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Transmitter attachment and release methods for short-term shark and stingray tracking on coral reefs

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Abstract This study details a simple and cost-effective means of attaching acoustic transmitters to coral reef sharks and stingrays, which potentially allows for retrieval and reuse on completion of tracks. Between 2008 and 2011 galvanised timed-releases were trialled in both static field tests and on blacktip reef sharks *Carcharhinus melanopterus*, cowtail *Pastinachus atrus*, and porcupine *Urogymnus asperrimus* rays in Coral Bay (-23° 08’ 41”, 113° 45’ 53”), Western Australia. The timed releases remained attached to animals for the duration required for tracking and in four out of five deployments transmitters were recovered after release from the animals. The use of modified Rototags for sharks and stainless steel darts for stingrays allowed rapid and effective attachment to animals, with limited impact on their welfare in the short term. External attachment for short-term tracking of coral reef-associated elasmobranchs should be considered as a complementary option to internal placement of transmitters in animals either by surgery or ingestion.

Introduction

Since the inception of studies using acoustic telemetry to track elasmobranchs in the 1960s, there have been two commonly reoccurring problems faced by researchers: firstly, transmitter retention for the duration of the study and secondly, recovery of the transmitter upon completion. Issues of transmitter attachment are particularly critical for studies that involve active tracking of animals. Unlike passive monitoring using fixed receivers, which may be ongoing for several years (e.g., Heupel and Simpfendorfer 2005; Papastamatiou et al. 2009; Speed et al. 2011), active tracking invariably takes place over short durations of a few hours to a few days. The aim of such studies is to provide detailed, fine-scale (m) tracks of animals by following the signal from the transmitter (e.g., McKibben and Nelson 1986; Nakano et al. 2003; Johnson et al. 2009). The intense nature of this field work means that it can usually only be sustained for a relatively brief time (usually no more than a few days) and for this reason, it is vital that a quick method of transmitter attachment is used that minimises stress and does not induce unusual behaviour by the study animal during tracking.

Ideally, active tracking should be long enough to capture the cycle of behaviour of interest, which is often one or more 24 hr periods in most instances (Nelson 1990). In some studies, researchers have trialled feeding transmitters to sharks concealed in bait, although short retention times and regurgitation of transmitters have complicated this approach (McKibben and Nelson 1986; Economakis and Lobel 1998; Papastamatiou et al. 2009). In addition, this method is often not selective in that it doesn’t allow the researcher to be selective about size or gender (but see Brunnschweiler 2009), and may not allow the researcher to gain other vital information about the individual being tracked. For these reasons, attaching the transmitter using a barbed dart inserted under the skin of the animal or inserting the transmitter into the body cavity of captured animals by surgery are most commonly used for this work. In particular, external tagging of rays has proved to be problematic on account of their dorso-ventral compression and lack of prominent dorsal fins to which transmitters can be attached (Le Port et al. 2008). Using the internal implantation approach also has the problem that it involves considerable trauma for the animals (Nelson 1990). Furthermore, transmitters cannot be retrieved after the tracks are completed, unless researchers are willing to euthanize the subject animals.

A pioneering study by Bass & Rascovich (1965) suggested that a buoyant transmitter attached externally with water soluble glue or an electromagnet might enhance the likelihood of transmitter retrieval. Since then, a range of technology has been developed for the timed release of external transmitters including electronic burn wires, as well as various types of corrodible links that are activated in seawater. Electronic burn wires enable the user to determine exactly when the transmitter should be released from the animal, although they are costly and for this reason, cheaper alternatives such as galvanic timed releases (GTR) have been used. Galvanic timed releases were initially designed for use in the fishing industry, although they are now also used by researchers to slowly corrode in seawater and eventually release transmitters attached to animals. However, release times of GTRs can be affected by environmental factors, with warmer water increasing the rate of corrosion and making detachment of transmitters somewhat unpredictable in the tropics. Nevertheless, such technology has been used extensively for tracking sharks in a variety of environments such as: Pacific angel *Squatina californica* (Ayres 1859) (Standora and Nelson 1977), grey nurse *Carcharias taurus* (Rafinesque, 1810) (Bruce et al. 2005; Bansemer and Bennett 2009), sandbar *Carcharhinus plumbeus* (Nardo 1827) (Rechisky and

Wetherbee 2003), white *Carcharodon carcharias* (L. 1758) (Bruce et al. 2006), grey reef *Carcharhinus amblyrhynchos* (Bleeker 1856) (Skomal et al. 2008) and whale *Rhincodon typus* (Smith 1828) (Gleiss et al. 2009) sharks. Tracking studies of marine reptiles such as crocodilians (Franklin, 2009) and turtles (Hazel, 2009) have also employed the use of GTRs.

The present study focuses on the attachment of external transmitters to reef sharks (Carcharhinidae) and stingrays (Dasyatidae) on a tropical coral reef. We used an external tagging technique because tracking was intended to commence within a few hours of attachment, and required that transmitters were retained for up to 24 hours. Furthermore, this method was judged this to be less traumatic for animals than internal tagging, as surgery and restraint of animals for long periods (> 10 minutes) were not necessary. A knowledge of restricted home ranges and repeated daily movement patterns (e.g., Cartamil et al. 2003; Collins et al. 2007; Speed et al. 2010), coupled with the use of external transmitters, also allowed the possibility of transmitter retrieval to be explored using buoyancy aids for the transmitter. Specifically, the aims of this study were to test whether: 1) external attachment would ensure retention for the duration of the tracking period, 2) using GTRs in a tropical environment would result in reduced retention time compared to the temperate water conditions in which they were designed for, and 3) an attachment design that includes both a floatation device and GTR would permit retrieval of transmitters upon completion of the track and leave minimal equipment attached to animals.

Methods

Study site

Field tests of GTRs and animal tracking were conducted in the lagoon of Ningaloo Reef, Western Australia near the township of Coral Bay. (-23° 08’ 41”, 113° 45’ 53”) (Fig.1). The lagoon is a shallow (1–10 m water depth) habitat, characterised by extensive sand flats, consolidated limestone platforms, and interspersed with coral reef patches. This area is known to have a high diversity of reef shark and stingray species (Stevens et al. 2009; Speed et al. 2011), and the complex coastline provides sheltered bays, ideal for monitoring short-term movement behaviour of these animals due to protection from the prevailing winds and reduced wave action.

Galvanic timed release static field test

Two B5 GTRs (International Fishing Devices inc.) were tested in Skeleton Bay, a known shark aggregation site within the lagoon of Coral Bay (Speed et al. 2011) between the 9th and 11th of November 2008. This model of GTR was designed and tested for water temperatures between 14–21°C, and was predicted to corrode after 48 hrs according to this model’s specifications. Both GTRs were placed on the sand 60 cm apart from one another and checked after 24 hrs, 48 hrs and 53.5 hrs. Each GTR was anchored using a 2 kg lead weight and suspended with 70 kg fishing line, which was attached to an identical float that was intended for use in animal tracking. A plastic zip tie was used to attach the GTR to the weight and an additional anchor line was attached from the weight to the float to avoid losing it once the GTR had released. Water temperature was monitored half-hourly with a temperature logger (VEMCO Minilog) for the duration of the experiment.

Transmitter attachment design and deployment

Reef sharks

Both v16 and v13 continuous acoustic transmitters (VEMCO) were trialled for external attachment on blacktip reef sharks (*Carcharhinus melanopterus*) (Quoy & Gaimard 1824). The end of each transmitter was scored using a P50, medium grit sandpaper and marine putty (Selley's Knead It Aqua) applied to one end. A small hole was formed in the putty and reinforced with steel eyelets. Alternatively, transmitter mounts with built-in eyelets are also available from VEMCO. Transmitters were then connected to a B5 GTR with 70 kg monofilament nylon fishing line (~20 cm long) and conical fishing floats. The line was also bound at either end of the exposed portion of the transmitter with two small cable ties, to avoid the transmitter resting and rubbing on the animal during tracking. The opposite end of the GTR was fastened to the female part of a Jumbo Rototag© by a cable tie, which threaded through a hole that had been drilled in the tag (Fig. 2). The tag was then applied to the first dorsal fin as per standard application of Jumbo Rototags© (Kohler and Turner 2001).

Prior to tracking, the range of continuous acoustic transmitters were tested in Skeleton Bay during August 2009. Both the v13 and v16 models were tested with a VR100 receiver and VH110 (VEMCO) directional hydrophone and it was determined that the maximum range was between ~ 280 and 300 m (see details in Speed et al. 2009).

Sharks were caught at the beach adjacent to Skeleton Bay using ~ 115 kg monofilament handlines with baited barbless hooks (see details in Speed et al. 2011). Acoustic transmitters were then attached to the first dorsal fin using the Rototag© applicator, after having first taken a dermal punch to avoid splitting the fin.

Stingrays

Transmitter preparation and rig design for stingrays differed slightly to the methods used for sharks, and was designed for use on both cowtail rays *Pastinachus atrus* (Forsskael 1775) and porcupine rays *Urogymnus asperrimus* (Bloch & Schneider 1801). Putty was attached to the float as well as the GTR, which was directly embedded within the putty and allowed to set overnight. A wire trace was looped directly through the GTR and crimped in three places before being surrounded in a thermal plastic sheath. This length of wire trace would be left after the transmitter would release, so it was designed to be as short as possible in order to have the least impact on the animal post-release. The other end of the wire was looped once more through a stainless steel dart and held in place by one of the crimps (Fig. 3).

Large dasyatid rays (W_D > 100 cm) were tagged using VEMCO v16 continuous transmitters attached externally using a Mares Cyrano 700 Pneumatic Spear gun that was modified to mount transmitters. The head pin (manufactured by Exmouth Light Engineering, Exmouth, Western Australia) allowed the mounting of the transmitter by securing the dart in a groove and trailing the wire tether and transmitter along the shaft, which was attached by a rubber band to prevent it floating off when in the water. Transmitters were attached to rays in their pectoral fins close to the central disc. To avoid penetrating the entire fin and causing potential harm to the animal, a cork was placed at the base of the pin shaft so that it could only penetrate to a fixed depth. This distance could be adjusted to suit the size of the ray. Animals were tagged from directly above while snorkelling and the transmitter was fired around 30–50 cm from the ray.

Shark and stingray tracking

Sharks and rays were tracked using a VR100 (VEMCO) ultrasonic receiver and a VH110 (VEMCO) solid aluminium directional hydrophone. The hydrophone was attached to the end of a telescopic pole that was fixed to the gunnel of a 4.5 m monohull boat with an outboard engine, similar to the method described by Holland et al. (1992). A distance of ~ 10 m was maintained to animals where possible to ensure strong signal reception from the transmitter and also minimise observer influence on animal behaviour. Visual confirmation of shark presence during the day was possible due to clear, shallow waters and was also possible at night due to reflective tape on the float. Rays were tagged in less than 6 m of water in sandy, lagoonal habitat within the Maud Sanctuary Zone, east of Lottie's lagoon and were all feeding when tagged. Tracking began before 10 am on each of three days and lasted for up to 9 hours, while one of these rays was also tracked a second time after re-location of the animal 24 hours after the initial track. No night tracks were possible due to bad weather. If transmitter signals were lost during tracking, a VH165 (VEMCO) omnidirectional hydrophone was used to provide a broader scan of the surrounding area in order to re-establish the position of the animal so that tracking could be resumed using the directional hydrophone.

Signals received from the transmitters were recorded in decibels (Db) every 3 seconds, which corresponded to an approximate distance of 0 (no detection) –100 (full detection and very close proximity). Coral reefs can create echoes or 'phantom' signals due to topographic complexity, although typically a signal of 90–100 Db corresponded to approximately 0–15 m distance from transmitter to hydrophone, which was also validated from static field testing. Two simple methods were used to plot the tracks of sharks and rays. The first method, used for plotting shark position data, used only positions that had > 90 dB recordings, which corresponded to animals being in close proximity to the boat. The average of these positions was taken for each hour and plotted in ArcMap©. The second method, used for plotting stingray tracks, involved standardising all position data by dividing each track into 30 minute intervals (600 waypoints per 30 minutes) and then one waypoint for each half an hour block of each track was randomly chosen using a random number generator to be plotted in ArcMap©.

Transmitter retrieval

In order to facilitate transmitter retrieval, our contact details were put on the float of the rig to enable the public to return a transmitter if it was found after it had detached from an animal and washed up onto a beach. In addition, we searched beaches both north and south of where each animal was tagged in an attempt to locate transmitters after the 48-hr attachment period had elapsed.

Results

Galvanic timed release static field test

Both GTRs were still attached after 24 hrs, which was the minimum time required for shark and ray tracking purposes. One of the GTRs had prematurely released by 48 hrs and the other released between 48 and 54 hrs (Fig.5). The minimum, mean and maximum water temperatures recorded for the duration of the experiment were, 20.8C°, 23.3C° (± 0.97 SD) and 24.7C° respectively. The mean water temperature throughout the experiment was therefore warmer than the water temperature range for which this model of GTR was originally designed (14 - 21° C).

Transmitter attachment design and deployment

The procedure of transmitter attachment for sharks took approximately five minutes from capture to release. All transmitters remained attached to animals for the duration of tracks and neither design appeared to inhibit movement. Once released, only the Rototag with a single nickel ring from the GTR remained attached to the animal. The use of reflective tape on floats provided an effective means of confirming the location of tagged sharks at night using a flashlight from the boat.

Each stingray was tagged successfully on the first attempt, which took no longer than 20 seconds. Once the transmitter released, the stainless steel dart and a wire trace (~ 6–10 cm in length) were left on the animal.

Shark and stingray tracking

Sharks

Two adult female blacktip reef sharks were successfully tracked, which were both tagged at the beach adjacent to Skeleton Bay. The first track lasted > 20 continuous hours, commencing at 14:48 pm and finishing at 11:26 am the following morning. The second track covered a two day period and was split into two separate tracking periods of 4 hrs 44 mins on the first day and 6 hrs 28 mins on the second day (Table I). Both animals remained within the lagoon during the tracking period and the first largely moved within Skeleton Bay (Fig. 6A). It was not possible to plot the track for the second shark owing to an insufficient number of clear detections. However, continuous signal detections were maintained throughout the respective tracking periods, although animals became difficult to track at low tide due to patches of exposed reef. Tracks were terminated due to either inclement weather or signal loss at low tide.

Stingrays

Three adult rays were successfully tracked, the first of which was a female cowtail ray of approximately 100 cm W_D that was tagged at 09:57 and tracked for 8 hrs and 47 mins (Fig. 6B and Table 1). The same ray was tracked again when the signal was re-established 24 h later and followed for a further 7 hrs and 12 mins. The second animal was also a female cowtail ray that was tagged at 08:30 and tracked for 8 hrs and 33 mins. The last track was obtained from a porcupine ray tagged at 10:00 and tracked for 8 hrs and 50 mins. While each ray remained relatively sedentary during the tracking periods, some small-scale movements (10-100 m) were made, with the greatest activity occurring around dusk. Immediately after tagging, the ray was followed by snorkeler for as long as possible with the boat following at a distance. This was to ensure the welfare of the animal post-tagging and also to confirm correct transmitter placement and attachments. After tagging, each ray settled on sand immediately adjacent to coral complex within 30–50 m of the tagging site. One porcupine ray remained stationary for almost 8 hours in the same location, before moving at dusk. During these stationary phases, observations were made by a snorkeler every 60 minutes to confirm the transmitter was still attached. In each case, feeding was observed suggesting ‘normal’ behaviours had resumed post-tagging.

Transmitter retrieval

A single shark transmitter was retrieved from a beach by a member of the public near the deployment site in Skeleton Bay. The other Transmitter was not relocated after the completion of the subsequent shark tracking period. All three transmitters deployed on stingrays were retrieved by members of the public walking along the beach of Bill's Bay approximately 4–5 km north of the tagging locations.

Discussion

Although the technical difficulties associated with tagging and tracking elasmobranchs in tropical reef environments are well recognised (e.g., Nelson 1977; Bres (1993); Simpfendorfer & Heupel 2004), the solutions to these problems are not always reported in detail within the literature. This can result in each new study having to re-invent through trial and error new solutions to the same problems. The current study is an attempt to build on existing concepts of transmitter attachment and act as a guide for researchers that are unfamiliar with such techniques. Moreover, given the proliferation of acoustic telemetry studies of elasmobranchs over recent decades (e.g., Nelson 1990; Sundström et al. 2001; Speed et al. 2010), it is incumbent on researchers to find and disseminate the most effective and least intrusive methods of tagging and tracking. A simple, cost-effective external attachment with a galvanic timed-release for transmitters allowed the successful tracking of sharks and stingrays in our study with minimum disturbance to animals, and in most instances retrieval of transmitters.

All transmitters remained attached to animals for the predicted deployment period however, detachment times were more variable. Even in static trials when GTRs were exposed to identical environmental factors, detachment times varied by several hours. For the current study, this was not an issue but might be an important consideration in situations where the retrieval of transmitters requires greater release time accuracy. Overall, release times remained broadly consistent with the predicted duration of 48 hrs stated by the GTR manufacturer for water temperatures between 14 and 21° C, suggesting that the use of GTRs for studies in tropical waters remains valid.

The use of modified Rototags on blacktip reef sharks provided a rapid and moderately invasive attachment technique for transmitters. The permanent placement of the Rototag served for identification of previously tagged animals once acoustic transmitters had detached. Early telemetry studies of reef sharks suggested that external attachment of transmitters might have caused abnormal behaviour due to trauma (Nelson and Johnson 1980), although recent work on juvenile bull *Carcharhinus leucas* (Müller & Henle 1839) and lemon sharks *Negaprion brevirostris* (Poey 1868) advocated external attachment because it was relatively quick and less invasive (Yeiser et al. 2008) than surgical implantation of transmitters within the animal. A recent tracking study used internal tagging for blacktip reef sharks, although the researchers waited for at least 48 hours prior to tracking to avoid changes in behaviour due to tagging trauma (Papastamatiou et al. 2010). The concurrent use of our external tagging technique might provide a means by which the extent and duration of "abnormal" behaviour due to the trauma of internal application of transmitters might be empirically tested. Regardless of the tagging method adopted, it is generally advocated that data collected from immediate post-tagging is removed from analyses in behavioural studies, which is generally the first few hours of tracking (Review by Sundström et al. 2001).

Early studies on blue sharks *Prionace glauca* (L. 1758) found that on release, tagged individuals immediately dived below the thermocline, which was thought to be a response to the trauma of external attachment of transmitters (Sciarrotta and Nelson 1977; Carey and Scharold 1990). Similarly, a recent study that trialled a new technique of external attachment of motion sensors to whale sharks observed comparable post-tagging behaviour (Gleiss et al. 2009). In the current study, tagged blacktip reef sharks made rapid movements away from the tagging location upon release, although appeared to resume “normal” behaviour within an hour. In the shallows of Skeleton Bay, this consisted of slow swimming in water depths of 1–2 m over the sand, which has been documented in a previous study using visual censuses (Speed et al. 2011). Likewise, stingrays swam away from the snorkeler immediately after tagging, but resumed behaviour that was consistent with feeding within a few minutes. Nonetheless, future studies to confirm these behavioural observations are required.

Nelson (1990) suggested that there was a trade-off between the immediate effects of the trauma of internal implantation of transmitters and the long-term irritation of an external transmitter rubbing against the skin. Long-term effects of irritation were not an issue in our study due to the brevity of tracking, although longer tracking periods (multiple weeks) with the same design would be possible with longer-lasting models of GTRs. For both stingrays and sharks, transmitter attachment design in the current study meant that there was only a small likelihood of abrasion on the skin. A further benefit of this design is that little instrumentation remains on animals after transmitter detachment, which could potentially attract bio-fouling and lead to infection (e.g., Jewell et al. 2011), although internal implantation techniques would remove the potential for bio-fouling. Earlier work has shown that the Rototags do not have long-term negative effects on the health of blacktip reef sharks (Heupel et al. 1998).

A number of transmitter attachment methods for stingrays have been trialled without negative effects to animal welfare including: inserting monofilament line through the tail to attach PSAT tags (Le Port et al. 2008), cinch tags attached to the spiracular cartilage (Collins et al. 2007) and a braided nylon harness passed through the spiracles in order to tow a transmitter (Blaylock 1990). In all cases, these attachment techniques require capture and restraint of animals, with the risks inherent for the researcher in handling potentially dangerous species as well as the trauma to the animals. In-water tagging using a spear gun as described here is not without risk, but arguably such risks, both for the researcher and the animal, are considerably reduced when there is no requirement for capture and restraint (Review by Sundström et al. 2001). Spear guns and spears have been used to deploy external transmitters on large elasmobranchs in situations where restraint of the animal is not possible due to practical or ethical issues, for example on nurse sharks *Ginglymostoma cirratum* (Bonnaterre 1788) (Pratt and Carrier 2001), manta rays *Manta birostris* (Donndorff 1798) (Dewar et al. 2008) and whale sharks (Wilson et al. 2006).

The opportunistic retrieval of transmitters once they had detached was partially due to the limited spatial scale (10s - 100s of m) of movements and site fidelity of subject animals, which is common in many reef associated species of elasmobranchs (e.g., Chapman et al. 2005; Lowe et al. 2006; Wetherbee et al. 2007; Dewar et al. 2008; O'Shea et al. 2010; Speed et al. 2011), as well as favourable wind and wave conditions. VHF radio transmitters have also been used previously to locate devices once they had detached from animals when at sea (e.g., Gleiss et al. (2009) and Houghton et al. (2009)). Future models of our rig could include a VHF transmitter within the float, which would increase the likelihood of tag retrieval at sea or once washed up on a beach.

Methods of attachment of acoustic transmitters in the current study provide both alternative and complementary techniques to internal implantation and/or ingestion of transmitters by animals. However, the goal of future tagging studies should be to find an attachment method for transmitters that is completely non-invasive and involves as little risk as possible both for the researcher and the subject animal. Hopefully, such innovation will be developed and current advances in transmitter attachment will continue to be disseminated within the research community.

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Figure Captions

Figure 1 Map of study area.

Figure 2 External attachment design for active tracking of reef sharks.

Figure 3 External attachment design for active tracking of for stingrays.

Figure 4 Optimal technique for in-situ tagging of large benthic rays with **a)** approach from the side and slightly from behind; **b)** Tag attachments from directly above in the pectoral fin close to the body; **c)** The movement of the ray is the force which detaches the spear from the tag rig, and **d)** the ray swimming away with the tag attached correctly with minimum invasion.

Figure 5 Water temperature and GTR release times for experiment duration.

Figure 6 A) Stingray tracks up to nine hours duration each, within the Maud Sanctuary Zone, Ningaloo Reef; numbers represent the starting points of each track and the points represent locations at 30 minute intervals, and B) Track of *C. melanopterus* within Skeleton Bay, Ningaloo Reef; each point represents an average position for each hour tracked.