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Preliminary estimate of post-release survival of immature porbeagles caught with rod-and-reel in the Northwest Atlantic Ocean

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ABSTRACT: The Northwest Atlantic (NWA) population of porbeagles *Lamna nasus* is susceptible to capture in rod-and-reel fisheries and most individuals are discarded alive due to catch and size limits. To estimate post-release survival, pop-off satellite archival tags were attached to porbeagles captured with rod-and-reel. Fourteen tags were deployed, of which 13 transmitted. All sharks for which we had data survived, giving a post-release survival rate of 100%. Following release, 6 individuals remained in surface waters for several hours to days, while 2 individuals immediately resumed normal diving behaviors. For the remaining sharks (n = 5), low tag transmission resolution precluded the detection of fine scale post-release behavior. The duration of initial depth-holding behavior was characterized using a break-point analysis of dive track variance, which suggests porbeagles exhibited a median post-release recovery period of 116 h (10th and 90th percentiles = 68.8 and 280.1 h) following capture and handling. Our preliminary study suggests immature porbeagles are resilient to capture and handling, although more data would provide stronger support for management recommendations.

KEY WORDS: Porbeagle · Survival · Shark

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1. INTRODUCTION

Capture as bycatch is a pressing threat to fish stocks (Davies et al. 2009), and slow-growing shark species with low reproductive output are particularly susceptible to overexploitation (Stevens et al. 2000). Management measures (e.g. catch limits, retention prohibitions, circle hook requirements, wire leader bans) are often employed for overexploited shark species in an effort to reduce fishing mortality (e.g. ICCAT 2015). Although such management measures may effectively reduce directed landings, incidentally captured sharks may still suffer unintended at-vessel or post-release mortality from injuries and physiological damage (Kneebone et al. 2013). Therefore, computing total catch and assessing the efficacy of management measures require quantification of both components of unintended fishing mortality (at-vessel and post-release mortality; e.g. Musyl & Gilman 2019).

The Northwest Atlantic (NWA) population of porbeagles *Lamna nasus* is particularly vulnerable to

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population declines (Natanson et al. 2002). Historically, this species was targeted commercially or taken as bycatch throughout much of its range (Francis et al. 2008), and population declines have occurred in multiple locations worldwide (Campana et al. 2002, Stevens et al. 2006). After the introduction of longline fishing pressure in the early 1960s, the NWA population declined precipitously in abundance, reaching a minimum in 2001 (Campana et al. 2013). Population dynamics modeling suggests fishing mortality must remain low for successful recovery to occur (Campana et al. 2013). In response to declines, catch and size limits have been utilized in the NWA to reduce rod-and-reel fishing mortality (i.e. Campana et al. 2002, NMFS 2007, ICCAT 2015). Despite these management measures, porbeagles remain susceptible to capture in rod-and-reel fisheries targeting tuna and pelagic sharks in the NWA (Hurley 1998, NOAA 2019) and no study to date has investigated the impact of rod-and-reel capture on porbeagles released alive. Therefore, this study utilized pop-off satellite archival tags (PSATs) to estimate post-release survival and characterize behavior following release for porbeagles caught with rod-and-reel in the NWA.

2. MATERIALS AND METHODS

Porbeagles were caught opportunistically in the NWA using rod-and-reel with 200 lb Jinkai fishing line set at a strike drag strength of 40 lb. Rods and reels were equipped with 16/0 non-offset Mustad circle hooks or 12/0 Mustad J-hooks baited with locally caught species (i.e. Atlantic mackerel *Scomber scombrus*) alive or dead, and whole or chunked. Fight time (time from when the shark was hooked until it was either secured alongside the vessel or brought onboard), sex, fork length (FL), and handling time (time from when the shark was secured alongside the boat or brought onboard until it was released) were recorded. Sharks were assigned an injury code modified from Marshall et al. (2015) and a release condition adapted from Manire et al. (2001) (Table 1). Before release, the hook was removed or the leader was cut.

Different pop-off schedules (in parentheses) characterized the PSATs used to observe post-release survival: Lotek Wireless (LW) PSATLIFE tags (28 d; n = 7), Wildlife Computers (WC) Survivorship PATs (sPATs; 30 d; n = 4), and Microwave Telemetry (MT) High Rate (HR; 30 d; n = 1) and Standard Rate (SR; 9 mo; n = 2) X-Tags. The short-term deployments were assumed to be long enough to detect mortality

Table 1. Injury codes (modified from Marshall et al. 2015) and release conditions (adapted from Manire et al. 2001) assigned to porbeagles captured with rod-and-reel

Indicator	Description
Injury code	
1	No visible trauma, hooked in jaw
2	Minor abrasions or small lacerations
3	Obvious trauma (i.e. lacerations on body, gut hooking)
4	Moribund
Release condition	
1	Burst swimming
2	Strong swimming
3	Sluggish swimming
4	Sank with no visible swimming effort

caused by trauma or stress during capture and handling, while the 2 SR X-Tags were deployed to observe delayed mortality over longer time spans. For 10 porbeagles, tags were attached using a stainless steel dart anchor (Hallprint) inserted into the dorsal musculature. The tags have a buoyancy rating of 8 g and the tag tethers were 2.3 g in water, ensuring tags would float if shed. To reduce the likelihood of premature tag shedding, for 4 porbeagles PSATs were looped through a hole in the dorsal fin (Moyes et al. 2006). In this case, a 5 mm diameter hole was drilled (Ryobi drill) through the dorsal fin, then flexible tubing with 136 kg test monofilament Jinkai fishing line was threaded through the hole and crimped with a stainless steel nicopress crimp sleeve. The PSAT was attached to this loop and centered behind the dorsal fin. PSATs were programmed to collect pressure (i.e. depth) and ambient temperature at 10–90 s intervals and report data at 5 (PSATLIFE, HR X-Tag) or 15–60 (SR X-Tag) min intervals or report daily minimum and maximum data (sPAT). PSATs were programmed to release prematurely if pressure remained constant for a predetermined number of days (LW: ±5 m for 3 d, MT: ±3 m for 2 d, and WC: ±4 m for 1 d), indicating a mortality or a shed tag floating at the surface or washed ashore. PSATs were programmed to release and transmit prematurely if pressure went below a predetermined threshold (LW: 1500 m, MT: 1250 m, and WC: 1400 m).

Post-release survival was determined using depth profiles from PSAT data downloaded from the ARGOS website (www.argos-system.org). To evaluate changes in diving behavior following release, hourly variance in depth was calculated from the tags transmitting at 5 min intervals (n = 6). A break-point analysis completed in R (v 3.5.1) was used to identify the hour in which variability at the beginning of the dive track differed the most from variability in the latter part of the dive track (Wichern et al. 1976). Extremely low hourly variance only occurred while an individual remained within surface waters, and variance markedly increased once an individual began utilizing a range of depths. The end of the recovery period was identified from a time series of absolute differences between mean variance prior to and after a given sampling hour. The maximum reduction in the absolute difference in variance occurred once an animal ceased any depth-holding behavior and began to move cyclically through the water column, indicating the end of the recovery period. For tags with lower transmission resolution (i.e. sPATs), sharks that exhibited minimal diving behavior following release were identified from the amount of time they remained in the top 50 m of the water column.

3. RESULTS

Opportunistic capture resulted in a random sample of 14 immature (Jensen et al. 2002) porbeagles tagged with PSATs (mean FL (±SD) 122.4 ± 38.8 cm; Fig. 1; Table 2). Data were successfully transmitted from tags on 13 of these individuals (FL 122.5 ± 40.3 cm). Fight time ranged between 1 and 76 min. All 13 (100%) sharks for which we had data survived until the tags popped off (between 12 and 246 d after release). Two tags attached with dart anchors shed

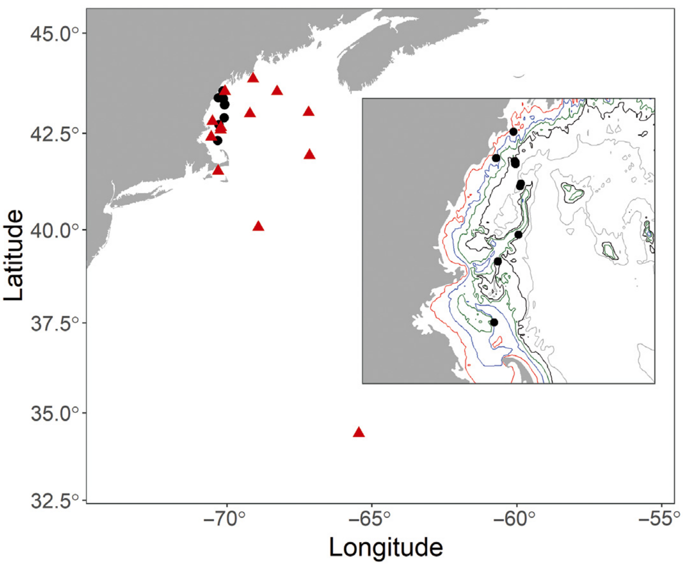

Fig. 1. Tagging (●) and pop-off (▲) locations for porbeagles captured with rod-and-reel. The inset shows 25 (red), 50 (blue), 75 (green), 100 (black), and 150 (grey) m depth contours at tagging locations

Table 2. Summary data for porbeagles captured with rod-and-reel. Fight and handling times are reported to the nearest minute. The breakpoint analysis recovery time indicates the total amount of time (h) the porbeagle exhibited depth-holding behavior based on analysis of hourly dive variance. M: male, F: female, FL: fork length, SR: standard rate, HR: high rate, sPAT: survivorship pop-off archival tag, NA: not available, DNR: did not report. Shark 2498 was removed from survival analysis

ID	Sex	FL (cm)	Injury code	Release condition	Fight time (min)	Handling time (min)	Tag type	Capture date	Capture location (°N, °W)	Pop-off date	Pop-off location (°N, °W)	Days at liberty	Distance traveled (km)	Breakpoint analysis recovery time (h)	Outcome
25516	NA	110	NA	NA	NA	NA	SR X-Tag	06/26/2015	43.216, 70.084	02/26/2016	43.032, 67.188	246	236	NA	Survived
25514	F	119	NA	NA	NA	NA	SR X-Tag	07/10/2015	43.235, 70.076	03/11/2016	40.073, 68.92	246	365	NA	Survived
161793	F	92	NA	NA	NA	NA	HR X-Tag	08/12/2016	43.569, 70.142	09/11/2016	43.56, 70.077	31	5	0	Survived
1815	F	94	NA	NA	NA	NA	PSATLIFE	09/10/2016	43.372, 70.124	10/07/2016	42.807, 70.5	28	70	0	Survived
2492	F	90	1	3	2	7	PSATLIFE	08/30/2018	43.400, 70.295	09/10/2018	41.539, 70.311	12	207	NA	Survived
2490	F	90	1	2	3	3	PSATLIFE	09/23/2018	43.398, 70.297	10/17/2018	41.941, 67.152	25	304	117	Survived
416	F	198	3	1	76	13	sPAT	06/12/2019	43.367, 70.125	07/13/2019	42.9997, 69.208	31	85	NA	Survived
2498	F	121	1	1	1	7	PSATLIFE	06/17/2019	43.359, 70.121	DNR	DNR	DNR	DNR	DNR	DNR
193	M	127	1	1	1	8	sPAT	06/18/2019	43.362, 70.128	07/19/2019	43.559, 68.274	32	151	NA	Survived
446	NA	152	3	2	8	6	sPAT	06/27/2019	42.723, 70.282	07/28/2019	42.656, 70.2087	32	10	NA	Survived
2499	F	110	2	1	1	5	PSATLIFE	06/27/2019	42.725, 70.282	07/24/2019	42.597, 70.220	28	15	115	Survived
819	F	209	3	2	23	17	sPAT	07/02/2019	42.900, 70.098	08/02/2019	42.411, 70.544	32	66	NA	Survived
2491	F	88	1	1	8	2	PSATLIFE	07/09/2019	43.380, 70.130	08/05/2019	43.873, 69.099	28	100	49	Survived
2494	M	114	3	1	5	3	PSATLIFE	10/01/2019	42.322, 70.315	10/28/2019	34.424, 65.460	28	975	350	Survived

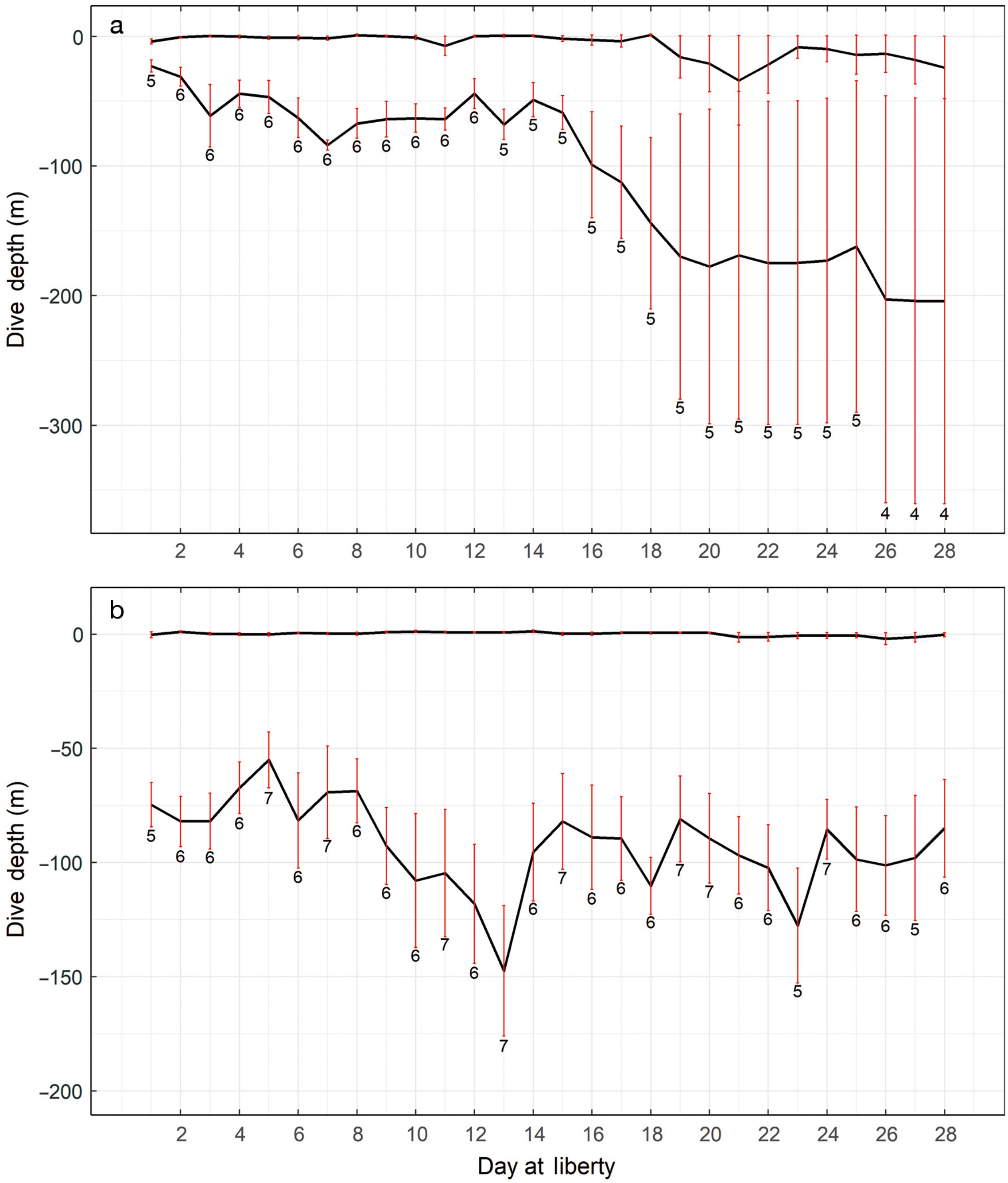

Fig. 2. Daily mean minimum (top line) and maximum (bottom line) dive depth of porbeagles captured with rod-and-reel. (a) porbeagles exhibiting a possible recovery period; (b) porbeagles exhibiting no recovery period or had insufficient data to conclude a recovery period. Note the y-axes differ in scale. Numbers below error bars indicate sample size. Changes in sample size represent tag shedding or variation in the number of tags with depth data available. Error bars represent ±1 SE

prematurely (12 and 25 d) but these individuals were included in survival analyses, given that most shark mortality occurs within the first few hours to days after release (e.g. Musyl & Gilman 2019).

Six sharks swam in surface waters (<50 m depth; Fig. 2) with limited vertical movement immediately following release, suggesting possible recovery periods. During these potential recovery periods, sharks spent 16.4–99.5% of time in the top 10 m and 61.6–100% of time in the top 20 m of the water column. Following the potential recovery periods, these same individuals spent 26.2–79.9% in the top 20 m of the water column, remained below 50 m for 1.2–56% of the time, and made regular dives to ≥100 m. Based on break-point analysis of hourly dive variance for individuals with high transmission resolution (example given in Fig. 3), recovery times ranged from 49 to 350 h, with a median of 116 h (10th and 90th percentiles = 68.8 and 280.1 h). For some individuals recovery behavior (based on the time spent in top 50 m of water column or breakpoint analysis of dive variance) could not be determined because of tag transmission resolution. In particular, SR X-tags (n = 2; no. 25 516 and 25 514) did not transmit data for the first several days at liberty and 3 sPATs (no. 416, 193, and 819) transmitted daily maximum depths of approximately >50 m for the first day at liberty and therefore shorter duration (<24 h) recovery periods could not be determined. However, the 2 individuals with high transmission resolution tags (no. 1815 and 161 793) that dove to >50 m immediately following release exhibited relatively consistent hourly dive

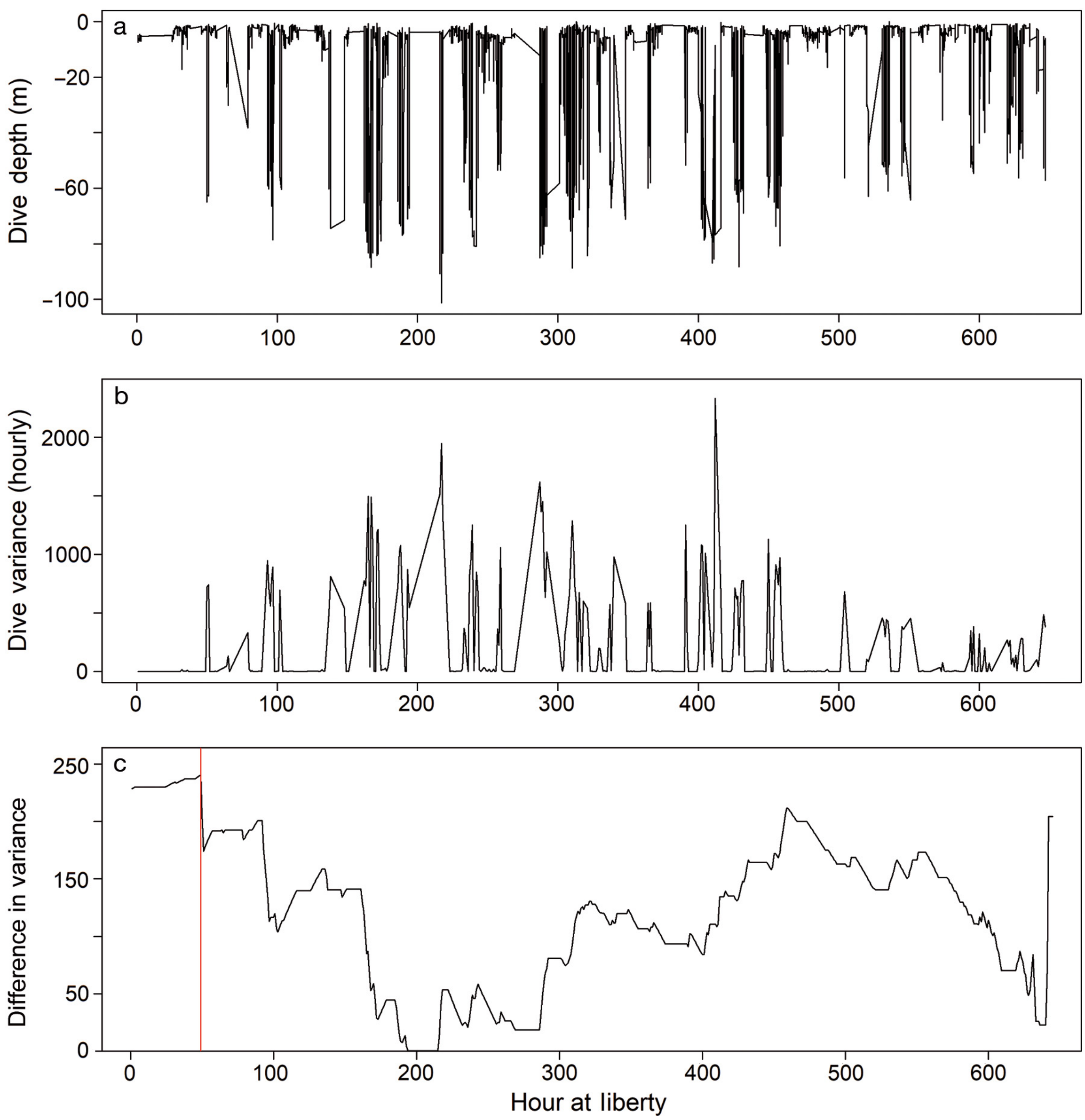

Fig. 3. Example breakpoint analysis for porbeagle no. 2491, showing (a) the time series of recorded dive depths, (b) hourly variance in depth, and (c) the absolute difference in mean variance for each successive hour at liberty from the remainder of the dive track. The near-zero variance at the start of the track in (b) indicates depth-holding at the surface and the maximum reduction in the absolute difference in variance between the start and end of the dive track (red vertical line in c) corresponds to the end of a 49 h recovery period for this individual

variance throughout monitoring, and therefore did not exhibit depth-holding behavior indicative of a recovery period upon release based on the breakpoint analysis of hourly dive variance

4. DISCUSSION

Our study suggested high (100%) post-release survival for immature porbeagles captured with rod-and-reel regardless of capture, handling, and release factors (i.e. injury code, release condition). Short-term (28 d) survival was the focus of this study and long-term delayed mortality (i.e. from infection or gut hooking and cessation of feeding) may have been underestimated. However, results from the deployment of two 9 mo tags suggests long-term survival may also be high for porbeagles. The survival rate in our study is consistent with those found for other shark species captured with rod-and-reel, including shortfin mako *Isurus oxyrinchus* (90%; French et al. 2015), blue shark *Prionace glauca* (87%; Howey et al. 2017), and blacktip shark *Carcharhinus limbatus* (90.3%; Whitney et al. 2017). Additionally, Sepulveda et al. (2015) found post-release survival of rod-and-reel caught common thresher sharks *Alopias vulpinus* to be 100% when mouth-hooked, although survival for tail-hooked individuals was 66%.

The observed depth-holding behavior was consistent with previously documented post-release behavior modification in porbeagles (Hoolihan et al. 2011), other pelagic fishes (Pepperell & Davis 1999), and other sharks (Campana et al. 2009, Hoolihan et al. 2011). Decreased vertical movement may be a consequence of physiological stress associated with capture and handling (Hoolihan et al. 2011), as porbeagles may need to reallocate energy from normal swimming patterns to restore homeostasis (Marshall et al. 2015). This study suggests porbeagles exhibit a recovery period following capture and handling that typically lasts ~116 h (4.8 d). Given the observed recovery behavior increases time spent in surface waters where rod-and-reel fishing for pelagic species occurs, captured and released porbeagles may be more vulnerable to recapture and/or predation from larger predators inhabiting surface waters.

5. CONCLUSIONS

Our findings suggest immature porbeagles are resilient to capture and handling in rod-and-reel fisheries in the NWA, and these are the first data of this kind that can be considered in management of this species. Based on our preliminary results, mitigation measures that increase the proportion of porbeagles released alive (i.e. catch limits, size limits) may be viable strategies for minimizing mortality in rod-and-reel fisheries. However, more data is necessary to obtain sufficient statistical power to better support management recommendations (Musyl & Gilman 2019) and evaluate how mortality rates or recovery periods vary with characteristics of the fishery.

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