European Journal of Wildlife Research (2023) 69:88
https://doi.org/10.1007/s10344-023-01718-7

RESEARCH

A tale of tails: the use of Eurasian beaver (*Castor fiber*) tails for ageing and individual identification

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Received: 4 April 2023 / Revised: 19 July 2023 / Accepted: 31 July 2023 / Published online: 10 August 2023

Abstract

With increasing technology and knowledge, the range of methods used to monitor wildlife is growing. As many invasive techniques have been shown to negatively impact study populations, the use of non-invasive methods is increasing. With Eurasian beaver (*Castor fiber*) reintroductions occurring across much of Europe, monitoring of beavers is becoming increasingly important; however, some frequently used techniques are invasive. We therefore aimed to examine potentially non-invasive methods of identifying and ageing them from the tail. Tails from previously deceased beavers were photographed with a Nikon D3500 DSLR camera across 3 distances: 'close', 'medium' and 'far', and the pattern of the scales were examined by eye to determine accuracy of individual identification. Photographs including a grey standard were used to determine the accuracy of ageing beavers from the colour of the tail. The accuracy of individual identification was 100% across all distances; however, the results from ageing showed the method to be inaccurate. The success of the individual identification shows that this method could be effectively used as a non-invasive method for monitoring beaver populations, especially in captivity.

Keywords Ageing · *Castor fiber* · Eurasian beaver · Individual identification · Non-invasive monitoring

Introduction

There are a number of methods for monitoring wildlife, both invasive and non-invasive. Some studies suggest that invasive monitoring has a limited impact on the study population, and the potential benefits outweigh the risk (Vucetich and Nelson 2007; Parris et al. 2010; Jewell 2013). This can be the case for some, more robust species. However, in recent years, the impact of invasive monitoring has been examined in many species, including less robust species such as grizzly bears (*Ursus arctos*) (Cattet et al. 2008) and Weddel seals (*Leptonychotes weddellii*) (Harcourt et al. 2010). These impacts can range from an increase in cortisol spikes (Harcourt et al. 2010) to increased mortality (Nuvoli et al. 2014; Green-Barber et al. 2017). Long-term studies on beavers have shown that repeated capture can have a negative impact on body mass in dominant individuals and also on reproductive success. However, this effect was most evident in the early years of capturing and became less notable over time (Mortensen and Rosell 2020).

With growing technology and knowledge, non-invasive methods can be used to collect data on wild animals, including individual identification and age data. Age can help researchers establish information such as population dynamics and welfare, and individual identification can be used to study factors such as behaviour, and also assess populations (Jędrzejewski et al. 2007; Mills 2012; Arso Civil et al. 2019; Hecht 2021). Non-invasive methods of obtaining this information can aid with conservation efforts, including reintroduction projects, while having less of an impact on the study population (Waugh and Monamy 2016). Although invasive methods are frequently used for monitoring individuals, Zemanova (2020) emphasises the role of non-invasive monitoring in wildlife conservation and how the 3R's theory (i.e. reduction,

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refinement and replacement), which is often incorporated into animal protection legislation, should be applied to wild as well as captive populations, as non-invasive monitoring can cover all three (Lindsjö et al. 2016)).

One method of individual identification that has been used in many other species, including green sea turtles (*Chelonia mydas*) (Carpentier et al. 2016) and cheetahs (*Acinonyx jubatus*) (Wilson 2007), is the use of natural markings, which can be examined using photographs collected in the field and using identification software. In brown bears (*Ursus arctos*), which generally lack distinctive features, facial recognition program BearID has been used to identify individuals with 83.9% accuracy (Clapham et al. 2020). Trail cameras can often be used to collect such data, and citizen science can be incorporated, which can allow for increased data collection and processing (Green et al. 2020).

As many species age, the colour of the integument (skin, feathers, fur, or scales) will change, allowing for exact age determination (e.g. Bergman and Beehner 2008; Castles et al. 2019). In some species this variation is continuous, allowing exact age to be determined (e.g. by measuring reflectance values), for example in male western bluebirds (*Sialia mexicana*) (Budden and Dickinson 2009) and blue tits (*Cyanistes caeruleus*) (Sheldon et al. 1999; Delhey and Kempenaers 2006). In other species, colour variation may only be used to determine age groups, as the variation is less continuous, for example iris colour in American kestrels (*Falco sparverius*) (Bortolotti et al. 2003) and sparrow hawks (*Accipiter nisus*) (Newton and Marquiss 1982).

This study examines potential methods of identifying and ageing beavers from the tail. There are two species of beaver (*Castor* spp.), the North American (*C. canadensis*) and Eurasian beaver (*C. fiber*) (Rosell and Campbell-Palmer 2022). They are ecosystem engineers, impacting both biotic and abiotic features and provide a wide range of ecosystem services, including increasing biodiversity (Law et al. 2016) and regulating water levels (Puttock et al. 2017). In the sixteenth century, Eurasian beavers were almost hunted to extinction for their fur and castoreum (Rosell and Campbell-Palmer 2022); however, a few stronghold populations remained, including in Telemark, Norway (Collet 1897). Telemark is now home to the Norwegian Beaver Project, one of the longest running beaver projects, which began in 1997 (University of South-Eastern Norway 2020). The Norwegian population has been a source for many Eurasian beaver reintroduction programmes, and they have since been reintroduced across much of Europe, with their range increasing by around 550% since the 1950s/60s (Deinet et al. 2013). Beavers are also kept in captivity in zoos, and in some areas they have been introduced into fenced enclosures, which are often seen as the first step towards a reintroduction. For example in England, there are over 25 semi-captive populations which have been released into fenced areas (Heydon et al. 2021).

To monitor these populations, many studies use PIT tags or ear tags for individual identification, which involves capturing (Rosell and Kvinlaug 1998; Rosell and Hovde 2001). PIT tags can only be read within close proximity to the beaver; however, fixed readers can be successful when placed at a lodge (Briggs et al. 2021) or along foraging trails (Farsund 2020). Coloured ear tags allow individuals to be identified at a greater distance but have single loss rates varying from 3.3 to 18.4% (Leege 1968; Windels 2013). Examining naturally occurring tail scars is a less invasive method of identification. However, this is ineffective in younger individuals who usually lack such scars (Mayer et al. 2020) as these can often be a result of territorial disputes.

Non-invasive methods of ageing beavers from the tail colour have been reported, with the colour of the tail becoming lighter as the beaver ages (Jenkins and Busher 1979). This however is based on observations of North American beavers, but as they are morphologically similar, it is expected a similar trend will be observed in the Eurasian beaver. The accuracy of these methods, however has yet to be examined. Brandt (1855) studied variation within Eurasian beaver tails, but results were limited by small sample size.

This study therefore aims to examine the accuracy of identifying and ageing beavers from the tail but with a larger sample size and photographic evidence. We hypothesised that individual Eurasian beavers can be identified from the epidermal scale pattern on the tail, using a relatively quick and simple method that requires no previous training. We also hypothesised that beavers could be aged from the colour of the tail, with the colour becoming lighter as the age of the beaver increases.

Material and methods

Study area and animals

This study was conducted in Bø, Nome and Midt-Telemark, Vestfold and Telemark, Norway, with Eurasian beavers from the Norwegian Beaver Project (NBP) hunting project. The beavers ($N = 113$) used were shot during the spring hunting period 1997–1999, and tooth irruption and root closure, or cementum annuli counts were used to determine age when the beavers were first obtained (van Nostrand and Stephenson 1964). After processing, all tails were put into storage in a walk-in freezer at a temperature of −20 °C and remained there until being used for this study. Although the tail samples used in this study were collected invasively, if successful, it is possible the methods of identification and ageing could be implemented out in the field using trail cameras.

We used a Nikon D3500 (DSLR) camera (Nikon Corporation, Tokyo, Japan) with an 18–55-mm lens (AF-P Nikkor) to photograph Eurasian beaver tails. Each tail was defrosted using warm water to speed up the process (access was limited due to COVID-19 pandemic, so it was not possible to allow them time to defrost without using water), then dried before being immediately photographed on a plain, cream-white background.

Individual identification

Monochrome photographs (JPEG) were taken of 100 tails selected using a random numbers generator (total = 113 tails, 100 selected to fit grid format). For each tail, 3 photographs were taken, one at each distance. Exact distances between the camera and the tail varied due to variation in tail size, so grid squares on the camera view finder were used to ensure consistent sizing, as inconsistencies could have impacted the results of this study ('close'—4 grid squares on the camera view finder, 'medium'—the length of the tail-filled three grid squares, 'far'—the length of the tail filled the length of two grid squares) (Fig. 1a–d). 'Cropped' photos were later created by cropping a 15.24 × 10.1 cm section from the 'close' photos at the widest part of the tail. In tails with scarring, the largest area without damage was used to ensure tail shape and scarring did not influence match selections.

Photos of the 100 tails were printed (15.24 × 10.1 cm) and each photo was labelled with corresponding tail number (each tail was assigned a number between 1 and 100) on the back to enable accuracy to be determined after the matching process was completed. The tails were sorted randomly into groups consisting of 25 tails, as this was a manageable number to examine (each group had the 'close', 'medium', 'far' and 'cropped' photos of each tail). Within each group, the photos were then separated according to the distance of the photo.

The 'close' photos (process repeated with 'medium' and 'far' photos) were laid out in a 5 × 5 grid, with the axis labelled 1–5 and A–E (Fig. 2). These were then matched with the 'cropped' photos (25 'cropped' photos, one corresponding with each 'close' photo) by eye. The 'cropped' photos were studied and key features (such as a distinctively shaped scale or pattern) outlined, and the photos in the grid were then checked for similar features, and the pattern of surrounding scales checked to determine whether photos were a match. For the final round of matching, a stopwatch was used to record the time taken. All photo matching was conducted by the first author, who had no experience in non-invasive individual identification or photo matching prior to this study.

Once a photo was matched, it remained in the grid to enable false positives and negatives to be calculated. Each cropped photo ($N = 25$ each round) was therefore checked against 25 potential matches (itself and 24 other individuals), resulting in 625 photo checks each round. Once all photos were matched, the process was completed again, matching 'cropped' and 'medium' photos, then 'cropped' and 'far'. The trial was conducted an additional 3 times with a different set of 25 individuals each time, with a total of 100 individual beavers being identified.

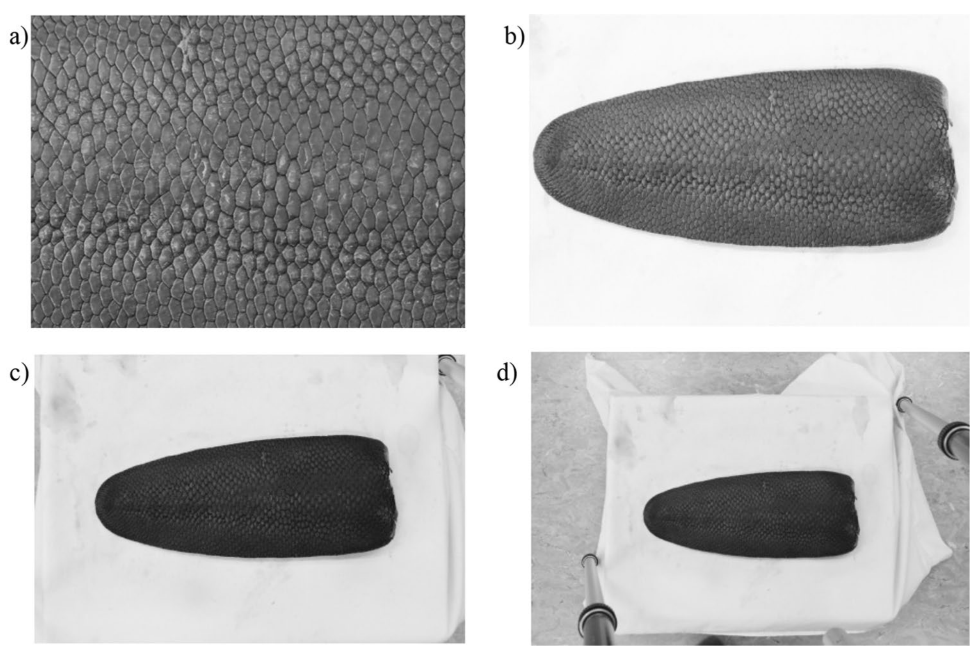

Fig. 1 Photographs of one of the tails used for individual identification, showing **a** 'cropped' photo used as an 'example' photo, and **b** 'close', **c** 'medium' and **d** 'far' photos (photos by R. Hinds)

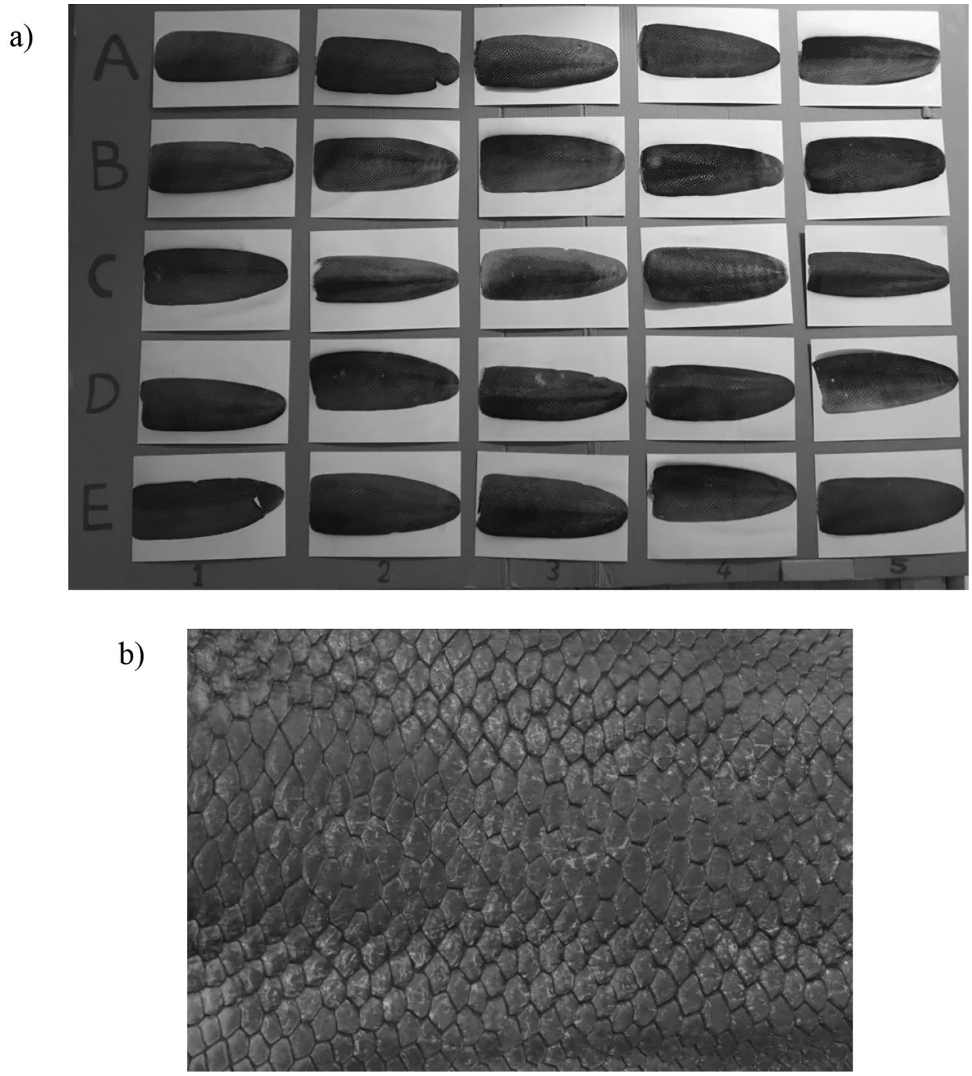

Fig. 2 **a** Photograph of the grid setup for the individual identification process for the 'close' photos, before being matched with 25 corresponding 'cropped' photos (**b**) (photos by R. Hinds)

Ageing

Additional photos of the 113 tails (also of known age, mean = 4.30, SD = 3.12 and ranging from 1 to 14 years) were taken in the lab with consistent lighting. The whole tail was included, filling the length of the frame, and a 19% grey card was included. An additional photo of the grey card and an X-Rite ColourChecker (reflectance values ranging 91.5736394356503–3.21941237074612) was used to calibrate the photos in micaToolbox to improve consistency across the dataset (Troscianko and Stevens 2015).

The camera was calibrated using the model linearisation function (plugins > micaToolbox > camera calibration > model linearisation function). The pre-loaded reflectance values matched those of the colour checker and the calibration model was named as the make and model of the camera. Reflectance values were matched to the corresponding square of the colour checker, and the results showed the JT linearisaton model as best fit. The results were saved and used to generate a multispectral image of each tail (plugins > micaToolbox > generate multispectral image). 'Visible' was selected as camera type, and the image was set as 'custom non-linear' as they were JPEG images. The grey card was included in the same photo and 'standard reflectance' set at 19. Image output for measuring red, green and blue (RGB) values was 'linear colour image'. The appropriate calibration model was applied, and the multispectral image saved as JPEGs.

Colour and brightness were both measured in Photoshop 2021 (Adobe, California, USA) as it allowed for the mean colour values of the tail to be taken more efficiently. Each tail photo was entered, and the 'select object' tool was used to select the tail. This allowed the whole tail to be selected without having to draw the outline by hand, making it less time consuming than conducting all analysis on micaToolbox. As Photoshop only allows for single point colour and brightness measurements, the 'blur' tool was used to calculate the mean of each tail (filters > blur > average). Once the image is processed, the colour picker tool can be used on any area of the tail to determine the red, green and blue measurements, along with the brightness.

Data analysis

Individual identification

Once each match was recorded, the answers were checked. The percentage of matches identified correctly and the number of false positives and negatives was calculated for each distance ('close', 'medium' and 'far') in Excel (Microsoft Corporation, Redmond USA 2007). A chi-square test was then conducted with the time taken to identify the tails at the 'close' and 'medium' distances, followed by 'medium' and 'far'. This was done to test the sub-hypothesis suggesting that identifying individuals would take longer as the photo distance from the tail increased.

Ageing

Results were entered into an Excel sheet along with the corresponding tail identification number, age and age group (both age and age group (yearlings 1, subadult 2, adult 3 + years old) included in analysis as some colour variation is continuous in some species, but can only be used to determine age group in others). A regression test was conducted to examine the relationship between each colour value and brightness and age/age group.

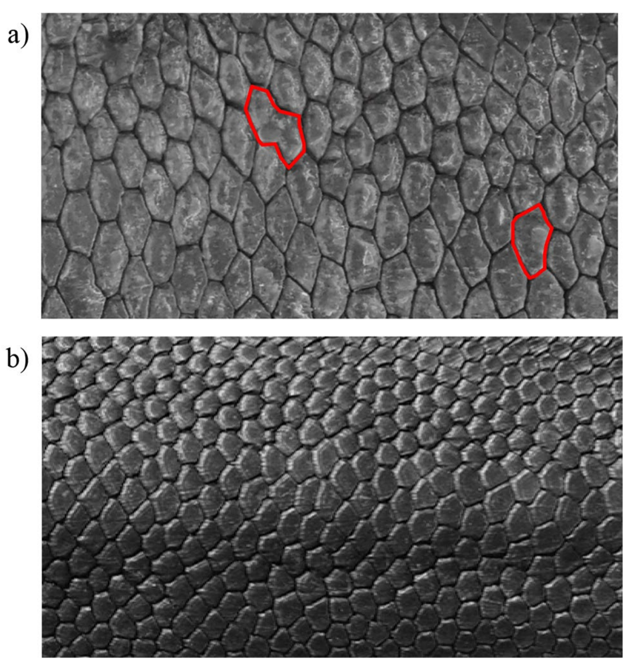

Fig. 3 Eurasian beaver tail with **a** many distinctively shaped epidermal scales, which can be used as focus areas for individual identification, **b** more scales with a regular shape, the unique pattern of which can be used for individual identification (photos by R. Hinds)

Table 1 Regression results from red, green and blue (RGB) colour analysis for Eurasian beaver tails from beavers from each age group (groups: 1 year old, 2 years old and 3 + years old)

	R^2adj	F	p value
Red	− 0.001	0.604	0.439
Green	0.001	0.979	0.325
Blue	0.007	1.766	0.187

Results

Individual identification

From the 100 tails identified, the accuracy across all three distances ('close', 'medium' and 'far') was 100%. As some tails had clear identifying features, such as a larger or differently shaped scale, the difficulty in identifying each tail varied; however, around 80% of the tails had a clear identifying feature and were therefore simple to match. Those without distinctive features, however could still be identified by studying the pattern of the scales (Fig. 3). The time taken to identify individuals at the 'close' and 'medium' distances did not vary significantly ($\chi^2 = 0.76$, $p = 0.38$). However, there was a significant difference between the time taken to match the photos at the 'medium' and 'far' distances ($\chi^2 = 196.89$, $p < 0.01$). On average, it took around 45 min for each round of photo matching.

Ageing

Brightness values (mean = 4% brightness) were not impacted by either age or age group (R^2adj = -0.02 and $F = 0.805$ ($p = 0.372$) for age groups ($N = 113$), and R^2adj = 0.004, $F = 1.378$ ($p = 0.243$) for ages ($N = 107$, some exact ages not recorded)). The RGB values showed similar results, with no statistically significant results observed for age group (Table 1) or age (Table 2).

Table 2 Regression results from red, green and blue (RGB) colour analysis for Eurasian beaver tails from beavers of varying age (range 1–14)

	R^2adj	F	p value
Red	0.012	2.313	0.131
Green	0.016	2.690	0.104
Blue	0.007	1.766	0.187

Discussion

The accuracy of the method of individual identification was 100%; therefore, we accept our hypothesis that individual Eurasian beavers can be identified by the pattern of epidermal scales on the tail. The methods used for ageing; however, failed to provide accurate results, therefore for this study, we reject the hypotheses that the colour of the tail becomes lighter as the age of the beaver increases in Eurasian beavers.

Individual identification

Throughout this study, the time taken to match all individual tails increased with distance. The level of detail captured in the photos was similar at the ‘close’ and ‘medium’ distances; however, the ‘far’ photos required much closer examination and therefore, the process took much longer. Despite the increase in time taken and difficulty (photos required more thorough checking as distance increased), accuracy remained constant across all distances.

Tests were conducted by eye, as some identification software (e.g. WildID) failed to make any correct identifications during initial trials. The trial consisted of a group of 25 tails as used in this study; however, as none was correctly identified, further trials were conducted by eye. The software may have failed due to the level of detail required to match the tails from the scale pattern, as features such as colouration and scarring, which are commonly used for individual identification, were omitted from this study. Further trials were conducted by eye. The method we used is simple, and potentially has a much wider application. Utilising software however would reduce the time taken to match individuals and will remove human error, while also allowing data collection in larger-scale monitoring programmes (Arzoumanian et al. 2005). Therefore, further study should be conducted to configure software that works with the fine level of detail required for beaver tails.

By conducting the three distances separately and using monochrome photos, it was not possible for other factors, including tail shape and colour, to be used to match the photos. Tail shape, including tail scars, can be used for individual identification. However, these can vary with time, so are less useful for longer-term projects. The tails used in this study were stored in a freezer prior to use, so it is possible that some cellular damage may have occurred. All tails were stored in the same freezer, were not defrosted prior to this study and were defrosted using the same method prior to use, so it is unlikely that this could have impacted results as all tails received the same treatment.

Grids of 25 tails were chosen as it is a manageable number for the researcher to examine, and as results were not checked until all had been completed, it was not possible to rule out any photos as being a potential match, as any previous matches may have been incorrect. Also, as beavers are territorial, individuals captured within a territory are therefore likely to be of the same family, or neighbours, limiting the number of potential matches in the field (subordinate individuals may also cross multiple territory borders on forays (Mayer et al. 2017)). As the sample size will be small (in normal circumstances, the maximum will be around 6 individuals per family), identifying individuals should be relatively quick and simple. This method would also be useful in enclosed reintroduction trials, where there is a limited number of known individuals. As mark-recapture models are commonly used in photographic identification (Marshall and Pierce 2012), one of the main problems is a result of large numbers of transient individuals (which is less common in beavers), or population sizes, as this can lead to bias, for example in survivorship estimates (Holmberg et al. 2008). Beavers are therefore an ideal species for photographic identification.

As there was 100% accuracy, further trials should be conducted. These would involve testing with a known beaver population, such as an enclosed population, where individuals can be identified (for example by external ear tags or tail scarring), enabling initial photos to be identified. Although initial trials may require an additional way of identifying beavers, many previous studies have used external tags to validate results (e.g. Carpentier et al. 2016; Reisser et al. 2008), and some use captive populations to examine pattern variation over time (Bansemer and Bennett 2008). If photos are taken of the tail prior to release; however, it will be possible to identify individuals without ear tags or PIT tags.

Trials should be conducted using trail cameras, some of which can have a higher resolution than the DSLR camera used in this study (e.g. Bushnell core DS no glow). The height they are placed at and orientation will affect the quality and detail captured in the images. However, Dytkowicz et al. (2023) show that trail cameras can capture sufficient detail to identify individuals when fitted with an additional lens. The scale pattern on the tail should also be monitored to determine if it varies during the lifetime of the beaver, with age or season. Although identifying scale patterns and markings do not vary in many species (e.g. Harmsen et al. (2017); Villafañe-Trujillo et al. (2018)), this has yet to be examined in beavers. As all beavers used in this study were from the hunting project (i.e. dead), and therefore not monitored over time, it is possible that the scale pattern will vary.

If it proves to be an accurate method in the field, it would benefit many beaver monitoring programmes, as the process can be done by eye and requires no training, and it would especially benefit reintroduction projects, as the impact of trapping is most prominent in the early years (Mortensen and Rosell 2020).

Ageing

Although the results showed no statistical difference in the red, green, blue or brightness variation between the ages or age groups, it is not possible to conclude that the method is inaccurate, as there were a number of limitations.

One limitation is the storage of the tails. Some of the tails used date back to 1997 when the NBP began (University of South-Eastern Norway 2020). They were stored in the freezer, and it is possible that some of the tails could have been damaged (e.g. freezer burn), resulting in discolouration of the tail (Kaess 1961; Schmidt and Lee 2009). Resources were also limited to one grey standard, including more would have limited the need for further calibration.

Further trials are therefore required, especially in the field with individuals of a known age using trail cameras. However, if initial field trials are unsuccessful, other non-invasive methods of ageing should be examined, such as the angularity of scales, as Brandt (1855) reports they become more angular with age.

Conclusion

The results from individual identification indicate that this method could potentially be used in non-invasive monitoring. Further trials are required using trail cameras with an external lens (Dytkowicz et al. 2023) to determine the accuracy in the field. As the method for ageing was inaccurate, field trials should also be conducted with living beavers of a known age. If successful, the methods described could be used to monitor beavers, especially captive and semi-captive populations, using non-invasive techniques.

Acknowledgements For advising this study, we thank Dr. V. Deecke, and the University of South-Eastern Norway and the University of Cumbria for facilitation. For their assistance, we thank C.A. Robstad and F. Bergan.

Author contribution R.H. conducted photo matching, wrote the main manuscript text and prepared figures, supervised by F.R. F.R. and M.D. completed initial reviews and edits to the manuscript. Further reviews and edits were completed by all authors. All authors were involved with the formulation and planning of the tail identification project.

Funding Open access funding provided by University Of South-Eastern Norway. This study was funded by the University of South-Eastern Norway.

Data availability Data can be accessed through the University of South-Eastern Norway data repository.

Declarations

Ethics approval This study was conducted using beavers that had been hunted in previous open seasons. Any beavers previously hunted outside the open season were approved by the Norwegian Directorate for Nature Management. Ethical approval was granted by the University of South-Eastern Norway Ethics Committee and University of Cumbria Ethics Committee.

Competing interests The authors declare no competing interests.

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