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Remote monitoring of crocodilians: implantation, attachment and release methods for transmitters and data-loggers

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Abstract. Crocodilians are by their very nature difficult animals to study. However, research on wild animals is essential for the development of reliable long-term management. Here, we describe methods for the acquisition and monitoring of behavioural and physiological variables from free-ranging crocodilians through the use of archival tags (data-loggers) and via satellite, radio and acoustic telemetry. Specifically, the attachment or implantation of electronic tags is described and examples provided of the type of data that can be collected. Our research group has used a combination of approaches to monitor the movements, diving activity, body temperatures and heart rates of crocodilians, including studies on the Australian freshwater crocodile (*Crocodylus johnstoni*), the estuarine crocodile (*Crocodylus porosus*) and the caiman (*Caiman latirostris*). Each approach or method presents unique challenges and problems, chiefly as a consequence of differences in body morphology and size of the crocodilian species, their behaviours and the habitats they occupy.

Additional keywords: alligators, archival tags, crocodiles, reptiles, satellite, telemetry.

Introduction

The ongoing advancement and miniaturisation of electronic tagging technology has provided the means to effectively study animals in the wild without disturbance. This offers major benefits in better understanding the ecological role of key animal species through the monitoring of natural behaviours and movement patterns (Wilson *et al*. 2007). Furthermore, physiological function can be assessed, such as body temperature, heart rate, muscle activity and feeding, thereby providing the potential to model the energy requirements of free-ranging individuals (Axelsson *et al*. 2007).

The use of remote monitoring technology (wildlife biotelemetry) especially comes to the fore when species are easily disturbed, difficult to observe in the wild and have the potential to move significant distances. Crocodilians typify these characteristics, being cryptic and shy semi-aquatic animals that live in habitats that are often inaccessible, and can spend considerable periods submerged and out of sight. Moreover, they can cover large distances in surprisingly short periods of time (Kay 2004*a*; Seebacher *et al*. 2005; Read *et al*. 2007). A range of different types of remote monitoring devices are now available that differ in the type of data they collect and the means by which they store and transmit this data. This includes the relay of data by VHF radio, acoustic or satellite transmission and the collection of biological data from location fixes. Telemetric studies on crocodilians have provided significant advances in our understanding of these easily disturbed animals (Joanen and McNease 1970, 1972; Goodwin and Marion 1979; Rodda 1984*a*, 1984*b*; Hutton 1989; Hocutt *et al*. 1992; Seebacher 1999; Seebacher *et al*. 2003, 2005; Kay 2004*a*, 2004*b*; Campos *et al*. 2006; Read *et al*. 2007; Brien *et al*. 2008). Radio-telemetry has been most widely used to track the movement patterns of crocodilians, including American alligators, estuarine crocodiles and caiman, but also to record body temperatures and heart rates from free-ranging animals (Rodda 1984*a*; Hutton 1989; Munoz and Thorbjarnarson 2000; Kay 2004*a*; Seebacher *et al*. 2005; Brien *et al.* 2008).

Although radio-telemetry has been proven to be effective over small to mid-spatial scales, satellite technology has been shown to be useful in documenting the large spatial movements and activities of estuarine crocodiles, especially in the marine environment, where VHF signals are greatly attenuated and distances to be covered can be large (Read *et al*. 2007). The disadvantage with satellite telemetry, however, is the cost of the transmitters and subsequent satellite time. Acoustic (ultrasonic) telemetry using fixed receiver stations has the potential to be extremely useful in monitoring crocodiles because signal transmission occurs through water and transmission operates irrespective of salinity

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(C. E. Franklin, unpubl. data). Here, the opportunity exists to conduct long-term studies because acoustic transmitters can be programmed to have a lifespan of greater than 10 years. Finally, archival tags (data-loggers) have been used to record diving behaviours, fine-scale movement patterns and heart rates of crocodilians (Seebacher *et al*. 2005; see below). Using this type of technology, large volumes of data can be stored within these tags and downloaded at a later time.

The remote monitoring of crocodilians presents several technical challenges and difficulties. First, the type of device to be employed needs to be decided on and this is chiefly dictated by the scientific questions being asked and the information or data that need to be collected. Each type of remote sensing device comes with advantages and disadvantages in terms of the type of data that can be collected and how it is either stored and/or transmitted. Second, battery power of the unit will make up a significant portion of the device's overall mass, and the trade-off between power, longevity and frequency of transmission needs to be given careful consideration. Third, animal capture and restraint, method of device attachment or implantation and the effective monitoring of animals after release are all factors that need to be meticulously assessed and determined before deployment. Here, we illustrate and describe a range of telemetry techniques employed successfully by our research group on crocodilians, which has provided valuable insight into the ecology of this enigmatic group of animals.

Archival tags (data-loggers)

Archival tags provide the opportunity to remotely collect large quantities of behavioural and physiological data *in vivo* from animals at high sampling frequencies. It is now possible to store more than four gigabytes of data and sample at frequencies greater than 500 Hz. For studies on crocodilians, archival tags are particularly useful in recording diving behaviour, fine-scale movements and heart rate.

The greatest challenge in using archival tags is retrieving them because data are stored on the device. For crocodilians, this can be highly problematic since they tend to be extremely wary of humans after initial capture and actively avoid recapture. To maximise the chance of retrieving the archival tags, radio-telemetry and/or acoustic telemetry is utilised to either locate the animal or alternatively the archival tag, which may have been inadvertently dislodged from the animal or jettisoned off by a time-release mechanism. In designing and building the package to be attached to the animal, it may therefore be important to incorporate radio and/or acoustic transmitters and to have adequate flotation, thereby maximising the chance of retrieving the data pack. We have outlined below three examples where we have used data-loggers to monitor the activities and physiology of crocodilians.

Case example 1. Recording diving behaviour in freshwater crocodiles

The diving behaviours of freshwater crocodiles, *Crocodylus johnstoni* (Krefft, 1873), were recorded in isolated waterholes in Far North Queensland. Time–depth recorders (Lotek Marine Technologies, St John's, Canada and Star-Oddi, Reykjavik, Iceland) were used to record diving events and were capable of detecting changes in water depth of ~4–6 cm and storing

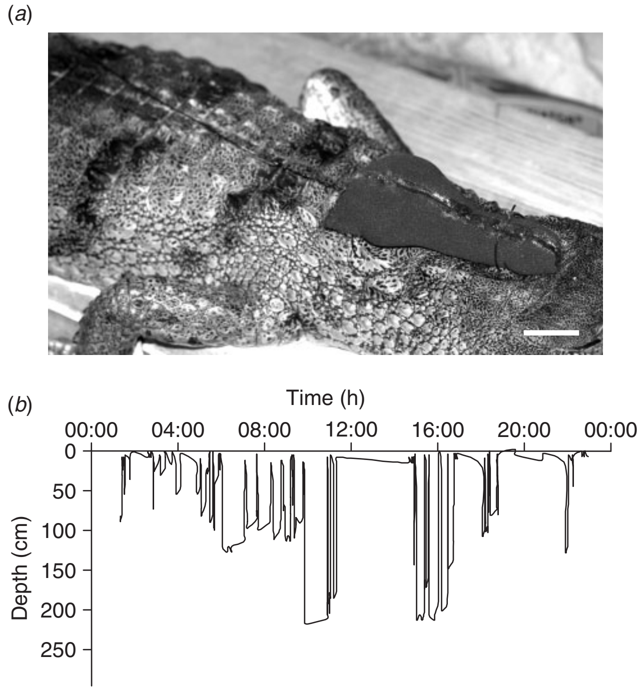

Fig. 1. (*a*) Freshwater crocodile (*Crocodylus johnstoni*) with an archival temperature and depth recorder (TDR) and VHF transmitter attached to the nuchal scutes. The tag and transmitter were encased in a neoprene sleeve that incorporated a polystyrene float. Scale bar = 1 cm. (*b*) Example of dive profile over 24 h from the TDR. Depth was recorded every 4 s.

2–3 weeks of data, sampling water depth every 4 to 9 s (Fig. 1*a*, *b*). The sampling frequency, however, can be increased (e.g. 20–30 s) to extend the duration of deployment to several months or longer. The data package attached to *C. johnstoni* comprised the cylindrical time–depth recorder (~60 mm long and 16 mm diameter), a VHF radio-transmitter (SirTrack, Havelock North, NZ) and a polystyrene float. These components were encased in a sleeve of neoprene (Fig. 1*a*) and weighted so that if the package was dislodged from the crocodile, it would float with the VHF aerial sitting upright and above the water surface, allowing easy detection. Two strands of plastic-coated stainless steel wire were threaded through the neoprene and around the logger or transmitter and these were used to secure the device to the animal.

Attachment and retrieval

C. johnstoni individuals ranging in body size between 5 and 25 kg were captured with nets and placed into Hessian sacks. Crocodiles were restrained with non-stretch cloth tape onto a wooden board and blind-folded to minimise stress. A local anaesthetic (lignocaine, Troy laboratories, Smithfield, Australia, 20 mg mL^{-1} with adrenaline 1 part per 100 000) was administered to the nuchal shield using a 23-gauge needle and syringe. The anaesthetic was allowed to take effect (~5 min) and 1.5-mm holes were drilled through the centre of four of the scutes to align with the wires from the data package. The wires were threaded through the holes in a manner that minimised any loops of wire being exposed to avoid the telemetry package being snagged (Fig. 1*a*). This often meant crossing the wires over and under the data-logger. The wires were then secured with crimp sleeves. The position of the time–depth recorder on the crocodile's nuchal shield was advantageous because when the animal was at the surface, the logger was always above the water surface, allowing a zero pressure recording.

Once fitted, the crocodiles were released at the site of capture and dive recordings were made for 5–20 days. Retrieval of the data packages was achieved by locating the animals via the radio-transmitters, capturing them in set nets and removing the data-loggers. Some animals proved to be highly skilled at evading recapture and greater than 8 hours have been required to recapture a single animal that remained in a 20–30 m^2 region of the waterhole. Despite this, our approach has proven to be a highly successful means to record dive behaviour in freshwater crocodiles, with the success rate of retrieving data-loggers ($n = 10$) from three field trips ranging between 70 and 100%. Fig. 1*b* shows a representative output from a time–depth recorder attached to a freshwater crocodile.

Case example 2. Recording heart rate in caiman

Heart rate was recorded from juvenile caiman, *Caiman latirostris* (Daudin, 1802) (∼1300 g). The study was undertaken at the University of Sao Paulo State University, SP, Brazil, where the animals were housed in large semi-natural enclosures, with native vegetation, large swimming pools and basking platforms (details in Micheli and Campbell 2008). A miniature electronic microprocessor-controlled data-logger, capable of making high-resolution electrocardiogram (ECG) recordings (512 Hz), was used to record heart rate. The data-logger was housed within a PVC tube (Fig. 2a) that was sealed by a double O-ring and silicon sealer.

Attachment

To attach the data-logger, caiman were restrained and a local anaesthetic (Lignocaine, Injetva, Sao Paulo, Brazil) was injected subcutaneously on the dorsal surface and between the ventral plates, in the areas of data-logger and electrode attachment. A rubber saddle was attached to the dorsal surface with nylon T-bar anchor tags (FD-64, Floy tag, Seattle, WA) inserted between the dorsal plates using a purpose-designed tagging gun (Floy). Crimp sleeves secured the rubber saddle to the caiman's body, and miniature cable ties secured the data-logger to the saddle. The ECG recording electrodes (7-strand Teflon-coated wire, 0.2 D, 40 L mm, A-M Systems, Sequim, WA, USA) exited the top of the logger housing and were secured by a single suture to each flank behind the front limbs. The exposed ends of the electrodes were hooked into the end of a 24-gauge hypodermic needle and pushed through the thinner skin immediately dorsal of the chest plates and lateral to the end of the pectoral girdle. The needle was advanced 2 cm towards the centre of the animal, keeping the end of the needle close to the ventral surface. The needle was withdrawn and each electrode left in the desired position. A drop of flexible rubber adhesive was placed on the electrode wound entry point to seal and secure its position. Using this setup, heart rate could be monitored for up to 14 days. Fig. 2*b* provides an example of the output from the heart-rate logger that was monitoring a 1.2-kg caiman.

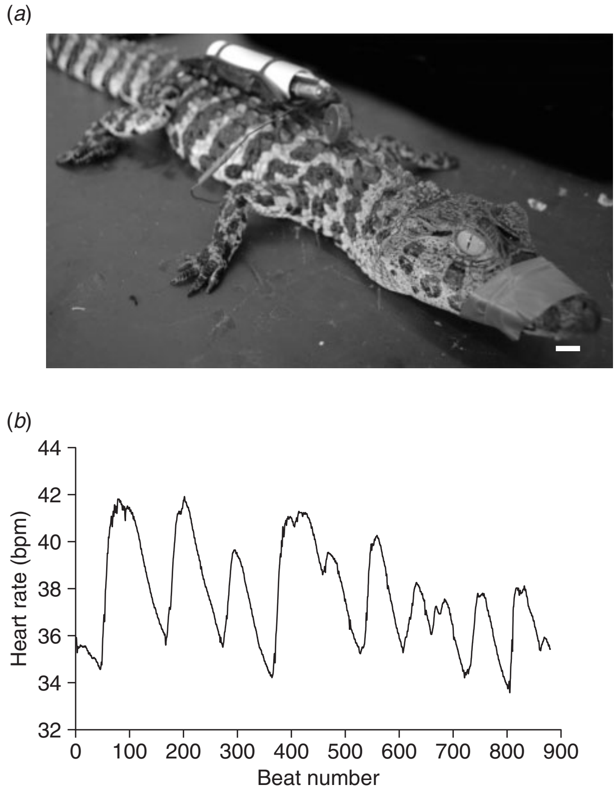

Fig. 2. (*a*) Heart rate data-logger attached to the dorsal surface of a caiman (*Caiman latirostris*). A rubber saddle was attached to the dorsal plates with nylon T-bar anchor tags and the logger could be easily removed and replaced within the saddle. Scale bar = 1 cm. (*b*) Instantaneous heart rate (*f*H) data from an archival tag attached to a free-ranging caiman. bpm = beats per minute.

Case example 3. Monitoring the movements of estuarine crocodiles in three dimensions

The diving behaviours and fine-scale movement patterns of large estuarine crocodiles, *Crocodylus porosus* (Schneider, 1801), were recorded in the North Kennedy River (14.606°S, 144.059°E), Lakefield National Park, Queensland. The North Kennedy is a large, tidal river system, extending >60 km inland and ranging in salinity from fresh water to full-strength seawater (salinity = 33). Multi-channel, custom-built data-loggers that incorporated a 3-dimensional accelerometer, compass, speed paddle, pressure (depth) sensor and ambient and body temperature sensors were deployed on 18 animals and recordings were made for between 3 and 16 days. A 4-gigabyte storage card allowed sampling frequencies to be set between 1 and 64 Hz. The electronics were housed in a water-tight acrylic resin capsule, which was in turn encased within a custom-built shell that was highly buoyant (Figs 3, 4). The outer shell was made from Q-CEL 7014 inorganic, hollow microspheres (PQ Australia Pty Ltd, Dandenong South, Victoria) mixed with a two-part urethane (BJB Enterprises (Trustin, CA, USA) WC-782 A/B), which was poured and set within a silicon mould. Also included within the microsphere–urethane casing were an acoustic transmitter (Vemco, Halifax, Canada, V16) and a VHF radio-transmitter. In water, the data and telemetric package was weighted such that

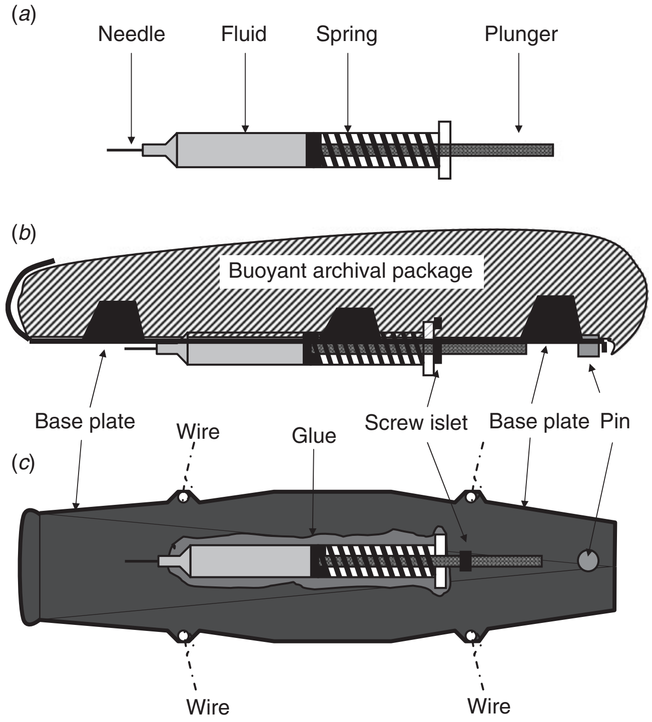

Fig. 3. Semi-schematic diagrams of self-releasing archival package. (*a*) Spring-loaded syringe filled with viscous fluid. (*b*) Lateral view of archival package, showing position of base plate and syringe. (*c*) Underside view of aluminium base plate and syringe. Wires were used to anchor the base plate to the nuchal scutes of the crocodile.

it floated upright, with the acoustic transmitter submerged and the aerial from the radio-transmitter extending above the water's surface.

Attachment and retrieval

One of the more significant challenges in deploying archival tags on estuarine crocodiles is retrieving the tag intact to allow the stored data to be successfully downloaded. The likelihood of recapturing estuarine crocodiles is low, so a timed-release mechanism needs to be employed to jettison the data pack off the crocodile after a set time. We conducted a pilot study where we used galvanic timed-release links (International Fish Device Inc, Waipu, New Zealand). However, these proved unreliable as a consequence of variation in the salinity of water in the North Kennedy River and the time crocodiles spent out of water, basking or resting on river banks. Once crocodiles moved into fresh water or onto land, the corrosion rate of the links was reduced, which greatly extended the time the archival tag remained on the crocodile. This made it impossible to predict the time of release. To address this problem, we designed a self-release mechanism using a fluid-filled, spring-loaded syringe and hypodermic needle (Figs 3*a*–*c*, 4*a*). This proved to be inexpensive to build and could be set to release the archival tag for deployment periods of days to weeks. The principle behind this time-release mechanism is that the spring-loaded syringe slowly advances the plunger and once the plunger moves past an islet on the flotation casing, the unit detaches from the aluminium base plate (Figs 3, 4). The base plate remains on the crocodile and corrodes off with time (as the crimps dissolve). The jettisoned unit is retrieved by locating it using radio and acoustic telemetry. The timing of the release can be controlled via four different parameters: the amount of fluid in the syringe; the type of fluid (i.e. viscosity); the gauge (size) of the needle; and the strength of the spring. The maximum time between activation and release was ~3 weeks. In our study, we used golden syrup for the fluid, a crimped 32-gauge needle and a 10-N spring. The base plate consisted of an aluminium plate with three recesses: one for a syringe; another to fit the islet screw through the plate; and the third to fix the pin that held the tracking device onto the plate (Fig. 3*b*, *c*). A high-density foam mat was glued to the aluminium base plate and provided cushioning against the skin of the crocodile when attached.

The data-logging units were positioned between the four largest scutes of the nuchal shield of the estuarine crocodile (Fig. 4*b*, *c*). The general area around the scutes was cleaned with a chlorhexidine scrub and rinsed with 70% ethanol. The area was anaesthetised using multiple subcutaneous injections of a local anaesthetic (lignocaine hydrochloride at 2 mg mL^{-1}), and single holes (1.5-mm diameter) were then drilled through each of the scutes using a battery-powered drill. The aluminium plate was the point of unit attachment to the crocodile and was secured with four stainless steel wires, which were threaded through the four nuchal scutes of the crocodile and then fastened with lead crimps. When the package was affixed, the spring-loaded syringe was activated and the crocodile was released. A representative output from the multi-channel data-logger is shown in Fig. 5. Fig. 5 shows changes in water depth, together with relative roll, pitch and sway of a 2.7-m female estuarine crocodile that undertook a short dive along the river bed.

Radio-telemetry

Radio-telemetry has been the most commonly used remote sensing method to record the movements of crocodilians. Transmitter attachment and deployment have been previously described (Goodwin and Marion 1979; Rodda 1984*a*; Hutton 1989; Kay 2004*a*, 2004*b*; Campos *et al*. 2005; Brien *et al.* 2008) and where positional fixes of crocodiles are required, the nuchal shield has been predominantly used as the site for transmitter attachment. Measuring the body temperature of crocodiles via radio-telemetry requires the transmitters to be located internally, which has been achieved by ingestion of radio-transmitters that act as pseudogastroliths (Grigg *et al*. 1998) or by surgical implantation into the peritoneal cavity (Seebacher and Grigg 1997; Seebacher 1999). In fish, surgical implantation is a well recognised method for the attachment of radio-transmitters, with the success of implantation and retention of the tags being dependent on several factors including surgical procedure, site of the incision, body morphology and environmental conditions (Jepsen *et al*. 2002). Similar factors need to be considered for implantation of transmitters in crocodilians. In a recent paper, Axelsson *et al*. (2007) described the use of a fully implantable, multichannel radio-telemetry system used to measure blood flow and pressure, ECG and body temperature in American alligators. Although used only on captive alligators, the potential for this technology to be used in field-based studies presents some exciting opportunities for the future.

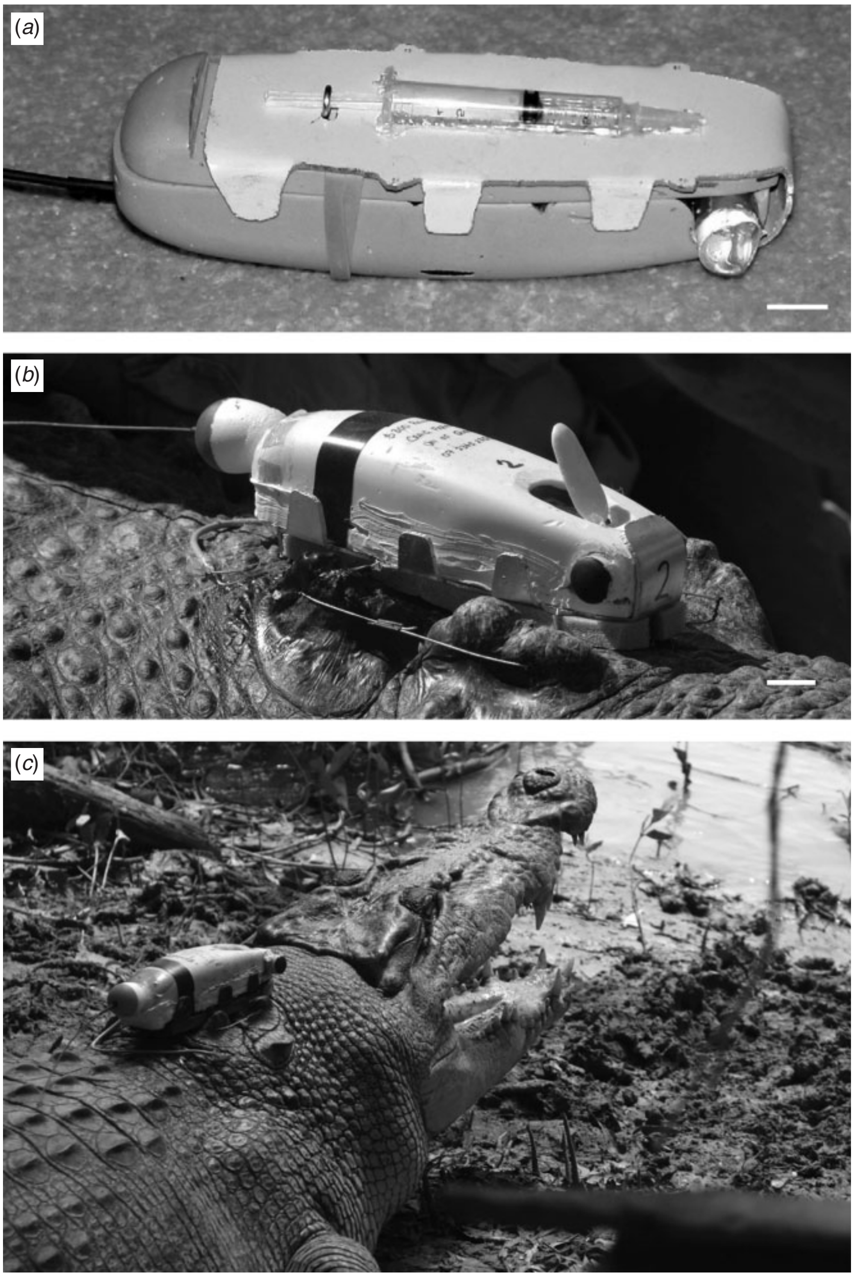

Fig. 4. Self-releasing and floating archival package attached to an estuarine crocodile (*Crocodylus porosus*). (*a*) Underside of the archival package showing base plate and syringe. Scale bar = 1 cm. (*b*) Close-up view of tag attachment to the nuchal scutes. Scale bar = 1 cm. (*c*) Release of estuarine crocodile with a self releasing archival package attached.

Case example. Continuous recording of body temperature of freshwater crocodiles

Continuous recordings of body temperatures were made from 10 freshwater crocodiles located within Rocky Creek (15.189°S, 144.342°E), Lakefield National Park over 4 weeks in July 2007. SirTrack radio-transmitters were surgically implanted into the peritoneal cavity to record core body temperature using an approach similar to that used by Seebacher (1999) and Seebacher *et al*. (2005). Surgery on *C. johnstoni* was performed under aseptic conditions and with full anaesthesia. We used Alfaxan CD-RTU (Jurox, Auckland) (10 mg mL^{-1} alfaxalone at 4 mg kg^{-1} body mass), which was injected intravenously via the cervical sinus. At this dose rate, the duration of anaesthesia lasted 40–60 min for a 5–10-kg animal, which was adequate time for implantation. Crocodiles were intubated (3-mm diameter tube) and hand-ventilated at 2–3 breaths min^{-1} using an ambi-bag. To implant the transmitter, a small incision was made on the flank of the abdomen, just posterior to the right hindlimb. The muscle

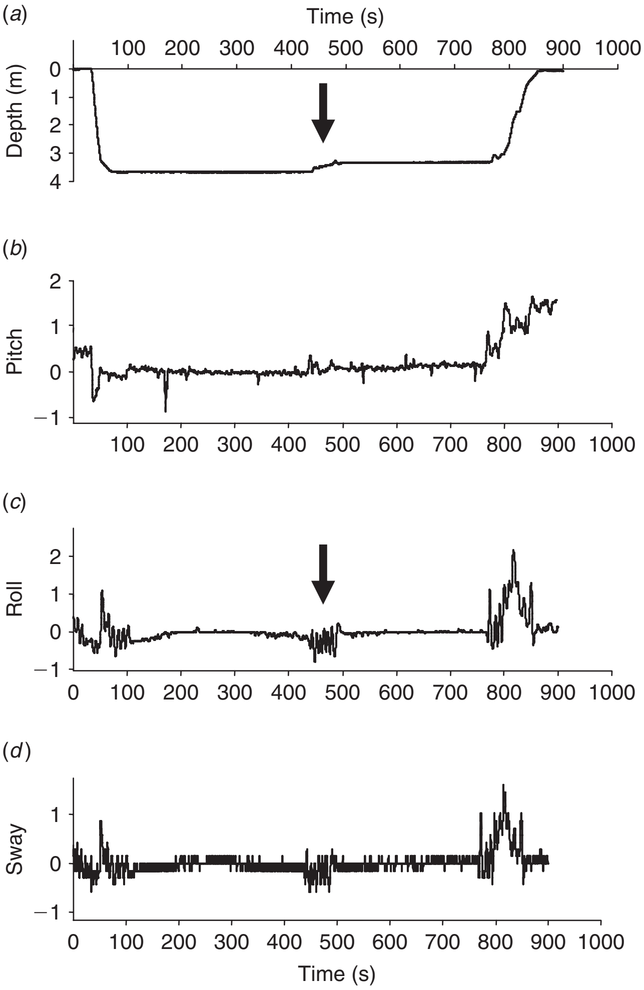

Fig. 5. Recordings of (*a*) water depth, (*b*) relative pitch, (*c*) roll and (*d*) sway during a dive by a 3-m female estuarine crocodile (*Crocodylus porosus*). Pitch, roll and sway were calculated from the output of a 3-dimensional accelerometer. The arrow indicates swimming underwater by the crocodile along the bottom of the creek bed.

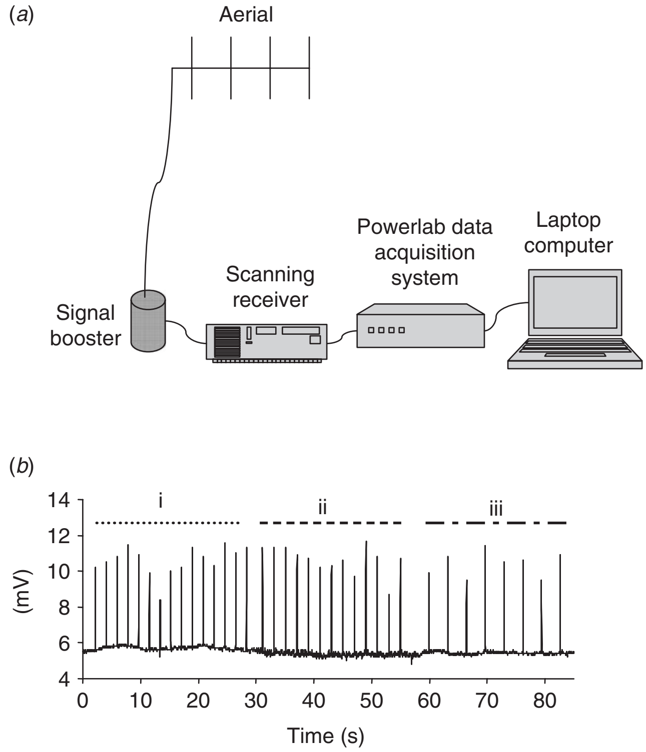

Fig. 6. (*a*) Schematic drawing of the field base-station for continuous and simultaneous recording of heart rate and body temperature from up to 10 freshwater crocodiles (*Crocodylus johnstoni*) implanted with radio-transmitters. (*b*) Trace of a Powerlab recording at 100 Hz of the body temperatures of three crocodiles (i, ii and iii). The radio receiver was set up to scan all transmitter frequencies. Each peak on the trace corresponds to a pulse transmitted by the temperature sensitive transmitters and the time interval between each pulse is closely correlated with body temperature of the crocodile.

layers beneath the skin were carefully separated to reveal the peritoneal lining. With haemostats securing the peritoneal lining, an opening was made and the transmitter was inserted in the abdominal cavity. Dissolvable sutures (Dexon or Maxon 4–0, D & G Monofil Inc, Manati, PA, USA) were used to close the peritoneal lining and muscle layers. The skin was closed with silk sutures (Ethicon 2–0, Somerville, NJ, USA) and the wound sprayed with Terramycin aerosol (oxytetracyline hydrochloride, Pfizer, West Ryde, Australia). Crocodiles were allowed to recover fully from anaesthesia (overnight) and then released at the site of capture.

Continuous recording system

Freshwater crocodiles are easily disturbed by human presence, so we utilised an automatic and continuous recording station (Fig. 6*a*), positioned at least 100 m from the waterhole to simultaneously monitor up to 10 individuals. The radio signals from the temperature-sensitive transmitters were received by a four-piece YAGI aerial, mounted 25 m directly above the waterhole that the crocodiles inhabited. A coaxial shielded cable from the aerial delivered signals to the base receiving station, which was positioned out of line of sight from the waterhole. A 12-V battery-powered aerial booster (Titley Electronics, Ballina, Australia) connected inline with the coaxial cable helped to reduce signal decay along the length of the coaxial cable. The cable was connected to a scanning radio-receiver that was able to sequentially record the pulses emitted from the temperature-sensitive transmitters from the 10 animals. The signal from the radio-receiver was directed to a Powerlab (ADInstruments, Sydney, Australia), which was in turn connected to a laptop computer running Chart 5.1 software (ADInstruments). This data-acquisition system allowed the output from the receiver to be sampled at 100 Hz and to continuously record and store data from the 10 animals simultaneously for several weeks. We backed up the data stored on the computer daily. Fig. 6*b* shows the output from Chart software from three crocodiles fitted with temperature-sensitive transmitters.

Satellite telemetry

Satellite telemetry has been effectively used to study the movement patterns and activities of a wide range of species, including

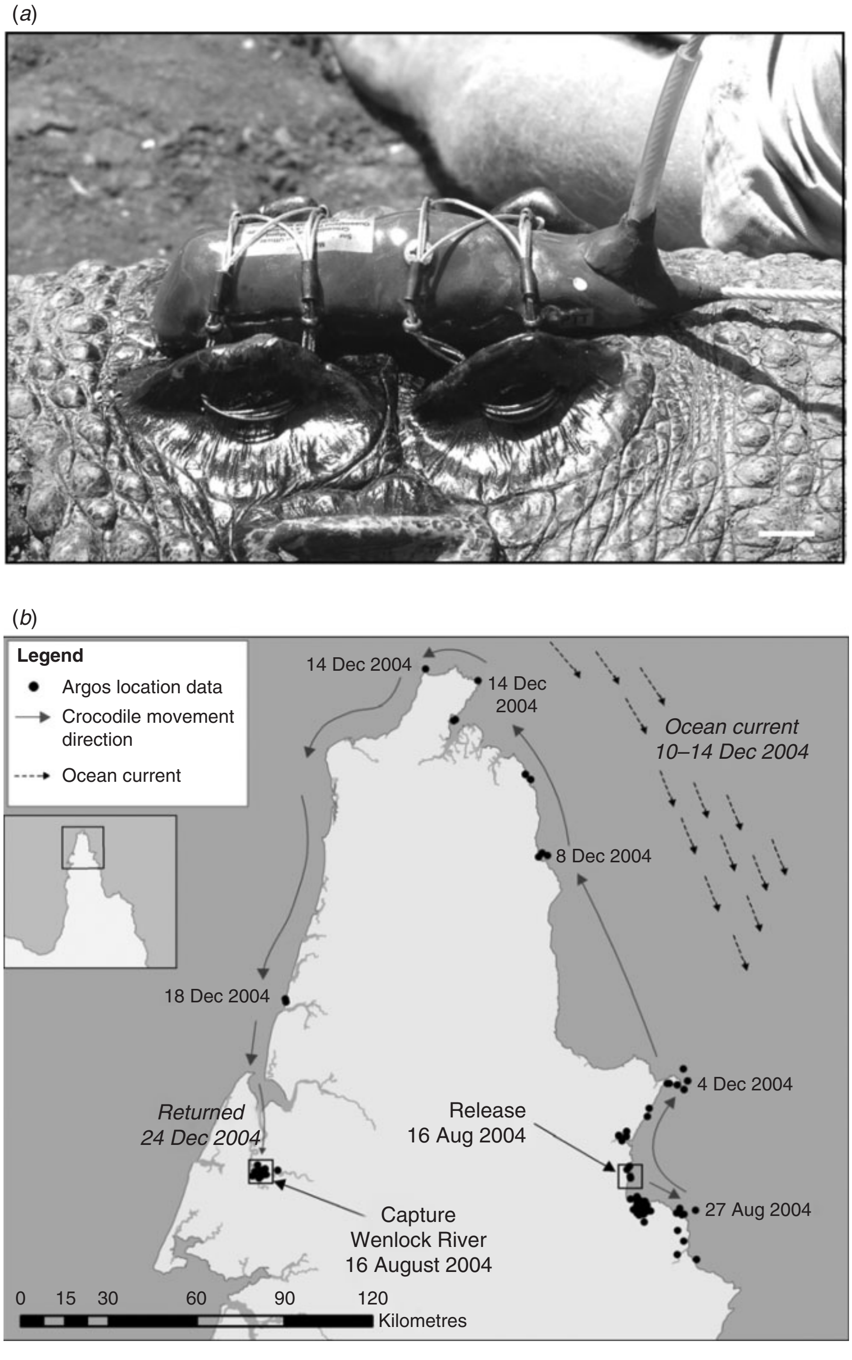

Fig. 7. (*a*) Attachment of a satellite transmitter to the nuchal scutes of a 4-m estuarine crocodile (*Crocodylus porosus*). Plastic-coated stainless steel wires were used to anchor the transmitter to the animal via twin holes in the four nuchal scutes. Scale bar = 1 cm. (*b*) Satellite tracking of an estuarine crocodile translocated from Wenlock River (12.2556°S, 141.934°E) on the west coast of Cape York Peninsula to the east coast, arrows show the crocodile's circumnavigation of the peninsula and return to capture site (figure modified from Read *et al*. 2007).

birds, large mammals and whales (e.g. Roshier and Asmus 2009). A key advantage of this type of biotelemetry is that it allows data to be collected from animals that inhabit remote locations that are difficult to access, and can transmit data from animals that move large distances. This technology has recently provided the opportunity to monitor the movements of estuarine crocodiles over large spatial and temporal scales (Read *et al*. 2007).

Case example. Satellite telemetry of estuarine crocodiles in Far North Queensland

We deployed fifteen satellite transmitters to determine the movement patterns and home-range requirements of adult-sized estuarine crocodiles. The transmitters used were KiwiSat101 platform terminal transmitters (PTT) (SirTrack, Havelock North, New Zealand) powered by a single C-sized lithium battery with a duty cycle of 24 h on and 72 h off and a repetition rate of 60 s. Based on the battery size, duty cycle and repetition rate, it was calculated that the PTT would transmit for a minimum period of 10 months. The package also contained a VHF transmitter to allow the tracking of the animals in real time. The electronics were packaged into epoxy resin with the flexible antenna for the PTT exiting the top surface of the package at ~45° posteriorly, whereas the antenna for the VHF transmitters exited the back of the package to trail along the back of the crocodile. The overall dimensions of the packages were 120 mm long by 32 mm wide and 24 mm high and a mass of 300 g.

Attachment

Satellite transmitters were attached to the four largest scutes of the nuchal shield of estuarine crocodiles (Fig. 7*a*). A similar preparation protocol (e.g. anaesthesia) as described for the attachment of archival tags (see above) was used. As the transmitters were being deployed for long-term transmission, we used a wiring configuration that utilised two holes being drilled into each of the four scutes, through which the wire was fed. The transmitters were attached to the scutes using plastic-coated stainless steel wire threaded through four steel loops on the sides of the transmitter and fastened using lead crimps (see Fig. 7*a*) The combination of attachment technique and battery supply appeared to be effective, because at least 50% of the PTTs deployed sent signals for a period >10 months and at least four PTTs sent signals for periods >15 months. The results of one study have already been published (Read *et al.* 2007) and Fig. 7*b* presents location fixes from a large estuarine crocodile that was translocated from the west to east coast of Cape York Peninsula, Northern Australia.

Acoustic (ultrasonic) telemetry

Acoustic ultrasonic telemetry has been successfully utilised to monitor aquatic animals and is effective in fresh water, estuarine and marine environments. A key advantage with this type of telemetry is that because of low power consumption, the lifespan of the tag can be programmed to last 8–10 years, allowing long-term studies to be conducted. A variety of sensors are available, including temperature and pressure (detecting water depth). Signals from the transmitters can either be picked up by automatic stationary receivers (e.g. Vemco VR2-W) or actively tracked (Vemco VR100).

Case example. Acoustic tracking of estuarine crocodiles

A pilot study was conducted to examine the effectiveness of acoustic telemetry to record the movements, body temperatures and diving activities of estuarine crocodiles, *C. porosus*, in a tidal river system and waterhole. Crocodiles ranging in body size from 2 to 5 m were implanted with either temperature or pressure-sensitive acoustic transmitters (Fig. 8). Acoustic transmitters

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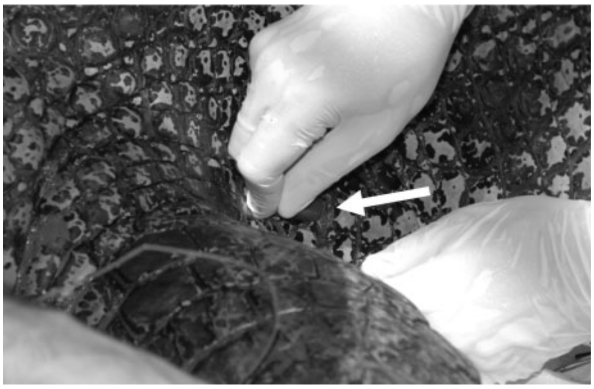

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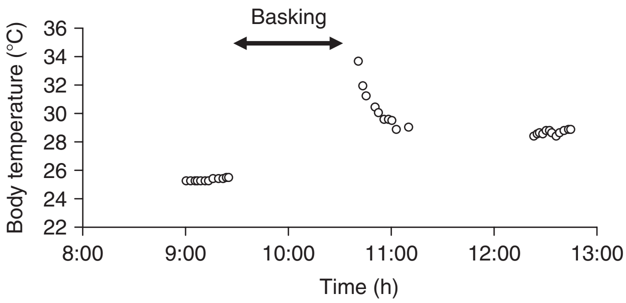

Fig. 8. (*a*) Insertion of a Vemco temperature sensing acoustic transmitter beneath the skin and behind the left forelimb of an estuarine crocodile (*Crocodylus porosus*). Arrow indicates location of incision and shows the acoustic transmitter being inserted. (*b*) Example of body temperature data collected from an estuarine crocodile implanted with a temperature sensitive acoustic transmitter. The start arrow indicates where the animal left the water to sun bask, and the end arrow shows when it re-entered the water.

used (V16, Vemco) were cylindrical, 72 mm long and 15 mm in diameter with rounded ends and implanted subcutaneously. To implant transmitters, crocodiles were restrained and the area immediately behind the left forelimb cleaned with a preoperative cleaning surgical scrub brush and sponge (BD E-Z Scrub 205, povidone–iodine, Becton, Dickson Company, Franklin Lakes, NJ, USA). The area was then rinsed with 70% ethanol. A local anaesthetic (lignocaine 20 mg mL^{-1} with adrenaline 1–100 000) was administered subcutaneously to the area with a 23-gauge needle and syringe. A disposable sterile surgical drape was placed on the ground, which served as an aseptic working area. Surgical instruments were rinsed in 70% ethanol. Using aseptic technique, a 2-cm incision was made and a small pocket formed under the skin, along a skin fold, using blunt-ended scissors. The transmitter, which had previously been soaked in 70% ethanol, was inserted into the pocket beneath the skin. Using reverse cutting, half-circle suture needles, the incision was tightly closed using gut sutures (size 2) and the area sprayed with a Terramycin antibiotic aerosol. The location of the transmitter was such that when the crocodile was at the water's surface, it remained well below the surface, allowing it to be detected. To calculate the depth of the crocodile and to correct for transmitter location, we measured the distance of the transmitter to the dorsal surface and head. The location of the transmitter provided excellent transmission, with animals being detectable from >500 m using a directional hydrophone and active tracking receiver. Recordings of crocodiles have continued for more than 9 months. We believe acoustic telemetry provides the best opportunity to conduct long-term monitoring studies (>5 years) on crocodilians. What remains to be determined is the retention success of these implanted acoustic transmitters (Butler *et al*. 2009; O'Connor *et al*. 2009).

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