Temporal, climatic and spatial variation in the distribution and activity patterns of the raccoon (*Procyon lotor*) in Hainich National Park, Germany

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Distribution of the raccoon (*Procyon lotor*) in Hainich National Park, Germany – A pilot study

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Abstract

The raccoon (*Procyon lotor*) has been a part of German fauna since the 1920s, following a number of releases and escapes from captivity. This study intends to investigate the distribution and activity patterns of this non-native mesopredator in Hainich National Park, which lies in Central Germany, in-between 3 core areas of established raccoon populations. I analysed metadata from over 12,000 camera trap pictures of raccoons, which were sampled by 120 camera traps distributed over Hainich National Park. I compared this to meteorological data covering the same area and spatial variables within a 4-km-buffer around the National Park. The study period covered winter and early spring during each of the 3 consecutive years 2017 to 2019.

A total of 2,300 raccoons were recorded by all camera traps across all study periods during 2,095 trigger events. Being highly mobile, the large majority of raccoons stayed not even one minute inside the camera frame. Over 99 % of recordings showed adults which might be explained by the study periods being temporally placed in-between reproductive cycles. Raccoons, both in their native and their new range, are known to be nocturnal animals, thus it was predictable that they were significantly more active during the night, defined as the period between one hour after sunset until one hour before sunrise. Activity during the rest of the day, especially during dusk, increased steadily with each month of the study period. General raccoon activity followed the same pattern until a sudden decrease in April. Ground temperature was the only climate variable for which a significant (positive) correlation could be shown. This was in accordance with studies on original and new raccoon range expansion. However, a dormant period, as shown for raccoons in a similar habitat in Germany, could not be seen.

Habitat preferences differed depending on the testing method: A considerable proportion of raccoons were sampled in mixed deciduous forest, while most raccoons per camera were sampled in mixed coniferous forest. Duncan's index of habitat preference points to a preference of mixed coniferous forest as well, and literature argues in favour of mixed deciduous forest where raccoons find important resources such as shelter in European beeches. Regarding the geographical distribution over Hainich National Park, raccoons were mainly sampled close to the border, to hiking and biking trails and to anthropogenic structures, especially the visitor magnet Canopy Walk, presumably for complementing their diet with crops from nearby fields and scavenged trash.

I conclude that the raccoon is an opportunistic generalist that thrives in Hainich National Park, though more studies are needed to understand the species' ecology in its new habitat.

Keywords: raccoon, *Procyon lotor*, Hainich National Park, Canopy Walk, camera trapping, nocturnality, ground temperature, habitat preference, European beech, *Fagus sylvatica*, anthropogenic influence.

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1. Introduction and background

1.1. The raccoon in Germany

The Northern Raccoon (*Procyon lotor*) is a medium-sized carnivore in the family of Procyonidae, native to the North American continent. It was initially imported into Germany in the 1920s as a zoo and hunting animal and for fur farming, but could soon make its entry into German fauna (Stubbe 1975).

Literature presents historical evidence of at least four separate introduction events: The earliest in 1927 until 1945; one was in Hamburg, one East of Berlin, the others were near lake Edersee, South-West of Kassel (Müller-Using 1959; Lutz 1984; Lutz 1995). Several authors speculate that more individuals could escape or were released during and after the Second World War (e.g. Lutz 1995). Indeed, recent genetic evidence points to more introductions as have historically been reported (Salgado 2018).

Low genetic diversity, a founder effect and genetic bottlenecks seem to have but little effect on the German raccoon population: After an initial lagging phase of several decades, it grew exponentially since the mid-1990s, based on German hunting statistics (Fischer *et al*. 2016; Salgado 2018). Hunting bags increased from around 9,000 shot raccoons in the hunting season of 2000/01 to 71,000 in 2011/12 (Fischer *et al*. 2016), to over 202,000 raccoons in 2019/20 (Deutscher Jagdverband 2021). In the federal state of Thuringia alone, hunting bags on raccoons went from 659 shot individuals in 2000/01 to 13,266 in the hunting season of 2019/20 (Deutscher Jagdverband 2019, 2021). It is probable that repeated introductions have helped European raccoon populations by providing new genetic material (Fischer *et al*. 2017; Salgado 2018).

Today, the raccoon has spread far over Germany and into neighbouring countries (Salgado 2018). In Germany, the three core areas of occurrence are in Central Germany (around lake Edersee and Kassel), in North-Central Germany (around the Harz Mountains), and in North-Eastern Germany (around Berlin) (Lutz 1995; Fischer *et al*. 2016). Hainich National Park, situated in Central Germany, lies in-between these core areas of raccoon occurrence. It is therefore highly probable, although never before scientifically investigated, that the raccoon has established subpopulations in this region already.

1.2. Raccoon ecology

The raccoon is spread far over the North American continent, from Canada in the North, down to the top of South America, excepting only the Great Basin Desert (Louppe *et al*. 2019; Kochmann *et al*. 2021). Temperature seems to be the main driver of raccoon range expansion (Louppe *et al*. 2019). While warmer regions in the North American continent hold larger raccoon populations, they can thrive in colder climates as long as appropriate resources are available (Zeveloff 2002). In that case they have been observed to adapt their behaviour towards sharing a winter den to sustain body heat (Zeveloff 2002).

In rural and protected areas, home ranges are between 153 and 394 ha in size in North America (Gehrt and Fritzell 1997; Chamberlain *et al*. 2003; Owen *et al*. 2015), and from 99 up to 1,400 ha in different parts of Germany in winter (Hohmann *et al*. 2000; Köhnemann 2007; Ortmann *et al*. 2011). Smaller mean home ranges around 50 ha have been reported for severe winters (Michler 2018). Home ranges typically consist of different types of forest but could also extend across arable land (Hohmann *et al*. 2000; Chamberlain *et al*. 2003; Owen *et al*. 2015). Between 11 and 17 % of home ranges are used as core areas, differing between the sexes, and were made up of mature deciduous or pine forest, with riparian zones in some regions of North America (Chamberlain *et al*. 2003; Ortmann *et al*. 2011; Owen *et al*. 2015). Studies on raccoons in Europe in general (Salgado 2018), in Austria (Duscher *et al*. 2018) and Germany in particular (Lutz 1995; Köhnemann and Michler 2009; Hermes *et al*. 2011), agreed on a preference for deciduous forest, if possible close to a body of water.

In its native as well as in its new range, the raccoon is known to be an adaptive generalist that even thrives in the presence of humans (Prange *et al*. 2004; Duscher *et al*. 2018). They are frequently present in urban and suburban areas though home ranges are smaller than in the countryside (Prange *et al*. 2004). Tardy *et al.* (2015) found that raccoons in Canada, exposed to low competitive pressure, favoured habitats containing a high percentage of forest and areas of anthropogenic usage. Duscher *et al.* (2018) identified human settlement to be a major attractor such that raccoons in Austria even established populations in otherwise unfavoured high altitudes.

Raccoons are known to be nocturnal animals, both in their native range and in Europe (García *et al*. 2012; Lesmeister *et al*. 2015), that can walk considerable distances in search of food and mates (Ortmann *et al*. 2011; Michler 2018).

Food choices include arable crops, fruits, nuts and plant matter, molluscs, insects, earth worms, and to a small degree amphibians and fishes (Engelmann *et* *al*. 2011; Hermes *et al*. 2011; Rulison *et al*. 2012; Michler 2020). In winter in particular, ingested biomass was chiefly made up of corn, molluscs and tree fruits (Michler 2020). In spring, plant matter was largely replaced by vertebrates, but earth worms and molluscs contributed the most to ingested biomass (Michler 2020).

1.3. Study objective

According to several sources, the raccoon is classified a native species in the German Federal Nature Conservation Act (*Bundesnaturschutzgesetz*, BNatSchG) (Michler and Köhnemann 2008; Muschik *et al*. 2010; Michler and Michler 2012). However, different paragraphs are referred to, none of which mention the cited classification. Possibly, the BNatSchG has since been changed in that regard. On the contrary, in the Federal Species Protection Regulation (*Bundesartenschutz-verordnung*, BArtSchV), raccoons are excepted from the group of specially protected native Mammalia. According to § 28a of the Federal Hunting Law (*Bundesjagdgesetz*, BJagdG), hunters are even invited, though not obligated, to hunt invasive species for the purpose of wildlife management within the hunting district. Raccoons are officially listed as an invasive species in accordance with The prevention and management of the introduction and spread of invasive alien species (Regulation No 1143/2014) (Nehring and Skowronek 2020). The BJagdG refers to Article 17 of Regulation No 1143/2014, which however confines eradication measures to the time frame of three months after discovery of the presence of the invasive species. In the case of raccoons, Article 19 takes effect which specifies "Management of invasive alien species that are widely spread" (Regulation No 1143/2014).

In order to be able to take management measures, Hainich National Park Administration needs information on the spread and size of the local raccoon population. This study's main aim is to get an overview over the distribution of this non-native mesopredator. It should also shed light on whether time, meteorological factors or human presence have an influence on the raccoon's spatial behaviour. This study is supposed to be the basis for further in-depth studies on raccoon ecology in Hainich National Park.

1.4. Research questions

This study addresses the following research questions:

1. How does raccoon activity vary over time?
2. How is raccoon activity influenced by climatic variables?
3. What kind of site are preferred by raccoons within Hainich National Park?

2. Materials and method

2.1. Study area

Hainich National Park is located in the West of the federal state of Thuringia (Fig. 1). Being situated close to the former inner-German border, the area has a history of military usage since 1935 which has shaped its ground and vegetation. After both the former GDR and the Soviet Union withdrew their troops following the German reunion, the area has largely been left untouched which resulted in the re-growth of a European beech (*Fagus sylvatica*) forest (Nationalpark Hainich 2017).

It became a German National Park in 1997. Today, Hainich National Park is part of the transboundary World Nature Heritage “Primeval Beech Forests” which to date includes 94 areas in 18 countries (M. Groβmann, personal communication, July 19, 2021).

With 75 km^2, Hainich National Park is one of the smaller German National Parks. About 25 km^2 of this is open land, mainly covering the Southern tip of Hainich National Park. The remaining 50 km^2 are a connected forest which earns the National Park the title of “largest unused area of deciduous woodland in Germany” (Nationalpark Hainich 2021). To the North, Hainich National Park is connected to the forest of the Nature Park Eichsfeld-Hainich-Werratal, which adds up to 160 km^2 covered by deciduous forest. It is correspondingly titled “the largest coherent deciduous woodland in Germany” (Nationalpark Hainich 2021).

European beech is the absolute predominant tree species, but other species like maple (*Acer* genus), ash (*Fraxinus* genus), whitethorn (*Crataegus* genus), oak (*Quercus* genus) and spruce (*Picea* genus) can frequently be found. Bush-encroachment in the open land is mainly due to regrowing whitethorn. The ground is rich in limestone. Hainich National Park has an altitude of between 300 to 500 m a.s.l., including a number of hills but lacking any real summits.

2.2. Materials

2.2.1. The Wild Boar Project from Hainich National Park

The data I analysed for this study was collected during a separate research project on wild boars (*Sus scrofa*) in Hainich National Park. For the Wild Boar Project, 100 cameras were installed in the National Park on a grid of 860 x 860 m (Fig. 1). An additional 20 cameras were installed overlooking wild boar wallows (Klamm *et al*. 2020).

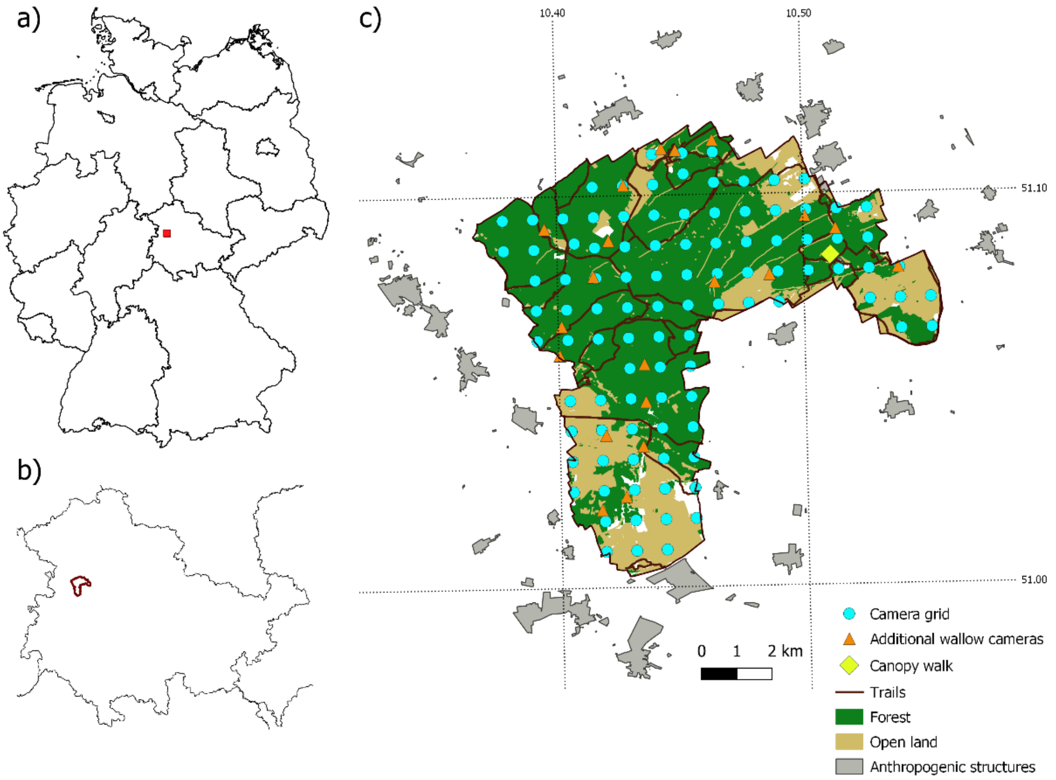

Figure 1: Location of Hainich National Park in a) Germany; and b) Thuringia. c) Location of camera traps and the Canopy Walk as well as coverage by different habitat types. Anthropogenic structures within a 4-km-buffer were included in the analysis of spatial relationships.

Camera traps used were of the model Extreme Ranger IR by Cuddeback. These were installed on wooden posts set up at the grid's intercept, if possible. If this was not possible, e.g. due to a tree at the exact intended position, the next possible location in the cardinal direction was chosen. The cardinal direction (i.e. N, E, S, W) was alternated for every set-up camera (Klamm *et al*. 2020).

Camera traps were set to shoot 5 pictures without delay when triggered, both day and night. The National Park's rangers were responsible for the maintenance of the cameras, such as changing batteries and SD-cards, protocolling the status-quo of the cameras as well as reading in the SD-cards and preliminary deleting any pictures that showed people, according to the EU's General Data Protection Regulation (GDPR) (Klamm *et al*. 2020).

Camera traps were active between 15th January and 15th April in the years 2017 to 2019. However, they were installed and dismantled with a margin to ensure that cameras were working during the entire period each year (Klamm *et al*. 2020). For that reason, it was possible for me to select a longer study period (see *2.3.1.*).

Tagging of the collected material was done based on Hainich National Park Administration's own standards by employees and students. First, pictures were divided into events (see *Appendix A* for definition of an event and tagging procedures). Then, details like species, sex and age were added with the software FotoWeb 8 and its extension FotoStation Pro 8.9 Client by FotoWare (Klamm *et al*. 2020). For raccoons specifically, sex was not discernible in the pictures and consequently left out. Age was divided into Adult, Subadult and Juvenile where Juvenile were the kits from the respective calendar year, Subadult below one year of age and Adult older than 1 year. When age could not be determined, it was labelled 'Not discernible' (A. Klamm, personal communication, April 28, 2021). Finally, the administration's staff added a column in which they determined the total amount of individual raccoons during each event. Thanks to that, I can assume that it was in fact different raccoons that were seen in the picture.

Of the parameters provided, these were the ones I used in this study:

- Species
- Camera ID
- Event begin date & time
- Event end date & time
- Amount Adult
- Amount Subadult
- Amount Juvenile
- Amount Not discernible

A total of 5 data series were provided; three for the grid-cameras per study period and two for the additional 20 cameras which were not yet installed for the study period of 2017.

2.2.2. Spatial data

The Hainich National Park Administration provided maps of trails and habitat types within the National Park. From the latter, I used the habitat categories Forest and Open land, as well as their more specific under-categories Pure and Mixed

Deciduous Forest, Pure and Mixed Coniferous Forest and Fallow ground, divided into the extent of bush-encroachment.

I downloaded additional maps covering infrastructure from the website for public geodata in Thuringia (Thüringer Landesamt für Bodenmanagement und Geoinformation 2020). These included villages, solitary houses, industrial areas, touristic attractions, in particular the Canopy Walk, and communal sports grounds. A map of the federal states of Germany, I downloaded from the GADM database (2018).

2.2.3. Meteorological statistics

The meteorological data used in this study was provided by the Hainich National Park Administration and collected in the weather station located in Weberstedt.

I used the following variables:

- Mean temperature in °C
- Ground temperature in °C
- Total amount of sunshine in hrs (h)
- Total amount of rainfall in mm
- Mean wind speed in km/h

The mean for each of these parameters per month and study period can be found in Table B1.

2.3. Method

2.3.1. Data analysis

I chose the time span from 19th December until 27th April because these dates were covered by all data series.

First, I summarised all data series by event begin date & time. This way, I obtained data where one row corresponded to one event. For these I calculated the event length and took the median number of raccoons sighted of each age class. For the total amount of raccoons, irrespective of age class, I took the number of individual raccoons for each event as provided by the administration's staff. Then, I added the spatial data to each camera location and the meteorological data to each date.

For the statistical analysis of research questions 1, 2 and 3a, I computed generalised linear models (GLM) for interactions independent of camera trap location. For research question 3b, I generated a linear mixed-effects model

(LMER) including camera trap locations because I hypothesized these to have an influence on raccoon activity. For the statistical models, I chose the significance level of $\alpha = 0.05$.

Additionally, I calculated Duncan's index of habitat preference, as used in Duncan (1983):

$$P = \frac{U_i}{A_i}$$

for U_i – proportion of all observations in habitat *i*
A_i – proportion of the study area covered by habitat *i*

Duncan's index can range from 0, meaning total avoidance of the habitat, to infinity, where 1 would mean that the animal uses a certain habitat in proportion to its availability, and any number x that the animal uses a certain habitat x-times as much as it is available.

Finally, I did Moran's I test for spatial autocorrelation between the activity and patterns of raccoon observations across the camera trap locations.

2.3.2. Analysis tools

In order to be able to analyse the spatial variables Distance to trails, the National Park's border and infrastructure, I employed the Geographic Information System programme *QGIS* (QGIS Development Team 2021). I created a buffer of 4 km around Hainich National Park. Then, I calculated the shortest distances from each camera trap location to the nearest trail, the border and anthropogenic structures, including those within the 4 km-buffer. Furthermore, I created Fig. 1 using *QGIS*.

All statistical analysis and graphical representation was done in *R* (R-Core-Team 2020), using the following packages:

- dplyr (Wickham *et al*. 2021)
- lme4 (Bates *et al*. 2015)
- ggmap (Kahle and Wickham 2013)
- ggplot2 (Wickham 2016)
- hms (Müller 2021)
- patchwork (Peders 2020)
- readxl (Wickham and Bryan 2019)
- sf (Pebesma 2018)
- sp (Pebesma and Bivand 2005; Bivand *et al*. 2013)
- suncalc (Thieurmel and Elmarhraoui 2019)
- tidyverse (Wickham *et al*. 2019)

2.3.3. Diel periods

Using the R-package suncalc (Thieurmel and Elmarhraoui 2019), I generated sunrise and sunset times for each date. Following the definition of Pépin *et al.* (2006), I ascribed each event begin time to one of the following four diel periods:

- Dawn – 60 minutes before until 60 minutes after sunrise
- Day – 61 minutes after sunrise until 61 minutes before sunset
- Dusk – 60 minutes before until 60 minutes after sunset
- Night – 61 minutes after sunset until 61 minutes before sunrise

3. Results

3.1. Event length and age class

There were a total 2,095 trigger events over all three study periods (Fig. 2a). Between one and 60 pictures (mean = 5.91 pictures) were taken per trigger event. Over all three study periods, a total of 12,384 pictures of raccoons were taken (Fig. 2b). Trigger events could last up to seven minutes, although the vast majority of trigger events was shorter than one minute (Fig. 3).

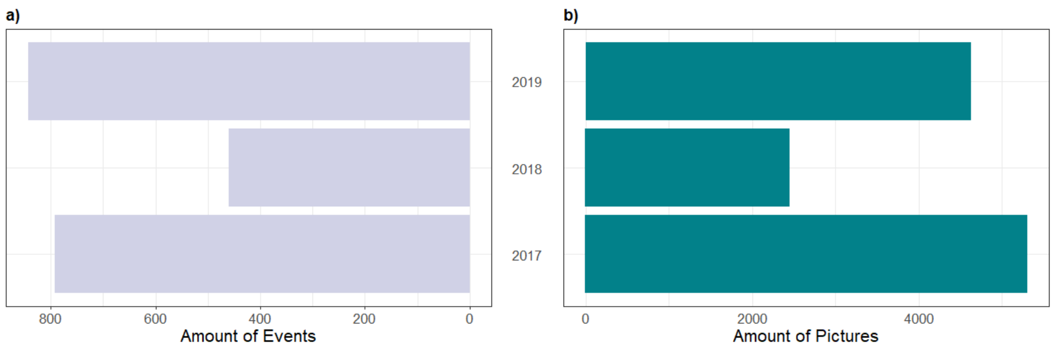

Figure 2: Number of a) trigger events; and b) pictures taken in each study period.

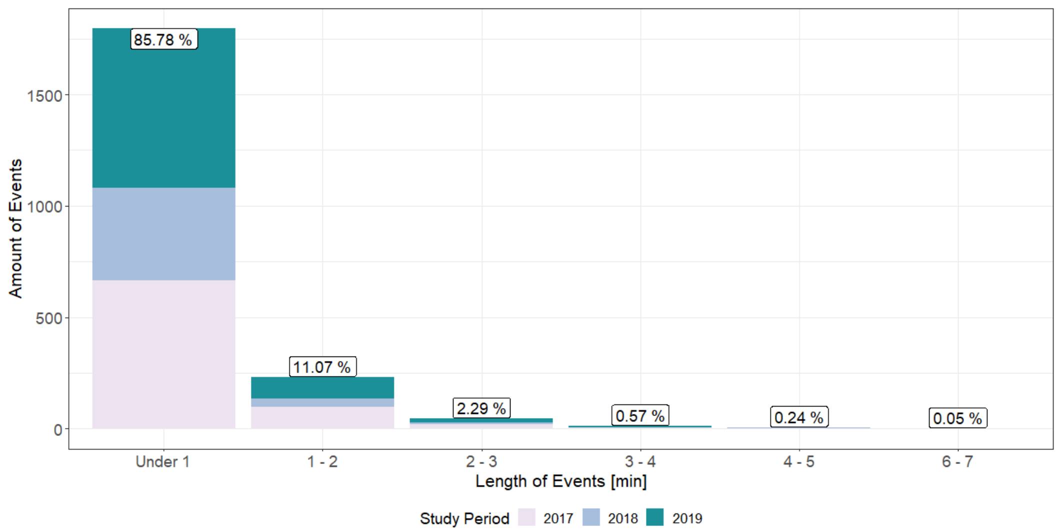

Figure 3: Amount and frequency of events with event lengths given as whole-minute-intervals. Up to seven minutes could pass between a raccoon triggering a camera until stepping out of frame. Most events lasted not even one whole minute.

During this study, a total of 2,300 raccoons were recorded by all camera traps. The total counts per study periods can be seen in Fig. 4. 99.09 % of all recorded raccoons were adults (Fig. 4). Only one juvenile (0.04 %) and eight subadults (0.35 %) were sampled across all three years. For 12 (0.52 %) of the sampled raccoons, the age category was *Not discernible* (Fig. 4). For exact numbers, see Table B2.

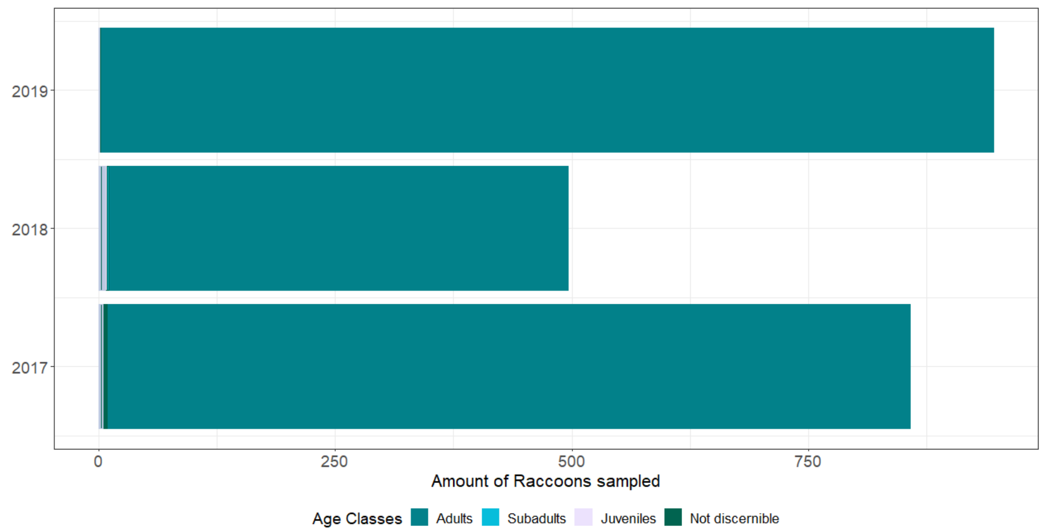

Figure 4: Total amount of raccoons of their respective age classes sampled in each study period. Of all raccoons sampled across all study periods, more than 99 % were adults.

There were almost equally as many raccoons sampled by camera traps as there were trigger events. On average, there were 1.1 raccoons per trigger event. Based on that, all future analysis will be done on the number of raccoons sampled. Since the age classes *Subadult* and *Juvenile*, as well as the *Not discernible* category amount to merely 1 % of all raccoons sampled on camera, the total amount of raccoons sampled will be regarded in the following analysis.

3.2. Variation in raccoon activity over time

3.2.1. Diel periods

Subdividing the day into four periods, as explained under *2.3.3.*, I could see that the majority of raccoons was sampled by camera traps during the hours of the night (Fig. 5). Exact numbers can be seen in Table B3.

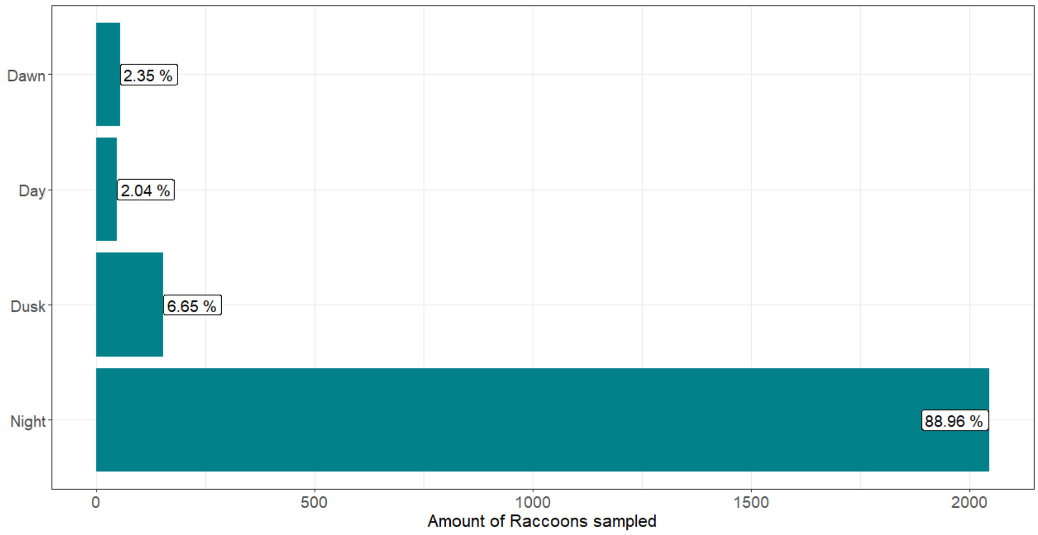

Figure 5: Over 88 % of all raccoons sampled across all study periods were sampled during the Night. The remaining diel periods Dawn, Day and Dusk sampled significantly less raccoons.

Q1a. Does raccoon activity vary by diel period?

I did a generalised linear model on the influence of diel periods on raccoon activity as captured on camera. Night had the biggest influence on raccoon activity, compared to Dawn, which seems to be the diel period when raccoons were least active (Tab. 1).

Table 1: Estimates and p-values of the generalised linear model (GLM) for each diel period. The diel period Dawn *served as reference. The asterisk (*) marks the significant p-value.*

Diel period	GLM estimate	p-value
Day	1.13	0.89
Dusk	1.26	0.83
Night	19.09	0.0004*

3.2.2. Hour of the day

In line with the diel periods, most raccoons were sampled in the hours between dusk and dawn, during the night (Fig. 6). Raccoon activity peaked between dusk and midnight. After midnight activity ceased somewhat, then increased again between 2 to 3 in the morning (Fig. 6). Daylight hours registered noticeably little activity. Between 7 in the morning and 17 in the afternoon, only 50 raccoons in total were sampled (Table B4). This trend was the same during each study period (Fig. 6).

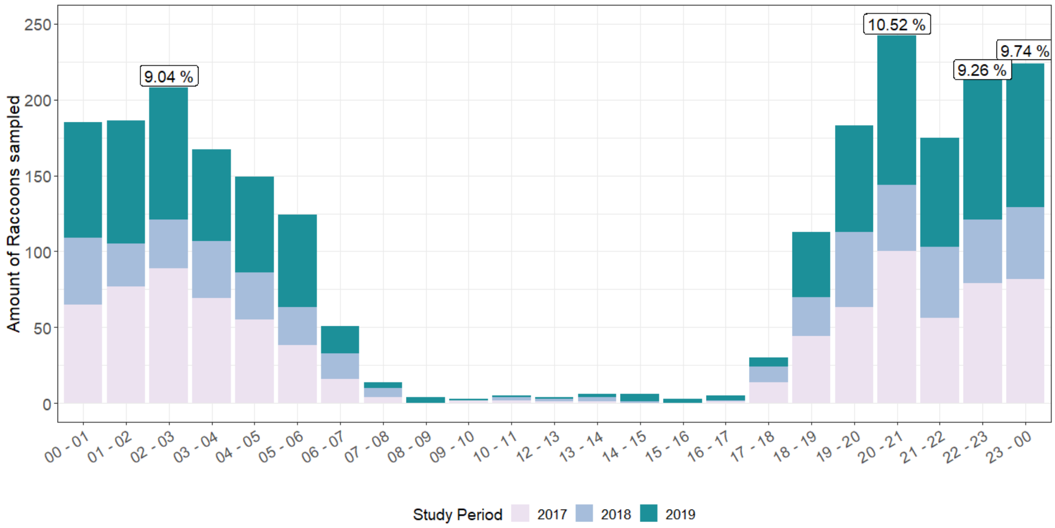

Figure 6: Total amount of raccoons sampled during each hour of the day. Most raccoons were sampled during the hours between dusk and dawn, with slightly more before than after midnight. Percentages are displayed for the top 4 1-hour-periods, during each of which more than 200 raccoons were sampled across all study periods.

Q1b. Does raccoon activity vary by hour of the day?

As Fig. 5 and 6 already suggested, the generalised linear model for the hour of the day indicates that raccoons were more active during the night than during the daylight hours (Tab. 2). Raccoon activity was lowest between 7 in the morning and 14 in the afternoon, with the absolute lowest estimate for 11 to 12 o'clock when no raccoons were observed in any study period (Tab. 2). It was highest between 2 and 3 in the morning; 20 to 21 and 23 to midnight registered also high activity (Tab. 2). Comparing the hours, the GLM estimates are not large enough, nor the p-values small enough to point to significant differences, in contrast to *Q1a*.

Table 2: Estimates and p-values of the generalised linear model (GLM) for each 1-hour-period of the day. Midnight to 1 o'clock served as reference. During 11 – 12 no raccoons were registered in any study period which is why it is left out of the model. Raccoon activity was generally low between hours 7 and 14 and high between hours 20 to 3 with a peak between 2 and 3 in the night.

Hour	GLM estimate	p-value	Hour	GLM estimate	p-value
01 – 02	0.15	0.83	**13 – 14**	-2.23	0.20
02 – 03	1.00	0.18	**14 – 15**	-1.43	0.52
03 – 04	-0.09	0.91	**15 – 16**	-1.93	0.47
04 – 05	-0.11	0.88	**16 – 17**	-2.18	0.26
05 – 06	-0.54	0.47	**17 – 18**	-1.55	0.14
06 – 07	-1.00	0.30	**18 – 19**	-0.80	0.29
07 – 08	-2.03	0.11	**19 – 20**	0.03	0.97
08 – 09	-2.09	0.34	**20 – 21**	0.61	0.38
09 – 10	-1.93	0.47	**21 – 22**	-0.12	0.86
10 – 11	-2.18	0.26	**22 – 23**	0.25	0.73
12 – 13	-2.09	0.34	**23 – 00**	0.80	0.26

3.2.3. Month of the study period

March registered most raccoon activity across all study periods, followed by February (Fig. 7). Since only a part of the month was sampled for both December and April (compare *2.3.1*), activity might, in reality, have been higher. See also Table B5 for specific numbers.

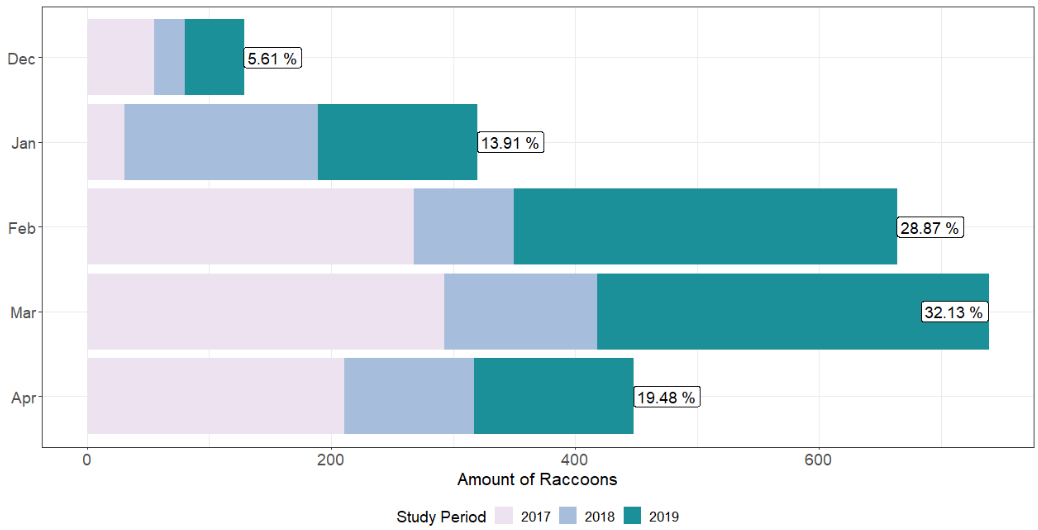

Figure 7: Amount and percentages of raccoons sampled each month of the study period.

Each diel period contributes a different proportion to the total amount of raccoons sampled, depending on the month (Fig. 8). It becomes visible that the proportion of raccoons sampled by night decreases, while a higher percentage of raccoons is sampled during the other diel periods, as the year advances (Fig. 8). This increase is most notable during *Dusk*.

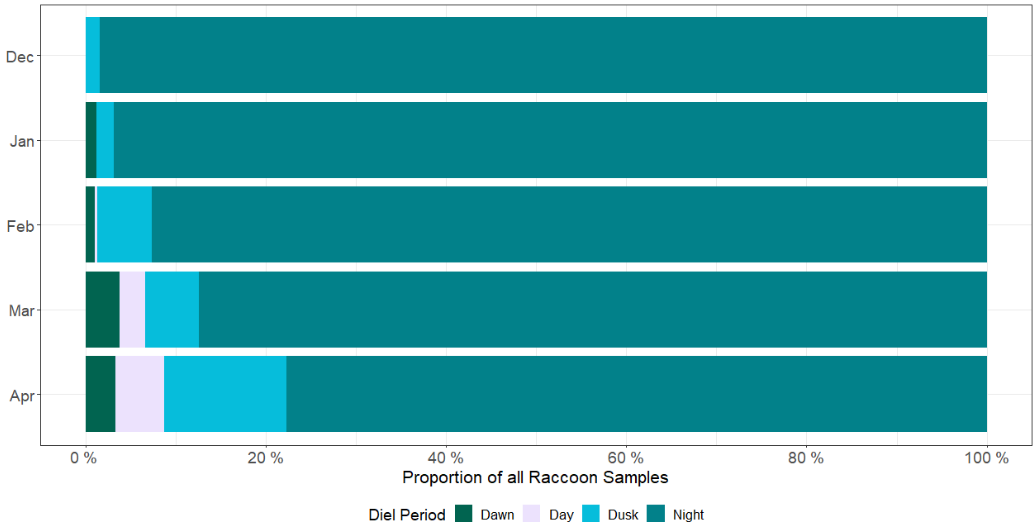

Figure 8: The proportion of the total amount of raccoons sampled during the night decreased as the study period progressed. At the same time, higher proportions of raccoons were sampled during the other diel periods.

Q1c. Does raccoon activity vary by month of the study period?

The generalised linear model for the months of the study period showed a steady increase in raccoon activity as the year advances, until March: Raccoon activity was lowest in December and highest in March (Tab. 3). In April, there was a sudden decrease in raccoon activity, even below the level of January which served as reference in the model (Tab. 3). No level of significance could be shown.

Table 3: Estimates and p-values of the generalised linear model (GLM) for each month of the study period. January served as reference. Raccoon activity was highest in March.

Month	GLM estimate	p-value
December	-2.64	0.30
February	2.07	0.31
March	2.24	0.27
April	-0.17	0.93

3.3. Variation in Raccoon Activity as a result of climate

Fig. 9 shows a decrease in raccoon activity in line with a drop in both mean and ground temperature. An increase in temperature, on the other hand, does not necessarily seem to result in an increase in activity. In the study periods 2017 and 2019, there was an increase in both temperature and activity around the beginning of March (Fig. 9a & c). In 2018, this increase was visible in the middle of January towards February (Fig. 9b). When comparing raccoon samples against an increase or decrease in wind speed or precipitation, no corresponding increase or decrease in activity can be seen (Fig. 10). Neither wind nor rain seem to have a clear effect on raccoon activity.

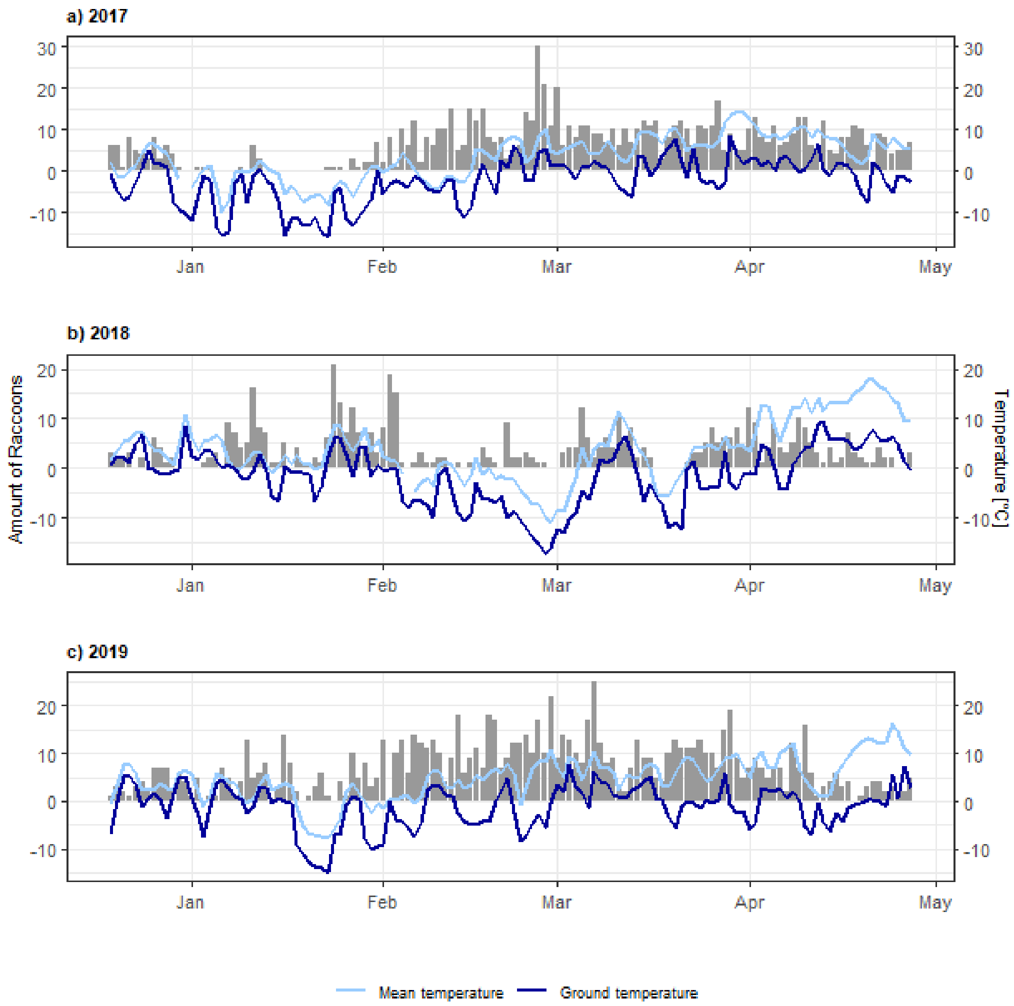

Figure 9: Timeline for mean and ground temperature (blue lines) as well as raccoon activity (grey bars) for the study period a) 2017; b) 2018; c) 2019. A decrease in temperatures coincided with a low amount of raccoon samples while an increase in temperature was not always accompanied by an increase in activity.

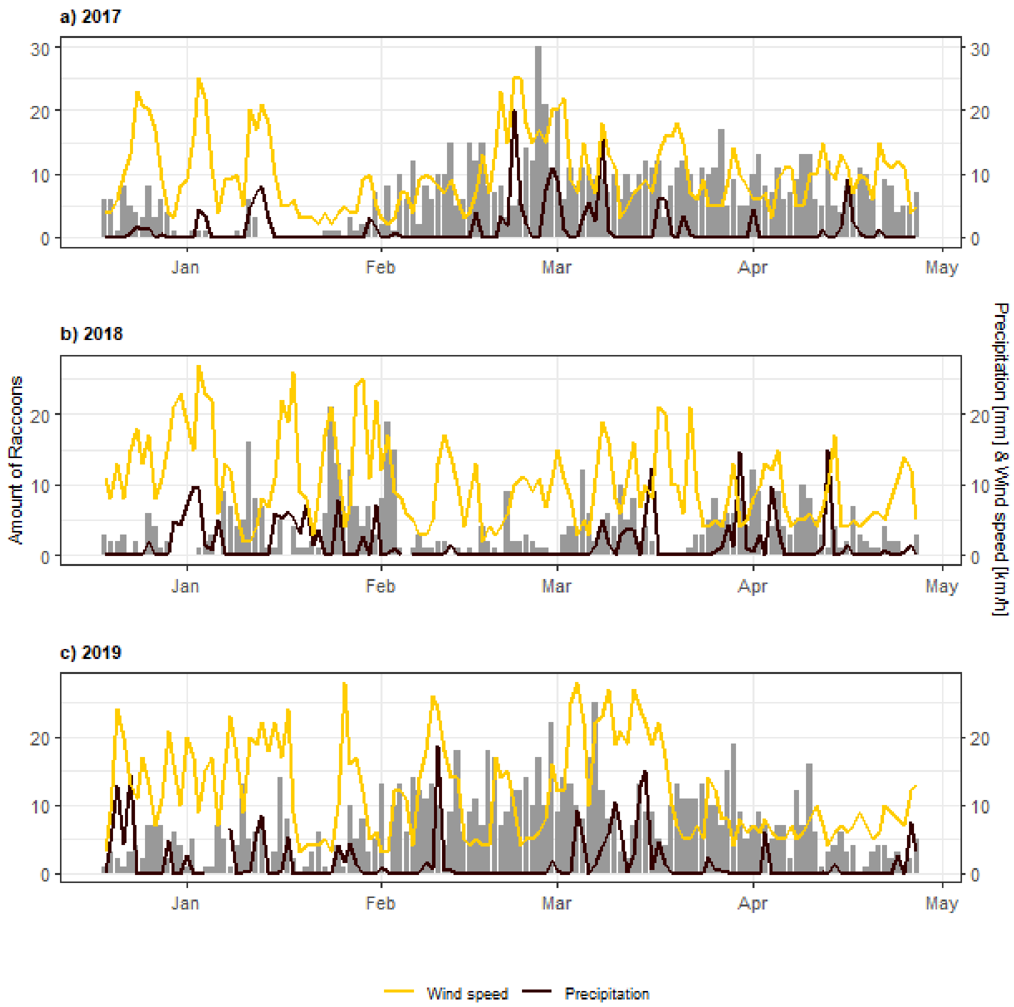

Figure 10: Timeline for wind speed and precipitation (yellow and brown line, resp.) as well as raccoon activity (grey bars) for the study period a) 2017; b) 2018; c) 2019. No relationship between the amount of raccoon samples and an increase or decrease in wind speed and precipitation becomes evident.

Q2. Is raccoon activity influence by climatic variables?

To see whether the climate variables had any effect on raccoon activity, I created a generalised linear model with the variables ground temperature, precipitation and wind speed. The amount of sun hours is left out of the analysis, since *3.2.1.* and *3.2.2.* already showed that raccoons were very little active during daylight hours during my study period. I chose ground temperature over mean temperature, because I judged that this would have the greater impact of the two since raccoons spend the majority of their active time during the night on the ground foraging.

Raccoon activity is positively correlated both to ground temperature and to wind speed (Tab. 4). Although the correlation is very small, it is significant for ground temperature (Tab. 4). Precipitation is negatively correlated to raccoon activity. Neither precipitation nor wind speed is significant (Tab. 4).

Table 4: The generalised linear model (GLM) for climatic variables points out a positive correlation between the amount of sampled raccoons and both ground temperature and wind speed. Only ground temperature has a significant effect on raccoon activity. The significant p-value is denoted by the asterisk (*). Precipitation had a slight negative, but non-significant effect on raccoon activity.

Climate variable	GLM estimate	Standard error	p-value
Ground temperature	0.029	0.0088	0.0009*
Precipitation	-0.009	0.0087	0.29
Wind speed	0.004	0.0096	0.64

3.4. Variation in raccoon activity as a result of landscape

3.4.1. Habitat

The ratio of cameras in forest habitat to those in open land is 11:4. Not all camera trap locations captured raccoons during the three study periods: Of the 120 camera traps distributed over Hainich National Park, 98 (81.7 %) recorded images of raccoons. Notably, no camera in the habitat *Fallow ground, lightly bush-encroached* sampled any raccoon across all study periods (Fig. 11). For exact numbers, see Table B6.

87.6 % of all raccoons were sampled on cameras located in forest habitat, the remaining 12.4 % were sampled in open land. While mixed deciduous forest was the habitat that registered most raccoons overall, most raccoons per camera were sampled in mixed coniferous forest (Fig. 11, Table B6).

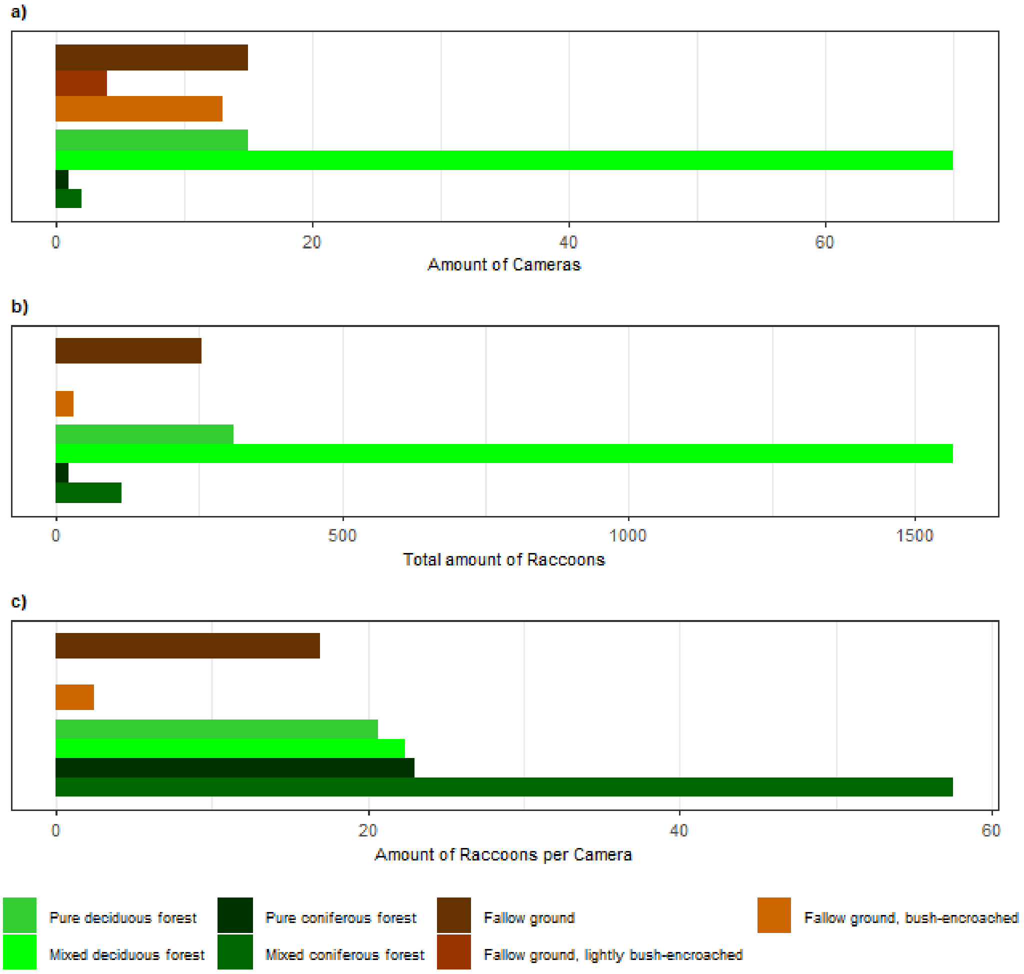

Figure 11: Number of a) cameras; b) raccoons sampled in total; and c) raccoons sampled per camera. Forest habitat was more visited than open land. Notably, no raccoon was sampled in lightly bush-encroached fallow ground. Most raccoon were sampled in mixed deciduous forest while most raccoons per camera were registered in mixed coniferous forest.

The top 10 camera locations captured at least 80 raccoons each and can be found in Table B7. The single most popular location was situated on fallow ground; it sampled a total of 225 raccoons which was 9.78 % of all raccoons sampled across all study periods (Fig. 11, Table B7). Of the remaining 9 top locations, 6 were situated in mixed deciduous forest, 2 in pure deciduous and 1 in mixed coniferous forest.

Q3a. Do raccoons prefer certain habitats within Hainich National Park?

Tab. 5 shows that not all habitat types were covered by camera traps in proportion to their size in Hainich National Park. Percentages of raccoon samples differed between the habitats which points to some extent to selective behaviour. Similar to Fig. 11b, by far most raccoons were sampled in mixed deciduous forest (Tab. 5).

When performing a generalised linear model on the number of raccoons sampled per camera in each habitat type, all forest types show a positive correlation on raccoon activity, while all open land categories show a negative correlation, except for *Fallow ground* which served as reference (Tab. 5). *Mixed coniferous forest* registered most activity, as it sampled the highest number of raccoons per camera (Tab. 5). The difference is quite large. However, no p-value points to a significant difference.

Table 5: Proportions of size, set-up cameras and raccoon samples per habitat i*; estimates and p-values of the generalised linear model (GLM) for raccoon activity performed on the amount of raccoons sampled per camera in each habitat, and Duncan's index of habitat preference. Fallow ground served as reference for the GLM.*

Habitat	Percentage of			GLM		Duncan's index *P*
	Total area A_i	All cameras	All observations U_i	Estimate	p-value	
Fallow ground	19.76	12.5	11.04	-	-	0.56
Fallow ground, lightly bush-encroached	0.09	3.3	0	-16.93	0.38	0
Fallow ground, bush-encroached	5.96	10.8	1.32	-14.47	0.27	0.23
Pure deciduous f.	11.11	12.5	13.48	3.73	0.77	1.21
Mixed deciduous f.	58.27	58.3	68.09	5.44	0.58	1.17
Pure coniferous f.	1.04	0.8	1	6.07	0.86	0.96
Mixed coniferous f.	1.48	1.7	5	40.57	0.12	3.38

Duncan's index of habitat preference shows a total and near total avoidance of both bush-encroached fallow ground types (Tab. 5). The forest types are about as much preferred as they are available, except for *Mixed coniferous forest* which is used over three times more than it is available (Tab. 5).

3.4.2. Distribution over Hainich National Park

Fig. 12a shows that most raccoons were sampled close to the border of Hainich National Park. A gradual increase in activity can be noted over the whole of the National Park (Fig. 12b). This increase was most pronounced towards February and March (Fig. 12b). Locations in the East and in the South-West of Hainich National Park, the latter including the single most visited open-land camera trap mentioned in *3.4.1.*, were already frequently visited by raccoons in December and January and increased in the following months. Other locations in the North and North-West registered hardly any raccoons in December and January and increased remarkably by February and March.

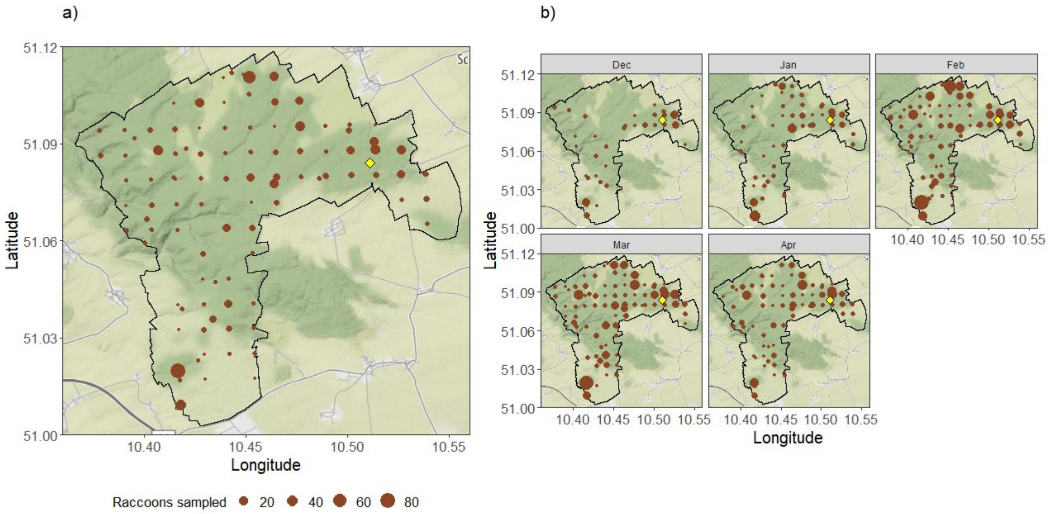

Figure 12: Number of raccoons sampled across Hainich National Park a) in total; and b) as they change over the months. The yellow square in the North-East indicates the location of the Canopy Walk. Most raccoons were sampled close to the Northern and South-Western border and around the Canopy Walk.

3.4.3. Proximity to anthropogenic locations

The camera locations varied greatly with regard to how close they were located to the nearest trail, the National Park's border and various forms of infrastructure. Tab. 6 gives an overview over the means and ranges of each of the three distance variables.

Table 6: Summary of the variables regarding the distance to trails, the National Park's border and infrastructure for all camera locations that recorded at least 1 raccoon across all study periods.

Distance to	Mean	Range
Nearest Trail	412.5 m	20.3 – 1511.6 m
Border	959.0 m	38.5 – 2473.4 m
Infrastructure	1229.5 m	146.7 – 2984.5 m

Fig. 13 suggests that there seems to be a negative relationship between each of the three distance variables and the number of raccoons sampled, i.e. the further a camera was located from either a trail, the border or any sort of infrastructure, the less likely it was that raccoons were captured on camera.

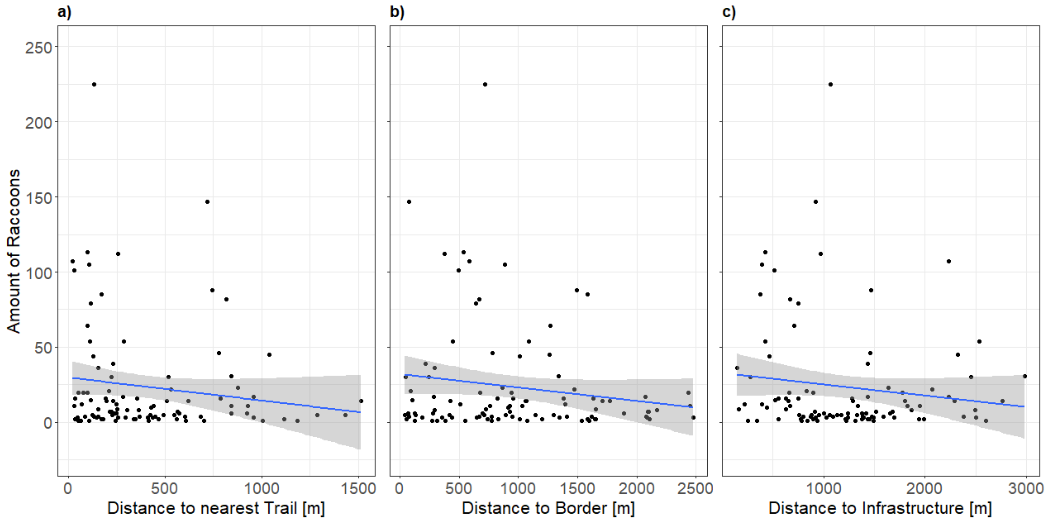

Figure 13: Number of raccoons sampled in relation to the distance to a) the nearest hiking or biking trail; b) the border of Hainich National Park; c) different types of infrastructure. The blue line illustrates a negative relationship between the total amount sampled and the three distance variables; grey shading represents the standard error.

Q3b. Does raccoon activity vary by distance to trails, border or infrastructure?

In line with Fig. 13, the linear mixed-effects model computed a slight negative relationship between the raccoon activity as registered by a camera location and all three distance variables (Tab. 7). This means that a camera location indeed did sample more raccoons if it was closer to a trail, Hainich National Park's border or any form of infrastructure within or around Hainich National Park. However, the t-values for either of these are very small (Tab. 7), such that I do not judge any of them to be significant.

Table 7: Estimates of the linear mixed-effects model (LMER) for each of the 3 distance variables show a slight negative correlation between the raccoon activity registered in a camera location and its distance to the nearest trail, Hainich National Park's border and infrastructure. t-values are not large enough that significance could be suggested for either correlation.

Distance variable	LMER estimate	Standard error	t-value
Trails	-0.008	0.010	-0.74
Border	-0.006	0.009	-0.64
Infrastructure	-0.007	0.011	-0.62

Doing Moran's I test for autocorrelation between raccoon activity and the camera trap's locations gave a p-value of 0.13. I therefore conclude that there is no significant autocorrelation between the camera locations.

4. Discussion

4.1. Event length and age classes

My results showed that three-quarters of sampled raccoons passed by the camera traps in under one minute. The raccoon is a highly mobile mesopredator which spends the majority of its active time foraging for which it can walk considerable distances in a night (Ortmann *et al*. 2011; Michler 2018). On average, raccoons travelled 4.3 and up to 10 km per night, with males being observed to travel about 1.5 times more than females (Michler and Köhnemann 2010; Ortmann *et al*. 2011). It should be pointed out that Ortmann *et al.*'s (2011) study excluded the winter completely and thus hardly overlapped with my study phase. The raccoon's locomotion behaviour makes it likely that raccoons are captured by camera traps close to each other, although autocorrelation could not be shown.

In my study, 99 % of all recorded raccoons were classified as adults. This might be explained by the reproductive cycle of raccoons: In Europe females mate between February and March, in mild winters up to four weeks earlier, and give birth to two to five kits around nine weeks later (Michler 2018). If mating proved unsuccessful, or none in the litter survived, a female could mate again in late summer, thus producing a litter in autumn (Michler 2018). According to their own standards, the Hainich National Park Administration defined juveniles as kits from the current calendar year and subadults as younger than one year of age (see *2.2.1.*). As the study periods ended in April, the kits which might have been born in each study year would not have left the birthing den yet, which is used for seven to eight weeks after parturition (Michler 2018). Those that had been born the autumn before would have been classified as *Subadult*. I suspect that a greater variety of age classes could be observed over summer and autumn. Further studies should take that into account.

4.2. Variation in raccoon activity over time

As expected, the majority of raccoons were sampled during the night, more specifically in the hours around midnight. In Müritz National Park, which has a similar climate and forest composition to Hainich National Park, raccoons have been well studied in the past two decades (e.g. Michler 2018). There, raccoons limit their activity between December and March entirely to the night hours between dusk and dawn (Ortmann *et al*. 2011; Michler 2018), which I observed as well. Only at the end of April they become more active about half an hour before sunset (Ortmann *et al*. 2011; Michler 2018). Locomotion generally started only after dark (Ortmann *et al*. 2011; Michler 2018). Like in the current study, Michler (2018) also found that raccoons, after an initial active phase between dusk and midnight, were immobile for about two to three hours after midnight before being active again.

As the study phase progressed, raccoons become more active during all four diel periods. In comparison, activity increased most during Dawn, Day and Dusk with each passing month. In my study, raccoons were most active in March and April. While Lesmeister *et al.* (2015) reported only slightly increasing detections during the first four months of each year in the East Central US, my findings are in line with studies on raccoons in Müritz National Park, which became more active in spring compared to winter during both day and night (Ortmann *et al*. 2011; Michler 2018). Notably, this is the main mating season for raccoons of that region (Michler 2018). Whether reproduction is the reason for a comparable increase in activity in Hainich National Park as well can only be ascertained if the study period covers longer parts of the year. Another possibility could be that more tourists visit the National Park with the rising temperatures of spring which presents new food resources to raccoons. More on that in *4.4*.

4.3. Variation in raccoon activity as a result of climate

Of the climatic variables tested, only ground temperature had a small but significant effect on raccoon activity. Louppe *et al.* (2019) found that temperature was the most important factor on whether a region is deemed suitable for raccoons to live in: Their models found that raccoons mainly inhabit temperate and dry sub-tropical regions, both in their native and non-native range. Similar models done in Austria and Germany also found that the mean temperature during the coldest month of the year was the most important predictor for the probability of raccoon presence (Duscher *et al*. 2018; Kochmann *et al*. 2021).

Raccoons in Müritz National Park chose mainly elevated sleeping dens in trees during the colder months of the year (Köhnemann and Michler 2009). This could mean that they are less sensible for cold ground temperatures.

Michler (2018) reported that raccoons showed the only prolonged phases of inactivity during periods when the ground was covered with considerable amounts of snow, up to 55 cm one winter, during extended periods of time, up to three months. When the ground was frozen, down to -18 °C, but not covered with snow, raccoons were still active regularly, and in mild winters they were as active as normally in spring (Michler 2018). Ortmann *et al.* (2011) concluded that Müritz raccoons do not have a dormant period, probably because of the lack of snow and strong winds, and because of the relatively mild temperatures. Contrary to this, Bartoszewicz *et al.* (2008) found raccoons in Western Poland to be inactive for up to 1.5 months when the mean temperature was below -10 °C. The effect of snow cover could not be determined due to it never surpassing 5 cm (Bartoszewicz *et al*. 2008). Whether raccoons in Hainich National Park exhibit dormant behaviour during harsh winters remains to be investigated, although I suspect that might be difficult to do, as winters in Central Germany become milder following global warming.

In their native range, raccoons have spread into the North of Central Canada, between 55 and 60º N (Louppe *et al*. 2019). This corresponds to the European region between Denmark's South and the Southern third of Sweden and Norway, but the raccoon has not expanded thus far North (Louppe *et al*. 2019; Kochmann *et al*. 2021), due to geographical barriers more as climatic reasons. As Zeveloff (2002) reported, raccoons inhabiting colder regions of North America have adapted to low temperatures by sharing a winter den to survive.

Exhibiting such excellent adaptability, it is no surprise that large parts of Europe are suitable habitat to and already colonised by raccoons (Louppe *et al*. 2019; Kochmann *et al*. 2021). Due to climate change, Louppe *et al.*'s (2019) models predict that in the future, more areas will become suitable: Raccoons will be able to expand to higher elevations, such as the Alps, as well as further to the North of Scandinavia, and far to the North-East, into Finland and over large parts of Russia.

4.4. Variation in raccoon activity as a result of landscape

While Lesmeister *et al.*'s (2015) study sampled raccoons in 99 % of camera trap locations, my study recorded them only in about 82 % of locations, which might be due to differences in habitat. According to my results, raccoons preferred forest habitat over open land. The most popular forest types were mixed coniferous forest (based on the number of raccoons sampled per camera, and Duncan's index) and mixed deciduous forest (based on the proportion of total raccoon observations). Most studies agreed on a preference for deciduous forest in both the native and the new range (e.g. Lutz 1995; Chamberlain *et al*. 2003; Salgado 2018), though core areas are reportedly also made up out of pine forest (Chamberlain *et al*. 2003; Owen *et al*. 2015). Of the broadleaf tree species in Müritz National Park, cavities especially in European beech were preferred as resting (Köhnemann and Michler 2009; Hermes *et al*. 2011) and birthing dens (Michler 2018).

My data shows a slight negative correlation between raccoon activity and the distance to trails, Hainich National Park's border and infrastructure, though none of them were significant. Fischer *et al*. (2016) read in their data a preference of raccoons in Germany for a mixture of forest and agricultural land with shelter on the forest edge and food in fields. As Hainich National Park borders mostly on arable land, it is likely that raccoons cross the border frequently to forage in the nearby fields. This behaviour has also been noticed in Ortmann *et al.* (2011).

A considerable amount of raccoons were sampled in the North-Eastern part of Hainich National Park where the Canopy Walk is located, a visitor magnet since its opening in 2005. Based on my results, I deduce that these human-used structures, despite being a disturbance, are primarily an appealing factor where raccoons can scavenge for food in human trash. As Tardy *et al*. (2015) and Duscher *et al.* (2018) revealed, raccoons preferably colonise areas close to human settlements, both in their native and new range. In areas with increasing competitive pressure, raccoons were observed to switch to foraging in corn fields at the edge of forests (Tardy *et al*. 2015). Several studies confirmed that the raccoon is an opportunistic feeder and able to adapt to local food offers (Engelmann *et al*. 2011; Salgado 2018). Balkenhol *et al.* (2011) reported that raccoons show increasing reluctance to traversing large fields. Thus, it is unlikely, though not impossible, that raccoons travel to nearby villages for scavenging.

The food choices disclosed for winter and spring, amongst others corn, fruits, molluscs, vertebrates and earth worms (e.g. Rulison *et al*. 2012; Michler 2020), can all be found in and around Hainich National Park. Engelmann, Köhnemann and Michler (2011) concluded that the raccoon will not spend much time foraging for rare things but rather consumes in larger quantities what is easy to find and access. Bartoszewicz *et al.* (2008) even found that up to 10 % of ingested biomass could be comprised of wild boar carcasses which certainly is a possibility, and would need to be verified, in Hainich National Park, where wild boars are abundant (Klamm *et al*. 2020). Studies in Europe agree that birds contribute only to a small degree to the ingested biomass (e.g. Bartoszewicz *et al*. 2008; Michler 2020). Frequently, concerns are expressed that raccoons negatively impact European bird populations. While this circumstance has not yet been proven in European studies (e.g. Michler and Michler 2012), in order to assess the raccoon's impact in Hainich National Park, more detailed studies, e.g. on faecal matter, are needed.

Considering that Hainich National Park is comparatively small, it is possible that any of these spatial relationships might become more apparent if raccoons were sampled over a larger area, for instance, including the Nature Park Eichsfeld-Hainich-Werratal.

4.5. Estimation of population size

It is possibly to estimate raccoon abundance in Hainich National Park without the necessity to identify individuals. Podgórski *et al.* (2020) and Palencia *et al.* (2021), amongst others, suggest the methods *Random Encounter Model* (REM), *Random Encounter and Staying Time* (REST) and *Distance Sampling with Camera Traps* (CT-DS) in different scenarios, none of which seem to have been done on raccoons in Europe. All methods include the distance between the sampled animal and the camera in the calculation, the REST-method even needs the time an animal spends in the picture frame (Podgórski *et al*. 2020; Palencia *et al*. 2021). The distance of the animal to the camera has been recorded during the Wild Boar Project (Klamm *et al*. 2020), though it was not provided for this study. Therefore, it should be possible to estimate the population density of the raccoon in Hainich National Park.

Fischer *et al.* (2016) reported that hunting bags increased strongest in the regions between the initial introduction sites lake Edersee and Wolfshagen. This includes the district where Hainich National Park is located: Hunting bags in the Unstrut-Hainich-district went from 0.1 to 0.5 individual per 100 ha back in the hunting season of 2000/01 to 0.5 to 1 individual per 100 ha in 2011/12 (Fischer *et al*. 2016). That corresponds to a five- to tenfold increase in a decade. The German Hunting Association reports more recent numbers: on average 1.5 to 6.23 individuals per 100 ha were shot in the hunting seasons 2014/15 until 2017/18 (Deutscher Jagdverband 2020a), which is the highest level possible. Compared to the hunting season of 2004/05, raccoon bags in the Unstrut-Hainich-district stayed at the same level or increased up to 2.84-fold until 2017/18 (Deutscher Jagdverband 2020b). Consequently, it is possible that 112.5 up to 467.25 individual raccoons live in Hainich National Park, which has an area of 7,500 ha. Considering that these latest numbers are already four years old, this number might, by now, be higher still.

4.6. Limitations and discussion of the method

The clear advantage of camera trapping is that it is a practical, robust method which is easy to implement. It is practical because it is a non-invasive method, thereby eliminating the need of approval by an ethics commission. Cameras need to be maintained but apart from that they do the work by themselves, sampling everything that triggers them. They do not require constant work effort from the National Park's staff, as for instance GPS tracking or live trapping would. Since camera traps were placed within the National Park, no approval by private ground owners was needed. Depending on the model, camera traps are weather resistant and settings can be chosen to provide the user with the desired data, with minimum delay in either video or picture format.

One disadvantage is the price as good camera models can be expensive, depending on the quality. Another is that camera traps give limited data since only a part of the area is covered. Anything moving behind the camera will not be noticed, although that is hopefully limited by a smart study design. Neither will it be known where an animal, which passes the camera, is traveling to. If a camera trap study aims to give indications of habitat preference, as the present one does, it should be designed in such a way that the placement of cameras represents the proportion of available habitats.

The present study is based on data which was collected as a side-product of another study. It is sustainable that the data collected came to good use. The regular placement of the grid cameras made an overview over raccoon presence possible and allowed for analysis of how the distances to trails, the border and anthropogenic structures influenced raccoon activity patterns. However, the animal of interest in Klamm *et al.*'s (2020) study was the wild boar which means that the camera trap set-up was not ideal for monitoring raccoons. Ideally, if the behaviour of the raccoon is of interest, camera traps could be placed in the areas where the present study has recorded most raccoons, which was close to the border in the North and the South-West as well as around the Canopy Walk. Since my results point to raccoons being attracted by the presence of humans, cameras could also be placed near the sitting benches which are distributed along the trails, although direct observations of benches might be problematic due to GDPR-regulations.

The timing of this study was another limitation which should be taken into account when planning future studies on raccoons. Sampling during the winter and a part of spring indicated an increase in activity towards the latter months of the study period, seemingly in line with increases in the mean temperature. In order to get reliable results on raccoon activity patterns and usage of different parts of Hainich National Park caused by changes in climate, it is necessary to sample them throughout the year. Especially with the increasingly intense summers following climate change, it is important to monitor wildlife, whether and to what extent they adapt. Possibly, raccoons become less active again when temperatures rise above a certain threshold. Furthermore, I suggested that the mating season of raccoons prompted the increased record of activity. It should be interesting to see how climate change might affect mating behaviour and timing of raccoons, in which case longer sampling periods are essential. I would also expect raccoon movement patterns to shift over the year as fruits ripen and raccoons switch resources.

4.7. Conclusion and suggestions for future research

This study has shown that the raccoon is a generalist who is only mildly influenced by changes in the weather. It is nocturnal and shows increasing activity as the year advances towards the second half of April. The raccoon appears to be most active close to the border of Hainich National Park in the North and the South-West as well as close to the Canopy Walk in the East. It can opportunistically exploit food resources that are readily available and even benefits from the presence of humans. The European beech forest in Hainich National Park provides it with an ideal habitat.

Although my results were comparable to findings in similar habitats in Germany, this study was necessary to lay the groundwork that future studies on the raccoon population in Hainich National Park can build upon. It will be particularly meaningful for future management measures. For a non-native species to be classified as invasive, economical, ecological and epidemiological impacts of that species on its surroundings have to be proven (Muschik *et al*. 2010). Previous studies, such as Duscher *et al*. (2017), could find no serious economic and ecological impacts. Only a low epidemiological meaning on German fauna and pet dogs could be ascribed to raccoons (Duscher *et al*. 2017). Hunting measures in accordance with § 1 of the Thuringia State Regulation Regarding the Exercise of Hunting in Hainich National Park (*Thüringer Verordnung über die Ausübung der Jagd im Nationalpark Hainich*, ThürJagdNPHVO) are allowed as far as the protective purpose of Hainich National Park is maintained and the hunt serves to protect agriculture, forestry and the fishing industry in the vicinity of Hainich National Park. This means that hunting raccoons is possible if it can be proven that they severely damage surrounding industries or jeopardise Hainich National Park's preservative objective by negatively impacting threatened species. My study has provided the Hainich National Park Administration with core areas of raccoon occurrence and activity patterns that can be used for developing a permanent monitoring scheme which ideally includes a regular estimation of raccoon population densities in order to detect changes.

In addition to the suggestions I have made earlier, regarding studies on the influence of human presence on the raccoon as well as a better approximation of population size, it might be interesting to investigate whether other inhabitants of Hainich National Park influence the raccoon's movement and behaviour, in particular other carnivores through competition. Furthermore, it would be valuable to know whether the raccoon's foraging behaviour affects other animal communities, such as the presence and abundance of bird and amphibian species, especially red-listed ones.

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Appendix A

Definition of event and tagging procedure

An *event* describes the initiation of a camera's trigger by the detection of an animal. It can consist of a single picture or a row of pictures. An event begins with any part of an animal, which reveals its species, being visible in the frame and ends with the animal completely stepping out of the frame. If at least one animal reappeared within two minutes in the camera frame again, it was judged that this was the same animal as before, and therefore added to the event. If group-living animals of the same species traverse the frame of the camera together or shortly after each other, this was also seen as a single event (Klamm *et al*. 2020).

After dividing the pictures into events, *tagging* was done according to Hainich National Park Administration's own standards: Additional information, including but not limited to species sampled, number of individuals, age, sex (if determinable), and number of pictures taken during the event, was added with the help of FotoWeb 8. This additional information was saved as an EXIF-file and added to each picture. For more information, consult Klamm *et al.* (2020).

Appendix B

Supplementary tables

Table B1: Overview over the mean climatic variables for each month of the study period.

Climate variable	Month / Study period	December	January	February	March	April
Mean temperature [°C]	2017	2.31	-2.80	2.38	7.27	7.59
	2018	4.77	3.41	-2.43	1.85	12.32
	2019	4.08	0.30	4.12	6.74	8.81
Ground temperature [°C]	2017	-2.88	-8.15	-2.00	0.70	0.33
	2018	1.72	0.32	-7.58	-3.86	3.59
	2019	1.38	-3.59	-2.56	1.28	-0.53
Sunshine [h]	2017	2.11	2.59	2.63	5.45	5.43
	2018	0.70	1.15	3.73	4.76	8.81
	2019	0.89	1.88	5.08	4.34	8.38
Precipitation [mm]	2017	0.47	1.15	2.02	1.79	0.81
	2018	0.85	2.92	0.12	1.94	1.40
	2019	3.15	1.45	0.90	2.69	0.76
Mean wind speed [$\frac{km}{h}$]	2017	10.92	9.03	10.89	10.55	9.04
	2018	14.00	13.42	8.43	9.71	7.85
	2019	13.46	13.48	10.54	15.16	7.26

Table B2: Number of raccoon age classes sampled in each study period.

Age class / Study period	Adults	Subadults	Juveniles	N.d.	Total
2017	849	5	0	4	858
2018	486	2	1	7	496
2019	944	1	0	1	946
Total	2,279	8	1	12	2,300

Table B3: Number of raccoons sampled in the diel periods of each study period.

Study period \ Diel period	Dawn	Day	Dusk	Night	Total
2017	14	10	86	748	858
2018	15	13	41	427	496
2019	25	24	26	871	946
Total	54	47	153	2,046	2,300

Table B4: Number of raccoons sampled, and percentages of the total, for each 1-hour-period. The asterisk (*) marks the top 4 times which sampled more than 200 raccoons each.

Hour	Number of raccoons	Proportion of the total in %	Hour	Number of raccoons	Proportion of the total in %
00 – 01	185	8.04	**12 – 13**	4	0.17
01 – 02	186	8.09	**13 – 14**	6	0.26
02 – 03*	208	9.04	**14 – 15**	6	0.26
03 – 04	167	7.26	**15 – 16**	3	0.13
04 – 05	149	6.48	**16 – 17**	5	0.22
05 – 06	124	5.39	**17 – 18**	30	1.30
06 – 07	51	2.22	**18 – 19**	113	4.91
07 – 08	14	0.61	**19 – 20**	183	7.96
08 – 09	4	0.17	**20 – 21***	242	10.52
09 – 10	3	0.13	**21 – 22**	175	7.61
10 – 11	5	0.22	**22 – 23***	213	9.26
11 – 12	0	0.00	**23 – 00***	224	9.74

Table B5: Number of raccoons sampled in the diel periods of each month.

Diel period \ Month	December	January	February	March	April
Dawn	0	4	7	28	15
Day	0	0	2	21	24
Dusk	2	6	40	44	61
Night	127	310	615	646	348
Total	129	320	664	739	448

Table B6: Number of cameras, raccoons sampled in total & raccoons sampled per camera in each habitat as well as percentages of raccoons sampled.

	Habitat	**Number of cameras**	**Total samples per habitat**		**Number of raccoons sampled per camera**	
Forest	Pure deciduous	15	310	13.48 %	20.7	14.48 %
	Mixed deciduous	70	1566	68.09 %	22.4	15.66 %
	Pure coniferous	1	23	1.00 %	23.0	16.08 %
	Mixed coniferous	2	115	5.00 %	57.5	40.21 %
Open land	Fallow ground	15	254	11.04 %	16.9	11.82 %
	Fallow ground, lightly bush-encroached	4	0	0.00 %	0.0	0.00 %
	Fallow ground, bush-encroached	13	32	1.39 %	2.5	1.75 %

Table B7: The 10 locations which sampled most raccoons across all study periods. Camera ID's between 1 and 100 belong to the original camera trap grid, Camera ID's between 222 and 241 describe the additional cameras set up at wild boar wallows. The latter were only installed after the study period 2017, which is why their count is given only for study periods 2018 to 2019.

Camera ID	**Habitat**	**Raccoons sampled in**				
		2017	2018	2019	Total	%
232	Fallow ground	-	15	210	225	9.78
1	Mixed deciduous forest	39	50	58	147	6.39
99	Pure deciduous forest	83	19	11	113	4.91
43	Mixed deciduous forest	45	27	40	112	4.87
224	Mixed deciduous forest	-	50	57	107	4.65
44	Mixed deciduous forest	69	18	18	105	4.57
41	Mixed coniferous forest	36	29	36	101	4.39
88	Mixed deciduous forest	37	8	43	88	3.83
71	Mixed deciduous forest	81	3	1	85	3.70
223	Pure deciduous forest	-	19	63	82	3.57