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research paper

Impact of satellite linked radio transmitting (SLRT) tags on the dorsal fin of subadult and adult white sharks (*Carcharodon carcharias*)

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ABSTRACT.—Satellite linked radio transmitting (SLRT) tags provide long-term, high accuracy, near real-time tracking data for marine wildlife. Adult white sharks (*Carcharodon carcharias* Linnaeus, 1758) in the northeastern Pacific at both Guadalupe Island, Mexico and Southeast Farallon Island, USA were tagged with SLRT oval and inline finmout tags. These tags provided up to 7.4 yrs of tracking data. A previous study showed structural dorsal fin damage for SLRT tagged juvenile and subadult white sharks off South Africa. Sharks tagged in the northeastern Pacific were resighted between 1 and 11 yrs post tagging and included 10 adults and 2 subadults. Sharks that were resighted did not exhibit significant fin deformation, although in one case the oval finmount tag did cause bending of the dorsal fin due to tag shape, weight, and placement of the tag on the dorsal fin. Four inline tags came off after deployments of at least 2.2 to 3.7 yrs (based on date of last message received), and two of these caused a tear to the trailing edge of the dorsal fin upon release. Overall, SLRT tags provided long-term tracking data and there was no apparent impact on the behavior or migration cycles of the sharks. Serious dorsal fin deformation seems to occur in the case of juvenile and subadult white sharks where the fin is rapidly growing and thus for tracking juvenile white sharks, alternate methods should be considered.

The advent of electronic tagging technology has revolutionized the study of the movement patterns and habitat preferences of migratory marine animals including the white shark (*Carcharodon carcharias* Linnaeus, 1758). Pop-up satellite archival tags (PSAT) offered the first insight into the behavior and migration patterns of northeastern Pacific white sharks (Boustany et al. 2002, Weng et al. 2007, Domeier and Nasby-Lucas 2008), but they are unable to provide tracks greater than one year. Another electronic tag developed for marine species is the satellite linked radio transmitting (SLRT) tag. The use of SLRT tags on white sharks at Guadalupe Island (GI), Mexico have allowed for multi-year tracks, producing data on the life history and migratory patterns of northeastern Pacific white sharks, particularly for females that were found to exhibit a 2-yr migration cycle associated with reproduction and pupping (Domeier 2012, Domeier and Nasby-Lucas 2012, Domeier and Nasby-Lucas 2013).

SLRT tags work best on species that consistently spend time at the surface, since the tags begin to actively transmit and provide location data once they are out of the water. Geographic locations are determined via Doppler-shift calculations made by the Argos satellite location and data collection service whenever a passing satellite receives two or more signals from a transmitting tag. SLRT tags are typically affixed to the dorsal fin by through-bolting with two to four bolts to secure the tag with the antennae high on the fin to optimize the successful signal transmission to the Argos Satellite system while the shark is at the surface.

For many species of sharks, the individual tagged shark is rarely recaptured or resighted, so the long-term impact of tag attachment on the shark is unknown. White sharks offer a unique opportunity to study the impact of tag attachment since subadult and adult sharks are philopatric to aggregation sites (Weng et al. 2007, Domeier and Nasby-Lucas 2008) and are frequently resighted and photographed by researchers and recreational cage divers. Jewell et al. (2011) reported observations of major dorsal fin deformities for juvenile and subadult white sharks that had carried an SLRT tag for 12–24 mo. This finding caused ethical concerns among both scientific and public communities, spurring the need to re-evaluate the use and impact of SLRT tags.

A long-term photo-identification monitoring program at Guadalupe Island (GI), Mexico (Domeier and Nasby-Lucas 2007, Nasby-Lucas and Domeier 2012, Sosa-Nishizaki et al. 2012) has provided the opportunity to study individual white sharks over a span of nearly two decades. A similar long-term photo-identification program exists in central California (Anderson et al. 2011). In light of previous studies that have reported adverse effects of SLRT tags to the dorsal fin of tagged juvenile and subadult white sharks (Jewell et al. 2011), the goal of this study was to use these photo-identification databases to identify resighted sharks and examine the long-term effects of SLRT tags on dorsal fins of subadult and adult white sharks tagged at GI and Southeast Farallon Island, California (SEFI).

Methods

White sharks were tagged at GI, Mexico (lat 29.12, long –118.27), and SEFI, USA (lat 36.69, long –122.99) as previously described (Domeier and Nasby-Lucas 2012). SLRT tag styles used were 5 SPOT5 3xAA oval finmount (Wildlife Computers, Redmond WA, USA), and 7 SPOT5 4xAA inline finmount tags. Antifouling paint was applied to the tags in all areas except the wet/dry sensors and the antennae. SLRT tags were affixed to the apex of the shark's first dorsal fin by drilling four small holes through the fin and securing the tag with plastic bolts. For each shark, sex and length [total length (TL)] were recorded, and photos were taken to identify the individual shark prior to release (Table 1).

Photographs of resighted sharks were collected from either recreational cage diving or research vessels. High-quality photographs from each year displaying the fin and tag were collected when available. GI sharks were identified using the Guadalupe Island white shark photo-identification database (Domeier and Nasby-Lucas 2007, Nasby-Lucas and Domeier 2012) and the SEFI shark was identified using the central California white shark photo-identification database (Anderson et al. 2011).

Table 1. Resighted tagged sharks indicating tag number and sex, total length (TL) in cm, date the shark was tagged, type of tag used, location the shark was tagged, years the shark was resighted post tagging, date of last resighting, date of the last message transmitted to the Argos satellite system, date of the last location transmitted to the Argos satellite system, and if the tag came off.

Tag	TL	Date tagged	Tag type	Tagging location	Years shark resighted	Date of latest resighting	Date of last transmitted message	Date of last transmitted location	Tag came off
85M	315	12/06/2007	Oval	GI	2012	11/15/2012	03/10/2014	03/05/2011	
97M	368	12/06/2007	Oval	GI	2008–2018	08/08/2018	11/20/2009		
79M	368	12/08/2007	Oval	GI	2008–2009, 2011–2012	08/14/2012	12/30/2010	04/08/2008	
146F	396	12/08/2007	Oval	GI	2008–2009, 2012, 2014	11/14/2014	07/19/2010		
77F	508	12/03/2008	Inline	GI	2009, 2011, 2013	10/19/2013	09/04/2016	05/01/2016	
14M	442	12/04/2008	Inline	GI	2009–2011	11/09/2011	12/09/2011	12/09/2011	
49M	457	12/04/2008	Inline	GI	2009, 2011, 2013–2015	12/07/2015	03/23/2013	10/03/2011	
33M	447	12/06/2008	Oval	GI	2010–2014	08/09/2014	03/19/2011	11/19/2010	
7M	457	12/07/2008	Inline	GI	2009–2012, 2014–2015	09/23/2015	07/30/2012	03/11/2012	X
FI2M	452	11/02/2009	Inline	SEFI	2011–2012	10/16/2012	04/02/2012	11/29/2011	X
6F	462	11/19/2009	Inline	GI	2014–2015	10/13/2015	01/28/2012	01/25/2012	X
19M	439	11/19/2009	Inline	GI	2010–2014, 2016–2017	09/04/2017	04/19/2012	04/10/2012	X

Results

Twelve SLRT tagged sharks were resighted in subsequent years, including four GI sharks tagged in 2007, five GI sharks tagged in 2008, two GI sharks tagged in 2009 and one SEFI shark tagged in 2009. These SLRT tags provided between 0 and 2706 days [mean 873 (SD 724)] of satellite tracking data (Table 1). The five oval finmount tags provided location data from 0 to 1185 days [mean 404 (SD 527)], while the eight inline finmount tags provided location data between 757 and 2706 days [mean 1208 (SD 679)]. Mean track duration was significantly longer for inline finmount tags than oval finmount (Mann-Whitney rank sum test, $P = 0.004$).

Tagged sharks were resighted multiple times from 1 to 11 yrs following tag deployment (Table 1). The longest duration between tagging and last resighting was for an oval finmount tag (97M) deployed in December 2007 and resighted in August 2018. This tag had excessive biofouling and the dorsal fin exhibited a slight deflection away from the side of the fin where the tag was attached (Figure 1). The longest duration of resighting for an inline finmount tag was 7 yrs (49M) (Figure 2). The inline finmount tag did not cause a bend in the dorsal fin.

The resighted tagged sharks included ten adults and two subadults [males mature at about 360 cm and females at about 450 cm TL (Francis, 1996, Bruce and Bradford 2012)]. The subadults included a 315 cm TL male (85M) with latest resighting 5 yrs after tagging, and a 396 cm TL female (146F) with latest resighting 7 yrs after tagging (Figure 3). Both subadults were tagged with oval finmount tags that exhibited biofouling, but the dorsal fins of these sharks did not show signs of deformation or bending 5 and 7 yrs post tagging, respectively.

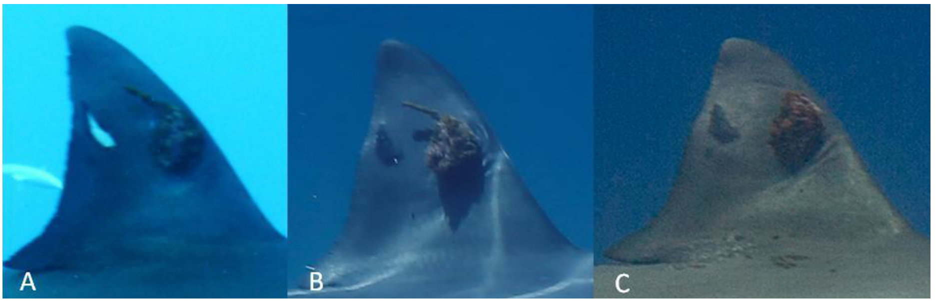

Figure 1. Dorsal fin of GI white shark 97M in (A) 2009, 2 yrs after tagging, (B) 2014, 7 yrs after tagging, and (C) 2017, 10 yrs after tagging.

The tags of four of the resighted sharks with inline finmount tags were shed after deployment durations of at least 2.2 to 3.7 yrs (based on date of last message received) (Table 1). These were sharks 6F, 7M, 19M, and FI2M (Figure 4). In all cases the bolt holes had healed. Since all four bolts do not break simultaneously when a tag is shed, the last bolt to break caused a tear in the trailing edge of the dorsal fin for two of the four sharks.

Discussion

The current study presents data on the performance and fin impact of 12 SLRT tags on white sharks tagged in the northeastern Pacific. Tagged sharks include both subadult and adult white sharks and all were resighted between one and 11 yrs post tagging with minimal impact to the dorsal fins. These tags provided multi-year tracking data with tracks as long as 7.4 yrs, resulting in multiple peer-reviewed publications with information on the life history of northeastern Pacific white sharks, data on the 2-yr migrations of mature females, and insights into the timing and location of mating, gestation, and pupping (Domeier and Nasby-Lucas 2012, Domeier et al. 2012a, Domeier et al. 2012b, Domeier and Nasby-Lucas 2013).

In this study, it was noted that the shape or placement of the tag had some effect on the fin and the successful data transmission of the tag. One oval finmount was found to cause a bend in the dorsal fin, while the inline finmount tag did not cause the same bending of the dorsal fin. The condensed shape and weight of the oval finmount tag may have caused the dorsal fin to bend. The oval finmount also required a lower placement on the fin which may have made it more difficult to extend the tag

Figure 2. Dorsal fin of GI white shark 49M in (A) 2011, 3 yrs after tagging, (B) 2014, 6 yrs after tagging, and (C) 2015, 7 yrs after tagging.

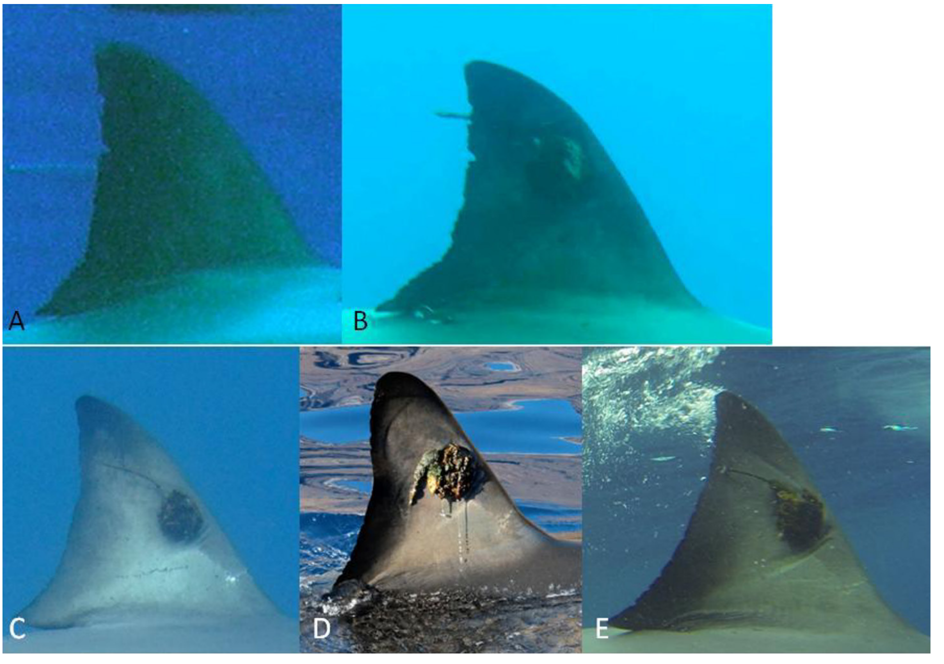

Figure 3. Dorsal fin of subadult (A) GI white sharks 85M in 2007, 2 mo before tagging and (B) 2012, 5 yrs after tagging and (C) shark 146F in 2009, 2 yrs after tagging, (D) 2012, 5 yrs after tagging, and (E) 2014, 7 yrs after tagging.

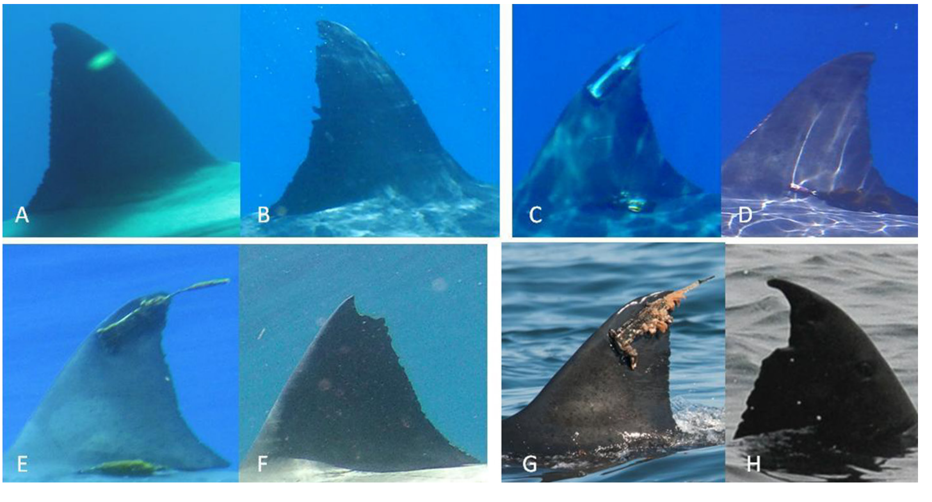

Figure 4. Dorsal fins of (A) GI white shark 6F in 2009 prior to tagging and in (B) 2014 after the tag came off, (C) GI white shark 7M in 2009, 1 yr after tagging and (D) 2012 after the tag came off, (E) GI white shark 19M in 2010, 1 yr after tagging and (F) 2013 after the tag came off, and (G) FI2M in 2011, 2 yrs after tagging and (H) 2012 after the tag came off.

out of the water when the shark was at the surface, and thus to activate the wet/dry sensor to turn on the tag and send messages to the Argos satellite array. For use with large sharks such as white sharks, the inline finmount is preferable due to its long-term tracking capabilities and lower impact on the dorsal fin. The inline finmount tags were deployed with plastic bolts so that the tags would eventually be shed when the plastic degraded and the bolts broke. Unfortunately, the bolts did not break at the same time, presumably causing them to tear the trailing edge of the dorsal fin in two cases. The sharks with the tears in the dorsal fins were resighted for an additional five yrs after the tag came off and no adverse effects were noticed in the behavior of the sharks. On a population level, moderate to severe fin damage (including complete amputation) is a common occurrence in white sharks from bites from conspecifics or boat damage (Domeier and Nasby-Lucas 2007).

The impact of the SLRT tags on the sharks in the current study were minor compared to previous results reported for juvenile and subadult white sharks (Jewell et al. 2011). The Jewell et al. (2011) study included six juvenile white sharks and at least five subadults (sex was not provided) and found that placement of SLRT tags on small sharks with a fin that is still rapidly growing can cause permanent gross deformation of the fin. Subadult and adult white sharks in the current study did not exhibit gross fin deformation.

Despite the use of antifouling paint, biofouling was noted in all tags 2-3 yrs post deployment. Biofouling is an issue as it can cover the wet/dry sensor and prohibit the tag from sending messages. Biofouling is one of the largest obstacles to high-quality data returns from electronic tags used in the marine environment.

In conclusion, this study shows that SLRT tags are a valuable tool for obtaining multi-year tracks for large white sharks with little impact on fins. These results show that SLRT tags did not appear to alter the behavior of the tagged sharks, since the SLRT derived tracks were similar to those derived by PSATs (Domeier and Nasby-Lucas 2012, Domeier and Nasby-Lucas 2008). Furthermore, the degree of physical impact to the dorsal fin was much less than the impact observed on juvenile and subadult white sharks (Jewell et al. 2011). The impact of SLRT tags on adult and large subadult white sharks varied from none to a tear in the trailing edge of the fin. Until there is a better method for collecting multi-year tracking data from white sharks, we conclude that the data that results from SLRT tags deployed on adult white sharks is worth the risk of a slight deformation to the dorsal fin. Inline finmount tags proved to be superior for use with adult white sharks over oval finmount tags, providing longer tracks and minimal impact to the dorsal fin. Although this study did not show damage to the fins of tagged subadult white sharks, previous studies have shown a significant impact to the fins of juvenile and subadult white sharks (Jewell et al. 2011), and it is recommended that SLRT tagging of juvenile white sharks should be avoided and other tagging options explored.

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