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Wildlife Research

Supplementary Material

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

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APPENDIX S1: *some notes on a method for individual identification*

Marking tail-mount attachments with a permanent black marker or reflective tape (Brutus, Australia) can be useful for identifying animals that are otherwise non-distinct. Both methods of marking were used in our study. If permanent marker was used, text or symbols needed to be printed largely and clearly in black ink on each side of the attachment tape to be seen. Markings using a permanent marker quickly faded with soiling of the attachment tape, and were difficult to detect at night on infrared triggering camera traps (HC600 Hyperfire, Reconyx, United States of America). Reflective tape was more effective for identifying the unique markings on individuals at night on camera traps, particularly when the animal's tail was just left or right of the centre field of view (e.g. Fig.S1(a)). A small amount of superglue, applied to the adhesive underside of the reflective tape, was needed to extend attachment duration. The superglued reflective tape typically lasted for 2–3 weeks before the reflective side of the tape started to degrade and fall off attachments. We found that circles and straight lines (e.g. Fig.S1(b)) worked best for detection on camera traps, and were distinct enough to be able to tell the difference between each individual marking.

Figure S1: (a) A greater bilby (*Macrotis lagotis*) captured on an infrared triggered camera trap with a unique identifying reflective tape symbol on the tail-mount attachment, and **(b)** some examples of reflective tape symbols used.

We recommend that reflective tape markings are only applied to the sides of tail-mount attachments (i.e. not facing the sky) to reduce the potential risk of aerial predator attraction (Fig.S2) (Hawkins 2004). Attraction from terrestrial predators (e.g. European red foxes; *Vulpes vulpes*, and feral cats; *Felis catus*) may still occur when using this method so we caution it's use in areas with abundant predators. However, reflective tape has been used on device attachments previously, and increased predation due to the markings was not evident for species exposed to predators which were controlled at low densities (e.g. MacGregor *et al.* 2013; MacGregor *et al.* 2015), or in free-ranging situations without predator control (e.g. Scott *et al.* 1999; Ealey and Dunnet 1956; Goldingay *et al.* 2010).

Figure S2: Reflective tape markings are applied to the sides of the attachment tape with a small amount of superglue. Image provided by Rick Stevens.

APPENDIX S2: *Habitat effects on GPS performance at Taronga Western Plains Zoo (Taronga WPZ)*

Global positioning system (GPS) sensors only function when units have a view of the sky and are able to receive information from satellites. When this view is obstructed by dense vegetation or cover, GPS performance is often reduced (Di Orio *et al.* 2003; Glasby and Yarnell 2013; Forin-Wiart *et al.* 2015; McMahon *et al.* 2017). We, therefore, wanted to test whether GPS performance varied by the different habitat types present at Taronga Western Plains Zoo (Taronga WPZ), resulting in either an increase in the time to successfully acquire a fix (TTF) or reduction in fix accuracy in habitats with greater canopy cover. Longer TTF will result in greater battery expenditure per fix, ultimately reducing the deployment time possible before battery depletion, and lower fix accuracy will reduce the quality of data obtained (Moen *et al.* 1996; Recio *et al.* 2011; Lotek Wireless Inc. 2019). Both metrics (TTF and accuracy) were used to compare GPS performance across habitat types at Taronga WPZ.

Methods

Greater bilbies (*Macrotis lagotis*) (hereafter bilbies) were released into a 110-ha fenced sanctuary at Taronga WPZ (more details in the main paper). Prior to bilby release, very-high frequency (VHF) transmitters (for device retrieval) and GPS sensors (Pinpoint-120 GPS, Lotek Wireless Inc., United Kingdom, see Table S3 for more details) were bundled together, and tail-mount attached to each animal (n = 16) to monitor movements and GPS performance over the first 24 weeks post-release.

For successful fix attempts (i.e. valid fixes), fixes were categorised by the habitat at the location of the fix. There are four main habitat types within the Taronga WPZ sanctuary; *Callitris glaucophylla* and mixed *Eucalyptus sp.* (predominantly *E. blakelyi*) woodland ('woodland'), tussock grassland ('grassland'), and *Acacia deanei* shrubland ('shrubland') (Fig.S3). As there was minimal variation in canopy cover between the wooded areas, these areas were combined ('woodland') for the purposes of analysis. To compare GPS performance across habitat types, valid fixes were uploaded as a vector layer in QGIS (version 3.12.3, QGIS Development Team 2021) and the "clip" function was used to first split points by the Taronga WPZ sanctuary fence line (i.e. removing inaccurate fixes outside site boundary), and then by constructed habitat polygons within the fenced area (Fig.S2).

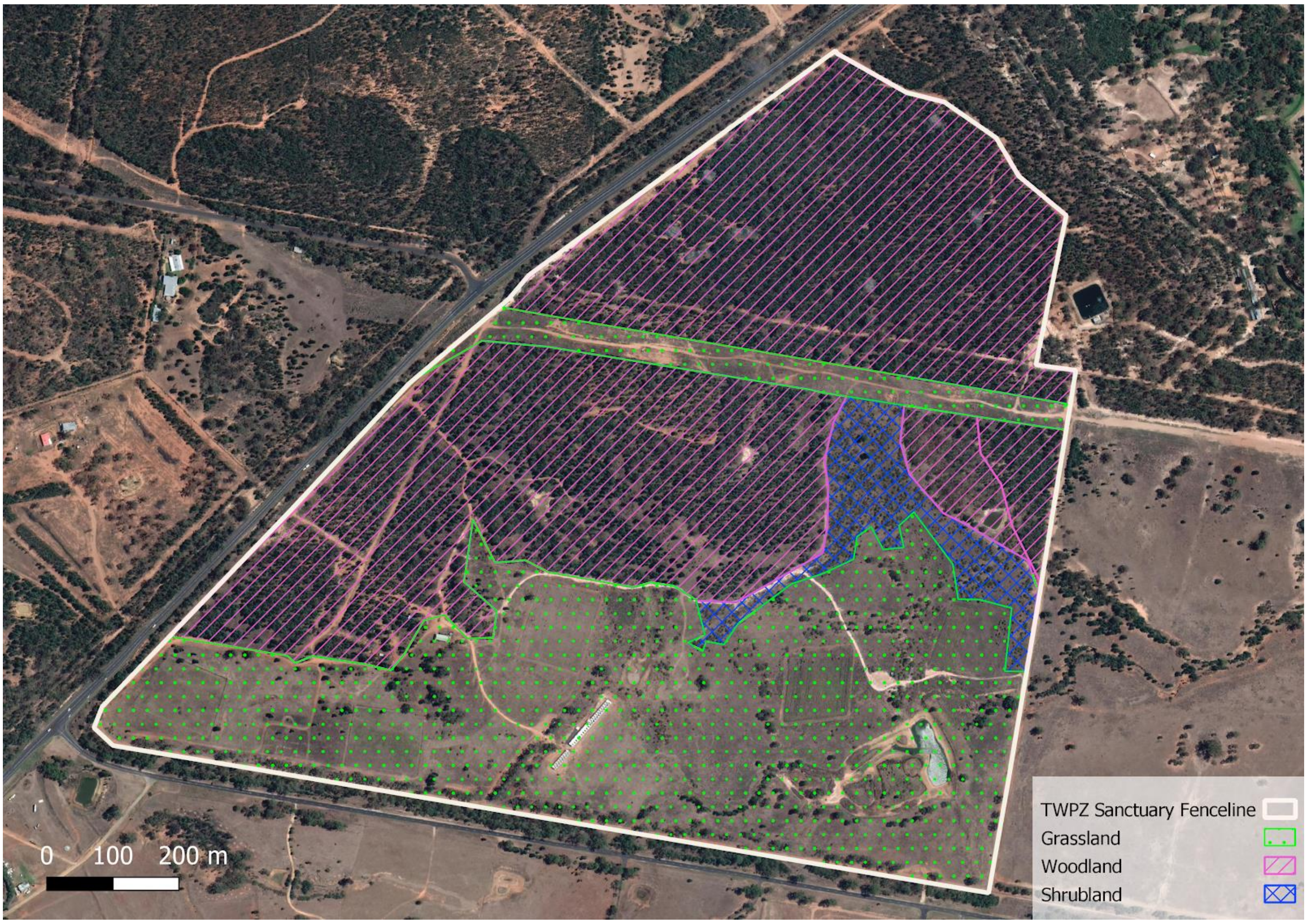

Figure S3: Habitat polygons within the Taronga WPZ fenced sanctuary created in QGIS. The fenced boundary and three habitat types (grassland, woodland and shrubland) within the site are indicated on the map. Woodland habitats include both *C. glaucophylla* (larger pink polygon) and mixed *Eucalyptus sp.* (smaller pink polygon) woodland.

Fixes that took longer than 40 seconds to be acquired were classified as GPS malfunctions and were removed before analysis. Time to fix was Box Cox transformed to account for the strong data skew using the 'MASS' package (version 7.3.53, Venables and Ripley 2002) in R (version 4.0.4; R Core Team 2021). Box Cox transformed TTF (BCTTF) was compared between habitats using an analysis of variance (ANOVA) and a Tukey post hoc test for pairwise comparisons in R (version 4.0.4; R Core Team 2021). The accuracy of fixes was estimated by the proportion of successful fix attempts (i.e. valid fixes) that were three dimensional (3D) and had a horizontal dilution of precision (HDOP) ≤ 5 (as described in the main paper). Fix accuracy was compared across habitat types using a test for equality of proportions. Significance was noted at the $P < 0.05$ level. Median, interquartile range (IQR), and the minimum and maximum (range) TTF in seconds was calculated for summary statistics. Mean BCTTF (± SD) was back transformed to report adjusted mean TTF (± SD).

Results

For valid fixes, GPS performance varied slightly by habitat (Table S1). The difference in median TTF between habitat types was 3 seconds. Accuracy, in terms of the proportion 3D and HDOP ≤ 5, also varied slightly by habitat type with 0.59% (%3D) and 2.72% (%HDOP ≤ 5), representing the maximum difference in accuracy between habitat types. Grassland habitat, with little to no canopy cover and the highest visibility of the sky, had the lowest TTF (95% CI: 7.23–7.29 seconds) and highest accuracy. These results indicate a marginal, but significant difference in TTF ($F_{2,14623}$ = 586.62, P = < 2.2e^{-16}), and accuracy (3D: X_2^2= 17.23, P = 0.0001, HDOP: X_2^2= 40.06, P = 2e^{-9}) between all habitat types. The habitat with significantly higher TTF (woodland) was still operating (95% CI: 9 – 9.06 seconds) within the best-case scenario based on manufacturer estimates (Lotek Wireless Inc. 2019).

Table S1: The number of (valid) fixes acquired per habitat type, adjusted mean TTF (± SD), median (IQR) and minimum and maximum (range) time to acquire a fix (TTF) in seconds (s), and GPS accuracy (i.e. proportion 3D and proportion of fixes with HDOP ≤ 5) over 24 weeks of GPS deployment on (n = 16) bilbies at Taronga WPZ.

Habitat type	Number of fixes acquired	Mean TTF (s ± SD)	Median TTF (s) (IQR)	Range TTF (s)	Proportion 3D fixes (%)	Proportion of fixes with HDOP ≤ 5 (%)
Shrubland	907	7.73 ± 1.09	7 (6–11)	5–39	99.56	93.88
Grassland	7190	7.26 ± 1.09	7 (6–10)	5–40	99.49	93.91
Woodland	6718	9.03 ± 1.09	10 (7–12)	5–40	98.90	91.16

Discussion

The small difference in TTF and fix accuracy obtained by GPS operating in different habitat types at Taronga WPZ is unlikely to greatly reduce the performance of units deployed. Unlike previous studies (e.g. Di Orio *et al.* 2003; Glasby and Yarnell 2013; Forin-Wiart *et al.* 2015; McMahon *et al.* 2017), fix accuracy was only marginally affected by the habitat type with 98.9% of fixes 3D, and 91.16% of fixes with a HDOP of ≤ 5 in areas with the greatest canopy cover and poorest visibility of the sky (i.e. woodland habitat). However, fix acquisition (i.e. the fix success rate) can be lower in habitats with poor sky visibility which may affect the overall performance of units (Glasby and Yarnell 2013; Forin-Wiart *et al.* 2015; McMahon *et al.* 2017), and the actual location of units can still vary greatly from the fix location (> 300 m locational error) despite low DOP (Lewis *et al.* 2007; Recio *et al.* 2011). Despite GPS performing well overall, it is recommended that units are tested in a known location, in habitats similar to the deployment location to ensure GPS units are functioning as expected prior to field deployment.

FIGURES AND TABLES

Table S2: The status of species in order: Peramelemorphia. Data was obtained on the 31/5/2021 from the International Union for the Conservation of Species website with specific pages for each species listed under URL (IUCN 2021).

Species name	Scientific name	Status[A]	URL
Pig-footed bandicoot	*Chaeropus ecaudatus*	EX	https://www.iucnredlist.org/species/4322/21965168
Clara's Echymipera	*Echymipera clara*	LC	https://www.iucnredlist.org/species/7015/21966942
David's Echymipera	*Echymipera davidi*	EN	https://www.iucnredlist.org/species/7017/21966774
Menzies' Echymipera	*Echymipera echinista*	DD	https://www.iucnredlist.org/species/7016/21967022
Common Echymipera	*Echymipera kalubu*	LC	https://www.iucnredlist.org/species/7018/21966845
Long-nosed Echymipera	*Echymipera rufescens*	LC	https://www.iucnredlist.org/species/7019/21966655
Golden Bandicoot	*Isoodon auratus*	VU	https://www.iucnredlist.org/species/10863/115100163
Northern Brown Bandicoot	*Isoodon macrourus*	LC	https://www.iucnredlist.org/species/40552/21966494
Southern Brown Bandicoot	*Isoodon obesulus*	LC	https://www.iucnredlist.org/species/40553/115173603
Bilby	*Macrotis lagotis*	VU	https://www.iucnredlist.org/species/12650/21967189
Yallara	*Macrotis leucura*	EX	https://www.iucnredlist.org/species/12651/21967376
Arfak Pygmy Bandicoot	*Microperoryctes aplini*	VU	https://www.iucnredlist.org/species/136538/21965745
Striped Bandicoot	*Microperoryctes longicauda*	LC	https://www.iucnredlist.org/species/84783217/21965649
Mouse Bandicoot	*Microperoryctes murina*	VU	https://www.iucnredlist.org/species/13389/21965585
Papuan Bandicoot	*Microperoryctes papuensis*	LC	https://www.iucnredlist.org/species/13390/21965507
Western Barred Bandicoot	*Perameles bougainville*	VU	https://www.iucnredlist.org/species/16569/21965819
Desert Bandicoot	*Perameles eremiana*	EX	https://www.iucnredlist.org/species/16570/21965953
Eastern Barred Bandicoot	*Perameles gunnii*	VU	https://www.iucnredlist.org/species/16572/21966027

Long-nosed Bandicoot	*Perameles nasuta*	LC	https://www.iucnredlist.org/species/40554/115173969
Giant Bandicoot	*Peroryctes broadbenti*	EN	https://www.iucnredlist.org/species/16710/21965270
Raffray's Bandicoot	*Peroryctes raffrayana*	LC	https://www.iucnredlist.org/species/16711/21965412
Seram Bandicoot	*Rhynchomeles prattorum*	EN	https://www.iucnredlist.org/species/19711/21967091

[A]Status according to the IUCN: LC = Least Concern; VU = Vulnerable; EN = Endangered; EX = Extinct; DD = Data Deficient

Table S3: List of tail-mount attached ABDs used for bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*) in the main paper, the manufacturer, extra features, and ABD weight and dimensions.

ABD model	**Species**	**Manufacturer[A]**	**Extra features**	**ABD weight (g)**	**Expected battery lifespan (days)[B]**	**Dimensions (length x width x depth cm)**	**Antenna length (cm)**
<u>GPS</u>							
Pinpoint-120 store-on-board GPS tag	*M. lagotis*	Lotek Wireless Inc., United Kingdom	Swift fix[C]	4.8	Rechargeable: multiple deployments possible	3 x 1.5 x 1	5
DIY micro GPS backpack	*P. nasuta*	Telemetry Solutions, United States of America	Remote data download, and “Smart GPS”[D]	8.6 (14g model)	Rechargeable: multiple deployments possible	4.5 x 1.4 x 2.1	0 (UHF Wireless)
<u>VHF</u>							
A2450	*M. lagotis, P. nasuta*	Advanced Telemetry Solutions, Australia	-	2.2	93	2 x 0.9 x 0.7	15
A2470	*M. lagotis*	Advanced Telemetry Solutions, Australia	-	3.1	150	2.4 x 1.3 x 0.6	Various used
ZV2T 123A	*M. lagotis*	Sirtrack, New Zealand	Mortality indicator[E]	8.8	76	4 x 1.2 x 1.2	25

[A] Manufacturers listed were correct at the time of use. Some manufacturers for the ABD models listed may have changed.
[B] Expected lifespan for VHF transmitters is standardised at 40 pulses per minute (ppm), with multiple ppm options available for each model.
[C] Swift fix enabled GPS collect locations faster than standard fixes, even for “cold” starts where GPS sensors need to relocate satellites. Fixes are processed post-deployment which reduces the time the GPS spends active during deployment (i.e. ephemeris information is obtained post-deployment).
[D] Smart GPS can be enabled to detect low activity and turn off the GPS below a specified activity threshold, saving battery life during animal inactivity.
[E] If movement is not sensed for 12 hours transmitter switches to a higher pulse rate at 80ppm

Table S4: Full list of attachment materials that were used (at Taronga WPZ and Taronga ZS) for each method of tail-mount attachment of ABDs to bilbies (*M. lagotis*) and long-nosed bandicoots (*P. nasuta*), a manufacturer, retail price, and the website of a potential supplier. Prices were sourced on 25/5/2021 from the websites listed. Prices will likely vary over time, and depending on the chosen manufacturer and supplier.

Species	**Item Description**	**Manufacturer**	**Retail price[A] ($AUD)**	**Supplier website**
M. lagotis	Codos electric clippers (CP-6800)	Codos Electronics Factory, China	77.26	https://discountpetmeds.com.au/codos-clippers-cp-6800-grey/
	Disposable razors (10 pack)	Bic®, International	4.09	https://www.woolworths.com.au/shop/productdetails/196087/bic-razor-disposable-twin-easy-sensitive
	Tensoplast® Vet (7.5 cm x 2.7 m)	BSN Medical Pty Ltd, Australia	7.86	https://www.vetnpetdirect.com.au/products/ELASTVET
	Electrical tape (18 mm x 20 m)	Nitto Denko Pty Ltd, Australia	2.64	https://www.bunnings.com.au/nitto-denko-18mm-x-20m-black-pvc-electrical-insulation-tape_p4430715
	Quick Fix superglue (3 ml)	Selleys®, Australia	3.77	https://www.bunnings.com.au/selleys-3ml-quick-fix-super-non-drip-gel-supa-glue_p1232153
	90 second Araldite (24 ml)	Selleys®, Australia	21.32	https://www.bunnings.com.au/selleys-24ml-araldite-90-seconds-epoxy-adhesive_p1231000
	Brutus reflective tape (50 mm x 10 m)	QEP, Australia	9.41	https://www.bunnings.com.au/brutus-50mm-x-10m-reflective-tape_p1091366
	Alcohol swabs (isopropyl alcohol 70%) (100 pack)	Aero Healthcare Pty Ltd, Australia	5.41	https://www.superpharmacy.com.au/products/aerowipe-alcohol-swabs-100-pack
P. nasuta	Soft fabric sticky back discs (8 pieces)	Velcro Pty Ltd, Australia	13.64	https://www.spotlightstores.com/sewing-fabrics/haberdashery/hook-loop/velcro-brand-sticky-back-for-fabric-dots/BP80341285
	Nexcare™ sports tape (25mm x 13.7 m)	3M, Australia	10.93	https://www.medshop.com.au/products/nexcare-sports-professional-sports-tape
	Micropore™ paper tape (25 mm x 9.1 m) (2 pack)	3M, Australia	6.35	https://www.medshop.com.au/products/nexcare-gentle-paper-tape-2-pk-micropore-tape
	Kwik Grip (40 g)	Selleys®, Australia	5.59	https://www.bunnings.com.au/selleys-40g-kwik-grip-gel-vertical-contact-adhesive_p1230119
	2-part waterproof epoxy resin (50 ml)	Telemetry Solutions, United States of America	19.80	https://www.telemetrysolutions.com
Both species	Nurse's scissors	Manicare, Australia	14.54	https://www.manicare.com.au/manicare/shop-our-products-/hand-and-nail/nail-scissors-and-trimmers/p/nurses-scissors%2C-blunt%2Fsharp-tips/32700.html?lang=en_AU#q=nur

				ses%2Bscissors&start=1

[A]All retail prices exclude Australian goods and services tax (GST)

Table S5: List of suitable adhesive tapes for tail-mount attachment of ABDs as advised by the veterinary team at Taronga WPZ (B. Bryant, 2021, pers. comm.), and as trialled in previous research for Peramelemorphia (Moseby and O'Donnell 2003; Finlayson *et al.* 2008; Hughes and Banks 2010; Fitzgibbon *et al.* 2011; Hope 2012; Moseby *et al.* 2012; MacGregor *et al.* 2013; Winnard *et al.* 2013; Cuthbert and Denny 2014; MacGregor *et al.* 2015; Coetsee *et al.* 2016; Groenewegen *et al.* 2017; Robinson *et al.* 2018; Steindler *et al.* 2018; Ross *et al.* 2019; Maclagan *et al.* 2020). A brief summary of each tape's features, recommended environments of use, manufacturer, and the website of a potential supplier is provided. Tensoplast® Vet tape is also known as Elastoplast® tape and is used interchangeably. Brown rigid Elastoplast® and Leukoplast® tapes (BSN Medical Pty Ltd, Australia) have also been trialled, and are not recommended for tail-mount attaching ABDs due to a lack of flexibility and high risk of causing tail injury (J. van Weenen, unpubl. data).

Tapes	Tape features	Recommended environments	Manufacturer	Supplier website
Tensoplast® Vet[A]	High durability, zinc oxide adhesive bandage	Arid, semi-arid, and some temperate environments[B]	BSN Medical Pty Ltd, Australia	https://www.vetnpetdirect.com.au/products/ELASTVET
Nexcare™[A]	Variety of tape options (e.g. for sensitive skin, breathability, waterproofing or flexibility)	All environments	3M, Australia	https://www.nexcare.com.au/3M/en_AU/nexcare-au/products/catalog/
Mefix®	Breathable, water resistant self-adhesive non-woven fabric tape used for sensitive skin	All environments	Mölnlycke®, Sweden	https://www.molnlycke.com/products-solutions/mefix/
Fixomull® stretch[A]	Hypo-allergenic adhesive non-woven polyester tape that is flexible and does not restrict blood circulation	All environments	BSN Medical Pty Ltd, Australia	https://medical.essity.com.au/brands/orthopaedics/category-product-search-o/tapes/adhesive/fixomullr-stretch.html
Micropore ™[A]	Highly breathable adhesive paper tapes for sensitive skin	All environments	3M, Australia	https://www.3m.com.au/3M/en_AU/p/d/v000184841/
Tenderfix™	Hypo-allergenic non-woven adhesive cloth tape that is	All environments	Medtronic, United States/Ireland (formerly	https://www.avacaremedical.com/kendall-tenderfix-medical-nonwoven-cloth-tape

	flexible with good adhesion		Kendall™ - Covidien™)	

[A]Adhesive tapes previously trialled for Peramelemorphia. Listed tapes and tape types not trialled in the main paper or previous studies should be tested in a controlled setting (e.g. on a captive animal) prior to their use in the field.
[B] As described in the main paper, frequent saturation of the Tensoplast® Vet tape, in combination with mud sticking to the tape, can cause injury. However, the Tensoplast® Vet tape is suitable for temperate environments with high drainage (e.g. sandy) soils or during periods of infrequent rain.

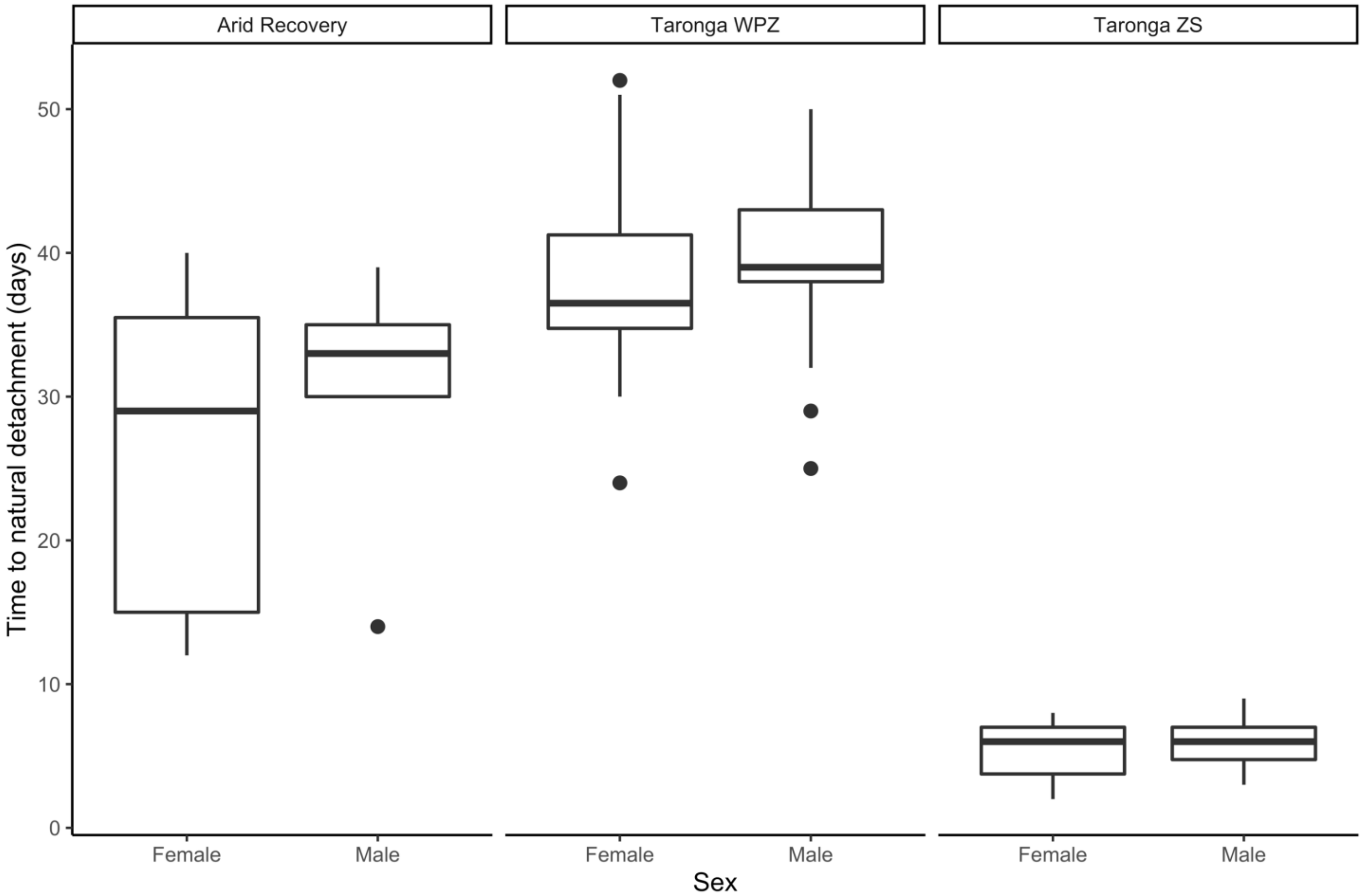

Figure S4: Time to natural detachment (TTND) of tail-mount attached ABDs in days (± IQR) for each site (Arid Recovery, Taronga WPZ, and Taronga ZS) and sex (female, male).

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