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Set free: an evaluation of two break-away mechanisms for tracking collars

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ABSTRACT

Context. One of the welfare and ethical challenges with tracking animals is ensuring that the tracking device is removed from the animal at the conclusion of the study. However, for animals that are not readily re-trapped, the impact of devices and alternatives for their retrieval are rarely examined. **Aims.** We compared the retention time of two types of break-away mechanisms for tracking collars deployed on mainland quokkas (*Setonix brachyurus*). **Methods.** We tested a cotton thread (CT) weak-link, where the collar was cut and then a looping stitch was made to link the cut ends of the collar. We compared collar retention time of this simple mechanism with a lightweight automatic micro timed-release device (mTRD, Sirtrack). **Key results.** Of the 17 radio collars with CT, the fates of 15 collars contributed to retention time data. Seven collars released: six fell off and were recovered 148 ± 64 (s.d.) days after deployment and another collar fell off 136 days after deployment but could not be recovered. Eight quokkas were recaptured (161 ± 109 days after deployment) and collars removed. Two quokkas were each tracked for over a year but then disappeared. Of the 11 GPS collars fitted with a mTRD, the fates of nine collars contributed to retention time data. Two released early at 16 and 29 days and were recovered. Seven fell off around the scheduled release date. There were two unknown fates. Re-trapped collared quokkas did not show evidence of injuries from wearing collars or any significant change in body mass ($P = 0.442$). **Conclusions.** The timing of release for the CT weak-link was unpredictable, with a third of the collars releasing within 1 year and 7/15 lasting only about 6 months. Over two-thirds (7/9) of the GPS collars fitted with timed-release device released on schedule while 2/9 released early. **Implications.** Tracking devices equipped with break-away mechanisms are essential for safeguarding animal welfare outcomes for species where the chance of recapture is not certain. For both break-away types examined in this study, the release timing was unpredictable and poor collar recovery rates show the importance of adding camera traps to monitor the outcomes for collared animals.

Keywords: animal welfare, bio-logging, drop-off, environmentally-degradable link, radio collar, tracking device, TRD, weak-link.

Introduction

Tracking devices are an important tool to study animal movements, use of habitat, and survival (Cochran and Lord 1963; Schladweiler and Tester 1972; Storm 1972; Kenward 1987; White and Garrott 1990). Since the 1990s, there has been increasing use of Global Position System (GPS) devices to quantify animal movement, which provide greater accuracy than older Very High Frequency (VHF) technology (Bunnefeld *et al.* 2011; Recio *et al.* 2011; Lanzone *et al.* 2012). However, even within advances in technology, some researchers have experienced difficulties with GPS collars (Matthews *et al.* 2013; Dore *et al.* 2020).

Over the years, tracking collars have become more reasonably priced, lighter, and have better performance (Kays *et al.* 2015; Portugal *et al.* 2018; Batsleer *et al.* 2020; Dore *et al.* 2020; Katzner and Arlettaz 2020). Collection of higher-resolution data and advances in processing of big data (Hooten 2017; McMahon *et al.* 2017; Browning *et al.* 2018) have improved our ability to retrieve and analyse large and complex data (Kays *et al.* 2015; Foley *et al.* 2020; Katzner and Arlettaz 2020). These advancements have enabled finer scale analyses of animal movement than possible previously or increasingly smaller animals. This is also likely to increase the number of animals being fitted with what can be a permanent collar or harness attachment (Hebblewhite and Haydon 2010; Kays *et al.* 2015; Hughey *et al.* 2018; Buil *et al.* 2019).

The most appropriate method to retrieve a tracking device is re-capturing the animal, where the animal can also be checked for signs of injury that could arise from being collared. Re-trapping may work for resident or philopatric populations, but for species or populations that are trap-shy or more mobile over space and time, the ability to re-capture or even re-locate animals with tracking devices is not always certain. At the conclusion of the study period, if the animal cannot be re-captured, then the collar will remain on the animal indefinitely. Some researchers have recorded problems with tracking devices, including potential impacts of attachment such as skin trauma (Merino *et al.* 2007; Berg *et al.* 2010; Fitzgibbon *et al.* 2011; Coetsee *et al.* 2016), vegetation and limb entanglement (Barron *et al.* 2010; Juarez *et al.* 2011; Coetsee *et al.* 2016), changes in behaviour (Wilson *et al.* 2004; Brooks *et al.* 2008; Dennis and Shah 2012; Gibson *et al.* 2013), and decreased survival (Xiong *et al.* 2009; Severson *et al.* 2019). Such issues make indeterminate collar attachment a significant animal welfare issue.

For animals that are not readily re-trapped, an option is to include a break-away mechanism in the collar. One method involves the inclusion of materials that expand according to neck growth and eventually break; e.g. expanding break-away with low density polyethylene (Strathearn *et al.* 1984), rubber (Soderquist 1993), elastic and Velcro (Robertson and Harris 1996). Another method is to include an environmentally-degradable link, such as corrodible bolts (Thalmann 2013; Povh *et al.* 2019), or cotton thread (Karl and Clout 1987; Hellgren *et al.* 1988; Merrill *et al.* 1998; Casper 2009; Cawthen and Munks 2011; Collins *et al.* 2014). Programmable collar release systems (timed-release devices; TRD) are increasingly available through commercial providers (Evans 1996; Merrill *et al.* 1998; Kochanny *et al.* 2009; Purcell 2010; Ruykys *et al.* 2011; Matthews *et al.* 2012; Cowan *et al.* 2020), or through open-source designs (Buil *et al.* 2019; Rafiq *et al.* 2019), and the recent miniaturisation of TRD (micro-TRD ~10 g) allows this approach to be used on smaller animals.

Few studies have provided adequate details about the mechanism function, retention and release time of break-away mechanisms (Evans 1996; Kochanny *et al.* 2009; Collins *et al.* 2014; Dore *et al.* 2020). The paucity of such knowledge makes it difficult to make an informed decision about the selection of break-away type for a given species. This is a particularly important consideration when working with conservation significant species and those that are exposed to public scrutiny (e.g. animals that are viewed as part of ecotourism ventures).

A factor that will determine the uptake and application of collar break-away methods is whether the mechanisms will release in the desired timeframe, balancing adequate data collection and prevention of potential long-term welfare impact (Matthews *et al.* 2013; Buil *et al.* 2019; Dore *et al.* 2020). For example, Cawthen and Munks (2011) used cotton thread weak-link on collars on brushtail possums (*Trichosurus vulpecula*), but showed short mean retention time and increasing project costs to replace the radio-collars that fell off prematurely. A similar outcome was reported for a study with juvenile red foxes (*Vulpes vulpes*) that necessitated regular recapture of animals and resulted in high costs (Robertson and Harris 1996). Although release failures might be reported, only one recent study mentioned a minor injury caused by tracking devices equipped with cotton thread weak-link and recommended adjustments (Sims *et al.* 2021).

Timed-release devices may also have issues with failures either through releasing earlier than scheduled, or not at all (Matthews *et al.* 2013; Dore *et al.* 2020). For example, Kochanny *et al.* (2009) deployed 21 store-on-board GPS telemetry collars with a releasable mechanism (model G2000; Advanced Telemetry System Inc. Isanti, Minnesota, USA) on white-tailed deer (*Odocoileus virginianus*); of these, eight collars failed to release. Furthermore, a recent study deployed four GPS collars with Sirtrack LiteTrack 140 TRD on red foxes but only one collar was retrieved (Main 2020).

The quokka is a marsupial species endemic to south-western Australia (Kitchener 1995). These medium-sized wallabies are listed under State legislation as Rare or Likely to Become Extinct, and as Vulnerable both nationally (EPBC 1999) and internationally on the IUCN red list (Burbidge and Woinarski 2020). In the northern part of their range (Spencer *et al.* 2019), quokka populations in the jarrah forest are fragmented and subject to a range of threats, including competition and predation by invasive species (feral pig *Sus scrofa*, red fox and feral cat *Felis catus*), decreased rainfall, and habitat loss due to *Phytophthora* dieback (Department of Environment and Conservation 2013). Altered fire regime is also a significant threat to quokka populations. Wildfire can devastate quokka habitat, and therefore carefully managed prescribed burning can be an important tool to manage habitat and reduce fuel load that could lead to potential wildfire (Bain *et al.* 2016).

As part of a broader study, we sought to identify the response of quokka to habitat change caused by prescribed burning. We fitted tracking collars to quokkas to study their movements before and after prescribed burning. Mainland quokkas are present in low numbers in the northern jarrah forest, which reduces overall trap success, therefore increasing the costs and efforts required to track these animals. Quokkas can also be elusive, trap shy, and can travel long distances outside their home range subject to habitat connectivity (Bain et al. 2020), reducing the likelihood of re-capturing the same individual multiple times. Therefore, to ensure animal welfare was not compromised, we equipped VHF and GPS collars with two types of break-away mechanism: cotton thread (CT) and micro-TRD (mTRD). This provided the opportunity to compare the fates of collars with these two break-away mechanisms.

Methods

Between July 2018 and September 2019, quokkas were captured with Thomas soft-wall traps (360 × 480 × 800 mm (*LWH*) Sheffield Wire Works, Welshpool, Western Australia) at five sites (Churchman, Wungong, Gordon, Chandler, and Marrinup forest blocks) in the northern jarrah forest of south-western Australia (Fig. 1). Individuals trapped overnight were removed from traps the following morning. Quokkas were weighed, microchipped, and basic details were recorded. Adult quokkas weighing >2 kg were fitted with a tracking collar (Fig. 2). After fitting collars, quokkas were released at point of capture. All handling was undertaken by experienced ecologists and this project was approved by Murdoch University Animal Ethics Committee (R3058/18) and Department of Biodiversity, Conservation and Attractions (FO25000082-2).

Seventeen VHF and three GPS collars were deployed with a cotton thread (CT) weak-link. VHF collars (M1820 ATS, Australia) weighed 27 g, with housing dimensions of 37 × 12 × 13 mm (*L* × *W* × *H*) and a battery life estimation of 390 days. GPS collars (model LiteTrack 30 Sirtrack, New Zealand) weighed 35 g, with housing size of 20 × 37 × 24 mm, a battery life estimation of 1 year, and with remote UHF download combined with VHF signal. CT weak-links were added to the collars by cutting the collar belt and stitching the two parts together with cotton sewing thread (Fig. 2) using a different number of stitch loops on each collar. The variation in number of loops aimed to test the best stitch configuration to avoid early release.

Eleven GPS collars with mTRD were deployed. The Sirtrack mTRD went out in the field for beta trials in 2016, but have had nothing published on them to date. The mTRD added 10 g to the weight of the collar. The mTRD had an independent battery and clock and were programmed to

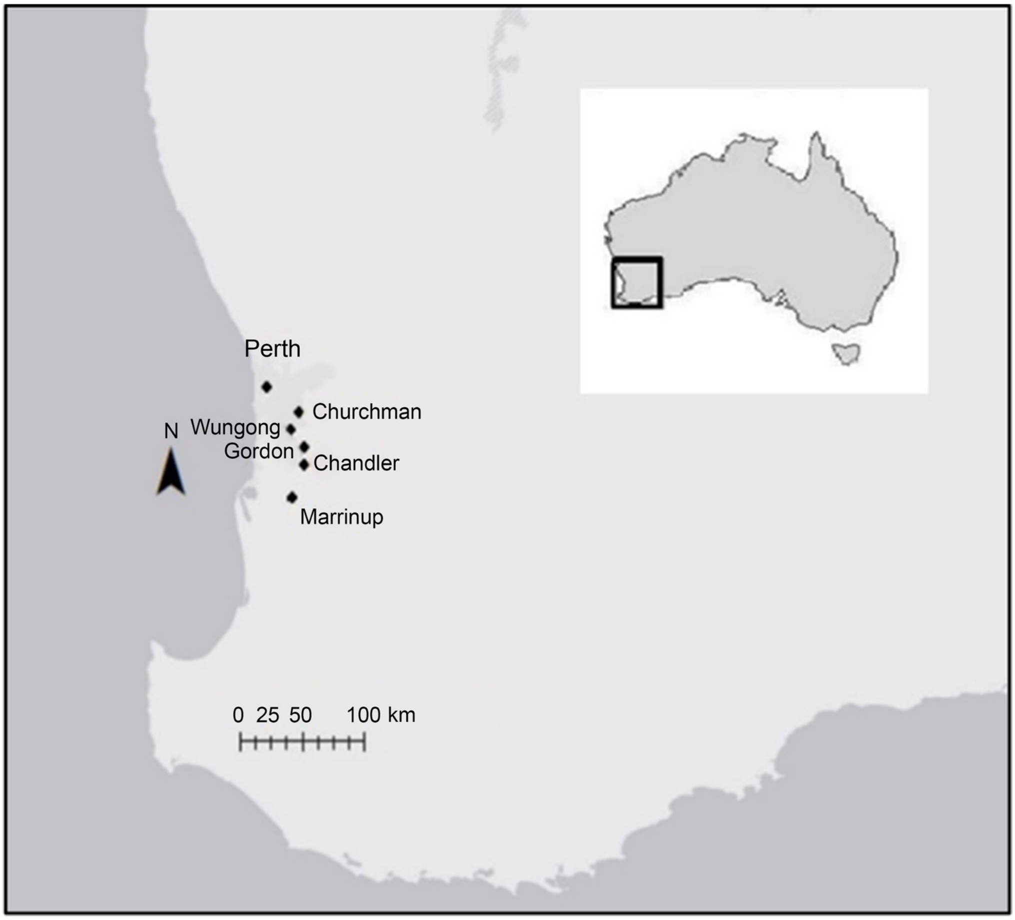

Fig. 1. Mainland quokka (*Setonix brachyurus*) study areas, in the northern jarrah forest of south-western Australia.

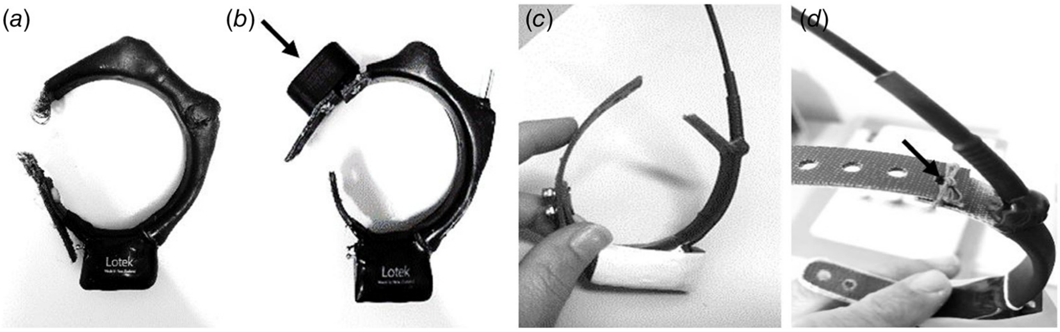

Fig. 2. The VHF and GPS collars that had been deployed on mainland quokkas (*Setonix brachyurus*). (*a*) Retrieved GPS Litetrack 30 collar without micro timed-release device, (*b*) the same type of GPS collar with micro-TRD (mTRD), (*c*) VHF collar belt cut to prepare for cotton thread (CT) weak-link insert and (*d*) cut sections sewn together with CT.

release at 300 or 350 days after deployment (the dates were scheduled differently for independent study sites).

Following collar deployment, quokkas were tracked twice per week. The period of attachment (retention time) was calculated from the date of initial deployment until the last known occasion of attachment. Re-trapping was carried out to replace VHF with GPS collars (year 2 of the study) and to retrieve collars that had not released at completion of the study, placing traps at the same initial trapping point the individual had been located and around nearby known refuge locations determined by radio-tracking. Additionally, 80 camera traps (Reconyx© HC600 Hyperfire, Reconyx Inc., Holmen, USA; 10–20 camera traps at each site, depending on the size of quokka habitat) were deployed to monitor quokka wellbeing and to confirm collar release. Camera trap locations were selected based on areas with presence of animal trails and quokka scats. Camera traps were attached to trees with cable locks (Master Lock Company Phython™, Wisconsin, USA) at a height of approximately 0.5 m and remained in the same position for 2 years. Camera traps were baited daily with cut-up pieces of apples during live trapping, and once per month when not trapping. Camera traps were set on high sensitivity passive infra-red trigger, rapid fire at five photos per trigger with no quiet period, to ensure as many photos as possible were taken of each quokka to facilitate individual identification. Individual quokkas were distinguished through unique markings and general home range locations. Camera trap photos for each individual were examined to determine the last date the collar was present and the first date that the collar was absent.

To determine the likely factors influencing retention time of collar attachments, we carried out multiple regression analysis to describe the relationship between CT weak-link retention time (dependent variable) against models including the number of cotton loops applied and the body mass (kg) and pes length (mm) of quokkas. We used Akaike's information Criterion (AIC) with a small sample correction (AICc) model selection and considered models with delta AICc values <2 to have strong support to distinguish among a set of possible linear models. To compare the retention time for the collars fitted with the two weak-link devices, retention time was compared by Kaplan–Meier curve with package 'survival analysis' in R (Therneau 2021). To test whether there were detrimental impacts of wearing a collar, changes in body weight before and after deployments were analysed using Shapiro–Wilk to test normality in a small sample size, followed by Paired Samples *t*-test.

Statistical analyses were performed using RStudio ver. 4.0.3. Significance values for all tests were set at $\alpha = 0.05$, and values of response variables are reported as means $\pm$ standard deviation (s.d.).

Results

We live-trapped 75 mainland quokkas across the five sites and 33 adult males weighing >2 kg were fitted with tracking-collars. Of those, 28 collars were modified with a break-away (Table 1).

VHF and GPS collars with cotton thread weak-link

Of the 17 radio collars with a CT weak-link, the fates of 15 collars contributed to collar retention data. Seven collars fell off at an average of 148 $\pm$ 64 (range 13–199) days after deployment. There was no correlation in retention time, animal morphometrics, or number of cotton loops, with the null model being the best model describing collar retention time (Table 2). Six collars were retrieved, while one collar was in mortality mode but could not be located (ID#2569; the animal was re-trapped a year later confirming that the collar had released). Two collars did not release for a minimum of 1 year after deployment (data from tracking): one animal (ID#2579) was last seen on camera trap 186 days after deployment (with collar) and was tracked

Table 1. The fate of 20 collars with a cotton thread weak-link (CT) and 11 collars with a lightweight Sirtrack (~10 g Sirtrack LiteTrack 30) automatic micro timed-release device (mTRD) deployed on quokkas (*Setonix brachyurus*).

Break-away type	Animal ID	Sex	Collar type	No. of cotton thread loops	Collar released	Determination of collar fate	Retention time (range = min to max deployment time)	Scheduled release time (days after deployment)	Time after scheduled release (days)
CT	2576	M	VHF	7	Released	Collar collected	13		
	2569	M	VHF	5	Released	In mortality signal	136		
	2480	M	VHF	3	Released	Collar collected	149		
	2587	F	VHF	7	Released	Collar collected	174		
	6274	M	GPS	4	Released	Collar collected	179		
	2480	M	GPS	6	Released	Collar collected	189		
	2637	M	VHF	6	Released	Collar collected	199		
	2579	M	VHF	6	[A]	Tracked	*398*[A]		
	2628	M	VHF	6	[A]	Camera trap	389[A]		
	2482	M	VHF	3	No	Animal re-trapped	12[B]		
	2560	M	VHF	3	No	Animal re-trapped	28[B]		
	2586	M	VHF	6	No	Animal re-trapped	159[B]		
	2486	M	VHF	6	No	Animal re-trapped	160[B]		
	2574	M	VHF	5	No	Animal re-trapped	173[B]		
	2572	M	GPS	3	No	Animal re-trapped	184[B]		
	2584	M	VHF	8	No	Animal re-trapped	215[B]		
	2627	M	VHF	3	No	Animal re-trapped	359[B]		
mTRD	2652	M	GPS	NA	Released early	Collar collected	16	300	−284
	2655	M	GPS	NA	Released early	Animal re-trapped	29	300	−271
	2568	M	GPS	NA	Released	Collar in recovery mode, animal re-trapped and collar removed	350	350	0
	2556	M	GPS	NA	Released	Mortality, collar collected	350	350	0
	2557	M	GPS	NA	Released	Camera trap	197[C] to 311[D]	300	−103 to +11
	2552	M	GPS	NA	Released	Camera trap	298[C] to 330[D]	300	−2 to +30
	2486	M	GPS	NA	Released	Camera trap	269[C] to 347[D]	300	−31 to +47
	2560	M	GPS	NA	Released	Camera trap	345[C] to 351[D]	350	−5 to +1
	2566	M	GPS	NA	Released	Camera trap	245[C] to 416[D]	350	−105 to +66
	2658	M	GPS	NA	[E]	Unknown fate	251+	350	
	2637	M	GPS	NA	[E]	Unknown fate	142+	300	

When collars were not retrieved, their fate was determined by camera trap or recapture where possible.
[A]Minimum deployment time (last time animal was tracked or seen on camera trap with the collar).
[B]Minimum deployment time (collar was retrieved through re-trapping the animal).
[C]Minimum deployment time (last time animal was seen on camera trap with the collar).
[D]Maximum deployment time, calculated to the date the animal was first seen on a camera trap without the collar.
[E]Collar fate not determined as the animal was not seen on camera trap, tracked or re-trapped after the date indicated.
collar type VHF, very high frequency; GPS, global positioning system.

for 398 days, and the second animal (ID#2628) was last seen on camera trap 389 days after deployment (with collar) but could not be re-trapped. The other eight quokkas were recaptured (161 ± 109 days after deployment) and collars removed; six of these collars had been on animals for more than 5 months.

Table 2. Comparison of fitted linear models (Gaussian distribution) for the deployment time (retention time in days) of cotton thread weak-link collars (CT), comparing the effect of average body weight (Model 1), cotton thread arrangement (Model 2) and pes length (Model 3). Dots indicate that the predictor variable was absent from the model.

	Intercept	Number of CT loops	Body weight	pes length	d.f.	logLik	ΔAICc	Delta	Weight	R^2
Null	148.43	.	.	.	2	−38.46	83.93	0.00	0.89	0.00
Model 1	199.11	.	−0.141	.	3	−38.07	90.14	6.21	0.04	0.11
Model 2	211.88	−11.688	.	.	6	−38.18	90.37	6.44	0.04	0.02
Model 3	164.91	.	.	−0.002	3	−38.38	90.76	6.83	0.03	0.08

GPS collars with a micro timed-release device

Of the 11 radio collars with mTRD, nine collars released. Two fell off before their scheduled release and were recovered at 16 and 29 days after deployment (Fig. 3). Seven collars released around their scheduled release date. Two collars were removed from animals (one collar went into recovery mode 250 days after deployment – the animal was re-captured, and the collar removed; the second was a mortality – the carcass was retrieved, and the collar removed) and the mTRD boxes monitored until they both released on their scheduled release date. For the other five collars that released around their programmed schedule, the collars could not be located but camera trapping data (Fig. 4) indicated that they had released somewhere between 35 ± 48 before to 22 ± 26 days after schedule. We could not locate any of these collars, despite extensive searching of the study sites.

The fate of the last two collars could not be confirmed. One collar was either in mortality or release function (251 days after deployment), but the faint signal from the collar was insufficient to locate it; the animal was never re-trapped or seen on a camera trap subsequently. We do not know the fate of one other quokka, which was observed on camera trap just a few times after deployment, tracked for 142 days, but then not re-captured or seen on camera traps subsequently (Table 1).

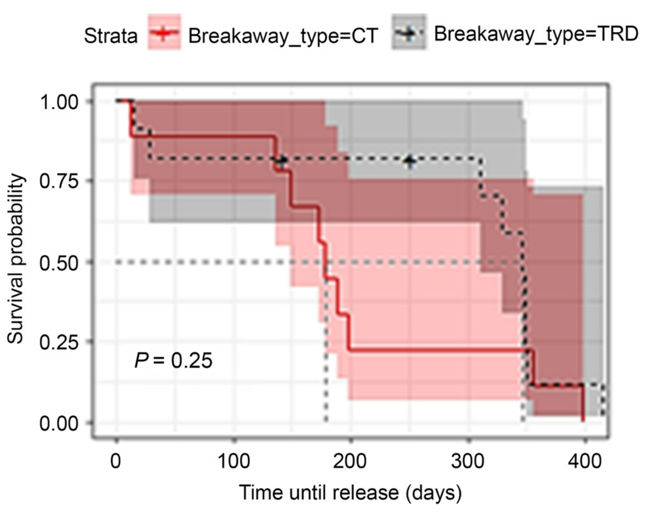

Fig. 3. The retention time for two types of tracking collar break-away (CT cotton thread and mTRD timed release device), showing collar retention in number of days since deployment. The GPS collars equipped with mTRD were programmed to release at either 300 or 350 days; dates shown were the maximum length of time these collars were retained as release could only be confirmed by camera trap images of the animals without their collar.

Comparison between cotton thread weak-link and micro timed-release device

CT collars had less reliability in terms of collar retention time, with three collars retained for more than 1 year. By contrast the seven mTRD boxes that did not fail early all released within a close range of their scheduled release date (Fig. 3). The difference in retention time between these two mechanisms was not statistically significant ($P = 0.250$).

Re-trapping

Collared quokkas that were re-trapped for collar removal demonstrated no visible neck abrasion or other injuries that could be caused by the collar or break-away mechanism. Of the 33 collared quokkas, 26 were recaptured at the end of the study. Recaptured quokkas showed no significant change in body mass over the period that they had been collared ($t_{25} = 0.79$, $P = 0.442$).

Discussion

We compared two types of tracking collar break-away mechanism and found no visible neck abrasion or other injury that could be caused by either the collars or break-away mechanisms. This supports other studies that reported weak-links did not cause negative impacts on the mammals studied (Cawthen and Munks 2011; Thalmann 2013; but see Sims *et al.* 2021). For both break-away types, the release timing was not 100% predictable. CT collars were less reliable, with three retained on the animals for over a year. By contrast all the mTRD devices that did not fail early released close to their scheduled release date.

Although authors rarely report failures, many attachment systems result in premature equipment release (Evans 1996;

Fig. 4. Five individual quokkas fitted with a GPS collar equipped with micro timed-release device (mTRD). The mTRD released around their scheduled dates, but the VHF signal stopped working and the collar could not be retrieved. Collar release was therefore confirmed by camera trap photos, showing last sighting with collar (left hand column) and first sighting without collar (right hand column) for the same five animals uniquely identified by location and natural body marks (e.g. notches in the ear margin).

Robertson and Harris 1996; Cawthen and Munks 2011; Kesler 2011), last longer than scheduled (Garshelis and McLaughlin 1998; Collins *et al*. 2014), or do not release at all (Kenyon *et al*. 2015; Sims *et al*. 2021). We aimed to determine the best cotton thread stitch arrangement to avoid early collar release, but found no significant relationship between collar retention time and the number of cotton thread loops stitched around the collar belt. The exact cause of breakage of the CT weak-link could not be determined, and the collars released independently of the cotton arrangement.

Our outcome is similar to the other studies that indicated the effectiveness of weak-links designed with cotton thread is highly variable (Cawthen and Munks 2011; Kenyon *et al*. 2015; Sims *et al*. 2021) and may not increase collar retrieval rates (Rayner *et al*. 2022). The relative retention time and breakage may be affected by alterations to the basic design (e.g. cotton thread thickness), habitat conditions (e.g. Thalmann 2013), animal strength, robustness and dexterity or behaviour (Garshelis and McLaughlin 1998). A review (Rayner *et al*. 2022) detailed that weak-links broke consistently during dasyurid studies, suggesting the breakages might be related to this group having strong forelimbs and exhibiting interactions between individuals through mating. Conversely, no weak-links broke to release the collars deployed on hare-wallabies, potentially due their weak forelimbs. Even though the mainland quokka is robust and exhibits interactions between individuals, our study found no correlation in collar retention time and animal morphometrics, with collars released or retained on the animals independently of body mass and pes length.

The devices with the CT weak-link had greater retrieval success than the collars equipped with mTRD, which failed to transmit VHF signals shortly after the scheduled release date and could not be located. After the scheduled release date, we carried out extensive ground searches for collars for several weeks, including adapting a Yagi antenna making it 3 m taller to improve receiver gain. It is not clear what caused the collars to fail to transmit a drop off signal. A recent review (Dore *et al.* 2020) has reported similar failure, where collars manufactured by Lotek and Tellus Micro had lower battery life, affecting early loss of VHF or UHF signals, impacting the ability to retrieve the collars. These collars have two independent batteries, one for the GPS beacon and another for the mTRD and, like another studies (e.g. Kochanny *et al.* 2009), we can only speculate that it could be either exhaustion of the beacon battery or weak recovery signal being absorbed by the ground and dense vegetation cover preferred by quokkas.

Of the 11 collars equipped with mTRD in our study, 18% released before their due date, a rate that is significantly greater than the average of 5% collars released before or after the due date in six studies reviewed by Matthews *et al.* (2013). Our 18% unknown collar failure rate is comparable to the average of 19% of collars with TRD failure reviewed by Matthews *et al.* (2013) but less than the 25% and 32% failure rates reported by Kochanny *et al.* (2009) and Cowan *et al.* (2020), respectively. A subsequent review of the functionality of 75 GPS collars equipped with electronic drop-off devices (Dore *et al.* 2020) reported that success of the drop-off mechanisms varied according to manufacturer, with ~50 to ~90% success. Most of our GPS collars released (64%), but because retrieval of mTRD collars was made difficult by their failure to transmit VHF signals shortly after the scheduled release date, we have had to rely on supplementary camera trapping to confirm the releases. This back-up added extra manual labour to create the quokka profiles (ID quokkas by unique markings) and to review 110 000 pictures. Despite the increased labour, we recommend the use of camera traps to monitor collared animals to similarly facilitate confirmation of collar release.

From the limited number of studies available, the outcomes of TRDs are highly variable. The main concern with these mechanisms is their confirmed release around the programmed date (Matthews *et al.* 2013), as the delays in activation of a TRD have implications for animal welfare and collar recovery, particularly in remote areas (Cowan *et al.* 2020). The specific time of collar release is also likely to be important for ensuring retrieval, as it would influence whether the collars fall off when the animals are active (midnight for nocturnal species such as quokkas) or located around rest areas (midday for nocturnal species). This could also influence the distance required to be searched to recover the devices.

Conclusions

Our study provides valuable information about <40 g collars equipped with CT weak links and mTRD. While most collars equipped with either mechanism released, CT weak links had less reliability and breakage of the cotton thread could not be predicted. Increasing the range of materials (e.g. different types of cotton threads) with various arrangement (e.g. the number of CT stitched around the collar belt) in different environments (wet/dry areas) may increase predictability of collars with this mechanism. Our poor mTRD collar recovery rates show the importance in adding camera traps to monitor the fate of collared animals. With the low numbers of individuals in our study sites, we were able to distinguish individuals from natural body marks and identify them from photos. For other species, marking animals (e.g. permanent ear tags) may be crucial to assist in individual identification from pictures to later confirm collar release; otherwise, it may be required to re-trap animals to retrieve collars.

We argue that tracking devices equipped with a break-away mechanism are essential for safeguarding animal welfare outcomes. Although weak-links do not always work as planned, because of material variations, habitat or animal behaviour, they do not cause additional problems compared to collars without links; however, they should work only as a back-up and not as a primary strategy for collar removal (Casper 2009; Matthews *et al.* 2013; Rayner *et al.* 2022). Here we contribute to knowledge about the fate of animals in tracking studies, and we call for continued systematic documentation of collar retrieval and potential impacts and mitigations of devices deployed on animals.

References

Bain K, Wayne A, Bencini R (2016) Prescribed burning as a conservation tool for management of habitat for threatened species: the quokka, *Setonix brachyurus*, in the southern forests of Western Australia. *International Journal of Wildland Fire* **25**, 608–617. doi:10.1071/WF15138

Bain K, Wayne AF, Bencini R (2020) Spatial ecology of the quokka (*Setonix brachyurus*) in the southern forests of Western Australia: implications for the maintenance, or restoration, of functional metapopulations. *Australian Mammalogy* **42**, 38–47. doi:10.1071/AM18036

Barron DG, Brawn JD, Weatherhead PJ (2010) Meta-analysis of transmitter effects on avian behaviour and ecology: meta-analysis of avian transmitter effects. *Methods in Ecology and Evolution* **1**, 180–187. doi:10.1111/j.2041-210X.2010.00013.x

Batsleer F, Bonte D, Dekeukeleire D, Goossens S, Poelmans W, Van der Cruyssen E, Maes D, Vandegehuchte ML (2020) The neglected impact of tracking devices on terrestrial arthropods. *Methods in Ecology and Evolution* **11**, 350–361. doi:10.1111/2041-210X.13356

Berg O, Arnemo J, Skei J, Kraabøl M, Dervo B, Dolmen D (2010) A comparison of external and internal attachments of radio transmitters on adult crested newts *Triturus cristatus*. *Amphibia-Reptilia* **31**, 229–237. doi:10.1163/156853810791069128

Brooks C, Bonyongo C, Harris S (2008) Effects of global positioning system collar weight on zebra behavior and location error. *Journal of Wildlife Management* **72**, 527–534. doi:10.2193/2007-061

Browning E, Bolton M, Owen E, Shoji A, Guilford T, Freeman R, McPherson J (2018) Predicting animal behaviour using deep learning: GPS data alone accurately predict diving in seabirds. *Methods in Ecology and Evolution* **9**, 681–692. doi:10.1111/2041-210X.12926
Buil JMM, Peckre LR, Dörge M, Fichtel C, Kappeler PM, Scherberger H (2019) Remotely releasable collar mechanism for medium-sized mammals: an affordable technology to avoid multiple captures. *Wildlife Biology* **2019**, 1–7. doi:10.2981/wlb.00581
Bunnefeld N, Börger L, van Moorter B, Rolandsen CM, Dettki H, Solberg EJ, Ericsson G (2011) A model-driven approach to quantify migration patterns: individual, regional and yearly differences. *Journal of Animal Ecology* **80**, 466–476. doi:10.1111/j.1365-2656.2010.01776.x
Burbidge AA, Woinarski J (2020) *Setonix brachyurus*. (amended version of 2019 assessment). In 'The IUCN Red List of Threatened Species 2020: e.T20165A166611530'. Available at https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T20165A166611530.en
Casper RM (2009) Guidelines for the instrumentation of wild birds and mammals. *Animal Behaviour* **78**, 1477–1483. doi:10.1016/j.anbehav.2009.09.023
Cawthen L, Munks S (2011) The design and testing of linen thread weak-links in brushtail possum radio-collars. *Australian Mammalogy* **33**, 33–35. doi:10.1071/AM10024
Cochran WW, Lord RD Jr (1963) A radio-tracking system for wild animals. *The Journal of Wildlife Management* **27**, 9–24. doi:10.2307/3797775
Coetsee A, Harley D, Lynch M, Coulson G, de Milliano J, Cooper M, Groenewegen R (2016) Radio-transmitter attachment methods for monitoring the endangered eastern barred bandicoot (*Perameles gunnii*). *Australian Mammalogy* **38**, 221–231. doi:10.1071/AM15029
Collins GH, Petersen SL, Carr CA, Pielstick L (2014) Testing VHF/GPS collar design and safety in the study of free-roaming horses. *PLoS ONE* **9**, e103189. doi:10.1371/journal.pone.0103189
Cowan M, Blythman M, Angus J, Gibson L (2020) Post-release monitoring of western grey kangaroos (*Macropus fuliginosus*) relocated from an urban development site. *Animals* **10**, 1914. doi:10.3390/ani10101914
Dennis TE, Shah SF (2012) Assessing acute effects of trapping, handling, and tagging on the behavior of wildlife using GPS telemetry: a case study of the common brushtail possum. *Journal of Applied Animal Welfare Science* **15**, 189–207. doi:10.1080/10888705.2012.683755
Department of Environment and Conservation (2013) Quokka *Setonix brachyurus* recovery plan. Wildlife Management Program no. 56. pp. 1–26. Department of Environment and Conservation, Perth, WA.
Dore KM, Hansen MF, Klegarth AR, Fichtel C, Koch F, Springer A, Kappeler P, Parga JA, Humle T, Colin C, Raballand E, Huang Z-P, Qi X-G, Di Fiore A, Link A, Stevenson PR, Stark DJ, Tan N, Gallagher CA, Anderson CJ, Campbell CJ, Kenyon M, Pebsworth P, Sprague D, Jones-Engel L, Fuentes A (2020) Review of GPS collar deployments and performance on nonhuman primates. *Primates* **61**, 373–387. doi:10.1007/s10329-020-00793-7
EPBC (1999) 'The Environmental Protection and Biodiversity Conservation Act 1999.' (Australian Government, Department of Sustainability, Environment, Water, Population and Communities: Canberra, ACT, Australia)
Evans M (1996) Home ranges and movement schedules of sympatric bridled nailtail and black-striped wallabies. *Wildlife Research* **23**, 547–555. doi:10.1071/WR9960547
Fitzgibbon SI, Wilson RS, Goldizen AW (2011) The behavioural ecology and population dynamics of a cryptic ground-dwelling mammal in an urban Australian landscape. *Austral Ecology* **36**, 722–732. doi:10.1111/j.1442-9993.2010.02209.x
Foley CJ, Sillero-Zubiri C, Börger L (2020) Open-source, low-cost modular GPS collars for monitoring and tracking wildlife. *Methods in Ecology and Evolution* **11**, 553–558. doi:10.1111/2041-210X.13369
Garshelis DL, McLaughlin CR (1998) Review and evaluation of breakaway devices for bear radiocollars. *Ursus* **10**, 459–465. https://www.jstor.org/stable/3873158
Gibson D, Blomberg EJ, Patricelli GL, Krakauer AH, Atamian MT, Sedinger JS (2013) Effects of radio collars on survival and lekking behavior of male greater sage-grouse. *The Condor* **115**, 769–776. doi:10.1525/cond.2013.120176
Hebblewhite M, Haydon DT (2010) Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**, 2303–2312. doi:10.1098/rstb.2010.0087
Hellgren EC, Carney DW, Garner NP, Vaughan MR (1988) Use of breakaway cotton spacers on radio collars. *Philosophical Transactions of the Royal Society B: Biological Sciences* **16**, 216–218.
Hooten MB (2017) 'Animal movement: statistical models for telemetry data.' (CRC Press/Taylor & Francis Group: Boca Raton)
Hughey LF, Hein AM, Strandburg-Peshkin A, Jensen FH (2018) Challenges and solutions for studying collective animal behaviour in the wild. *Philosophical Transactions of the Royal Society B: Biological Sciences* **373**, 20170005–20170005. doi:10.1098/rstb.2017.0005
Juarez CP, Rotundo MA, Berg W, Fernández-Duque E (2011) Costs and benefits of radio-collaring on the behavior, demography, and conservation of owl monkeys (*Aotus azarai*) in Formosa, Argentina. *International Journal of Primatology* **32**, 69–82. doi:10.1007/s10764-010-9437-z
Karl BJ, Clout MN (1987) An improved radio transmitter harness with a weak link to prevent snagging (nuevo arnés para colocar radiotransmisores en aves). *Journal of Field Ornithology* **58**, 73–77.
Katzner TE, Arlettaz R (2020) Evaluating contributions of recent tracking-based animal movement ecology to conservation management. *Frontiers in Ecology and Evolution* **7**, 519. doi:10.3389/fevo.2019.00519
Kays R, Crofoot MC, Jetz W, Wikelski M (2015) Terrestrial animal tracking as an eye on life and planet. *Science* **348**, 2478–2478. doi:10.1126/science.aaa2478
Kenward R (1987) 'Wildlife radio tagging: equipment, field techniques, and data analysis.' (Academic Press: London, Orlando)
Kenyon M, Streicher U, Pei KJ-C, Cronin A, van Dien N, van Mui T, van Hien L (2015) Experiences using VHF and VHF/GPS-GSM radio-transmitters on released southern yellow-cheeked gibbons (*Nomascus gabriellae*) in South Vietnam. *Vietnamese Journal of Primatology* **2**, 15–27.
Kesler DC (2011) Non-permanent radiotelemetry leg harness for small birds. *The Journal of Wildlife Management* **75**, 467–471. doi:10.1002/jwmg.44
Kitchener DJ (1995) 'Quokka (*Setonix brachyurus*).' (Reed Books: Sydney, Australia)
Kochanny CO, Delgiudice GD, Fieberg J (2009) Comparing global positioning system and very high frequency telemetry home ranges of white-tailed deer. *Journal of Wildlife Management* **73**, 779–787. doi:10.2193/2008-394
Lanzone MJ, Miller TA, Turk P, Brandes D, Halverson C, Maisonneuve C, Tremblay J, Cooper J, O'Malley K, Brooks RP, Katzner T (2012) Flight responses by a migratory soaring raptor to changing meteorological conditions. *Biology Letters* **8**, 710–713. doi:10.1098/rsbl.2012.0359
Main MT (2020) 'An investigation into the spatial distribution, habitat selection and resource usage of the red fox (*Vulpes vulpes*) inhabiting urban reserves within Perth, Western Australia.' (Edith Cowan University)
Matthews A, Green K, Kitchener A (2012) Seasonal and altitudinal influences on the home range and movements of common wombats in the Australian Snowy Mountains. *Journal of Zoology* **287**, 24–33. doi:10.1111/j.1469-7998.2011.00881.x
Matthews A, Ruykys L, Ellis B, FitzGibbon SI, Lunney D, Crowther MS, Glen AS, Purcell B, Moseby K, Stott J, Fletcher D, Wimpenny C, Allen BL, Van Bommel L, Roberts M, Davies N, Green K, Newsome T, Ballard G, Fleming P, Dickman CR, Eberhart A, Troy S, McMahon C, Wiggins N (2013) The success of GPS collar deployments on mammals in Australia. *Australian Mammalogy* **35**, 65–83. doi:10.1071/AM12021
McMahon LA, Rachlow JL, Shipley LA, Forbey JS, Johnson TR, Olsoy PJ (2017) Evaluation of micro-GPS receivers for tracking small-bodied mammals. *PLoS ONE* **12**, e0173185. doi:10.1371/journal.pone.0173185
Merino S, Carter J, Thibodeaux G (2007) Testing tail-mounted transmitters with *Myocastor coypus* (Nutria). *Southeastern Naturalist* **6**, 159–164. doi:10.1656/1528-7092(2007)6[159:TTTWMC]2.0.CO;2
Merrill SB, Adams LG, Nelson ME, Mech LD (1998) Testing releasable GPS radiocollars on wolves and white-tailed deer. *Wildlife Society Bulletin* **26**, 830–835.

Portugal SJ, White CR, Börger L (2018) Miniaturization of biologgers is not alleviating the 5% rule. *Methods in Ecology and Evolution* **9**, 1662–1666. doi:10.1111/2041-210X.13013

Povh LF, Bencini R, Chambers BK, Kreplins TL, Willers N, Adams PJ, Wann J, Kobryn HT, Fleming PA (2019) Shedding light on a cryptic macropodid: home ranges and habitat preferences of translocated western brush wallabies (*Notamacropus irma*). *Australian Mammalogy* **41**, 82–91. doi:10.1071/AM17041

Purcell BV (2010) Order in the pack: ecology of *Canis lupus* dingo in the southern Greater Blue Mountains World Heritage Area. PhD thesis. University of Western Sydney.

Rafiq K, Appleby RG, Edgar JP, Jordan NR, Dexter CE, Jones DN, Blacker ARF, Cochrane M, Shepard E (2019) OpenDropOff: an open-source, low-cost drop-off unit for animal-borne devices. *Methods in Ecology and Evolution* **10**, 1517–1522. doi:10.1111/2041-210X.13231

Rayner K, Sullivan M, Sims C, Cowen S (2022) A pain in the neck: weak links are not a reliable release mechanism for radio-collars. *Australian Mammalogy* **44**, 117–125. doi:10.1071/AM20065

Recio MR, Mathieu R, Maloney R, Seddon PJ (2011) Cost comparison between GPS- and VHF-based telemetry: case study of feral cats *Felis catus* in New Zealand. *New Zealand Journal of Ecology* **35**, 114–117.

Robertson CPJ, Harris S (1996) An expandable, detachable radio-collar for juvenile red foxes (*Vulpes vulpes*). *Journal of Zoology* **239**, 382–387. doi:10.1111/j.1469-7998.1996.tb05457.x

Ruykys L, Ward MJ, Taggart DA, Breed WG (2011) Preliminary spatial behaviour of warru (*Petrogale lateralis* MacDonnell Ranges race) in the Anangu Pitjantjatjara Yankunytjatjara Lands, South Australia. *Australian Mammalogy* **33**, 181–188. doi:10.1071/AM10034

Schladweiler JL, Tester JR (1972) Survival and behavior of hand-reared mallards released in the wild. *The Journal of Wildlife Management* **36**, 1118–1127. doi:10.2307/3799240

Severson JP, Coates PS, Prochazka BG, Ricca MA, Casazza ML, Delehanty DJ (2019) Global positioning system tracking devices can decrease Greater Sage-Grouse survival. *The Condor* **121**, duz032. doi:10.1093/condor/duz032

Sims C, Rayner K, Knox F, Cowen S (2021) A trial of transmitter attachment methods for Shark Bay bandicoots (*Perameles bougainville*). *Australian Mammalogy* **43**, 359–362. doi:10.1071/AM20035

Soderquist TR (1993) An expanding break-away radio-collar for small mammals. *Wildlife Research* **20**, 383–385. doi:10.1071/WR9930383

Spencer PBS, Bain K, Hayward MW, Hillyer M, Friend JAT (2019) Persistence of remnant patches and genetic loss at the distribution periphery in island and mainland populations of the quokka. *Australian Journal of Zoology* **67**, 38–50. doi:10.1071/ZO19055

Storm GL (1972) Daytime retreats and movements of skunks on farmlands in Illinois. *The Journal of Wildlife Management* **36**, 31–45. doi:10.2307/3799186

Strathearn SM, Lotimer JS, Kolenosky GB, Lintack WM (1984) An expanding break-away radio collar for black bear. *The Journal of Wildlife Management* **48**, 939–942. doi:10.2307/3801442

Thalmann S (2013) Evaluation of a degradable time-release mechanism for telemetry collars. *Australian Mammalogy* **35**, 241–244. doi:10.1071/AM12041

Therneau TM (2021) A package for survival analysis in R. R package 3.2-13. Available at https://CRAN.R-project.org/package=survival

White GC, Garrott RA (1990) 'Analysis of wildlife radio-tracking data.' (Academic Press: San Diego)

Wilson RP, Kreye JM, Lucke K, Urquhart H (2004) Antennae on transmitters on penguins: balancing energy budgets on the high wire. *Journal of Experimental Biology* **207**, 2649–2662. doi:10.1242/jeb.01067

Xiong W, Liang H, Yu X, Cong L, Zhang Z (2009) Food limitation and low-density populations of sympatric hamster species in North China. *Contributions to Zoology* **78**, 65–75. doi:10.1163/18759866-07802003

Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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