HABITAT USE AND MOVEMENTS PATTERNS OF OCEANIC WHITETIP, BIGEYE THRESHER AND DUSKY SHARKS BASED ON ARCHIVAL SATELLITE TAGS

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SUMMARY

As part of a larger program to determine the habitat use and movement patterns of pelagic and semi-pelagic sharks, satellite pop-up archival transmitting (PAT) tags have been deployed on sharks in the U.S. Atlantic Ocean and Gulf of Mexico. One oceanic whitetip shark tagged in the western Gulf of Mexico moved 238 km, and rarely dove below 150 m. The most frequently occupied depth was 25.5-50 m and temperature was 24.05-26 °C. A bigeye thresher shark moved 51 km and was found most frequently between 25.5-50 m and 20.05-22 °C. The bigeye thresher dove up to 528 m with deeper dives occurring during the day. For dusky sharks, the majority of time spent was at 0-40 m deep but did dive to depths of 400 m. Dusky sharks occupied temperatures of 20.05-24 °C over 50% of the time. Tagged dusky sharks had varied movement patterns with one shark moving from south Florida (USA) to the North Carolina/Virginia (USA). A second shark also tagged off south Florida traveled south towards Cuba while a third shark moved little. While data for some species is limited, these results will be useful in providing habitat use data as inputs to Ecological Risk Assessments.

RÉSUMÉ

Dans le cadre d'un programme plus vaste visant à déterminer l'utilisation de l'habitat et les schémas de déplacement des requins pélagiques et semi-pélagiques, des marques archives électroniques pop-up reliées par satellite (PAT) ont été apposées sur des requins dans l'océan Atlantique des États-Unis et dans le golfe du Mexique. Un requin océanique marqué dans l'ouest du golfe du Mexique a parcouru 238 km et se déplaçait rarement à une profondeur inférieure à 150 m. La profondeur la plus fréquemment occupée variait entre 25,5 et 50 m et la température était de 24,05 à 26 ° C. Un renard à gros yeux a parcouru 51 km, nageant la plupart du temps à une profondeur oscillant entre 25,5 et 50 m à une température de 20,05ºC à 22ºC. Le renard à gros yeux a atteint une profondeur allant jusqu'à 528 m et se déplaçait à des profondeurs plus importantes pendant la journée. En ce qui concerne les requins de sable, ils ont passé la majorité de leur temps à une profondeur oscillant entre 0 et 40 m, mais ont cependant atteint des profondeurs de 400 m. Les requins de sable se déplaçaient dans des eaux présentant des températures variant de 20,05 à 24º plus de la moitié du temps. Les requins de sable marqués présentaient des schémas de déplacement variés et un requin s'est déplacé du Sud de la Floride (États-Unis) jusqu'en Caroline du Nord (Virginie, États-Unis). Un deuxième requin marqué au large des côtes du Sud de la Floride s'est déplacé en direction de Cuba alors qu'un troisième requin s'est peu déplacé. Bien que les données de certaines espèces soient limitées, ces résultats seront utiles, car ils fournissent des données sur l'utilisation de l'habitat pouvant être utilisées dans les évaluations des risques écologiques.

RESUMEN

Como parte de un programa más amplio para determinar el uso del hábitat y los patrones de movimiento de los tiburones pelágicos y semipelágicos, se han colocado marcas transmisoras de archivo pop-up por satélite (PAT) en tiburones en el océano Atlántico estadounidense y en el Golfo de México. Un tiburón océanico marcado en el Golfo de México occidental se trasladó 238 km, y rara vez se sumergió por debajo de 150 m. La profundidad que ocupaba más frecuentemente era de 25,5-50 m y la temperatura de 24,05-26 °C. Un zorro ojón se trasladó 51 km y se encontraba de manera más frecuente entre 25,5-50 m y entre 20,05-22 °C de temperatura. El zorro ojón se sumergió hasta 528 m, y las inmersiones más profundas las realizaba durante el día. Los tiburones areneros pasaron la mayoría de su tiempo en aguas de

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0-40 m de profundidad, pero llegaron a sumergirse a profundidades de 400 m. Los tiburones areneros ocuparon temperaturas entre 20,05-24 ºC durante más del 50% del tiempo. Los tiburones areneros marcados han variado los patrones de movimiento; un tiburón se trasladó desde el Sur de Florida (Estados Unidos) a Carolina del Norte/Virginia (Estados Unidos). Un segundo tiburón, marcado también en aguas del Sur de Florida, viajó hacia Cuba mientras que un tercer tiburón se movió poco. Aunque los datos para algunas especies son limitados, estos resultados serán útiles a la hora de facilitar datos sobre el uso del hábitat como entradas para las evaluaciones de riesgo ecológico.

KEYWORDS

Behavior, diving, habitat, migrations, pelagic environment, tagging

1. Introduction

Pelagic sharks are captured by a wide range of commercial fisheries but are a particularly common as bycatch of pelagic longline fisheries targeting tuna and swordfish. With the demand increasing in the international shark fin trade (Clarke et al. 2007) catches of pelagic sharks are likely to increase in the future. There is increasing concern over the status of pelagic shark populations and an urgent requirement for better data collection and information on their biology and habitat use to aid management and ensure sustainable use of these resources.

Ecological risk assessment (ERA), also known as productivity susceptibility analysis (PSA), is a tool that can be used to evaluate the vulnerability of a stock to becoming over-fished, based on its biological productivity and susceptibility to the fishery or fisheries exploiting it. Data necessary for calculation of ecological risk assessments include but are not limited to information on geographic distribution of fisheries, shark distribution and range, and vertical and horizontal utilization as well as the basic life history of the species in question. To this end, we provide data on the vertical and horizontal movements of pelagic and semi-pelagic shark species obtained using satellite pop-off archival transmitting tags.

2. Methods

Sharks were opportunistically tagged with pop-up archival transmitting (PAT) tags on commercial longline vessels monitored under the National Marine Fisheries Service's (NMFS) Pelagic Observer Program (Beerkircher et al., 2004) or Shark Bottom Longline Observer Program (Hale et al. 2010). PAT tags have been used to collect movement and habitat data on a number of large pelagic sharks (e.g. Weng et al., 2007; Pade et al. 2009; Skomal et al., 2009) and their use is described in detail elsewhere (e.g. Block et al. 1998). The satellite transmitters used in this study were Mk10 manufactured by Wildlife Computers (8345 154th Avenue NE, Redmond, WA 98052).

PAT tags were programmed for deployment periods of 120 and 150 days. Data collection frequency was set to every 60 sec. For oceanic whitetip, *Carcharhinus longimanus*, and bigeye thresher shark, *Alopias superciliosus*, tags were programmed to record depth and temperature binned into six hour histograms (00:00; 06:00; 12:00; 18:00) of the following ranges: depth (m): 0; 0.5-25; 25.5-50; 50.5-75; 75.5-100; 100.5-125; 125.5-150; 150.5-175; 175.5-200.5-250; 300.5-350; 350.5-400; and greater than 400 m; temperature (ºC): 0-8; 8.05-10; 10.05-12; 12.05-14; 14.05-16; 16.05-18; 18.05-20; 20.05-22; 22.05-24; 24.05-26; 26.05-28; 28.05-30; 30.05-32 and greater than 32ºC. The automatic release feature was enabled with tags programmed to regard depth variations less than 5 m for 96 hours as constant depth. For dusky shark, *Carcharhinus obscurus*, tags were programmed to record depth and temperature binned into four hour histograms (00:00; 04:00; 08:00 12:00; 16:00; 20:00) of the following ranges: depth (m): -1; -0.5-20; 20.5-40; 40.5-60; 60.5-80; 80.5-100; 100.5-140; 140.5-180; 180.5-220; 220.5-260; 260.5-300; 300.5-340; 340.5-380; and greater than 380 m; temperature (ºC): 0-8; 8.05-10; 10.05-12; 12.05-14; 14.05-16; 16.05-18; 18.05-20; 20.05-24; 24.05-26; 26.05-28; 28.05-30; 30.05-32; 32.05-34; and greater than 34ºC. The automatic release feature was enabled with tags programmed to regard depth variations less than 3 m for 72 hours as constant depth. Pop-off positions from tags that detached prematurely for reasons other than constant pressure can be erroneous because the tag may drift at the surface for the pre-set time period before uplinking to the satellites. In this study, for tags that had an early pop-off and when the geolocations indicated a clear direction of drift after uplinking, (i.e., depth=0 m for several days and a significant departure from the previous latitude and longitude) the area in which true pop-off occurred was estimated by plotting the location and direction of drift and visually estimating the area of pop-off.

PAT tags were rigged with 300-lb monofilament leaders and a Pfleger Institute of Environmental Research (PIER) nylon "umbrella" dart. After capture the shark was either restrained alongside the research vessel or brought on-board. Captured sharks were measured in cm fork length and sex recorded. A small incision was made with a knife at the midline of the first dorsal fin approximately 5 cm below the fin base and the dart inserted into the dorsal musculature, seating the anchor at a depth of approximately 10 cm.

A proprietary software package from the tag manufacturer (WC-GPE2 Suite Version 2.00.0021, Wildlife Computers, USA) was used to correct for light attenuation and estimate longitudes from the transmitted light level data. The initial refinement of the data for accuracy was followed using an algorithm developed by Carlson et al. (2010). We further employed an error propagation analysis relating latitude to the solar elevation and time of day (Sibert et al. 2009). The final estimates of longitude and latitude geolocation were processed through the Kftrack program (Sibert et al., 2003) that is incorporated into the WC-GPE2 software package. The data were smoothed using a state-space Kalman filter and the resulting migratory pathways represented the most probable track for each shark considered in the analysis.

3. Results and discussion

Two oceanic whitetip sharks, two bigeye thresher sharks, and eight dusky sharks have been tagged since 2007. Of those sharks tagged, useable data was obtained from one oceanic whitetip and one bigeye thresher shark and three dusky sharks (**Table 1**).

3.1 Oceanic whitetip shark

The oceanic whitetip shark was tagged in the western Gulf of Mexico on 27-May-2007 at 24.57 N and 93.45 W, about 640 km from the Mississippi Delta. The shark moved a straight-line distance of 238 km during the track moving southeast to the edge of the continental shelf about 300 km north of the Yucatan Peninsula where depths (**Figure 1**). During the track, the shark rarely dove below 150 m staying above the thermocline, and only one dive to 256 m was recorded. The most frequently occupied depth during the entire track was 25.5-50 m (49.8% total time) and temperature was 24.05-26 °C (44.7% total time) (**Table 1**).

Data indicates oceanic whitetip shark are largely an epipelagic species spending the majority of its time at or near the surface. Mean proportions of time at depth for each bin averaged 2.8% near the surface, 25.4% between 0.5-25 m, 49.8% time between 25.5-50 m, and 20.2% time between 50.5-75 m. The remainder of time (1.8%) was spent below 75 m. Temperatures primarily occupied were between 24.05-26° C (44.7% of time) with little time spent at temperatures below 18° C (1.6%) or above 26° C (4.6%) (**Table 2**).

3.2 Bigeye thresher shark

The bigeye thresher shark was tagged in the Gulf of Mexico on 27-March-2008 at 28.56 N, 89.71 W. The shark moved a straight-line distance of 51 km from tagging to pop-off but moved south to the edge of the continental shelf but then back north towards the United States during the track (**Figure 2**). The most frequently occupied depth during the entire track was 25.5-50 m (27.3% total time) and temperature was 20.05-22 °C (52.5% total time) (**Table 3**).

A previous study by Weng and Block (2004) reported the depth and temperature distributions of the bigeye thresher sharks showed a strong diel movement pattern. In their analysis, the bigeye thresher shark spent the majority of the daytime (84%), below the thermocline between 300 m and 500 m and the majority of nighttime (80%) closer to the surface. However, in our study the mean proportions of time at depth did not show the strong diel variations in depth. This could be attributable to the depth limitations of the shark's location around the continental shelf, rather than a lack of diurnal behavior. For example, an analysis of the first 24 days of the track when the shark occupied deeper water depths indicated large diurnal variation in behavior. As the shark moved into shallower water closer to the continental shelf, large fluctuations in depth were not apparent.

3.3 Dusky shark

Based on geolocation data from initial tagging location to pop-off location, dusky sharks generally traveled about 10 km day^{-1} and traveled an average of 863 km. Overall, mean proportions of time at depth revealed dusky sharks spent the majority of their time in waters of 0-40 m but did dive to depths of 440 m and occupied temperatures of 20.05-24ºC over 59.7% of the time (**Table 4**).

Sharks tagged varied in their movement patterns (**Figure 3a, 3b**). One shark that was tagged off Key Largo, Florida in January moved up the east coast of the U.S., spent some time meandering around the Charleston Bump before continuing north to the North Carolina/Virginia border in June. A second shark also tagged off Key Largo, Florida in March traveled south towards Cuba before the tagged sent data 2 weeks later. The third shark caught off North Carolina in March pulled the tag early in the deployment. Estimates of the pop-off location suggested that the shark moved little from where it was initially tagged.

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Table 1. Species, fork length (FL cm), tagging and pop-off localities, and days at liberty for pelagic sharks.

Species	*Shark number*	*FL (cm)*	*Sex*	*Tagging location*	*Pop-off location*	*Days at liberty*	*Distance moved (km)*
Oceanic whitetip shark	OWT1	148	M	24.57 N, 93.45 W	23.62 N, 91.38 W	58	238
Bigeye thresher shark	BEYE1	203	M	28.56 N, 89.71 W	28.81 N, 89.27 W	120	51
Dusky shark	DUSK1	209	M	24.87 N, 80.39 W	36.12 N, 73.86 W	150	1538
Dusky shark	DUSK2	214	F	25.02 N, 80.28 W	23.33 N, 80.07 W	14	187
Dusky shark	DUSK3	180	M	34.82 N, 75.62 W	Estimated	3	~40

Table 2. Average proportions of time spent at depth and time spent at temperature for oceanic whitetip shark.

	Day		*Night*		*Combined*	
Depth Bin	*Average proportion of time*	*Standard error*	*Average proportion of time*	*Standard error*	*Combined*	*Standard error*
0	2.41	0.98	3.91	2.16	2.78	0.91
25	26.52	1.82	22.06	2.84	25.41	1.54
50	49.09	1.71	51.74	2.73	49.75	1.45
75	20.44	1.15	19.58	1.97	20.23	0.99
100	1.50	0.29	2.67	0.85	1.79	0.31
125	0.04	0.02	0.04	0.02	0.04	0.02
150	0.00	0.00	0.00	0.00	0.00	0.00
175	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
250	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
350	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00
400+	0.00	0.00	0.00	0.00	0.00	0.00

	Day		*Night*		*Combined*	
Temperature Bin	*Average proportion of time*	*Standard error*	*Average proportion of time*	*Standard error*	*Combined*	*Standard error*
8	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00
16	0.03	0.02	0.09	0.07	0.05	0.03
18	1.44	0.34	1.89	0.69	1.55	0.30
20	11.54	1.10	10.36	1.83	11.25	0.94
22	12.95	0.72	15.45	1.39	13.58	0.64
24	22.19	1.57	30.47	2.54	24.26	1.36
26	46.29	2.48	39.91	4.49	44.69	2.18
28	5.56	1.50	1.81	0.93	4.62	1.15
30	0.00	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00
32+	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. Average proportions of time spent at depth and time spent at temperature for bigeye thresher shark.

	Day		*Night*		*Combined*	
Depth Bin	*Average Proportion of time*	*Standard error*	*Average Proportion of time*	*Standard error*	*Combined*	*Standard error*
0	0.94	0.41	2.90	0.41	1.42	0.33
25	8.45	0.92	27.68	2.06	13.21	0.98
50	24.85	1.99	34.74	2.19	27.30	1.61
75	24.65	1.92	23.89	2.12	24.46	1.54
100	16.59	1.74	6.49	0.90	14.09	1.35
125	7.71	1.21	2.96	0.82	6.53	0.94
150	2.42	0.54	0.87	0.23	2.03	0.41
175	2.89	0.62	0.42	0.15	2.28	0.47
200	3.43	0.62	0.06	0.04	2.59	0.47
250	4.17	0.85	0.00	0.00	3.13	0.64
300	2.74	0.60	0.00	0.00	2.06	0.45
350	0.91	0.36	0.00	0.00	0.69	0.27
400	0.26	0.16	0.00	0.00	0.19	0.12
400+	0.00	0.00	0.00	0.00	0.00	0.00

	Day		*Night*		*Combined*	
Temperature bin	*Average proportion of time*	*Standard error*	*Average proportion of time*	*Standard error*	*Combined*	*Standard error*
8	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00
14	1.30	0.52	0.00	0.00	0.98	0.40
16	10.67	1.79	0.14	0.09	8.08	1.38
18	4.53	0.91	1.17	0.30	3.70	0.69
20	10.12	1.51	4.55	1.07	8.75	1.18
22	54.85	2.63	45.41	2.86	52.52	2.11
24	16.58	1.73	42.78	3.04	23.04	1.64
26	1.28	0.22	4.39	0.69	2.05	0.25
28	0.54	0.26	1.55	0.32	0.79	0.21
30	0.14	0.14	0.00	0.00	0.11	0.11
32	0.00	0.00	0.00	0.00	0.00	0.00
32+	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Average proportions of time spent at depth and time spent at temperature for dusky shark.

	Day		*Night*		*Combined*	
Depth bin	*Average proportion of time*	*Standard error*	*Average proportion of time*	*Standard error*	*Combined*	*Standard error*
-1	1.86	5.82	2.10	5.33	1.97	5.59
20	43.60	32.50	43.36	36.22	43.48	34.31
40	31.99	24.04	21.28	21.44	26.81	23.42
60	11.19	16.06	8.31	11.58	9.79	14.13
80	4.01	7.05	5.22	8.17	4.59	7.63
100	2.78	6.82	4.30	8.29	3.52	7.60
140	3.25	10.04	7.71	13.43	5.41	12.00
180	1.05	3.78	5.92	15.36	3.41	11.27
220	0.19	1.05	1.49	5.49	0.82	3.94
260	0.03	0.26	0.21	1.89	0.12	1.33
300	0.03	0.33	0.05	0.30	0.04	0.31
340	0.01	0.11	0.02	0.17	0.02	0.14
380	0.01	0.12	0.02	0.16	0.01	0.14
380+	0.00	0.00	0.02	0.19	0.01	0.13

	Day		*Night*		*Combined*	
Temperature bin	*Average proportion of time*	*Standard error*	*Average proportion of time*	*Standard error*	*Combined*	*Standard error*
8	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.05	0.50	0.03	0.35
12	0.00	0.00	0.11	0.91	0.05	0.65
14	0.08	0.90	0.13	0.94	0.10	0.92
16	0.18	1.86	0.43	2.77	0.30	2.36
18	3.19	13.86	2.86	11.39	3.02	12.68
20	14.72	29.10	13.61	27.66	14.17	28.37
24	58.75	39.82	60.61	39.39	59.68	39.58
26	21.34	33.89	19.93	32.28	20.64	33.07
28	1.65	8.27	2.16	9.89	1.90	9.11
30	0.09	1.08	0.11	1.13	0.10	1.10
32	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00
34+	0.00	0.00	0.00	0.00	0.00	0.00

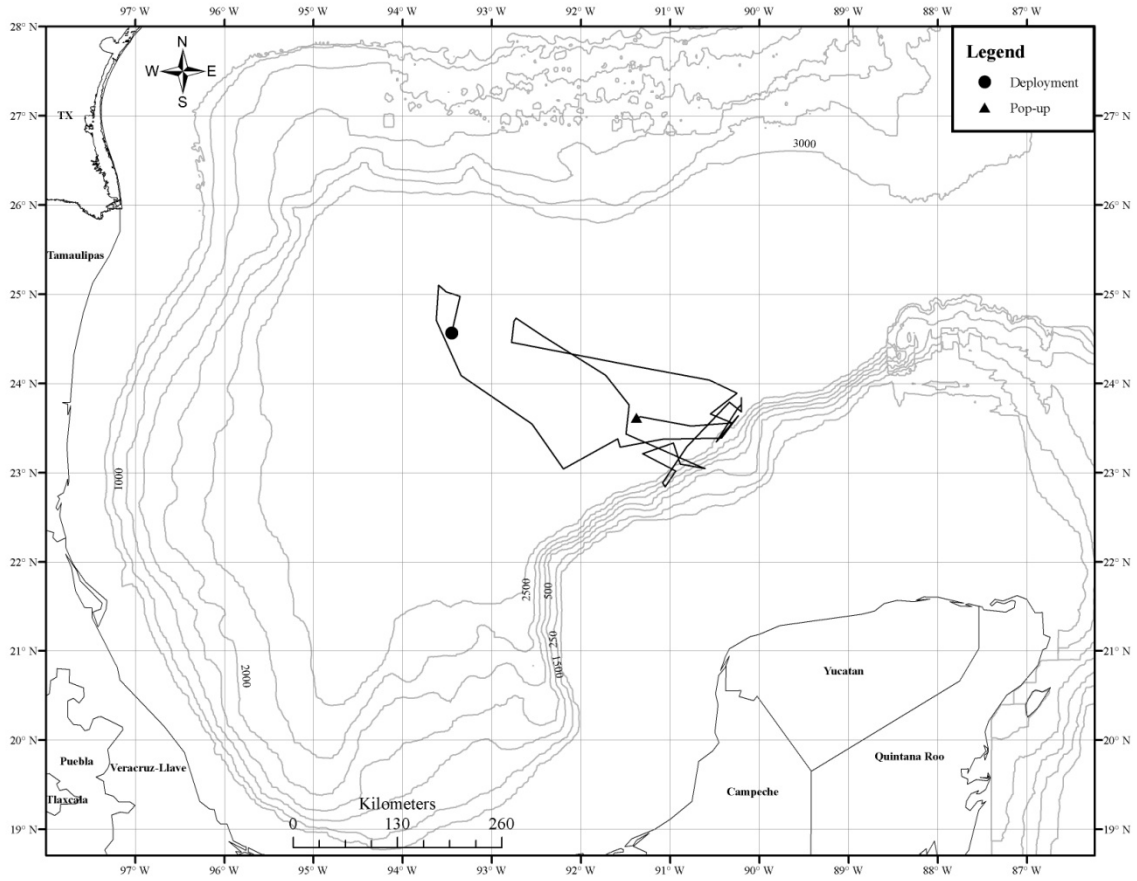

Figure 1. Horizontal movements of oceanic whitetip shark. All shark tracks are from areas off the United States Atlantic coast and Gulf of Mexico.

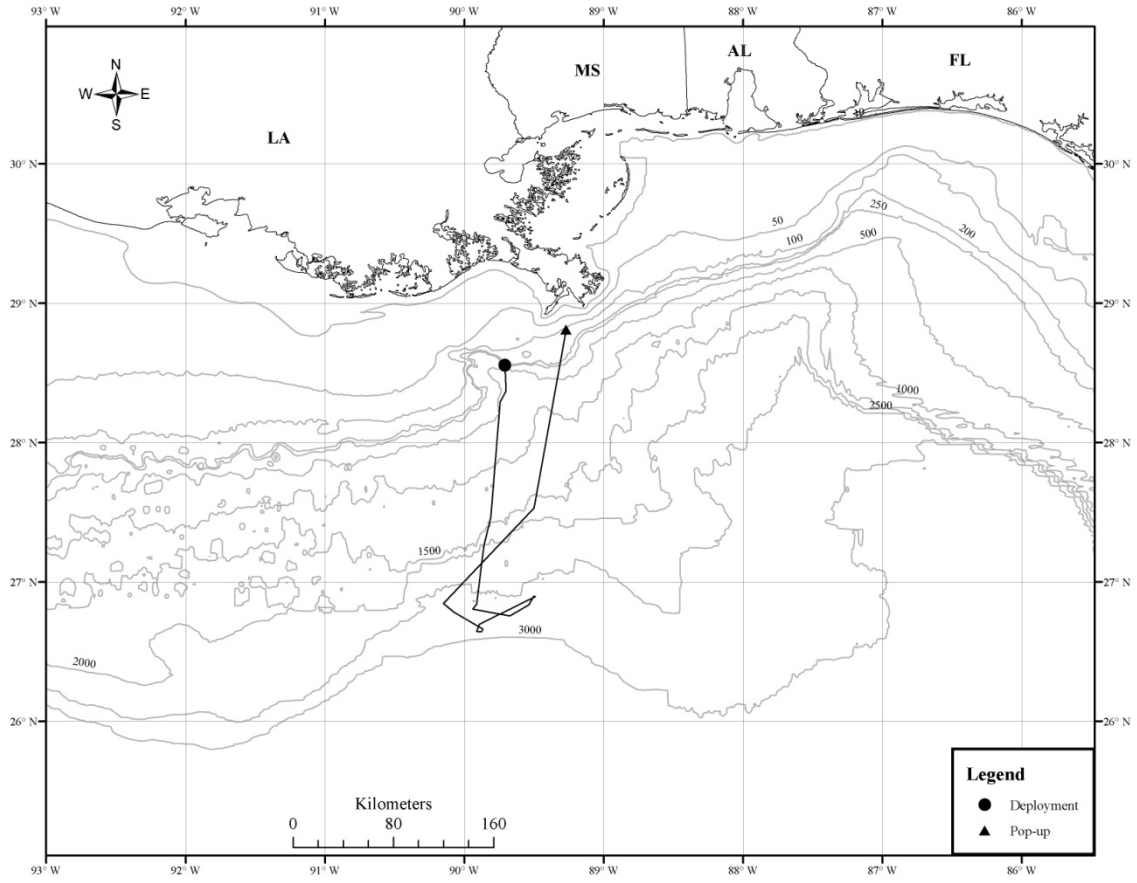

Figure 2. Horizontal movements of bigeye thresher shark. All shark tracks are from areas off the United States Atlantic coast and Gulf of Mexico.

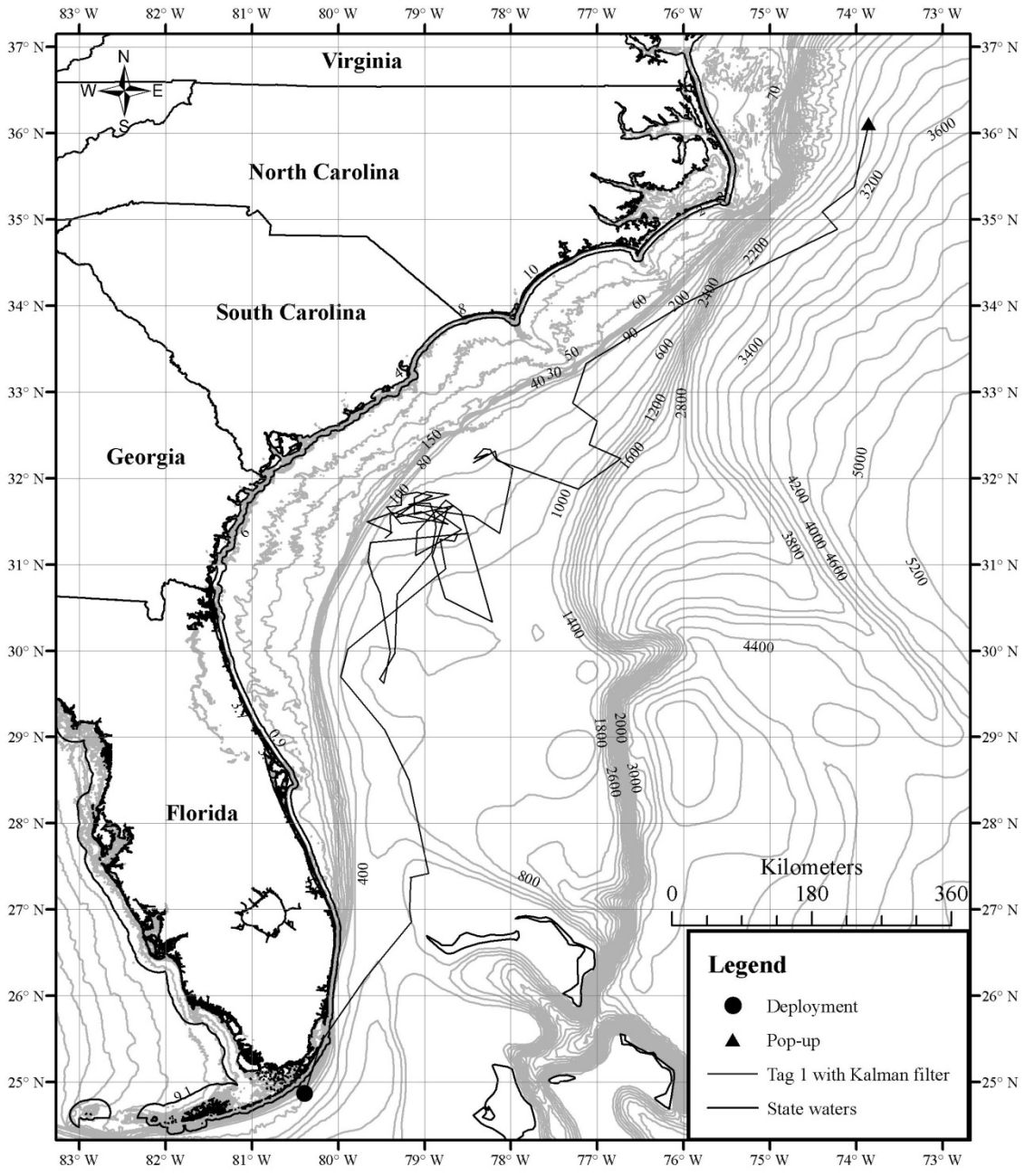

Figure 3a. Horizontal movements of dusky shark. All shark tracks are from areas off the United States Atlantic coast and Gulf of Mexico.

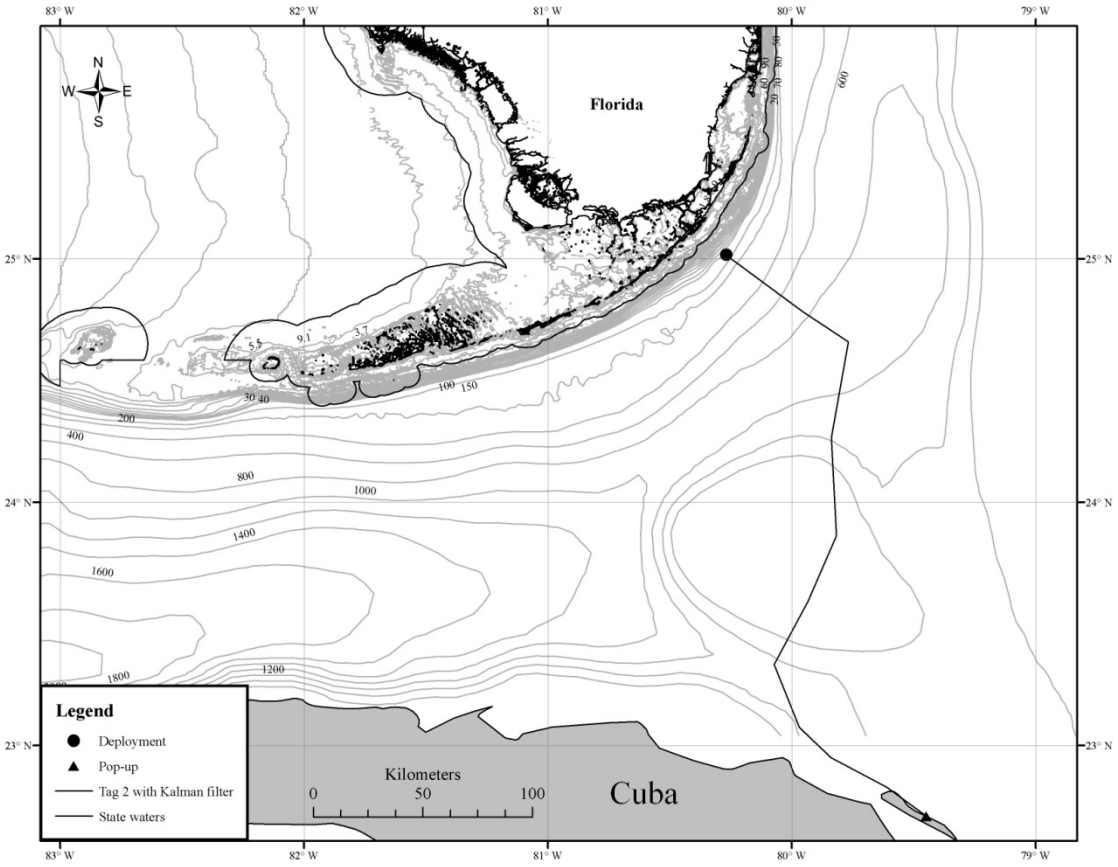

Figure 3b. Horizontal movements of dusky shark. All shark tracks are from areas off the United States Atlantic coast and Gulf of Mexico.