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Development of a tag-attachment method to enable capture of fine- and landscape-scale movement in black-cockatoos

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Abstract. This study reports on a successful trial of a double-tag mounting protocol using both satellite and GPS tags on captive black-cockatoos (Forest Red-tailed Black-Cockatoo *Calyptorhynchus banksii naso*, Baudin's Black-Cockatoo *Zanda baudinii* and Carnaby's Black-Cockatoo *Z. latirostris*). The aim of the study was to assess the feasibility and tolerance of a novel back-mount and a double-mount protocol combining a back- and tail-mount in black-cockatoos. We trialled solar 3D Global Positioning Systems (GPS) tags, standard solar and battery-operated GPS and Platform Terminal Transmitter (PTT) tags, and developed an attachment method to fit back-mounted solar-powered UvA-BiTS GPS tags to captive black-cockatoos. We investigated the effect of a variety of different types of tail-mounted satellite tags on the operational ability of the primary UvA-BiTS units and the feasibility of the double-mounted tag system with regard to tolerance by the birds. Our study determined that the combination of a 7.5-g UvA-BiTS GPS tag and 17-g Telonics TAV 2617 satellite tag was best tolerated by the birds and was the optimal tag system for use on birds to be released. This system enables capture of movement data to better understand the ecology of black-cockatoos, and identify critical feeding, roosting and breeding habitats, thereby informing conservation management initiatives to conserve these threatened species.

Introduction

The movement ecology of birds has been heavily researched but often focuses simply on describing and measuring movement itself. Studies rarely investigate the reasons for and factors affecting movement patterns, such as food availability, habitat, breeding and predation (Holyoak *et al.* 2008; Sekercioglu 2010). Tracking birds also poses many difficulties to research and management efforts including the vast distances that they can cover, as well as difficult terrain and habitat in which they reside.

Parrots and cockatoos present particular challenges to tracking studies given their strong beaks and natural desire to chew tracking devices. As suggested by Kennedy *et al.* (2015) and Groom *et al.* (2015), the risk of damage to, and destruction of, expensive tracking devices has often prevented their use in these species. Recent technological improvements, together with reductions in the size and cost of tracking devices, have made telemetry a much more viable option, with successful use of radio-transmitters on the Scarlet Macaw *Ara macao* (Myers & Vaughan 2004) and Rosy-faced Lovebird *Agapornis roseicollis* (Ndithia & Perrin 2006), Global Positioning System (GPS) transmitters on the Kea *Nestor notabilis* (Kennedy *et al.* 2015), and satellite PTT tags on Carnaby's Black-Cockatoo *Zanda latirostris* (Groom *et al.* 2013) and Baudin's Black-Cockatoo *Z. baudinii* (Yeap *et al.* 2015).

Previous research has shown that black-cockatoos are well-suited for tail-mounted Argos satellite tags (Le Souef *et al*. 2013), with retention times often exceeding battery life (Le Souef *et al.* 2013; Groom *et al.* 2015; Yeap *et al.* 2015). However, although these studies were well suited to landscape-scale characterisation of species movement, they were limited by both battery life and data resolution. Depending on its programming schedule, a typical satellite tag can provide several usable position fixes a day (Thomas *et al.* 2011). In contrast, GPS units allow collection of much larger volumes of data with resultant higher accuracy and precision, and can provide information regarding individual position and behaviour. Typically, GPS tags now combine acquisition of location observations with tri-axial accelerometer measurements (3D GPS), facilitating a multi-scale approach to studying bird movements and behaviour. In addition, solar recharge capabilities can greatly prolong the working life of tags; this facility is available in both satellite and GPS tags. Ultimately the choice of tag is dependent on the questions asked and the limitations of the attachment method that are imposed by the species.

Carnaby's Black-Cockatoo, Baudin's Black-Cockatoo and the Forest Red-tailed Black-Cockatoo *Calyptorhynchus banksii naso* are species endemic to south-western Western Australia. All three taxa are listed as threatened under the Federal *Environment Protection and Biodiversity Conservation Act 1999* (SEWPaC 2012). In Western Australia, all three are listed under Schedule 1 (species that are rare or likely to become extinct) of the Western Australian *Wildlife Conservation Act 1950* (DEC 2007, 2012). Black-cockatoos are threatened by multiple factors including: habitat loss and fragmentation; competition with other bird species and feral bees for nest-hollows; poaching; disease; and anthropogenic factors such as vehicle-strike and illegal shooting (Saunders *et al.* 2011). Significant declines in black-cockatoo numbers have been observed from the 1980s (Saunders & Ingram

1998), and thus all are the subject of species Recovery Plans (DEC 2007, 2012). Flock movements, habitat use and critical feeding and breeding sites across these species' distribution ranges remain largely unknown (DEC 2007, 2012). Previous tracking research has been limited to the urban and peri-urban areas of the Swan Coastal Plain, and generally has not coincided with long-distance migratory movements to breeding areas, and has involved only two of the three target species (Groom 2015; Yeap *et al.* 2015). Tracking across the complete annual migratory cycle of these species is required to address the aims of the Recovery Plan and facilitate long-term conservation planning (DEC 2007, 2012). Our previous work (Yeap *et al.* 2015) has shown that individually tagged birds integrate with wild flocks and function effectively as indicators of flock movement.

Black-cockatoos are some of the most destructive bird species, both in the wild and in captivity (Johnston 2013). All three Western Australian species are specialist foragers that routinely manipulate large hard eucalypt capsules to extract the seeds. Thus they are likely to pose some of the greatest challenges to the long-term persistence and functionality of tracking devices. We trialled several different combinations of trackers and attachment types on captive individuals of all three species to inform and optimise tag deployment strategies for wild birds. Given the destructive capability of our study species, our results should be broadly applicable to most other cockatoos (some of which are Critically Endangered) and other large parrots.

Methods

Feasibility of the double-tag method was tested via a multi-stage process. In this paper, the term 'double-tag' refers to the attachment of two separate tags to an individual bird. Previous tag deployments have used battery-powered tags and placement ventrally on the tail. We tested the use of solar tags that require dorsal placement for battery recharge. Both dummy (non-functional) and live tags were used during the trials to assess: (1) optimal tag placement, (2) bird tolerance to back-mounts, (3) bird tolerance to two tags (double-tag), (4) the feasibility of using a dorsal satellite/GPS combination tail-mounted tag, and (5) any possible message interference between the GPS and Platform Terminal Transmitter (PTT) tags used.

The birds used in this study were either not-for-release education birds, or wild birds in the final stages of rehabilitation, which were all housed at Kaarakin Black Cockatoo Conservation Centre (KBCCC), Martin, Western Australia.

Cadaver trial

Before deployment of the double-tag system on live birds, we trialled the attachment procedure on black-cockatoo cadavers. We were then able to establish landmarks for attachment to ensure consistent positioning on each bird. Tail-mounts followed the protocols of Le Souef *et al.* (2013) and Groom *et al.* (2015). To deploy back-mounted solar GPS tags, we first attached a flexible plastic backing plate (~1 mm thick) to the feathers using adhesive cloth tape (Bear Black Gaffer Tape, Saint Gobain Abrasives Pty Ltd, Thomastown, Victoria, Australia). Two strips of tape were used, one at the top of the backing plate and one at the bottom. The tape made several turns over the feathers and backing plate, so that tape adhered to tape. Three to four feathers were used to secure the backing plate. If possible, two separate rows of feathers were used to improve stability of the plate. The backing plate approximated the shape of the tag and was a dark colour to reduce visual cues to the bird and conspecifics. It had attachment holes matching the positioning of the eyelets on the tag to facilitate attachment of the tag to it. It was centred over the bird's vertebral column, 10 mm posterior to the pectoral girdle and 20 mm anterior to the pelvic girdle. The GPS tag was then glued (Selleys Ultra Repair Glue; Selleys, Padstow, New South Wales, Australia) and tied to the backing plate using braided nylon fishing-line (Fireline®, Berkley®, Spirit Lake, Iowa, USA) using the eyelets on the tag. Any feathers on the bird's neck that might obscure the solar panel were trimmed. This attachment method allowed the tag to be shed with the feathers, or to be removed easily by the bird if not tolerated.

Tolerance of double-tag mounting protocol and solar-only GPS/satellite tail-mount: preliminary aviary trial

To test tolerance of the back-mounted GPS tag on live birds, we attached the tag using the protocol above to one Forest Red-tailed Black-Cockatoo, one Baudin's Black-Cockatoo and one Carnaby's Black-Cockatoo. These birds were all in the final stages of rehabilitation before release back to the wild, and were housed in a pre-release flight aviary (6 m × 64 m).

To minimise stress to the birds during attachment, tags were fitted under isoflurane gaseous anaesthesia (induced at 5% isoflurane, 1.5 L/min. oxygen, maintained on 2% isoflurane). The birds were weighed and given a subcutaneous injection of Hartmann's solution (Compound Sodium Lactate, Baxter Healthcare Pty Ltd, Old Toongabbie, NSW) under anaesthesia. Supplementary heat during anaesthesia was provided by positioning the birds on a Mistral-Air® Warming Blanket (The 37°Company, Amersfoort, The Netherlands). Each bird was placed prone (Figure 1), which allowed for dorsal attachment of the 7.5-g GPS tag (University of Amsterdam, The Netherlands—UvA-BiTS 2CDSe). Once extubated, the bird was loosely wrapped in a towel and placed into a secure pet-carrier to recover. All birds were standing and mobile within 30 minutes of extubation. Supplemental heat during recovery was maintained with an infrared heat lamp. The tagging procedure took a maximum of 15 minutes. Once recovered from anaesthesia, birds were returned to the flight aviary and their behaviour was observed. Correct operation of each tag was tested by downloading data using the UvA-BiTS antenna and base station. After 2 hours of observation and data collection, the bird was captured, and the GPS tag was removed, under manual restraint, by cutting the quills of the feathers used for attaching the base-plate. The underlying skin and feathers were checked for abnormalities before release of the bird.

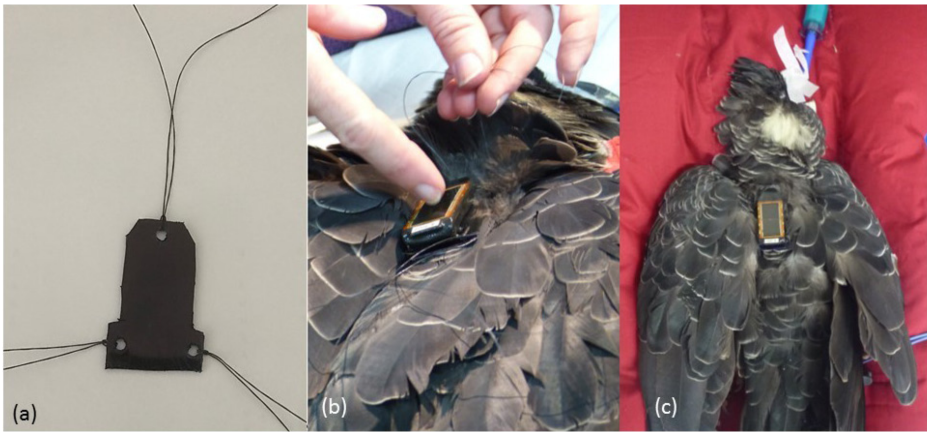

Figure 1. Back-mount of solar-powered UvA-BiTS tag on a black-cockatoo: (a) backing plate with braid attachment ties, (b) backing plate and UvA-BiTS tag attached to feathers between the shoulders of a Carnaby's Black-Cockatoo, and (c) final attachment on a Carnaby's Black-Cockatoo. Photos: Lian Yeap & Jill M. Shephard

Figure 2. Double-mount of satellite and GPS tags dorsally on a black-cockatoo: Microwave Telemetry PTT-100 (at right) attached to dorsal aspect of central rectrices, and UvA-BiTS (5CDLe) (at left) attached to the feathers on the back of a Carnaby's Black-Cockatoo. Photo: Lian Yeap & Jill M. Shephard

Tolerance of double-tag mounting protocol and solar-only GPS/satellite tail-mount: extended aviary trial

Six 'not-for-release' birds (four Carnaby's Black-Cockatoos and two Forest Red-tailed Black-Cockatoos) were each tagged with two tags, a back-mounted GPS tag and a tail-mount. Two of the Carnaby's Black-Cockatoos had tail-mounts that were solar-powered tags, which required mounting on the dorsal aspect of the tail. In addition, a fifth Carnaby's Black-Cockatoo was tagged with a single dorsal tail-mounted solar tag that combined both GPS and satellite capability, so a back-mounted GPS tag was not fitted to this bird. A total of seven birds was used in the trial (Table 1). All live satellite tags were programmed to transmit for 5 hours, every fifth day. The expected battery life using this schedule was 233 hours (Telonics 2014).

GPS back-mounts were attached using the protocol already described, and tail-mounts followed the protocols of Le Souef *et al.* (2013) and Groom *et al.* (2015). Dorsal tail-mounts followed the ventral tail-mounting protocol except that the tag was positioned on the dorsal aspect of the tail (Figure 2). The tags used in this study were Microwave Telemetry PTT-100, Telonics TAV 2617 and UvA-BiTS GPS (2CDSe, 5CDLe). Each Microwave Telemetry solar tag (PTT-100) had its antenna at an angle of 45° to the surface of the tag, which prevented the antenna being tied to the feather shafts as described for the ventral tail-mounts. All procedures were performed under isoflurane general anaesthesia as described previously. Birds were weighed and blood was collected for a routine blood profile (ZA1 Avian Profile, Vetpath Laboratories, Perth, Western Australia). Where birds were handled to remove trackers at the end of the study, weight measurements and blood collection were repeated under anaesthesia. Birds were not reweighed or bled if they removed their tracking devices or lost their tracking devices through feather moult. In this trial we were interested in how long the tags would be retained and we did not remove tags unless they were damaged by the bird and/or posed a welfare risk. The double-tagging procedure took an average of 45 minutes. The combined weight of the tags (including mounting materials) was <5% of total body weight, which is within suggested recommendations (Cochran 1980).

The cockatoos were housed in their normal aviaries before, during and after the attachment trials. The not-for-release education Carnaby's Black-Cockatoos were housed together in an aviary adjacent to the food-preparation kitchen, where they were easily observed by KBCCC staff. Staff were asked to observe feeding and

Table 1. Tag combinations and duration of their attachment to black-cockatoos. Species: CBC = Carnaby's Black-Cockatoo, FRTBC = Forest Red-tailed Black-Cockatoo; sex: F = female, M = male; mount: DT = dorsal tail-mount; VT = ventral tail-mount: DB = (dorsal) back-mount; tag status: D = dummy, L = live; dates for attachment and detachment are given as day, month, year; and the durations of attachment (far right column) are given in days.

Black-cockatoo			*Tag*						
Identity (& microchip no.)	*Species*	*Sex (& weight, g)*	*Combination (& weight)*	*Mount*	*Status*	*Dimensions (mm)*	*Attachment*	*Detachment*	*Days*
Katanning (0006397AF1)	CBC	M (571)	Microwave Telemetry GPS/ Satellite Solar PTT-100 (22 g)	DT	L	64 x 23 x 16.5	21.5.15	11.11.15	175
Denmark (0006FO5157)	CBC	M (613)	Microwave Telemetry Solar PTT-100 (9.5 g)	DT	D	38 x 17 x 12	22.5.15	2.6.15	12
			UvA-BiTS GPS (2CDSe) (7.5 g)	DB	L	52 x 22 x 9	22.5.15	19.6.15	29
Harmony (000638A9AF)	CBC	F (632)	Microwave Telemetry Solar PTT-100 (9.5 g)	DT	L	38 x 17 x 12	21.5.15	9.6.15	20
			UvA-BiTS GPS (5CDLe) (13 g)	DB	L	61 x 25 x 10	21.5.15	26.5.15	6
Chasey (0006E6A1E3)	CBC	M (551)	Telonics TAV 2617 (17 g)	VT	L	64.3 x 20.3 x 8.4	21.5.15	5.1.16	230
			UvA-BiTS GPS (2CDSe) (7.5 g)	DB	L	52 x 22 x 9	21.5.15	1.6.15	12
Carnie (0007259858)	CBC	M (631)	Telonics TAV 2617 (17 g)	VT	D	64.3 x 20.3 x 8.4	19.6.15	3.3.16	259
			UvA-BiTS GPS (2CDSe) (7.5 g)	DB	L	52 x 22 x 9	19.6.15	30.6.15	12
Squeak (000725960E)	FRTBC	M (630)	Telonics TAV 2617 (17 g)	VT	D	64.3 x 20.3 x 8.4	19.6.15	1.8.15	44
			UvA-BiTS GPS (2CDSe) (7.5 g)	DB	L	52 x 22 x 9	19.6.15	19.6.15	0
Wubba (0006E6CD44)	FRTBC	M (498)	Telonics TAV 2617 (17 g)	VT	D	64.3 x 20.3 x 8.4	19.6.15	21.7.15	33
			UvA-BiTS GPS (2CDSe) (7.5 g)	DB	L	52 x 22 x 9	19.6.15	23–24.6.15	5–6

preening behaviour, flight activity and interaction between birds and to report any abnormalities. Birds were observed during normal husbandry procedures (i.e. aviary cleaning, food delivery).

The remaining birds were housed in a large flight aviary. All birds were given behavioural-enrichment items, such as Marri *Corymbia calophylla* capsules and branches and Radiata Pine *Pinus radiata* cones several times per week.

Results

Tag placement and tolerance

The positioning of the back-mounted GPS tag was very successful, and none of the birds in the GPS back-mount trial showed interest in the tag, which stayed in position on the back between the shoulders. The tag moved with the feather shafts, so birds were able to preen around and under the tag at will, and in all trials the birds were routinely observed roosting with the head tucked next to the tag. Perching and flying behaviour was observed to be normal, and all data downloads were successful.

With the exception of one UvA-BiTS GPS tag in the extended double-tag aviary trial, tags remained in place for 5–29 days (Table 1). Tags were removed by the cockatoos, or manually removed because of partial detachment of the tag from the backing plate, most likely as a result of the birds preening and nibbling at the attachment points or through allopreening. GPS back-mount tags were less well tolerated by the Forest Red-tailed Black-Cockatoos. One bird began to chew the tag whilst recovering from anaesthesia in the pet-pack, emphasising the need to observe birds closely before release back into the aviary and into the wild. This tag subsequently was removed by the bird several hours after deployment.

Retention of the ventral tail-mounts was high. Both Carnaby's Black-Cockatoos retained the tag for ≥230 days (Table 1), which was almost beyond the calculated battery life of the units based on the programming schedule. Retention was longer in the Carnaby's Black-Cockatoos than in the Forest Red-tailed Black-Cockatoos, but it is unclear if this reflects a difference in species' tolerance. For at least one of the Forest Red-tailed Black-Cockatoos, tag loss after 33 days appears to have been because of poor attachment rather than removal by the bird as the intact tag was observed to have moved down and eventually slid off.

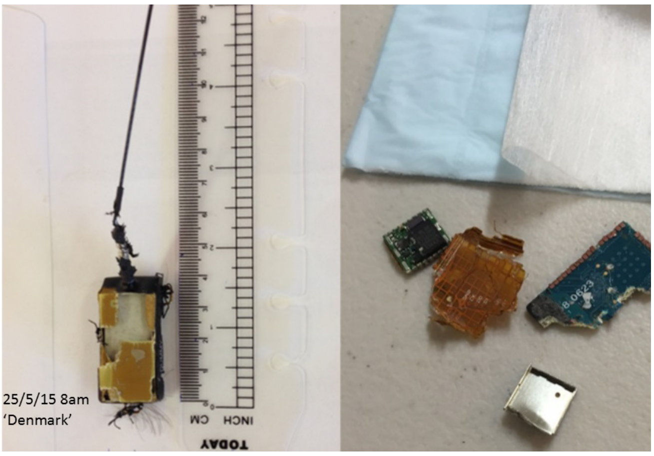

Figure 3. Satellite and GPS tags removed by black-cockatoos. Microwave Telemetry tail-mount PTT (left) and UvA-BiTS tag (right) chewed off by the birds to which they were attached (left, Carnaby's Black-Cockatoo; right, Forest Red-tailed Black-Cockatoo). Photos: Lian Yeap & Jill M. Shephard

Figure 4. Moulted central rectrices with Telonics TAV 2617 satellite tag still attached to both feathers of a Carnaby's Black-Cockatoo. Photo: Lian Yeap & Jill M. Shephard

Tolerance of double-tag mounting

The optimal double-mounted tag combination was the 7.5-g UvA-BiTS GPS and 17-g Telonics TAV 2617 satellite tag, as trialled on Carnaby's Black-Cockatoos 'Chasey' and 'Carnie'. This combination was well tolerated by the birds, and facilitated the collection of both GPS and satellite data at the required temporal resolution to support tracking releases in the wild.

There did not appear to be any effect of using a double-tag back- and tail-mount on the birds. In the six birds with the double-mount, no differences in behaviour, flight or feeding were reported by KBCCC staff. Where birds were recaptured for removal of the back-mounted GPS tag, there were no abnormalities of the feathers or skin underlying the back-mount. Blood-screening results were compared with the reference ranges established by Le Souef *et al.* (2013), and no abnormalities were noted. The blood profile assessed complete blood cell count (indicators of inflammation or infection), muscle enzymes (indicators of injury), kidney and liver function, blood glucose and electrolytes.

Feasibility of dorsal tail-mounting

All solar dorsal-mounted tail-tags were well tolerated by the birds. However, the Microwave Telemetry satellite/GPS tag (PTT-100) failed to recharge as, at rest, the bird's primary wing-feathers covered the solar panel. Interestingly, despite the angled (45°) antenna pointing outwards away from the tail, the bird did not chew it. The tag was naturally moulted with the two central rectrices after 175 days. The Microwave Telemetry 9.5-g solar tag was mounted on a bird with only one fully erupted rectrix ('Denmark'). The normal protocol requires two central rectrices. The tag had a tendency to hang slightly off to the side of the feather to which it was attached. This tag stayed in place for 12 days before being recovered from the floor of the aviary in multiple pieces, having been chewed off by the bird (Figure 3).

Signal interference

There was no interference during signal transmission between the satellite and GPS tags with the double-mounted tag system. Data transmissions and downloads from both tags in the double-mounted tag system were of the same quality and frequency as from single-mounted tags.

Discussion

In this study we trialled the use of solar 3D (triaxial accelerometer) GPS tags as well as standard solar and battery-operated GPS and PTT tags. We were particularly interested in the feasibility and tolerance of a novel back-mount and a double-mount protocol combining a back- and tail-mount.

The success of the back-mounts in particular was surprising and very encouraging as we had expected that the birds would quickly remove them. UvA-BiTS tags have been used successfully to track marine species such as gulls (Camphuysen *et al.* 2015; Thaxter *et al.* 2015), and raptors (Schlaich *et al.* 2015) and vultures (Donázar *et al.* 2015). Our study was the first to trial UvA-BiTS tags on a cockatoo. As Carnaby's Black-Cockatoos are renowned for their strong beaks and destructive feeding behaviour (Johnston 2013), we developed a means of attachment that maximised tolerance of the tag through careful positioning on the bird. This attachment method would not prevent the tag being chewed by another bird in the aviary; however, such behaviour was not observed during the project. Using tags and attachments that were dull-coloured (khaki-green or black) probably reduced any visual stimulation to investigate the tag. GPS tags attached with harnesses have been successfully used to track the New Zealand Kea, a parrot also known for being both inquisitive and destructive (Department of Conservation New Zealand 2014). The Kea nests on the ground (Kea Conservation Trust 2016) so the risk of a harness snagging on the nest is low. Radio-transmitters attached with harnesses have similarly been used to track the Kakapo *Strigops habroptila*, another ground-dwelling New Zealand parrot

(Powlesland *et al.* 1995). Carnaby's Black-Cockatoos nest in tree-hollows, with the female entering the hollow tail first (Saunders 1982), so the risk of a harness or collar snagging and endangering the bird is significant. Given the threatened status of Carnaby's Black-Cockatoo and the intention to use these tags on birds for release, the attachment method has to minimise the risk of harm to the bird. Results of our study showed no evidence of the tag interfering with the birds' ability to fly, feed or perch, and there was no effect on the skin or feathers underlying the tag. We concluded that the back-mounting technique (which, unlike a harness design, has no straps) would pose the least risk of snagging or entanglement whilst also allowing the tag to be moulted naturally with the attached feathers. No birds engaging in nesting behaviour were used in this study, so we cannot be sure that the UvA-BiTS tags will not snag on protrusions in nest-hollows. However, this is unlikely given that the tag is dorsally mounted, and the attachment is designed to enable the tag to be lost with the feathers, therefore in the event of snagging, the tag attachment would likely detach with the small feathers on the back, allowing the bird to break free. In these trials, a bird quickly removed a UvA-BiTs tag if this was irritating it. Therefore, we consider it unlikely that these tags would pose a long-term snagging risk.

Our study determined that solar-powered PTTs can be successfully attached to the dorsal aspect of the central rectrices and retained for long enough to provide useful data. Unfortunately, because of the positioning of the wings at rest, the tips of the primary feathers sat directly over the PTT solar panel, effectively blocking exposure to sunlight. As a result, the tag battery failed to recharge and stopped transmitting data. We investigated means of elevating the tag with neoprene pads to position the solar panel above the feathers, but this made the unit too bulky, unstable and potentially uncomfortable for the bird and hence was not trialled further. Thaxter *et al.* (2014) encountered similar recharging issues when trialling UvA-BiTS tags secured with leg-loop harnesses in Lesser Black-backed Gulls *Larus fuscus*. They attempted to elevate the device with neoprene pads to reduce feather overlap and improve solar exposure but, after release, no transmissions were received from the tag and, when the bird was sighted again, the tag was missing, probably lost soon after release of the bird (Thaxter *et al.* 2014). This is further evidence to support the use of back-mounted solar-powered tags.

Battery-powered PTTs attached ventrally to the central rectrices proved to be well tolerated by black-cockatoos, with one tag staying in place for 259 days before being moulted out, still securely attached to the central rectrices (Figure 4). This period exceeded the expected battery life for the tag. Aviary trials in 2013 (Yeap unpubl. data) using dummy Telonics TAV2617 tags on Carnaby's Black-Cockatoos had retention times of up to 274 days and, when tags were retrieved intact, they appeared to have been moulted out still attached to both central rectrices. This previous study showed that the central rectrices tend to moult out simultaneously, and we did not observe partially attached tags because of birds moulting out only one central rectrix. It was noted in the current study that when a tag was attached to only rectrix (only one central rectrix erupted at the time of this study), the tag sat unevenly and was removed by the bird after 3 days. The extra movement was clearly an irritant to the bird, and it is recommended that tail-tags are always attached to two central rectrices. It is interesting to note that, in the present study, both Carnaby's Black-Cockatoos retained the tail-mounted Telonics tags for >200 days, compared with a maximum of 44 days for the Forest Red-tailed Black-Cockatoos. Whether this apparent difference in tolerance reflects a difference between species or between individual birds is still to be determined. The not-for-release education birds used in the trials were habituated to regular interaction with humans, hence their behaviour towards the tags may not be indicative of behaviour in wild birds. Wild birds spend more time flying and foraging to meet their basic requirements, therefore would likely have less time available to investigate the tags attached to them.

Overall, the tags that we investigated in this study were well tolerated by the birds, and retention times exceeded expectations. Six of the seven birds were fitted with both UvA-BiTS GPS and tail-mounted PTT tags. Two birds retained both tags for 12 days, the remaining birds retained them for shorter periods. In the case of 'Harmony' and 'Chasey', the UvA-BiTS tags were removed manually when the tag partially detached, to preserve the units for future trials. In most other cases, there were underlying reasons for detachment of one or both tags. In the case of 'Denmark', the Microwave Telemetry tail-mounted tag could not be attached to two central rectrices, as one was missing at the time of the study; accordingly, the tag appeared to sit in a lopsided manner. As previously noted, the antennae of the Microwave Telemetry tags sat at an angle of 45º; we suspect that this combination of factors probably played a role in the relatively short retention time for this unit. Irrespective of this, it is unlikely that the solar dorsal tail-mount would have been effective, as again there was significant overlap of the wings across the solar panel. In the case of Forest Red-tailed Black-Cockatoo 'Squeak', the UvA-BiTS tag was chewed off in the post-anaesthetic recovery period, which highlights the need to closely monitor birds during recovery (distracting them if necessary) to ensure that the tags are not removed prematurely.

When black-cockatoos were fitted with two live tags, there was no evidence of interference with the transmissions from these. In all cases, the Telonics tags functioned normally and transmitted data according to their programming whilst UvA-BiTS tags were in place. Similarly, data were downloaded normally from the UvA-BiTS tags whilst the Telonics tags were active. In the case where the UvA-BiTS was combined with a Microwave Telemetry solar PTT, the latter tag failed to function because of inadequate solar recharging, so we cannot comment conclusively on interference between the devices.

Although all measures were taken to ensure that tags were securely attached to the birds, the attachments were designed (and tested) to ensure that the tags could be moulted out naturally with the feathers on the body or tail, or removed physically by breaking the mounts (braid ties). Black-cockatoos are thought to have a 1–2-year moult cycle (Cameron 2007), so it is unlikely that a tag would remain on a bird for longer than this.

By successfully developing an effective attachment method for the back-mounted UvA-BiTS tags and trialling the concurrent use of GPS and satellite tags on captive birds, we have validated this tracking system for future use in wild birds. Tracking data will provide information at both an individual and population level, and will mark a major advance in our ability to understand the spatial and movement ecology of these black-cockatoo species, and significantly enhance our capacity to address the aims of the species' Recovery Plans. Although this study focused on black-cockatoos, this attachment method could readily be applied to other parrots and cockatoos around the world, providing a means of increasing spatial data collection to better understand their ecology and conservation.

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