EXPLORING PREMATURE DETACHMENT OF RADIO-TRANSMITTERS USED ON BATS IN TELEMETRY SURVEYS

by

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Submitted in partial fulfillment of the
requirements for Departmental Honors in
the Department of Environmental Sciences
Texas Christian University
Fort Worth, TX

May 3, 2021

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Abstract

To understand wildlife ecology, one common strategy is a technique known as telemetry. This technique involves attaching radio-transmitters to animals. For volant species, such as bats, transmitters are attached to their backs with an adhesive. However, one issue is that it is easy for the bats to remove the transmitter. The loss of transmitters early in surveys is not only costly, but limits the amount of data that can be collected. Thus, there is a real need to extend the length of time a transmitter remains on a bat. To address this, we conducted a two-part behavioral observation study in the bat flight facility at TCU. In part 1 from April to September 2019, we tested 1) two currently available transmitter brands and 2) three different prototype designs to determine if the overall shape and size of the transmitter impacted the length of time they remained attached. We found that regardless of transmitter brand or design, the antennas incurred a significant amount of damage, suggesting the bats used the antennas to grab and pull them off. Thus, for part 2 from August to September 2020, we conducted a series of trials to establish the effectiveness of three coatings at preventing bats from damaging the antennas. We found that transmitters did not remain attached significantly longer with cayenne pepper, nail-biting deterrent, or Tabasco sauce on the antenna, suggesting that either 1) bats were not deterred by the three coatings we selected, or 2) bats may not be chewing the antennas or putting them in their mouths to provide leverage to remove them. Overall, our study revealed that bats can and will remove transmitters by grooming them off using the antennas and we recommend that future research focuses on integrating the antenna into the body of the transmitter as a preventative measure.

Table of Contents

Introduction

For wildlife management strategies to be effective, wildlife practitioners need to have an appropriate understanding of the ecology of the target animal, including resource use, habitat requirements, population dynamics, and activity patterns (Cagnacci et al. 2010). Many of these ecological traits can be identified by gathering data on the movement patterns and mobility of a species (Allen & Singh 2016). One commonly used strategy to acquire such information is through a technique known as telemetry (Guthrie et al. 2011). This technique involves attaching radio-transmitters to an individual animal and then tracking and recording their location via the signal emitted from the transmitter (Dressler et al. 2016). The types of tracking devices that are most commonly used for tracking wildlife are geolocators, very high frequency radio transmitters (VHF), satellite transmitters, and global positioning system receivers (GPS receivers; Thomas et al. 2011). With the exception of geolocators, these methods all involve attaching a transponder to the animal that either emits or receives a signal, which is then used to locate the animal.

Geolocation involves measuring ambient light intensity levels to determine sunrise and sunset times. These times are then used to estimate the location of an attached archival device. However, the tag must be recovered from the animal to retrieve the location data (Thomas et al. 2011). VHF radio transmitters emit a radio-frequency signal that can be received by the user with an antenna and receiver, instead of using a satellite (Mech & Barber 2002). This technology is relatively low-cost, provides reasonable accuracy, and can have a long battery life. Satellite transmitters consist of units attached to the animal known as platform transmitter terminals (PTTs), which transmit pulses to be detected by a polar-orbiting satellite. This system collects data from the PTT and distributes its location information to the user (Britten et al. 1999).

Satellite transmitters tend to be more expensive and less accurate, but require no researchers monitoring the individuals in the field, which is helpful for tracking of far-ranging animals (Mech & Barber 2002). Another satellite technology commonly used is GPS tracking. Rather than sending signals to a satellite, GPS devices receive transmissions from satellites in orbit to accurately pinpoint the device's location (Recio et al. 2011). Originally, GPS receivers had to be collected to obtain the location data they stored. Now, there are options for remote data retrieval from these devices without recovering it from the animal (Mech & Barber 2002).

Telemetry devices are available in a number of sizes, shapes and designs and can be attached via a variety of methods. As a general rule, the weight of the attached device should not exceed 5% of the body weight of an animal (Sikes et al. 2016), as any excess weight may have adverse effects on the behavior, movement, and survival of the individual being tracked (Calvo & Furness 1992). This recommended limit is now the most universally accepted estimate to determine appropriate tag weight for any species, whether they are terrestrial, volant, or aquatic (Markham 2008). Thus, the shape, type and design of the device used, and therefore survey technique used, is dictated by the size of the focal species. For example, large terrestrial animals ranging from 350 to 6,300 kg, such as elephants (Telonics Inc. 2018; Grogan et al. 2020) and moose (Moen et al. 1996), are most commonly fitted with devices attached to collars around their necks. As these animals are heavier, the devices and batteries can be larger, extending battery life to up 3 years and allowing the more complex heavier devices to be used, such as GPS and satellite transmitters (Telonics Inc. 2019). However, when anatomy and ecology could be impacted by the placement of such devices on large animals, ankle devices and head harnesses have been used, as with rhinoceros and giraffe respectively (Singh & Bais 2018; Deacon & Smit 2017; D'haen et al. 2019). Satellite and GPS collars, albeit lighter in weight with lower battery lives, are also widely used on other various animal taxa, including large carnivores ranging from 100-350 kg such as bears (National Park Service 2019), tigers (Rozhnov et al. 2011), and lions (Tumenta et al. 2013), as well as medium sized canines ranging from 10 to 45 kg such as African wild dogs (Whittington-Jones et al. 2014) and coyotes (Andelt & Gipson 1979). Again, there are a number of medium sized species among which collars are not suitable or could impede their survival and breeding success, such as anteaters. In these cases, body harnesses have been designed to accommodate such issues (Blanco et al. 2017).

Among smaller species ranging from 180 to 700 g, we observe a corresponding decrease in the size of collars and often researchers are limited to using the lighter satellite transmitters (Thomas et al. 2011). These lighter devices are commonly used on various small terrestrial species, including European brown hares (Ullmann et al. 2020), Tasmanian devils, and spotted-tailed quolls (Andersen et al. 2020). Moreover, there are an increasing number of smaller species for which collars and alternatives such as harnesses and anklets are not suitable. In these instances, a different method of attachment is applied, which involves glue. For reptile species, such as crocodiles and turtles, devices are glued to the scales on the back of the neck or to their shells, respectively (Kay 2004; Snape et al. 2020). For those species whose movement could be impeded by such an attached device, such as lizards and snakes, one option is to implant devices just under the skin (Mech & Barber 2002). For even smaller species ranging from 9 to 180 g the devices are limited to geolocators and VHF radio-transmitters where available, and in most cases these are attached using glue (Thomas et al. 2011).

For volant species this can be even more challenging as weight cannot be added that would limit or unbalance flight, so attaching devices to wings may not be appropriate. In a study focused on tracking a variety of seabirds, tracking devices were attached either to a ring around the leg, to feathers in the center of the back, or to tail feathers, using waterproof cloth-backed tape (Wilson et al. 2002). Teflon ribbon harnesses are also used to attach the device to birds of various sizes (Alonso et al. 2020). Additionally, for bats the patagium extends to their hind feet, which prevents any device from being attached to their ankles. Therefore, the best option is that in which the transmitters are attached to the back of the bats with an adhesive, which has the least impact on flight. Since GPS and satellite transmitters tend to be larger and heavier, small bat species are restricted to VHF radio-transmitters due to their minimum size being small and lightweight enough for the bat to carry (Shafer et al. 2019).

However, one issue with this attachment is that it is easier for the bat to remove. Transmitters remain attached on the bats for an average of 9 days (O'Mara et al. 2014). In many cases, this is well under the battery life of the transmitter (up to 22 days; Naef-Daenzer et al. 2005), so it is not only costly, but limits the amount of data that can be collected. The longer the device is attached, the more information can be gathered, which leads to better understanding of the species' ecology. In other words, when the transmitters detach from the bats, their movement can no longer be tracked.

There is therefore a real need to find a way to extend the length of time a transmitter remains on a bat and/or prevent them from detaching. To accomplish this, we need to know why and how these transmitters are being removed. Therefore, in this study we set out to 1) determine how the transmitters are being removed, and then 2) explore a method to prevent premature detachment based on the results of part 1.

Part 1: Transmitter Trials

Methods

Mist Netting Surveys

Bats used in behavioral trials were wild-caught from local parks in the Fort Worth area in Texas (for further details see Smith 2017). Preliminary acoustic surveys revealed that these parks had a diverse and active bat community, including an abundance of evening bats (*Nycticeius humeralis*; Fig. 1). Thus, we used the evening bat as our study species, because it was easy to capture at mist netting surveys and its small size (~9 g) would allow us to more readily determine any impacts the transmitter attachment may have had. Note that federal and state permits were not required to catch and handle bat species found in north central Texas. However, permits and permissions were obtained as required to be in local parks after dusk.

Figure 1: Evening bat (*Nycticeius humeralis*)

From March to September 2019, we set up a combination of single, double, triple, and quadruple high mist netting systems with 3-18 m length monofilament nets from Avinet Inc. (Dryden, NY) in a variety of locations throughout the local park system (Fig. 2). We opened nets ten minutes before dusk and kept them open for up to 2 hours to encompass the primary activity period of evening bats.

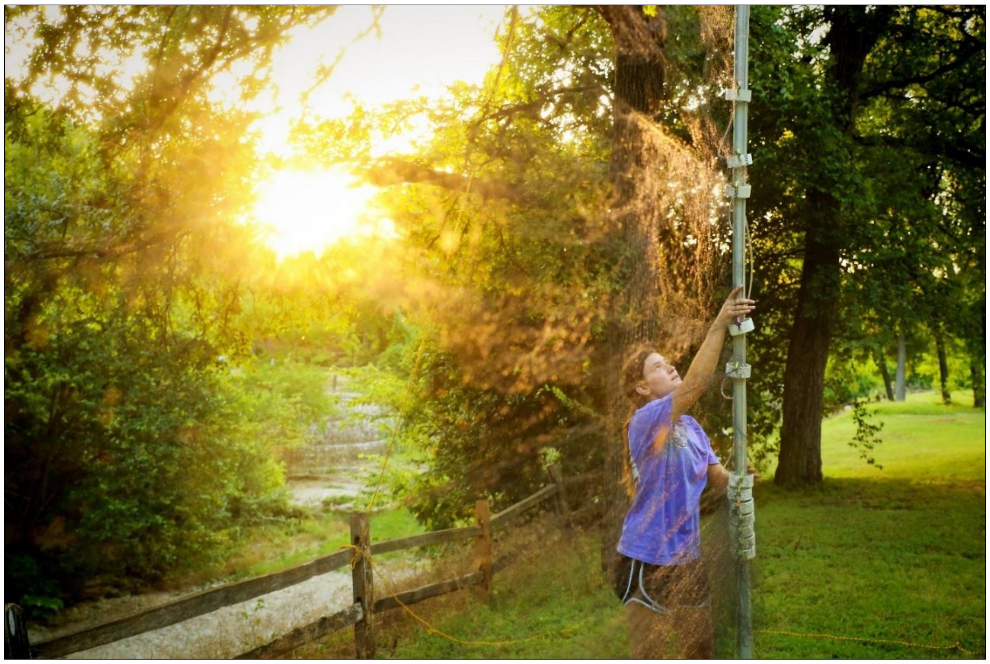

Figure 2: Triple high mist netting set up at local park in Fort Worth.

Once caught, we removed the bats from the nets and established whether a bat was 1) pregnant, 2) lactating, 3) carrying young, 4) injured, or 5) federally endangered (note that no federally endangered bats were known to reside in north central Texas at the time of survey; Fig. 3). If any bats were identified as one of the above categories, it was immediately taken away from the mist nets and released. We placed all other bats into individual cloth bags and continued to mist net until the nets had been open for 2 hours or 10 bats had been captured. We then transported all captured bats to a flight facility on TCU's campus (see below).

Figure 3: Evening bat being removed from mist net.

Note that for mist netting surveys, an Institutional Animal Care and Use Protocol (IACUC permit #16-08) was in effect. Federal regulations required an approved protocol to be in place to use animals in research, teaching, and testing under the Health Research Extension Act (HREA) and key amendments to the Animal Welfare Act (AWA). All methods also followed guidelines provided in Sikes et al. (2016).

Flight Facility

The flight facility in which the bats were housed was a stand-alone building with an internal meshed area of approximately 17 m by 10 m (Fig. 4). To keep conditions, such as temperature and humidity, as natural as possible, the flight facility was equipped with a series of screen-covered windows and doors, essentially making it an open-air enclosure. Additionally, no artificial lights were installed within the flight facility and only headlamps were used while inside. We provided water in a custom-made shallow galvanized steel tray (2 m x 1 m x 1.5 cm) placed on the floor in the center of the meshed area, which was kept filled and available to the bats at all times. We also provided roosting opportunities for bats in the form of soft puppy carriers and carpeted cat houses that mimic the natural cavities in which evening bats generally roost. For further information on the flight facility refer to Bienz (2016).

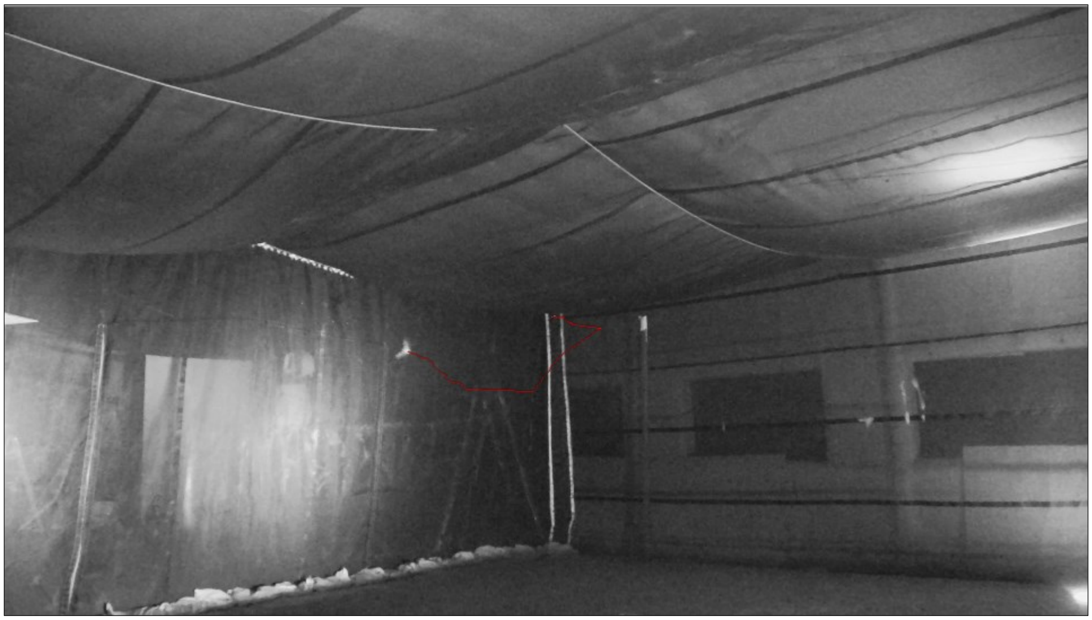

Figure 4: Picture of bat flying in flight facility.

Once in the flight facility, we processed the bats (i.e., recording sex, age, forearm length, and weight). To aid the identification of each bat, we painted their toenails with unique combinations of non-toxic orange, pink, purple, blue, and green piggy-paint nail varnish.

Transmitter Trials

From April to September 2019, we conducted a series of transmitter trials to establish the length of time a transmitter remained on a bat. For these, we used two different brands of dummy transmitters, both designed to resemble the VHF transponders that are currently available for radio-tracking bats equivalent to the size of evening bats (Fig. 5). For the first set of trials from March to June, we used transmitters from Wildlife Materials LLC, weighing approximately 0.45 g, which comprised a metal body coated in epoxy with a 25-gauge metal wire antenna (hereafter referred to as WM transmitters). We attached these dummy transmitters to a total of 30 bats. As another form of identification, we labelled each transmitter with a unique number (see Fig. 5). Note that we did not use the same bats in the second set of trials.

Figure 5: Dummy transmitter used in first set of transmitter trials.

From July to September 2019, we conducted a second set of transmitter trials using dummy transmitters designed by the Pacific Northwest National Laboratory (hereafter referred to as PNNL transmitters). We used 3 different designs: a cylinder shape weighing nominally 0.393 g, a semi-cylinder weighing 0.384 g, and a semi-cylinder with a ledge weighing 0.389 g (A, B, and C, respectively in Fig. 6). Each had a 32-gauge wire antenna. We attached these dummy transmitters to a total of 45 bats (15 per design) and again, we labelled each transmitter with a unique number (Fig. 7).

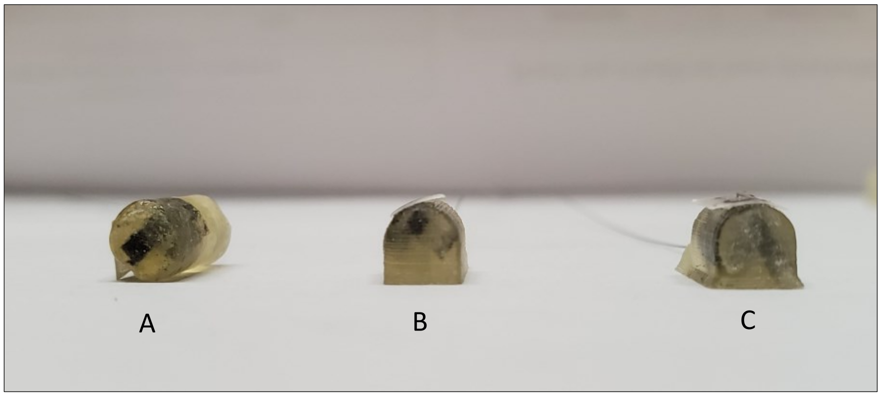

Figure 6: Three transmitter shapes tested in the second set of transmitter trials.

Figure 7: Example of transmitter used in second set of transmitter trials.

To attach all the transmitters, we first trimmed the hair from between the shoulder blades of the bat using a pair of curved-edge cosmetic scissors. We then used a Finishing Touch Personal Hair Remover to trim the remaining hair in the area as short as possible. We applied an adhesive, such as perma-type cement, to both the trimmed area of the bat and transmitter, and waited for 5 minutes for the adhesive to become tacky before placing the transmitter on the bat.

Finally, we held the transmitter in place until the adhesive set. Once the transmitter was deemed secure, we released the bat into the main enclosure of the flight facility.

On a daily basis, we proceeded to check on the bats at approximately 8 am, 12 pm, 4 pm and 8 pm. During each check we recorded whether the transmitter was still firmly attached, partially attached, or detached, and noted any damage to the transmitter or more specifically the antenna. If the transmitter was found to be detached from a bat, the following dusk we released the bat at its site of capture. All remaining bats were provided with flying prey items caught in light traps nightly to support and maintain natural flight activities, as well as being supplemented with mealworms where necessary. For further information on supplementary feeding protocols see Bienz (2016).

All animal research protocols conducted in these trials and care of bats within the flight facility followed the guidelines of the American Society of Mammalogists (Sikes et al. 2016) and were approved by the TCU Institutional Animal Care and Use Committees (IACUC #16-09 and #16-08). As such, the number of bats kept in the flight room at any one time was limited to 10 and when temperatures in the flight facility exceeded 38°C for >2 days consecutively (i.e., outside temperatures were forecast to exceed 40°C) we did not house bats in the flight facility.

Finally, we collected and photographed all recovered transmitters after they had been detached (where possible). As a measure of antenna damage, we recorded the number of points of damage along each antenna (Fig. 8).

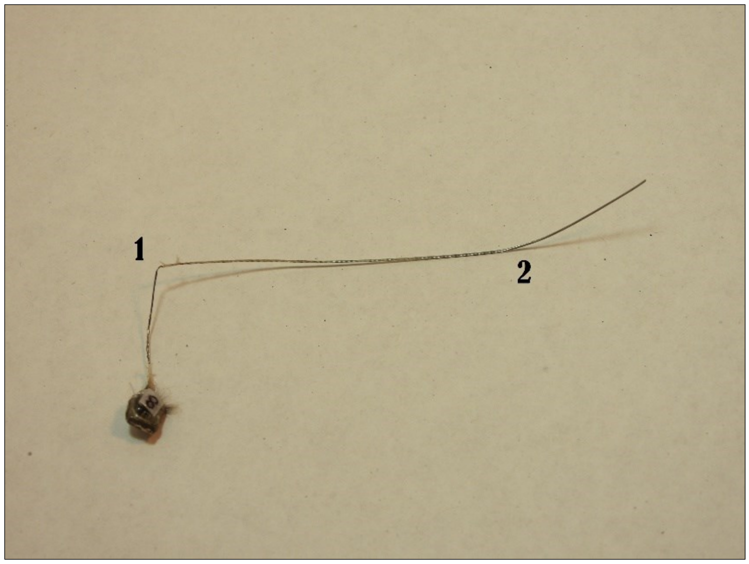

Figure 8: Damaged transmitter with numbered points of damage.

For our analysis, we first compared the two different transmitter trials to determine if the brand of transmitter influenced the length of time the transmitters remained on. In other words, we examined whether the brand of the transmitter deterred the bats from being able to detach the transmitter as readily. For this, we used a two-sample *t*-test assuming unequal variances to establish if the length of time transmitters were attached varied significantly between the two transmitter brands. We also compared the number of transmitters in each of the different transmitter trials that showed signs of damage using a chi square test to assess significance. We then compared the two different transmitter brands to determine if the brand of transmitter influenced the amount of damage observed, using a two-tailed *t*-test to assess significance. Finally, we determined whether the number of days transmitters remained attached was correlated to the amount of damage recorded for each transmitter trial. For this, we conducted a Pearson's Rank Correlation analysis. For all statistical analysis we used Minitab statistical software (Minitab 2017; $\alpha = 0.05$).

Results

For the transmitter trials, a total of 75 bats were successfully used from 15 April to 24 September 2019. Overall, the minimum length of time a transmitter remained attached was 0.5 days with the maximum exceeding 30 days. More specifically, WM transmitters remained attached from 3.5 days to a maximum of 16.5 days, while PNNL transmitters remained attached from 1 day to a maximum that would have exceeded 30 days. Comparing the number of days transmitters became detached or were groomed off by bats for the two transmitter brands, we found that WM transmitters remained attached significantly longer than PNNL transmitters (Fig. 9; t = 2.551, df = 69, P = 0.0129).

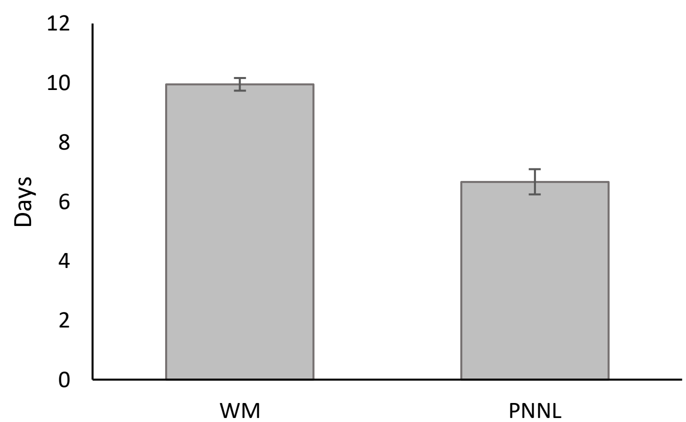

Figure 9: Mean number of days transmitters remained attached on evening bats for the 2 transmitter brands used. Error bars indicate ± standard error.

When we compared the number of transmitters with damage to the number of transmitters without damage for each brand, we found that of the 30 WM transmitters tested, a significantly larger proportion had signs of antenna damage (19 out of 30; Fig. 10; χ^2= 6.760, df = 1, P = 0.0093). In contrast, among the 45 PNNL transmitters used, we noted that significantly fewer transmitter antennas were damaged (12 out of 45; Fig. 10; χ^2= 21.160, df = 1, P<0.0001).

When comparing the two brands with each other, we found that 36.7% more WM transmitters showed signs of damage compared to the PNNL transmitters (Fig. 10). Furthermore, this difference was significant (χ^2= 14.400, df = 1, P<0.0001).

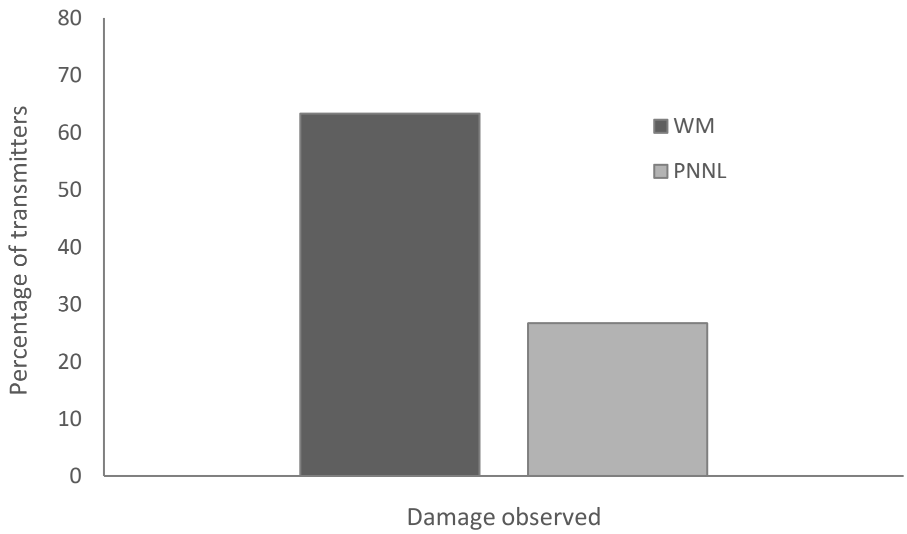

Figure 10: Percentage of transmitters with observed damage for the 2 transmitter brands used.

When we compared the amount of damage observed to the antennas as measured by the number of bends, we found that fewer bends were recorded in the antennas of the WM transmitters compared to the PNNL transmitters, although this difference was not significant (Fig. 11; t = -0.912, df = 17, P = 0.375).

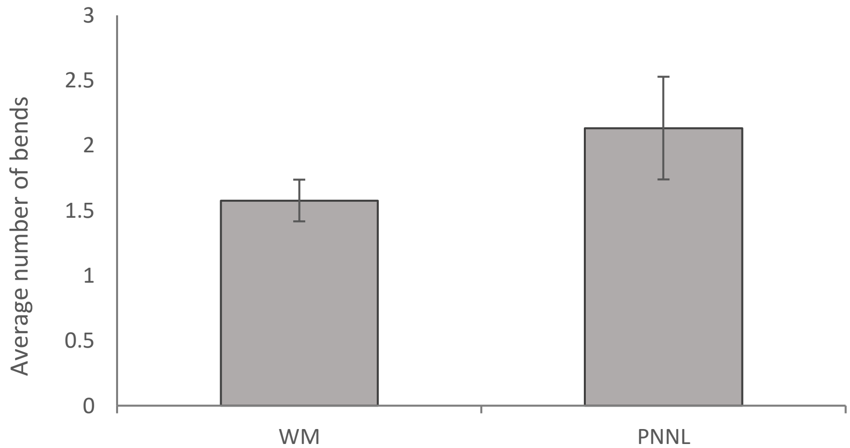

Figure 11: Average number of bends observed among the 2 transmitter designs used.

In the WM transmitters, we found there to be no correlation between the amount of damage observed and the length of time the transmitter remained on the bat (where the correlation coefficient was 0.21). Similarly, we found a moderately positive correlation between amount of damage and length of transmitter attachment in PNNL transmitters (where the correlation coefficient was 0.46).

Discussion

From our results in part 1 to assess the length of time and damage observed on different brands of transmitters, we found that WM transmitters remained attached significantly longer than PNNL transmitters, but WM transmitters showed significantly more signs of damage in comparison to the PNNL transmitters.

More specifically, WM transmitters remained attached an average of ~3 days longer than the PNNL transmitters. We acknowledge that this may have been a result of the adhesive used to attach the transmitters. For the PNNL transmitters, we used an eyelash glue, known to be more effective at adhering lighter devices to wildlife (Göth & Jones 2001). In contrast, we used

Vetbond and surgical cement for the heavier WM transmitters. Furthermore, examining the medians of the dataset (i.e., in addition to the means), we found that the median number of days WM transmitters remained attached was 9.5 days, while the median for PNNL transmitters was 2 days, with 60% of them remaining attached for 4 days or fewer. These results suggest that either the adhesive used was particularly ineffective or that the lighter transmitter was easier to remove. Thus, it is more likely that the type of adhesive used primarily influenced the length of time each transmitter type remained attached. We, therefore, recommend that future research include behavioral trials that test the effectiveness of different adhesives. Nevertheless, even with WM transmitters remaining attached for up to 10 days, this only represented ~50% of the battery life potential and it, therefore, would be economically and ecologically more efficient if these transmitters remained on the bats for up to 20 days. The fact that we noted a lot of variety in the length of time the transmitters remained attached from <1 day to 16 days among the WM transmitters and 30 days among the PNNL suggests that the adhesive used did not influence the removal of the transmitters. Moreover, the results of our study suggest that it is not necessarily the weight or shape of the transmitters that determines how long the transmitters remain attached. This, in turn, poses the question "Why are these transmitters coming off?"

We noted that the antennas provided leverage for the bats to remove the transmitters more readily. Across both sets of transmitter trials, we witnessed bats grabbing the wires with their feet and attempting to pull the transmitter off or put the antenna in their mouths, where they proceeded to pull or chew the wire. On 5 occasions with the smaller gauge wire, the bats even severed the antenna entirely. As the antenna is an integral part of the transmitter, any damage to the wires would render the transmitter useless, at which point it is inconsequential how long the transmitter remains attached.

In regard to antenna damage, our study showed that across both sets of transmitter trials, more than 40% of antenna wires showed signs of damage. Regardless of transmitter type, the significant amount of damage on the antennas was universal, indicating that the thinner antenna on the PNNL transmitters did not significantly alter the ability of the bats to grab and pull them off.

Our results also indicate that transmitter removal may have been dependent on the individual bat. Among telemetry studies conducted in the field, it is not uncommon for there to be anecdotal accounts that subsets of bats removed their transmitters in the first few days after release, while other bats of the same species did not. Furthermore, many researchers actually forecast and account for this equipment loss in their budgets. In another recent study conducted in our flight facility, we found that bats spend less time flying and more time grooming within the first few days following transmitter attachment (Smith & Bennett in prep). We also noted considerable variation among the bats tested with some individuals spending more time grooming than others. This variation in individual bat behavior supports the current study in which a proportion of the antennas were found with damage, while other antennas showed no signs of damage. Such results suggest that in any study conducted, a number of transmitters will be lost quickly or damaged despite the protocols put in place (i.e., minimum number of days a transmitter will be attached = 1).

Given that a large proportion of the damage occurred due to chewing, it may be possible to deter bats from damaging the antennas by modifying the design of the antennas to prevent bats from grabbing and using them as leverage to pull transmitters off. One potential suggestion would be to make the antennas more rigid, so the bats cannot manipulate them. If such design options are not feasible, then we recommend that further steps are taken to alleviate damage to the antennas by physically deterring bats from chewing them. To investigate this potential option, we conducted a set of trials (Part 2) in which we tested if distasteful coatings, such as cayenne pepper, nail-biting deterrent, and Tabasco sauce, could be used for this purpose.

Part 2: Antenna Taste Trials

Methods

Refer back to Part 1 Sections: *Mist Netting* and *Flight Facility* for full methods.

Antenna Taste Trials

From August to September 2020, we conducted a series of antenna trials to establish the effectiveness of 3 coatings at preventing bats from damaging antennas. The coatings we tested included cayenne pepper, nail biting deterrent, and Tabasco sauce (Fig. 12). We applied these coatings to the antennas of dummy transmitters designed to resemble the VHF transponders that are currently available for radio-tracking bats equivalent to the size of evening bats (Fig. 13).

Figure 12: Three coatings tested in the antenna trials.

Figure 13: Transmitters used in antenna trials labeled and color-coordinated with their respective coating.

We conducted these antenna trials using dummy transmitters designed by the Pacific Northwest National Laboratory (again, hereafter referred to as PNNL transmitters). More specifically, we used a semi-cylinder shape with a ledge weighing 0.389 g, with a 32-gauge wire antenna. Five of these antennas were coated with Tabasco sauce, 5 with cayenne pepper, 5 with nail biting deterrent, and 5 with no coating as a control group (labeled on the transmitter with the letters T, H, N, and C, respectively; Fig. 13). We attached these dummy transmitters to a total of 20 bats (5 per coating) and we labelled each transmitter with its corresponding letter and a number.

To attach all the transmitters in a similar technique to the previous transmitter trials, we first trimmed the hair from between the shoulder blades of the bat using a pair of curved-edge cosmetic scissors. We then used a Finishing Touch Personal Hair Remover to trim the remaining hair in the area as short as possible. We applied an adhesive, such as perma-type cement, to both the trimmed area of the bat and transmitter, and waited for 5 minutes for the adhesive to become tacky before placing the transmitter on the bat. Finally, we held the transmitter in place until the adhesive set. Once the transmitter was deemed secure, we released the bat into the main enclosure of the flight facility.

On a daily basis, we proceeded to check on the bats at approximately 8 am, 12 pm, 4 pm and 8 pm. During each check we recorded whether the transmitter was still firmly attached, partially attached, or detached, and noted any damage to the transmitter or more specifically the antenna. If the transmitter was found to be detached from a bat, the following dusk we released the bat at its site of capture. Note that all animal research protocols conducted in these trials and care of bats within the flight facility (detailed in the *Transmitter Trials* section above) followed the American Society of Mammalogists guidelines (Sikes et al. 2016) and were approved by the TCU Institutional Animal Care and Use Committees (IACUC #1920-6). Finally, we collected and photographed all recovered transmitters after they had been detached (where possible). As a measure of antenna damage, we again recorded the number of points of damage along each antenna.

For our analysis, we first compared the three different antenna coatings with the control to determine if the presence of distasteful coating influenced the length of time the transmitters remained attached. In other words, we established whether the taste of the coating deterred the bats from detaching the transmitter as readily. For this, we used a non-parametric Kruskal-Wallis test to establish if the length of time transmitters were attached varied significantly between the four antenna groups. We then compared the percentage of transmitters in each trial that showed any signs of damage to the antennas and used a Chi squared test to determine if any differences observed were significant. Next, we compared the four different antenna coatings to determine if the type of coating influenced the amount of damage observed. For this, we used a non-parametric Kruskal-Wallis test to assess significance. Finally, we determined whether the number of days transmitters remained attached was correlated to the amount of damage recorded for each transmitter trial. For this, we conducted a Pearson's Rank Correlation. Again, for all statistical analysis, we used Minitab statistical software ($\alpha = 0.05$).

Results

For the antenna taste trials, a total of 10 bats were successfully used from 26 August to 17 September 2020. Overall, the minimum length of time a transmitter remained attached was 1 day with a maximum of 23 days. More specifically, transmitters with control antennas remained attached from 1 day to a maximum of 23 days, transmitters with cayenne pepper remained attached from 1 day to a maximum of 12 days, transmitters with nail biting deterrent remained attached from 1 day to a maximum of 23 days, and transmitters with Tabasco remained attached from 1 day to a maximum of 2 days (Fig. 14). Comparing the number of days transmitters became detached or were groomed off by bats for the 4 antenna coatings, we found there to be no significant difference of the length of attachment between control antennas and antennas coated in cayenne pepper, nail-biting deterrent, or Tabasco sauce ($H = 5.429$, df = 4, $P = 0.143$).

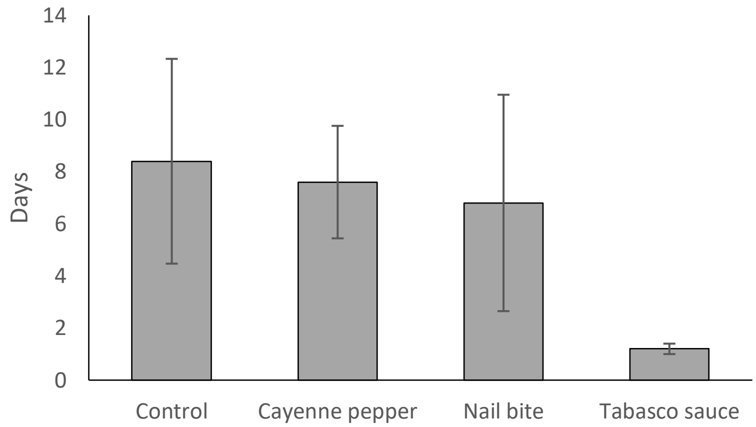

Figure 14: Mean number of days transmitters on evening bats remained attached for the 4 antenna coatings used. Error bars indicate ± standard error.

When we compared the number of transmitters with damage to the number of transmitters without damage, we found that antennas coated in Tabasco sauce had little to no signs of damage (Fig. 15). Note that this coating was tested last in the latter weeks of the trials on bats that had already groomed off previous transmitters (i.e., these transmitters were attached directly to skin, rather than short hair). Furthermore, this period was particularly humid (daily humidity >60%) and prevented the glue used to attach the transmitters to the bats for drying effectively. As a result of these factors influencing the Tabasco antenna trials, we excluded them from the following statistical analyses. Thus, comparing antennas with no coating to antennas with nail-biting deterrent and cayenne, we found no significant difference in the percentage of transmitters observed with damage (χ^2=0.6818, df = 2, P = 0.7111).

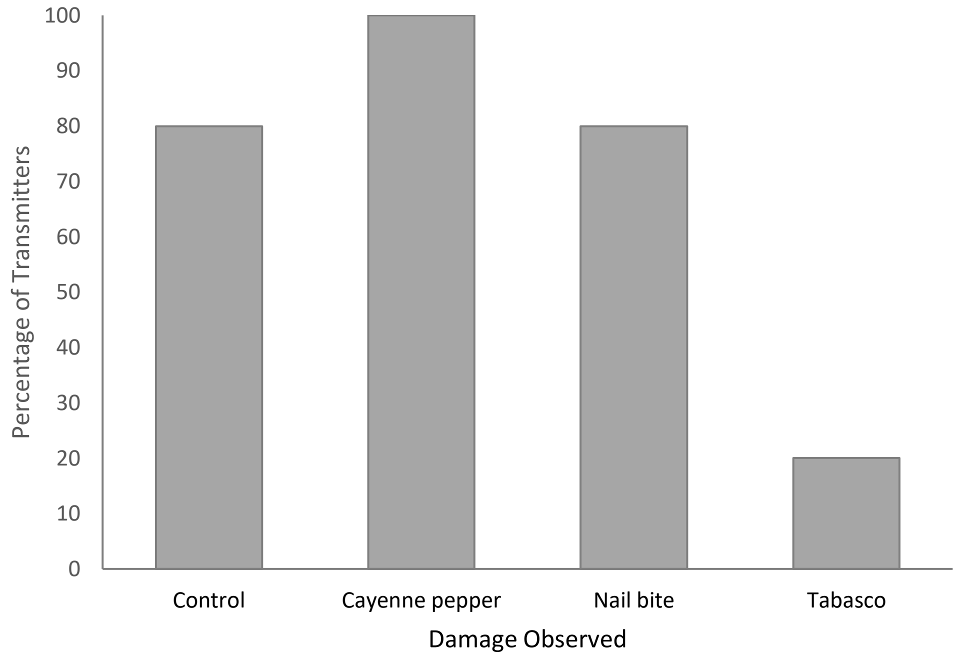

Figure 15: Percentage of transmitters with observed damage for the 4 antenna coatings used.

When comparing the amount of damage observed, in other words the number of bends between antenna coatings, again we found that fewer bends were recorded in the antennas with Tabasco sauce (Fig. 16). For the same reasons as given above, we excluded the Tabasco antenna data from the analysis. Thus, comparing the antennas without a coating to those antennas with cayenne pepper and nail-biting deterrent, we noted very little difference between all three (Fig. 16) and we confirmed that this pattern was not significantly different (H = 4.67, df = 2, P = 0.097).

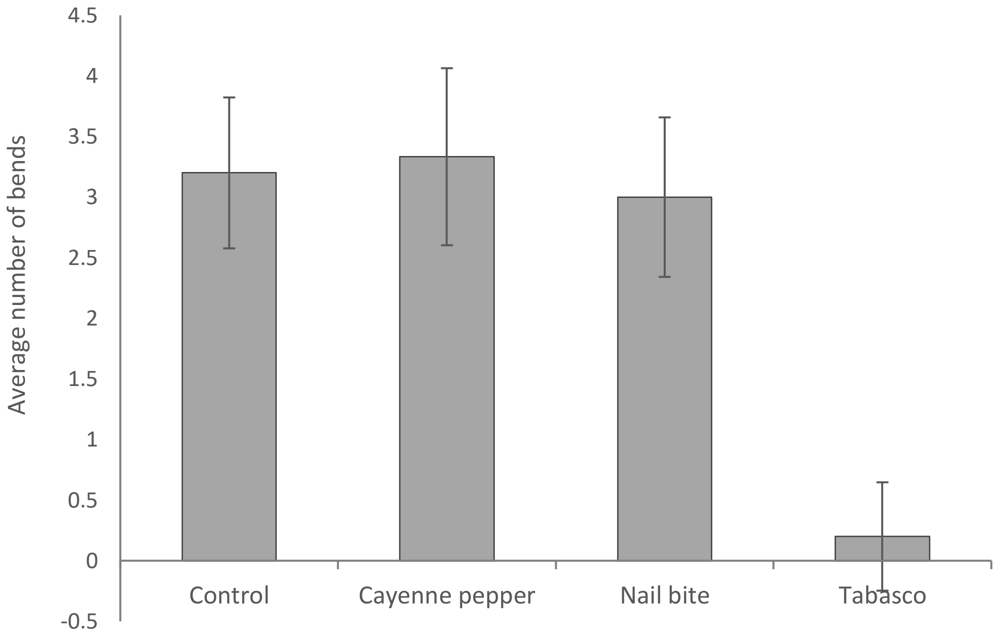

Figure 16: Average number of bends observed among the 4 antenna coatings used.

Assessing whether the number of days transmitters remained attached was correlated to the amount of damage recorded for each transmitter trial, our results showed that transmitters with damage were not removed faster among any of the trials (Table 1).

Table 1: Result of the Pearson's Rank Correlation test comparing the number of days transmitters remained attached with the amount of damage to the antenna recorded for each antenna taste trial.

Antenna coating	Correlation coefficient	Relationship
Control	0.71	Strong positive
Cayenne pepper	0.28	Weak positive
Nail bite	0.42	Moderate positive
Tabasco	-0.25	Weak negative

Discussion

From our results in part 2 to assess the length of time and damage observed on transmitters with different antenna coatings, we found that transmitters did not remain attached significantly longer with cayenne pepper, nail-biting deterrent, or Tabasco sauce on the antenna, and none of the transmitter antennas with coatings showed significantly fewer signs of damage in comparison to the control.

Furthermore, examining the medians of the dataset (i.e., in addition to the means), we found that the median number of days transmitters with no coating remained attached was 8 days, while the median for cayenne pepper transmitters was 10 days, for nail-biting deterrent transmitters was 3 days, and for Tabasco sauce transmitters was 1 day. These results also suggest that none of the coatings effectively prevented bats from removing the transmitters prematurely. Furthermore, the results potentially suggest that in the case of the nail-biting deterrent and the Tabasco-covered antennas, transmitters were removed >5 days faster than the control. We speculate that this finding was not due the presence of a coating on the antennas, but rather the conditions of high humidity during glue application at the time the transmitters were attached. This rationale is supported by the fact that the two transmitters that were affixed at the beginning of the trials remained attached for up to 23 days. As we noted a lot of variety in the length of time the transmitters remained attached from <1 day to 23 days among the control transmitters with no coating and similar variations among the other transmitters, we conclude that that the antenna coating used did not influence the removal of the transmitters. In other words, the results of our study suggest that the presence and type of antenna coating do not play a significant role in transmitter attachment.

In regard to antenna damage, our study showed that across the four sets of antenna taste trials, >40% of antenna wires showed signs of damage (equivalent to our previous trials). Regardless of antenna coating, all antennas showed similar amounts of damage, indicating that bats were still able to damage the antennas in some way regardless of the type of coating present. Thus, damaged antennas were not removed significantly faster than intact antennas.

The overall results of this second set of trials suggest that either 1) bats were not deterred by the 3 coatings we selected, or 2) bats may not be chewing the antennas or putting them in their mouths to provide leverage to remove them.

Conclusion

Our study revealed that bats can and will remove transmitters by grooming them off themselves and others, despite the brand or design of the transmitter attached. The first part of our study revealed that bats are consistently damaging antennas, potentially as a means to remove the transmitters. These results suggest that if we could modify the antennas in some way, we could increase the time transmitters remained attached. Both anecdotal observations made during this study and observations in other studies (Smith 2019) revealed that antennas provided leverage for the bats, as they grab them with their feet and put them in their mouths. For example, much of the damage we recorded to the antennas showed signs of being chewed. However, despite this evidence, the second part of our study demonstrated that bats may not be putting the antennas in their mouths to pull them off as frequently as we had assumed, as transmitter antennas were damaged and transmitters removed regardless of the presence or type of the distasteful antenna coating. We acknowledge that coatings we used may not have been distasteful to bats as anticipated. Yet, it still may be worthwhile to test the effectiveness of other distasteful antenna coatings or more specifically conduct studies that examine the physiology of bat taste.

Nevertheless, while our trials did not uncover a method to prevent premature detachment, they did demonstrate the tendency of bats to indiscriminately remove transmitters using the antennas as quickly as possible. This finding is not surprising, as a foreign object attached to any wild animal is likely to cause discomfort and stress. However, if the length of time a transmitter remains on a bat is to be extended, our study confirmed that the antennas still need to be modified to prevent bats from being able to grab them. Thus, we recommend that the antenna be integrated into the body of the transponder as a preventative measure. Again, we acknowledge that technology may not have advanced to this level yet, but new and innovative advancements may be an option in the future.

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