Othercats**", "**Personality**", "**Outdoors**", "**Hunting**", "**Gender**", "**Neutered**", "**Breed**" and "**Area**" "Age" and "Weight" contained the age and the weight of the cats. "Othercats" contained information about how many other cats the participants estimated to live in the same area as them. "Personality" was defined as careful or exploring. "Outdoor" described how the cat gained access to the outdoor areas. Here there was three categories: free access with a cat flap, limited access with a cat flap, or the owner lets the cat in/out. "Hunting" contained the estimates of how often the cat successfully hunts, ranging from rarely/never to daily/almost daily. We also collected information about what breeds the cats were ("Breed"), their gender "Gender", and whether or not the cat was gonadectomized ("Neutered"). "Area" described what kind of area the participants lived in: city, rural or residential. After we

received the data from the second survey, the participants received a package containing a GPS unit, USB charger and cat collar. We also included a set of instructions and a form for filling in the cats' schedule (containing information about when the cat went outside and came back inside) and a pre-payed postage sticker. The participants collected data for one week each. When each participant was finished, they were asked to mail the equipment back to NMBU.

Cats with obvious track errors and fewer than 2 tracks were not included in the study. I chose not to look any further into "Breed" as most cats were mixed, or "Neutered" as only a total 4 participating cats were not gonadectomized. The data collected from "Personality" showed that we had very few "careful" males (n=2) in rural settings, and more exploring cats (n=73) than careful cats (n=31) in total. Thus, the personality data was not included in the study.

### 2.1.3 Data collection and processing

The GPS tracks was collected using an iGotU GT-120 USB Travel Logger GPS unit (Figure 3; Global Mobile Action, Inc). The GPS was mounted on a collar and placed around the neck of the cat (Figure 2). The GPS units were put on the cat before it went outside and was taken off and the battery re-charged when the cat returned inside. The GPS unit was turned off while it was charging and turned, and placed on the cat, when the cat went outside. The GPS units were set to register plots every 5 seconds. Power saving mode was turned off to get more accurate location data.


**Figure 3**. *The GPS unit iGotU GT-120 USB Travel Logger attached to a collar. Photo: Bettina Bachmann.*

Before we started data collection activities, we performed a pilot study to calibrate and fine-tune the GPS unit settings. The data was collected from August 2019 till November 2019. Tracking data (coordinates and time stamps) were extracted from the GPS unit using the accompanying software @Trip PC. We used R (R Development Team, 2020) to run a script to find errors in the data. The errors were mainly tracks with wrong date and/or no coordinates, or files with tracks from more than one cat present. These errors were removed manually in notepad. Files were then converted to KML files that could be visualized in Google Earth, and Rdata for processing in R-Studio. The Rdata files was then changed to 20 minutes intervals, as it would not be necessary for home range analysis to have 5 second intervals. The data collected from the second survey was merged with the home range data in R. A script in R fixed a mislabelled gender ("Hunn" to "Female") as well as merging "Residential" and "City" into "Urban", giving the two variables urban and rural in the "Area" category. The ages of the cats were simplified by separating them into two classes. The ages were divided in "age.categ" with categories young (<4 years) and adult (>4 years). The hunting classes were also simplified into "hunt.simple" "rarely/never" False/True, which separates all other classes of hunting into one category, and rarely/never in the other.

### 2.1.4 Home range estimates

Home range sizes of individual cats were estimated using two different methods. Minimum convex polygon (MCP) is a method where the outmost points are connected to form a polygon, as well as all points with less than 180◦ inner angle (Baillo & Cachon 2018; Gregory 2017). MCP 95% includes 95% of the GPS locations recorded from all the tracks gained from individual cats and excludes the outmost points that are furthest from the centre (Gregory 2017). Kernel density estimation (KDE) uses utilization probability, which means that the points that are not included in the home range estimate are those most spread out (Baillo & Cachon 2018). Clusters of points are therefore retained. Normally one would use 95% of the GPS locations with KDE method as well, but this can be adjusted for both methods (Gregory 2017). These two methods differ in their approach and will often have different results (Baillo & Cachon 2018; Gregory 2017). Some points are left out from MCP that are included in KDE and *vice versa* (Figure 4).

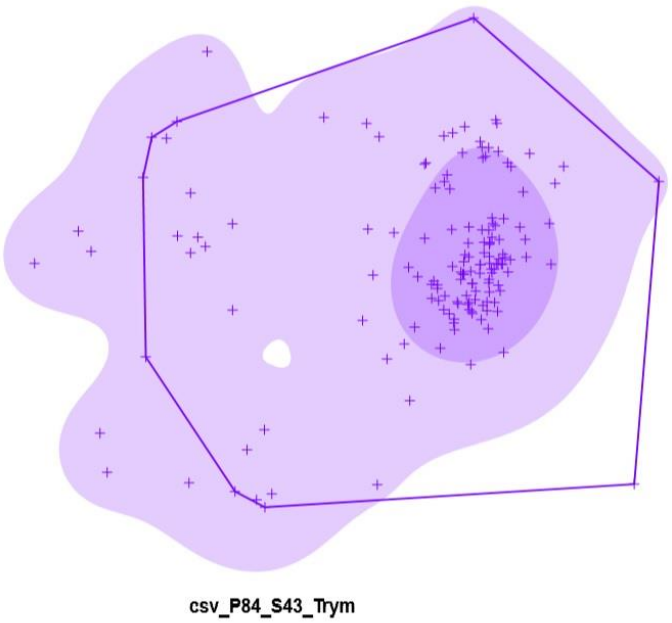


**Figure 4**. *Home range estimates made in R (R Development Team, 2020). Here shown for the cat P84-S42-Trym. KDE50 is shown in the darker coloured area, KDE95 is shown in the lighter coloured area and MCP95 is shown by the dark lines.*

The home range analysis was conducted in R using the "adehabitatHR" (Calenge & Fortmann-Roe 2020) and "sp" packages (Bivand et al. 2013). I calculated MCP 95%, KDE 95% and KDE 50% to investigate whether age, gender, hunting or area affected home range size. I performed linear regressions using the "my.lm" function in R. I fitted the model with log transformed home range sizes to normalize the distribution and to make the patterns in the data more visible.

I compared different a-priori candidate models using AIC (Akaike information criteria). The response variables were the home range sizes (MCP 95% KDE 95% and KDE 50%), while the predictor variables were "Gender", "hunt.simple", "age.categ" and "Area". The most complex model included all the prediction variables and one response variable (Table 1)

Previous studies have used both radio telemetry and GPS units to collect the data. Both MCP and KDE methods have been used as well. MCP was the most common method before, and KDE seems to be the preferred method in newer studies (Hall et al. 2016). To be able to compare the data with both older and newer studies, I choose to use both methods for this thesis.

**Table 1.** *Set of candidate models for KDE 95%, KDE 50% and MCP 95% home ranges. "Gen" refers to gender of the cats, "Hunt" to hunting (using the simplified hunting categories with hunt.simple), Age refers to the age of the cats (using the simplified age.categ), and Area refers to urban and rural areas.*

| Response variable | Candidate model | Prediciton variables | $R^2$ | F-statistics | P value | AIC |
|---|---|---|---|---|---|---|
| KDE 95% | Model 1 | Gen, Age, Area | 0.1524 | 5.62, 4 and 98 DF | 0.0004 | 321.014 |
| | AIC selected model | Gen, Age, Hunt + Area | 0.1948 | 5.11, 6 and 96 DF | 0.0001 | 317.728 |
| | Model 2 | Gen, Age, Hunt, Area | 0.2223 | 3.651, 11 and 91 DF, | 0.0002 | 318.637 |
| | Model 3 | Area, Age, Hunt | 0.1693 | 6.196, 4 and 98 DF | 0.0001 | 319.067 |
| KDE 50 % | Model 1 | Gen, Age, Area | 0.1237 | 4.601, 4 and 98 DF | 0.001 | 320.329 |
| | Model 2 | Gen, age, Hunt + Area | 0.1589 | 4.212, 6 and 96 DF | 0.0008 | 317.986 |
| | AIC selected model | Gen, Age, Hunt, Area | 0.1985 | 4.157, 8 and 94 DF | 0.0002 | 314.8556 |
| | Model 3 | Area, Age, Hunt | 0.1385 | 5.1, 4 and 98 DF | 0.0008 | 318.579 |
| MCP 95% | Model 1 | Gen, Age, Area | 0.1108 | 7.352, 2 and 100 DF | 0.001 | 344.609 |
| | Model 2 | Gen, Age, Hunt + Area | 0.1705 | 4.494, 6 and 96 DF | 0.0004 | 341.244 |
| | AIC selected model | Gen, Age, Hunt, Area | 0.1705 | 4.494, 6 and 96 DF | 0.0004 | 341.244 |
| | Model 3 | Area, Age, Hunt | 0.1342 | 4.952, 4 and 98 DF | 0.001 | 3.43 |

# 3. Results

## 3.1 Cats and households

From the 111 participating cats, only 4 were not neutered (3,60 %). These 4 cats were all females. The cats' ages varied from 1 to 15 years and the mean age was 5 years, while the median was 4 years. The mean weight was 4,7 kg and the median weight was 4,5 kg. More than half of the cats were let in and out by their owner (58%), and most of the remaining cats had a cat flap with free outdoor access (33%). The 13 households that failed to complete did so because the cat did not tolerate the collar, the cat died, the GPS was lost or broken, or the people in the household were prevented from participating. From the 51 participating females, data from 46 females were included in the analysis, and data from 58 of the 60 participating males were included. A total of 104 cats were included in the study (Table 2).

**Table 2**. *The number of participating households and cats from the home range study of domestic cats in south-eastern Norway.*

| | Answered survey 1 | Invited to join | Answered survey 2 | Recieved GPS | Participants that completed | Failed to complete |
|---|---|---|---|---|---|---|
| Households | 307 | 176 | 123 | 112 | 89 | 13 |
| Cats | | | | 135 | 111 | 24 |
| Females | | | | | 51 (46) | |
| Males | | | | | 60 (58) | |

## 3.2 Home range analysis

Results show that mean home range size varied between the MCP and the KDE methods, and between KDE 95% and KDE 50% (Table 3). Cats in rural areas had larger home ranges in general (Table 4), but the core home range (KDE 50%: p=0.481) was not significantly larger for cats in rural areas (Table 7). There was an equal number of males (n=41) and females (n= 44) in urban areas, but in rural areas there was very few females (n=2) compared to males (n=17).

**Table 3**. *Mean and median home range sizes (ha) for males and females, with standard error, minimum and maximum home range sizes and minimum and maximum CI levels.*

| | Method | Mean | Median | SE | Min | Max | CI 2,5% | CI 97,5% |
|---|---|---|---|---|---|---|---|---|
| Females | MCP 95% | 2.00 | 0.90 | 0.50 | 0.00 | 19.0 | 0.10 | 14.70 |
| Males | MCP 95% | 3.60 | 1.30 | 0.80 | 0.00 | 41.2 | 0.20 | 17.10 |
| Females | KDE 95% | 3.10 | 1.40 | 0.70 | 0.00 | 27.0 | 0.30 | 20.60 |
| Males | KDE 95% | 6.00 | 2.20 | 1.60 | 0.00 | 86.0 | 0.30 | 23.90 |
| Females | KDE 50% | 0.40 | 0.20 | 0.30 | 0.00 | 4.4 | 0.00 | 3.10 |
| Males | KDE 50% | 0.80 | 0.30 | 0.10 | 0.00 | 16.9 | 0.00 | 10.90 |
| Total | MCP 95% | 2.89 | 1.00 | 0.52 | 0.01 | 50.86 | | |
| Total | KDE 95% | 4.70 | 1.62 | 0.95 | 0.05 | 87.70 | | |
| Total | KDE 50% | 0.65 | 0.20 | 0.17 | 0.01 | 20.02 | | |

**Table 4**. *Mean and median home range sizes, standard error, minimum and maximum home range sizes (ha), minimum and maximum CI levels for cats divided by urban and rural areas.*

| | Method | Mean | Median | SE | Min | Max | CI 2,5% | CI 97,5% |
|---|---|---|---|---|---|---|---|---|
| Urban | MCP 95% | 2.2 | 0.4 | 0.4 | 0.0 | 16.1 | 0.1 | 14.7 |
| Rural | MCP 95% | 6.1 | 2.1 | 2.2 | 0.5 | 41.2 | 0.6 | 30.7 |
| Urban | KDE 95% | 3.3 | 1.5 | 0.5 | 0.0 | 22.4 | 0.5 | 20.7 |
| Rural | KDE 95% | 11.1 | 4.3 | 4.4 | 0.7 | 86.0 | 1.0 | 58.9 |
| Urban | KDE 50% | 0.4 | 0.2 | 0.1 | 0.0 | 4.9 | 0.0 | 3.3 |
| Rural | KDE 50% | 1.6 | 0.4 | 0.9 | 0.1 | 16.9 | 0.1 | 10.2 |

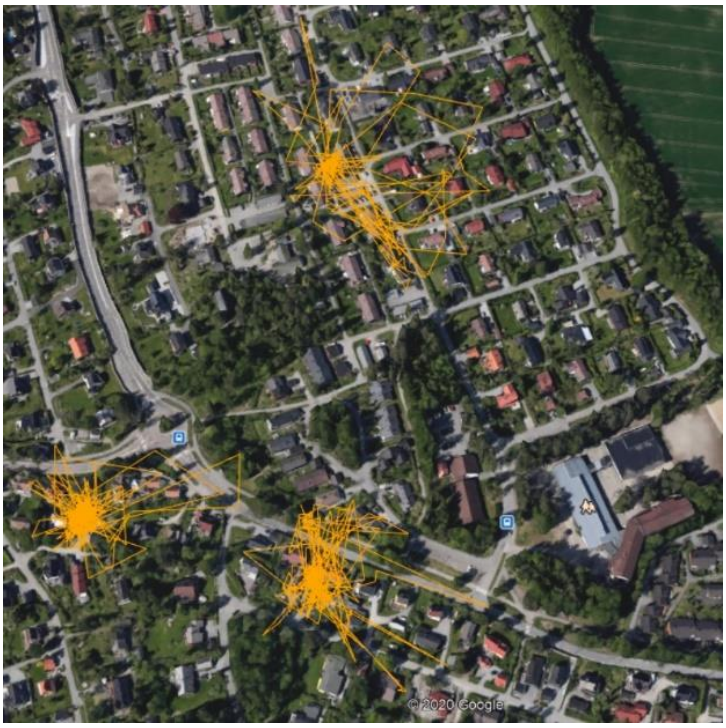


**Figure 5.** *The home ranges of 3 participating cats in an urban area, shown in Google Maps using KML files generated in R.*

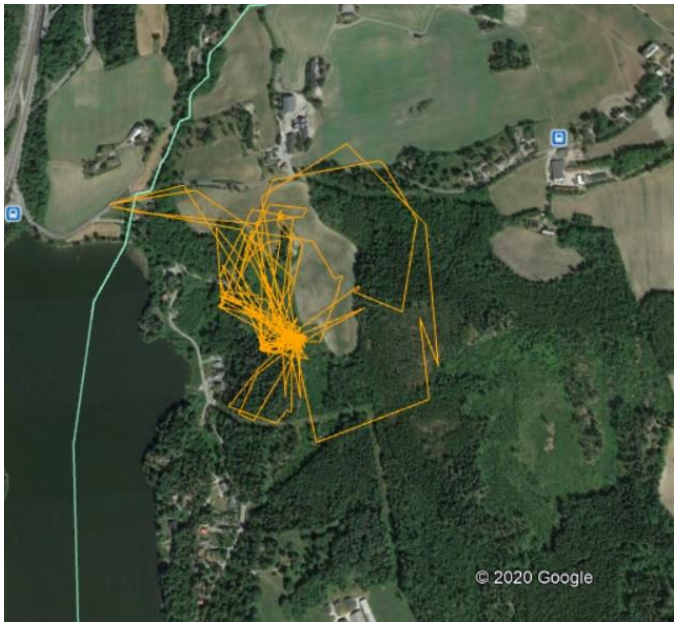


**Figure 6**. *The home range of the cat with the largest mean home range, shown in Google Maps using a KML file generated in R.*

The home range sizes varied from 0 ha to 41.2 ha with MCP 95 %, from 0 ha to 86 ha with KDE 95% and from 0 ha to 16.9 ha with KDE 50% (Tables 3-4; Figure 6).

**Table 5**. *The AIC selected* l*inear regression model with MCP 95% as response variable "Gender" * "Age" * "Hunting" * "Area" as predictor variables. Adjusted R-squared: 0.1705, F-statistic: 4.494 on 6 and 96 DF, p-value: 0.0004711 AIC: 341.244.*

| | Estimate | Std. Error | T value | Pr(> \| t \| ) |
|---|---|---|---|---|
| (Intercept) | -3.9416 | 0.2998 | -13.146 | < 2e-16 *** |
| GenderFemale | -0.8876 | 0.3671 | -2.418 | 0.01749 * |
| age.categadult | -0.8610 | 0.3633 | -2.370 | 0.01970 * |
| hunt.simpleTRUE | -0.7307 | 0.4324 | -1.690 | 0.09420 . |
| AreaRural | 1.1228 | 0.3581 | 3.135 | 0.00228 ** |
| GenderFemale:hunt.simpleTRUE | 1.0823 | 0.4973 | 2.176 | 0.03199 * |
| age.categadult:hunt.simpleTRUE | 0.9839 | 0.5028 | 1.957 | 0.05330 . |

**Table 6**. *The AIC selected* l*inear regression model with KDE 95% % as response variable, "Gender" * "Age" * "Hunting" + "Area" as predictor variables. Adjusted R-squared: 0.1948, F-statistic: 5.113 on 6 and 96 DF, p-value: 0.0001353 AIC: 317.728.*

| | Estimate | Std. Error | T value | Pr(> \| t \| ) |
|---|---|---|---|---|
| (Intercept) | -3.4727 | 0.2675 | -12.982 | < 2e-16 *** |
| GenderFemale | -0.64422 | 0.3275 | -1.967 | 0.052062 . |
| age.categadult | -0.8840 | 0.3241 | -2.782 | 0.007583 ** |
| hunt.simpleTRUE | -0.7049 | 0.3858 | -1.827 | 0.070751 |
| AreaRural | 1.1879 | 0.3195 | 3.718 | 0.000338 *** |
| GenderFemale:hunt.simpleTRUE | 0.9657 | 0.4437 | 2.177 | 0.031967 * |
| age.categadult:hunt.simpleTRUE | 0.9128 | 0.4486 | 2.035 | 0.044626 * |

**Table 7.** *The AIC selected* l*inear regression model with KDE 50% as response variable, "Gender" * "Age" * "Hunting" * "Area" as predictor variables. Adjusted R-squared: 0.1985, F-statistic: 4.157 on 6 and 96 DF, p-value: 0.0002751 AIC: 314.855.*

| | Estimate | Std. Error | T value | Pr(> \| t \| ) |
|---|---|---|---|---|
| (Intercept) | -5.6105 | 0.2678 | -20.948 | < 2e-16 *** |
| GenderFemale | -0.4876 | 0.3279 | -1.487 | 0.08910 |
| age.categadult | -0.8461 | 0.3245 | -2.608 | 0.02087 * |
| hunt.simpleTRUE | -0.6931 | 0.3862 | -1.795 | 0.01633 * |
| AreaRural | 1.1119 | 0.3199 | 3.476 | 0.48129 |
| GenderFemale:hunt.simpleTRUE | 0.9294 | 0.4442 | 2.092 | 0.00444 ** |
| age.categadult:hunt.simpleTRUE | 0.8883 | 0.4491 | 1.978 | 0.06960. |
| GenderFemale:AreaRural | -2.0574 | 0.8696 | -2.366 | 0.02004 * |
| Hunt.simpleTRE:AreaRural | 1.2016 | 0.7771 | 1.546 | 0.12541 |

### 3.2.1) Home range size and gender

Males have larger home range sizes than females for both MCP and KDE methods (Table 3; Figure 7). For the MCP 95% method, the difference in home range size between genders was significant (p=0.017, SD =0.367) (Table 5). Males 1.8 times (45%) larger mean home range size than females. Males also had a larger maximum home range area than females (7% larger), but the smallest home range sizes were the same for both genders (Table 3).

With the KDE (95%) method, average home range size of males was 1.9 times (49%) larger than for females. The largest home range size for males was 3.2 times (69%) larger than for the females, and the smallest home range size was the same for both genders (Table 3). The linear regression did not show any significant differences between the genders (p=0.052, SD=0.327; Table 6), thus there was only a trend.

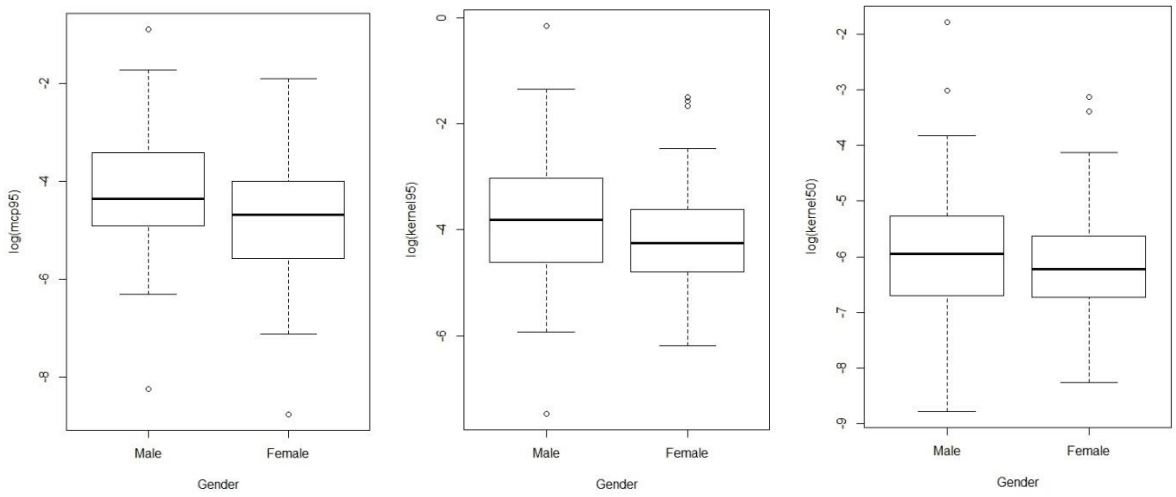


**Figure 7**. *Box plots showing the median home range sizes (ha) for the cats in south-eastern Norway, with upper and lower quartile (25% of data is greater or less than this value), the maximum and minimum value without outliers, and outliers.*

The core area, calculated with the KDE (50%) method, was twice as large (50%) for males on average. However, this difference was not significant (p=0.089, SD=0.327) (Table 7). The maximum core size was 3.85 times (74%) larger for males, but males and females had the same minimum core home range sizes (Table 3).

### 3.2.2) Age and home range size

There were 47 adult cats (27 males, 20 females) and 56 young cats (31 males, 25 females). Older cats tended to have smaller home ranges than younger cats in general (Figure 8). This was significant for all methods; MCP 95% (p=0.007, SE =0.324; Table 5) and KDE 95% (p=0.019, SE= 0.363; Table 6), and for the core area KDE 50% (p=0.020, SE=0.324; Table 7).

Mean home range size for young males was 5.1 ha and mean home range for adult males was 6.9 ha. Young females had a mean of 3.8 ha and adult females had a mean of 2.3 ha.

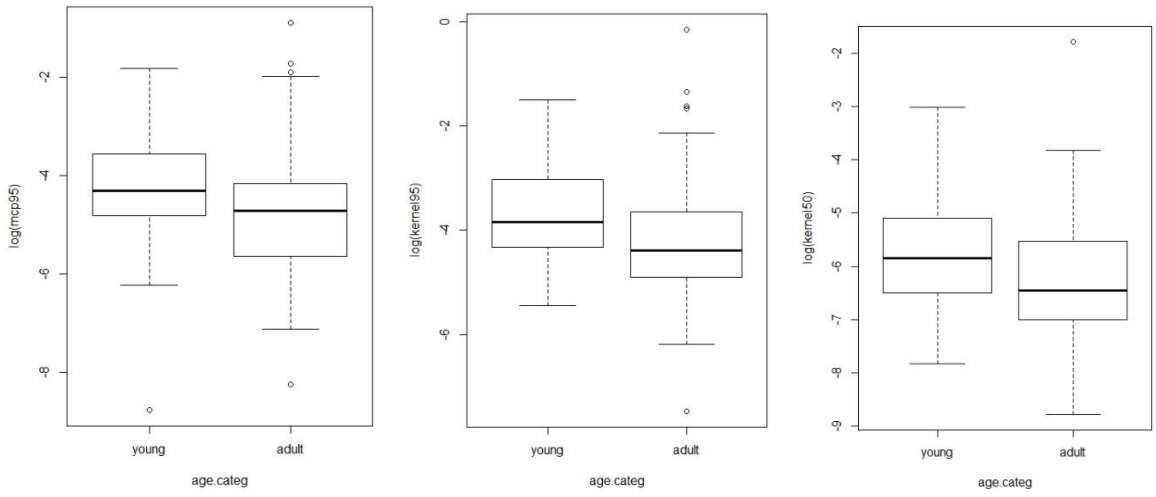


**Figure 8.** *Box plots showing the median home range size (ha) for young and adult cats in south-eastern Norway, with upper and lower quartile (25% of data is greater or less than this value), the maximum and minimum value without outliers, and outliers.*

### 3.2.3) Home range size and predation rate

There was no significant correlation between home range size and hunting (MCP 95%: p= 0.070, SE= 0.432; KDE 95%: p=0.094, SE=.0385; Tables 5-6), expect for the core home range (KDE 50%: p=0.016, SE=0.386; Table 7). The results show that cats that hunt have a larger core home range (Table 7). However, results were marginally not significant for MCP 95% and KDE 95% methods, suggesting a trend where larger home range size results in more hunting. Results show a trend for home range size and hunting having a positive correlation, although.

In the case of gender and age, results show that females that do not hunt have smaller home ranges than those that do (MCP 95%: p=0.031, SE= 0.497; KDE 95%: p=0.031, SE= 0.433; KDE 50%: p= 0.004, SE= 0.442). Results also show that adult cats that hunt tend to have larger home ranges than those that do not. This difference was significant with KDE 95% (p= 0.044, SE=0.448 ), and showing a trend with the MCP 95% (p=0.053, SE=0.502) and KDE 50% (p=0.069, SE=0.449) methods (Tables 5-7). Due to the small number of cats in rural areas, I was unable to test any difference in hunting behaviour between rural and urban cats.

## 4.1 Discussion

### 4.1.1 Results

#### 4.1.1.1 Home range analysis.

The current study is the first to report home range size for pet cats in Norway. Home range sizes observed in the current study were highly variable (Table 3). This is consistent with previous studies (Kays et al. 2020, Table 8). The mean home range size observed among domestic cats in southern Norway was larger than those studied in Australia, the UK, the US, and New Zealand (Hanmer et al. 2017; Horn et al. 2011; Kays et al. 2020; Thomas et al. 2014) (Table 8).

Home range size is affected by several factors. Among these factors are cat densities, whether the cat live in urban or rural areas, is domestic or feral and what type of personality and social ranking they have (Braastad 2012; Hanmer et al. 2017; Meek 2003; Thomas et al. 2014).

Meek (2003) found that the domestic cats in his study was either "wandering" or "sedentary". The cats that were wandering had larger home ranges than the cats that were sedentary, although he could not determinate the cause of this difference. Braastad (2012) states that the personality and social rank of the cats will affect its roaming behaviour and home range size. According to Braastad (2012), cats with high social ranks cover larger areas and are bolder. Tschanz et al. (2011) found that differences in the cats' personality will affect its hunting behaviour as well. Thomas et al. (2014) found that cats will range further at night than during the day. Unfortunately, the data from "Personality" in this study was skewed, so it was not possible to investigate the effect of personality on home range size.

Both previous studies (Hall et al. 2016; Hanmer et al. 2017; Kays et al. 2020) and this study found that cats in rural areas have larger home ranges than cats in urban areas, likely because of the lower density in rural areas. This difference in home range sizes was also visible visually (Figures 5-6). Hall et al. (2016) found that owned cats in rural areas had 14.4 times larger home ranges than in urban areas. However, Kays et al. (2020) did not find this difference between rural and urban dwelling cat to be as large Hall et al. (2026) did. Kays et al. (2020) used human population density to establish the difference between rural and urban areas in their study. The data we collected from the participants, which included the cats' age, gender, predation rate, age, breed and personality, was collected through a survey. Whether the cat lived in an urban or rural area was based entirely on the owners' interpretation of what is an urban or rural area, which could influence the results.

**Table 8.** *Comparison of home range sizes from this study and results from other studies for domestic cats. The table contains the mean home range (ha), mean home range (ha) for both genders, whether the studied cats were using domestic or feral cats, the number of cats included in the study and the country in which the study took place. When there is only one number available for home range size, the number represents the total mean home range size. Where there is three numbers present, the first number is the total mean, the second number is for males and the third number is for females.*

| Study | Mean HR, Male/Female | Number of cats | Method | Country |
|---|---|---|---|---|
| This study | 2.89<br>3.60 /2.00 | 104 | MCP 95% | Norway |
| Horn et al. 2011 | 1.83 / 1.93 | 11 | MCP 95% | US |
| Meek 2003 | 2.29<br>4.2 / 2.4 | 15 | MCP 100% | Australia |
| Thomas et al. 2014 | 1.94 | 20 | MCP 95% | UK |
| This study | 4.70<br>6.00 / 3.10 | 104 | KDE 95% | Norway |
| Hanmer et al. 2017 | 1.66 | 43 | KDE 95% | UK |
| Horn et al. 2011 | 5.86 / 1.95 | 11 | KDE 95% | US |
| Kays et al. 2020 | 3.6 | 875 | KDE 95% | Several |

According to Kays et al. (2020), the variance in data from GPS tracked domestic cats sharply decreased after 5 days and become most precise after 10 days. Our cats were tracked for 7 days, which is above the 5 days where the variance sharply decreased.

#### 4.1.1.2) Gender and home range size

Males had larger home ranges than females in this study, although this difference was only statistically different with MCP 95%. For KDE9 5% and 50%, this was just a trend. All male cats in our study was gonadectomized, removing their need to include several females in their home ranges.

Previous studies with domestic cats have shown both that male and female home range size differ significantly (Hall et al. 2016; Kays et al. 2020) and that they do not (Hamner et al. 2017; Horn et al. 2011; Kim et al. 2019). In a meta-analysis by Hall et al. (2016) where they analysed 25 studies with a total of 469 domestic cats, males had significantly larger home ranges than females (on average of 1.88 times larger) home range than females. Neutering males will not always change their roaming behaviour, according to Hall et al. (2016). Hall et al. (2016) argue that males that are neutered before they reach sexual maturity are more likely to have the same home range size as females. Hall et al. (2016) states that this is because their behaviour might not be altered from gonadectomising after reaching sexual maturity. Kays et al. (2020) also found a significant difference between males and females (males had larger home ranges). Both Kays et al. (2020) and Hall et al. (2016) had larger sample size than other studies.

Authors found that feral males have home ranges that include several females' home ranges, while the females' home range size is based mainly on prey availability, suitable areas to raise young and the density of other cats (Kim et al. 2019; McGregor et al. 2015). Authors agree that it is expected to find larger home range areas for feral males, than females (McGregor et al. 2015; Thomas et al. 2014).

#### 4.1.1.3) Age and home range size

Young cats had significantly larger home ranges than adult cats. Admittedly, the age categories used in this study were rather simplified and arbitrary in order to fit the regression model, but the result still makes sense. Cats tend to have larger home ranges when they are young, as they have more energy, are more exploratory and may not have a properly established home range yet - causing them to roam more (Kays et al. 2020). Older individuals will perhaps no longer be able to defend the area to the same extent (Hall et al. 2016). Hall et al (2016) found that young and adult cats have larger home ranges than older cats (>8 years),

but adult cats (> 2 years) do not have larger home range than young cats (<2 years) in general. These findings are supported by Kays et al. (2020), that found that younger males in rural areas tend to roam further than other cats. They also found that cat movement declined by age. Adult cats are thought to have generally higher social rank than younger cats, declining by age (Braastad, 2012).

#### 4.1.1.4) Home range size and predation rates

Contrary to my prediction, home range size did not influence hunting behaviour, although the core home range was larger for the cats that hunted (Table 7). Most owners reported no kills or that the cat rarely brought prey home.

Loyd et al. (2013) used cameras on 55 cats in rural (15%) and urban areas in the US to investigate hunting behaviour. Their results showed that 2 of 3 kills were eaten on site or not returned home, and that reptiles constituted most of the kills, followed by small mammals and birds. It is therefore likely that prey return rate was underestimated by owners in this study. McDonald et al. (2015) also found that owners underestimated the predation rate of their cat.

McDonald et al. (2015) also found that younger males hunted the most, and that the most common prey was small mammals and birds. Small mammals make up more percentage of the kills than birds in many studies, and small mammals are predated more during the night than in the daytime (Barrat 1997; Loyd et al. 2013; McDonald et al. 2015; Woods et al. 2003). Cats predate local populations of reptiles as well as birds and small mammals and are opportunistic (Loyd et al. 2013). Woods et al. (2003) found that keeping the cats indoor at night reduced predation of small mammals, but not birds. The kind of prey returned to the home by cats participating in the current study was not noted. Unfortunately, we did not think about separating the type of prey returned by the cats in our study, making it impossible to say what species was preferred by the cats in our study. The predation rate in this study could also have been underestimated like in previous studies.

van Heezik et al. (2009) argue that some studies show little effect of domestic cat predation. They also state that predation by cats can be compensatory or additive. McGregor et al. (2015) found that cats contributed to decline of small mammals despite the low density in northern Australia. McGregor et al. (2015) also argue that Australia have no predator of the same size in the north. These local effects will be different for each country or even region.

It is important to know the home range sizes of domestic cats in different countries (Thomas et al. 2014) to be able to understand their potential impact on local wildlife. As urbanisation of rural areas are occurring more and more in several countries (Pillay et al. 2018; Thomas et al. 2014, van Heezik et al. 2009) cat density will also increase in these areas. Several authors suggest making a buffer zone around these new rural areas that borders to urban areas, to protect the local wildlife. Home range size estimates will help to make the right size of these buffer zones (Hanmer et al. 2017; Thomas et al. 2014) and to help understand the impact of cats on local wildlife (Ferreira et al. 2016).

### 4.1.2 Conclusion

It is not possible to determine the direct impact of cats on local wildlife in the current study. Future research should therefore include owner reports of prey returned during the period of data collection. If possible, using cameras on cats to directly observe predation events would be useful. It is necessary to both get good estimates of prey return rates, as well as to know what species that are predated.

Home range sizes vary between rural and urban areas, as well as between countries. Home range size is also affected by age, gender, personality and social ranking, as well as outdoor access. This should be taken into consideration when the impact of the cats on local wildlife is measured. Norway have almost no feral cats, and many cats that go outdoors are gonadectomized. The density of domestic cats is not affected by food availability when the cats have a home where they are fed, so prey availability will not have any impact on the density, thus cat density can have impact on the prey abundance. Since cats hunt different prey during the day (birds) and in the night (small mammals), keeping the cat indoor at night can reduce the predation of small mammals. Whether the predation by local cat is additive or compensatory is also important to study to estimate their ecological imprint.

There are more cats living in urban areas than in rural in south-eastern Norway, which indicates that future studies on the ecological imprint of cats should be done in these areas. As cats in south-eastern Norway seem to have larger home ranges in general than in other studied countries, they will also require a larger buffer zone than in other countries, to protect local wildlife.For future studies in Norway, the definition of rural and urban areas should be taken into consideration, and a definition should be made before the data is collected. This could standardized for future similar research to make the data easily comparable. The dataset needs to be large enough to get equal numbers of both males and females in rural and urban areas to

make a good comparison. It is possible to select for more participants in rural areas in future research.

Studies have shown varying results regarding female and male home range sizes. Some found significant differences between the genders, others did not. The timing of the gonadectomising of the cat can play a role, as the behaviour can remained unchanged if the cat was neutered after reaching sexual maturity. Domestic neutered males seem to have larger home ranges than females when the sample size is large enough. I suggest giving this more attention in future studies, as well as collection data about the age of the cat when it was gonadectomized.

The dataset also needs to be large enough to have enough both “Careful” and “Exploring” cats it the personality is to be included in the study. I also suggest increasing to 10 days of tracking for each cat.

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