A semi-automated method to study family size and age structure of the Eurasian Beaver *Castor fiber*

Master thesis proposal at the Biology Department

Science Faculty

University of Bern

Written by

Nicolas Stettler

Supervisors: Dr. Stefano Canessa, Prof. Dr. Raphaël Arlettaz

Institute of Ecology & Evolution

Division of Conservation Biology

Abstract

After the Eurasian beaver (*Castor fiber* Linnaeus, 1758) was nearly driven to extinction in the early 19th century, the species has flourished ever since it has been re-introduced in large parts of Central Europe, starting in 1922 (Stocker, 1985). Based on this timeline, much of our knowledge about the species was gained during a time of marked population growth well below carrying capacity (D. J. Halley et al., 2021). Now that the species is approaching said capacity in some areas, the question arises, what and to what extent do we see change in the life history and ecology of the beaver?

Our focus lies specifically on the family size and age structure of beaver families at high territory densities. As our pilot study - in the form of a bachelor thesis - yielded surprising trends in both aspects, we thus aim to further develop our methods and gain more insight in the intricacies of the beavers life history traits at high population densities.

Using a specific configuration of three camera traps per territory, we are able to identify and age beavers based on traits of the beaver tail. However, identification based on scars and colouring anomalies of the tail requires considerable manual work and expertise. Hence, we are developing methods to reduce the manual work involved by using a series of algorithms and machine learning. Going from an almost fully manual analysis-pipeline to a computer-assisted workflow will enable us to more efficiently identify individuals and thus allow analysis on a larger scale.

To streamline our method, we improve on previous studies in several ways. By optimizing camera positioning and lens optics, we are able to achieve a higher resolution allowing for easier identification to begin with. Furthermore, SIFT algorithms will be deployed to match scale patterns in the beaver's tail. Additionally, an automated method to measure the tail dimension will aid in distinguishing individuals by creating a multi-dimensional trait space. The tail dimensions also allow us to assign each individual to a given age class and thus give insight into the age structure of the beaver families.

Keywords: Eurasian beaver, family size, age structure, density-dependence, life history, carrying capacity

Table of contents

1. Introduction **4**

Benefits and conflicts *4*

Knowledge gap *4*

Goals of this study *6*

2. Materials & Methods **7**

2.1. Development phase 7

Study site *7*

Improve optics *8*

Improvements to the measurement accuracy *9*

Program to efficiently work with images *10*

Territory assignment *13*

2.2. Testing phase 14

Study site *14*

Study design *15*

3. Expected results **18**

4. Working plan and schedule **19**

5. Budget **21**

6. List of material and equipment **22**

7. Literature **23**

1. Introduction

Growth is not unlimited – a concept that is well known and widely applicable in ecology (Solomon, 1949). As universally recognized this concept is, the more complex is the interplay of the driving forces behind it. By studying density-dependence of the family structure, we isolate one particular component being possibly linked to slowing down population growth of the Eurasian beaver *Castor fiber*. The semi-aquatic mammal has nearly gone extinct in the early 19th century and our knowledge of mostly comes from the time after it's reintroduction, where the species was growing nearly exponentially.

In the field of conservation biology, the Eurasian beaver is often regarded as among the best comeback stories (Halley et al., 2012). At its lowest point in the early 1800s, the population was estimated at around 1'200 individuals, scattered across eight isolated subpopulations across Europe (Halley et al., 2021). Since then, the European beaver has reclaimed large parts of its original distribution. In Switzerland, where the beaver was absent for more than a century, the beaver has repopulated the Swiss plateau to a large extent, with a current estimate from the national beaver survey in 2022 of around 4'900 beavers (Angst et al., 2023).

Benefits and conflicts

The increase in beavers is not welcomed by everyone (Kaphegyi et al., 2015). With the increase in population size, there has also been an uprise in conflicts caused by or related to beavers (Angst et al., 2023). This includes building dens underneath infrastructures such as flood protection dams or roads, undermining their stability, flooding of agricultural land, or direct feeding damage (Angst et al., 2023). On the bright side, it has been shown in numerous cases that the beaver has a positive effect on many different species groups. As an ecosystem engineer, the Eurasian beaver is able to construct habitats according to its own preferences by building dams in small rivers. The modulation of the riverine habitats has a significant impact on biotic and abiotic characteristics in the surroundings, which can benefit a wide range of species groups including but not limited to terrestrial and aquatic invertebrates, fish, amphibians, birds and water plants (Rosell et al., 2005). Damming of rivers has also been shown to benefit water management as it helps in retaining water upstream, thus reducing the risk of severe floods but also droughts (Puttock et al., 2021).

The direct and indirect benefits for nature and humans, provided by the presence of beavers has long been recognized and today, conservation strategies can even include the beaver as a helping force for habitat restorations (Castro et al., 2017, Angst & Auberson in prep.). Yet, given this broad spectrum of benefits and problems caused by beavers, it should be of no surprise that the species is currently the object of controversial discussions (Kaphegyi et al., 2015). In winter 2025 the federal hunting ordinance has been revised, allowing the culling of beavers, if they cause considerable damage that cannot be prevented with reasonable protective measures (Schweizerischer Bundesrat, 2024). Since such interventions are „individual measures" on single beavers and „individual measures" are meant to be a certain number of animals from a local population, it is crucial to know how many animals are to be removed. However, to sustain a (genetically) healthy population, such actions should stem from well-informed decisions. Having exact estimates of the population size and dynamics is therefore a necessary foundation for informed, rational management decisions.

Knowledge gap

In general, much of the knowledge about the Eurasian beaver was gained during a period where the Eurasian Beaver was expanding throughout Europe (Halley et al., 2021). Now that the population is reaching saturation in some regions, this poses the question of whether increasing density might bring about changes in life history and ecology. The knowledge about such changes would not only

be in the interest of understanding density dependence but also key for future management decisions, especially when these management decisions include lethal forces.

In Switzerland, the current population estimate from the 2022 national survey (Angst et al., 2023) is based on indirect observations of signs of beavers. All territories are differentiated into individual/couple territories or family territories, where individual territories are estimated to hold 1.5 and family territories five individuals (Angst, 2010), the latter consisting of two adults and two generations of offspring. However, recent studies conducted in Norway have suggested that in areas with high population density, the offspring might delay dispersal and stay longer with the family than the suggested two years (Mayer et al., 2017). This in turn could then lead to increased family size under high population density (Rosell & Campbell-Palmer, 2022).

Meier (2023) further investigated this suggestion in Switzerland and compared family sizes in regions with high and low population densities. While she found a tendency towards larger families in high population densities, neither high nor low population densities had an average of five individuals per family, the value used as an estimate by the national survey (Angst et al., 2023). However, as the study did not investigate all adjacent territories at a site and the families were only sampled for 10 days, some individuals might've been missed or miss-assigned. In a follow-up study in 2023-24, we thus specifically looked at a system of adjacent beaver territories in an optimized grouping of camera traps to identify visiting beavers and possibly solidify the prior results of family size and age structure by Meier (2023).

In the five active territories that we could analyze in our pilot study, we found an average of 6.2 individuals per territory with a surprising shift in age class. Instead of the typical two adults per family, the number of adults ranged from two to up to six adults per family. However, due to the small sample size, we lacked statistical power to generalize our findings, thus leading us to formulate the present proposal for a more robust study.

Figure 1: An adult beaver swimming along the shoreline. They are easily recognized by the flat surface area and the lack of nose hair (in contrast to Nutria).

Goals of this study

In detail, this study aims to answer the following ecological questions:

1. how large family groups can grow in areas in Switzerland with high population densities;
2. whether the potential increase in family size is linked to the delay of dispersal first observed by Mayer et al. (2017) and thus generally also linked back to population density.

Additionally, we aim to provide a framework to efficiently answer such questions with camera traps. As Mortensen & Rosell (2020) could show, capturing and handling beavers can have significant effects on body mass and fitness of individuals, hence a non-invasive approach to prevent any negative impact on the species is preferable.

However, camera trapping also comes with many challenges. Previous proposed methods to study family size of Eurasian Beavers using camera traps were associated with amount of manual work (Minnig et al., 2022; Schwaiger & Schwemmer, 2012). As this not only applies to Eurasian Beavers but general work with camera traps, there is a high interest for efficient solutions in dealing with the output by camera traps (Beery et al., 2019; Greenberg, 2020; Leorna & Brinkman, 2022). The uprisal of AI in recent years holds the promise to reduce the amount of manual worked involved significantly. However, there is a lack of a general and straightforward tool that can be used, especially without the need for extensive coding knowledge (Christin et al., 2019). We hereby also aim to provide a sort of guideline on how current tools can be efficiently connected and used to enable a straightforward data evaluation pipeline.

Besides answering questions in regard to the density dependence of the Eurasian Beaver, this study therefore also aims to pave way to allow for easier and more efficient follow-up studies. Secondly, the guidelines along with the study design will also be shared with the governing bodies, thus allowing for better educated management decisions.

2. Materials & Methods

The project will be divided into two parts. The first part will focus on the methodology of using camera traps to collect reliable data about beavers. By mounting camera traps in a specific way, it is possible to identify beavers on an individual level; however, to date this requires considerable manual work. Hence, in the first part of this study we will work on an optimized method that leverages both advancements in artificial intelligence and image recognition algorithms but also in technology as a whole.

In the second part, we will implement our improved methodology to evaluate the family size and age structure of beavers in an area of high territory density in Switzerland. This part is following our prior pilot study which studied age structure and family size at a very small scale. Here we aim to reproduce our findings but with an increase statistical power.

2.1. Development phase

Study site

To develop our method and test camera traps in the field, we will return to some of the territories that we evaluated in our prior study. Since at this stage of the study we are not interested in the empirical results, we can re-use the camera trap locations from 2023-24, even though there might be some spatial and temporal fluctuation in the activity itself. The area is located in the Belpauen, between Belp and Rubigen, just adjacent to the western bank of the river Aare but separated from it by a dam, to protect it against major flooding. The area is subject to moderate continental climate with cold winters and warm summers (MeteoSchweiz).

The study area is part of the Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung (BLN) site number 1314 (*Aarelandschaft zwischen Thun und Bern*), Bundesinventar der Auengebiete von nationaler Bedeutung site number 69 (*Belper Giessen*) and Bundesinventar der Amphibienlaichgebiete von nationaler Bedeutung site number BE973 (*Belpau*) and BE968 (*Aareaue bei Belp*). The land is owned by the Burgergemeinde Belp which is granting us the permit to use the access roads by car as well as mapping the area and setting up the camera traps.

Figure 2: The landscape in the study site has been heavily modified by beavers in the past 30 years.

Improve optics

As it is rather difficult to identify sex and age in beavers, let alone identify them, a specific camera trap setup is needed. In our previous study, we used a method first proposed by Schwaiger & Schwemmer (2012) and then further optimized by Minnig et al. (2016). The cameras were installed along beaver paths, elevated to a height of 1.8 m using a metal construction and pointed vertically to the ground in order to get a near-planar image of the beaver's tail. The scars as well as the size and shape of the tail could then be used to identify each beaver individually.

One of the major limitations in the prior studies using camera traps was the image quality itself, mainly limited by resolution of the imaging sensor but also the focusing distance. Conventional camera traps use a fixed focusing distance that allows subjects to be sharp within an interval of around 2 m to infinity. As the camera traps were mounted at a height of 1.8 m and pointed straight to the ground, the photos of the beaver's tail would therefore lack crucial sharpness to identify scars and other traits used for identification (Figure 3).

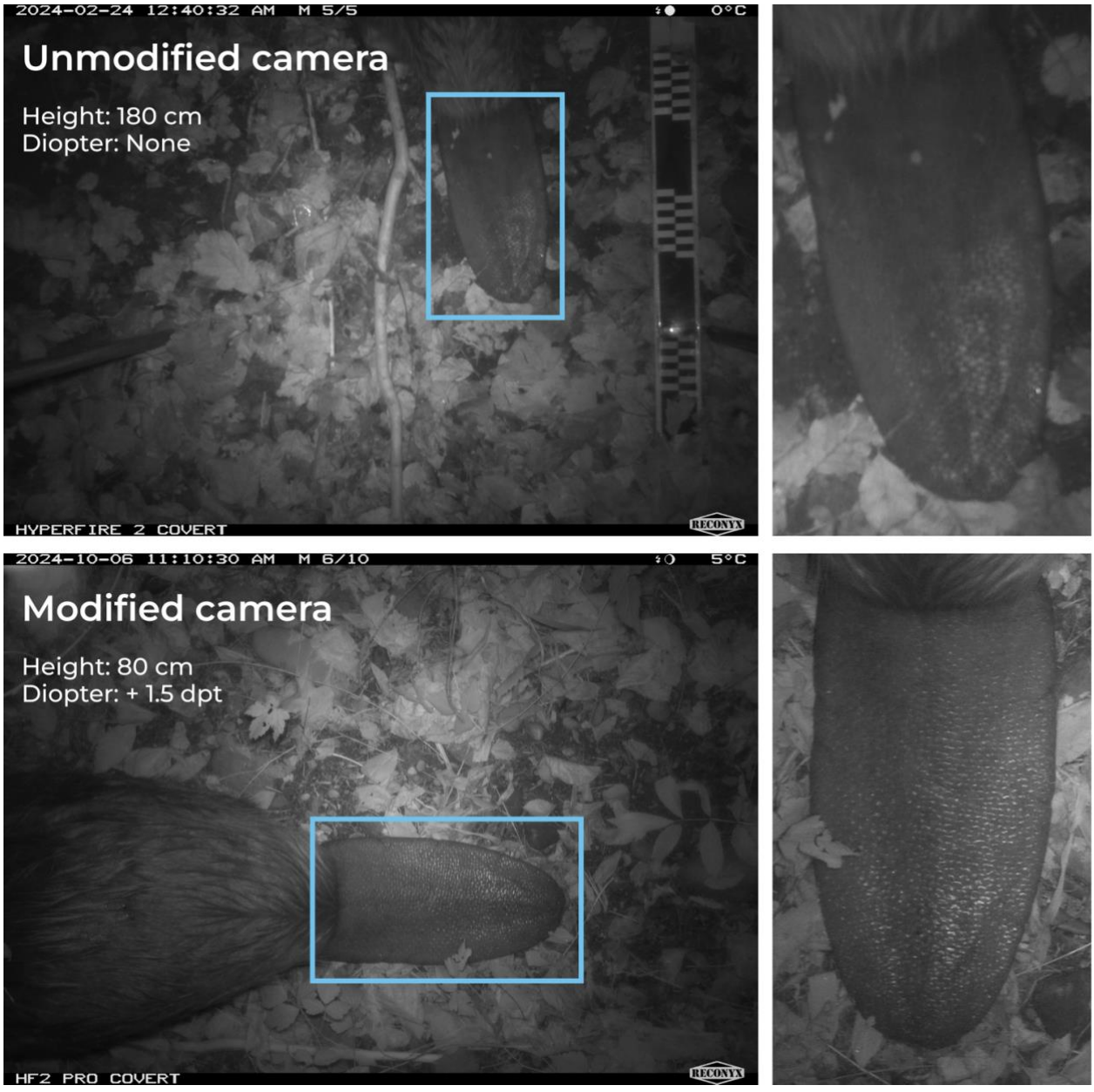


Figure 3: Two Images of the individual TSI once using the previous camera trap setup and once using the improved setup. In the image with the unmodified camera, marks are difficult to identify and distinguish from dirt on the tail and the scale pattern is only slightly visible. Using the improved camera trap setup marks and scars on the tail are clearly visible as well as the scale pattern. Dirt or foliage can be clearly distinguished from marks on the tail.

Due to the nocturnal nature of many target species, camera traps use infrared light flashes to allow for images during the night and avoid disturbing the animal. However, these cameras are thus often limited in their resolution to maximize sensitivity at each photo site (pixel). The camera trap model used in our prior study, the Reconyx Hyperfire 2, which is widely used in ecological studies, is limited to 3 MP files (2048 x 1440 pixels). To capture small details of the tail, a higher resolution would allow for easier identification and possibly also automation. While there are many models (of other brands) that market a higher resolution, this is most often only achievable for daytime images using a secondary imaging sensor. In other cases, the higher resolution is achieved through interpolation which can result in image artifacts without a net gain in image quality.

We also compared images taken by a variety of camera trap models. These models were tested in a study by Dytkowicz et al. (2023) using a similar experimental setup, by whom we also obtained the images from. As their camera trap models performed worse than the images we obtained in early trials with the Reconyx Hyperfire 2, we decided to continue using this model for the study described in this proposal.

To improve the image quality while using the same camera trap model, we will make three adjustments to the design. In order to maximize the resolution on the tail (pixels/ tail area [cm^2]), we will change the camera trap mounting height down to 80 cm. From trial runs this proved to be a sweet spot between good image quality of the tail and a large field of view. The field of view is an important factor in the way that it increases the likelihood that the beaver's tail is visible in the image frame. To accommodate the loss of field of view, we will rotate the camera orientation by 90°. This allows us to cover more space along the beaver's path of movement and this increases the likelihood, that there is a good image of the beaver's tail in the series.

To accommodate the shorter distance in terms of focus, we will add a + 1.5 diopter (20 mm diameter, provided by Fielmann Thun) to the front of the camera using a 3D-printed lens holder. The whole mount together with the diopter is removable, because we seek to modify the cameras in a non-permanent manner. This improves the flexibility of use of the camera traps so that theoretically, the cameras can also be used in projects that don't require a close focusing distance.

Early trial runs suggest that by implementing these simple changes, we have already achieved a significant increase in resolution (Figure 3). By improving image quality as a whole, we will be able to obtain a much clearer view on scars and other identification traits of the tail.

Improvements to the measurement accuracy

Besides identification of beavers at the individual level, we will also take measurements of the tail to assign them to an age class (juvenile, sub-adult & adult). Tail dimensions can also then be used to aid with identification of each beaver. Besides the already labour-intensive visual identification, the prior studies were faced with the challenge of inaccurate measurements of the tail dimensions. In general, the error in measurements originated mostly due to the fact that the tail varied in positioning. The beaver's tail is a highly agile organ; therefore, its orientation relative to the camera can fluctuate strongly. The tail could for example be lifted, angled or skewed, which could then result in perspective skewing, which in turn introduced variation in measurement especially along the longitudinal axis.

One other factor contributing to such variation is that in some cases, the camera itself could not be positioned perfectly parallel to the ground. Depending on where exactly the beaver's tail was positioned in the image, the calibration from pixel to cm might have been incorrect to some extent. As we were using a wooden ruler for reference, the calibration was only done in one direction. In the upcoming trials, we will therefore test the addition of a ground panel with a raster on it to allow to correct for perspective skewing.

Lastly, the measurements especially along the longitudinal axis were sometimes inaccurate as the start of tail was difficult to determine. By definition, the tail starts at the point where the fur ends, and the beaver scales start to be visible. However, depending on the state of the fur (wetness and direction), the start of the tail could be covered by more or less fur. Through the improvement in image quality, we aim to improve the measurements further, as the start of the tail should also be more defined.

Program to efficiently work with images

With the number of cameras left in the field for several weeks, the number of images can quickly reach several ten thousand images. This not only depends on the activity of the beaver, but other factors can influence the total count drastically. A camera trap which is set to a high sensitivity can trigger repeatedly without any animals in the image. This can happen for example, if the location is exposed and wind can move the camera, or there are surfaces like stones that are able to warm rapidly. Last but not of least impact, other wildlife, particularly mice, can also trigger the camera frequently during the night, leading to a much higher image count than originally expected. It is therefore necessary to efficiently process the large batch of images.

In order to reduce the time required to process all the images, several workflow improvements will be trialed and reported on, that leverage powerful algorithms and programs. This mainly includes the function of Megadetector (Beery et al., 2019) to get rid of empty images. We will then use Timelapse by Greenberg (2020) to process the image series to single events and identify all events triggered by beavers. Secondary instance segmentation and SIFT algorithms will then be employed to recognize the beaver's tail and measure its dimensions.

Megadetector and Timelapse to process batch of images to beaver events

We will use Megadetector Version 6 to process the entire batch of images to identify empty images and distinguish between animals, humans, and vehicles. Using timelapse (and the episode function), the image series (10 images per series) will then be processed into single events (Figure 4). Consecutive series that are triggered within 2 minutes from the start of the event will automatically be grouped together into one event. In the case that another beaver passes through the camera within these 2 minutes, the event can still be managed manually and split up into two. If Megadetector does not detect any animals in any of the images of a given event, the event will be removed automatically. Additionally, a visual inspection will allow us to quickly discard any events triggered by mice and other animals.

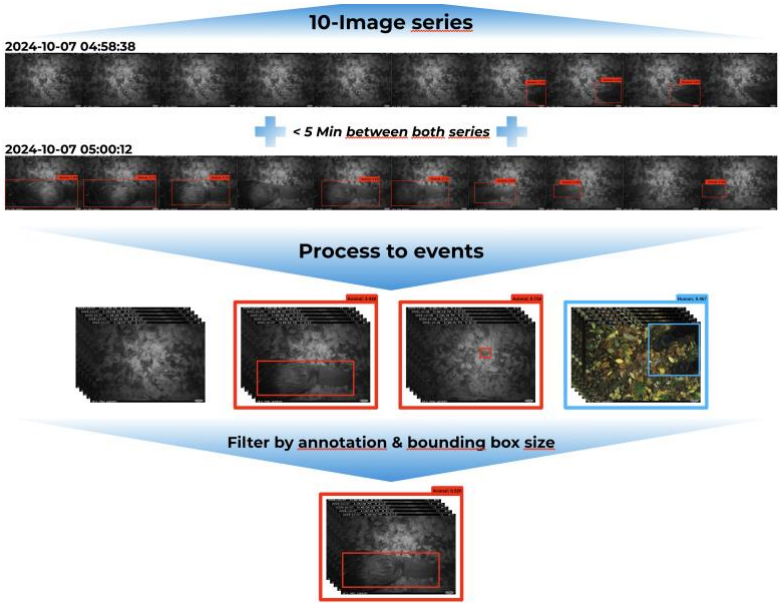


Figure 4: Method to process the image series to singular events using Timelapse and Megadetector.

Fast-RCNN for tail measurements

After removing all empty events and events triggered by other species, images where the beaver's tail is fully visible in the frame will be manually selected. Following that step, we employ a Fast-RCNN algorithm to detect and mask out instances of beavers and their tail. The algorithm will be previously trained on a training set of around 500-700 images stemming from earlier trial runs. Using the marked instances of the beaver's tail, the tail dimensions can then be measured fully automatically. To calibrate the dimensions, a raster is placed on the ground at the point of setting up the camera. Thereby, the pixels can be calibrated to actual distances and using the grid we can also correct for perspective skewing. As described in Figure 5 below, the measurements on tail dimension can be achieved automatically. Nevertheless, in case of false or inaccurate identification of the tail, we are still able to manually overwrite the measurements.

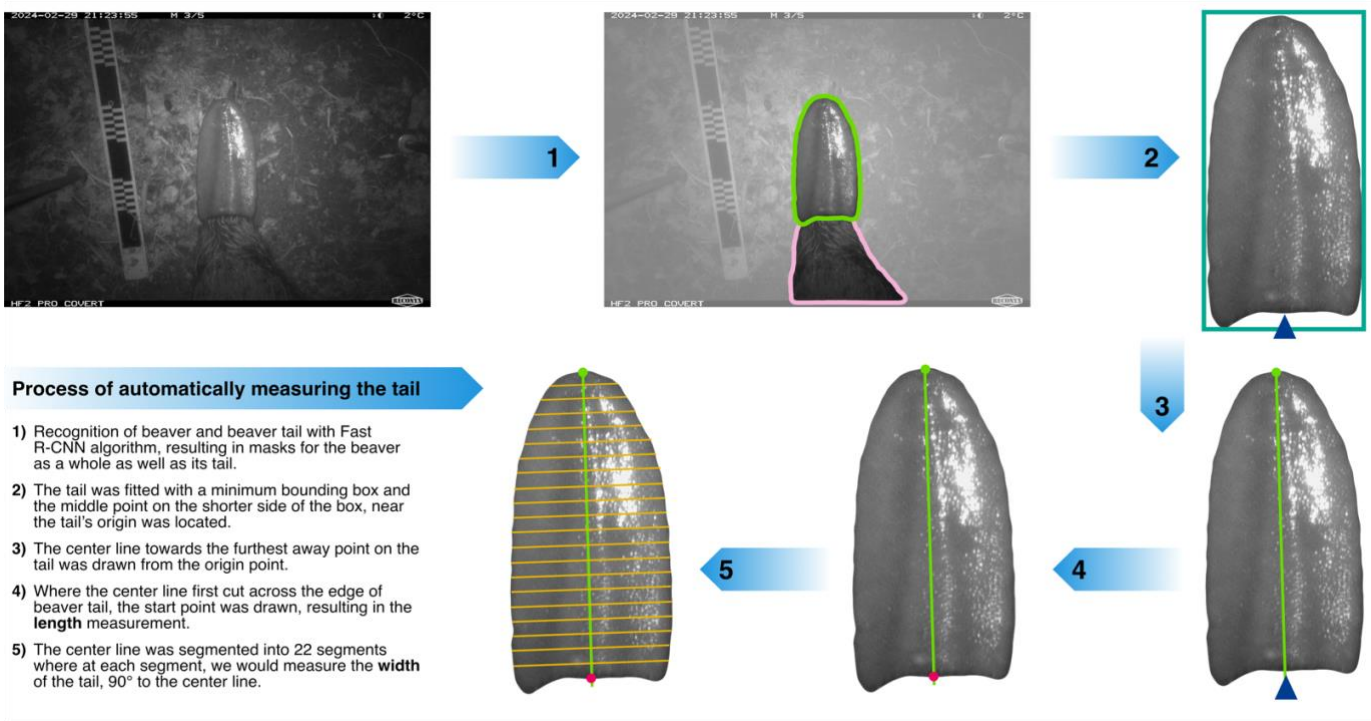


Figure 5: Description of processing steps to calculate length and widths of the beaver tail.

The average and confidence interval of each individual's measurements will then be used to assign the beavers to an age class (Table 1). Our classification criteria slightly deviate from the suggested values by Rosell & Pedersen (1999). This is owed to the fact that we do not just take one measurement across the middle point of the tail, but rather an average across about 50% of the tail in the middle area.

Table 1: Measurements of tail of the 3 age classes, adjusted from Rosell & Pedersen (1999).

Age class	Length	Average width
Juvenile	< 24 cm	< 11 cm
Sub-adult	24-27 cm	11-14 cm
Adult	> 27 cm	> 14 cm

Additionally, the measurements of the tail dimension will be used to assist in identification of the different beaver individuals. Here we will not only focus on the length and width of the tail at different points on the tail, but also the change of the width along the longitudinal axis. Here we propose several different measurements that can be used alongside each other:

- The average and standard deviation of the decrease of width across the last 6 measurements at the tip to the tail will be used to quantify the shape of the tail end. It will also allow us to distinguish between V- or U-shaped tails.
- The number of measurements that are within 1 cm from the start of the tail will specify the base of the tail, whether it has a more rounded shape or it is straighter.
- The average and standard deviation across the first 5 and also the last 5 width measurements to get a broader idea of the tail dimensions.

SIFT Algorithm for recognition

In our prior study, identification on an individual level was made visually using scars, coloring anomalies as well as the shape of the tail itself. Overall, this process required a lot of time, mainly also due to the limited image quality. Besides the improvements made in regard to the image quality, we also strive to employ a SIFT-algorithm to further assist and streamline identification.

In general, SIFT-algorithms are already widely applied in individual identification of various species and there are already tools available to help in individual identification. However, these are mostly species-specific and do not yet include beavers. Nevertheless, we will trial several options that are already available to date. Additionally, we will also trial the SIFT-algorithm at different scales. First, we will employ a SIFT-Algorithms to match scars and coloring anomalies on the beaver's tail. Secondly, we will try to extract the scale pattern on the beaver's tail, which we can then match against the collected database. So far, the latter has been proven to be accurate in identifying individuals using high-quality images (Hinds et al., 2023). We will therefore be able to assess whether our improved camera trap optics allow the pattern matching to work in situ as well.

Figure 6: Extraction of scale patterns on the beaver's tail.

Multidimensional trait-space

Working with camera traps can bring up many unforeseen issues. It would therefore be naïve to only focus on one method to identify the individuals. Instead, we are aiming to integrate our different ways of identification and measurements to create a multi-dimensional trait space. This trait space could be made up of absolute dimensional values such as the length and width of the tail. Using pattern matching, we'll also have relative dimensional values. These dimensions will not have an absolute number but will allow us to quantify relative distances between each other.

To identify clusters inside this multi-dimensional trait space, we could use a K-means algorithm. This will then provide us all the necessary information on each individual and allows us to recreate the movement pattern of that specific individual.

Territory assignment

After each event is assigned to an individual, we can recreate a capture history for each animal. Based on that, a territory of origin will be assigned. If the beaver is captured at a camera trap in the territory center, the individual will be directly assigned to this territory. If a beaver is never recorded at a territory center, it will be assigned to the territory in which it was found the most often. In the rare case of a beaver being found at two territory centers or across multiple territories with equal frequencies, the temporal history will be taken into account. In such a case, assignment priority will be given to the territory which had sightings across more nights.

2.2. Testing phase

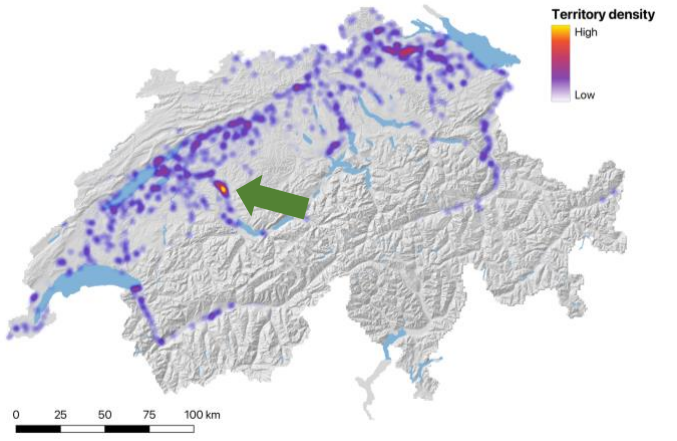
Figure 7: A flooded forest near Belp.

Study site

As done in our previous study, we will focus on the area with the highest territory density in Switzerland, however in this case, we will increase the area of coverage and in total sample 45 territories in and surrounding the Belpauen near Belp and Rubigen. The area is subject to moderate continental climate with cold winters and warm summers (MeteoSchweiz) with the elevation of the water bodies ranging between 500 m.a.s.l. and 600 m.a.s.l.

The study area is part of the Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung (BLN) site number 1314 (*Aarelandschaft zwischen Thun und Bern*), Bundesinventar der Auengebiete von nationaler Bedeutung site number 69 (*Belper Giessen*) and Bundesinventar der Amphibienlaichgebiete von nationaler Bedeutung site number BE973 (*Belpau*) and BE968 (*Aareaue bei Belp*). The land is owned by the Burgergemeinde Belp which granted us the permit to use the access roads by car as well as mapping the area and setting up the camera traps.

Table 2: Details of study area, measurements taken from the weather station of Bern Airport just adjacent to the northwestern border of the territory (MeteoSchweiz).



Name	Belpauen
WGS coordinates	46°88'99.28", 7°53'38.39"
LV95 coordinates	2'607'255.89, 1'193'205.73
Mean elevation m.a.s.l.	515 m.a.s.l.
Average daily temperature	7.7 °C
In winter (90 days)	-0.35 °C
In summer (90 days)	16.01 °C
Annual precipitation	1107.05 mm

Figure 8: Population density of C. fiber in Switzerland. The study area is marked with a green arrow. The data was provided by Angst et al. (2023) and visualized in QGIS using heat map with Kernel shape bi-quadratic with a radius of 3 km and a weighting for individual to family territories of 1:5. Background: ©Swisstopo

Study design

Finding territories

Before putting out camera traps into the field, it will be necessary to find all active territories in the given study area. Additionally, areas of high activity within the territory boundaries have to be located in order for the camera traps to capture a lot of activity.

As the beaver is active during the night, we will use a survey conducted during the day to initially identify all active beaver territories (occupied lodges and signs of activity in the vicinity). We will base our search for territories on the national survey that took place in 2022. All water bodies within a radius of 1 km from territories mapped in 2022 will also be checked and mapped in order to minimize chances of missing newly established territories by expanding beaver populations.

The survey locates beaver lodges and the respective territory boundaries using various traces (see Figure 9). While the beaver lodges usually remain rather stationary for longer periods of time, the territory boundaries change dynamically and are more difficult to map. Territory borders will be determined using the following criteria. (1) Looking at the territory along a water arm, signs of beavers are most abundant near its lodge. The frequency of signs decreases with distance and should drop of significantly at the territory border. (2) Beavers regularly mark their territory borders with scent. (3) If two territories are very close to each other, there might be territory overlap to some extent, and it will also be difficult to identify a drop in beaver signs along the water body. The territory border will then be placed in the middle between both lodges, if no scent markings or structures such as beaver dams could be identified. If such signs are instead present, the territory border will be placed at the structure or scent marking.

A B

C D

Figure 9 (A-D): Examples of beaver traces found during the mapping. A: Typical gnawing mark. B: Typical lodge of C. fiber at the shore. C: Traces of C. fiber feeding on grass in agricultural land. D: A small beaver dam to maintain the water level in the upper part of the river where the lodge is situated.

Camera traps and territories

Based on the preliminary survey, we will then choose all adjacent territories in the given area where we set up camera traps. In each territory we will install three camera traps. One camera trap will be positioned near the active beaver lodge, where beavers are likely to pass by the camera. Hence, this camera does not necessarily need to be placed right beside the lodge, but possibly just up- or downstream of it, if there is for example a suitable passage between two water bodies.

The other two camera traps will be installed closer towards the expected territory boundaries. These cameras are to be placed at locations where we expect beaver activity to be high. Points of high activity are for example exits out of the water, paths leading the beaver into the forest, territory markings, feeding places or crossings between two water bodies.

The camera traps will be left at their location for a total of 3 weeks or 21 nights. According to our prior study, we estimate that after 21 nights, all individuals belonging to the family should have been captured at least once. After this period, the cameras will be repositioned to a new location to cover additional territories. The relocation of camera traps will in total require 3 days, since around 10-15 camera traps can be relocated per day. However, this also depends strongly on the accessibility of the site.

Due to the fact that all individuals should be captured across the whole site, the temporal shift should not bias the results regarding family size and age structure. Activity within each 21 days are also comparable; however, this is not the focus of our study and thus, we judge it appropriate to reposition the cameras to increase sample size.

Figure 10: The camera trap setup to identify the beavers by its tail. The camera traps were secured with a cable and a small lock. Additionally, information about the study with contact details was attached to each metal frame.

Baiting

To increase the likelihood of capturing all individuals of a territory, sugar beets will be added to the camera at the territory center. As done in our prior study, sugar beets will only be added at the territory center in order to only attract beavers from the corresponding territory. If we were to place sugar beets at the territory borders, artificially increasing the trapping rate would come at the risk of instigating territorial fights. In total around 5-8 kg of sugar beets will be added to the camera traps in 2 sessions. The first will be added upon installation of the camera traps, with the second one being added after day 10 in case all sugar beets are consumed.

How many camera traps

We are aiming for a total of 30 cameras allowing us to cover 10 territories every 3 weeks. With 3 or possibly 4 sampling sessions, we could cover 30 or even 40 territories. From previous studies, we estimate the total picture count to be at around 300'000 images with around 150 to 200 individuals. Obviously, this is number is highly dependent on various factors which are not in our power to influence. Nevertheless, we judge the estimate to be realistic and it highlights again the importance of an efficient workflow.

Statistics

All statistical analyses will be carried out in R Studio 2024.04.0+735 (R Core Team, 2024) with R version 4.4.2.

3. Expected results

As we set out to answer similar questions to our prior study, but try to answer it on a larger scale, we generally expect the results to be comparable, but more reliably generalizable.

Family size & Age structure

In regard to family size, we generally expect a similar outcome to our prior study, with higher observed family sizes than the assumed five individuals used in the national beaver survey (Angst et al., 2023).As we could already observe in the previous study, we expect that increase in family size to reflect an increase in adults per family and not from a higher number of juveniles. In contrary, we expect to see very few juvenile beavers indicating that offspring is rare but then delays dispersal in order to increase its fitness and the likelihood to find its own territory.

This would further suggest that in the study area, the population is very close to or has reached carrying capacity. We could already show that sub-ordinate beavers often explore beyond territory borders in search of their own territory. We thus hypothesize that the population has reached a threshold wherein the void space resulting from a disappearing territory will be quickly filled by sub-ordinate beavers.

Conservation relevance

Our observed changes in the beaver's life history might also have implications concerning the relaxation of the protection of the beaver. This aims to reduce the time needed to lethally remove beavers that might cause any conflicts or create risks. However, higher densities reflecting a higher number of adult beavers per family could mean that killing a problematic beaver family might alleviate the problem for a shorter timeframe than expected, as there are many subordinate beavers from adjacent families waiting for an open territory.

Traded off against the high costs of killing beaver families, this reduced efficiency of lethal removal would further highlight the need for a more long-term solution. This also means that instead of working against beavers, the governing bodies and the management are required to work with beavers and find ways to profit from the ecosystem services provided by the beaver while also reducing and mitigating emerging conflicts.

By giving beavers the space to create and modify habitats, we would thus not only profit through direct ecosystem services like water retention, the modification of the habitat may also benefit a wide range of species.

4. Working plan and schedule

2025	Jan	***Camera trap meeting*** ▪ Present Bsc results ▪ Present and discuss ideas for Msc ***Write proposal*** ***Test optimized camera trap module*** ▪ Finalize Camera lens holder ▪ Trial mat for measurements
	Feb	***Biology25*** ▪ Present Bsc results ▪ Present and discuss ideas for Msc ***Test optimized camera trap module*** ▪ Generate training and test data
	Mar	***Finalize proposal*** ***Trial SIFT algorithm*** ▪ Early tests to see whether image quality is improved enough ***Trial TrapTagger***
	Apr	***Trial SIFT algorithm*** ▪ Early tests to see whether image quality is improved enough
	May	***Optimize Workflow*** ▪ Conceptualize whole workflow
	Jun	***Optimize Workflow*** ▪ Implement and program workflow ***Annotate training set for tail measurements*** ▪ Using CVAT.ai and training set from winter
	Jul	***Optimize Workflow*** ▪ Implement and program workflow
	Aug	***Optimize Workflow*** ▪ Implement and program workflow ***Plan survey*** ▪ Choose area to be surveyed ***Write first chapter of the Msc (Methods)***

	Sep	***Beaver Symposium 17-19. September*** ▪ Present and discuss the method ▪ Exchange with international scientists
	Oct	***Survey*** Present First Results in CB Seminar
	Nov	***Camera traps in the field*** ▪ First session (starting 6. & 7.11) ▪ Second session (starting 27. & 28.11) ***Data analysis*** ▪ *Survey data*
	Dec	***Camera traps in the field*** ▪ Third session (starting 18. & 19.12) ***Data analysis*** ▪ Identification
2026	Jan	***Data analysis*** ▪ Identification ▪ Family size ▪ Age structure ***Camera trap meeting*** ▪ Present finalized method
	Feb	***Data analysis*** ▪ Reserve ***Write the results and discussion***
	Mar	***Write the results and discussion***
	Apr	***Finalize Msc thesis*** ***Present Msc Final Results***
	May	
	Jun	

5. Budget

Camera trap and necessary accessories

The camera traps (Reconyx Hyperfire 2) will be provided by the CB group, info fauna and Uni Basel. Additionally, SD Cards are available for all cameras. From previous experience, one set of batteries (12 Li-Ion AA) should last the whole study duration. To accommodate for unforeseen failures, we calculate an excess of around 50 batteries. In total we thus need just short of 600 batteries. There will probably be batteries available already, but we might need to buy a few more.

For each camera trap we additionally need a diopter lens as well as the 3D printed lens holder. Additionally, 2 screws to are required to mount the lens holder to the camera casing.

Name	#	Cost per piece	Total cost
Reconyx Hyperfire 2	30	0	0
SD Cards	30	0	0
Batteries Energizer Li-Ion	400	2.69	1076
Lens diopter	30	14	420
Lens holder	30	5	150
Screws	60	?	40
			1'686

Camera trap mount

For one camera trap mount we require three Rohrnippel of ½ x 800 mm (54 already available), two 90° connectors (36 available) and two Armierungseisen of size 250 mm x 8 mm (72 available). Additionally, we need 2 Unterlagsscheiben of size XY and a Reconyx camera mount as well as some small screws, four nails and a mat for the measurements.

Name	#	Cost per piece	Total cost
Doppelrohrnippel ½ 800mm	24	11.50	276
90° Connectors	24	2.95	70.8
Armierungseisen	24	0.875	21
Unterlagsscheiben 15 x 35 mm	24	?	20
Reconyx Universal Mount	12	29	348
Mats	1	12	12
Nails and Screws	24	4	96
			843.8

Additional expenses

Besides the materials listed above, we require a license for CVAT.ai for 3 months to generate the training set for the Fast R-CNN algorithm to recognize the beaver's tail. Besides that, no additional software licenses are necessary. We do calculate in another 300 CHF to factor in unforeseen expenses such as cost for sugar beets, additional software licenses or price increases in the materials listed above.

Name	#	Cost per piece	Total cost
CVAT.ai	3	34	102
Reserve	1	300	300
			402

Total expenses

Name	Total cost
Camera traps	1'686
Camera trap mount	843.8
Additional expenses	402
	2'931.8

6. List of material and equipment

Name	Totally required
Camera traps	30
Camera mounts	30
Sugar beets	100 kg

7. Literature

Angst, C. (2010). Mit dem Biber leben Bestandeserhebung 2008 Perspektiven für den Umgang mit dem Biber in der Schweiz. *Umwelt Wissen Nr. 1008.*, 156.

Angst, C., Auberson, C., & Nienhuis, C. (2023). Biberbestandeserhebung 2022 in der Schweiz und in Liechtenstein. In *info fauna – Biberfachstelle und Fornat AG*.

Beery, S., Morris, D., & Yang, S. (2019). Efficient Pipeline for Camera Trap Image Review. *ArXiv Preprint*. http://arxiv.org/abs/1907.06772

Castro, J., Pollock, M., Jordan, C., Lewallen, G., & Woodruff, K. (2017). *The Beaver Restoration Guidebook Working with Beaver to Restore Streams, Wetlands, and Floodplains*. https://www.fws.gov/oregonfwo/promo.cfm?id=177175812

Christin, S., Hervet, É., & Lecomte, N. (2019). Applications for deep learning in ecology. In *Methods in Ecology and Evolution* (Vol. 10, Issue 10, pp. 1632–1644). British Ecological Society. https://doi.org/10.1111/2041-210X.13256

Dytkowicz, M., Hinds, R., Megill, W. M., Buttschardt, T. K., & Rosell, F. (2023). A camera trapping method for the targeted capture of Eurasian beaver (*Castor fiber*) tails for individual scale pattern recognition. *European Journal of Wildlife Research*, *69*(2). https://doi.org/10.1007/s10344-023-01654-6

Greenberg, S. (2020). *Automated Image Recognition for Wildlife Camera Traps: Making it Work for You*. https://speciesclassification.westus2.cloudapp.azure.com/

Halley, D. J., Saveljev, A. P., & Rosell, F. (2021). Population and distribution of beavers *Castor fiber* and *Castor canadensis* in Eurasia. In *Mammal Review* (Vol. 51, Issue 1, pp. 1–24). https://doi.org/10.1111/mam.12216

Halley, D., Rosell, F., & Saveljev, A. (2012). Population and Distribution of Eurasian Beaver (*Castor fiber*). *Baltic Forestry*, *18*(1), 168–175.

Hinds, R., Dytkowicz, M., Tania, M., Megill, W. M., & Rosell, F. (2023). A tale of tails: the use of Eurasian beaver (*Castor fiber*) tails for ageing and individual identification. *European Journal of Wildlife Research*, *69*(5). https://doi.org/10.1007/s10344-023-01718-7

Kaphegyi, T. A. M., Christoffers, Y., Schwab, S., Zahner, V., & Konold, W. (2015). Media portrayal of beaver (*Castor fiber*) related conflicts as an indicator of changes in EU-policies relevant to freshwater conservation. *Land Use Policy*, *47*, 468–472. https://doi.org/10.1016/j.landusepol.2015.04.014

Leorna, S., & Brinkman, T. (2022). Human vs. machine: Detecting wildlife in camera trap images. *Ecological Informatics*, *72*. https://doi.org/10.1016/j.ecoinf.2022.101876

Mayer, M., Zedrosser, A., & Rosell, F. (2017). When to leave: the timing of natal dispersal in a large, monogamous rodent, the Eurasian beaver. *Animal Behaviour*, *123*, 375–382. https://doi.org/10.1016/j.anbehav.2016.11.020

Meier, M. (2023). *Family size and age composition of the Eurasian beaver (*Castor fiber*) in Switzerland. Does high population density lead to larger families?*

Minnig, S., Angst, C., Jacob, G., Ch], S. M., & Biberfachstelle, C. A. (2016). Genetic monitoring of Eurasian beaver (*Castor fiber*) in Switzerland and implications for the management of the species. *Russian Journal of Theriology*, *15*(1), 20–27.

Minnig, S., Stocker, G., Angst, C., & Sigrist, B. (2022). *Testing for Eurasian beaver (*Castor fiber*) family size and structure in three regions of Switzerland with different population densities Testing for*

Eurasian beaver (Castor fiber) family size and structure in three regions of Switzerland with different population densities. https://www.researchgate.net/publication/363771914

Mortensen, R. M., & Rosell, F. (2020). Long-term capture and handling effects on body condition, reproduction and survival in a semi-aquatic mammal. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-74933-w

Puttock, A., Graham, H. A., Ashe, J., Luscombe, D. J., & Brazier, R. E. (2021). Beaver dams attenuate flow: A multi-site study. *Hydrological Processes*, *35*(2). https://doi.org/10.1002/hyp.14017

R Core Team. (2024). *R: A Language and Environment for Statistical Computing* (2024.04.0+735). R Foundation for Statistical Computing.

Rosell, F., Bozsér, O., Collen, P., & Parker, H. (2005). Ecological impact of beavers *castor fiber* and *castor canadensis* and their ability to modify ecosystems. *Mammal Review*, *35*(3–4), 248–276. https://doi.org/10.1111/j.1365-2907.2005.00067.x

Rosell, F., & Campbell-Palmer, R. (2022). *Beavers: Ecology, Behaviour, Conservation, and Management*. Oxford University Press. https://doi.org/10.1093/oso/9780198835042.001.0001

Rosell, F., & Pedersen, K. V. (1999). Bever.[The beaver.]. *Oslo: Landbruksforlaget*.

Schwaiger, M., & Schwemmer, H. (2012). *Evaluation der Fotofallen-Methodik zur individuellen Erkennung bei Bibern*.

Schweizerischer Bundesrat. (2024). *Verordnung über die Jagd und den Schutz wildlebender Säugetiere und Vögel*.

Solomon, M. E. (1949). The Natural Control of Animal Populations. *Source: Journal of Animal Ecology*, *18*(1), 1–35.

Stocker, G. (1985). *Biber (Castor fiber L.) in der Schweiz*.