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Telemetry tails: a practical method for attaching animal-borne devices to small vertebrates in the field

K. A. Cornelsen[A,*], C. M. Arkinstall[B], J. van Weenen[C], A. K. Ross[A,D], J. C. Lawes[A], K. E. Moseby[A], A. Elphinstone[E] and N. R. Jordan[A,E]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
K. A. Cornelsen
Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW, Australia
Email: cornelsen.kate@gmail.com

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ABSTRACT

Context. Continued miniaturisation of tracking technology increases its utility in animal applications. However, species morphology often dictates the type of animal-borne device (ABD) that can be used, and how it is attached. The morphology of species within Peramelemorphia preclude them from the standard collar attachment of ABDs for terrestrial mammals. **Aims.** This paper describes a method for the tail-mount attachment of ABDs, and deployment results for Peramelemorphia across arid, semi-arid and temperate Australia to (a) test the performance of attachments and ABDs in the field and (b) discuss the animal welfare considerations for this attachment method. **Methods.** Tail-mount attachment of ABDs were field-tested on a total of 80 greater bilbies (*Macrotis lagotis*), and 14 long-nosed bandicoots (*Perameles nasuta*). **Key results.** Time to natural detachment (TTND) was between 2 and 52 days, with 65.74% (142 of 216) remaining on until manual removal. For ABDs that were manually removed, attachments were retained for up to 94 days. The method used for tail-mount attachment of ABDs to long-nosed bandicoots resulted in significantly shorter TTND compared with the method used for bilbies, and environmental factors (high temperatures and rainfall) had a negative effect on TTND. Tail-mount attached global positioning system (GPS) sensors collected large quantities of accurate data, with a maximum fix success rate of 83.38%. Damage to GPS (antenna breakage and water ingress) during deployment, however, impacted performance. In environments with frequent rainfall and waterlogged soils, the tape on a small proportion (6.25%) of (n = 192) attachments to bilbies caused tail injury. All injuries were resolvable, with most requiring minimal to no veterinary intervention. **Key conclusions.** Attachment longevity can be affected by how the ABD is mounted to the tail, the species and the deployment environment. The environment can also affect which adhesive tapes are suitable for ABD attachment. However, this method is highly modifiable, practical for field application and can have long retention times relative to other temporary methods. **Implications.** This ABD tail-mount attachment method adds another tool to the telemetry tool-kit, with all the benefits of a low-tech, low-cost, passive drop-off type attachment. This method has demonstrated practicality for Peramelemorphia, with potential application to other suitable small vertebrates.

Keywords: animal biotelemetry, animal welfare, animal-borne device, conservation research, GPS, Peramelemorphia, radio-telemetry, small vertebrates, tail-mount attachment.

Introduction

Advances in the form and function of animal-borne devices (ABDs) have increased their utility in ecology and conservation research. ABDs can collect information on an animal's state (e.g. location and activity), and the environment in which they live (e.g. air temperature, depth) (Rafiq *et al.* 2021*b*). Data can be collected by tracking an animal and manually recording its location (e.g. via radio-telemetry) or remotely (e.g. via satellite global positioning system (GPS); see Rafiq *et al.* (2021*b*) for a detailed description of sensors used in ecological research). Traditional tracking methods (e.g. very-high frequency (VHF) radio-tracking) are still commonplace in the telemetry research of smaller taxa (Bridge *et al.* 2011; Mitchell *et al.* 2019; Börger *et al.* 2020). Often, researchers will need to compromise ABD functionality to satisfy recommended device-to-body-weight thresholds. As a general rule, ABDs should weigh ≤5% of an animal's body weight (Brander and Cochran 1969; Kenward 2001). However, this threshold is arbitrary and may not always be the best compromise between ABD functionality and animal welfare (O'Mara *et al.* 2014; Tomotani *et al.* 2019). In addition to the 5% threshold, and as examples, 1% has been used for southern elephant seals (*Mirounga leonina*) (McMahon *et al.* 2008), 1.5% for ring-necked pheasants (*Phasianus colchicus*) (Venturato *et al.* 2009) and greater bilbies (*Macrotis lagotis*) (Moseby *et al.* 2012), 3% for black-browed (*Thalassarche melanophrys*) and grey-headed (*T. chrysostoma*) albatrosses (Phillips *et al.* 2003), and 4% for long-nosed bandicoots (*Perameles nasuta*) (Chambers and Dickman 2002). Although ABDs, particularly sensors (e.g. GPS), are now becoming increasingly compact and capable of collecting considerable data of relevance to a species' ecology, researchers must – and are ethically obliged to – consider the welfare impacts before attaching ABDs, and continue to monitor any impacts during deployment (Hawkins 2004; Latham *et al.* 2015). Species size, morphology and behaviour often dictates which ABDs it is possible to use, and how they should be attached.

Bilbies (family Thylacomyidae) and bandicoots (family Peramelidae) are marsupials from the order Peramelemorphia. Peramelemorphia includes all marsupial omnivores, all of which are endemic to Australia, Papua New Guinea, and Indonesia (Seram) (Braithwaite *et al.* 1983). Over half of the species within Peramelemorphia are currently listed as vulnerable or endangered, with 14% of described species already presumed extinct (Supplementary Table S2), due to multiple threatening processes (e.g. introduced predators and competitors, and habitat loss or degradation) (Braithwaite *et al.* 1983; Southgate 1990; Long *et al.* 2005; Moseby *et al.* 2011; Hope 2012; IUCN 2021). Reintroductions of Peramelemorphia into regions where key threats have been eliminated or managed to non-threatening levels can conserve and allow repopulation of species within their former ranges (e.g. Moseby and O'Donnell 2003; Richards and Short 2003). However, this conservation strategy requires a period of post-release monitoring to confirm success (IUCN and SSC 2013). Because species within Peramelemorphia are largely nocturnal and solitary, survivorship is difficult to ascertain from indirect signs of presence (e.g. tracks and scats), and species (particularly bilbies) can move large distances in a short space of time, ABDs are often required for post-release monitoring (Braithwaite *et al.* 1983; Moseby and O'Donnell 2003; Southgate *et al.* 2005). Additionally, ABD data collected can increase our understanding of Peramelemorphia ecology and behaviour.

Collars are the standard form of attaching ABDs to terrestrial mammals (Kenward 2001; Matthews *et al.* 2013). However, the lack of a prominent jaw and the presence of digging forelimbs in Peramelemorphia make it difficult to attach collar ABDs both logistically and without any negative animal welfare impacts. Peramelemorphia collars would need to be fitted perfectly (typically while the animal is sedated) to ensure that they did not slip off or damage the neck region (Seebeck and Booth 1996; Richards and Short 2003; Coetsee *et al.* 2016; Sims *et al.* 2020). Even when fitted perfectly, fluctuations in weight (losses or gains), which can occur rapidly when Peramelemorphia are first reintroduced or translocated to a site (Moseby and O'Donnell 2003; Richards and Short 2003; Dunlop and Morris 2018; J. van Weenen, unpubl. data) and seasonally with the abundance of food (J. van Weenen, unpubl. data), can cause collars to tighten or loosen – increasing the risk of injury or death (due to limbs getting stuck between the collar and neck after weight loss) (Murphy and Serena 1993; Seebeck and Booth 1996; Richards and Short 2003; J. van Weenen, unpubl. data). ABDs can be glued directly to the skin with adhesive (Kenward 2001; Coetsee *et al.* 2016). This attachment method, however, has highly variable retention times in Peramelemorphia (a few hours to a week) (Coetsee *et al.* 2016) and other small vertebrates (10 days to several weeks) (Kenward 2001). Pectoral harnesses have also been trialled for attachment of ABDs to Peramelemorphia with limited success and rapid detachment of ABDs (<24 h) (Murphy and Serena 1993). A combination of suturing and gluing intraperitoneal attachments achieves more consistent and longer retention times of 3–4 weeks, with the compromise of reduced VHF signal transmission (30–50 m) (Coetsee *et al.* 2016; Groenewegen *et al.* 2017). However, suturing can introduce infection, and requires sedation of the animal and veterinary expertise for ABD attachment (Richards and Short 2003; Barron *et al.* 2010; Coetsee *et al.* 2016; de Milliano *et al.* 2016; Groenewegen *et al.* 2017).

To avoid the hazards and logistical constraints associated with collaring, suturing, harnessing or gluing ABDs to animals, an alternative ABD attachment method was developed, which involved mounting an ABD to the animal's tail using adhesive tape. The method was developed in 1997, specifically to provide a low-risk monitoring tool for greater bilbies (hereafter bilbies) released on Thistle Island, South Australia, particularly because visits to the island were intermittent. The technique was initially evaluated using captive bilbies at Monarto Zoo, where a series of adhesive tapes used for VHF attachment were trialled for their suitability. The key findings from this initial work was that (a) trimming and shaving the tail was necessary to get the tape to adhere to the animals skin, (b) some adhesive tapes (brown rigid strapping Elastoplast® tape) were unsuitable because of their lack of flexibility over time, (c) it was critical not to tape the VHF transmitter to the tail, rather it was necessary to create a pocket above the tail in the tape where the ABD was then not applying pressure to the surface of the tail (which would otherwise result in a tail ulcer), and (d) the tape always began on the side of the tail to avoid the edge of the tape being on the bottom or top of the tail where there is potentially additional pressures being placed (via the weight of the transmitter or the weight of the tail). The evaluation of captive animals included veterinary assessment of the condition of the tail in the weeks after application, with the technique deemed suitable if the above critical steps were addressed. After successful trials in captivity, the method was evaluated in the field in 1998, on Thistle Island, and found to provide a successful low-risk option for tracking survivorship of animal's post release. Included in the 1998 evaluation was the use of the ABD attachment method on juvenile and subadult animals for which it was found to be similarly effective. It was identified that transmitters should be applied as close as possible to the base of the tail to reduce the chance of foreign objects (e.g. grass seeds) and soil working their way in under the tape with the forward motion of the animal. It was also discovered that tail hair growth eventually lifted the adhesive tape off the tail (in conjunction with soil working its way under the tape) and seemed to lead to the tape, and attached transmitter, eventually loosening its grip and sliding off the tail. However, this usually occurred after several months of attachment. With the success of the attachment technique, training was provided to other researchers involved in the reintroduction of the species at Arid Recovery (Moseby and O'Donnell 2003), and it has since been used and adapted for several studies of bilbies at Arid Recovery (Moseby *et al.* 2012; Steindler *et al.* 2018; Ross *et al.* 2019*a*) and at Scotia Sanctuary (Finlayson *et al.* 2008), and adapted for multiple studies on Peramelidae spp (e.g. Groenewegen *et al.* 2017; Robinson *et al.* 2018; Maclagan *et al.* 2020).

Mounting ABDs using this tail-mount attachment method reduces animal handling because the attachment is temporary. Similar to gluing, tail-mount attached ABDs should naturally detach from the animal over time, and so animal recapture is not necessary for device retrieval. In addition, the adhesive tape provides stability and support to tail-mount attached ABDs, not provided by gluing directly to the skin, with the aim to extend attachment duration. It is important that attachments have reasonable longevity to reduce the number and frequency of animal recaptures required for sufficient data. For trap-shy animals, and species prone to capture myopathy, a low number of recaptures and ABD reattachments is preferred, and may be ethically preferable (Kenward 2001; Hawkins 2004; Matthews *et al.* 2013; Latham *et al.* 2015). Tail-mount attachments to bilbies are known to last for up to 2–3 months or longer in the field, and individuals have had successive transmitters attached for over a year (Moseby and O'Donnell 2003; Moseby *et al.* 2012; Steindler *et al.* 2018). The longevity of attachments, however, can be affected by extrinsic (e.g. heat and rain) or intrinsic (e.g. digging behaviour) factors (Moseby and O'Donnell 2003; Hope 2012; Cuthbert and Denny 2014), but a detailed analysis of the factors that may cause early detachment of tail-mounted ABDs has not yet been done.

Our aim was to provide ample detail on how to effectively use this tail-mount attachment method for monitoring Peramelemorphia using various ABDs (including GPS), and give examples of the performance, and potential limitations, of attachments and attached ABDs from field deployments. The applications of this tail-mount attachment method are not restricted to the examples given in this paper. The same technique can also be applied and modified to other species of similar morphology (e.g. any vertebrate with a robust long tail, especially those without a distinct neck region). In addition to small terrestrial mammals, tail-mount attachment of ABDs has been trialled in reptiles (e.g. Kerr *et al.* 2004; Romijn *et al.* 2014; Riley *et al.* 2017), a semi-aquatic mammal (Rothmeyer *et al.* 2002), and a variety of avian species (e.g. Woolnough *et al.* 2004; Le Souëf *et al.* 2013; Harmata 2016; Yeap *et al.* 2017) due to the behavioural (e.g. chewing and damaging devices), physical (e.g. limiting full range of movement), or animal welfare (e.g. trauma due to surgical implants) constraints of attachment alternatives. It is not the intention of this paper to provide an exhaustive list of all variants of the tail-mount attachment method, but to demonstrate its practicality in the field with examples from multiple studies, sites, and species.

Materials and methods

Study sites

Field deployments of tail-mount attachments were trialled on a total of 80 bilbies and 14 long-nosed bandicoots at four different sites across Australia (Table 1). At Taronga Western Plains Zoo (Taronga WPZ) bilbies were released into a 110-ha fenced area where introduced predators (red fox; *Vulpes vulpes*) and herbivores (European rabbit; *Oryctolagus cuniculus*) had been removed. At Arid Recovery bilbies were released into a 3700-ha fenced area where feral cats (*Felis catus*) and *O. cuniculus* were present (Ross *et al.* 2019*a*). At Currawinya National Park (Currawinya NP) bilbies were released into a 2800-ha fenced reserve where *O. cuniculus* were present but introduced predators were removed. Long-nosed bandicoots were free-ranging within the Taronga Zoo complex and nearby Sydney Harbour National Park (Taronga ZS), and were captured for ABD attachment. Different ABD models and combinations were attached to animals at each site (Table 1) and weighed between 0.09 and 2.20% of the animal's body mass. For details on the different ABD models used at each site and their features, see Table S3. All studies were approved by the relevant animal ethics committees and under current scientific licence.

Table 1. Number of total animals (N) and type of ABD attached (either VHF-only transmitters: VHF, or bundled VHF and GPS: VHF and GPS) to bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*), at trial sites (Taronga WPZ, Arid Recovery, Currawinya NP, Taronga ZS) and climates.

Site	Climate	Species	N	ABD attached	Mean % ABD weight relative to male weights (±s.d.)	Mean % ABD weight relative to female weights (±s.d.)
Taronga Western Plains Zoo, New South Wales (Taronga WPZ)	Temperate: no dry season	*M. lagotis*	23	VHF and GPS	0.47 ± 0.18 (n = 13)	0.65 ± 0.06 (n = 8)
				VHF	0.14 ± 0.05 (n = 11)	0.22 ± 0.04 (n = 9)
Arid Recovery Reserve, South Australia (Arid Recovery)	Desert: hot (arid)	*M. lagotis*	42	VHF	1.09 ± 0.46 (n = 20)	1.33 ± 0.32 (n = 22)
Currawinya National Park, Queensland (Currawinya NP)	Grassland: hot (semi-arid)	*M. lagotis*	15	VHF and GPS	0.36 ± 0.05 (n = 5)	0.65 ± 0.07 (n = 7)
				VHF	0.15 ± 0.02 (n = 5)	0.28 ± 0.04 (n = 7)
Taronga Zoo, and nearby Sydney Harbour National Park, New South Wales (Taronga ZS)	Temperate: no dry season	*P. nasuta*	14	VHF and GPS	0.96 ± 0.32 (n = 9)	1.57 ± 0.42 (n = 5)
% range					0.09–1.87	0.17–2.20

Note: Weight for males and females were averaged for multiple reattachments before calculating % ABD weight. Climate information is based on the Köppen climate classification (Stern *et al.* 1999). The % range indicates the % ABD weight relative to the lightest and heaviest male, and female across all four sites. Data from Arid Recovery was obtained from Ross *et al.* (2019*b*).

Animal capture

Animals were either captured in cage traps with bait (e.g. peanut butter and rolled oats), or with spotlights and hand-held nylon fishing nets (Ross *et al.* 2019*a*) and transferred into cloth capture bags for ABD attachment. Animals were captured once at Arid Recovery in June 2017 (Ross *et al.* 2019*a*), and multiple times at Taronga WPZ (December 2018–March 2020 and July 2020–April 2021), Currawinya NP (April 2019–February 2020), and Taronga ZS (June–September 2018). Animal recaptures (median, interquartile range (IQR)) at Taronga WPZ occurred every 40 (29–48.5) days, and every 20 (10.5–26.5) days at Taronga ZS. The maximum number of reattachment events per animal at Taronga ZS was restricted to three, as determined by our animal ethics approval. Only attachments that naturally detached before animal recapture were included in the analysis of attachment longevity. Attachments for which the date of detachment was not known (n = 7) were removed from the analysis. Animals preyed on before the end of the study (n = 14) at Arid Recovery were also removed from the analysis.

Method for tail-mount attachment of ABDs to bilbies

Tails were prepared for attachment by removing hairs around a basal section of the tail (Fig. 1). For a full list of the equipment and materials used for tail-mount attachment of ABDs at Taronga WPZ and Taronga ZS, see Table S4. Starting 5 mm from the animal's rump, electric clippers were used to remove all hair from a region of the tail corresponding to the width of the adhesive tape, plus a 5-mm hair-free buffer at the proximal and distal end of the attachment area. The Tensoplast® Vet tape (BSN medical Pty Ltd, Australia) used was 7.5 cm wide, thus approximately 8.5 cm of each individual's tail was shorn.

Fig. 1. A bilby tail was prepared for attachment by using electric clippers and disposable razors to remove all hair from the tail. This required manual restraint of the animal in a capture bag while the attachment was being completed. Only the tail needed to be exposed for attachments. Image provided by N. R. Schoefield.

Disposable razors were then used to remove smaller patches of hair missed by the clippers. If there was mud or loose debris on the tail this was removed from the shaved section of tail with alcohol wipes (with 70% isopropyl alcohol) or a soft-bristled brush. All the hair and debris were thoroughly removed to maximise attachment longevity.

To mount the ABD to the animal's tail, Tensoplast® Vet tape was used. For footage of an ABD being tail-mounted to a bilby see the video (available in the Dryad Digital Repository at https://doi.org/10.5061/dryad.vq83bk3sm). Before the tape was applied to the tail, the tape was checked for any loose threads or fraying edges because this could wrap around and constrict the tail or get caught on vegetation. If any were found these were trimmed with scissors. For attachments containing both VHF and GPS, the two separate parts were bundled together tightly with at least three layers of electrical tape (Fig. 2*a*). Starting on the animal's side (i.e. not on the top or bottom of the tail), the Tensoplast® Vet tape was wrapped over and under the tail until the tape just overlapped the first layer of tape (Fig. 3*a*). The tape was pressed to the tail without pulling tight to prevent constriction and swelling of the tail. The bundled or single ABD was stuck to the adhesive side of the tape and positioned along the dorsal midline of the animal, allowing enough room for the ABD to 'float' above the animal's tail (Fig. 3*b*). The ABD was elevated off the tail by leaving a 2–3-mm gap between the bottom of the ABD and the top of the tail, which was held in place by pinching the tape together underneath, and around the elevated ABD. This step was necessary to prevent pressure being applied to the tail by the mounted ABD. If a GPS sensor was used, this was positioned with an unobstructed view of the sky (i.e. above the VHF transmitter). To check the correct height was achieved, the handle of a pair of nurse's scissors was slid

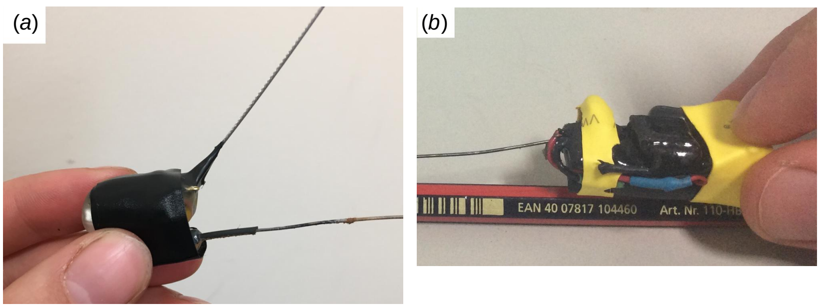

Fig. 2. Multiple tracking devices were securely bundled before mounting to the tail. A temporary seal can be applied for ease of removal and for replacing expired units after use. For example, a GPS and VHF unit can be tightly bundled with (*a*) electrical tape or (*b*) heat shrink prior to attachment. Image (*b*) was provided by T. Garman.

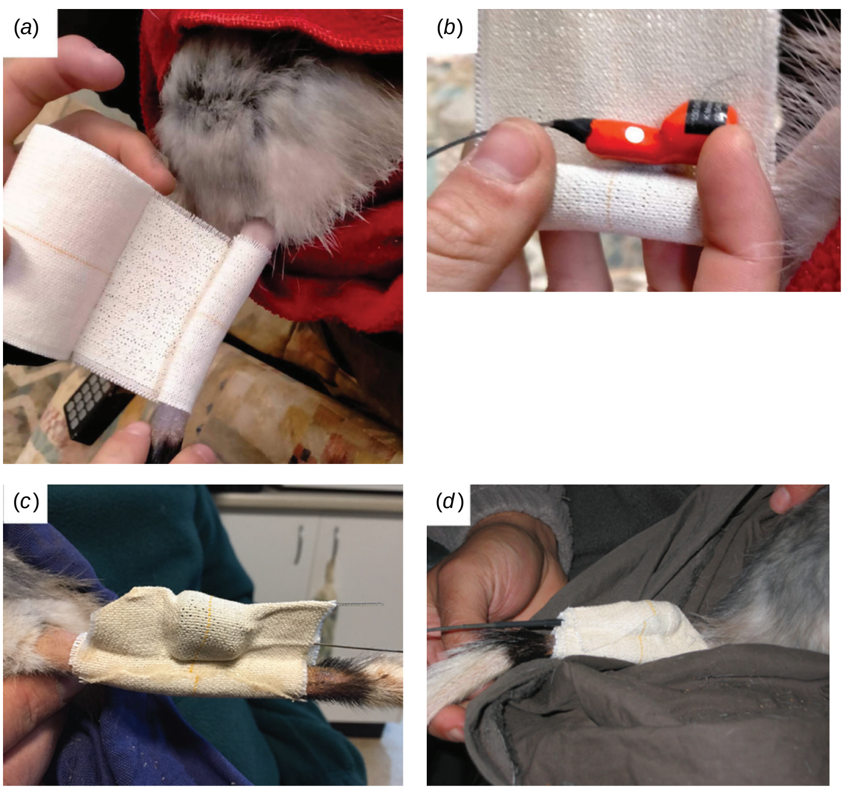

Fig. 3. For tail-mount attachment of an ABD to a bilby Tensoplast® Vet tape was wrapped around the animal's tail, starting on the animal's side, and (*a*) wrapping over and under the tail until the tape just overlapped the first layer of tape. The ABD was then (*b*) stuck to the adhesive underside of the tape in line with the dorsal midline of the animal. The tape was then wrapped over and under the tail again until it (*c*) terminated on the same side that the tape was applied, before the mounted device or (*d*) opposite side the tape was applied, just after the mounted device. Images provided by (*a, b*) N. R. Schoefield, and (*d*) the Arid Recovery team.

along the tape in the gap between the ABD and the top of the tail. For GPS with an external antenna, no more than 10 mm of the antenna was exposed outside the top edge of the attachment to reduce the potential for antenna breakage. Once the desired position was reached, the tape was pinched around the ABD to seal, and wrapped over and under the tail again. The tape was cut and lightly pressed to the tail on the same side that the tape was applied, before the mounted device (Fig. 3*c*). Alternatively, the attachment was finished by extending the tape over the ABD, and terminating on the opposite side that the tape was applied, just after the mounted ABD (Fig. 3*d*). Either finish was suitable and had a maximum thickness of two layers of tape.

The attachment was finished by cutting and sealing the tape with a very thin line of Selleys Quick Fix superglue (Selleys, Australia) along the seam and edges (Fig. 4). Gluing helped seal the edges of the tape to prevent them from fraying and coming loose with wear. Care was taken to avoid gluing the antenna because this made the section of antenna rigid and prone to breaking. If attachments were marked with reflective tape this was stuck to the sides of the attachment with a small amount of superglue. For a more detailed description of this method for individual identification see Appendix S1. We caution against using any form of cotton markings or attachments due to the potential for an exothermic reaction with the superglue (Akelma *et al.* 2017). At Currawinya NP, and for most attachments at Taronga WPZ, when mounting bundled ABDs (VHF and GPS) to the tail a small amount of 90 s Araldite (Selleys, Australia) was applied over the superglued edges to smoothen any hard edges of the tape, preventing it from scratching the tail.

Fig. 4. A very thin line of superglue was used to seal the seam and edges of the tape. Image provided by the Taronga Conservation Society Australia (TCSA).

If reattachments were required, or if the ABDs notably malfunctioned (e.g. antenna breakage causing reduced VHF signal strength), we aimed to recapture animals before the ABD naturally detached. ABDs were manually removed by cutting the old tape off the animal's tail with nurse's scissors (i.e. one blunt end and one sharp end). The blunt end of the scissors was slid in a gap between the tape and tail and the tape was cut lengthways along the tail, below and to the side of the mounted ABD. Care was taken to avoiding cutting the skin of the animal during removal.

Method for tail-mount attachment of ABDs to long-nosed bandicoots

An alternate tail-mount attachment method was recommended for long-nosed bandicoots (J. Anson and V. Leo, pers. comm., 2018), and was used to test for any variation in performance between the two tail-mount attachment methods.

For tail-mount attachment of ABDs to long-nosed bandicoots, a small smear of Selleys Kwik Grip contact adhesive (Selleys, Australia) was applied directly to the dorsal proximal end of the tail. Nexcare™ sports tape (3M, Australia) was then cut into a wide triangle (5 cm width on the dorsal side of tail tapering to a 1-cm width on the ventral side of tail) so that the tape went almost the whole way around the proximal end of the tail and over the unset glue, leaving a small gap between the edges of the tape on the ventral side of the tail (Fig. 5*a*). The gap in the tape reduces the risk of tail constriction and enables better movement. The tape was as long (or slightly longer) as the length of the ABD (not including the antenna) to minimise chance of ABD rubbing against the tail.

The GPS sensor was coated with a waterproof epoxy (Telemetry Solutions, United States of America) prior to attachment, and the GPS and VHF were bundled together by using two strips of heat shrink with the VHF positioned to the side of the GPS sensor (Fig. 2*b*). This ensured the VHF did not cover the top of the GPS sensor, blocking satellite reception. Soft Velcro® (Velcro Pty Ltd, Australia) discs of fabric were then glued to the bottom of the ABD bundle and to the sports tape on the tail to provide stability, particularly for the GPS, which needed to be positioned with an unobstructed view of the sky. Two lengths of Micropore™ tape (3M, Australia) were loosely placed around the tail and ABD, with one length around the widest part of the ABD, and another where the VHF antenna started. The single layer of paper tape smoothened the mounted device and provided extra stability without constricting the tail (Fig. 5*b*). Initially, the ABD bundle was glued directly to the sports tape at the central midline of the tail, but the packages were detaching too quickly, in some cases overnight, so the soft Velcro® circles provided the extra stability for the sensor to stay attached for longer periods of time and also ensured the GPS was positioned appropriately. Only

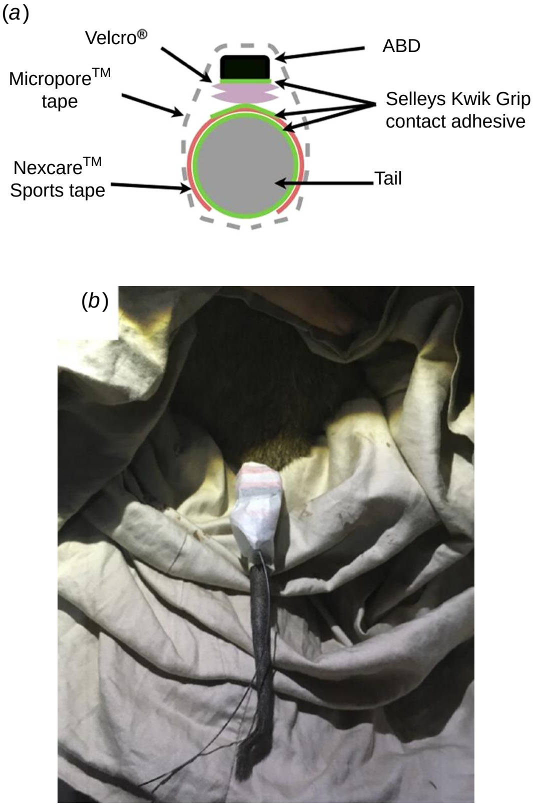

Fig. 5. (*a*) A cross-sectional diagram of the tail-mount attachment method used for long-nosed bandicoots and (*b*) a completed attachment. Images provided by H. Tsanidis.

attachments using the modified 'Velcro® method' were used for analysis of attachment performance.

Attachment performance

Attachment performance was assessed by measuring time to natural detachment (TTND) of the ABD. Available attachment data were pooled across sites (Taronga WPZ, Arid Recovery, Taronga ZS) and species (*M. lagotis, P. nasuta*) to compare TTND between the sexes (male vs female) and methods used for each species. An analysis of variance (ANOVA), and Tukey *post hoc* test for pairwise comparisons were used to test for significant differences in TTND between groups at the $P < 0.05$ level.

Environmental variables (temperature and rainfall) were recorded at each site and used to test for their effect on TTND. Environmental data were obtained from the Bureau of Meteorology (Australia) (2021) and local weather stations. Due to the lower number of attachments, and shorter deployment period at Taronga ZS (24 attachments over 95 days) and Arid Recovery (28 attachments over 40 days), environmental variation (temperature and rainfall) over the deployment periods was limited for those sites. Thus, only the Taronga WPZ attachment data (164 attachments over 770 days) and 33 detached ABDs were used to model environmental effects on TTND. A linear mixed model regression via restricted maximum likelihood (REML = T) was run in R (version 4.0.4; R Core Team 2021, R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/) using the package 'lme4' (version 1.1.23; Bates *et al.* 2015). Individual bilbies were added as a random effect to the model to account for multiple re-attachments of ABDs to individuals. The correlated terms ($0.6 \leq r \leq -0.6$), mean rainfall, and mean minimum daily temperature were removed from the model. Sex, mean maximum daily temperature, and rainfall frequency (i.e. proportion of days with >0 mm of rainfall over total days attached) were used as fixed effects for candidate models. The final model, with the lowest AIC (with REML = F), contained mean maximum daily temperature and rainfall frequency as fixed effects. The effect size (i.e. slope) and significance of the fixed effects on TTND were compared to the null model (i.e. no effect) using a parametric bootstrap with 1000 simulations in the R package 'pbkrtest' (version 0.5.1; Halekoh and Højsgaard 2014).

Global positioning system sensor performance

Global positioning system sensors were tail-mounted to long-nosed bandicoots (at Taronga ZS) and bilbies (at Taronga WPZ and Currawinya NP), and were scheduled to collect data on animal movements (Tables 2, S3). GPS performance was assessed based on the proportion of 'valid'

Table 2. GPS schedule (GPS active hours), settings (fix interval in minutes (min) and programmed GPS time-out in seconds (s)), and length of study in weeks for the three sites (Taronga ZS, Taronga WPZ, Currawinya NP) and species (*P. nasuta*, *M. lagotis*) trialled.

Site	Species	Length of study (weeks)	GPS active hours (AEST)	Fix interval (min)	Programmed GPS time-out (s)
Taronga ZS	*P. nasuta*	14	18:00–06:00	20	120
Taronga WPZ	*M. lagotis*	24	1 h after last light to first light[A]	60	40
Currawinya NP	*M. lagotis*	24	1 h after last light to first light[A]	60	40

GPS were scheduled to turn on when animals were active (i.e. at night) (see Table S3 for GPS models used).
[A]Active hours varied depending on season and day length.

(i.e. location acquired) to 'invalid' (i.e. location not acquired) fixes (i.e. fix success rate; FSR), number of satellites acquired, horizontal dilution of precision (HDOP), the time taken to acquire a location (TTF), and the time the GPS sensor remained on, with or without successfully obtaining a location (GPS time-out; GTO). The number of satellites used on each fix attempt determines whether fixes are three dimensional ($\geq$4 satellites: 3D), two dimensional (3 satellites: 2D) or not acquired at all ($\leq$2 satellites) (Moen *et al.* 1996). The HDOP measures the relative accuracy of a horizontal position based on the geometric quality of a GPS satellite configuration (El-Rabbany 2006). Fixes that are 3D and have lower HDOP will have higher accuracy (Lewis *et al.* 2007; Dennis *et al.* 2010; Adams *et al.* 2013; Lotek Wireless Inc. 2019). Both metrics (HDOP and number of satellites acquired) can be used to screen data accuracy. The HDOP of a fix is only an estimate of its accuracy, but a good compromise is met between removing data and data accuracy when only fixes with an HDOP of $\leq$5 are retained (Lewis *et al.* 2007). The proportion of valid fixes that were 3D, and had an HDOP of $\leq$5 was used to assess the accuracy of GPS units from field deployments. Note that studies requiring lower accuracy (e.g. long-range dispersal) may be able to use a higher proportion of valid fixes per deployment.

At Taronga WPZ, GTO and TTF were highly skewed due to a small number of GPS malfunctions. At Taronga WPZ the GPS remained on for longer than the programmed time-out period (40 s) on 1.25% of scheduled attempts. These outliers were removed from the data before analysis. For summary statistics, the median and IQR for GTO and TTF were calculated.

Results

Attachment performance

At Taronga WPZ, 23.17% (38 of 164) of attachments naturally detached before animals were recaptured a median of 40 days later (including $n = 5$ attachments where TTND was unknown but animals were recaptured), and on all (24) attachments at Taronga ZS (excluding $n = 2$ attachments where animals were not recaptured and ABDs could not be recovered after detachment). At Arid Recovery, and for animals that were not preyed on, 42.86% (12 of 28) of attachments naturally detached over the study period (40 days). The total number of dropped attachments was lower for the attachment method used for bilbies (50 of 192 attachments), and higher for the method used for long-nosed bandicoots (24 of 24 attachments). The maximum time an ABD remained attached before manual removal was 94 days.

For all ABDs that naturally detached from the tail, and for attachments where the date of detachment was known ($n = 69$), TTND was between 2 and 52 days, with the method used for bilby attachments having a significantly higher mean TTND ($\pm$s.e.) of 35.62 $\pm$ 1.40 (median = 37, range = 12–52) days than the mean TTND ($\pm$s.e.) of 5.67 $\pm$ 0.40 (median = 6, range = 2–9) days for the method used for long-nosed bandicoots ($F_{1,66} = 235.78$, $P = <2 \times 10^{-16}$; Fig. 6, Table 3). TTND between sexes was not significant overall ($F_{1,66} = 2.97$, $P = 0.09$) or for individual sites (Taronga WPZ; $F_{1,31} = 0.05$, $P = 0.82$, Arid Recovery; $F_{1,10} = 0.43$, $P = 0.53$, Taronga ZS; $F_{1,22} = 0.26$, $P = 0.62$) (Fig. S4). Slightly different methods of attachment were trialled at Taronga WPZ over the course of the study. There was no significant difference in TTND after modifications were made to the glues used for sealing attachments (superglue vs superglue and Araldite) ($F_{1,30} = 0.82$, $P = 0.37$) or ABDs (VHF-only vs bundled VHF and GPS) attached ($F_{1,30} = 0$, $P = 0.99$) at Taronga WPZ. There was a significant, negative effect on TTND for both mean maximum daily temperature (β_{temp}) and frequency of rainfall (β_{rain}) during attachment (PBtest statistic = 8.45, $P = 0.03$, $\beta_{\text{temp}} = -0.63$, $\beta_{\text{rain}} = -37.32$) at Taronga WPZ (Fig. 7).

Animal welfare impacts and considerations

Animal welfare impacts were monitored for all animals studied, and were assessed by checking the animal's tail for injury before reattachment, or by confirming that devices had naturally dropped from the tail for single attachments. A small proportion (6.25%) of ($n = 192$) attachments to bilbies caused tail injury. All injuries were resolvable, with most (10 of 12) requiring minimal intervention for recovery (e.g. removal of the ABD and resting the tail from reattachment until minor skin irritation or scabbing resolved). However, two injuries were severe (wounds with partial or complete necrosis of a portion of the tail) and required extensive veterinary intervention for recovery. Injuries only occurred at Taronga WPZ, and this was most likely related to the high volume and frequency of rain, contributing to and in combination with, the waterlogging of heavy clay soils. Eleven (out of 12) injuries occurred with at least 48.4 mm of rainfall over the attachment period, with all injuries occurring with greater than 7.2 mm of rain. The two severe tail injuries occurred during periods of a high volume (72.6 mm and 188.8 mm – approximately 13.13% and 34.15% of the average annual rainfall for this region, respectively) and frequency of rainfall (64.10% and 27.27% of days attached) (Bureau of Meteorology (Australia) 2021). With frequent saturation of the Tensoplast® Vet tape, the skin underneath the tape softened, and when the tape became compacted with wet mud this dried and formed a hard crust around the edges of the tape, resulting in a small number of injuries due to the tape macerating the tail. For 24 attachments over 95 total attachment days at Taronga ZS, the method described, and different attachment materials used (Nexcare™ and Micropore™ tapes), did not result in

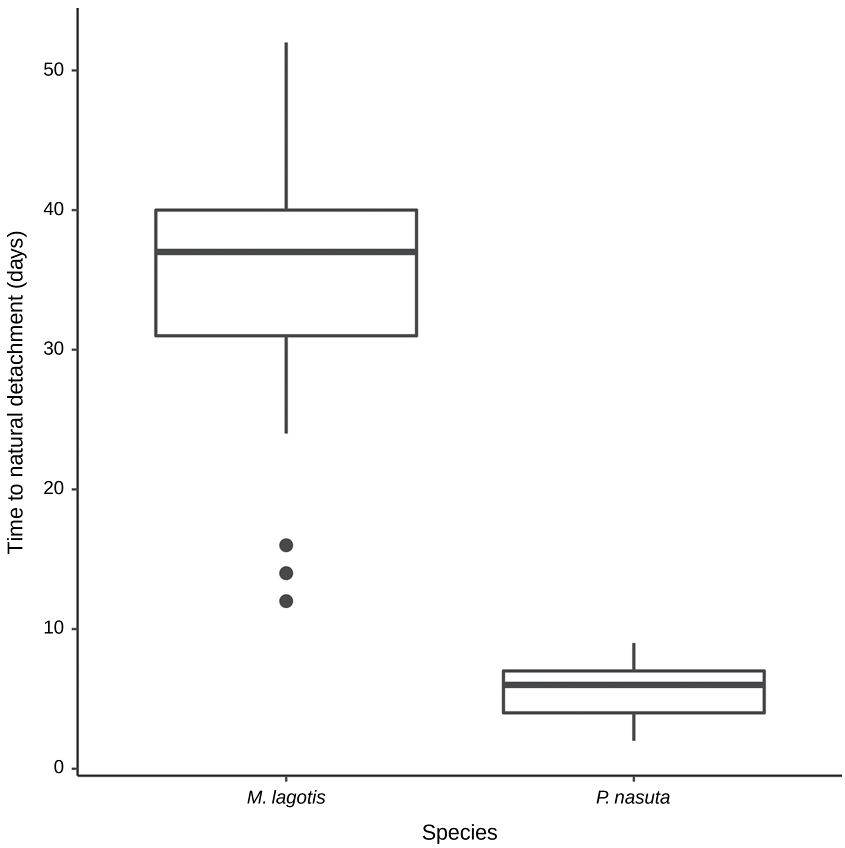

Fig. 6. Time to natural detachment (TTND) of an ABD in days (±IQR) using the two different methods of tail-mount attachment for bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*).

any tail injuries for long-nosed bandicoots despite a high volume (up to 15.8 mm) and frequency of rainfall (up to 71.43% of days attached) during attachments, and similar soils (i.e. low water holding capacity). However, Taronga ZS attachments had significantly shorter TTND, and fewer attachments relative to bilbies, which may have prevented similar injuries occurring (Table 3).

Global positioning system sensor performance

Tail-mount attached GPS sensors had an FSR of 83.38% at Taronga WPZ, 47.42% at Currawinya NP, and 66.87% at Taronga ZS (Table 4). The Pinpoint-120 GPS (Lotek Wireless Inc., United Kingdom) trialled at Taronga WPZ and Currawinya NP post-processed fixes after deployment, which greatly reduced TTF, and fixes could be obtained in a minimum of 4 s. This compares with a minimum of 61 s for the micro-GPS backpack (Telemetry Solutions, United States of America) without fix post-processing trialled at Taronga ZS. Based on manufacturer estimates (Lotek Wireless Inc. 2019) and median TTF, units at both Taronga WPZ and Currawinya NP were performing at best-case scenario (TTF < 14 s). At both sites (Taronga WPZ and Currawinya NP) the Pinpoint-120 GPS performed with higher accuracy (% 3D and % HDOP ≤ 5) than the micro-GPS backpack used at Taronga ZS. For the results of GPS performance across the different habitat types at Taronga WPZ, see Appendix S2.

Damage to ABDs (GPS and VHF) during deployment reduced their functionality. The antennas on ABDs trialled at Taronga WPZ snapped on 12.96% (7 of 54) deployments. Antenna breakage was more common at Currawinya NP (approximately 30–40% of deployments resulted in broken antennas), and likely contributed to the lower proportion of valid fixes. For VHF antennas, depending on the position of the break, effective perception range was often <20 m after antennas snapped. At Taronga WPZ, strain at the base of the GPS antenna caused the waterproofing to fail, and water to wick down and into the electronics on one batch (all seven GPS units). To mitigate the risk of water damage to remaining units on subsequent deployments, heat shrink (~1.5 cm in length and 1.5 mm in diameter) was applied to the base of the antenna. With the heat shrink applied, antennas were still able to flex and water ingress did not occur on any further GPS. The micro-GPS backpack used at Taronga ZS had a UHF wireless antenna and was able to be waterproofed effectively (with epoxy), preventing the practical issues (e.g. antenna breakage and water ingress) experienced on tail-mount attached ABDs with an external antenna.

Discussion

This tail-mount attachment method has been used successfully for over 20 years; however, our study is the first to

Table 3. The number of detached ABDs (*N*) for bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*) for each sex.

Species	*N*	Median TTND (IQR) (days)	Range TTND (days)	Mean TTND (days ± s.e.)	Number of male detachments (number of total males)	Number of female detachments (number of total females)
M. lagotis	45	37 (31–40)	12–52	35.62 ± 1.40	22 (14)	23 (15)
P. nasuta	24	6 (4–7)	2–9	5.67 ± 0.40	16 (7)	8 (5)

Only detached ABDs where the date of detachment was known ($n = 69$) are included. Attachment performance was measured based on median (IQR), minimum and maximum (range), and mean (±s.e.) time to natural detachment (TTND) in days. Taronga WPZ and Taronga ZS had multiple reattachments. The number of total animals of each sex are given in the parentheses.

provide exhaustive detail on this method for ABD attachment to Peramelemorphia, and an in-depth summary of the limitations and animal welfare considerations for its use in the field. We also introduce a novel modification of this method for attachment of GPS with possible applications for other, lightweight sensor technologies, and potentially to other small terrestrial vertebrates.

Attachment performance

Tail-mount attachment of ABDs is a practical and reliable method for monitoring Peramelemorphia, particularly bilbies, for extended periods of time in the field. Animal-borne devices were tail-mounted to conscious, restrained animals without veterinary supervision. Tail-mount attachment of ABDs to bilbies lasted over 3 months in the field, with reattachments possible over a semicontinuous period of ~25 months. This supports findings by Moseby *et al.* (2012) and Steindler *et al.* (2018), with attachments lasting 2–3 months or more, and by Moseby and O'Donnell (2003), with reattachments possible for extended periods of time of over 12 months without injury. This is much longer – and less variable – than what is possible by gluing ABDs directly to the skin (Kenward 2001; Coetsee *et al.* 2016). Despite high attachment longevity overall, the frequency of rain and daily maximum temperature had a significant, negative effect on the TTND of tail-mounted ABDs. This supports findings by Moseby and O'Donnell (2003) where longevity was notably reduced in the summer months (late December to February) and by Hope (2012) and Cuthbert and Denny (2014) where rainfall and humidity reduced TTND. This is the first study, however, to indicate a statistically significant ($P < 0.05$) reduction in TTND due to environmental factors. Both rainfall frequency and maximum daily temperature had a significant, negative effect on TTND at Taronga WPZ, but the frequency of rain during attachment had a larger effect, suggesting that frequent rainfall is more likely to limit attachment longevity. Taronga ZS received frequent rain, and most areas of the site were densely vegetated. At Taronga ZS, tail-mount attached ABDs likely repeatedly snagged on vegetation during deployment, which may have further limited attachment longevity.

Morphological and behavioural differences among species indicate that a single method of attachment is unlikely to suit all species and/or study requirements. Our results suggest that this method of tail-mount attachment may be more effective for bilbies than bandicoots. Although our sample size was relatively small for long-nosed bandicoots compared with bilbies, and a slightly different method of tail-mount attachment was used, previous studies achieved a similar TTND for other Peramelidae spp (e.g. 3–35 days; Winnard *et al.* 2013; Robinson *et al.* 2018; Maclagan *et al.* 2020). Bandicoots have a thinner, less robust tail (i.e. less surface area for the tape to adhere to) relative to bilbies, and conspecific aggression can result in tail loss

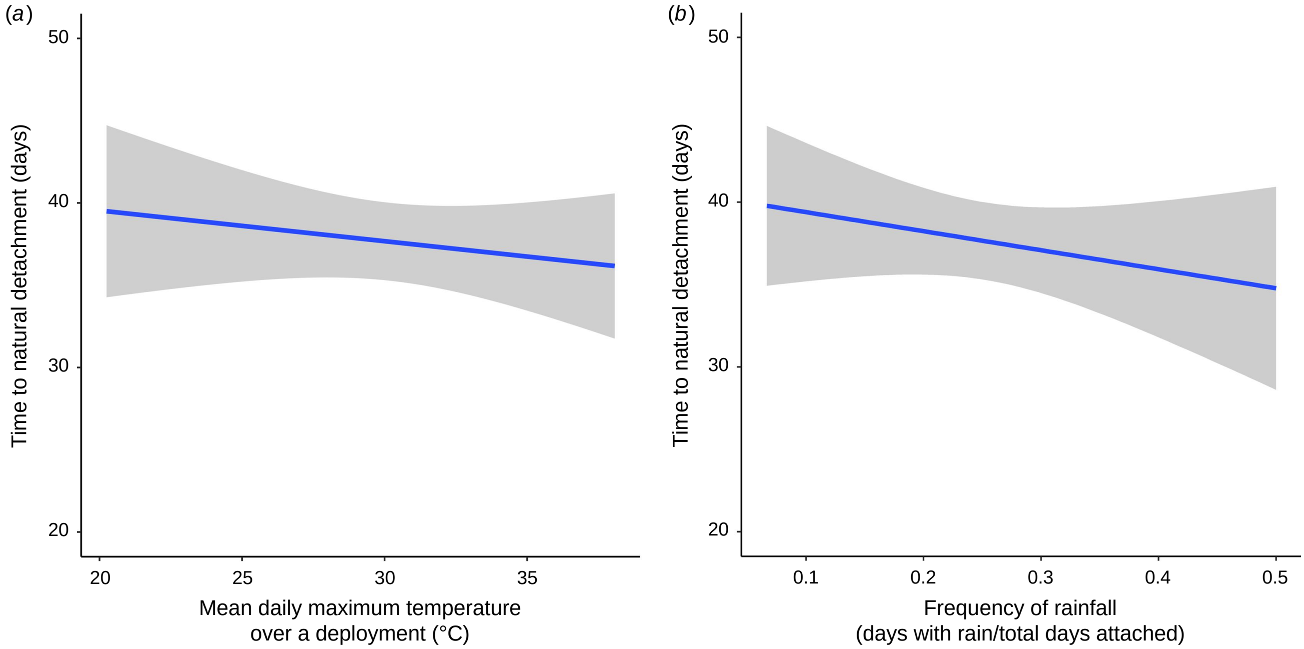

Fig. 7. Time to natural detachment (TTND) of an ABD in days over (*a*) mean maximum daily temperature and (*b*) the proportion of days with rain during attachment (rainfall frequency) for 33 detached ABDs on bilbies at Taronga WPZ. Plots include a linear trend line (method = 'lm') with 95% confidence intervals (grey area). Linear trendlines indicate a negative relationship between mean daily maximum temperature and rainfall frequency and TTND.

Table 4. GPS performance for bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*) at Taronga WPZ, Currawinya NP, and Taronga ZS.

Site	Species	Number of fixes acquired	FSR (%)	Proportion 3D fixes (%)	Proportion of fixes with HDOP ≤ 5 (%)	Median TTF (IQR) (s)	Range TTF (s)	Median GTO (IQR) (s)
Taronga WPZ	*M. lagotis*	14 930	83.38	98.92	92.14	8 (6–12)	5–40	9 (6–13)
Currawinya NP	*M. lagotis*	3835	47.42	96.74	89.78	8 (5–12)	4–40	13 (8–13)
Taronga ZS	*P. nasuta*	2917	66.87	71.20	85.88	67 (64–82)	61–120	75 (65–120)

Sensor performance was measured based on the fix success rate (FSR) (i.e. number of fixes acquired from scheduled attempts), median (IQR) and minimum and maximum (range) time to fix (TTF) in seconds (s), median (IQR) GPS time-out (GTO) in seconds (s) for all scheduled attempts, and the accuracy (% 3D and % HDOP ≤ 5) of fixes obtained (see Table S3 for GPS models used).

(Woolford *et al.* 2008), as observed with some long-nosed bandicoots captured without a tail at Taronga ZS (J. Lawes, pers. comm.). These factors likely contributed to the significantly different TTND between the two similar, but morphologically and behaviourally distinct species.

In addition to the environmental and species-specific effects, attachment materials can also impact TTND. The use of different adhesive tape and different methods of tail-mount attachment at Taronga ZS may have also reduced TTND. It is important that candidate attachment materials and methods are tested for longevity, because more time before detachment will reduce the number of recaptures required for viable data, which is an important consideration for animal welfare. Attachments in previous studies using Fixomull® (BSN Medical Pty Ltd, Australia) tape had a TTND of 3–22 days (Robinson *et al.* 2018) or 7–33 days (Winnard *et al.* 2013), and 14–35 days for a combination of Fixomull® and Micropore™ tapes (Maclagan *et al.* 2020). No glue was applied to the seam and edges of the tape. To prevent the edges of the tape unravelling and the ABD detaching from the tail, a very small line of glue can be applied along the edges and seam of the attachment (as in the method used for bilbies). If this method is used the longevity of attachments using alternate tapes may be extended, but this requires testing. With the Tensoplast® Vet tape, the most common cause of ABD detachment was tail hair regrowth, which lifted the tape off the tail (VHF-only attachments), or the ABD package tilting and gradually pulling the tape away from the tail (bundled ABD attachments), resulting in the tape eventually loosening its grip entirely and sliding off the tail. For bundled ABDs, the orientation of the VHF unit can be changed to the side of the GPS to lower its profile, and potentially reduce tilting of the ABD package. However, this would increase the area over which pressure is applied to the top of the tail by the ABD, and may increase the risk of injury. We found that attachment longevity could be safely extended by using tape that has not been stored for extended periods of time, pressing – but not pulling – the tape to the tail while wrapping, ensuring all hair is thoroughly removed from the attachment area and that the tail is clean (free from mud and debris), and by cutting the top proximal edge of the tape at a 45° angle to the horizontal (as in Fig. 3*d*) to reduce snag and increase the surface area for the adhesive seal.

Animal welfare impacts and considerations

We found that frequent saturation and soiling of the Tensoplast® Vet (also known as Elastoplast® elastic adhesive) tape can damage the skin and cause tail injury in some environments. The same tape was used for tail-mount attachment of ABDs to eastern barred bandicoots on French Island, Victoria, with one out of six attachments causing skin necrosis (Coetsee *et al.* 2016; Groenewegen *et al.* 2017). Similar to Taronga WPZ, French Island is an environment that experiences periods of frequent rainfall and waterlogged soils (Groenewegen *et al.* 2017). This suggests that tail injuries are more likely to occur in these environments when using the Tensoplast® Vet tape. However, we found this tape to be suitable in arid and semi-arid sites or in temperate regions with sandier, high drainage soils (at Thistle Island), and during periods of infrequent rain at Taronga WPZ (i.e. during drought). If tapes are fitted too tightly they can restrict blood flow to the tail, causing or necessitating tail amputation (Hope 2012; Coetsee *et al.* 2016). Both tail-mount attachment methods used for bilbies and long-nosed bandicoots in this study, over a total of 905 attachment days and 216 attachments, did not cause tail constriction. With careful attachment of the ABD, and selection of tapes to suit different species and environments, injuries can be mitigated (see Table 5 for suggested mitigations).

Global positioning system sensor performance

The tail-mount attachment method is able to accommodate individual and bundled ABDs to collect a high volume of data on species. Tail-mounted GPS sensors collected up to 14 930 fixes over 24 weeks (Table 4), and performance of sensors (FSR: 47.42–83.38%, and % 3D: 71.20–98.92%) was similar to or higher than previously tested lightweight GPS attached using alternate methods (e.g. Blackie 2010; Dennis *et al.* 2010; Glasby and Yarnell 2013; McMahon *et al.* 2017; Sánchez-Giraldo and Daza 2019). The small 'tiny-tech' components of lightweight GPS sensors can limit performance, and their typical applications (to small animals that move and behave differently to large animals) can make it difficult to compare performance with traditional, heavier sensors (Dennis *et al.* 2010; Adams *et al.* 2013). In a comparable study, lightweight GPS (<15 g) were collar-attached to pygmy rabbits (*Brachylagus idahoensis*), with a high number of malfunctions (GPS functioned as expected for 14% of cases) (McMahon *et al.* 2017). At Taronga WPZ, the number of malfunctions was relatively low, with software failures (GPS time-out errors) occurring on 1.25% of (n = 17 905) scheduled fix attempts. Antennas snapping on GPS, however, limited sensor performance (number of fixes, FSR, and TTF) at Currawinya NP. At Taronga WPZ, the antenna on the GPS was deliberately flattened during attachment (as in Fig. 3*d*), which may have prevented the it from frequently snapping. However, this created greater strain at the base, likely causing the manufacturer's waterproofing to fail on an entire batch of seven GPS. More flexible antennas and waterproofing material should be trialled on the Pinpoint-120 GPS used at Taronga WPZ and Currawinya NP to reduce antenna breakage and adequately protect the units from water ingress. The behaviour of species (e.g. burrowing vs denning in dense clumping vegetation) may also place greater strain on attachments and attached ABDs, which can increase the risk of damage to ABDs.

A small amount of data was lost due to some challenges with GPS retrieval (e.g. animals that were never recaptured and/or ABDs never recovered). There is a risk that data will be lost when using GPS units that store data on the device, and when using ABDs with a finite power source (Matthews *et al.* 2013; Ripperger *et al.* 2020). To ensure all data are retrieved, ABDs with remote download can be used. The costs of GPS with this functionality (e.g. for ongoing data downloads, devices, and software), however, is higher than GPS that store data on board, and with more rapid battery depletion (KAC, pers. obs 2021; Ripperger *et al.* 2020). To extend battery life, GPS can be programmed to process fixes (i.e. collect ephemeris data) after deployment (e.g. the Pinpoint-120 GPS used at Taronga WPZ and Currawinya NP) (McMahon *et al.* 2017; Lotek Wireless Inc. 2019). This can reduce the time required for GPS to obtain a fix, and thus lower battery drain per fix. For smaller taxa, where ABD weight and battery size (i.e. capacity) is limited, post-processing of fixes can help avoid the common trade-off between ABD size and data output (McMahon *et al.* 2017; Rafiq *et al.* 2021*b*). Radio frequency identification (RFID) tags and loggers can be used as an alternative to GPS for remote data collection and download in smaller taxa (Ripperger *et al.* 2020; Rafiq *et al.* 2021*a*). With recent development of open-source, customisable RFID tags (e.g. Rafiq *et al.* 2021*a*), this may also be a more affordable option than GPS. This method for tail-mount attachment of ABDs can easily be modified to accommodate various ABD types, such as RFID tags, to take advantage of novel sensor technologies.

Wider implications in small vertebrate telemetry

New and emerging animal-borne technologies can only be used if there is an appropriate method for their attachment

Table 5. List of known injuries that can occur due to tail-mount attachment of ABDs, the likely causes, and effective mitigations used.

Injury	Likely causes	Mitigations
Mild skin irritation	Blunt razors were used for hair removal, not enough hair was removed and hairs were caught in the tape, pulling and irritating the skin or foreign objects (e.g. long grass seeds) worked their way underneath the tape and caused irritation.	(a) A new razor is used for each attachment to ensure all hair is removed without the razor catching on the skin. (b) The amount of hair removed from the tail should be the length of the tape, including at least a 5 -mm hair-free buffer at either edge of the tape. This ensures hair does not catch during sealing. Using electric clippers first then disposable razors will ensure all hair is thoroughly removed from the attachment area. (c) The tape is attached as close as possible to the base of the tail to prevent foreign objects and soil working their way underneath the tape with the forward motion of the animal.
Minor abrasions and wounds at the edges of the tape	Too much superglue was applied to the tape causing it to scratch the tail as the animal moved or the mounted ABD tilted and the superglue at the edges of the tape rubbed against the tail.	(a) A minimum amount of superglue is used to seal the seam and edges of the tape. (b) For bulkier ABDs (e.g. bundled GPS and VHF), which are more likely to tilt and rub against the tail, a non-wicking quick-setting adhesive can be applied (90 s Araldite) over the set superglue to smoothen any hard edges of the glue. Again, a minimum amount is used.
Skin ulceration	The ABD was not elevated off the tail causing it to press onto the tail as the animal moved.	ABDs are elevated off the tail, leaving a 2–3-mm gap between the top of the tail and the bottom of the mounted ABD.
Tail constriction and swelling	The tape was pulled tight while wrapping the tail, too many layers of tape were used or too much superglue was applied which shortened the tape, and constricted the tail. In extreme cases tail constriction can lead to limited blood flow to the tail, necessitating or causing tail amputation (Hope 2012; Coetsee *et al.* 2016). Loose threads on material tapes (e.g. Tensoplast® Vet tape) can also present a constriction hazard if it wraps around the tail.	(a) Tapes start on the side of the tail, and are wrapped around the tail without pulling on the tape. (b) A max thickness of two layers of tape is applied to the tail for mounting ABDs. (c) A minimum amount of superglue is used to seal the seam and edges of the tape. (d) Tapes are checked for any loose threads prior to attachment, and any found are trimmed off the tape with scissors.
Skin maceration and necrosis	Frequent saturation of the tape softened the skin, and wet mud stuck to the edges of the tape, forming a hard crust when dry, resulting in tail maceration and subsequent necrosis of the tail.	Tapes that can withstand frequent saturation and soiling, while maintaining breathability and flexibility, can be used in environments with frequent rain and waterlogged clay soils (which form hard crusts when dry) to prevent injury (see Table S5 for suggested alternate tapes). We recommend that novel tapes are trialled in a controlled environment (e.g. in captivity) prior to their use in the field.

that is both effective for data collection and suitable for animal welfare outcomes. For small vertebrates, and particularly for mammals, which do not conform to the morphology or behaviour required for standard attachment (e.g. collaring), alternate options that are practical in the field, satisfy the requirements of the study, and have a low risk of negative animal welfare outcomes to the animals studied are limited (Opiang 2009; Rychlik *et al.* 2010; O'Mara *et al.* 2014; Coetsee *et al.* 2016). Tail-mount attachments have been used for several decades as an alternative to collaring for Peramelemorphia, but the potential applications of this method are not likely to be limited to just bilbies and bandicoots.

Animal welfare generally requires that ABD attachments are temporary. Therefore, attachments either require manual removal or use materials which detach (i.e. drop off) from animals naturally. There are two options for drop-off type attachments: (a) attachments that are programmed to detach at a specific time and date (e.g. Cypher *et al.* 2014; Rafiq *et al.* 2019; Klauder *et al.* 2021), and (b) attachments that passively detach due to natural degradation of materials (e.g. Opiang 2009; O'Mara *et al.* 2014; Evens *et al.* 2018; Rayner *et al.* 2021; Ross *et al.* 2022).

The tail-mount attachment method used for Peramelemorphia has all the typical benefits of a low-tech, low-cost, passive drop-off type attachment; ABD attachment does not require any veterinary expertise, and the materials for attachment (adhesive tapes and glues) are relatively inexpensive and easy to obtain. For details on the materials required for tail-mount ABD attachment, their cost, and potential suppliers see Table S4. However, unlike similar passive drop-off type attachments, TTND can be relatively long (several months vs several days or weeks), which sets it apart from other methods (e.g. Kenward 2001; Opiang 2009; Coetsee *et al.* 2016; Evens *et al.* 2018; Rayner *et al.* 2021). Our results suggest that this drop-off type attachment method is likely to stay attached longer in drier, colder climates with sparser vegetation, and be better suited to species with a long and robust tail, like bilbies, which are unlikely to lose their tail (i.e. not reptiles that readily drop their tail for predator defence). Due to the potential for broader applications, we encourage further discussion on how this method can be refined or modified to suit a range of species and studies.

Telemetry research on small vertebrates continues to progress. With advances in tracking technology, and its novel applications, there is now more opportunity to study these species and contribute to conservation research. In sharing the lessons learnt from over two decades of implementing the tail-mount attachment of ABDs to Peramelemorphia, we hope that the use of this novel attachment method is received as a practical alternative for future field attachment of ABDs to bilbies, bandicoots and potentially other small vertebrates.

Supplementary material

Supplementary material is available online.

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Data availability. Data, R code, and video footage that supports this study are available in Dryad Digital Repository at https://doi.org/10.5061/dryad.vq83bk3sm.

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Author affiliations

[A]Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW, Australia.

[B]School of Agriculture and Food Sciences, The University of Queensland, Street Lucia, Qld, Australia.

[C]Department for Environment and Water, South Australia, Adelaide, SA, Australia.

[D]Evolution and Ecology Research Centre, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW, Australia.

[E]Taronga Institute of Science and Learning, Taronga Conservation Society Australia, Mosman, NSW, Australia.