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Satellite tracking of whale sharks using tethered tags

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Abstract

Aggregations of whale sharks, *Rhincodon typus*, occur each year off South Africa (Indian Ocean) and in the waters surrounding Utila, Bay Islands, Honduras (Caribbean Sea), where they form the basis of a whale shark ecotourism industry. In 1998 and 1999 the Shark Research Institute deployed tethered satellite tags on five whale sharks in an effort to gather information on their diving profiles and both long-term and short-term movements. Satellite tags were attached to the sharks by divers using tag anchors placed in either the skin or musculature of the shark, and tethers from 1.5 to 7 m were used with varying degrees of success. Tethered tags provide real-time data about the habitat use and diving profiles of whale sharks, and may be recovered if they detach prematurely from the host animals. An unexpected finding was that the sharks dived regularly to depths of >320 m, which may have contributed to premature detachment of the tags due to drag and, as result, the hydrodynamics of the tag were refined. Sharks tagged off the coast of KwaZulu-Natal, South Africa, travelled northwards. One shark tagged off the coast of Utila Bay Islands, Honduras, travelled to the Swan Islands, then moved along the Yucatan Peninsula and into the Mexico Basin, while the second shark tagged off Utila travelled to the coast of Belize. This study confirms that tethered satellite tags are effective tools in monitoring travel paths and habitat use of whale sharks when real-time data is needed.

Keywords: Whale shark; Satellite telemetry; Indian Ocean; Caribbean Sea; Argos; Tagging

1. Introduction

The whale shark, *Rhincodon typus*, is the largest fish in the sea, attaining a length of approximately 18–20 m. The whale shark is thought to be circumglobal in tropical and warm-temperate seas. An epipelagic oceanic and coastal species, it is generally seen close to the surface (Compagno, 1984, 2001). The first whale shark known to science was a specimen found in 1828 at Table Bay, South Africa (Smith, 1829), and strandings occur along the South African coast as south as the Cape of Good Hope in waters as cool as 10 °C. By 1986, there had only been 320 recorded sightings of the shark in all of Western scientific literature (Wolfson, 1986), a measure of the rarity of the species.

Comparatively large numbers of whale sharks have been seen in the Sea of Cortez and off Mexico between Cabo San Lucas and Acapulco from March to August (Eckert, pers.com), in the Gulf of Mexico (Baughman and Springer, 1950), and the Caribbean Sea (Gudger, 1939) where they have been observed feeding amid schooling blackfin tuna, *Thunnus atlanticus*. Congregations of the sharks have only been recorded in a few areas. In the Indian Ocean, whale sharks congregate at Ningaloo Reef in March and April when the coral spawn (Taylor, 1996), and gathering of the giant fish now supports an ecotourism industry (Coleman, 1997). Congregations of the sharks also occur in the Seychelles in August and November (Rowat, pers. comm.), and along the coast of East Africa (Gifford, 1994, 1995, 1997, 1998). Aerial surveys along 650 km of the Kenyan coast over a 2-month period in 1986 resulted in the sightings of 21 sharks, the largest number ever reported in the scientific literature up to that time (Wolfson, 1986). However, the greatest concentrations of the sharks appear to occur off Mozambique and the northern coast (KwaZulu-Natal) of South Africa from October through April. In South African waters, 95 whale sharks were observed between Durban and Umtentweni, a distance of 110 km, on 15 January 1994 (Gifford, 1994) during an aerial survey conducted by the Shark Research Institute (SRI). Subsequently, Beckley et al. (1997) reported a number of strandings and other records of whale sharks along the South African coast from the Western Cape to KwaZulu-Natal.

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Scant data about whale sharks exist because the species was never considered commercially viable due to its scarcity. The situation changed in recent years with the demand for shark products in Asian markets. For example, in 1999 fishermen along India's Saurashtra coast slaughtered more than 1000 whale sharks (Indian Express, 29 March, 1999 ed.). The sharks were not consumed in India; with the exception of liver oil, the whale shark products were exported to China, Hong Kong and Taiwan. The primary objective of this study was to determine the annual movements of whale sharks in the Indian Ocean and Caribbean Sea in order to concentrate our resources on securing government protection for the sharks in areas where they are at risk from targeted fishing efforts. Although it was thought, due to their coloration, that whale sharks remained close to the surface throughout the day, satellite telemetry enabled us to gather data about the sharks' movements within the water column throughout each 24-h cycle.

In 1993, to document the seasonal movements of whale sharks along the eastern coast of South Africa, the Shark Research Institute (SRI) initiated both an aerial survey program and a tagging program. In 1998, the tagging program was expanded to the Caribbean Sea. In 1998, in an effort to accumulate data at a faster rate and discover the vertical habitat use of the sharks, SRI began using satellite telemetry. This paper discusses the problems encountered utilizing tethered satellite tags on whale sharks, and suggestions on how results may be improved.

Fish (including many species of sharks) have been tagged with passive ID tags for more than a century, but satellite telemetry is a comparatively new technology. Priede (1979, 1981, 1982) employed satellite telemetry to track a basking shark for 17 days in the Firth of Clyde off the west coast of Scotland. Eckert tracked whale sharks both in the Sea of Cortez and in the Philippines utilizing satellite telemetry with varying degrees of success (Eckert, pers. comm). Researchers also attached archival tags to two whale sharks in Australian waters (Stevens, pers. comm); one was tracked for 4 h, the second for 26 h. Long-term attachment of the tags to the host animals proved to be the greatest hurdle.

2. Methods

2.1. Satellite telemetry

ARGOS DCLS earth orbiting satellite system provides autonomous, daily, global locations for monitoring wildlife (Argos, 1996). The system consists of two operational TIROS-N satellites in low-Earth (830–870 km), near polar orbits with on-board radio receiver and transmitter units, a series of Earth-based receiver stations, several Earth-based Global Processing Centers (GPCs) and a radio-frequency transmitter (commonly known as Platform Transmitter Terminal or PTT) attached to the host animal.

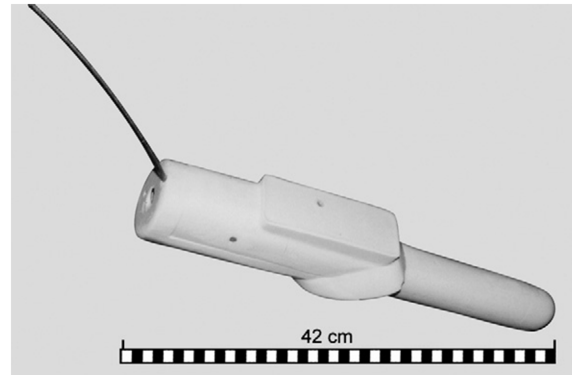

Fig. 1. Wildlife Computer satellite tag. Each tag used in this study was painted with blue anti-fouling paint to reduce attachments of marine organisms and reduce its visibility to large fish.

At present, two types of satellite tags are used to track whale sharks: pop-up tags, which archive and transmit data after detachment from the host animal, and tethered tags, which provide real-time data. When this study began, however, only tethered tags were available.

For this study, custom designed satellite-linked time-depth-recorders manufactured by Wildlife Computers of Redmond, Washington were used (Fig. 1). Each PTT was encased in a positively buoyant cylindrical syntactic foam housing that measured 5 cm × 42 cm. The encased PTT consisted of a 1/2 W Seimac transmitter and microprocessor with on-board sensor to monitor maximum depth. The transmitters were programmed to collect data on the amount of time the PTT spent at a pre-programmed depth summed over 6-h time periods. Upon surfacing, the PTT transmitted the previous 24 h data divided into four histograms for each measured variable (Table 1). Each PTT was powered by four lithium 'C' cell batteries. The built-in microprocessor provided for programming of the transmitter, including the depth intervals of the histograms and the transmission cycle. The vertically oriented antenna at the sea surface was positioned to produce optimal transmissions to passing satellites. All PTTs used in this study were painted with dark blue anti-fouling paint to reduce attachment of marine organisms and minimize their visibility to marine animals.

Table 1
Comparison of tag anchors, placement depth of tag anchors, tether length and duration of attachment

PTT#	Sex of shark	Size of shark (m)	Type of tag anchor	Tether length (m)	Date tagged	Location of tagging	Duration of attachment (days)
05003-1	F	7	Type I	3	8 March 1998	Cape Vidal, South Africa	17
05003-2	M	7	Type I	7	25 October 1998	Cape Vidal, South Africa	7
05003-3	M	8	Type II × 2	7	23 January 1999	Cape Vidal, South Africa	>2
18738	M	8	Type I	4.5	18 February 1999	Utila, Honduras	132
18739	M	8	Type III	1.5	31 December 1999	Utila, Honduras	31

2.2. Attachment of satellite tags

Attachment of satellite, ultrasonic and passive visual tags usually involves baiting a shark, capturing it by hook and line and restraining it either on or alongside the support vessel. In the case of whale sharks, a species that feeds primarily on plankton and reaches lengths of 12 m and longer, this was not practical. In this study, free-swimming whale sharks were tagged by free divers. SCUBA was not used.

The tagging applicator was a rubber-powered speargun. Applicators used in South Africa were manufactured by Rob Allen, a Shark Research Institute volunteer, while those used in the Caribbean were manufactured by JPL Spearguns, Inc.; both designs were very similar. The applicators were spears, 6.5 mm in diameter.

Dissection by SRI staff of 7 and 8 m whale sharks that stranded on the South African coast indicated the thickness of skin in the first lateral ridge below the first dorsal fin measured between 10 and 15 cm. Two sharks (05003-1 and 05003-2) were tagged using spears that had a rubber stop ring/shock absorber 15 cm (6″) from the anterior to limit penetration of the tag anchor to the sharks' dermal layer of skin. A spacer rod was used in conjunction with stop rings located 17 cm from the anterior of the spear on shark (05003-3), and stop rings were set at 18 cm for two sharks (18738 and 1873) in order to place the tag anchors in the musculature of the shark.

2.3. Tag anchors

Details of the tagging are given in Table 1. The Type I tag is a cylindrical stainless steel dual-winged 'drop tip', 8 mm in diameter and 70 mm in length. The anterior has a sharpened tri-cut tip, and the posterior is machined to take the spear shaft that propels it. The cable to which the tether is shackled passes through an opening midway in the tag anchor (Fig. 2). The Type I anchors were designed by Shark Research Institute volunteer Rob Allen and manufactured by SRI-South Africa. Type I tag anchors were used on sharks 05003-1, 05003-2 and 18738.

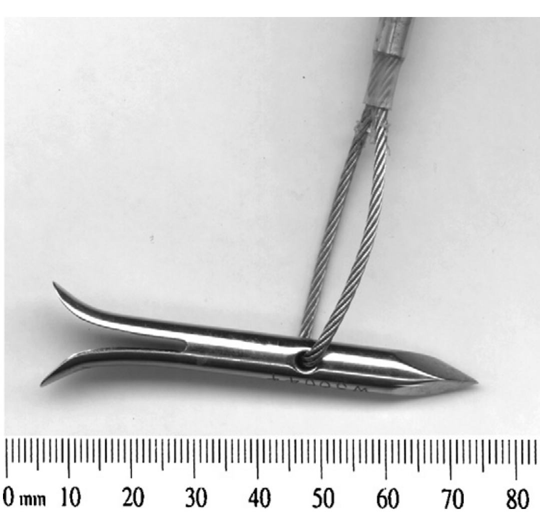

Fig. 2. Type I tag anchor.

Type II is similar to Type I but has a hinge that aids in securing it in or just below the dermal layer of the shark's skin. Two of the Type II tag anchors were used, together with a spacer rod (to produce uniform penetration of the anchors) in shark 05003-3. The Type II anchor tags were manufactured by SRI-South Africa.

Type III is similar to Type 1, but is single-winged, made of titanium and has a narrower sharper point. Type III, used in shark 18739, was designed and machined by Piotr Nawrot in the USA.

2.4. Tethers

The tags were attached with 125 lb stainless steel tethers, and a variety of lengths were tested. From 1994 to 1996, Eckert (pers. com.) satellite tags were attached to 13 whale sharks in the Sea of Cortez using tethers that varied from 4 to 15.4 m in length. Long tethers may allow the tag to rise to the surface for greater periods of time, and thus result in longer transmissions to the satellite system. A long tether may be more able to absorb a sudden acceleration of a shark, but carries the risk of entanglement in the event the shark performs a 'barrel roll'. Field tests in South Africa, where the sharks often frequent shallow water (<10 m), suggested that a long tether could snag on underwater obstructions.

2.5. Northern KwaZulu-Natal and Mozambique and tagging protocol

The nearshore environment is characterized by coral reefs but in some areas the seabed drops to the edge of the continental shelf within a few km of shore. Most of the whale sharks encountered along this stretch of coast travel between the backline of breakers and 500 m from the shore, and are easily seen from the air. Whale sharks were located by microlight aircraft and their position radioed to the tag team on board the boat. The boat crossed the path of the oncoming shark, the tag team entered the water to wait for the shark to approach, and the boat moved away from the immediate area. The first tagger implanted the tag-anchor in the shark and the second tagger attached the size-adjusted tether and PTT to the tag-anchor by means of a shackle.

2.6. Utila Island and tagging protocol

Utila (and the Bay Islands of Roatan and Guanaja) are formed by the Bartlett Ridge, an undersea extension of the Sierra de Omoa mountain range in northern Honduras. Utila has a fringing coral reef and its shallow continental shelf extends to the Cayos Cochinos archipelago some 20 km distant. Reef pinnacles on this shelf, rising to within 11–17 m of the surface, support dense congregations of marine life. Spotter aircraft was not used; off Utila, whale sharks were found below shoals of feeding blackfin tuna. The tag team, on board an 11.4-m fiberglass sport-fishing vessel with flying bridge (tuna tower), approached the tuna shoal and divers entered the water alongside the shark. From that point onward the method of attaching the tag was the same as in South Africa.

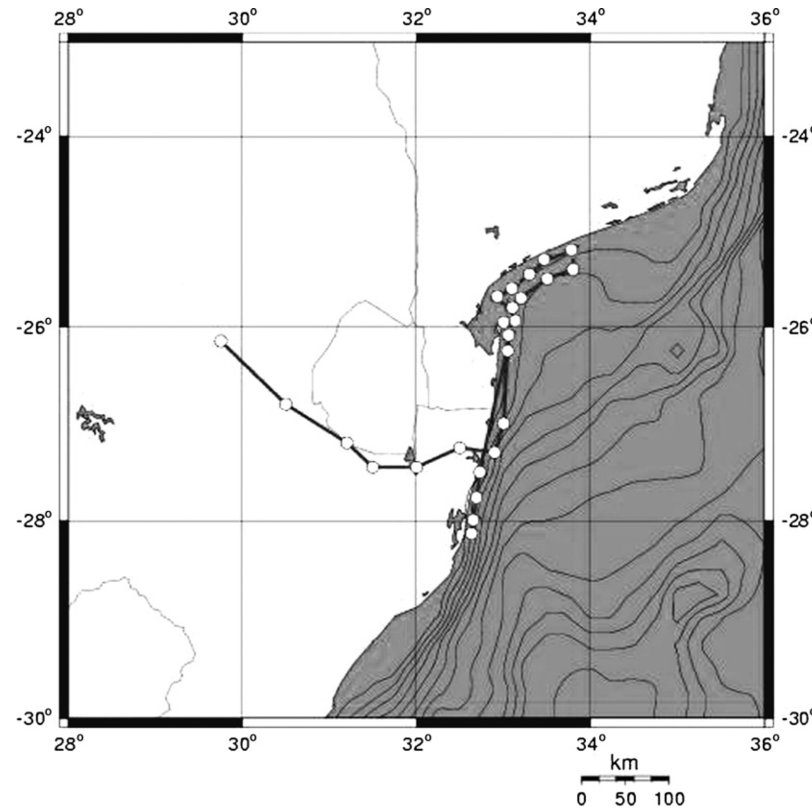

Fig. 3. Track of PTT 05003-1. This shark was tagged at Cape Vidal, South Africa on 8 March 1998. The shark traveled northwards along the coast to Xai-Xai, Mozambique, then southwards to Sodwana. Seventeen days after deployment, transmissions from the tag indicated that it was traveling inland. The tag was recovered near Witbank by the Endangered Species Unit of the South African Police, returned to the Shark Research Institute and redeployed as PTT 05003-2.

3. Results

3.1. Whale shark PTT 05003-1

Results are shown in Fig. 3. This 7-m female whale shark was tagged on 8 March 1998 off Cape Vidal, KwaZulu-Natal, South Africa using a Type I tag anchor and a tether 3 m in length. She travelled northeast along the coast of northern KwaZulu-Natal and Mozambique to Xai Xai, a distance of 499 km. Then the shark swam in an easterly direction and into the Agulhas current, at which time she swam in wide circles diving to depths of 20 m before heading in a southeasterly direction towards the coast of South Africa. Just 17 days later, opposite the fishing/diving resort of Sodwana, the tag moved due west. Subsequent transmissions confirmed the tag had become detached from the host animal and was moving inland. The Endangered Species Unit (ESU) of the South Africa police was contacted. Using a helicopter, foot patrols and coordinates supplied by Argos, the ESU recovered the tag in the home of two fishermen.

3.2. Whale shark PTT 05003-2

Results are shown in Fig. 4. This whale shark, a 7-m male, was tagged on 25 October 1998 off Cape Vidal, KwaZulu-Natal, South Africa with a Type I tag anchor and a 7 m tether. He travelled in a southerly direction and transmissions indicated that the shark remained in shallow water close to shore. Six

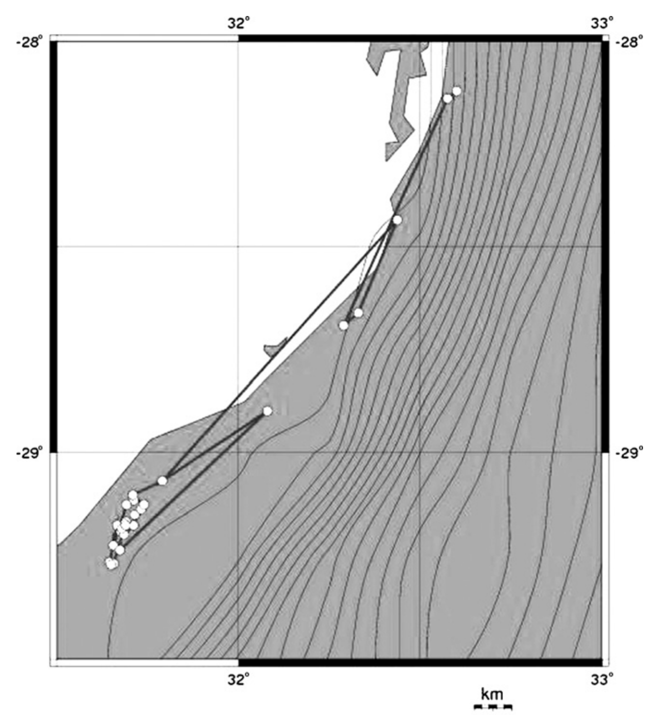

Fig. 4. Track of PTT 05003-2. This shark was tagged at Cape Vidal, South Africa on 25 October 1998. Seven days later the tag, tether and tag anchor washed ashore 90 km to the south at Richard's Bay. The tag was recovered and redeployed as PTT 05003-3.

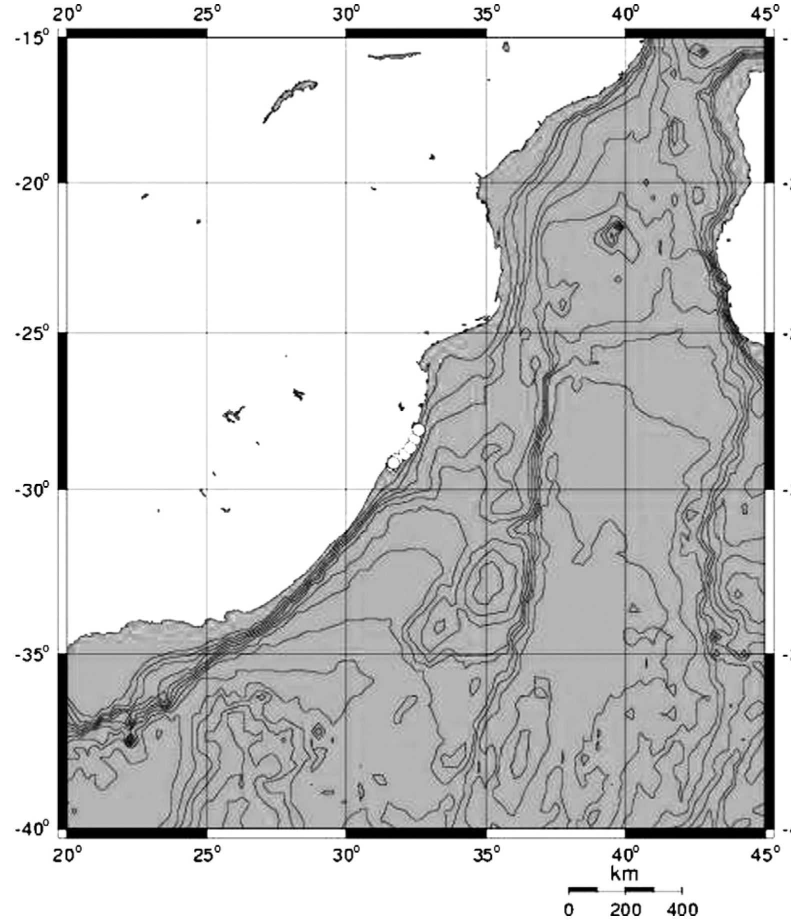

Fig. 5. Track of PTT 05002-3. Transmissions ceased on the second day after deployment. The shark was observed, with tag attached, after the final transmission. The on/of switch was sealed when the tag was repaired following recovery in April 1998, and it was thought the battery may have been depleted shortly after redeployment as PTT 05002-3.

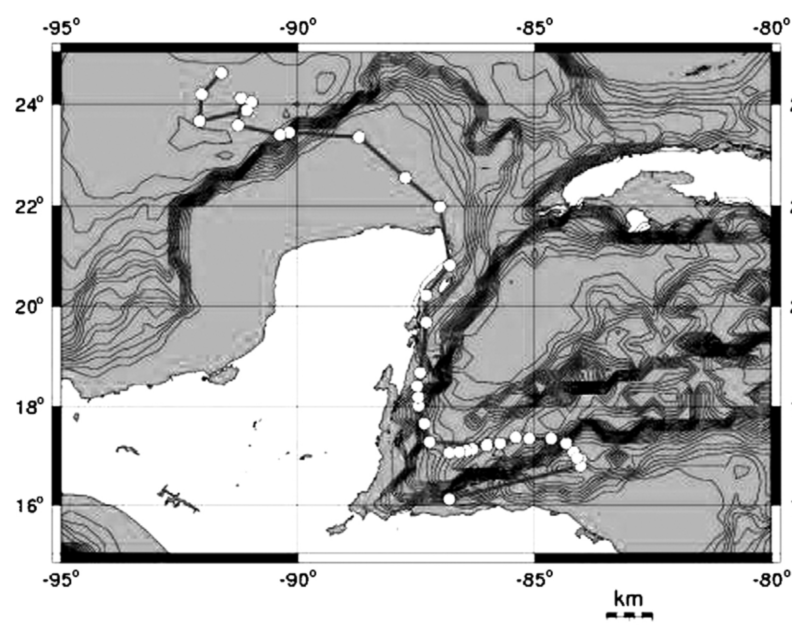

Fig. 6. Track of PTT 08738, deployed 18 February 1999 in the Caribbean Sea off Utila, Bay Islands, Honduras. The shark traveled to the Swan Islands where it remained for 7 days before heading west to the coast of Belize. The shark traveled along the eastern flank of the Yucatan Peninsula, passing the island of Cozumel where the shark, with tag attached, was observed by scuba divers. Then the shark crossed the Campeche Bank and went into the Mexico Basin.

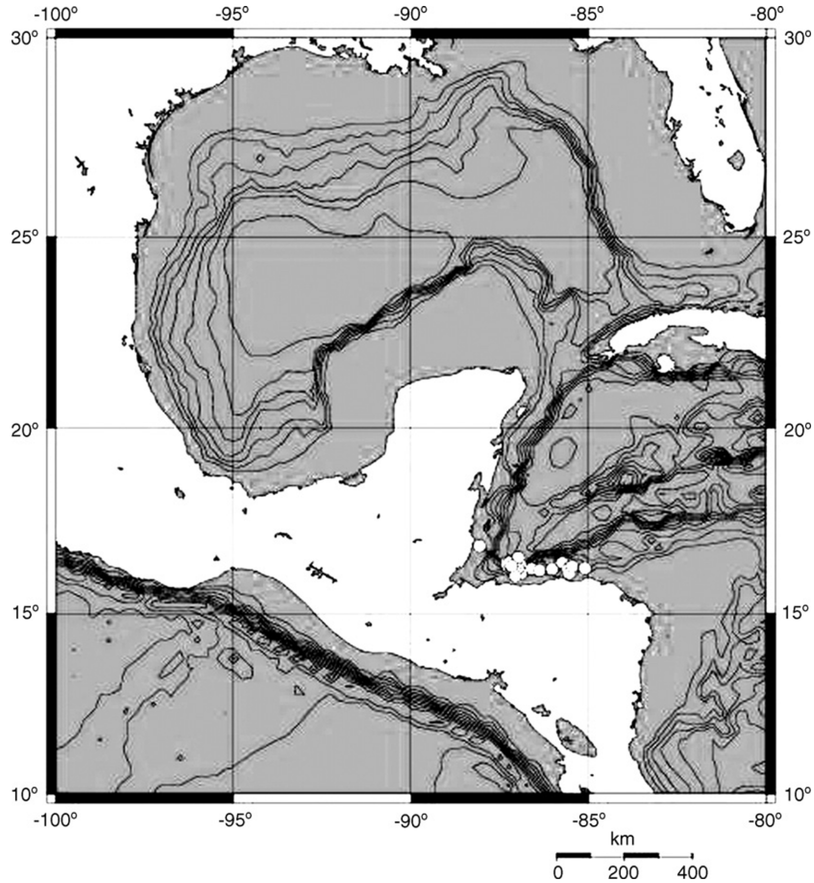

Fig. 7. Track of PTT 08739 in the Caribbean Sea. The tag was deployed at Utila on 31 December 1999, and apparently detached off the coast of Belize 31 days later.

days after tag deployment, the shark entered Richards Bay, a major seaport on the South African coast, 90 km south of Cape Vidal. Two days later the tag, with tag anchor and tether attached, drifted ashore.

3.3. Whale shark PTT 05003-3

Results are shown in Fig. 5. This 8-m male whale shark was tagged on 23 January 1999 at Cape Vidal, KwaZulu-Natal, South Africa. During field trials, prior to deployment of this tag, a Floy-type dart was tested but the design was rejected after it failed to penetrate the shark's epidermis. Instead, the tag was tethered to two Type II tag anchors. Transmissions ceased 2 days after the tag was deployed, and that day, the shark with tag attached, was seen off Sodwana, 65 km to the north of Cape Vidal. This tag had been deployed earlier (PTT 05003-1 and PTT 05003-2) and by 23 January 1999, the battery may have had little life remaining. It is also possible that the detached from the host animal and the weight of the double anchor system prevented it from floating to the surface.

3.4. Whale shark PTT 18738

Results are shown in Fig. 6. This 8-m male shark was tagged 18 February 1999 at Utila, Bay Islands, Honduras using a Type I tag anchor, and a 4.5 m tether. Data from the satellite tag revealed that the shark travelled to the Swan Islands and remained there for 7 days, making dives to 320 m. It was of interest that this shark moved along seamounts rather than across the open sea. Then the shark swam along the coast of the Yucatan Peninsula where it was seen by divers at Cozumel. The shark crossed the Campeche Bank and into the Mexico Basin. Transmissions ceased on 29 June 1999.

3.5. Whale shark PTT 18739

Results are shown in Fig. 7. This 8-m male whale shark was tagged on 31 December 1999 at Utila, Bay Islands, Honduras using a Type III tag anchor and a 1.5 m tether. When this shark was tagged, it was feeding at the surface amid a shoal of black-fin tuna. The shark remained offshore over deep water, which suggests the shark continued feeding on upwellings containing zooplankton (Fig. 8). The shark made repeated dives to depths of >320 m. The tag apparently detached off the coast of Belize 31 days after deployment, but transmissions continued until June 2000.

4. Discussion

Along the South African coast, whale sharks were initially located by fixed wing aircraft. However, fixed wing aircraft have serious limitations. The aircraft are too fast, the turning arc too wide, takeoffs and landings are restricted to airfields that may not be near the area of the sea where the sharks are swimming, and

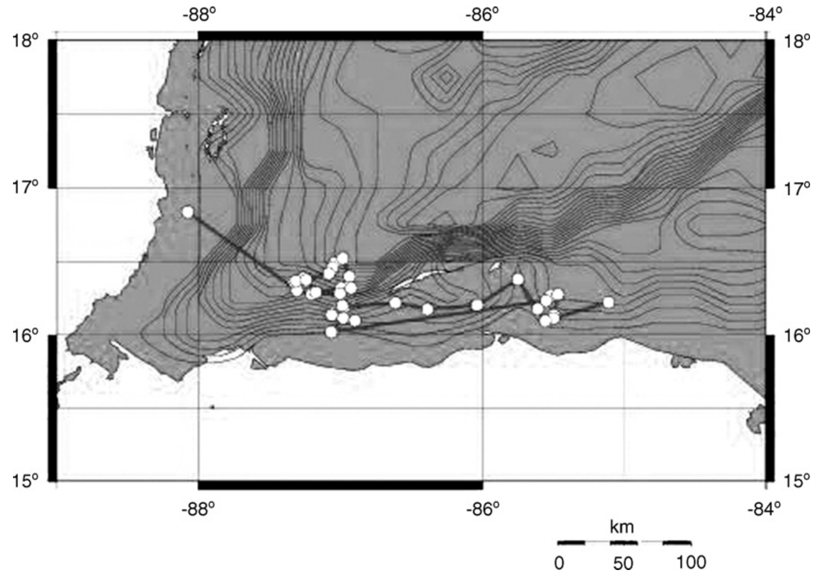

Fig. 8. Close-up view of track of PTT 08739.

they are expensive to operate. By contrast, microlight aircraft served our purpose; it can be flown at low airspeeds and have a tight turning radius. Easily transportable, microlight aircraft can take off and land on the beach and are comparatively inexpensive to purchase, maintain and operate. Although microlight aircraft were not used off Utila, this means of locating whale sharks may be employed there in the future.

4.1. Transmitter design

The transmitter housing continued to be refined throughout this study. Although a dummy tag was used in trials preceding deployment, when PPT 05003-01 was deployed, its antenna was in the correct position to transmit data when the shark was moving slowly beneath the surface. When the tag was floating on the surface, however, the extreme buoyancy of its anterior section caused the antenna to be submerged, and when being towed underwater the tag's angle resulted in increased drag. Before redeployment as PTT 05003-02, a small amount of weight was added to the anterior of the tag and Wildlife Computers provided syntactic foam that was added to the posterior of the tag. This modification corrected the angle of floatation, permitting the tag to float above and behind the shark, and reduced the drag. In October and November 1999, Stevens Institute of Technology in Hoboken, New Jersey, USA, conducted hydrodynamic tests on PTT-08739 and refined the design by the addition of a series of wings that reduced drag to 1.8 kg (4 lb) at 25 nm/h.

4.2. Transmitter attachment

Attachment of the transmitter to the whale shark for an extended period remains the major problem. PTT 05003-01, PTT 05003-02 and PTT 08738 were attached with Type I tag anchors, while PTT 08739 was attached with a Type III tag anchor. PTT 05003-03 was attached with 2 Type II (hinged) tag anchors; the first tag anchor was placed in the shark's first dorsal ridge the second was placed 15 cm posterior to it. A spacer rod 1 m in length was used in conjunction with the tag applicator in an attempt to ensure uniform penetration depth of the tag anchors, and both tag anchors were coated with a gel antiseptic immediately prior to deployment. Initially, we were overly cautious in limiting penetration depth of tag anchors to the dermal layer of the shark's skin and better results were obtained by placing them in the musculature of the shark.

Disadvantages of a tethered system are related to the likelihood of entanglement, particularly in areas where there is considerable boat traffic and rock reefs. Along the KwaZulu-Natal coast of South Africa whale sharks travel so close to the beach (50–500 m) that several sharks strand each year and entanglement of a tether in rocks or reefs is a significant hazard. This is not a problem in the waters surrounding Utila, however, a video taken of the deployment of PTT 18738 indicated the shark's caudal fin was coming into contact with the tag as it was being towed, suggesting that either a longer or shorter tether might reduce the likelihood of premature detachment.

ADS processing from Service Argos provided locational data received from the satellites, LC 3 being the most accurate, 2, 1, A, B were less accurate in that order, and Z transmissions were disregarded. The Satpak program supplied by Wildlife Computers converted additional data about the sharks' diving profiles (depth, duration and time of day) from the platform sensors into a format that permitted interpretation. OMC Generic Mapping tools (http://www.gmt.soest.hawaii.edu) was used to plot the track of the PTTs.

Locational data were combined with diving depth and other environmental data to provide clues about the species' habitat use. Transmissions from the tags indicated the sharks ranged through the water column from the surface to depths of >320 m. It had been thought, due to their coloration, that whale sharks remained close to the sea surface; instead we found they swam to depths of >320 m, often several times a day. This finding was also confirmed by a study conducted by Rachel Graham (pers. com.). It was also of interest that one of the whale sharks (PTT 18738) tagged in the Caribbean moved along seamounts rather than across the open sea.

Because the tags were also programmed to record maximum diving depth, when transmissions indicated a PTT was remaining at the surface for several days it was a signal the tag had detached from the host animal. At that time, we either attempted recovery of the PTT or notified Service Argos that no further processing was necessary.

5. Conclusion

Satellite telemetry is a useful tool in tracking the global movements of whale sharks. In contrast to traditional tagging programs that take many years to accumulate information, it provides real-time data. Indeed, it is the only tool available at present that provides such data about the species movement through the water column.

Long-term batteries are able to power transmission of data for up to a year, however, PTT design needs refinement to minimize or eliminate drag that may result in premature detachment and the use of biologically inert materials, such as Dacron, Nylon or Teflon, in manufacture of tag anchors should be explored. In this study, tag anchors placed in the musculature of the shark had a higher retention rate than those placed in the dermis. When a tag detaches prematurely from a host animal recovery and redeployment of the tag on another animal may be possible. It is essential that tags are programmed to transmit diving depths in order to ascertain when the tag detaches from the host animal and avoid using satellite time unnecessarily. Data retrieved to date supports anecdotal information regarding the occurrence of this species in nearshore waters and offshore islands.

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