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Observing post-release mortality for dusky sharks, *Carcharhinus obscurus*, captured in the U.S. pelagic longline fishery

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ABSTRACT

The latest stock assessment for the dusky shark, *Carcharhinus obscurus*, in the western North Atlantic Ocean indicates the population is overfished and experiencing overfishing. As part of a rebuilding plan, the commercial and recreational retention of dusky sharks has been prohibited since 2000. Despite this prohibition, dusky sharks are bycatch in multiple fisheries, including the pelagic longline fishery; however, post-release mortality (PRM) rates have not been empirically determined for this gear. Herein we estimated PRM of dusky sharks captured by the US pelagic longline fleet in the western North Atlantic Ocean utilizing pop-up satellite archival transmitting (PSAT) tags. One hundred and twenty three dusky sharks were captured on commercial pelagic longline gear and time on the hook, based on hook timer data, ranged from 0.8 to 8.1 h (4.3 ± 0.28 h). No at-vessel mortality (AVM) was observed for any dusky sharks in this study. Prior to release, 50 PSAT LIFE tags (Lotek Inc.) were attached to dusky sharks (females n = 12, 209 ± 8 cm FL; males n = 4, 198 ± 7 cm FL; unknown sex n = 34, 214 ± 7 cm FL) to assess PRM rates in the pelagic longline fishery during a 30 day attachment period. Forty-three of the 50 deployed tags reported data with deployment times ranging from 1 to 28 days (11.2 ± 9.8 days). Four dusky sharks were in poor condition at release and two individuals suffered PRM, which occurred within two hours after release. Total mortality rate (AVM + PRM) in the current study was 5.1%, far below estimates reported for bottom longline gear (~97%), and reinforces the notion that PRM should be evaluated by species, season, and gear type.

1. Introduction

Sharks represent a group of marine organisms that are exploited globally by recreational and commercial fisheries as both the target species (e.g. Worm et al., 2013) and or as bycatch (e.g. Molina and Cooke, 2012). Although bycatch is often discarded, capture and handling can often lead to death (e.g. Gallagher et al., 2014). The coupling of life history traits such as late maturity and slow growth limits the resiliency of this group of fishes to recover from these anthropogenic pressures (e.g. Stevens, 2000; Musyl and Gilman, 2019) on a global scale (Lewison et al., 2004; Ellis et al., 2017). These circumstances have mandated bycatch mitigation measures and management plans in various regions of the world (e.g. Ellis et al., 2017; Musyl and Gilman, 2019).

The dusky shark, *Carcharhinus obscurus*, inhabits coastal and pelagic ecosystems circumglobally in temperate, subtropical and tropical marine waters (Compagno, 1984). In the territorial waters of the United States (U.S.) within the western North Atlantic Ocean, dusky sharks range from the New England states to Florida and throughout the northern Gulf of Mexico (GOM) (Castro, 2011). Based on genetic analyses (Benavides et al., 2011) and their highly migratory nature (Kohler et al., 1998), dusky sharks are managed as a single stock in this region (National Marine Fisheries Service (NMFS), 1999). Stock assessments indicate this population is overfished and has been experiencing overfishing since 1990 (Southeast Data, Assessment, and Review (SEDAR), 2016). Even though dusky shark retention has been prohibited for several decades (NMFS, 1999), stock assessment model analysis suggests stock recovery will not occur until 2108 (SEDAR, 2016). A potential limiting factor in the recovery process is the impact of incidental

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capture in multiple commercial (e.g. bottom and pelagic longline; bottom longline and pelagic longline, respectively) and recreational fisheries (Morgan et al., 2009; NMFS, 2016). The U.S. pelagic longline fishery operates within the U.S. Exclusive Economic Zone (EEZ) and on the high seas, employs thousands of people, and is a high value fishery responsible for approximately 66% of the total highly migratory species (HMS) landed value in U.S. waters (NOAA Safe Report, 2017). The pelagic longline fishery is highly regulated, including, but not limited to, mandatory maintenance of logbooks, 100% electronic monitoring, exclusive use of circle hooks (since 2004, minimum hook size of 16/0), utilization of several types of dehooking and leader cutting devices and a requirement to leave no more than three feet of gangion material attached if a hook is left in place (NMFS, 2016). Based on observer coverage, self-reporting and modeled extrapolation, the pelagic longline fleet interacted with thousands of dusky sharks between 2008 and 2014; however, the fate of these released sharks is unknown (NMFS, 2016).

At-vessel (AVM) and post-release (PRM) mortality are important metrics for estimating total mortality, calculating population size and setting catch limits, especially for vulnerable species such as dusky sharks (e.g. Davis, 2002; Sulikowski et al., 2017). These inputs are essential for calculating total fishing mortality and stock biomass and aid in the development of biologically acceptable catch limits for a given fishery (Alverson, 1999; Davis, 2002). Fishery observers can provide estimates of AVM, but obtaining PRM rates is more difficult given the fate of a released shark is unknown. Consequently, marine fisheries management utilizes conservative (“worst-case scenario”) PRM estimates when data are not available or surrogate rates are applied from different species and/or gear types. For example, the Dusky Shark Working Group (SEDAR, 2011) used the difference (6%) between AVM (13%) and PRM (19%) for blue sharks, *Prionace glauca*, and added that difference to the AVM Pelagic Longline Observer Program data. The use of this surrogate data, resulted in a 44.2% total discard mortality rate for dusky sharks captured in the pelagic longline fishery. Using such proxies can have major consequences, especially if the relationships between AVM and PRM rates vary substantially among species and gear types. To prevent such a scenario, the NMFS has prioritized obtaining accurate PRM estimates for all HMS species and gear types. Recent estimates of total discard mortality for dusky sharks captured in the bottom longline fishery are between 88% and 97% (Morgan and Burgess, 2007; Marshall et al., 2012; Marshall, 2015). However, to date, no studies have directly quantified the mortality of dusky sharks associated with pelagic longline fisheries. Given the status of the dusky shark population in the western North Atlantic Ocean and the lack of direct estimates of PRM rates in the pelagic longline fishery, the objective of the current study was to estimate AVM and PRM rates for dusky sharks captured on pelagic longline gear using survivorship pop-up archival satellite transmitting (PSAT) tags.

2. Methods

Commercial pelagic longline gear was deployed from two vessels off Wanchese, North Carolina using experienced pelagic longline captains and crew. Each vessel conducted one day and one night set approximately 48 km offshore over a 36 -h period in May 2016 (Fig. 1). With the exception of mainline length, gear configuration was kept identical to methods used in that region to remove bias. Mainline length was 8–13 km whereas commercial sets are typically 44–88 km in length. Shorter mainlines were used so that each gangion on every set could be equipped with a hook timer (HT 600, Lindgren-Pitman, Inc.). Between 150–175 gangions, each constructed of a 20 m 1.8 mm diameter monofilament leader (Lindgren-Pitman, Inc), weighted swivel (Lindgren-Pitman, Inc.) and 16/0 circle hook (Mustad, # 39960-DC), were attached to the 3.5 mm diameter monofilament mainline (Lindgren-Pitman, Inc), spaced approximately 25 m apart, and baited with whole squid (*Loligo* sp.). According to NMFS pelagic longline observer data, average soak time within this fishery is approximately 8.3 h, with an interquartile range of 7.1 to 9.3 h (Cushner S., NMFS, pers. comm.) and mainline length varies from 44 to 88 km in length (NMFS, 2016). Thus, for the purposes of the study herein, each longline set soaked for nine hours (timing started when first hook was deployed). Hook timers were activated when a fish applied tension to the leader and provided a detailed record for time on the line (TOL) for each captured shark. Following the nine hour soak, the mainline was retrieved and the status of each hook recorded (i.e. bare hook, bite off, fish captured). At haulback, the location of capture, TOL, sea surface temperature (SST), estimated fork length (so sharks did not need to be removed from the water) and injury condition of each dusky shark were recorded prior to tagging. A shark was given an injury condition of (1) if there were no visible signs of trauma to the body (e.g. no blood or skin abrasions) and the shark was hooked in the jaw; (2) if minor skin abrasions or small lacerations were present on the body, multiple hooks observed in the jaw, and/or trailing monofilament from a previous capture was observed; (3) if there were obvious signs of trauma, such as lacerations on the body, broken jaw, or gut hooking; or (4) if the shark was moribund (modified from Marshall et al., 2015).

Prior to release and regardless of assigned capture condition, the first 50 sharks that were captured were tagged with a satellite tag to measure PRM. Here, a Lotek PSAT LIFE tag was attached to each shark using a stainless-steel dart anchor (Hallprint®, SSD, 57 mm x 15 mm, Victoria Harbor, Australia). The 13 cm tether consisted of 136 kg monofilament line (300-lb test extra-hard Hi-Catch, Momoi Fishing Net Mfg. Co. Ltd., Ako City, Hyogo Prefecture, Japan) with heat shrink tubing to minimize abrasions to the animal. Tags were inserted into the dorsal musculature just below the first dorsal fin and in line with the insertion of the fin with a 2 m tagging pole following the protocols of Hoffmayer et al. (2014). All dusky sharks were tagged *in situ* and at no point were removed from the water. Following tag attachment, the line was cut less than 1 m above the hook and a release condition adapted from Manire et al. (2001) (1- burst swimming, 2- strong swimming, 3- sluggish swimming, 4- sank with no visible swimming effort) was assigned.

Two components of mortality were estimated, AVM and PRM. At vessel mortality was defined as a shark that was dead upon capture, while PRM was defined as a shark spending three consecutive days at a constant depth and temperature, as determined by tag data, after release (Heberer et al., 2010; Marshall et al., 2015; Campana et al., 2016). If a mortality event occurred prior to each tag's preprogrammed 28 day deployment duration, the PSAT LIFE tags were equipped with a constant depth fail-safe release that jettisoned the tag from the shark if a constant depth (± 3 m) was maintained for 72 h (indicative of a mortality event). Tags collected daily minimum and maximum depth (up to 2000 m) and ambient temperature (range -5 to 35 °C). Following pop-off and data transmission, tag reports were downloaded from the ARGOS website and post-processed using the Lotek TagTalk software (ver. 1.10.8.14). In addition to determining the PRM rate, binomial 95% confidence intervals were calculated to determine the uncertainty around this estimate; however, due to the low sample size, more data are required to support a more meaningful analysis. All analyses and figures were completed in SigmaPlot v12.5, MATLAB v9.1 and ArcGIS v10.4. All means are reported with corresponding standard errors and statistical tests were considered significant at $\alpha = 0.05$.

3. Results

Six hundred and seventy three hooks were deployed during the four pelagic longline sets, which resulted in 175 hook bite-offs and the capture of 123 dusky sharks (Mean size: 202 ± 28 cm FL; range 167–243 cm). Dusky shark TOL ranged from 0.8 to 8.1 h with a mean of 4.3 ± 0.3 h. Mean injury and release condition codes for all captured dusky sharks were 1.8 ± 0.1 and 1.3 ± 0.1, respectively (Table 1). No AVM was observed for dusky sharks caught in this study. Average SST over the course of the study was 24 ± 0.2 °C.

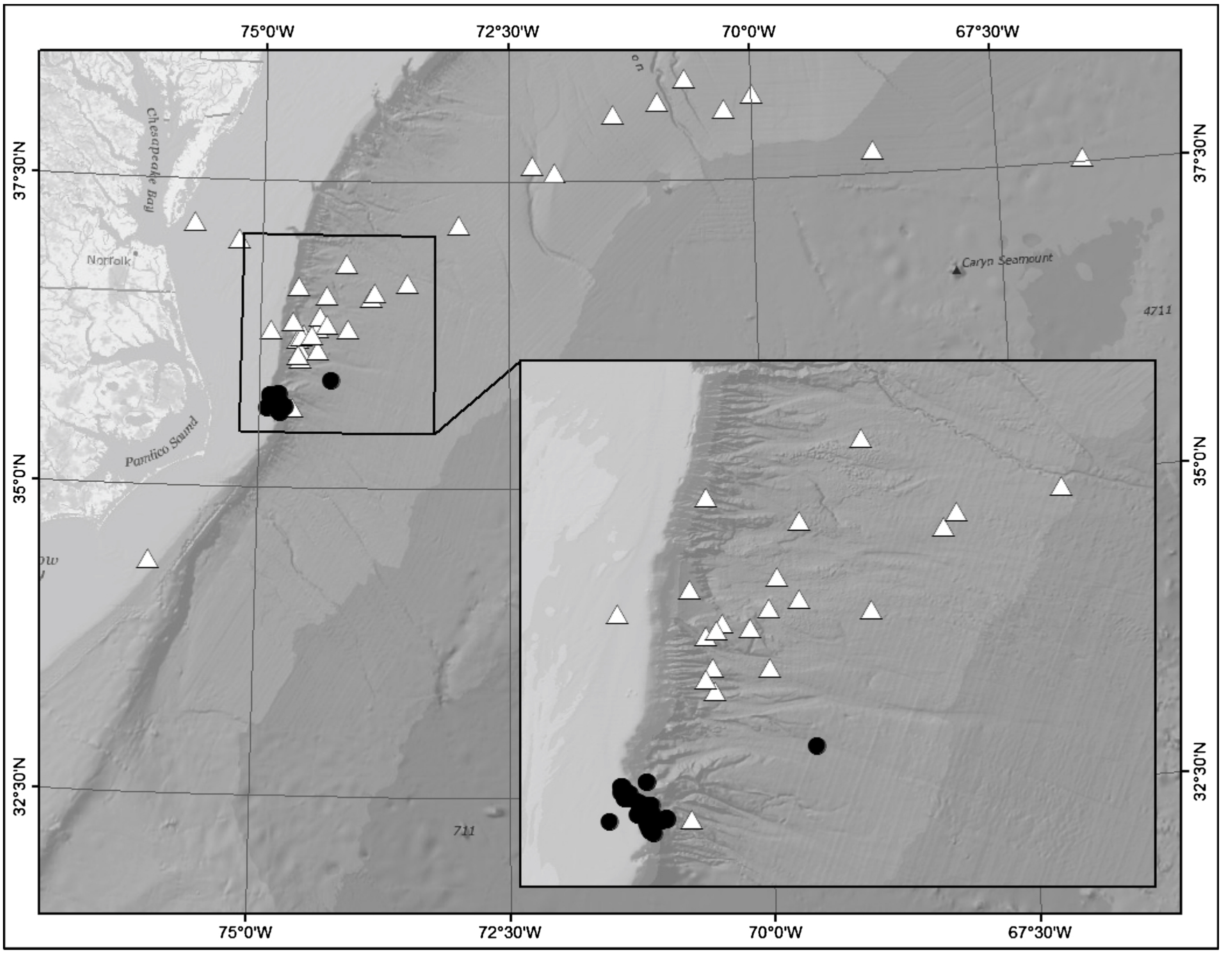

Fig. 1. Deployment (n = 50, circles) and pop-off (n = 43, triangles) locations for dusky sharks, *Carcharhinus obscurus*, captured and tagged with Lotek PSAT LIFE satellite tags in the western Atlantic Ocean. Seven tags failed to report data.

Table 1
Injury code and release condition of 50 dusky sharks, *Carcharhinus obscurus*, captured with pelagic longline gear and affixed with a LOTEK PSAT LIFE satellite tag. Injury codes and release conditions represent at-vessel observations. Sample size (**n**) and time on the line are provided for each code/condition.

		Time-on-the-Line (hour)	
Injury Code	n (%)	Range	Mean (± SD)
1 (No outward injury, hook in jaw)	40 (80.0)	1:53 – 6:13	4:13 ± 0.05
2 (Lacerations on body, multiple hooks in jaw)	8 (16.0)	2:35 – 6:38	5:27 ± 0.06
3 (Lacerations on body, broken jaw, gut hooked)	1 (2.0)	6:12	–
4 (Moribund)	1 (2.0)	6:05	–
		Time-on-the-Line (hour)	
Release Condition	n (%)	Range	Mean (± SD)
1 (Burst swimming)	21 (52.0)	1:53 – 6:38	4:33 ± 0.06
2 (Strong swimming)	13 (26.0)	2:30 – 6:13	4:55 ± 0.05
3 (Sluggish swimming)	7 (14.0)	2:35 – 6:00	3:57 ± 0.06
4 (Sank with no visible swimming effort)	4 (8.0)	3:00 – 6:05	4:05 ± 0.06

Fifty PSAT LIFE tags were deployed on dusky sharks (females n = 12, 209 ± 8 cm FL; males n = 4, 198 ± 7 cm FL; unknown sex n = 34, 214 ± 7 cm FL). Forty-three of the 50 tags subsequently transmitted data (86%) with deployment times ranging from 1 to 28 days (mean = 11.2 ± 9.8 days) (Table 2). Although the depths were not constant, four tags remained on sharks less than three days, the minimum number of days to identify a PRM event, and were subsequently removed from analyses. Thirty-one tags released prematurely (i.e. < 28 days) due to an assumed tether failure. However, despite these premature detachments, the PSAT LIFE tags captured daily activity patterns and vertical profiles from 37 tags, which indicated post-release survival (Fig. 2). Two sharks recorded constant depth readings immediately following release that we considered PRM events. One shark that was at first considered an AVM (injury code and release condition of 4), recovered and was at liberty for 8 days prior to premature release of the satellite tag.

Despite four dusky sharks being assigned a release condition of 4, these sharks survived the capture and tagging process. However, two

Table 2
Biological, tag-deployment, and post-release outcomes for dusky sharks, *Carcharhinus obscurus*, captured with pelagic longline gear.

Shark	ID	FL (cm)	Sex	TOL (hours)	Date tagged	Tag latitude ° N	Tag longitude ° W	Time at liberty (days)	Pop-up latitude ° N	Pop-up longitude ° W	Release Code	Injury Code	Release Condition	Outcome
1	1452	NA	NA	NA	5/25/16	NA	NA	12	37.5708	72.0347	1	1	NA	Survived
2	1453	NA	NA	6:05	5/25/16	35.7167	74.865	8	36.6667	68.7589	1	1	A	Survived
3	1455	213	NA	6:07	5/25/16	35.7233	74.8633	3	36.1175	74.4236	1	2	A	Survived
4	1456	177	NA	3:09	5/25/16	35.6190	74.7869	4	36.5942	73.8517	3	1	A	Survived
5	1457*	NA	NA	3:11	5/24/16	35.6683	74.8267	< 3	36.3553	74.6686	1	1	A	Survived
6	1458	175	F	1:53	5/25/16	35.7517	74.8733	28	36.9217	74.5728	1	1	A	Survived
7	1459	NA	F	4:14	5/24/16	35.695	74.7833	28	37.3353	75.0675	1	1	A	Survived
8	1460	NA	NA	6:05	5/25/16	35.7267	74.8633	8	37.0907	73.005	4	4	A	Survived
9	1461	244	NA	NT*	5/25/16	35.73	74.85	4	38.1867	69.9911	3	1	A	Survived
10	1463	NA	NA	NA	5/25/16	NA	NA	NR	NR	NR	1	1	A	NR
11	1464	NA	NA	5:46	5/25/16	35.73	74.85	NR	NR	NR	1	1	A	NR
12	1465	177	NA	6:00	5/25/16	35.6883	74.8009	NR	NR	NR	1	1	A	NR
13	1466	163	NA	3:31	5/25/16	35.6409	74.7974	28	36.2542	74.5681	1	1	A	Survived
14	1467	137	NA	5:13	5/24/16	35.6967	74.7983	18	37.0169	75.2356	1	1	A	Survived
15	1469	NA	NA	6:12	5/25/16	35.7167	74.865	26	36.9175	74.5867	1	1	A	Survived
16	1470	203	F	5:54	5/25/16	35.6807	74.7820	4	36.2389	74.4828	2	2	A	Survived
17	1471	125	NA	4:18	5/25/16	35.7517	74.8783	NR	NR	NR	1	1	A	NR
18	1472	190	M	5:54	5/25/16	35.6553	74.7361	28	58.4333	74.5861	2	1	A	Survived
19	1473	185	F	2:30	5/25/16	35.7517	74.8733	8	36.3000	74.4258	2	1	A	Survived
20	1474	177	F	6:13	5/25/16	35.6856	74.7972	12	37.6367	72.2594	2	1	A	Survived
21	1475	150	NA	4:44	5/25/16	35.7533	74.8783	10	36.6753	73.5319	1	1	A	Survived
22	1476	203	NA	6:12	5/24/16	35.6542	74.7389	0	35.6536	74.6617	2	3	A	Mortality
23	1477*	203	NA	5:48	5/25/16	35.6542	74.7389	< 3	36.6383	74.6192	1	2	A	Survived
24	1478	305	F	6:38	5/25/16	35.7250	74.8633	7	38.3306	70.6875	1	2	A	Survived
25	1479	NA	NA	NA	5/25/16	NA	NA	28	38.7186	73.9261	1	1	NA	Survived
26	1480	126	NA	5:06	5/25/16	35.7653	74.7964	25	37.7186	75.6947	2	1	A	Survived
27	1481	183	NA	6:05	5/25/16	35.7217	74.8633	28	37.3575	75.5856	1	1	A	Survived
28	1485	NA	NA	4:10	5/25/16	35.7400	74.8717	5	36.2808	74.8894	4	1	A	Survived
29	1486	203	NA	3:01	5/25/16	35.6122	74.7799	28	38.0392	71.4203	1	1	A	Survived
30	1487		NA	4:23	5/25/16	35.7367	74.8733	NR	NR	NR	1	2	A	NR
31	1488	164	NA	3:41	5/25/16	35.6372	74.7956	7	36.3936	74.4014	1	1	A	Survived
32	1489*	NA	NA	2:49	5/24/16	35.7050	74.8283	1	36.2117	74.4014	1	1	A	Survived
33	1490	190	NA	4:02	5/24/16	35.7183	74.8517	10	37.5358	66.6225	1	1	A	Survived
34	1491	NA	NA	4:53	5/25/16	35.7437	74.8700	5	38.1408	70.9686	1	1	A	Survived
35	1492	152	NA	2:10	5/24/16	35.7017	74.8200	12	36.2967	74.1144	1	1	A	Survived
36	1493*	177	F	3:26	5/25/16	35.6242	74.7894	3	36.0461	74.5911	1	1	A	Survived
37	1495*	151	F	6:05	5/25/16	35.6655	74.7801	< 3	36.8217	74.1453	2	2	A	Survived
38	1496	NA	NA	4:09	5/25/16	35.8767	75.2767	< 3	36.0800	74.6189	1	1	A	Survived
39	1498	137	NA	5:10	5/25/16	35.6680	74.7830	NR	NR	NR	1	1	A	NR
40	1499	164	M	3:00	5/25/16	36.6220	74.7879	8	36.1186	74.6000	4	1	A	Survived
41	1500	177	F	5:28	5/24/16	35.6521	74.7450	10	36.5502	73.8914	2	1	A	Survived
42	1502	164	NA	3:00	5/25/16	35.6116	74.7771	28	38.1989	73.6792	2	1	A	Survived
43	1503	177	NA	2:35	5/25/16	35.6334	74.7943	28	37.6339	75.3331	3	2	A	Survived
44	1506	177	NA	3:07	5/25/16	35.6178	74.7863	28	36.9422	74.5483	4	1	A	Survived
45	1507	177	NA	5:07	5/24/16	35.7653	74.7964	NR	NR	NR	1	1	A	NR
46	1510	125	NA	6:12	5/25/16	35.7350	74.8733	8	38.0706	70.2778	1	2	A	Survived
47	1511	NA	NA	5:19	5/25/16	35.6450	74.9133	16	34.3911	76.0492	1	1	A	Survived
48	1512	177	F	2:40	5/25/16	35.6334	74.7953	6	36.3286	74.3356	3	1	A	Survived
49	1513	138	F	3:42	5/25/16	35.6372	74.7956	0	36.5656	74.3328	2	1	A	Mortality
50	1514	190	F	3:37	5/25/16	35.6356	74.7944	28	37.1264	75.6044	2	1	A	Survived

Note: Fork length was estimated; * denotes sharks removed from mortality analysis.
NT; No timer.

sharks (1476 and 1513) with a release condition of 2 suffered PRM (5.1%). The 95% confidence intervals around the PRM rate ranged from 0.6 to 17.3%. Mean injury code, release condition code and TOL of those two dusky sharks were 2.0 ± 0.0, 2.0 ± 1.4, and 4.8 ± 1.7 h, respectively. Time-on-the-line of 1–3 h resulted in 0% PRM, while TOL of 3–5 h and ≥ 5 h each accounted for one PRM event (the two sharks listed previously; Fig. 3ab). Regardless of TOL, the majority of the sharks exhibited minimal signs of injury from pelagic longline capture (95%), and most (78%) were released in good condition (Fig. 3 a,b). Since only two PRM events were observed in the study, a larger sample size is needed to better identify causal variables.

4. Discussion

One of the biggest challenges facing fisheries managers is reducing bycatch (Musick, 1999; Afonso et al., 2011). Understanding the fate (dead or live) of discarded fishes is essential for properly characterizing total fishing mortality and its resulting implications for estimates of stock status (Sulikowski et al., 2017). In addition, PRM estimates have a practical application that aids managers in the development of biologically realistic catch limits for a given fishery (e.g., Alverson, 1999; Benoît et al., 2015; Sulikowski et al., 2017). Also vital to management is understanding the relationship between mortality estimates and key variables linked to those events. For example, gear configuration, bait type, environmental parameters, and biology of the species of interest, can lead to best practices that will reduce overall mortality of that species (e.g. Carruthers et al., 2009; Capizzano et al., 2015; Ellis et al., 2017) and extend fishing opportunities. However, obtaining this information can be difficult due to challenges associated with cost and the ability to collect representative samples. As such, AVM and PRM studies have only been conducted for a limited number of elasmobranchs (Hoolihan et al., 2011), and even fewer studies have been able to

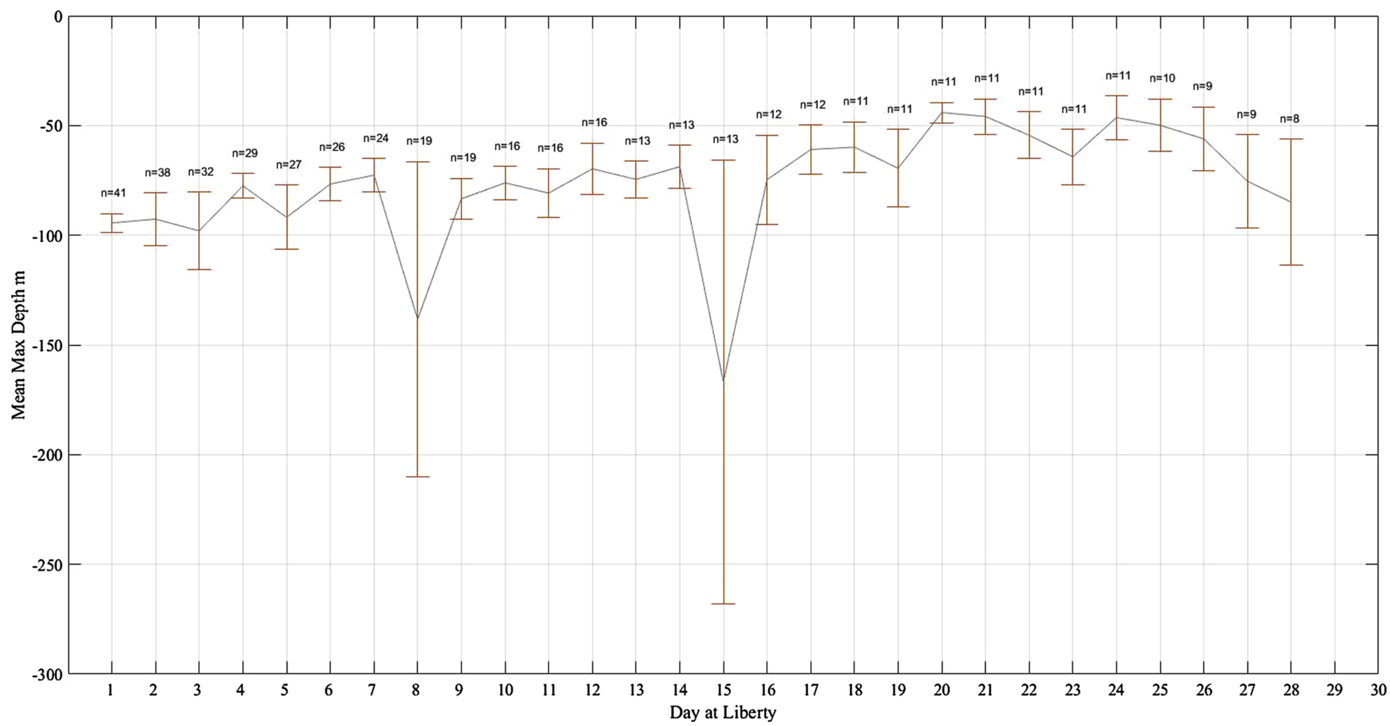

Fig. 2. Daily mean max depth plots representing 41 dusky sharks, *Carcharhinus obscurus*, that remained alive after release and whose satellite tags transmitted a daily minimum and maximum depth. Numbers above each day at liberty post-release indicate sample size/remaining attached tags on that given date. Change in sample size on any given day represents early tag detachment. Vertical bars above and below each data point on a given date represent the standard error.

investigate the relationships between mortality and the aforementioned variables in sharks (e.g. Dapp et al., 2016; Campana et al., 2016; Ellis et al., 2017). While fishing practices vary (e.g., vessel size, mainline length, hook/bait configurations, soak time) across all the different regions the pelagic longline fleet fishes (Musyl et al., 2011) here gear was fished in line with how commercial vessels typically fish off North Carolina. Thus, the AVM and PRM presented herein, are representative of the fishery in the geographic region this study was conducted.

Previous studies reporting fishing mortality rates of specific shark species in both pelagic longline and bottom longline fisheries have documented a wide range of estimated rates (0%–90%) among species and gear types (Beerkircher et al., 2002; Diaz and Serafy, 2005; Morgan and Burgess, 2007; Campana et al., 2009; Morgan and Carlson, 2010; Hutchinson et al., 2015; Ellis et al., 2017). The current findings represent the lowest published PRM estimates (5%) for dusky sharks, a stark contrast to that of Marshall et al. (2015) who reported a 29% PRM rate for dusky sharks caught on bottom longline gear. Moreover, no AVM (0%) was observed for any of the 123 dusky sharks caught in this study, which again is in contrast to the estimated AVM of nearly 40% (dead or moribund individuals) reported by Marshall et al. (2015) for dusky sharks captured by bottom longline gear. Interestingly, although the values for AVM and PRM in the current study were lower than for dusky sharks caught on bottom longline (Marshall et al., 2015), the relationship between the two mortality types was similar (PRM = AVM + 6%). Although the AVM + 6% rule was used to estimate a PRM rate of 44.2% for dusky sharks in the pelagic longline fishery (SEDAR, 2011), that estimate is well above values obtained in the current study. In addition, while limited, observer data obtained within our general sampling area and time frame suggests that interaction with and AVM of dusky sharks is variable. For example, ranging from 0 to 47% AVM from March to May (Cushner S., NMFS, pers. comm.). Collectively, this information suggests that future work should focus on the temporal and spatial variability in AVM/PRM within this fishery. Finally, the two mortalities that were observed in the current study occurred within 24 h of release, a time frame widely observed for several sharks species captured with fixed gear, including dusky sharks (Heberer et al., 2010; Marshall et al., 2015; Campana et al., 2016; Whitney et al., 2016).

The knowledge of how a species' physiology is affected by the interaction with a specific gear type is important as inferences can be made relative to the causes producing the observed PRM rates (Marshall et al., 2015). For example, dusky sharks are obligate ram ventilators and need to force oxygenated water over their gills in order to respire (Liem and Summers, 1999). In general, bottom longline gear is set on the substrate and has relatively short leader lengths (~2 m; Marshall et al., 2015) limiting a shark's movement and their ability to ram ventilate. Thus, sharks that rely on ram ventilation must compensate for decreases in oxygen availability by increasing swimming speed and/or mouth gape (Carlson and Parsons, 2001). In addition, during the warmer months of the year, hypoxic and anoxic conditions can occur at or near the bottom due to eutrophication and water column stratification (Rabalais et al., 2002), which can further exacerbate the respiratory stress. The combination of short gangion lengths and hypoxic and anoxic conditions would result in rapid asphyxiation following hooking and would contribute to mortality when sharks are caught during these conditions (Morgan and Burgess, 2007). In comparison, pelagic longline gear drifts at or near the water's surface with longer leader lengths (> 20 m), presumably allowing the sharks to remain swimming while on the line in oxygenated waters. While not directly comparable, these gear and environmental differences between bottom longline and pelagic longline may have resulted in the much lower morality rates observed in the current study. However, since the current study was conducted during a specific temporal period, further research regarding the effects of temperature on the PRM of dusky sharks captured in the pelagic longline should be explored.

Previous research suggests soak time and water temperature are the main factors affecting mortality for sharks captured with bottom longline gear (Morgan and Burgess, 2007; Morgan and Carlson, 2010; Marshall et al., 2012; Gallagher et al., 2014). While the depth the hooks were fishing or the temperatures that they were experiencing are not known, given the length of mainline, spacing of floats, gangion length, geographic location and the time of year did not vary/were consistent during the study, all tagged sharks were assumed to have been captured

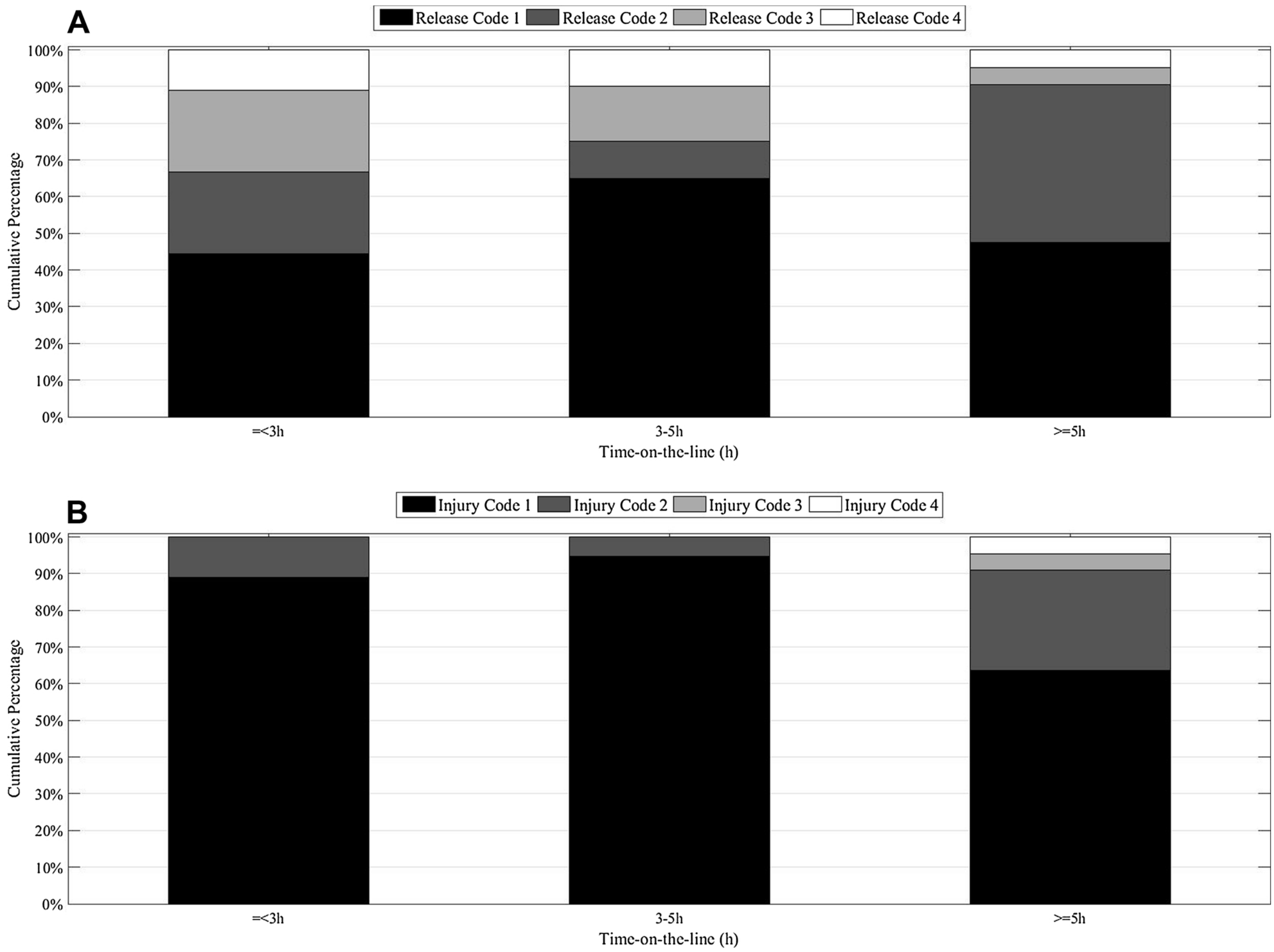

Fig. 3. a and b. At-vessel (A) release condition and (b) and injury code of the 43 dusky shark, *Carcharhinus obscurus*, tags that transmitted data as a function of binned TOL. Release conditions we defined as (1) burst swimming, (2) strong swimming, (3) sluggish swimming, (4) sank with no visible swimming effort while injury conditions of (1) represented no visible signs of trauma to the body, (2) if minor damage was present, (3) if there were obvious signs of trauma, and (4) if the shark was moribund (see methods for full description). Columns represent cumulative percentages.

in similar environmental conditions. Given this, and since total mortality was low, temperature did not appear to be associated with the mortality in dusky sharks in the current study. However, future studies should investigate how this abiotic parameter influences survival over varying temporal regimes. Mean TOL for dusky sharks captured was 4.3 h with no AVM observed. Over this same period, 39% of the dusky sharks caught on bottom longline were either moribund or dead (Marshall et al., 2015). Research has suggested that cooler water temperatures positively correlate with increased survival of sharks captured on fixed gear. For example, Gallagher et al. (2014) found a significant increase in survival of several shark species (including dusky sharks) that were captured at deeper hook depths. Since dissolved oxygen content increases with decreasing temperature, the ability to overcome any oxygen deficits produced by the capture event would be greater in cooler waters (e.g. Skomal and Bernal, 2010) and is enhanced by the ability to actively ram ventilate via a longer gangion (Gallagher et al., 2014). Collectively, the aforementioned data reinforce the possibility that the longer gangions and mobility of the gear provided dusky sharks on pelagic longline the ability to reduce their metabolic rate (swim down to cooler water; Skomal and Bernal, 2010) and ram ventilate (Liem and Summers, 1999) allowing for higher survival and faster recovery than those observed from previous bottom longline studies.

While direct comparisons among species and between gear types (bottom longline vs pelagic longline) cannot be made (i.e different gear configurations and soak times), the limited information that exists suggests that mitigation measures can be effective in reducing PRM in sharks. For example, Moyes et al. (2006) found that moribund blue sharks had blood chemistry values that were indicative of exhaustive exercise, a possible result of long soak times and suggested shorter soak times may lead to better survival rates. Using a generalized linear model, Campana et al. (2009) found fishing gear and techniques appear to be the main factors influencing hooking mortality in blue sharks and health status of the shark at release contributed to PRM. Afonso et al. (2011) reported that the use of circle hooks (as opposed to J hooks) suspended in the middle of the water column reduced the bycatch of several demersal elasmobranch species. Finally, results of Tolotti et al. (2013) indicated that setting longline hooks at depths greater than 100 m could reduce the bycatch of oceanic whitetip sharks, *Carcharhinus longimanus*. Based on the aforementioned data and the observations from the current study, requirements already in place seem sufficient to keep AVM and PRM low in the pelagic longline fishery and could be sufficient mitigation measures to reduce mortality for dusky sharks.

The results herein illustrate the importance of providing empirical data when estimating AVM and PRM on species and gear specific bases. "Borrowing" values from other species and/or gear types, while necessary for some data poor situations, in this case, overestimates the discard mortality for this species on pelgaic longlines (e.g. Gallagher et al., 2014). Relatively low AVM and PRM rates reported herein indicate dusky sharks are resilient to the capture and handling stress experienced in the pelagic longline fishery, especially when compared to estimates derived for the same species using bottom longline gear (97%; Marshall et al., 2015). Estimating AVM and PRM associated with the pelagic longline fishery across a larger sample size, a wider geographic range, set of gear configurations and environmental conditions would provide a more comprehensive evaluation and should be considered in future studies. Based on the total fishing mortality estimates collected in this study (AVM and PRM) for dusky sharks captured on pelagic longline fishing gear, the PRM rate occurring within the pelagic longline fishery will need to be updated for future stock assessments.

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