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Development of a system for remotely monitoring vaginal implant transmitters and fawn survival

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Vaginal implant transmitters (VITs) are commonly used to determine the time of birth for ungulates to enable the capture and marking of their offspring. However, the use of VITs requires frequent monitoring and hence, high manpower and/or aviation costs. Similarly, offspring equipped with traditional telemetry transmitters necessitate large efforts for effective monitoring. The alternative described here uses communication between the VIT or offspring's transmitter and the parent's collar to monitor the status of the VIT or offspring's transmitter (Vectronic Aerospace, Berlin, Germany). The parent's collar uses its satellite communication capabilities to forward this information to the investigator when appropriate. I describe the development and successful deployment of this system in a study of black-tailed deer *Odocoileus hemionus columbianus*.

Reproductive rate and juvenile survival are key measures of population processes (Gaillard et al. 1998, Eberhardt 2002) that may be used in population models or to assess ecological conditions (Whittaker and Lindzey 1999, McCoy et al. 2014). In ungulates, researchers commonly use vaginal implant transmitters (VITs) to assist with estimating these vital rates (Johnstone-Yellin et al. 2006, Bishop et al. 2007). The VIT is expelled during parturition (accompanied by a change in VHF pulse rate), and by monitoring and homing in on the VIT signal, the investigator can locate, enumerate and mark the offspring. Offspring are typically marked with a very high frequency (VHF) transmitter that includes a mortality detection function, and the offspring's survival is subsequently monitored. VITs also minimize the problems of left truncation of life histories that are commonly associated with the opportunistic capture of offspring (Gilbert et al. 2014), which can result in overestimation of survival rates.

Timely information on VIT expulsion and offspring mortality is needed to capture offspring while their location is known (near the VIT) and to accurately determine the proximate cause of mortality. Hence, Johnstone-Yellin et al. (2006) recommended monitoring VITs 2–3 times a day. Depending on the objectives of the study, frequent monitoring of offspring is also likely to be desirable (e.g. once a day or three times a week). Consequently, many man-hours of field monitoring are typically required to capture offspring and assess causes of mortality. Moreover, because the power output of VHF transmitters for VITs and telemetry transmitters for neonates or juveniles is low and antennas are short, the strength of the radio signals from these devices is correspondingly weak. This creates a major challenge for effective monitoring of VITs and neonates, especially in remote locations or in rugged landscapes. Because of these challenges, I worked with Vectronic Aerospace to develop a system for remotely monitoring VITs and fawn survival utilizing the adult female's collar for communication.

Study area

Working with Washington Dept of Fish and Wildlife staff, I conducted this study at seven locations in western Washington, USA (45.6–48.3°N, 124.7–122.3°E), named after their respective Game Management Units (Pysht, Satsop, Mason, Capitol Peak, Vail, Coweeman and Washougal). These were selected as representative of ecological and timber management conditions found throughout western Washington.

Material and methods

The Washington Dept of Fish and Wildlife initiated a study of the effects of forest management on black-tailed deer *Odocoileus hemionus columbianus* reproduction in 2009. In 2012–2014, I deployed VITs and fawn collars from Vectronic Aerospace GmbH (Berlin, Germany, <www.vectronic-aerospace.com/wildlife.php?p=Implants>, <www.vectronic-aerospace.com/wildlife.php?p=UHF_ID_Tags>), which communicated their status to the female deer's collar. When appropriate, the female deer's collar then relayed this information to the investigator via satellite and email.

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VITs

VIT physical construction and programming varied among years. In 2012, the wings of the VITs consisted of commercially available wings designed for cattle but trimmed to have a span of 6.0 cm and the temperature sensor was located at the antenna (posterior) end of the VIT. Because these wings were somewhat difficult to compress when placing the VIT in the insertion tubes, in 2013 I used wings recycled from ATS (Advanced Telemetry Systems, Isanti, MN) VITs (<https://atstrack.com/tracking-products/transmitters/product-transmitters.aspx?serie=M3900>) which were more flexible and had a span of 6.3 cm. In addition, several 2012 VITs recorded premature low temperatures which I attributed to partial protrusion of the VIT. To ameliorate these issues, the sensor was relocated to the wing (anterior) end of the VIT in 2013. Because several of the 2013 VITs fell out prematurely, I reverted to the trimmed cattle VIT wings in 2014.

VIT programming also varied among years. In 2012 and 2013, VIT triggering was based on temperature alone. In 2013, VITs also included an accelerometer which recorded activity (range 1–255, with increasing scores indicating increased activity levels). Based on the sensor record maintained in the adult female's collar and the deployment history for each 2013 VIT, triggering in 2014 was as depicted in Fig. 1.

Fawn collars

The physical construction and programming of fawn collars changed little among years. The collar was made of an elastic band which had three folds stitched into it with cotton thread with variable numbers of rows of stitches such that the stitching degraded and folds opened over time and as the fawn grew. Fawn collars were programmed the same in all years (Fig. 1).

Both VITs and fawn collars sent a coded ultra-high frequency (UHF) transmission every 5 s. The code contained the transmitter identification number, its status (triggered or not), and the sensor values.

Female deer collars

Adult female deer were fitted with Vectronic GPS Plus collars (<www.vectronic-aerospace.com/wildlife.php?p=VertexPlus>). These collars recorded information about the female deer (GPS locations, activity record, mortality sensor, etc.). In addition, GPS collars received and processed the coded transmissions from the VITs and fawn collars as depicted in Fig. 2. Programming of VIT and fawn collar IDs was done in any of 3 methods: by connecting the collar to a computer using Vectronic's software; by satellite message sent to the collar; or using Vectronic's handheld terminal to communicate with the collar in the field. Typically, I programmed the female deer collars with the VIT identification numbers prior to deployment with the collar connected to a computer and programmed the fawn collar identification numbers via satellite message about a month prior to fawning.

The record of every attempt by the female deer collar to receive UHF transmissions was retained in the female deer collar. I used these records to evaluate the performance of the system and determine optimum settings for particular features.

Programming of the female deer collar determined if event messages should be sent by satellite (Fig. 2). I set the pre-programmed delays for fawn collars at 1 h in 2012, 18 h in 2013 and 20 h in 2014 (Results). In addition, whenever the female deer's collar sent GPS fix data messages, the collar sent a status message indicating the status of the identification numbers that it had received. In our system, this occurred every 20 h. In 2012–2014, fawn mortality did not generate an event message, so I used status messages to detect fawn collars in mortality mode.

Both VITs and fawn collars were equipped with VHF transmitters with the pulse interval determined by their status (triggered or not). Thus, team members could check or confirm the state of the transmitter in the field, and use the VHF signal to locate fawning and fawn mortality sites. I maintained all data from female deer collars, VITs, and fawn collars in a comprehensive database using Vectronic's software (GPS Plus X).

Captures

I contracted the capture of female black-tailed deer by net gunning from a helicopter in 2012–2014 and fitted each deer with GPS Plus collars and VITs. Each deployment was for a maximum of 2 years, and team members captured fawns from the radio-marked female deer in the year of capture and the following year and fitted them with expandable fawn collars. I conducted all captures in compliance with Washington Dept of Fish and Wildlife Policy on Wildlife Restraint or Immobilization (M6003).

Data handling and analysis

I compiled the VIT sensor records (n = 890 623) from female deer collars and determined the first date and time when each VIT had a temperature < 34°C that was not followed by a return to normal unexpelled temperature (> 37.5°C) and called this TempDropStart. This was considered to be the start of the VIT being expelled and was used to determine the delay in notification of an expelled VIT. I considered any event messages prior to TempDropStart as premature.

Because I deployed VITs over similar but varying dates due to variation in capture dates and fawning dates, I calculated the relative time of deployment for each premature Expelled or No Contact message as p Deploy time = (Message datetime – Deploy datetime)/(TempDropStart – Deploy datetime). For female deer that had premature messages, I evaluated the influences on premature message occurrence using the Recurrence platform in JMP ver. 12.1.0 (SAS Inst.) where the intensity of recurrence was modeled as $I(t) = \left(\frac{\beta}{\theta}\right)\left(\frac{t}{\beta}\right)^{\beta-1}$ (a power nonhomogeneous poisson process, Nelson 2003), where t is time and β and θ are fitted variables which can be modified by categorical or continuous covariates. To determine if premature messages differed for individual female deer or over time, candidate models were developed in which β and θ contained effects for p Deploy time and female deer independently or in combination. Due

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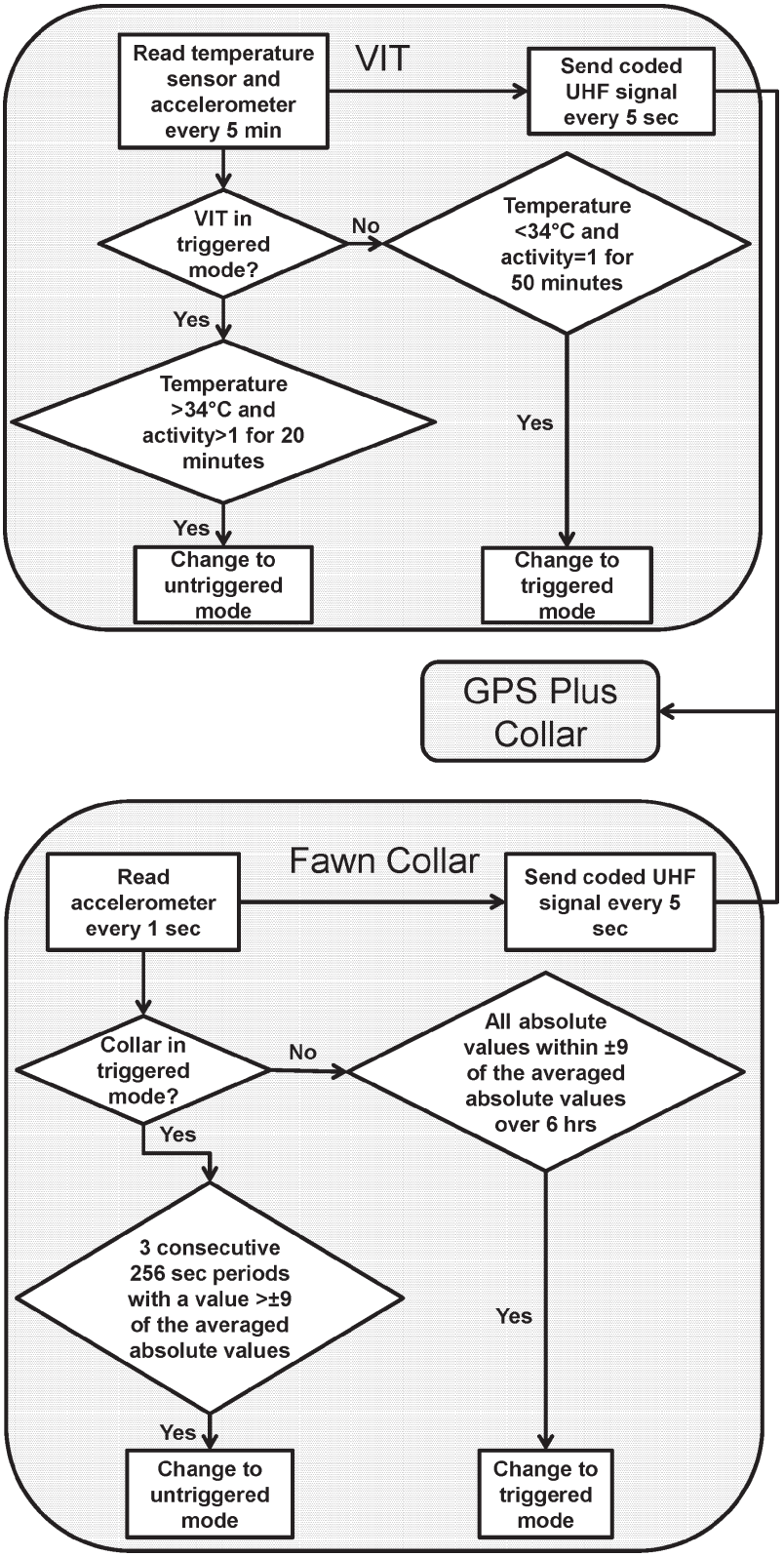

Figure 1. Flow diagram for VIT (vaginal implant transmitter) and fawn collars as programmed in 2014 for deployment on black-tailed deer in western Washington, USA. UHF = ultra-high radio frequency.

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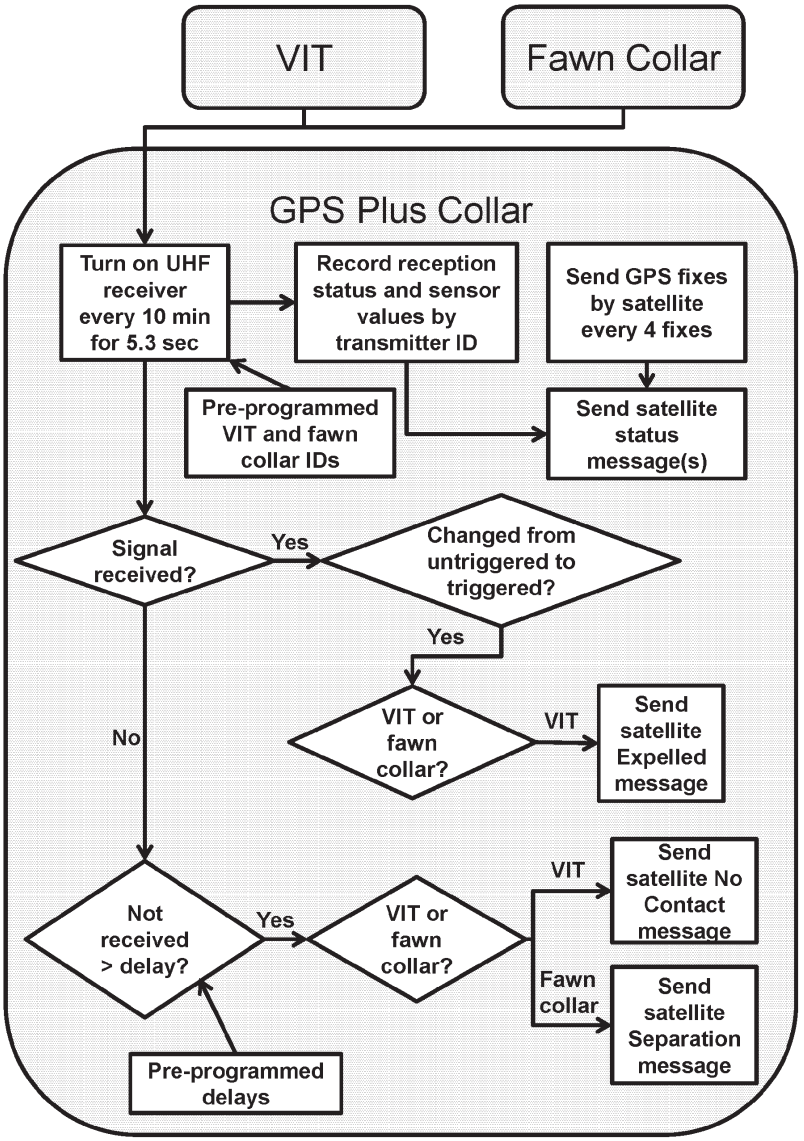

Figure 2. Flow diagram for GPS Plus female black-tailed deer collar (Vectronic Aerospace) programming, 2012–1014 in western Washington, USA. UHF = ultra-high frequency, ID = individual identification, GPS = global positioning system.

to the limited sample size, I did not evaluate interactions or models with > 2 covariates. I used information theoretic model selection based on Akaike's information criterion corrected for small sample size (AIC_c) (Burnham and Anderson 2002) for model comparison. For this and other analysis, I considered models with $\Delta AIC_c < 4$ as competitive. If there were competing models, I model-averaged over the models in the 95% model confidence set (Symonds and Moussalli 2011).

For fawn collars, I compiled the sensor records (n = 4 792 429) and used the first date and time of transmitter triggered (mortality) as the date and time of mortality. When there was no such record (transmitter never recorded triggered) and field records showed a mortality, I assigned it to 10 minutes later than the last regularly received record. I considered Separation event messages prior to the mortality date and time as being premature.

As with Expelled and No contact messages, I used the JMP Recurrence platform to model effects on intensity of recurrence of premature Separation messages due to female deer, fawn, time during deployment, whether or not the message occurred during the first week of deployment (hiding phase), and month of the year (in case there were seasonal effects). These were entered independently and in combination but without effect interactions, and used information theoretic model selection (Burnham and Anderson 2002) to compare these models. To avoid Separation messages associated with disruption of the female deer – fawn bond with the birth of new offspring, I only considered separation messages that occurred between the birth of the fawn and 1 May of the following year.

Results

VITs

I deployed VITs in 70 pregnant female deer, 2012–2014. Of these, 15 died before the VITs were expelled. In describing automated monitoring results, sample sizes vary because

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some outcomes applied to some situations but not to others. For instance, female deer that died between capture and the birth season might provide information on premature low temperature records, but not on whether an Expelled message was received before a No contact message. Similarly, a VIT that came out early may have had records of previous low temperatures, but the temperature record may have been too irregular to allow identification of Temp DropStart. Sample sizes given below are for all does that provided suitable data for each comparison.

Of the 47 female deer collars which sent both No contact and Expelled messages and for which the Temp Drop Start could be determined, 98% sent Expelled messages first with a median delay of 0.33 h (range 0.17–7.33 h). No contact messages were a median of 9.2 h later (range 1–117 h).

Between a week after deployment and before TempDropStart, 22% of 68 female deer recorded at least one temperature < 34°C, but the extent of this varied greatly among years (and VIT designs). Only one female deer in 2014 had temperature records < 34°C (n = 74), accounting for 0.47% of her temperature records and all of these were < 18 h before TempDropStart.

These low temperatures resulted in premature Expelled event messages. In 2012, of 15 female deer for which Temp Drop Start could be determined, 40% sent a total of 219 premature Expelled messages (range 1–106 each). Of 18 similar female deer in 2013, 33% sent a total of 181 premature Expelled messages (range 1–157 each). In 2014, none of 16 similar female deer collars sent premature Expelled messages. This included the single 2014 female deer with temperature records < 34°C, but no messages were sent because the activity conditions for the trigger were not met.

Twelve percent of 68 female deer sent a total of 65 No contact messages between a week after deployment and TempDropStart (range 1–50 each). Model selection for premature No contact messages indicated that female deer and p Deploy time influenced β where coefficients for the eight deer ranged 1.158 + –0.763–2.571 and –2.476 × p Deploy time, with $\theta = 0.161$ (Fig. 3). There were no competing models (i.e. $\Delta AIC_c < 4$, Supplementary material Appendix 1 Table A1). Premature no contact intensity was highest at the beginning for all but one deer (Fig. 3) and the exception also showed declining intensity near the end of deployment.

Of the 68 female deer, 18% sent a total of 414 Expelled messages between a week after deployment and Temp DropStart (range 3–141each). Model selection for these premature Expelled messages indicated that female deer and p Deploy time influenced θ and β (Supplementary material Appendix 1 Table A2) where coefficients for θ for the 13 deer ranged 0.686 + –0.412–0.313 and –0.271 × p Deploy time, while β ranged 6.909 + –5.832–7.391 and –3.273 × p Deploy time. There were no competing models. Most deer had a higher intensity of premature Expelled messages near the end of deployment (Fig. 3).

Fawn collars

Of 42 mortalities of 2013 and 2014 fawns, 62% were indicated first by satellite status message a median of 0.24 days after mortality (range 0.00–5.54 days), with Separation messages sent a median of 1.57 days later (range 0.75–7.50 days). Status messages indicating fawn mortality were never received for 38% of the fawn mortalities, with Separation events occurring a median of 0.75 days after mortality (range 0.04–3.19 days).

In 2012 (when the separation delay was set at 1 h), 22 fawns sent 1300 premature Separation messages before messaging was turned off in late July.

In 2013 and 2014, prior to 1 May the year after their birth, 20 fawns generated 54 premature Separation messages (range 2–14 each). Unlike the premature VIT messages, there were numerous competing models for premature Separation messages (Supplementary material Appendix 1 Table A3). There were seven models in the 95% confidence set (Symonds and Moussalli 2011) which consisted of a fawn age influence on θ, intercept only (for θ and β), fawn age influence on β, first week influence on θ, fawn age influence θ and β, fawn age and first week influence on θ, and fawn age and first week influence on β. I weighted the predictions of these models by their AIC_c-weights to obtain an overall estimate of the intensity of premature Separation messages (Fig. 4). This indicated that premature

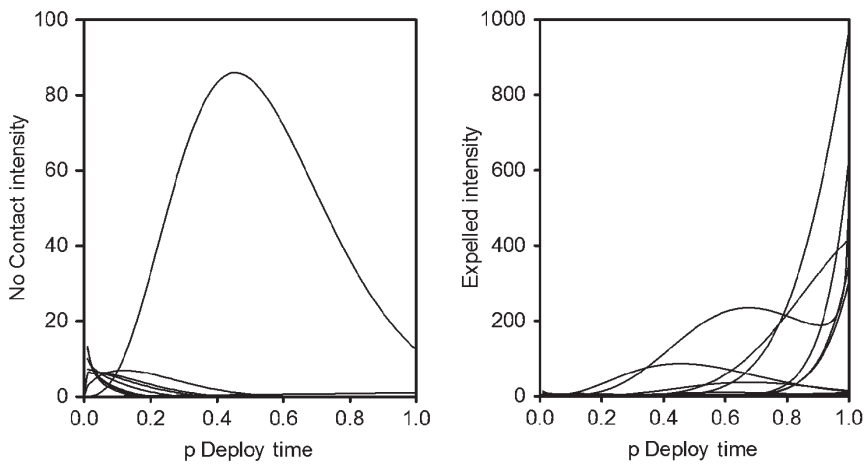

Figure 3. Modeled intensity of premature No contact and Expelled event messages over VIT (vaginal implant transmitter) deployment for 8 (No contact) and 13 (Expelled) female black-tailed deer in western Washington, USA, 2012–2014. Each line represents a single deer.

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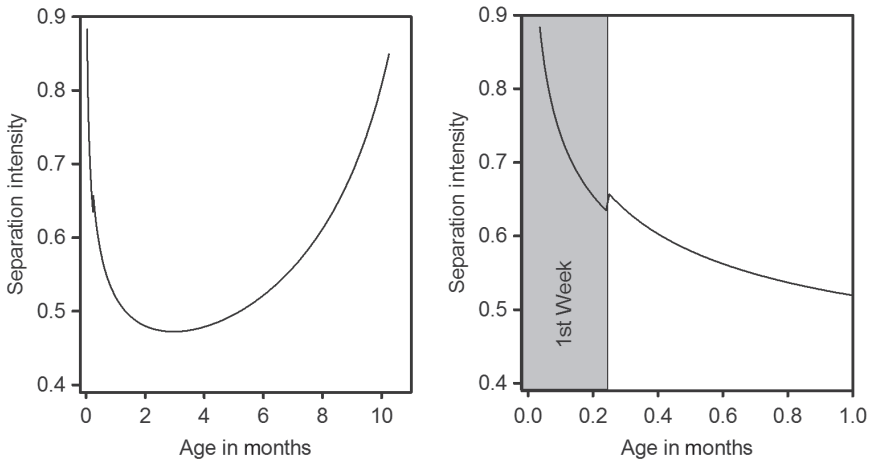

Figure 4. Modeled intensity of premature Separation event messages prior to 1 May the year after parturition (left) and during the first month (right), showing the difference during the first week (hiding phase) for fawn collars on black-tailed deer in western Washington, USA, 2013–2014.

Separation intensity was highest immediately after parturition and late in a fawn's first year. The discontinuity at the age of 0.25 months indicated that intensity was slightly lower during the hiding phase. Models with effects for individual doe or fawn or month were not competitive, indicating that premature Separation messages were not a function of female deer–fawn pair behavior or collar characteristics and that there were no seasonal effects detected.

Notification by satellite message was generally reliable and timely. Of 425 event messages, the median delay between the event time and an email being sent was 3.5 min (range 5 s – 32 h).

Discussion

I successfully used the system I describe to receive prompt information on a VIT being expelled or a fawn mortality. However, refinements to the system have increased its functionality. Low VIT temperatures in 2012 and 2013 resulted in numerous premature Expelled event messages. In 2012, I attributed premature Expelled messages to partially expelled VITs, which was reduced by moving the temperature sensor to the anterior end of the VIT. In 2013, wing design was evidently poorly suited to the Vectronic VITs, and several fell out prematurely. In 2014, with the addition of activity in the trigger, no premature Expelled messages were received.

It is not certain when in the birth process the VIT is expelled. It is also not certain how long fawns remain at the birth site (and in the vicinity of the VIT) but this is thought to typically be 12–24 h (Johnstone-Yellin et al. 2006). Examination of sensor records that included activity indicated that the VIT came to rest a median of 0.76 h after the start of the final temperature decline (range 0.17–5.00 h). Thus, prompt response in tracking down the VIT could, in some instances, result in fawn capture before female deer–fawn pair bond formation, or even interrupt the birth process.

Premature VIT event messages were rare for most deployments, but when they occurred, it was usually near the end of deployment. This was probably due to the VIT being fit poorly in those individuals (Bishop et al. 2007). The reason for premature No contact messages is not clear as the VIT and the female deer collar are continuously in proximity to each other. However, most of the No contact messages occurred earlier in deployment and these can be ignored because the fawning season was quite restricted (≈18 May – 12 June). Furthermore, when the VIT was expelled, this was detected consistently with Expelled event messages.

For VITs, the functioning of this system is conceptually straightforward in that when the VIT is expelled at fawning, its temperature drops and it stops moving which causes it to go into triggered mode. The female deer's collar detects that the VIT has gone into triggered mode and sends an event message. For fawn collars, the dynamics are more complex and uncertain. Most of our fawn mortalities were due to predation. During a predator's attack, a female deer may flee and be out of UHF range when the fawn's collar enters mortality mode, or she may stay in the vicinity or return later in search of the fawn. Limited static field-testing has indicated that UHF reception drops from 100% to 0% when the distance between the female deer's collar and the fawn collar is 100–200 m. As a result, fawn mortalities were detected by both 1) UHF transmission of mortality status, or 2) inferred by lack of reception of the UHF transmissions (i.e. Separation message), depending on the dynamics of each predation event.

Due to their small size, fawns are consumed quickly and typically dismembered by large predators (cougars *Puma concolor*, coyotes *Canis latrans* and American black bears *Ursus americanus*), so prompt inspection of the kill remains is necessary to determine which predator was involved. Satellite status messages provided prompt notification of mortality for the majority of fawn mortalities. However, fawn and female deer were evidently separated by the predation event for a substantial number of fawn mortalities (38%), in which case the Separation events provided notification somewhat less promptly (typically 12 h later).

The continued occurrence of premature Separation messages in 2014 suggests that the duration of separation required for this event should be extended beyond 20 h. While this will further delay notification, it is important to reduce the number of premature Separation messages

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because every one of them requires a field visit to determine if the Separation event corresponds to a mortality (by checking the VHF pulse interval of the fawn collar). These premature Separation events are contrary to our expectation in that, although our team does not frequently observe female deer with their fawns, I would not expect them to be >100 m apart for extended periods. In 2016, I plan to investigate this further by deploying lightweight GPS collars on some fawns.

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Supplementary material (available as Appendix wlb.00177 at <www.wildlifebiology.org/appendix/wlb-00177>). Appendix 1.

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