MOVEMENTS AND ENVIRONMENTAL PREFERENCES
OF DUSKY SHARKS, *CARCHARHINUS OBSCURUS*,
IN THE NORTHERN GULF OF MEXICO.

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SUMMARY

This document examines movement pattern and environmental preference data collected from dusky sharks in the northern Gulf of Mexico (GOM) using pop-up satellite archival tag technology. Prior to this study, few data existed on essential fish habitat (EFH) of dusky sharks in the GOM. During summer 2008-2009, pop-up satellite archival tags (PSAT) were attached to 10 (8 adult, 2 sub-adult) dusky sharks in the northern GOM. All tags reported data, with deployment durations ranging from 7 to 124 days. A total of 426 total days of movement and habitat preference data were acquired. Dusky sharks traveled distances >200 km, primarily utilizing GOM waters along the continental shelf edge from the Desoto Canyon to the Texas/Mexican border. They spent 75% of their time between 10 - 125m, and 70% of their time between $23 - 30^{o}C$. One dusky shark moved into the southern GOM (Mexican waters), which demonstrates the need for shared stock management of this species. This study represents the first use of PSAT technology to address critical gaps in information on habitat and behavior of dusky sharks in the GOM. Such information is imperative to the development of effective management strategies for population recovery of dusky sharks in the GOM and wider U.S. South Atlantic Ocean.

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1. **INTRODUCTION**

The dusky shark occurs in warm-temperate and tropical waters and is commonly found from the surf zone to depths in excess of 400 m (NMFS, 2006). This species ranges throughout the US EEZ in the western North Atlantic from Georges Bank to Texas (Compagno, 1984). Even though juvenile dusky sharks occupy coastal nursery grounds from New Jersey to South Carolina, they are rarely found in areas of reduced salinities or estuaries (Musick et al. 1993). Dusky sharks are considered highly migratory with several individuals tagged off New England being recaptured in the southwestern Gulf of Mexico (GOM) (Kohler et al. 1998). Due to this highly migratory behavior and recent genetic data (Heist and Gold 1999), it is hypothesized that there is a single stock of dusky shark in the western North Atlantic Ocean. Like many shark species, dusky sharks are very susceptible to over exploitation because of their slow growth (k=0.039), late age of maturity (19-21 years), and low fecundity (2 to 12 pups) (Natanson et al. 1995). Furthermore, dusky sharks could be more susceptible to over-exploitation than many other shark species based on the suggestion that they could have a 24 month gestation period and a triennial reproductive cycle (Branstetter and Burgess, 1996; Romine et al., 2009).

A stock assessment for dusky sharks in the western North Atlantic Ocean and the GOM was conducted by Cortés et al. (2006), who concluded that catch and landings data show a decreasing trend from the early 1990's to present and that dusky sharks have been "very heavily exploited" and are "particularly vulnerable to exploitation". Four of the five data sets used in this assessment indicated that mean size of dusky sharks landed had decreased, and that the majority individuals were immature (Cortés et al. 2006). Furthermore, all age-structured stock assessment models estimated depletions from 62 to 80% with respect to unexploited stock levels (Cortés et al. 2006). A recent demographic analysis of dusky sharks from the northwest Atlantic reported that population levels would decline at even low levels of fishing, making this species one of the most vulnerable to excessive fishing mortality, suggesting that stringent regulatory measures are required for populations to reach recovery levels (Romine et al. 2009). To compound the issue, very little data exists on the essential fish habitat requirements for young of the year, juvenile, and adult dusky sharks in the south Atlantic and GOM (Table 1). The objective of this study was to determine movement patterns and environmental preferences of dusky sharks in the northern GOM using pop-up satellite archival tag (PSAT) technology.

2. MATERIALS AND METHODS

Pop-up Satellite Archival Tags (PSAT) were used to provide data on movements, activity patterns, and environmental preferences of dusky sharks in the GOM. PSATs were selected for our research primarily due to the lack of need for recapture of the tagged sharks, and PSAT technology has proven extremely useful for collecting long-term data on large fishes that rarely swim at the surface (Simpfendorfer and Heupel, 2004).

Current-generation PSATs are capable of simultaneously sampling, at relatively high frequencies, parameters of the physical oceanographic environment experienced by large fish and storing those data for specified periods of time. These tags were programmed to record and archive at prescribed intervals 1) pressure (depth), 2) ambient temperature, and 3) light intensity with relatively high levels of precision.

Sharks were caught using recreational hook-and-line gear and were brought alongside the vessel as quickly as possible to minimize capture trauma. Sharks were sexed, measured for total length (TL) using a measuring tape, and tagged using a tagging pole, which was used to insert an anchor into the dorsal musculature of the shark at the base of the dorsal fin base. Following tag attachment, the hook was removed, and the shark was released. Shark weights were estimated using a length to weight regression equation (Kohler et al., 1996). A global positioning system (GPS) location of the vessel, sea surface temperature, surface salinity and time of release were recorded at the time of shark release.

Data Analysis

The statistical package R was used to analyze the horizontal movement data (geolocation values), which included the use of the state space Kalman filter (Sibert et al., 2004; Nielson and Sibert, 2007) to estimate geolocation errors, movement patterns and most probable tracks of the sharks (e.g. trackit and ukfsst). Because of the likelihood of light-based geolocation errors, the association of movement patterns (using tag-archived temperature data) to bathymetry was examined to reduce the error estimates (Galuardi et al. 2008; 2010).

Satellite track locations were imported to ArcMap (Environmental Systems Research Institute, Inc., Redkands, CA, USA) and projected using the global WGS 1984 PDC Mercator. Kernel densities and animal home range were calculated using the kernel density estimator from Hawth's Tools extension for ArcMap (Beyer, 2004). This tool calculates a fixed kernel density estimate using the quartic approximation of a true Gaussian kernel function. The smoothing factor (also referred to as the bandwidth or h statistic) used was 20 km for dusky sharks. The smoothing factor selected is based on careful inspection of the mean daily movements for each individual. For animal home range delineation, the 50 and 95 percent volume contours were calculated by including on average x% of the points that were used to generate the kernel density estimate (Simpfendorfer and Heupel, 2004). Areas within the contours were calculated using the spatial statistics toolset in ArcMap 9.3.

PSAT temperature and depth data were analyzed using histogram analysis to determine behavior and environmental preferences of individually tagged dusky sharks. To investigate diel differences in behavior and habitat utilization, data records were separated into periods of nighttime (2001 to 0630) and daytime (0631 to 2000). Paired t-tests were used to compare time at temperature and time at depth between nighttime and daytime.

3. RESULTS

Ten dusky sharks were successfully PSAT-tagged in the northcentral Gulf of Mexico (GOM) and temperature, depth and movement data were retrieved for those sharks. Behavioral data on movements, and temperature and depth preferences were obtained for all tagged sharks, totaling 426 days of tracking time (Table 2). The 10 dusky sharks were caught at various locations approximately 70 km southwest of the Mississippi River Delta (Fig. 1). Based on the known size at maturity for dusky sharks (290 cm TL; Natanson et al, 1995), eight of the ten dusky sharks PSAT-tagged in this study were adults (all female), and two of the sharks were sub-adults (1 male: 1 female). The mean retention time for PSAT tags during this study was 43 ± 12 days.

General Movements

The mean distance traveled for all tagged sharks in this study was 705 ± 245 km and ranged from 151 to 2759 km (Table 2). Mean daily distance traveled was 18.0 ± 2.5 km/day and ranged from 8.9 to 31.0 km/day. Overall, the dusky sharks appeared to primarily utilize northern GOM waters along the continental shelf edge, primarily from Desoto Canyon to the Texas/Mexican border (Fig. 2). The majority (n = 7) of the dusky sharks made a net movement to the west, whereas three moved eastward.

Several of the tags popped-up just east of the eastern portion of the Flower Gardens Banks National Marine Sanctuary (FGBNMS), suggesting that this area may be an essential habitat for the species. One area of high concentration occurred in the vicinity of the Mississippi Canyon, where half of the tagged dusky sharks visited. Interestingly, all of the tracks show movement along the edge of the canyon; however, none of the tagged sharks traversed the open waters of the canyon itself (Fig. 2). This demonstrates the importance of the shelf edge habitat to this species.

One dusky shark left United States territorial waters and entered Mexican waters in the southern GOM (Fig. 2). Dusky shark 5 traveled over 2700 km in 89 days, ending up in the Bay of Campeche, Mexico approximately 200 km north of the Mexican coast. This is a significant finding since it documents the movement of this prohibited species into an area where dusky sharks are not managed. Additionally, several of the dusky sharks in this study moved west along the continental shelf edge; however, the tag retention time was relatively short (~30 days).   Kohler et al. (1998) found similar a movement pattern with the use of conventional tags on dusky sharks. In fact, several dusky sharks that were tagged in the Atlantic Ocean off the east coast of the United States were recaptured in the Bay of Campeche in the southern GOM (Kohler et al. 1998).

Home Range

The home range of all dusky sharks tagged during July 2008 and 2009 appears to occur primarily over continental shelf edge waters from Desoto Canyon to the shelf edge off the Texas-Mexican border (Fig. 3). Mean home range size for dusky sharks at the 50 and 95% utilization was 6,193 km^2 (1,817-24,013 km^2) and 30,899 km^2 (9,477-124,991 km^2), respectively (Table 3). When totaled, the 50 and 95% kernel distribution for all

dusky sharks was 18,727 and 151,781 km^2 (Table 3). Three dusky shark hotspots were evident; two on either side of the Mississippi Canyon and one along the shelf edge just east of the FGBNMS (Fig. 3).

One dusky shark (Dusky 5) traveled to the southern GOM in an 89 day period, which resulted in a 50 and 95% Kernel distribution of 24,013 and 124,991 km^2, respectively (Table 3). Beyond this one track, the rest of the sharks utilized shelf edge waters of the northern GOM (Fig. 3). The track of Dusky 5 does demonstrate that shelf edge and open water habitats in the southern GOM are also utilized by this species.

Dusky Depth and Temperature Preferences

Dusky shark depth and temperature preferences ranged from 0 to 573.5 m, and 8.8 to 32.6 °C, respectively (Table 4). Interestingly, nine of the ten dusky sharks visited the surface at least once a day while being tracked (Table 4). Also, three sharks ventured into depths greater than what was currently known for this species (> 400m). They spent the majority of their time (75%) between 10 and 125m, and a third of their time between 20 and 50m (Fig. 4a). They preferred a wide temperature range, spending 70% of their time between 23 and 30°C, with approximately 50% of their time between 25 and 29°C (Fig. 4b). There was only no apparent difference in time spent at depth and temperature between nighttime and daytime (Fig. 4).

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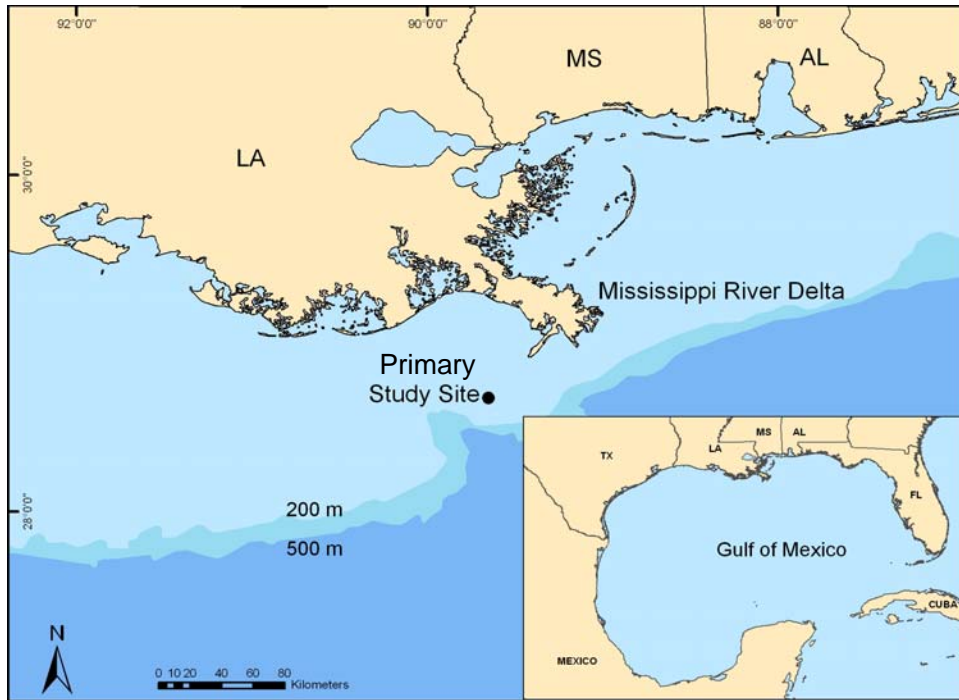
Figure 1. Map of study area in the northcentral Gulf of Mexico off Louisiana. Dusky shark tagging locations are depicted by black circle.
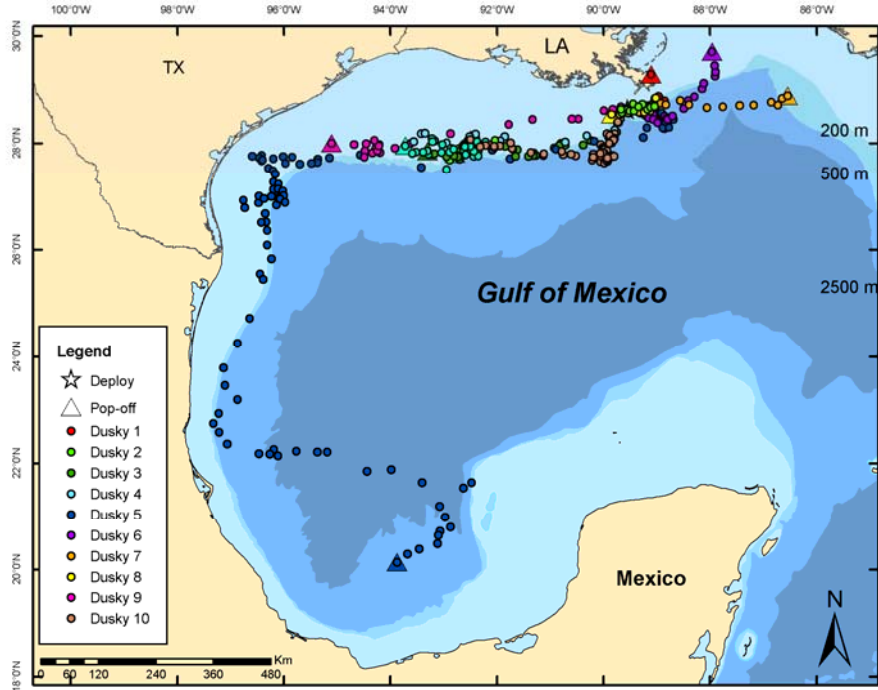
Figure 2. Map depicting daily location estimates of dusky sharks tagged during the study. The star denotes the tagging locations, whereas the triangle denotes individual popup locations.
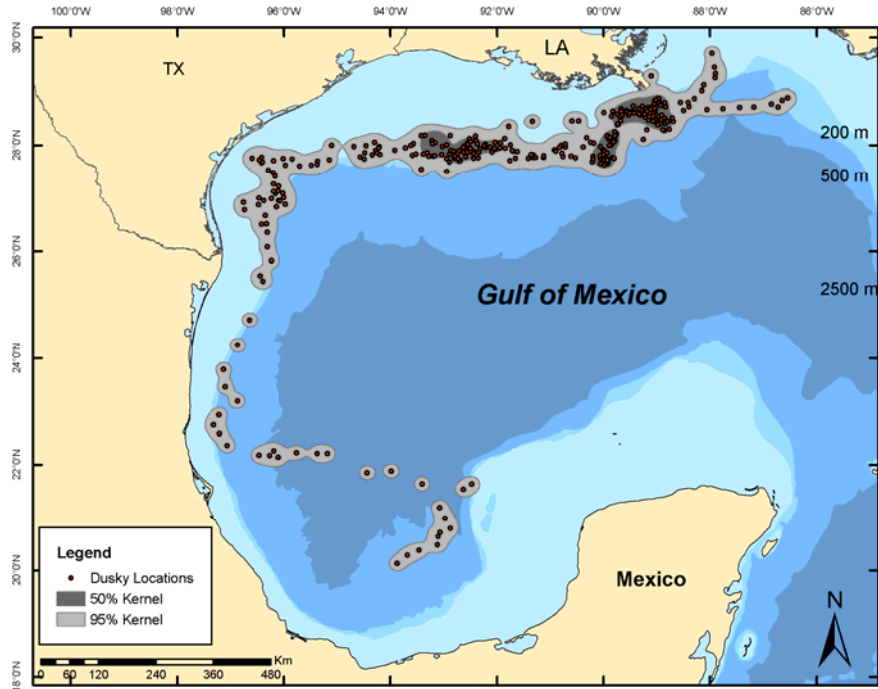
Figure 3. Map depicting the home range estimates for dusky sharks in the north central Gulf of Mexico. The 50% and 95% kernel distributions are presented. Mean home range size was 30,899 km^2.
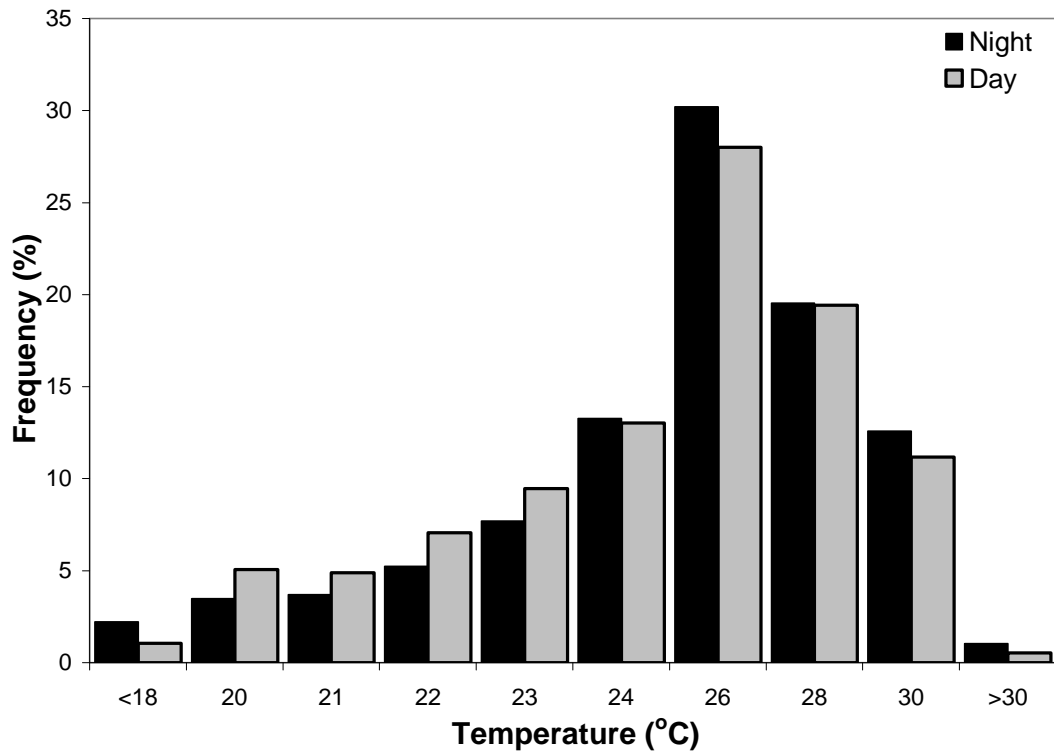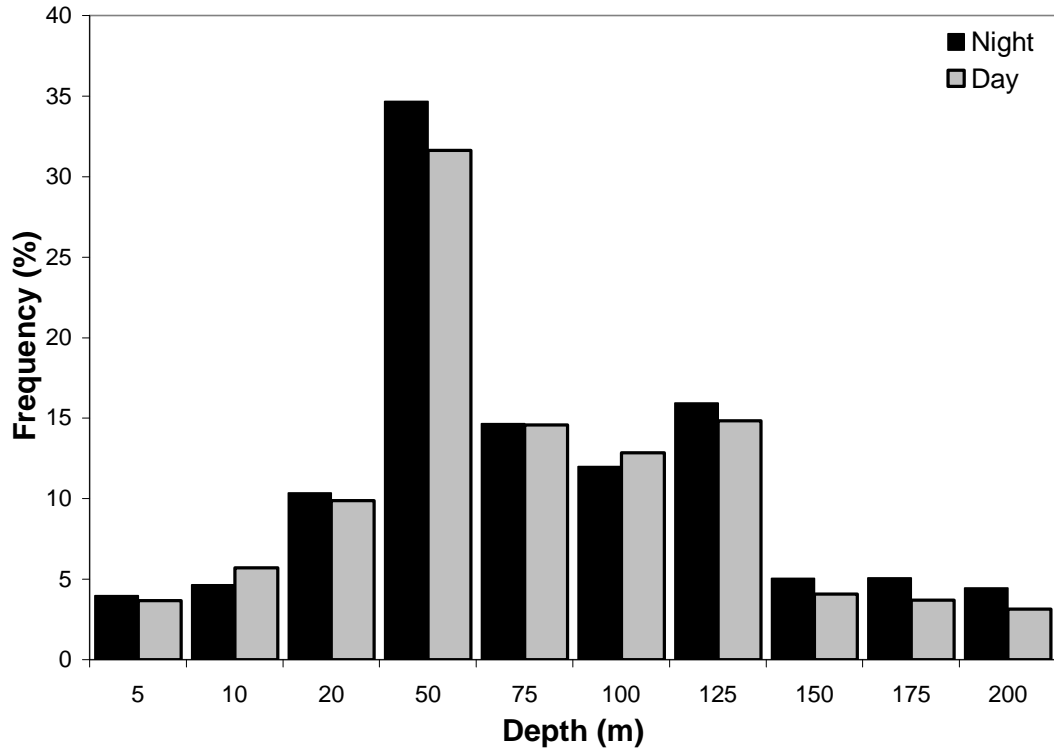
Figure 4. Time spent at (a) depth (m), and (b) temperature (^{o}C) histograms for all dusky sharks during the study. Black bars indicate nighttime and gray bars indicate daytime.

Table 1. Dusky shark life history and habitat characteristic table from the 2006 Final
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Marine Fisheries Service. (NMFS, 2006)

Table 10.4 Dusky shark (*Carcharinus obscurus*) Life History and Habitat Characteristics

Life Stage	Species Distributions		Habitat Characteristics			
	Location	Season	Temp (°C)	DO (mg/l)	Sal (ppt)	Depth (m)
			B = bottom and S = surface			
Neonate and young of the year (YOY)	Nearshore waters from Cape Hatteras to Bogue Banks and off Holden Beach, NC	Oct and Nov; pupping April and May off Holden beach	no data	no data	no data	no data
	SC coastal waters	transient or overwintering nursery (Nov)	18	no data	no data	no data
Juvenile	In the coastal waters of Martha's Vineyard, MA (off East and South Beaches of Chappaquiddick Island)	summer secondary nursery	17-24	no data	no data	4.8-19.2
	Exposed nearshore waters in Virginia, rarely enter the estuaries (one juvenile female (79cm PCL) caught in lower Chesapeake Bay in August of 1990	summer secondary nursery	no data	no data	no data	no data
	Nearshore waters from Cape Hatteras to Holden Beach, NC	summer secondary and overwintering nursery grounds	18.1-22.2	no data	no data	4.3-15.5
	SC coastal waters	transient or overwintering nursery (Nov)	18	no data	no data	no data
Adult	Pelagic waters offshore the Virginia/North Carolina border and south to Fort Lauderdale, FL Nearshore waters beginning at the border of Georgia and Florida south to Fort Lauderdale	Migrations moving north-south with the seasons	Unk	Unk	Unk	Unk

Table 2. Summary of PSAT tracking data for dusky sharks (*Carcharhinus obscurus*)
tagged in the northcentral Gulf of Mexico.

Shark ID	Species	Sex	TL (cm)	Maturity stage	Date tagged	Tagging location Lat. (°N)	Long. (°W)	Pop-up location Lat. (°N)	Long (°W)	Number of track days	Linear displacement (km)	Rate of movement (km/day)
1	Dusky	F	290	Mature	7/03/2008	28.632	89.551	29.286	89.106	14	151	10.8
2	Dusky	F	305	Mature	7/03/2008	28.632	89.551	27.802	92.784	27	432	16.0
3	Dusky	F	305	Mature	7/18/2008	28.632	89.555	27.851	93.303	32	488	15.3
4	Dusky	F	280	Mature	7/09/2008	28.632	89.555	27.951	93.722	124	1102	8.9
5	Dusky	F	265	Mature	7/09/2008	28.632	89.555	20.133	93.873	89	2759	31.0
6	Dusky	F	290	Mature	7/03/2008	28.632	89.562	28.872	88.292	16	314	19.6
7	Dusky	F	280	Mature	7/02/2009	28.633	89.562	28.883	86.544	17	309	18.2
8	Dusky	M	246	Immature	7/10/2009	28.633	89.562	28.554	89.848	6	183	30.5
9	Dusky	F	268	Mature	7/02/2009	28.633	89.562	28.000	95.105	32	665	20.8
10	Dusky	F	240	Immature	7/02/2009	28.632	89.555	28.069	92.500	68	633	9.3

Table 3. Home range estimates for PSAT-tagged dusky sharks, *Carcharhinus obscurus*, using 50% and 95% kernel distributions.

Shark ID	Total length (cm)	50% kernel (km^2)	95% kernel (km^2)
1	290	3,934	23,707
2	305	1,817	13,413
3	305	8,788	29,926
4	280	3,387	28,559
5	265	24,013	124,991
6	290	3,064	17,752
7	280	6,394	22,179
8	246	2,478	8,963
9	268	6,134	30,023
10	240	1,922	9,477
Mean		6,193	30,899
All		18,727	151,781

Table 4. Range (and mean) of depth and ambient water temperature for PSAT tagged dusky sharks (*Carcharhinus obscurus*) tagged in the northcentral Gulf of Mexico.

Shark ID	Species	Depth (m)			Temperature (^{o}C)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	Dusky	0	193.7	41.5	16.2	31.6	25.3
2	Dusky	0	472.0	43.2	9.8	31.0	25.6
3	Dusky	0	184.2	52.1	15.4	30.2	24.5
4	Dusky	0	267.6	55.5	14.2	30.2	24.7
5	Dusky	0	480.0	49.0	9.4	31.4	24.6
6	Dusky	2.0	573.5	43.2	8.8	30.8	23.7
7	Dusky	0	123.7	25.6	17.8	29.5	25.2
8	Dusky	0	221.0	50.1	14.4	30.6	22.7
9	Dusky	0	143.0	44.5	15.8	32.6	25.2
10	Dusky	0.7	223.2	46.0	15.1	31.5	24.0

The number 0 under the Minimum depth column = surface