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*Research Article*

# Pilot acoustic tracking study on young of the year scalloped hammerhead sharks, *Sphyrna lewini*, within a coastal nursery area in Jalisco, Mexico

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**ABSTRACT.** A preliminary experience to study, on a small scale, the movements of the young of the year (YOY) *Sphyrna lewini* (Griffith & Smith, 1834), in the Mexican Central Pacific, using acoustic telemetry within a nursery area. From October to December 2014 seven sharks were tagged with ultrasonic transmitters and tracked for 68 days within a 14 $km^2$ area associated to a river mouth. The quick shark handling allowed their release in less than two minutes and excellent health condition. Although recaptured sharks up to 105 days after tagging did not show symptoms of scar infection, a slight abrasion in the shark skin was observed after 51 days. The ultrasonic transmitter retention was 75%, and the site fidelity was complete (F = 1) during the first ninety days. For the 135-day period, fidelity was 0.63 (0.40-0.80), and the estimated attrition rate was 0.73 (0.34-1). Ninety-seven percent of detections occurred on soft bottoms and less than 30 m depth. The YOY *S. lewini* stayed active 24 h a day and performed estimated movements of 11.96 km during that time. The home range for all tagged sharks was estimated to be 4.82 $km^2$ using the minimum convex polygon method (MCP) and 4.89 $km^2$ using the kernel utilization distribution method (95% KUD). The KUD estimation showed two core areas within the study area, is the one located in front of the river mouth the most used.

**Keywords:** *Sphyrna lewini*, Sphyrnidae, telemetry, juvenile, site fidelity, home range.

## INTRODUCTION

Coastal zones are used as a nursery area for many shark species (Diemer *et al.*, 2011; Ward-Paige *et al.*, 2015; Yates *et al.*, 2015). Heupel *et al.* (2007) suggested that a shark nursery area could be defined based on three primary criteria for the newborn or young of the year (YOY, *i.e.*, individuals <1-year-old): 1) sharks are more commonly encountered in the area than in other areas, 2) sharks tend to remain or return for extended periods, and 3) the area or habitat is repeatedly used throughout the years. Generally, nursery areas are usually highly productive, turbid, shallow areas, generally outside of the feeding grounds of adult sharks (Springer, 1967), that provide protection for the young against predators and availability of food during their initial development (Castro, 1993; Simpfendorfer & Milward, 1993; Carlson, 2000). The coastal habitats used as nursery areas by the sharks are usually bays (Clarke, 1971; Munroe *et al.*, 2015), coastal lagoons (Heupel & Simpfendorfer, 2008; Curtis *et al.*, 2011), mangroves (Snelson & Williams, 1981; Morrissey & Gruber, 1993; Chapman *et al.*, 2009), and river mouths (Heupel *et al.*, 2006; Heupel & Simpfendorfer, 2008).

*Sphyrna lewini* presents a circumglobal distribution in temperate coastal waters and tropical seas (Compagno, 1984). It is a species with high commercial value in the fisheries of countries like Australia, South Africa or Brazil (FAO, 2017) and is highly prized in the Asian market for having fins of considerable size and quality (Abercrombie *et al.*, 2005). However, high fishing pressure led to the decline of many of its populations, as in Costa Rica where the population is estimated to have fallen by 50% since 2002 (SINAC, 2012), 95% in Mauritanian waters since 1999 (FAO, 2013) or 73% reported in Queensland, Australia between 2005 and 2016 (QLD DEEDI, 2017). *S. lewini* is an abundant species in Mexican waters, especially in the Pacific region. Important catches have been reported in the region comprising the entrance of the Gulf of California, including the coastal waters of Nayarit and southern Sinaloa, Isabel Island and the

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Marias Islands Archipelago (Pérez-Jiménez *et al.*, 2005; Torres-Huerta *et al.*, 2008; Márquez-Farías *et al.*, 2009; Furlong-Estrada *et al.*, 2015), Michoacán (Anislado-Tolentino, 2000; Anislado-Tolentino *et al.*, 2008), and Gulf of Tehuantepec (Alejo-Plata *et al.*, 2006; Bejarano-Álvarez *et al.*, 2011; CITES, 2013). During at least seven decades an artisanal shark fishery has operated in the entrance to the Gulf of California (Pérez-Jiménez *et al.*, 2005; Furlong-Estrada *et al.*, 2015), where *S. lewini* has been reported the most important species around Isabel Island (Pérez-Jiménez *et al.*, 2005). In the Gulf of Tehuantepec, *S. lewini* has been reported the second most important species (Alejo-Plata *et al.*, 2006). In the three regions *S. lewini*, catches are mainly composed of neonates and juvenile sharks, which in many cases may represent more than the 90% of total catch (Torres-Huerta *et al.*, 2008; Furlong-Estrada *et al.*, 2015). Neonates accounted for 56.8% of the total catch of *S. lewini* in the Gulf of Tehuantepec between 1996 and 2003, where a yearly 6% reduction of the population was estimated by Soriano-Velásquez *et al.* (2006).

In the last decades, acoustic telemetry has become an essential tool to know more precisely the movements and habitat use of different shark species in nearshore areas. For example, this allowed to know how *Carcharhinus leucas* uses different parts of the nursery area according to the time of day (Heupel & Simpfendorfer, 2008), *C. amboinensis* performs seasonal movements (Knip *et al.*, 2011), or that *Sphyrna tiburo* leaves the nearshore area when salinity and temperature change (Heupel *et al.,* 2006). Thanks to telemetry, it was observed an increase of the habitat range of *C. limbatus* during their first development months (Heupel *et al.*, 2012), or that it remains constant for *S. tiburo* (Heupel *et al.*, 2006). Differential movement patterns between day and night have been observed for *S. lewini* in a bay of the Oahu Island, Hawaii, with an increase of the activity and habitat range during the night due to feeding activity (Holland *et al.*, 1992, 1993; Lowe, 2002). Therefore, thanks to ultrasonic telemetry, it is possible to know more precisely how and when coastal sharks use nearshore habitats. The knowledge of the spatial ecology can help determine whether a marine protected area (MPA) may be the better conservation strategy for a shark population (Simpfendorfer *et al.*, 2011). On the other hand, fine-scale movement data tracking from previous studies can be used to improve the conservation management of shark populations, as the delimiter of a more effective MPA or a better fishery management plan can be designed (Simpfendorfer *et al.*, 2010, 2011; Wiegand *et al.*, 2011).

Fishers' ecological knowledge and previous research showed that *S. lewini* uses the coastal zones of south Jalisco as nursery areas, and YOY were observed from mid-June to mid-March (Corgos *et al.*, 2016). This document has the purpose of carrying out a pilot study in a nursery area of *S. lewini* in Jalisco, assess the methodology for YOY tagging and obtain the first data of small-scale movement patterns of this species to create a baseline of knowledge for subsequent studies.

## MATERIALS AND METHODS

The study was carried out in a 14 $km^2$ area located in the south coast of Jalisco known as Rebalsito (Fig. 1). This zone is a 7 km long, high-energy beach in which the mouth of the Purificación River is in its middle part (19º17'71"N, 104º54'88"W). The hydroclimatic conditions of the zone show an evident seasonal pattern, with three differentiated periods: mixed, semi-mixed, and stratified (Ambriz-Arreola *et al.*, 2012; Kozak *et al.*, 2014).

The mixed period runs from February to May, when the Mexican Coastal Current (MCC) is stronger (Gómez-Valdivia *et al.*, 2015), the absence of rain (and input of continental water through the rivers), and especially, the coastal upwelling events (López-Sandoval *et al.*, 2009) cause a notable decrease in the surface seawater temperature (<25°C), and high salinity (34.5, Kozak *et al.,* 2014). The stratified period runs from July to November, when the MCC weakens and the rainy season is present (Filonov *et al.*, 2000), it is characterized by higher surface seawater temperature (>28°C) and lower salinity (<34, Kozak *et al.*, 2014). The semi-mixed period is a transition period and occurs in December, January, and June, and temperature and salinity have intermediate levels between the two periods. The variability in the rain volume each year determines the opening (July-August) and closing periods (November-December) of the river mouths. Physical characterization of the bottom was carried out to obtain the bathymetric profile and the type of substrate using a Lowrance Sonar HDS-7 Gen2 Touch. Eighteen longitudinal transects were performed with a distance between them ranging from 200 m in the deepest zone to 50 m in the shallowest. A more detailed characterization was carried out in the areas where a bottom with greater structural complexity was observed to obtain a more accurate bottom profile.

Shark pups were caught using an experimental longline with 30 barbless circular hooks (Corgos *et al.*, 2016). Biological data were taken from each caught shark (total length TL, fork length FL, weight, sex and umbilical scar status), and afterward, each shark was tagged and released in the same capture area. A shark was considered a neonate when showed the umbilical scar partially or entirely open, considering that it has less than 15 days old (Duncan & Holland, 2006). The

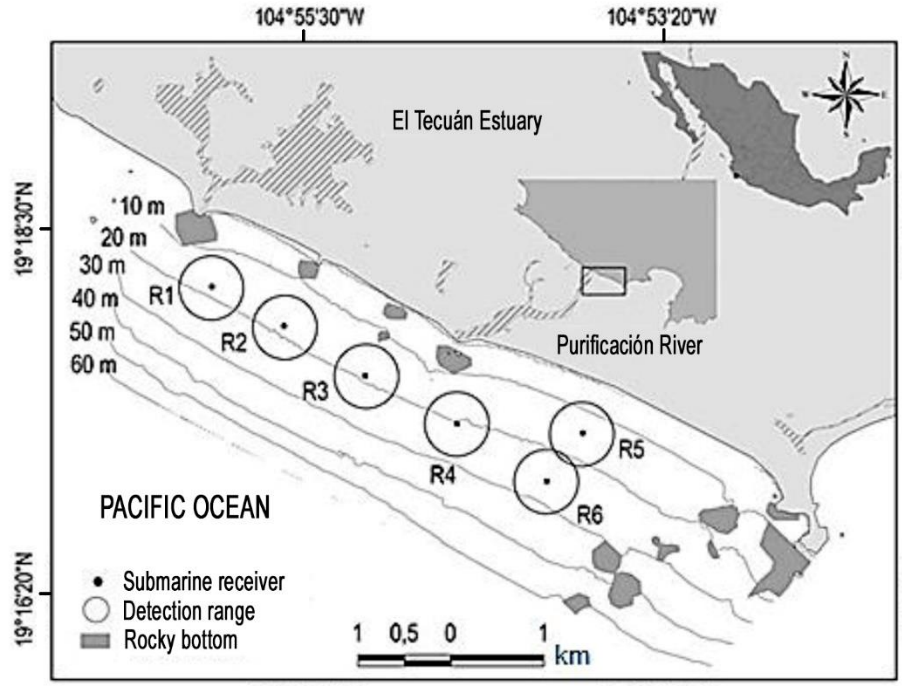


**Figure 1.** Study area with positions of the VR2W underwater receivers showing a 350 m radius detection range.

release health condition was recorded following the "vitality code" used in previous studies of shark tagging (Hueter & Manire, 1994; Hueter *et al.*, 2007): Condition 1 (Good): No revival time required when the shark is returned to the water. Rapid swimming away upon release, usually with a vigorous splash, Condition 2 (Fair): No revival time required. Slow but strong swimming away upon release, Condition 3 (Poor): Short revival time (up to 30 s) required. Once revived, slow but sometimes atypical swimming away upon release. Condition 4 (Very poor): Long revival time (more than 30 s) required. Once revived, limited or no swimming observed upon release but respiration functional. Condition 5 (Dead): Dead upon removal from gear, or moribund and unable to revive even after long resuscitation time.

Tags used were T bar anchor FD94 (Floy-Tag) and Vemco V9-2H ultrasonic transmitter attached to a modified dart tag (reduced and sharpened stainless-steel FH-69, Floy-Tag, Fig. 2). Each V9 transmitter weights 2.9 g in the air and is 21 mm long and 9 mm diameter. All tags were programmed with a 60 s nominal code transmission delay (40-80 s range) during the first month, 90 s (60-180 s range) for the second month, and 120 s (110-250 s range) for the rest of the battery life (up to 231 days).

The total weight of the tag and anchoring was 4.4 g, with a total length of 70 mm. The dart was inserted on the right side, on the base of the first dorsal fin, and the T tag on the left side to identify the shark in case of trans-


**Figure 2.** External anchoring system for the Vemco V9-2H ultrasonic transmitter. The stainless-steel dart tag FH-69 (Floy-Tag) modified and reduced and attachment to the transmitter are shown.

mitter loss. All efforts were made to minimize animal suffering during capture, and tagging procedures followed American Fisheries Society guidelines (Jenkins *et al.*, 2014).

Two methods tracked tagged sharks: 1) active tracking from a boat and 2) passive tracking by using six underwater VEMCO VR2W receivers. Daytime was divided into four periods: dawn (06:00-9:59), day (10:00-17:59), dusk (19:00-21:59), and night (22:00-5:59); with the purpose of looking for differences in the use of the area based on the time of day.

A continuous 48 h active tracking was carried out on 28 October, 2014 on the first tagged shark, and 24 h on the following two tagged sharks (29 October). Subsequently, a weekly active tracking was carried out until February 12, 2015, after tracking three consecutive times without detecting any of the tagged sharks in the study area or adjacent zones (100 km of coastline). Weekly active tracking consisted in dividing the 7 km long by 2 km wide zone in a grid of 800 m per side and check during 120-220 s with a VH165 (Vemco) omnidirectional hydrophone for the presence of the tagged sharks. When a tagged shark was detected within the grid, a VH110 (Vemco) unidirectional hydrophone was used to locate their exact position. The location of the VR2W underwater receivers was decided after the first active tracking experience. These were placed at a distance of 800 m from each other, 800 m from the shore and from 2.5 km to the north of the river mouth and up to 1.5 km to the south, ranging from 14 to 30 m depth (Fig. 1). The receiver located in front of the river mouth was placed with a stainless-steel screw bracket in the sandy bottom (Villegas-Ríos *et al.*, 2013) on 19 December 2014 and the rest were attached to a rope with weight and buoy on 9 January 2015. Each receiver was placed at 1-1.5 m from the bottom. All receivers were removed on 10 March to download data. We conducted range tests in the nursery area to determine the maximum distance of detection of the ultrasonic transmitters by the receivers. These tests were performed at a maximum distance of 600 m from the VR2W receivers. One V9-2L range test tag, with a nominal delay of 7 s was lowered to a depth of 15-20 m, and we waited for an interval of 30-60 s every 50 m until the 50 m distance was reached. In the two places where the range test was performed, the receivers were able to listen to the transmissions in a range of 390 m or less, however, 23.3% of detections occurred between 290 to 325 m, 36.7% of detections occurred between 240 and 285 m, and 61% of detections occurred between 160 to 200 m.

The ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA) and Statistica 12 (Statsoft Inc., Tulsa, OK) software were used for the spatial analysis and its representation. The calculation of the home range was obtained with the Adehabitat package for R software (Calenge, 2006). Two methods were used to analyze the home range: "minimum convex polygon" (MCP) (Mohr, 1947) and the Kernel Method (Silverman, 1986; Wand & Jones, 1995) which calculates the "Utilization Distribution" (UD). The results are expressed as mean ± SD. The model "Joint live encounters and dead recovery data" from the Mark program was used (White & Burnham, 1999) to estimate the survival and fidelity to the habitat. The same program was used to estimate the attrition rate, which is the total abandonment rate of the study area, *i.e.*, the sum of natural mortality, fishing mortality and emigration rates (Duncan & Holland, 2006). U-Care program was used for the goodness-of-fit test for the model (Choquet *et al.*, 2009).

## RESULTS

Seven juvenile *S. lewini* were tagged with ultrasonic transmitters between 27 October and 8 December 2014: four females and three males with a TL ranging between 53.7 and 72.1 cm (Table 1). All sharks showed a wholly healed umbilical scar, so they were considered YOY. Taking biological data and tagging each shark took less than 2 min, which allowed releasing most sharks in an optimal health condition (71.4% released in state 1). The relation weight of the transmitter/weight of the organism relation never exceeded 0.65%.

Four of the seven tagged *S. lewini* were caught and reported by fishermen, another shark disappeared from the area after numerous recordings in the underwater receivers on previous days, and another one was detected in the same position for two months after 53 days of normal detections. In these last two cases, it could have been due to predation, unreported fishing (probably) or tag loss. The average attrition rate of tagged sharks was estimated to be 0.73 (0.34-1) for a 135 day period, although the goodness-of-fit test showed that there is not enough number of tagged sharks for an accurately adjusted model.

Two of the recaptures obtained by the fishermen had severe injuries inflicted by other predators, which suggests that besides high fishing mortality they have significant natural mortality (Fig. 3c).

Three sharks recaptured between 9 and 51 days after released had the transmitter correctly anchored. Another one was caught after 105 days without the transmitter. In periods of less than 51 days, the transmitter retention rate was 100%, while in periods of up to 105 days it was 75%. These recaptured sharks (after 9 and 51 days since they were tagged) did not show symptoms of scar infection (Figs. 3a, 3b). We also observed that after 51 days the transmitter caused a slight abrasion in the shark skin, which wasn't present in the individual recaptured after nine days indicating that this type of anchoring can cause some damage on the medium-long term.

### Habitat use

The study area has a bathymetric profile with a gentle slope of 2.4%, and depths of up to 60 m at 2.5 km from the shore (Fig. 4).

The study area showed a soft substrate in 87% of the area and a central rocky part in front of the river mouth and in both ends which add up to an area of 0.33 $km^2$. More than 99% of the detections during active tracking were located at a depth of less than 30 m (less than 1.5 km from the shore), and approximately 70% were located between 10 and 20 m depth (Fig. 4).

**Table 1.** Biological data, tagging date. Monitoring, and free time (days) of young of the year *S. lewini* tagged in the "Rebalsito" nursery area (South Jalisco). *Represents probable tag lost (lost, unreported catch, or natural death). %W: shows the percent of the transmitter weight (g) in the air with respect to the shark weight (g) in the air.

| ID | TL (cm) | Weight (g) | Sex | %W | Tag date | Electronic tracking (days) | Freedom time (days) |
|---|---|---|---|---|---|---|---|
| 16300 | 70.4 | 1400 | H | 0.31 | 27/10/2014 | 29 | 51 |
| 16299 | 53.7 | 680 | M | 0.65 | 28/10/2014 | 28 | 46 |
| 7762* | 56.2 | 750 | H | 0.59 | 28/10/2014 | 40 | 44 |
| 16304 | 57.9 | 910 | M | 0.48 | 6/11/2014 | 68 | --- |
| 16301 | 63.1 | 1110 | M | 0.4 | 24/11/2014 | 58 | 105 |
| 16302 | 72.1 | 1800 | H | 0.24 | 8/12/2014 | 1 | 9 |
| 17491* | 64.4 | 1400 | H | 0.31 | 8/12/2014 | 22 | 23 |

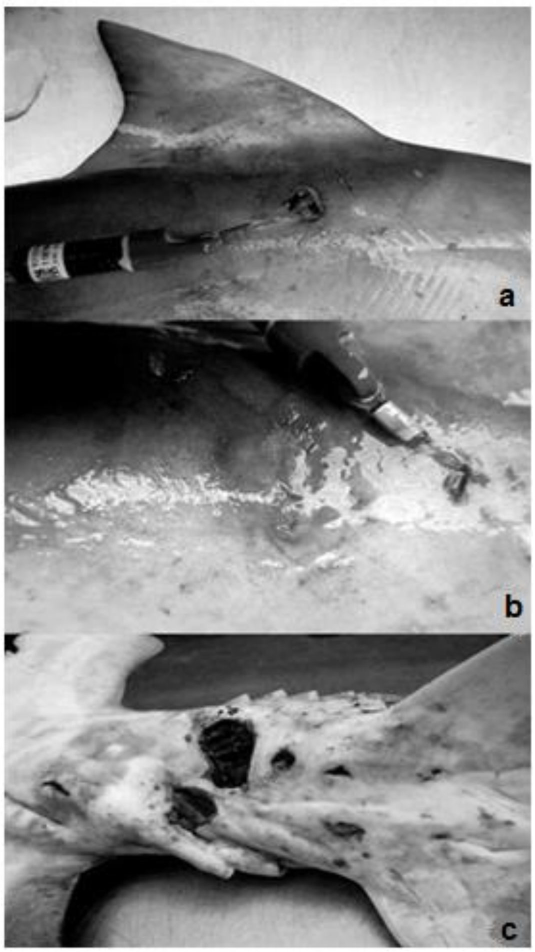


**Figure 3.** a) Ultrasonic transmitter attached to two recaptured sharks after 9 and 51 days, b) also shows the abrasion injury caused by the tag, c) shows injuries caused by predators.

Through the characterization carried out in the area, it was estimated that 97% of the active tracking detections took place in the soft bottom not associated with the rocky zones. During the active tracking, a considerable decrease of the effectivity in the identification of tagged sharks was observed at night close to the rocky zones, and also during the daytime when wind speed exceeded 8 knots. The effectiveness of transmitters identification by the VR2W, based on the total pings detected, ranged between 32.2 and 40.3%.

The higher percentage of detections were obtained at depths greater than 20 m. Taking into account the daily time scale, during the dusk (27%) and night (24.4%) periods than during the dawn (4.9%) and day (21%) periods. Moreover, shark #16300 was detected at a depth of 35-40 m during a night tracking. No individuals were detected at depths greater than 29 m during the other daytime periods. Due to the small number of tagged sharks, and the short period of active tracking, a length-depth analysis will not be strong enough. However, it was observed that for individuals smaller than 60 cm TL, 47.5% of the total active tracking detections were recorded at depths shallower than 15 m. While sharks larger than 60 cm TL showed the 78.1% of the detections at depths deeper than 15 m. The area between 15 and 20 m depth showed the higher overlap for both groups, with a 40.2% of the detections for sharks smaller than 60 cm TL and 55.1% of those over 60 cm TL. The site fidelity was complete (F = 1) in the first 88 days meaning that all detections and recaptures by the fishermen took place within the study area. From the beginning of the study to the last recapture (135 days), the estimated average fidelity was $F \approx 0.63$ (0.40-0.80).

## Spatial distribution

Tracked sharks were detected between 25-40% of the total time in the study area during the 24 and 48 h active tracking. All tagged sharks were detected within the study area with a probability of 63.6 ± 29% taking into account 17 active tracking samplings. During the first

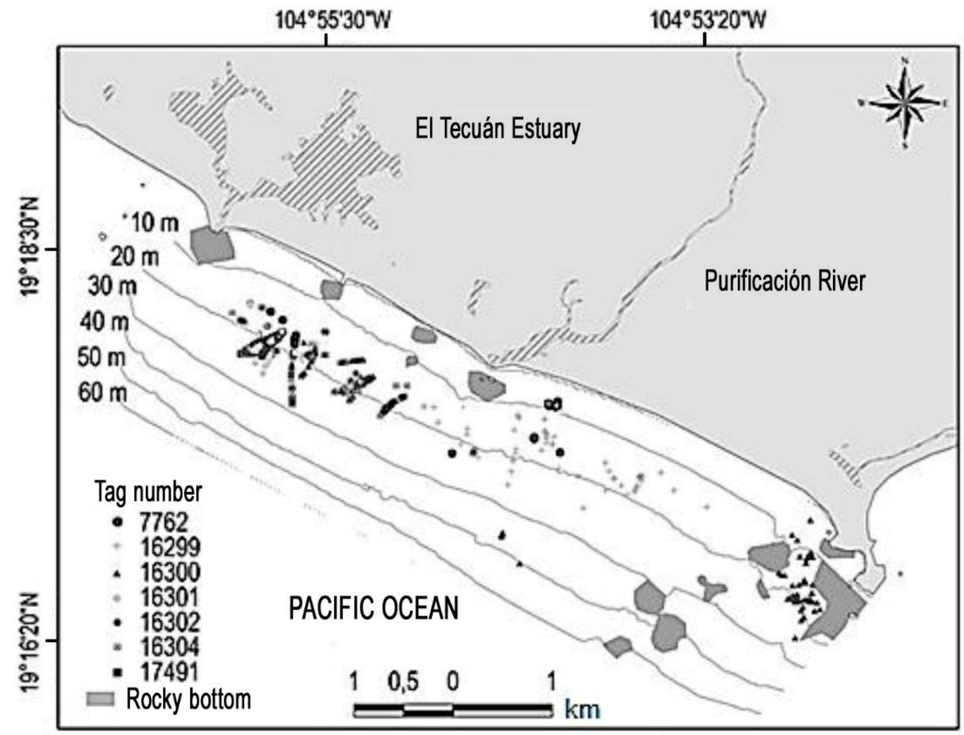


**Figure 4.** Tagged sharks' location during active tracking for the whole sampling period (27 October 2014 - 10 February 2015). Bathymetry and bottom type are also shown.

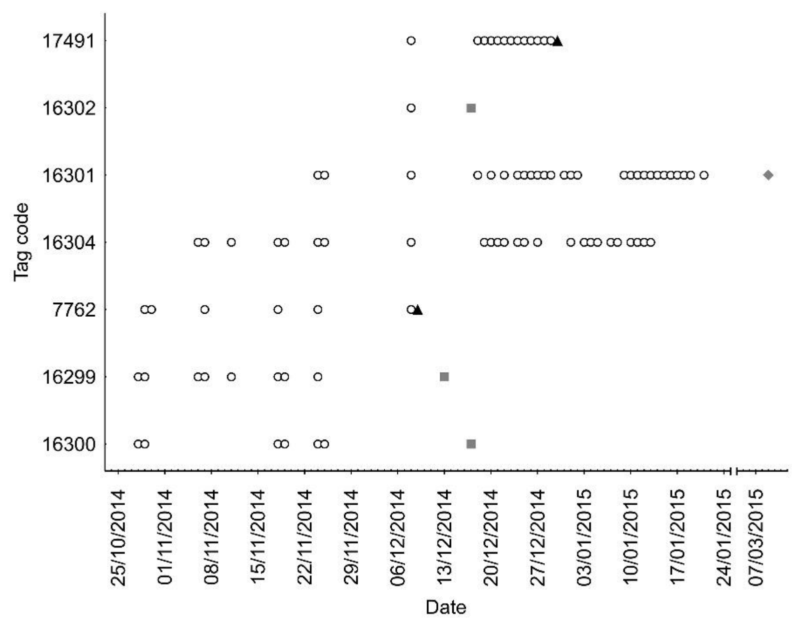


**Figure 5.** Detection history (active + passive tracking) of tagged sharks within the study area. (■): shark recapture by fishermen, (♦): recapture by fishermen outside of the study area, and (▲): lost shark (unreported catch, natural death or tag loss).

month of passive tracking, only three sharks were expected to be alive and were detected with a probability of 50 ± 15% (Fig. 5).

Taking into account the total detections obtained (active and passive tracking) 88.6% were located within a 1.5 km radius of the river mouth during the night (22:00-05:59), during the day (10:00-17:59)

13.5% were located 4 km to the south of the river mouth, and 36.2% between 1.5 and 2.7 km to the north of the river mouth. During the active tracking tagged sharks were always located within a 2.5 km radius of the river mouth in the dusk and night periods, with 65.2% of detections less than 1.5 km from the river mouth, while during the dawn and day periods they dispersed between 2.7 km to the north of the mouth and up to 4 km to the south.

Tracked sharks showed movement during 24 h a day. No periods were observed in which they remained motionless, but there were periods in which they stayed in a reduced area for several hours. The most frequent movement pattern consisted on finding the sharks 1-3 km to the north or the south of the river mouth during the day. At dusk, they would move from their location to the vicinity of the river mouth, where they stayed for up to 8 h, probably feeding, and then move to zones further away from the river mouth, preferentially to the north zone or outside of the study area.

The last detection of a tagged *S. lewini* in the study area was recorded on 21 January 2015. This shark was recaptured on 9 March 2015 at Bahía de Navidad, 30 km to the south from tagging location.

## Home range

The active tracking was difficult due to the high mobility of sharks and the interval of pings of the tags. During this tracking, we were able to estimate the distances traveled by the sharks during periods that ranged from 2 to 24 h, for instance: 11.96 km during 24 h for shark #16300, 3.68 km in 6 h for shark #16299 or 3.52 km in 4 h for shark #16301. It was usual to lose track of sharks at intervals between 20 and 60 min during long-time tracking. The estimated average speed for the full tracked shark was $0.58 \pm 0.17$ km $h^{-1}$, while for non-full tracked sharks was $0.39 \pm 0.17$ km $h^{-1}$.

The estimated home range by the MCP method ranged from 1.2 to 6.5 $km^2$ (average of $2.8 \pm 1.9$ $km^2$) (Table 2). The estimation through the KernelUD method results in the values of 50 and 95% of the estimation of the distribution of utilization (Table 2).

Fifty percent represents the core area of the home range for each shark, which varied between 0.04 and 6.05 $km^2$ (average of $1.50 \pm 1.29$ $km^2$). Ninety-five percent ranged between 0.4 and 25.28 $km^2$ (average of $8.35 \pm 8.45$ $km^2$) (Fig. 6). Shark #16302 was excluded for these calculations because was only detected for one day and captured by fishermen nine days after tagging.

Shark #17491 was detected almost exclusively in receiver 3, and the program was unable to calculate a significant home range. The MCP varied between the individuals within the periods: 0.00001-0.88 $km^2$ at dawn, 0.09-3.66 $km^2$ during the day, 0.04-1.81 $km^2$ at dusk, and 0.03-1.24 $km^2$ at night. Fifty percent KUD oscillated between 0.23-9.27 $km^2$ and 0.17-4.18 $km^2$ during the dawn and day respectively, 0.03-2.06 $km^2$ at dusk and 0.03-1.36 $km^2$ at night. For 95% KUD, the periods were comprised between 1.68-43.95 $km^2$ at dawn, 1.34-23.8 $km^2$ in the day, 0.13-8.22 $km^2$ at dusk, and 0.15-5.28 $km^2$ during the night (Table 2).

Common zones which are used by all the sharks and zones that were only occupied by some of them were identified, that is why the home range was calculated by taking the detections of all sharks as one. An MCP of 4.82 $km^2$ and a 50% KUD of 0.55 $km^2$, and 95% KUD of 4.89 $km^2$ were obtained. The home range of all the *S. lewini* was also estimated as a set but separating the four periods (Table 2). The KUD estimations tagged sharks showed two core zones, one in front of the river mouth and another one north of the mouth (Fig. 7).

The estimated MCP was less than 95% KUD for five of the six sharks, being closer to 50% KUD or intermediate values between 50 and 95%. A similar pattern was observed for three of the four sharks with a larger number of detections in active tracking, which showed lower a home range (KUD) in the night period than during the day. The MCP was very similar to 95% KUD when the estimation included all tagged sharks (4.82 and 4.89 $km^2$, respectively).

Similar shark mobility during the 24 h period was observed; however, the largest movements were detected during the dawn and at dusk. In these periods, the signal of the tagged shark was easily lost during active tracking due to their greater speed of movement. During the night tagged sharks remained close to the river mouth, for this reason, the KUD was lower than those at dawn and/or dusk. The KUD during the day was the largest in five of the six *S. lewini,* as in this period the sharks did not show a specific aggregation zone, being able to find the same individual during this interval on one day to the north of the mouth and another day to the south.

## DISCUSSION

Our study suggests high site fidelity and a clear pattern of small-scale daily movements of the YOY *S. lewini* within the nursery area. Complete site fidelity was observed within the first three months of the study for YOY *S. lewini.* The recapture of a tagged individual at a distance of 30 km (105 days after tagging) would suggest a large dispersion of the YOY sharks after remaining for 3 to 6 months near the river mouth. The small number of receivers and the two tagged sharks that are estimated to have survived after January limit

**Table 2.** Minimum convex polygon (MCP) and kernel utilization distribution (KUD) home range estimated for total and daytime category (dawn 06:00-09:59, day 10:00-17:59, dusk 19:00-21:59 and night 22:00-05:59) for each tagged shark and all together. *Indicates insufficient detections to calculate one or more of the home ranges.

| Tag number | MCP ($km^2$) | | | | |
|---|---|---|---|---|---|
| | Dawn | Day | Dusk | Night | Total |
| 16300 | 0.79 | 3.66 | 0.22 | 1.24 | 6.47 |
| 16299 | 0.16 | 1.23 | 1.57 | 0.88 | 3.20 |
| 7762* | <0.001 | 0.09 | 0.04 | <0.001 | 2.10 |
| 16304 | 0.20 | 0.59 | 0.87 | 0.07 | 2.06 |
| 16301 | 0.14 | 0.16 | 0.77 | 0.31 | 1.59 |
| 17491* | --- | 0.65 | --- | --- | 1.22 |
| All | 0.88 | 5.56 | 1.81 | 2.49 | 4.82 |
| | 50% KUD ($km^2$) | | | | |
| | Dawn | Day | Dusk | Night | Total |
| 16300 | 9.27 | 4.18 | 1.25 | 1.14 | 6.05 |
| 16299 | 0.58 | 0.76 | 2.06 | 0.6 | 1.14 |
| 7762* | --- | 1.05 | 0.03 | 0.56 | 2.04 |
| 16304 | 1.19 | 1.49 | 1.10 | 0.85 | 1.24 |
| 16301 | 0.23 | 0.49 | 0.51 | 1.36 | 0.46 |
| 17491* | --- | 0.17 | 0.03 | 0.03 | 0.04 |
| All | 1.47 | 3.51 | 0.43 | 0.22 | 0.55 |
| | 95% KUD ($km^2$) | | | | |
| | Dawn | Day | Dusk | Night | Total |
| 16300 | 43.95 | 23.8 | 7.29 | 5.28 | 25.28 |
| 16299 | 2.15 | 4.85 | 8.22 | 3.27 | 7.15 |
| 7762* | --- | 6.67 | 0.13 | 3.70 | 9.30 |
| 16304 | 5.10 | 5.88 | 4.81 | 3.81 | 4.83 |
| 16301 | 1.68 | 2.64 | 2.76 | 5.14 | 3.16 |
| 17491* | --- | 1.34 | 0.22 | 0.15 | 0.40 |
| All | 7.61 | 15.79 | 3.32 | 2.65 | 4.89 |

the estimation of the KUD for a more extended period. Duncan & Holland (2006) reported periods of up to a year of residency in the nursery area for YOY *S. lewini* within the Kane'Ohe Bay (Oahu, Hawaii). This difference could be related to the variability of the environmental conditions of a nursery area associated with a river mouth with the input of seasonal water or the presence of large predators. The great input of nutrients and organic matter discharged by the river plume during the rainy season generate a suitable habitat for zooplankton development (Schettini *et al.*, 1998) and the beginning of the benthic pathway, initiated by benthic copepods and polychaetes, and ends in benthic dwelling fishes and large predator as Sciaenids and Lutjanids (Day *et al.*, 2012). Therefore, there is an optimal foraging area for *S. lewini* near the river mouth. The stomach content of YOY *S. lewini* from the region showed a significant presence of fishes of the families Lutjanidae, Haemulidae, Sciaenidae, and Paralichthyidae, as well as penaeid shrimps (Corgos *et al.*, 2016). On the other hand, the closing of the river mouth would cause a decrease in the abundance of prey and could trigger the dispersion of YOY *S. lewini*. The greater predation probability probably determines the longer residence time reported for *S. lewini* in the Kane'Ohe Bay once they leave the bay and arrive in the open ocean. Meanwhile, in the present study, the sharks can move to adjacent zones through shallow waters and avoid large predators.

YOY *S. lewini* remained active 24 h a day during the active tracking, although several times we lost the shark track during several minutes or even hours. Some factors influenced the loss of shark tracks. First, the increased shark activity observed during the dusk and night periods, combined with the transmission delay of the ultrasonic transmitters (especially after the first month). Second, environmental noise produced sound overlapping that prevented the detection of the entire ping sequence. The noise generated by the wind (Cato, 2008; Hobday & Pincock, 2011) and the biological activity of organisms such as snapping shrimps, mantis shrimps and dolphins present in the area are capable of generating sounds at the same frequency as ultrasonic transmitters (69 kHz) (Radford *et al.*, 2008; Janik, 2009;

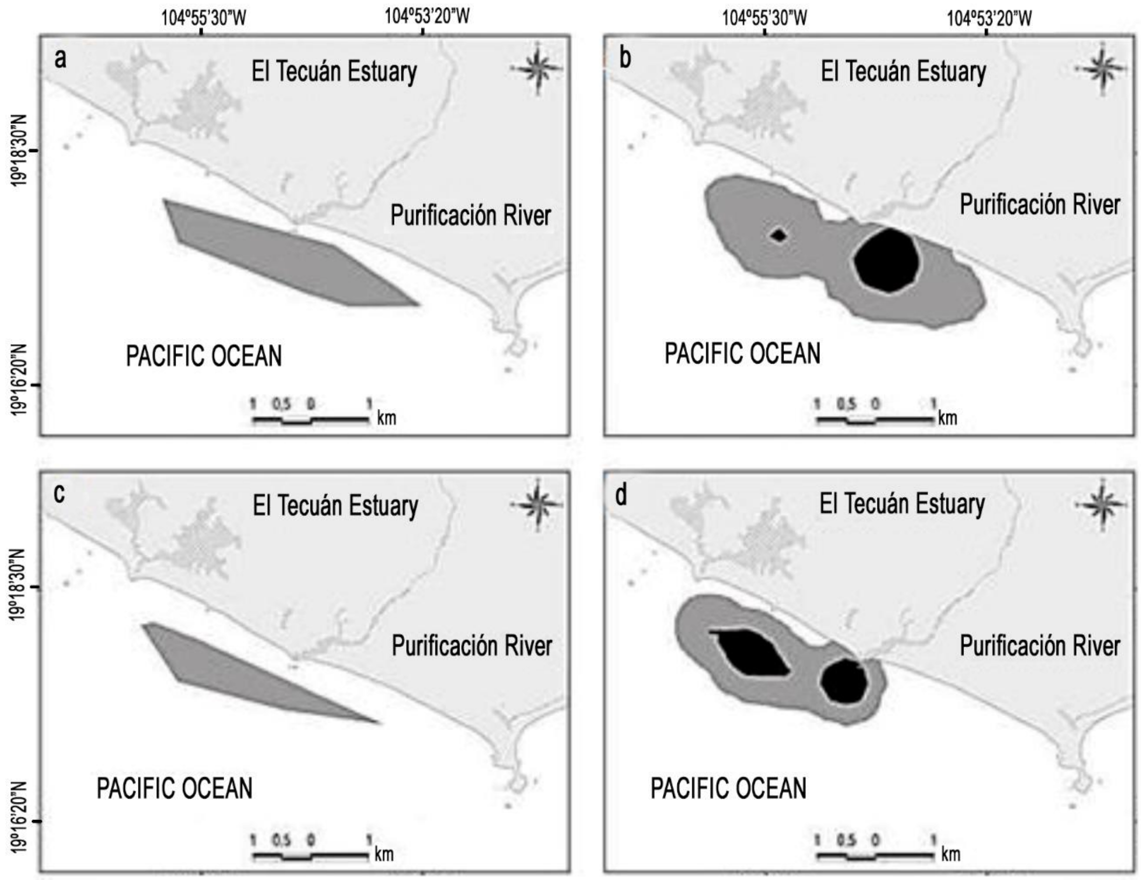


**Figure 6.** Home range maps for two tagged *S. lewini*. a-b) shark #16299 and c-d) shark #16304. a,c) Minimum convex polygon (MCP) and b,d) kernel utilization distribution (KUD). The black area represents 50, and grey 95%.

Cagua *et al.*, 2013). The bottom substrate also influenced the active tracking, as the rocky areas prevent optimum pin reception (Selby *et al.*, 2016). Even so, the displacement recorded in the #16300 shark for 24 h was more than double the 5.1 km reported by Duncan & Holland (2006) on one day between the catch and recapture of YOY *S. lewini*. However, they used conventional tagging, and it is probable that the real distance traveled was higher than the estimated. It can be considered that YOY *S. lewini* are very active, nevertheless their displacements are smaller than other juvenile coastal sharks like *Carcharhinus plumbeus*, (up to 60 km in 24 h, Rechisky & Wetherbee, 2003), or *Negaprion brevirostris* (more than 40 km per day; Reyier *et al.*, 2014). These "relative" small displacements are responsible for having a relatively small home range, if compared to other species YOY such as *Negaprion brevirostris* (10-30 $km^2$, Yeiser *et al.*, 2008) or *Carcharhinus amboinensis* (35.78 $km^2$ average, Knip *et al.*, 2011). However, the estimation of the MCP home range in the present study is double than that previously estimated for *S. lewini* in Kane'Ohe Bay: 1.26 ± 1.12 $km^2$ (Holland *et al.*, 1993) and 1.41 ± 0.41 $km^2$ (Lowe, 2002). Also, the KUD home range estimation in the present study is much higher than the 1.31 ± 0.65 $km^2$ obtained by Lowe (2002). This difference may be due to 1) the short duration of these studies, which never exceeded from 72 h of telemetry active tracking, 2) the YOY *S. lewini* prioritize the protection against predators for the habitat selection (Duncan & Holland, 2006) by using reduced areas of the bay as a core area. This pattern that has also been described for *C. limbatus* (shark and prey distribution were not correlated) appeared to be related to the evasion of predators (Heupel & Hueter, 2002).

YOY *S. lewini* are predators that move outside of its core area, usually during the night, looking for food (Holland *et al.*, 1993; Duncan & Holland, 2006). In the present study, sharks remained in a reduced area during the daytime, but they did not show a single core area of residence during this period, they have a higher KUD than other periods. As an example, shark #16300 moved about 4 km during the dawn of its first active tracking, from the mouth of the river to the southern part of the study area remaining within one $km^2$ area until dusk, then moved again to the immediate vicinity

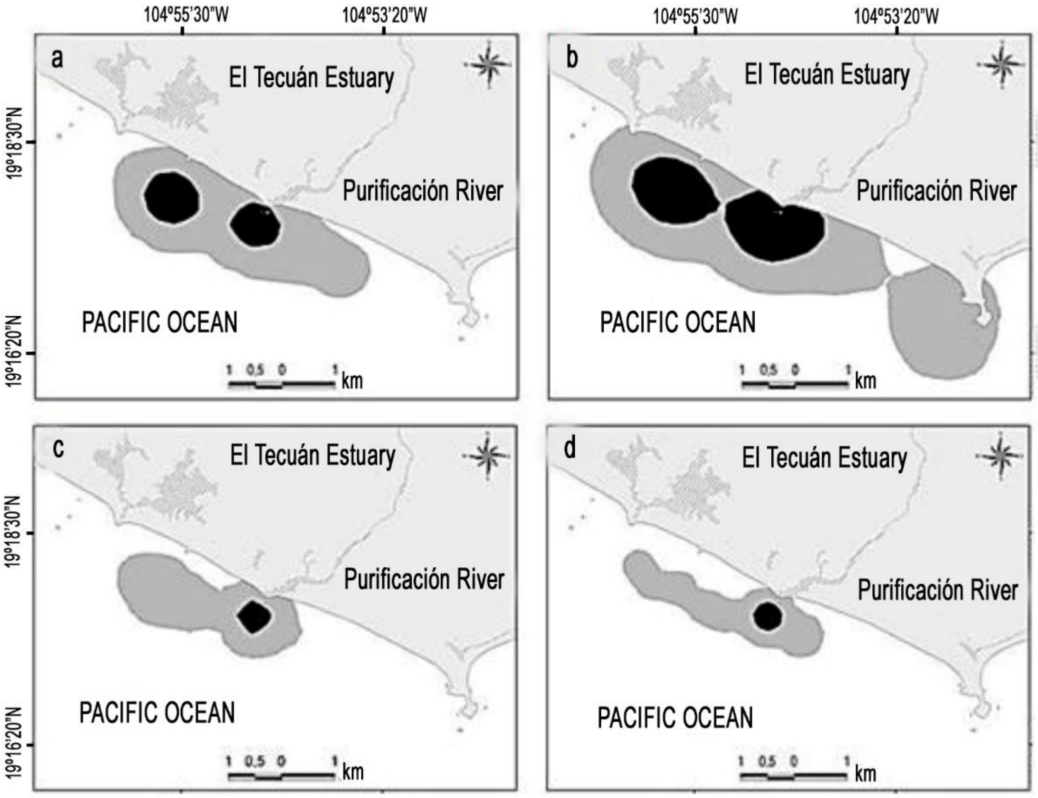


**Figure 7.** Graphic representation of the KUD home range estimation for all tagged sharks. The black area represents 50% and grey 95% for different daytime periods: a) dawn, b) day, c) dusk, and d) night.

of the river mouth. Therefore, YOY *S. lewini* showed a daily movement pattern with greater activity during the dark periods, and a spatial distribution pattern correlated with that of their potential preys during the night.

The attrition rate estimated in the present study was lower (if we consider the lower limit) than the 0.85-0.93 reported for YOY *S. lewini* in Kane'Ohe Bay (Duncan & Holland, 2006), or that of 0.61-0.92 reported for *Carcharhinus limbatus* (Heupel & Simpfendorfer, 2002), although it is similar to that estimated for *Negaprion brevirostris* 0.38-0.65 (Gruber *et al*., 2001). However, this would be much greater if we consider one full year (taking into account the fishing effort and the observed dispersion after the close of the river mouth). Further investigations with a large number of tagged sharks will be needed to obtain accurate estimations.

The size of the shark, habitat or purpose of the study, are points to consider at the time of choosing the kind of tagging (Thorstad *et al*., 2013; Smircich & Kelly, 2014; Jepsen *et al*., 2015). In tagging experiences with YOY *S. lewini* (prior to conducting this pilot study) it was observed that the application of nylon-head, plastic dart tag (Dicken *et al*., 2006; Hueter *et al*., 2007; Heupel & Simpfendorfer, 2008; Hoyos-Padilla *et al*., 2014; Tavares *et al*., 2016) caused a large-sized wound. On the other hand, tag size (136 mm) could cause swimming drag, mainly due to the wide surface where they can embed algae, polychaetes or barnacles (Dicken *et al*., 2006). For this reason, we used small T-bar anchor plastic tags (75 mm total length) with a less aggressive application. Although the anchoring of T-bar tags is weaker than dart tags, the compact muscle of the YOY *S. lewini* allows an optimal anchoring and retention of this kind of tags. The recapture of a tagged shark after 105 days with the T-bar tag correctly inserted and a healed wound showed the feasibility of this tag type for juvenile *S. lewini* studies.

During this work, our first goal was to cause as little damage and behavior modification as possible of tagged sharks. For this reason, we chose the smallest ultrasonic transmitter possible with a battery life longer than six months (Vemco V9), avoiding great swimming drag, which consequently would cause poor nutrition and/or a higher possibility of being hunted (Jepsen *et al.*, 2015). Besides, we achieved that the tag and the anchor set met the "2% rule": The relation of the weight of the tag to the biomass of the animal must not exceed 2% (Jepsen *et al.*, 2002, Smircich & Kelly, 2014). Tag retention depends on several factors such as the anchoring method, size, and location of the tag or species studied (Broadhurst *et al.*, 2009a, 2009b; Jepsen *et al.*, 2015). In the present study, the anchoring designed for the external placement of the ultrasonic transmitter showed higher retention than studies using PSAT tags (pop-up satellite archival tag) (Musyl *et al.*, 2011), especially during the first two months (Witt *et al.*, 2014). Although there was a noticeable growth in recaptured organisms and the tag weight/animal biomass proportion was adequate, the skin abrasion observed in one of the recaptured sharks discourages the use of this anchoring method for future studies.

This first analysis of the use of the nursery area by YOY *S. lewini* in a coastal area of the Mexican Central Pacific provided valuable information. The first estimations of site fidelity, home range, or distances travelled for these sharks in a nursery area associated to a river mouth generated an important research baseline for further investigations in the area and the entire Mexican Pacific, as large concentrations of juvenile sharks were found near the river mouths in Sonora (Bizzarro *et al.*, 2009) South Sinaloa-North Nayarit (Torres-Huerta *et al.*, 2008; Márquez-Farías *et al.*, 2009), Michoacán (Madrid *et al.*, 1997, Anislado-Tolentino & Robinson-Mendoza, 2001), Oaxaca (Alejo-Plata *et al.*, 2007) and Chiapas (Soriano Velásquez *et al.*, 2006; Bejarano-Álvarez *et al.*, 2011).

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