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A Method for Attaching Tracking Devices to Crocodilians

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Electronic tracking devices (VHF, satellite, GPS, etc.) are the most direct and accurate method of quantifying individual movement patterns in crocodilians (Franklin et al. 2009). The manner of attachment includes: neck collars (Joanen and McNease 1970; Taylor 1984), back harnesses (Kushlan and Mazzotti 1989), surgical implantation (Franklin et al. 2009; Hocutt et al. 1992; Magnusson and Lima 1991), ingestion (Magnusson and Lima 1991), and direct attachment to either the head, neck or tail using pins, wires or nylon line, usually inserted through holes drilled in the keeled scutes or osteoderms (Brien et al. 2008; Franklin et al. 2009; Kay 2004; Martin and da Silva 1998; Muñoz and Thorbjarnarson 2000; Read et al. 2007; Seebacher et al. 2005; Strauss et al. 2008; Webb and Messel 1978a). However, protocols for attachment often lack important details (Strauss et al. 2008), and due to difficulties with recapture, it is usually assumed rather than demonstrated that animal and tissue health at the attachment site has not been unduly compromised.

In crocodilian species and/or size classes where the nuchal rosette comprises robust, strongly keeled osteoderms (e.g., *Crocodylus porosus* > 2.5 m total length [TL]), the rosette provides a convenient point of attachment on the mid-dorsal surface of the neck, which appears to give good signal attenuation (Franklin et al. 2009; Kay 2004). Transmitters can be bedded between the keels and attached with wires laced through holes drilled through the bony keels, but this method is dependent upon the presence of well-developed keels (Franklin et al. 2009; Kay 2004). The method described here was used with large *C. porosus*, and allows transmitters to be mounted on the mid-dorsal neck and secured with wire running under the length of the nuchal rosette, without collars and without needing strong keels for attachment. It should thus be suitable for all species and size classes of crocodilians with or without strong keels. The method involves four stages: (a) positioning subcutaneous stainless steel wires under the rosette; (b) making a transmitter mounting platform that is a mold of the central length of the rosette; (c) locking the transmitter to the platform with the wires; and (d) using additional molding material to extend and shape the platform so that it forms a complete mold of the rosette on the ventral side, and a dome on the dorsal side that encases and protects the transmitter. Based on recaptures, the attachment method is considered benign with regard to animal health.

Materials and methods.—Thirty satellite transmitters were attached to 29 Saltwater Crocodiles, *Crocodylus porosus* (total lengths [TL] 250–452 cm) captured in the Northern Territory of Australia (Kakadu National Park [N = 20], Mary River [N = 6], Blyth River [N = 2], Adelaide River [N = 1]) between September 2005 and September 2008 (Table 1), and their movements monitored weekly for the duration of transmission life. Four individuals were recaptured between 383 and 1049 days after the transmitter was first attached.

Adult male *C. porosus* (> 3.1 m TL, Webb et al. 1978) were the target group (N = 26, mean = 381 ± 7.1 cm TL), but one smaller male (250 cm TL) and two females (301 cm and 313 cm TL) with reduced keel size were included. Crocodiles were mostly caught by harpoon at night (N = 15) or with baited cage traps (N = 14) (Walsh 1987; Webb and Messel 1977), and one individual (61687, 312 cm TL) was caught in a drying pond. Crocodiles were caught in or adjacent to tidal saline (N = 20, saline) and non-tidal freshwater wetlands (N = 10), and were released at the site of capture (N = 19, 63.3%) or relocated (N = 11, 36.7%) as part of a relocation experiment (Table 1). All were individually numbered by scute clipping (Richardson et al. 2002).

Three types of satellite transmitter were trialed in this study (Sirtrack: Lower Hut, New Zealand), with general specifications from Read et al. (2007). The following transmitters were used: the KiwiSat 101 platform terminal transmitter (PTT; both satellite and VHF capability, 12 cm x 3.2 cm x 2.4 cm high, 300 g, N = 10); KiwiSat 101 PTT (satellite only, 9.3 cm x 4.3 cm x 3.4 cm high, 170 g, N = 16); and the smaller KiwiSat 202 PTT (satellite only, 8.5 cm x 3.2 cm x 2.0 cm high, 100 g, N = 4). All transmitters had 1 or 2 flexible aerials (approx. 20 cm long), stainless steel attachment loops (5 mm diameter, 2–3 on each side) on the transmitter base, and a salt switch which disabled transmissions when the transmitter was under water in saline areas (Fig 1). Five transmitters had an additional haul-out switch designed to turn the transmitter off if a crocodile was either in fresh water or on land for more than a few hours (Table 1).

After capture, each crocodile was immobilized with an intramuscular injection of pancuronium bromide (Astra Zeneca: North Ryde, New South Wales, dosage rates described in Bates 2001). The nuchal rosette area was disinfected with Betadine and injected with a local anaesthetic, Xylocaine (Astra Zeneca: North Ryde, New South Wales). Two stainless steel needles (230 mm by 3 mm diameter) were forced through the skin on the posterior side of the rosette, and with the aid of pliers, run subcutaneously under the osteoderms of the rosette to the anterior side. The two needles were then drawn through carrying two strands of stainless steel wire (breaking strain 41–68 kg) that had been soaked in 100% ethanol. There were thus two sets of two stainless steel wires (each approx. 50 cm in length) protruding through the skin at the

Table 1. Attachment details and performance of 30 satellite transmitters attached to 29 *Crocodylus porosus* (27 male, 2 females*) captured in the Northern Territory of Australia, between September 2005 and September 2008. One crocodile (61688^) was recaptured after 1049 days and attached with a new transmitter (34011^). First five transmitters contained haul-out switches. Transmitters 34008, 34010 and 34011 were still active at the time of writing (13 May 2009).

Crocodile Transmitter #	Total Length (m)	River system capture location	Relocated (Yes/No)	Release site habitat	Attachment date	Longevity (days)	Satellite transmitter model (KiwiSat)
60683	3.67	Mary	N	Tidal	12-Sep-05	164	101 (includes VHF)
60682	3.85	Mary	Y	Tidal	12-Sep-05	388	101 (includes VHF)
60684	3.99	Mary	N	Tidal	13-Sep-05	76	101 (includes VHF)
60689	4.38	South Alligator, Kakadu	N	Non-tidal	14-Sep-05	0	101 (includes VHF)
60690	3.55	South Alligator, Kakadu	N	Tidal	16-Sep-05	308	101 (includes VHF)
61682*	3.13	South Alligator, Kakadu	N	Non-tidal	04-Oct-05	279	101
61685	4.52	South Alligator, Kakadu	N	Non-tidal	04-Oct-05	1162	101
61681	3.82	South Alligator, Kakadu	N	Non-tidal	06-Oct-05	883	101
61684	4.11	South Alligator, Kakadu	N	Non-tidal	07-Oct-05	1169	101
60687	3.87	South Alligator, Kakadu	N	Non-tidal	24-Oct-05	744	101 (includes VHF)
61687	3.12	South Alligator, Kakadu	Y	Tidal	26-Oct-05	660	101
60685	3.98	Mary	Y	Tidal	02-Nov-05	49	101 (includes VHF)
61679	3.67	Mary	Y	Tidal	02-Nov-05	384	101
60686	3.81	Blyth	Y	Tidal	05-Nov-05	464	101 (includes VHF)
61678	3.03	Blyth	Y	Tidal	05-Nov-05	772	101
60688	3.94	South Alligator, Kakadu	N	Non-tidal	11-Nov-05	60	101 (includes VHF)
61688^	4.21	Mary, Kakadu	N	Non-tidal	14-Nov-05	368	101
61683	2.50	South Alligator, Kakadu	N	Non-tidal	22-Nov-05	1209	101
61686	3.71	South Alligator, Kakadu	N	Tidal	08-Dec-05	1172	101
60681	4.00	South Alligator, Kakadu	N	Tidal	07-Feb-06	4	101 (includes VHF)
68553*	3.01	Adelaide	N	Tidal	27-Jul-06	819	101
61680	3.80	East Alligator, Kakadu	Y	Tidal	14-Oct-06	16	101
68551	4.02	Mary	Y	Tidal	26-Oct-06	244	101
68550	3.33	Kapalga Causeway, Kakadu	Y	Tidal	01-Feb-07	240	101
68548	3.75	Kapalga Causeway, Kakadu	Y	Tidal	01-Feb-07	660	101
68549	3.21	King River, Kakadu	Y	Tidal	04-Aug-07	268	101
34008	3.57	Magela Ck, Kakadu	N	Tidal	03-Apr-08	404	202
34009	4.00	East Alligator, Kakadu	N	Tidal	06-May-08	328	202
34010	4.23	East Alligator, Kakadu	N	Tidal	16-May-08	360	202
34011^	4.23	Mary, Kakadu	N	Non-tidal	29-Sep-08	224	202

FIG. 1. Four strands of stainless steel wire threaded subcutaneously under the nuchal rosette of a 4.21 m TL Estuarine Crocodile (*Crocodylus porosus*) used to anchor the transmitter in place. KiwiSat 202 Platform Terminal Transmitter (PTT) placed in the middle of the four nuchal scutes with attachment loops angled outward and antennae pointed towards tail. Photo by G. Lindner.

anterior and posterior ends of the rosette (Fig 1).

The mold was constructed in two parts. First, a bed of marine epoxy ("Selleys Knead-it Aqua" with limited exothermic reaction) the width of the transmitter was made along the top of the rosette. The transmitter was positioned on this bed with the aerial/s posterior. Each of the subcutaneous wires was then threaded back through the attachment loops on both sides of the transmitter, tightened and crimped with aluminum or lead sleeves that locked the anterior and posterior wires together. Additional epoxy was then used to complete the mold of the rosette, maximizing the surface area of contact between the rosette and the mold, with the upper surface shaped into a dome encasing the transmitter (Fig. 2). Two openings were left in the mold to ensure the two terminals of the salt switch were exposed. In most cases the mold was sprayed with black paint after the epoxy had hardened and prior to release of the crocodile.

The mass (in air) of the transmitter plus mold was: KiwiSat 101 PTT unit (satellite and VHF) 500–520 g; KiwiSat 101 PTT (satellite only) 350–370 g; and KiwiSat 202 PTT (satellite only) 220–250 g. Given the smallest crocodile in this study was 250 cm TL (approximately 52 kg, Webb and Messel 1978b) and the largest was 451 cm TL (approximately 355 kg, Webb and Messel 1978b), transmitter units were 0.1 to 0.7% of body mass, and thus well within recommended limits of 3–5% of body mass (Kenward 2001). The time required to fit a transmitter declined from 45 to 30 minutes with experience.

Results.—The overall mean transmission life was estimated at 463 ± 69 days (N = 30, range 0–1209 days, Table 1), with 67.8% (N = 18) lasting more than 308 days and 14.3% (N = 4) exceeding 1162 days. As the actual time a transmitter remains attached to a crocodile is difficult to determine due to difficulties in recapturing individuals, transmission life was used as a minimum index of attachment life, as a transmitter with an expired battery can remain attached. Transmission life did not differ significantly (t = 1.09, df = 28, P > 0.284) between relocated crocodiles (376.82 ± 247.02 days) and those released at the site of capture (512.26 ± 432.38 days). Three transmitters ceased transmitting within 16 days, one of which failed because it had a salt and haul-out switch that interacted technically to switch the transmitter off permanently in fresh water. The failure of the other two transmitters could have been due to the haul-out switch turning off the transmitter if the crocodiles entered fresh water and did not return to salt water, which would be required to re-activate the transmitter.

Of the remaining 27, a further three stopped transmitting between 49 and 76 days, one of which also had the salt switch and haul-out switch anomaly. It indicates a maximum failure rate of 20%, two of which were due to electronic failure. As a detached transmitter will not transmit under water, attachment failure could be responsible for the other four transmitters (13.3%), although it could equally be due to interference with transmissions when crocodiles moved into heavily vegetated swamps under a closed tree canopy.

One crocodile was recaptured after 1049 days with the transmitter missing (368 days of transmission). There was no sign of necrosis, subcutaneous wires, or any damage to the nuchal rosette. It appeared that the subcutaneous wires had pulled through when the transmitter and mold detached, which likely resulted due to failure of the crimped sleeves. The crocodile appeared healthy (large fat deposits in neck and base of tail), and fresh injuries noted when it was originally caught had healed. It was refitted with a new transmitter (34011) that was still transmitting after 224 days (13 April 2009).

Three *C. porosus* were recaptured with transmitters still attached after 383 days (60687, re-caught 11 November 2006), 424 days (60689, re-caught 12 November 2006), and 951 days (61683, re-caught 30 June 2008). When the transmitters were removed, there was no sign of infection, tissue necrosis or damage to the skin or tissues of the rosette. One of these individuals (61683, 951 days) had grown 60.5 cm TL between captures, with the nuchal plate growing out and around the site where the wires entered the skin. This crocodile was the smallest (250 cm TL) in the study and was released *in situ* with transmitter still attached. Of the remaining

FIG. 2. Satellite transmitter attached to the nuchal rosette of a 4.23-m TL Estuarine Crocodile (*Crocodylus porosus*). Stainless steel wires threaded beneath the nuchal rosette were used to anchor the transmitter in place and marine epoxy was moulded to the crocodile to secure the entire unit in place. Photo by G. Lindner.

two, the mold was undamaged in one (383 days), but broken away on the edges in the other (424 days). In the latter case salt had been mixed with the epoxy on the untested assumption that it would counter the haul out switch at the time of mounting; it may well have weakened the epoxy material. In none of the recovered transmitters were there any teeth marks or damage consistent with attacks on the neck region by conspecifics.

Discussion.—Our study reaffirms that the nuchal rosette is a good site for attaching transmitters to crocodilians, and that use of a mold held in place with subcutaneous wires is an effective method of attachment, with apparently limited adverse effects on the animals, that is well suited to long-term movement studies. In cases where young animals may be growing rapidly, and transmissions are only required for a short period of time, it would be possible to use some form of temporary erodible pin to release one end of the transmitter after a known time (Goodyear 1993) so that it can pull the wires through the skin. In terms of physical dimensions, the height of the mold on the neck is set by the height of the transmitter being attached, and thus it would appear that the lower the profile of the transmitters, the shorter the mold dome on the top of the neck. In our study, the height and robustness of the keels of individual crocodiles was largely irrelevant to the attachment process, making us confident that it can be used with crocodilian species that are not strongly keeled. Indeed, the whole concept of mounting an object on the rosette, using a mold with subcutaneous wires, was pioneered by the authors (GW, CM, DO) in conjunction with Cooper-Preston (1991), when she successfully mounted visual numbered tags on *C. johnstoni* (1.3–1.8 m long; N = 18), which have limited keeling. Recaptures < 2 years later had indicated no ill effects and several individuals were observed with numbered ID tags after 4 years (Cooper-Preston, pers. comm.). We are confident the method can be adapted for attaching electronic devices (VHF, GPS, satellite) to all crocodilians, given that the size of devices is appropriately scaled to animal size.

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