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Tools and Technology

Using Radio-Frequency Identification Technology to Monitor Eurasian Beavers

ALEXANDER J. A. BRIGGS, *Department of Science, Natural Resources and Outdoor Studies, University of Cumbria, The Barn, Rydal Road, Ambleside, LA22 9BB, United Kingdom; and Faculty of Technology, Natural Sciences and Maritime Sciences, Department of Natural Sciences and Environmental Health, University of South-Eastern Norway, Gullbringveien 36, 3800 Bø i Vestfold and Telemark, Norway*

CHRISTIAN A. ROBSTAD, *Faculty of Technology, Natural Sciences and Maritime Sciences, Department of Natural Sciences and Environmental Health, University of South-Eastern Norway, Gullbringveien 36, 3800 Bø i Vestfold and Telemark, Norway*

FRANK ROSELL,[1] *Faculty of Technology, Natural Sciences and Maritime Sciences, Department of Natural Sciences and Environmental Health, University of South-Eastern Norway, Gullbringveien 36, 3800 Bø i Vestfold and Telemark, Norway*

ABSTRACT The use of radio-frequency identification (RFID) offers new potential in remote wildlife monitoring to reduce the invasive nature of studies requiring direct contact with study animals. Facilitated by the emergence of new technology, RFID can remotely identify individual animals implanted with passive-integrated-transponder (PIT) tags. We aimed to establish and assess a new technique for remote RFID for remotely and noninvasively monitoring a wild population of a semi-aquatic mammal, the Eurasian beaver (*Castor fiber*). A fixed reader was installed from June 2018 to July 2019 at beaver lodges within the territories of 8 family-groups in Vestfold and Telemark, Norway, for 3 nights per lodge, with RFID antennas at lodge entrances. Microchipped beavers were detected when entering or leaving the lodge. The family-group size recorded using RFID was compared to the known family-group size based on live capture records and direct observations. The family-group size recorded using RFID was smaller than the known family-group size. However, testing suggested that individuals inhabiting a lodge with a fixed reader installed had a high probability of detection (98.44%). Fixed readers are effective where the identification of individuals at a focal point is appropriate, with unique applications for monitoring species with high fidelity to lodges or dens, or species that exhibit central-place foraging behavior. Research using RFID through fixed PIT tag readers should be given priority for noninvasive beaver population monitoring. Whereas fixed PIT tag readers may not record entire beaver family-groups, they provide an accurate and efficient alternative to other monitoring techniques. © 2021 The Authors. *Wildlife Society Bulletin* published by Wiley Periodicals LLC on behalf of The Wildlife Society.

KEY WORDS *Castor fiber*, Eurasian beaver, fixed readers, microchips, noninvasive methods, PIT tags, radio-frequency identification, remote monitoring, RFID.

Radio-frequency identification (RFID) involves the detection of passive-integrated-transponder (PIT) tags, also known as microchips, passing within range of an antenna (Boarman et al. 1998). Passive-integrated-transponder tags are permanently implanted tags detected by RFID, through antennas emitting an electromagnetic field (Boarman et al. 1998). When a PIT tag passes an antenna, it uses the energy of this field to transmit its unique identity number, which is then detected by the antenna (Boarman et al. 1998). Developments in RFID technology to detect PIT tags remotely have reduced invasive monitoring, and increased the efficiency and accuracy of population monitoring for multiple species (Boarman et al. 1998, Sutherland and Singleton 2003, Taylor et al. 2012).

Automatic, fixed-position PIT tag readers, (hereafter fixed readers) are remote monitoring systems that record the encounter of PIT-tagged animals at specific locations (Boarman et al. 1998). Fixed readers may be left in the field to monitor continuously without the need for human observation as PIT tags do not use internal batteries, although fixed readers do require batteries (Sutherland and Singleton 2003, Gibbons and Andrews 2004, Nord et al. 2016). Such systems originated as monitoring methods for fisheries being first developed by Prentice et al. (1987) and later becoming an established monitoring method for wild fish populations (Fängstam 1993, Gibbons and Andrews 2004, Zydlewski et al. 2006). Recent studies have adapted fixed readers to solve monitoring issues for Chatham Island

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[1]*E-mail: frank.rosell@usn.no*

taiko (*Pterodroma magentae*; Taylor et al. 2012), desert hamster (*Phodopus roborovskii*; Scheibler et al. 2013), platypus (*Ornithorhynchus anatinus*; Macgregor et al. 2015), great tits (*Parus major*; Nord et al. 2016), and mountain chickadees (*Poecile gambeli*; Tello-Ramos et al. 2018).

By using fixed readers, it is not necessary to recapture PIT tagged animals to monitor them after initial capture. Fixed readers, therefore, have the potential to reduce invasive capture events during capture-mark-recapture studies (Sutherland and Singleton 2003, Taylor et al. 2012). This enables the monitoring of individuals with a low probability of recapture due to behavioral or physiological traits (Sutherland and Singleton 2003, Taylor et al. 2012). Taylor et al. (2012) achieved a 100% recapture rate using fixed readers to monitor Chatham Island taiko at burrows, compared to 50–60% using leg bands identified through hand-capture, video recording, and burrow scopes. Similarly, Pengilly and Watson (1994) achieved a >94% recapture rate of red king crabs (*Paralithodes camtschaticus*) within a fishery processing system.

Fixed readers are effective at monitoring activity at focal points, but their suitability is limited to subjects with a high site fidelity, such as territorial animals and central-place foragers (Sutherland and Singleton 2003). Fixed readers are highly applicable to species with a high fidelity to denning or resting sites, as shown by studies using antennas at roost entrances to study lesser short-tailed bats (*Mystacina tuberculata*; O'Donnell et al. 2011), and at burrow entrances to study salamanders (*Plethodon* spp.; Connette and Semlitsch 2012), and wild house mice (*Mus musculus*; Sutherland and Singleton 2003). While fixed readers have not been widely used in the study of semi-aquatic mammals, Macgregor et al. (2015) studied platypus using in-stream antennas. Wild individuals were captured and implanted with PIT tags either during a 7 month period 4 years before the main study, or during the 15 months leading up to the main study. Of these individuals, 43% and 72% were recaptured with fixed readers, respectively. The rates of recapture were comparable to recapture rates for live capture studies, demonstrating the effectiveness of RFID for the study of semi-aquatic mammals (Macgregor et al. 2015). To date, no studies have used RFID for the study of semi-aquatic mammalian family-group sizes.

Both extant species of the order *Castor*, the Eurasian (*C. fiber*) and the North American beaver (*C. canadensis*) are large, semi-aquatic rodents that form territorial social family-groups, consisting of one breeding pair (monogamous adults) and their offspring, grouped into kits, yearlings, and 2-year-olds (subordinate adults; Wilsson 1971, Campbell et al. 2005). Family-groups inhabit multiple lodges, generally inhabiting one at a time, although individuals in a family-group may simultaneously inhabit multiple lodges and burrows (Busher 2007, Müller-Schwarze 2011). Riverbank lodges are composed of multiple underwater entrances to branch-covered tunnels leading to feeding and sleeping chambers in the riverbank (Wilsson 1971).

Behaviors within lodges are predominantly inactive and include social interactions between family members and rest (Wilsson 1971, Mott et al. 2011). Periods of activity occur away from lodges, when beavers predominantly forage, travel, and patrol, but will also spend time on construction behaviors and territory defence (Lancia et al. 1980, Sharpe and Rosell 2003, Graf et al. 2016). As central-place foragers, beavers will also bring vegetation back to lodges to feed (Haarberg and Rosell 2006).

The behavior of beavers, being semi-aquatic and nocturnal, makes population monitoring particularly difficult (Rosell et al. 2006, Swinnen et al. 2015). Methods used to monitor the number of animals in a family-group often rely on capture-mark-recapture studies (Rosell and Hovde 2001, Campbell et al. 2012, White et al. 2015, Graf et al. 2016, Mayer et al. 2017). Noninvasive studies use direct observation (Rosell and Nolet 1997; Rosell et al. 1998, 2006), camera traps (Severud et al. 2011), and filming within lodges (Patenaude-Pilote et al. 1980, Bloomquist and Nielsen 2009, Mott et al. 2011). However, drawbacks to these methods highlight the potential of RFID for the noninvasive monitoring of animals in a family-group. For example, capture-mark-recapture studies necessitate repeated recaptures and are therefore intrinsically invasive, while direct observation introduces the potential for human error (Estes et al. 1982, Maloney et al. 2005), and the presence of an observer may alter the behavior of the animal under observation (Brown et al. 2013). Święcicka et al. (2014) found issues observing beavers due to their nocturnal behavior. Similarly Rosell et al. (2006) found that kits were undercounted. Severud et al. (2011) and Swinnen et al. (2014) found the majority of images collected by remote camera traps did not contain the target species, and the data requires large amounts of time to process. Furthermore, Bloomquist and Nielsen (2009) found that using filming within lodges, visual individual identification was rarely possible, and all individuals were not simultaneously visible, therefore complete family-group counts were not possible.

Baker and Hill (2003) suggested the possibility of using fixed readers to monitor beavers. Several population monitoring studies have used PIT tags and handheld readers for the identification of captured beavers when handled (e.g., Rosell and Hovde 2001, Goodman et al. 2012). However, as far as we know, there has been no application of fixed readers to monitor free-ranging beavers.

We aimed to develop a new RFID technique, using fixed readers specialized to account for the monitoring challenges of beaver, and assessed the effectiveness of this technique for monitoring the number of animals in a family-group. This was achieved by developing a fixed reader and applying this to detect beavers (previously PIT tagged) passing an antenna at lodge entrances. We tested the hypothesis that the fixed reader would record all members of each family-group studied, and provide an accurate and efficient alternative to other monitoring techniques.

STUDY AREA

Data were collected from June 2018 to July 2019 on the Straumen, (59°29′N, 09°153′E) and Saua (59°444′N, 09°307′E) rivers, in Nome and Midt-Telemark municipalities, Vestfold and Telemark, Norway (Fig. 1). These were slow

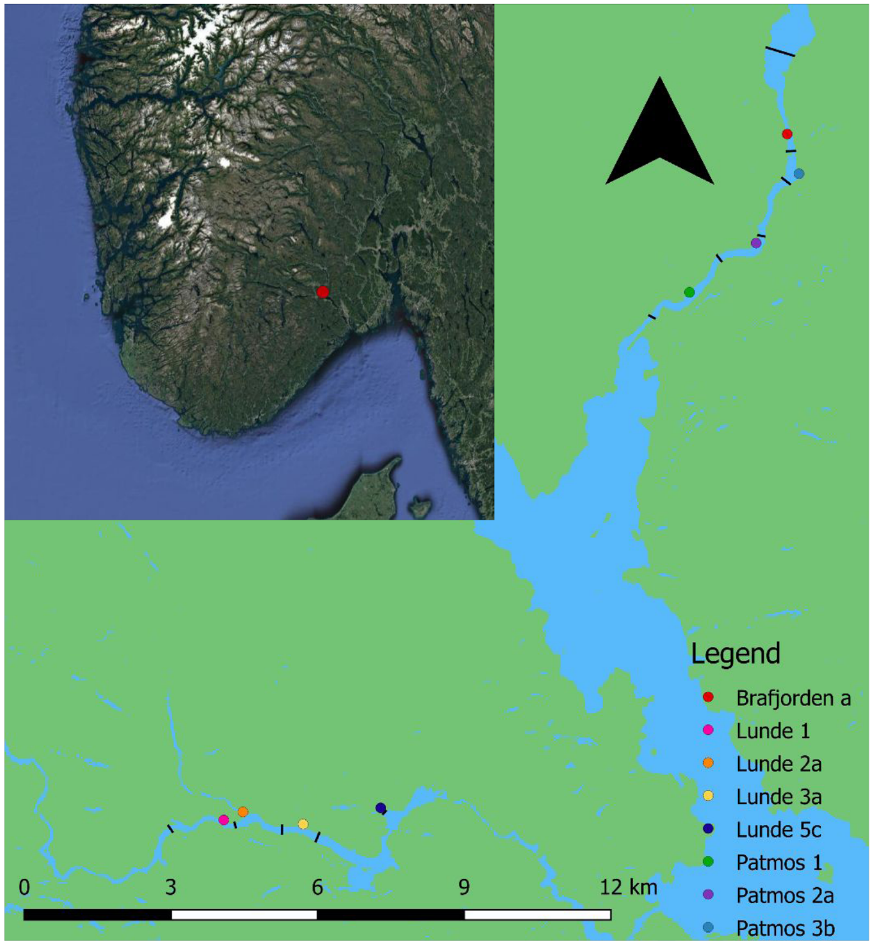

Figure 1. The study area used to test automated, fixed-position passive integrated tag readers in Vestfold and Telemark, Norway. Black lines denote territory boundaries for family-groups, while red markers show the positions of beaver lodges studied on the Straumen (59°29′N, 09°153′E, Nome municipality) and Saua (59°444′N, 09°307′E) rivers in Sauherad municipality from June 2018 to July 2019 (based on satellite imagery from Landsat 8; United States Geological Survey, VA, USA).

flowing rivers varying in width from 20 to 150 m (Campbell et al. 2012). The countryside around the rivers was mixed agricultural land (pastoral and arable) and forest dominated by Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and grey alder (*Alnus incana*), alongside European aspen (*Populus tremula*), willow (*Salix spp.*), downy birch (*Betula pubescens*), and rowan (*Sorbus aucuparia*; Haarberg and Rosell 2006). The study area had a mean annual temperature of 4.6° C and a mean annual precipitation of 790 mm (Campbell et al. 2012).

Beavers recolonized the study rivers in the 1920s (Olstad 1937). The population expanded with low pressure from hunting and natural predators limited to small populations of lynx (*Lynx lynx*; Campbell et al. 2012). Population densities along both rivers were at carrying capacity (Campbell et al. 2012).

METHODS

Verification of Active Lodges

Territories of family-groups were previously determined by radio tracking (Campbell et al. 2005), GPS tagging (Graf et al. 2016, Mayer et al. 2017), locations of scent mounds, and direct observations (Rosell et al. 1998; Campbell et al. 2012, 2013). In autumn 2017 and 2018 we carried out surveys to identify the main lodge in each territory. We approached each lodge by boat and examined for evidence of beaver activity. Beaver activity leaves conspicuous and unmistakable sign such as freshly gnawed branches, tracks, fresh branches and mud on lodges, and food caches collected before winter (Wilsson 1971, Swinnen et al. 2017). We recorded positions of active lodges using a Garmin eTrex 30× (Garmin Corp. Olathe, KS, USA) handheld GPS unit (Fig. 1).

PIT Tag Implantation

From 1997 to the present, continuous capture–mark–recapture studies have been carried out on the study rivers by the Norwegian Beaver Project (NBP; Rosell and Hovde 2001, Mayer et al. 2017, Graf et al. 2018). Beavers were captured with landing nets and implanted with a combination of colored metal (National Band and Tag Co., Newport, KY, USA) and plastic (Dalton Tags, Newark, UK) ear tags (Campbell et al. 2012), and subcutaneous PIT tags in the neck (for full method see Rosell and Hovde 2001). Implanted PIT tags were ISO (International Standards

Organisation) compliant, full duplex-B transponders (ISO 11784/11785; Avid Identification Systems, Inc., Norco, CA, USA; Trovan Ltd., Douglas, Isle of Man, UK; Destron Fearing Corp., South St. Paul, MN, USA; Sharpe and Rosell 2003, Campbell et al. 2012). The tagged population consisted of 64 PIT tagged beavers across 18 family-groups in autumn 2018.

Development of Fixed Reader

We used a Trovan LID650/665 (Trovan Ltd., Douglas, Isle of Man, UK) fixed reader, with custom built antennas (BTS-ID, Helsingborg, Sweden). The system consisted of 2 square antennas, with apertures 43 cm high and 62 cm wide, connected by cable to loggers above the water. We encased the antennas in stainless steel to prevent damage from beavers. We stored readings on an external USB drive attached to the primary logger. Each logger was powered by pairs of 30 and 72 Amp-hour (Ah) 12-volt lead acid calcium batteries and stored in a sealed stainless steel box (Fig. 2). The system, purchased in 2018, had an initial cost of US$3,327.

Installation and Use of Fixed Reader

We studied the main lodge in 8 family-groups, 44.44% of all tagged groups. Ten could not be studied due to multiple (>2), deep (>150 cm) entrances, or sediment-filled water, which made determining the lodge structure and entrance locations difficult. No lodges studied had more than 2 entrances. At study lodges, a researcher entered the water wearing waders to examine the lodge and locate entrance tunnels. We fixed antennas at the opening to each entrance tunnel using cable ties to attach antennas to the lodge structure. Small gaps around the outside of the antenna were covered with sticks, providing camouflage and ensuring that beavers passed through the antenna. We placed loggers in waterproof cases on the bank or lodge, chained to a tree and camouflaged using netting and vegetation (Fig. 3). We installed the fixed reader during daylight when beavers were likely to be inactive within the lodge to increase the chance that family members would be recorded when they left the lodge in the evening. The installation of equipment took an average of one hour and 28 minutes (SD = 0.03, range = 00:30–02:28). The fixed reader was placed for 3 nights per lodge. At lodges where 30-Ah batteries were used ($n = 2$), a second visit to the lodge to replace the batteries was necessary. These visits were as brief as possible, averaging 24 minutes (SD = 0.02, range = 00:08–00:39), to minimize human disturbance to the family-group. Findlay et al. (2017) suggest that in the case of the Eurasian otter (*Lutra lutra*), monitoring at entrances to lodges or burrows with cameras was far enough away from sleeping chambers to prevent disturbance to the study animals.

When a beaver implanted with a PIT tag passed through the antenna, the loggers took readings continuously while the tag was in range. We counted multiple readings from the same tag in one minute as one detection. Whereas a similar study by Macgregor et al. (2015) used 10 seconds, our focus on individual identification meant the number of detections was not relevant. When a new tag was recorded, this was counted as a separate detection. The logger recorded the time, date, and PIT tag number, which we used to identify the individual using the long-term, capture-mark-recapture records from the NBP.

In-Situ Testing

We tested the reliability of the fixed reader to record PIT tags in-situ at 4 lodges used for the main study and one additional random lodge in July 2018, after the 3-day study period for each lodge was complete. A full-scale model beaver was used, made of wood covered in a beaver pelt with a PIT tag placed under the hide, simulating the subcutaneous position of tags in live beavers. At each antenna, a researcher passed the model into the lodge 30 times at the inside edge of the antenna loop, (within approximately 15 cm of the antenna), and 30 times at the center of the

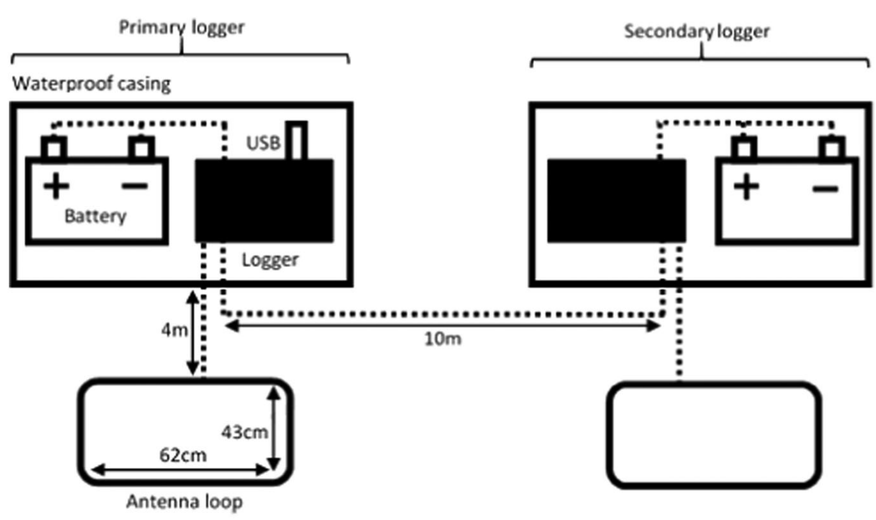

Figure 2. Schematic layout of an automated, fixed-position passive integrated tag reader used to monitor the number of Eurasian beaver family-group members in Norway during June 2018 to July 2019, with antennas loops placed around lodge entrances.

Figure 3. Photographs of the experimental radio-frequency identification set-up used to monitor Eurasian beaver in Norway during June 2018 to July 2019. (Top left) An automated, fixed-position passive integrated tag reader, with 2 loggers and corresponding antennas. The loggers were installed on the surface of the lodge in waterproof metal boxes (top right) and connected to underwater swim-through antennas attached to the lodge structure around entrance tunnels (bottom).

loop, to test the effects of beaver position. This was filmed, to give accurate times, and compared to data from the fixed reader to check for missed detections.

Monitoring Family-Groups

We compared the individual family-group members recorded by the fixed reader at each lodge to known family-group size. We calculated known family-group size using individuals captured by capture-mark-recapture monitoring and direct observation, which continued throughout the study period. We assumed that each family-group consisted of a minimum of one adult male and one adult female, and that juvenile individuals observed within one year had not dispersed. To account for the dispersal of individuals away from the family-group, a second estimate for known family-group size was made, with nondominant adult individuals aged 2 or more not recorded by fixed readers, removed from the known family-group size. We calculated detection probabilities for each lodge by dividing the number of individuals recorded by the total individuals at each lodge. Across all lodges a mean detection probability and standard deviation were taken. Data were normally distributed (Shapiro-Wilk, $P = 0.09$); therefore, we used an independent sample *t*-test to test for a difference between the size of family-groups recorded using RFID and the known family-group size. In addition, we left the fixed reader in place for 57 days following the 3 night (4 day) study period at 2 lodges (Patmos 2a and Bråfjorden a) to investigate whether the study period produced a representative of individuals inhabiting a lodge. We performed statistical analysis in the software packages R Studio 1.2.5019 (RStudio Inc., Boston, MA, USA) and Excel 1911 (Microsoft Corp., Redmond, WA, USA).

Ethical Statement

All procedures involving the trapping and handling of animals were approved by the Norwegian Experimental Animal Board and Norwegian Directorate for Nature Management, and landowner permission was obtained at each beaver lodge. No long-term effects of disturbance to animals or lodges were observed.

RESULTS

In-Situ Testing

The antennas used fitted lodge entrances well, ensuring that beavers inhabiting a lodge were recorded when entering and "exiting". During *in-situ* testing on the five lodges, the fixed reader recorded 98.44% of simulated entries/exits ($n = 450$).

Monitoring Family-Groups

Over 24 nights, 125 detections were made of 20 individuals across 8 family-groups (Table 1). Across all lodges, adult males (at least 2 years old) and juveniles (males and females up to 2 years old) had mean detection probabilities of 0.59 ($SD = 0.42$) and 0.63 ($SD = 0.48$) respectively; adult females had a lower mean detection probability of 0.56

(SD = 0.43). The mean family-group size recorded using RFID was lower ($\bar{x} = 2.50$, SD = 1.07) than the mean known family-group size ($\bar{x} = 4.38$, SD = 1.77; $t_{15} = 8.03$, $P < 0.001$=). The mean known family-group size, reduced to account for dispersal ($\bar{x} = 3.63$, SD = 1.41), remained greater than the mean family-group size recorded using RFID ($\bar{x} = 2.50$, $\bar{x} = 1.07$; $t_{15} = 9.14$, $P < 0.001$; Table 1). At lodges where the fixed reader was left in place for 57 additional days ($n = 2$), the family-group size recorded averaged 4.50 (SD = 2.13; Table S1, available online in Supporting Information), in comparison to the known family-group size that averaged 4.38 (SD = 1.77). Additionally, we found an average of 9.88 detections (SD = 15.45, range = 1–42, $n = 6$) during summer compared to an average of 5.75 during autumn (SD = 8.49, range = 17–29, $n = 2$).

DISCUSSION

The number of individuals recorded with RFID was lower than known family-group size. Therefore, we fail to accept our hypothesis that the fixed reader recorded all individuals in each family-group studied. This may have been due to the family-group moving away from lodges identified as active in the winter to other lodges in the territory by the time these lodges were studied, primarily in summer. Alternatively, this could have been due to the springtime dispersal of subordinate individuals away from the family-group (Hartman 1997), or subordinate individuals spending time away from the lodge during extra-territorial forays (Mayer et al. 2017). However, the reduced known family-group size accounting for dispersal also remained larger than family-group size recorded by RFID. When testing fixed readers, the use of other monitoring methods, such as very high-frequency (VHF) radio or GPS tracking, could be used to confirm whether individuals are inhabiting a lodge. Using fixed readers over longer periods may reveal lodge occupancy and dispersal patterns. At the two lodges where the fixed reader was left in place for an extended period, the number of individuals was greater; however, further research should be conducted into the optimal study period for this technique. *In-situ* testing showed that any individuals using the lodge had a high detection probability. Only 1.56% of simulated entries/exits were not recorded; therefore, this method may result in a similarly small proportion of missed individuals. Perhaps the angle of the PIT tag in relation to the antenna may affect whether a recording is made or not, potentially resulting in some missed individuals. Testing with a model beaver had a high detection rate; therefore, data collected by the fixed reader were considered accurate.

Fixed readers are comparable to filming within lodges, as both methods identify individuals within a family-group at a fixed position (Patenaude-Pilote et al. 1980, Bloomquist and Nielsen 2009, Mott et al. 2011). However, unlike direct observation or video identification inside lodges using external ear and tail markers, fixed readers can provide a definite identification of each animal recorded, with no possibility of observer error. Passive-integrated-transponder tags are lightweight, low cost, and require less effort to use during monitoring (Sutherland and Singleton 2003). While

Table 1. Number of detections and proportion of family-group recorded at each Eurasian beaver lodge monitored using an automated, fixed-position PIT tag reader in Norway during June 2018 to July 2019.

Family-group	Study dates	No. of RFID detections	Family-group size (captured/seen)	Family-group size from RFID	Family members captured/seen (age/sex)[a]	Family members from RFID (age/sex)	% total family-group recorded
Patmos 1	24–29 Oct 2018	17	7	4	Apple (F, 8+), Morten (M, 9), Gry (unknown), Mason (M, 5), Tatjana (F, 2)[a], Stephanie (F, 2)[a], Simona (F, 1)	Apple (F, 8+), Morten (M, 9), Gry (unknown), Mason (M, 5)	57.14
Patmos 2a	8–11 May 2019	42	6	4	Jen (F, 1), Anders (M, 7), Tom (M, 2), Giles (M, 2), Joar (M, 3), Tilla (F, 9+)	Tom (M, 2), Giles (M, 2), Joar (M, 3), Tilla (F, 9+)	66.67
Patmos 3b	1–6 Nov 2018	29	3	3	Mattanja (M, 2), Leigh (F, 12), Laurits (M, 12)	Mattanja (M, 2), Leigh (F, 12), Laurits (M, 12)	100
Bråfjorden a	8–11 June 2018	19	2	2	Dylan (M, 6), Leslie (F, 13+)	Dylan (M, 6), Leslie (F, 13+)	100
Lunde 1	25–30 June 2018	7	4	2	Waltraut (F, 6+), Odd Arne (M, 4+), Suvimaria (F, 2), Lea (F, 2)[a]	Waltraut (F, 6+), Suvimaria (F, 2)	50
Lunde 2a	15–18 July 2018	7	6	2	Richard (M, 3), Brita (F, 1+), Gyda (F, 14+), Leaf (F, 4)[a], Lasse (M, 14), Lottie (F, 3)[a]	Richard (M, 3), Brita (F, 1+)	33.33
Lunde 3a	18–22 July 2018	1	3	1	Kyle (M, 6+), Solveig (F, 5+), Molly (F, 2)[a]	Solveig (F, 5+)	33.33
Lunde 5c	27–30 July 2018	3	4	2	Yasmin (F, 6), Rudolph (M, 7), Kim (unknown, 0), Josselin (M, 2)	Kim (unknown, 0), Josselin (M, 2)	50

[a] Individuals removed when accounting for dispersal in family-group size.

fixed readers have a relatively high initial cost, PIT tags may be implanted into an entire family-group or population cost-effectively and with few visits to the field, rather than discretely tracking individuals, highlighting the application of fixed readers to monitor large family-groups or populations without the need for repeated captures of individuals (Sutherland and Singleton 2003). Where a large number of individuals in a population are PIT tagged, current monitoring requiring regular repeated captures to monitor the population could be simplified using fixed readers, which could be used for permanent continuous monitoring (Macgregor et al. 2015). Our method also reduces the number of observer hours required to monitor a population using direct observation and potential for human error or ambiguity present in direct observation or camera-based methods (Estes et al. 1982, Maloney et al. 2005, Bloomquist and Nielsen 2009). Overall, our approach could increase the efficiency of population monitoring, where it may otherwise be impossible or impractical to continuously monitor family-groups or geographic areas over long periods.

Fixed readers may be applied for continuous population monitoring, especially if used with multiple readers to simultaneously monitor all lodges within a family-group's territory. Future study should focus on seasonal variation in detection probability. Whereas our sample size was low, the average detections per season suggest summer is the most effective time to collect data, due to higher activity rates. However, studies conducted during spring and autumn may make results more reliable, as signs of activity are prominent at these times, reducing human error in study lodge selection. Using other monitoring methods such as direct observation, detection probability may vary temporally, due to factors such as light levels (Rosell et al. 2006). Therefore, although our study cannot state that fixed readers will record entire family-groups, the method provides an alternative to study beaver populations to a greater accuracy and efficiency than other monitoring techniques. For example, RFID could improve the noninvasive monitoring of population changes in relocated beaver populations, which are increasingly common in landscape rewilding projects (Halley 2011, Goodman et al. 2012, Stringer and Gaywood 2016).

Fixed readers can be used to monitor the presence of many individuals with spatial and temporal accuracy, albeit limited to focal points. Therefore, the technology also provides a technique to monitor a species' behavior (such as the differences in activity levels between different age and sex classes) without the need for tagging individuals with accelerometers or GPS. Furthermore, the technology provides the tools to study the spatial and demographic structures of a population, such as overall population size, or the geographic distribution of a population at a reintroduction site, without the need for repeated invasive recaptures. Future study should include using fixed readers to monitor family-groups on land, at positions likely to be revisited by beavers such as at territorial scent marks and foraging sites. Our study demonstrates the application of fixed readers to provide an alternative method to overcome traditional monitoring issues for beavers.

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SUPPORTING INFORMATION

Additional supporting information may be found online. Supporting Information includes examples of data showing lodge occupancy by family-group.