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# Performance of tail-mounted transmitters on American beavers *Castor canadensis* in a northern climate

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Tail-mounted transmitters have been used successfully in temperate regions of North America and Europe but have not been tested in more northern parts of American beaver *Castor canadensis* range. We deployed 63 tail-mounted transmitters on adult beavers in Voyageurs National Park, Minnesota (USA; 48°30′N, 92°50′W), at the southern edge of the boreal forest. Mean transmitter retention time was 133 days (range = 18–401, SD = 101), with only 7% retained > 12 months. Males and females did not differ in retention times. Retention time was similar for transmitters deployed in fall (n = 38, $\bar{x}$ = 135 days) and spring (n = 21, $\bar{x}$ = 130 days). In 24 cases where we confirmed beavers lost transmitters, 63% tore through the side of the tail, 25% pulled out through a widened attachment hole, and 13% had the lock-nut unscrew. Beavers chewed off or pulled out whip antennas on 50% of transmitters before they were detached from the tail, which reduced VHF signal strength and detection distance. The likelihood that an antenna would be damaged increased 3.8 times for each day of deployment up to 371 days. On average, beavers with transmitters lost 23% of their body mass and 26% of tail thickness over winter, and regained similar percentages over the growing season. Retention rates and retention times of tail transmitters were much lower in Voyageurs National Park relative to more southern areas in the United States where intra-annual variability in body condition is considerably less. Our results reaffirm that methodologies developed for wildlife telemetry or other research and monitoring techniques should be tested under different environmental conditions to ensure objectives can be met in a safe and efficient manner.

Beavers, *Castor* spp., are difficult to monitor with external telemetry transmitters. Their fusiform bodies are adapted to swimming, and collars mounted around the neck (Arjo et al. 2008) or the base of the tail (Rothmeyer et al. 2002) have demonstrated low retention rates in trials. Surgically implantable transmitters in beavers have been used successfully in North America (Davis et al. 1984, Smith et al. 2016) and Europe (Herr and Rosell 2004). Tail-mounted transmitters, first used on American beavers *C. canadensis* in the 1990s (Rothmeyer et al. 2002), have several advantages over body implants. First, they are relatively easy to mount and do not require general anesthesia or extensive surgery (Arjo et al. 2008). Second, because they are externally mounted with a long whip antenna, they should transmit farther than body implants with coiled antennas (Rothmeyer et al. 2002, Arjo et al. 2008).

Baker (2006) and Rothmeyer et al. (2002) reported limited success with early tail-mounted designs using modified cattle ear tags in Colorado and Wyoming, USA. Arjo et al. (2008) improved this design, including adding a nylon sleeve around the bolt to reduce rubbing and eliminate widening of the attachment hole. They field tested the new design on 29 wild beavers in Arizona, USA with good success: mean retention time was 343 days (± 44 SE), with 83% of beavers retaining transmitters for six months and 55% for 12 months. Several studies have used similar designs in Illinois (McNew and Woolf 2005, Bloomquist and Nielsen 2010) and Massachusetts, USA (DeStefano et al. 2006). Beavers in northern climates experience longer periods of nutritional restriction during winter than beavers in more southern climates; therefore tail transmitter performance may differ between these regions (Rothmeyer et al. 2002). We report the performance of tail-mounted transmitters on American beavers in a northern climate.

## Material and methods

### Study area

Voyageurs National Park (VNP; 48°30′N, 92°50′W) is an 883 km$^2$ protected area in northern Minnesota, USA, with 36% of the area comprised of large lakes. Vegetation is characterized as southern boreal forest dominated by aspen *Populus* spp., white birch *Betula papyrifera*, balsam fir *Abies* *balsamea*, spruce *Picea* spp. and pine *Pinus* spp. (Faber-Langendoen et al. 2007). Climate consists of warm, humid summers (mean July temp = 18.6°C) and cold, dry winters (mean January temp = − 16.1°C), with a mean annual temperature of 2.8°C (Kallemeyn et al. 2003). Ice generally forms in late November and persists until late April or early May; mean period of ice-duration in the large lakes in VNP from 1990–2014 was 145 days (SD = 17) (VNP, unpubl.).

## Methods

We captured beavers using Hancock live-traps during May (2006–2010) and September–October (2006–2009, 2011–2014). Trapping methods followed Windels (2014) but are briefly described here. Traps were set near active lodges and checked daily. We applied two uniquely numbered no. 3 monel ear tags (National Band and Tag Company, Newport, KY) to each captured beaver (Windels 2014). We restrained each beaver in a burlap sack to record weight (± 0.1 kg), zygomatic breadth (± 0.1 mm), maximum tail length (± 0.1 cm), and tail width at midpoint (± 0.1 cm). We classified beavers as male or female based on the presence of an externally palpated baculum (Osborn 1955), genetic analysis (Williams et al. 2004), or necropsy of recovered dead beavers. All beavers were later classified as kit (< 1.0 year old), subadult (1.0–3.0 years old), or adult (> 3 years old; Windels 2014).

We focused trapping at lodges along shorelines of large lakes. Bank lodges were most commonly trapped and typically consisted of sticks, aquatic vegetation and mud or clay piled against an excavated bank of soil or on sloping bedrock. In shallow lake bays, lodges were generally free-standing structures built of sticks, submergent and emergent vegetation, and mud or clay.

In fall 2006, we attached a modified ear-tag transmitter with mortality sensor (Advanced Telemetry Systems, Isanti, MN; model M3530, weight 35 g, whip antenna 30.5 cm, 8-h mortality sensor, expected battery life 421 days) to the tails of adult beavers following the protocol of Arjo et al. (2008). We attached transmitters midway along the long axis of the tail and 2 cm lateral to the spine to avoid damaging the bone and vascular or nerve tissue. The attachment area was sterilized using Betadine (Purdue Products, Stamford, CT) and isopropyl alcohol wipes and the skin around the attachment site was sprayed with a topical analgesic (6% Lidocaine; Dermal Source, Portland, OR). We used a cordless drill with a sterilized 6-mm diameter bit to drill the attachment hole. We filled the hole with hydrophilic antibiotic ointment and placed a section of nylon tubing into the hole, cutting the tubing flush with the top and bottom of the tail. We used a stainless steel machine bolt, cleaned with isopropyl alcohol, to attach the transmitter to the tail in the following order (from dorsal to ventral side of the tail; Fig. 1A): machine screw, 25-mm diameter steel washer, ear-tag transmitter, nylon tube, 25-mm neoprene washer, 25-mm diameter steel washer, nylon lock nut secured with thread glue (Loc-Tite). Screw length ranged from 25–33 mm and was selected to fit the thickness of the tail such that the end of the screw did not extend past the lock nut. We tightened the lock nut with a wrench until the transmitter assembly was tight against the tail but did not overly compress the flesh, and could rotate with minimal force. We used this technique for the first 14 attachments, then modified it so that the bolt head was on the bottom of the tail to reduce the profile of the attachment. We attached most transmitters in 5–15 min and total handling time was < 30 min.

Based on unsatisfactory transmitter performance from September 2006–April 2007, we again modified the attachment during May 2007. We replaced the 25-mm steel washer with a 13-mm steel washer on top to further reduce the transmitter profile. We also replaced the 25-mm neoprene and steel washers on the bottom with 38-mm washers to increase surface area and reduce transmitter loss through the attachment hole (Fig. 1B). Last, we used a sharpened 6-mm diameter stainless steel hollow leather punch driven by 2-kg hammer to make the attachment hole instead of the cordless drill. The hole made by the sharpened punch was cleaner and tended to bleed less than the hole created using the drill bit. All beaver capture, handling and transmitter attachment methods conformed to guidelines of the American Society of Mammalogists (Sikes et al. 2011) and were approved by Institutional Animal Care and Use Committees of the US National Park Service or Northern Michigan University.

We monitored transmittered beavers from September 2006 to September 2009. Beavers were monitored at least monthly during May–October by boat or aircraft, and 2–3 times per week in January–March by snowmobile. Unsafe ice conditions during ice formation (~ early November–mid-December) and break-up (~ early April to early May) precluded monitoring during those times. We recovered transmitters from dead beavers or when possible after they detached from the tail. We attempted to retrieve transmitters

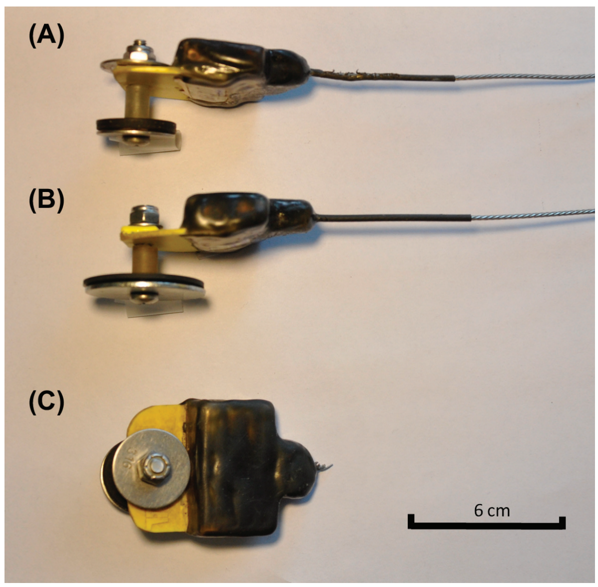


Figure 1. Modified cattle ear tag VHF transmitter design used on American beavers in Voyageurs National Park, Minnesota, USA (after Arjo et al. 2008). (A) Tail-mounted transmitter with 25-mm neoprene and steel washers used in fall 2006. (B) Transmitter with 38-mm neoprene and steel washers used in spring 2007. (C) Typical location of broken antenna.

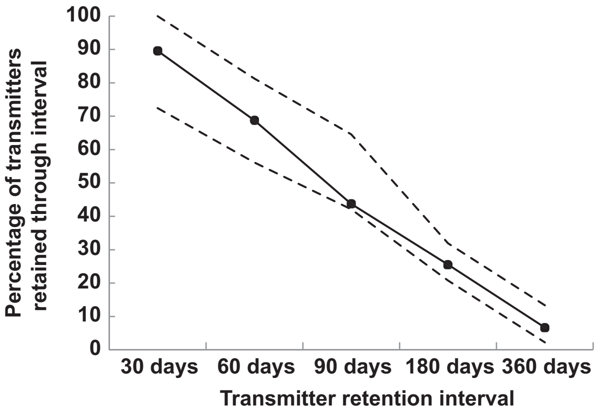


Figure 2. Retention rates of 58 tail-mounted transmitters attached to American beavers in Voyageurs National Park, Minnesota, USA, September 2006–May 2007. The actual date of most transmitter fates could not be reliably determined but were known to occur within a range of dates. Dashed lines represent retention rates calculated using minimum and maximum values from the range of dates determined for each transmitter fate.

in water up to 1.5 m deep; the combination of low water clarity and deep organic substrate generally made transmitter recovery difficult. When a transmitter was in mortality mode inside a lodge, we only excavated the lodge to search for the transmitter if we knew the lodge was abandoned.

We combined information from telemetry locations, recovered transmitters, and recaptures during live-trapping (2008–2014) to determine transmitter fates and identify a range of dates during which the fate occurred. We truncated the upper end of the range to two years in two cases, as this approximated the maximum transmitter battery life. We estimated the date of fate as the median date between the last verified contact and when the transmitter was known to be detached or the dead beaver was recovered. Exceptions were when contact was lost with transmittered beavers, when we used the date of the last verified contact. We calculated the proportion of transmitters retained through the end of 30, 60, 90, 180 and 360 day intervals, excluding transmitters within intervals where we could not monitor for transmitter loss for the entire period; i.e. when transmitters were replaced, lost during trapping events, contact was lost, or after the beaver was dead. We used t-tests assuming unequal variances to compare mean retention times by sex or season of deployment. We used linear regression to relate body mass and tail size at initial deployment to retention time. We used logistic regression to estimate the probability of antenna damage with increasing retention time. We conducted analyses using JMP 7.0 (SAS Inst.) and considered results significant at $\alpha = 0.05$.

## Results

We deployed 63 transmitters on 58 beavers (21 M:37 F). Five beavers that lost transmitters received a second transmitter on the opposite side of the tail, and one beaver also received a third transmitter by reusing the attachment hole when the lock-nut came off. Four deployments from May 2007 were omitted from analyses: two beavers died of capture-related hypothermia and two others were never located or recaptured after deployment and likely emigrated from the study area.

Transmitter retention rates declined steadily over the first 90 days after deployment then declined more slowly, with only 26% of transmitter attachments lasting $\geq 180$ days and 7% lasting 360 days (Fig. 2). Nearly 56% of deployed transmitters were lost (including those 'likely lost') and an additional 19% were classified as 'unknown – transmitter loss or mortality' (Table 1). In the 24 cases where we recaptured beavers with missing transmitters, 15 (63%) tore through the side of the tail, six (25%) pulled out through a widened attachment hole, and three (13%) had the lock nut unscrew (Fig. 3). Investigation of wounds suffered when transmitters were lost suggested wounds healed within a few months. One beaver was caught $> 1$ year after transmitter loss and seven more $> 2$ years after transmitter loss, and the tails all appeared healthy and without infection. Three transmitters were lost when beavers were recaptured in Hancock traps and the transmitter tore through the side of the tail after the attachment became caught in the mesh of the trap. Two other beavers with transmitters were recaptured $\geq 1$ time in Hancock traps without transmitter loss. Ten transmitters were successfully monitored for 57–248 days before contact was lost due to transmitter failure or emigration from the study area.

Two beavers were confirmed to have been preyed upon outside of the lodge, likely by wolves. One dead beaver was retrieved from inside a lodge, where we found that the transmitter had detached before the beaver died. Ten transmitters were detected in mortality mode within a lodge and could not be retrieved nor did we recapture the beaver, therefore, we could not determine if the transmitter detached in the lodge or the beaver died in the lodge. One additional transmitter was in mortality mode in a lodge but the transmitter

Table 1. Fate and mean retention times of tail-mounted transmitters deployed on American beavers in Voyageurs National Park, MN, USA.

| Fate | n | Mean retention time (days) | SD | Range |
|---|---|---|---|---|
| Transmitter loss[1] | 24 | 124 | 109 | 18–401 |
| Likely transmitter loss[2] | 9 | 84 | 50 | 19–166 |
| Transmitter loss-trap | 3 | 212 | 173 | 28–371 |
| Beaver died | 2 | 170 | 31 | 148–192 |
| Unknown-transmitter loss or mortality[3] | 11 | 82 | 44 | 18–160 |
| Unknown–lost contact | 10 | 187 | 80 | 57–345 |
| Total | 59 | 133 | 101 | 18–401 |

[1]Beaver was recaptured to confirm tag loss or lock-nut unscrewed and tag fell off.
[2]Transmitter recovered or located in water but beaver not recovered.
[3]Transmitter detected in mortality mode but not recovered and unknown if beaver is alive.


Figure 3. Examples of American beaver tails when transmitters pulled back through attachment hole (A; dorsal view) or tore through the side of the tail (B; ventral view), Voyageurs National Park, Minnesota, USA.

was later retrieved on land 60 m from the lodge. We detected additional transmitters in mortality mode inside the lodge (n = 6) or under water near the lodge (n = 5) but later recaptured these beavers to confirm that the transmitter had been lost. Another transmitter lost inside a lodge in fall 2006 (confirmed by recapture of the beaver that fall) was recovered on top of the same lodge in fall 2014, presumably when a beaver encountered the transmitter in the water near the lodge and moved it onto the lodge along with lodge building materials. We suggest that transmitters detected in mortality mode inside the lodge or under the water near the lodge were a result of transmitters detaching and therefore we treated this group as such in the analysis.

Mean retention time was 133 days (n = 59, range = 18–401, SD = 101; Table 1). Transmitters deployed in fall had similar retention times (n = 38, $\bar{x}$ = 135 days, range = 18–371, SD = 96) to those deployed in the spring (n = 21, $\bar{x}$ = 130 days, range = 28–401, SD = 113; $p = 0.85$). Retention times were also similar between sexes (males: n = 25, $\bar{x}$ = 135 days, SD = 115; females: n = 34 $\bar{x}$ = 132 days, SD = 92; $p = 0.91$). Beavers were heavier and had thicker tails in the fall than in the spring (Table 2). Transmitter retention times were not related to body mass or tail size at the time of deployment for either season (all $p > 0.08$). Beavers with transmitters lost an average of 23% of their body mass and 26% of tail thickness over the winter period but regained similar proportions over the growing season. Low numbers of recapture events in the season immediately following transmitter deployment precluded analyses relating changes in body mass or tail size to transmitter retention times.

Eighteen transmitters were recovered where we could examine the condition of the antenna. Nine (50%) were intact, six (33%) were chewed off and missing most of the antenna, and three (17%) had the antenna pulled from the base of the transmitter housing (potting; Fig. 1C). The nine transmitters with damaged antennas were retained on beavers > 98 days. The probability of an antenna being pulled out or damaged increased dramatically with increasing retention time from 19 to 371 days (odds ratio = 3.8, $p < 0.01$).

## Discussion

Using the design modifications described by Arjo et al. (2008), mean retention rate for tail-mounted transmitters in VNP was 133 days with only 7% lasting ≥ 360 days. The low retention rate was not a consequence of high adult mortality or emigration from the study area, as adult survival in VNP is high (Smith et al. 2016) and few adult beavers left the study area. Transmitter retention rates in VNP were much less than reported in more temperate regions such as Arizona, USA ($\bar{x}$ = 343 days, 68% retained ≥ 300 days, Arjo et al. 2008) and Illinois, USA (N = 62, $\bar{x}$ = 295 days, 4.5% of beavers lost transmitters during study, Bloomquist and Nielsen 2010). Similar to our results, a study in Massachusetts (USA) using the design of Arjo et al. (2008) also had relatively low retention rates from transmitters pulling out the side of the tail (DeStefano et al. 2006, S. DeStefano pers. comm.). Moreover, retention rates in VNP were even lower than those reported in Colorado, USA ($\bar{x}$ = 154 days; Baker 2006) using an earlier transmitter attachment design that Arjo et al. (2008) attempted to improve.

Transmitter manufacturer did not seem to influence retention rates. This study and Arjo et al. (2008) used ATS model M3530 while Bloomquist and Nielsen (2010) and others from Illinois (McNew and Woolf 2005, Havens et al. 2013) used Telonics (Mesa, AZ) model ET-7, which is similar in size, shape and weight. DeStefano et al. (2006) used both types. Instead, we suggest that in addition to attachment design, beaver physiology and behavior also play a role in tail-mounted transmitter retention. For American beavers, maximum body size (and likely tail size and thickness) appears to occur in the more temperate midcontinent regions with longer growing seasons (Baker and Hill 2003). Mean body mass of adult beavers caught in fall (19.1 kg) and spring (16.7 kg) in this study were less than those reported for adults in fall in Colorado, USA (20.9 kg; Breck et al. 2001) or fall and spring in Arizona, USA (22.4 kg and 23.4 kg, respectively; Arjo et al. 2008). Beavers in northern climates can face severe nutritional restriction in winter, losing up to 25% of their body mass as they metabolize fat reserves or catabolize protein (Smith and Jenkins 1997,

Table 2. Body mass and tail size at time of initial deployment of tail-mounted transmitters on American beavers for fall 2006 and spring 2007 deployments, Voyageurs National Park, MN, USA. Seasonal change in body mass and tail thickness (3 cm lateral to spine at mid-length) are presented for a subset of beavers captured in the season after deployment (i.e. fall 2006–spring 2007 or spring 2007–fall 2007).

| | Condition at deployment | | | | | | | | Seasonal change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | n | Mass (kg) | SD | Tail length (cm) | SD | Tail width (cm) | SD | Tail thickness (mm) | SD | N | Δ mass (kg) | Δ tail thickness (mm) |
| Fall | 38 | 19.1 | 2.3 | 29.7 | 1.7 | 14.1 | 1.2 | 10.1 | 2.0 | 4 | –4.6 | –4.1 |
| Spring | 21 | 16.7 | 1.7 | 29.8 | 1.6 | 13.1 | 1.0 | 7.7 | 1.3 | 5 | 4.9 | 5.4 |

Smith et al. 2016, this study). When attached in the fall, dramatic changes in body condition over winter, particularly in the fat-storing tail (Aleksiuk 1970), likely resulted in the transmitter assembly becoming too loose, and thereby increased the likelihood that the transmitter assembly would be caught on sticks or other materials and tear out. Conversely, when attached in the spring when the tail is most thin, there may not be enough tissue to hold the transmitter in place. Though beavers in temperate regions lose mass and fat deposits overwinter, these losses are less extreme than they are farther north, and therefore retention of tail transmitters is relatively higher in more southern environments (C. Nielsen pers. comm.).

Beavers in northern climates construct lodges primarily of sticks and mud, which are generally freestanding in ponds but also along the banks in lakes or large rivers (Baker and Hill 2003). Beavers also build food caches near their lodges that they access under the ice during winter to provision food (Baker and Hill 2003). Beavers in these environments may be more likely to have small sticks or branches catch under the washer assembly leading to transmitters pulling out. Our experience with transmitter loss from the metal mesh of Hancock traps suggests that getting caught on branches is a common cause of transmitter loss. We initially used 25-mm washers as in Arjo et al. (2008), but six transmitters were lost when the hole widened and the washer pulled through the hole. Our switch to a 38-mm washer in spring 2007 eliminated this problem, but may have exacerbated the problem of additional surface area for the transmitter assembly to snag on branches or other objects in and around the beaver lodge.

Damage or loss of the whip antennas was common in our study, and the likelihood of damage occurring increased dramatically with increasing retention time. Baker (2006) reported similar rates of antenna damage (61%) for ATS model 3530. An advantage of tail-mounted transmitters is that the external whip antenna improves detection distance over coiled antennas in implant transmitters (Rothmeyer et al. 2002). Though not quantified, we detected noticeably reduced transmitter signal strength when antennas were damaged. The single-post, nylon sleeve attachment method we used (Arjo et al. 2008) allowed the transmitter to freely rotate to reduce entanglements. A drawback to allowing this movement, however, may be that beavers can more easily reach the antenna where they can pull it from the potting, chew through it, or bend it back and forth enough to separate it (Baker 2006). We are uncertain if beavers can generate enough force by pulling on the antenna with their teeth to remove the transmitter. DeStefano et al. (2006) also had damaged antennas (S. DeStefano pers. comm.), but Arjo et al. (2008) and others did not report issues with damage to antennas or beavers removing transmitters.

We do not suggest that tail transmitters are ineffective for monitoring beaver survival and movements as they appear to be an inexpensive and efficient means to monitor beavers in warmer climates like those in Arizona (Arjo et al. 2008) or Illinois (McNew and Woolf 2005, Bloomquist and Nielsen 2010). Likewise, despite their propensity to pull out of the tail, tail-mounted transmitters did not result in lower survival (one year) from beavers receiving peritoneal implant transmitters (Smith et al. 2016). When beavers equipped with tail-mounted transmitters were pooled with beavers that received implants, Smith et al. (2016) also did not find any significant differences in survival between transmitter-equipped or ear-tagged only beavers over an 8-year study. Rather, researchers looking to use tail transmitters in more variable northern climates should recognize that retention times may be substantially less unless other modifications can be made. Because of the high percentage of transmitters tearing from the side of the tail, double-post designs that straddle the spine should be used with extreme caution in northern climates as they may result in more serious injury or death if the beaver gets caught on sticks or other objects. Improvements to a tail-mounted system for beavers should consider a low-profile transmitter that minimizes the chance for entanglement and can better accommodate large changes in tail condition over the expected life of the transmitter. Until a more effective tail-mounted method is developed for northern climates, peritoneal implant transmitters may be a more reliable method to monitor survival and movements (Smith et al. 2016).

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