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Evaluating the Condition and Discard Mortality of Monkfish, Lophius americanus, Following Capture and Handling in the Sea Scallop Dredge Fishery

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Final Report

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Introduction

The incidental capture of nontarget organisms, known as bycatch, remains an unavoidable occurrence for all fisheries (Kirby and Ward, 2014). One of the most challenging issues facing fisheries management is the post-release mortality of these bycaught species due to its difficulty to predict and the variability among species and gear type (Benoit *et al*., 2010, 2013; Depestele *et al*., 2014), which makes it inherently difficult to conduct proper stock assessments. Since there have been few studies conducted on post-release mortality across species, fisheries managers typically assign conservative estimates of mortality which limits total allowable catch and may negatively impact the economic contribution of fisheries (Knotek *et al*., 2018).

Due to the continued increase in global fishing efforts and the economic and ecological impact of the post-release mortality of bycatch, there is a growing need for research in this arena. To this end, this research is required across a wide range of species due to the inherent species-specific differences in how animals physiologically and behaviorally cope with the stressors of capture.

It is unadvisable to generalize post-release mortality because bycaught species differ in their ability to recover and survive from a capture and handling event. For example, yellowfin bream (*Acanthopagrus australis*) and sand whiting (*Sillago ciliate*) demonstrated post-release mortality rates around 30% within four days of capture in gillnets, while goldlined seabream (*Rhabdosagrus sarba*) and common silver belly (*Gerres subfasciatus*) displayed 100% post-release mortality (Broadhurst *et al*., 2009). Even within the same species, organisms are affected differently between fishing gear types. For example, the post-release mortality of Pacific halibut (*Hippoglossus stenolepis*) caught by trawl gear was 78% compared to halibut captured via hook and line which was 33% (Davis and Olla, 2001). Therefore, addressing the issue of species and gear type specific post-release mortality for species of economic importance is invaluable.

One such economically valuable finfish is the monkfish *Lophius americanus* whose targeted fishery grossed over $19 million in 2015 (Lowther and Liddel, 2016). *L. americanus* also constitutes a substantial 13% of the bycatch in the scallop dredge fishery, an industry which itself was worth over $440 million in 2015 (Lowther and Liddel, 2016). Although monkfish are commonly caught in scallop dredge gear, Weissman *et al*. (2018) represents the only study regarding the effects of capture and handling in this fishery. They observed that while 80%

remained physically intact, behavioral and physiological analysis indicate most of the captured fish may exhibit a cryptic stress response (Weissman *et al*., 2018). Weissman *et al*. (2018) demonstrated that vitality reflex responses decreased significantly and blood lactate and plasma cortisol concentrations increased significantly as aerial exposure duration increased. While the stress response to capture and handling was analyzed by Weissman *et al*. (2018), there is no data to determine the ultimate fate of monkfish that are returned to the sea after enduring such physiological trauma.

Studies designed to quantify the post-release mortality of other captured species have been conducted through the use of satellite tags which allows the animal to return to its natural environment with no restrictions (Campana *et al*. 2016, Musyl and Gilman 2018, Nielsen *et al*. 2018). Pop-off satellite archival tags (PSAT), which record temperature and depth of the tagged animal at designated intervals, have been successfully deployed to calculate post-release mortality for many bycaught species including blue sharks (*Prionace glauca*), porbeagle (*Lamna nasus*), shortfin makos (*Isurus oxyrinchus*), silky sharks (*Carcharhinus falciformis*), and Pacific halibut (*Hippoglossus stenolepis*) (Campana *et al*. 2016, Musyl and Gilman 2018, Nielsen *et al*. 2018). PSATs have been demonstrated to have a reporting rate of almost 80% after detachment (Musyl *et al*. 2011), as well as retention periods of weeks to months (Peklova *et al*. 2014, Chiang *et al*. 2015) – a sufficient period considering most studies report mortality due to fishing effects occur within 3-10 days post-release (Pollock and Pine 2007, Ellis *et al*. 2017). By analyzing the depth and temperature profiles of the tagged individual, researchers are able to determine whether a mortality event has occurred and how long after release. Preliminary data indicated that PSATs can be effectively utilized for monkfish with a secure attachment site through the dorsal bone and without interference on swimming or bottom-dwelling activities.

The work presented here is the first study to estimate discard mortality for the monkfish in any fishery. According to the most recent monkfish stock assessment performed in 2013, monkfish are not overfished (NEFSC 2013); however, discard mortality estimates should be determined proactively to avoid overfishing especially in the scallop dredge fishery where monkfish contribute to 13% of the overall bycatch (Lowther and Liddel, 2016). The objective of the current study was to determine the post-release mortality for *L. americanus* captured in the scallop dredge fishery by attaching PSATs to a subset of bycaught monkfish.

Materials and Methods

Fishing protocol

Trials were conducted aboard commercial sea scallop fishing vessels (*F/Vs Friendship* and *Reliance*; 83 ft to 99 ft in length) and across three, week-long cruises between June and September 2017 in the offshore waters of Georges Bank (Fig. 1). Fishing was conducted according to methods described by Weissman *et al*. (2018) and reflected typical commercial fishing practices to ensure our results reflected the fishery. This included using a standard New Bedford scallop dredge (14 ft. dredge width; 4 inch ring size; 10.5 inch mesh twine top) towed at 4.5-5 kts. across a range of commercially indicative tow times (10 to 90 minutes). Air temperature was recorded at the start of each sampling using a digital thermometer and bottom water temperature was recorded at the start of each day using Hobo Water Temp Pro v2 temperature loggers (Onset Computer Corporation, Bourne, MA).

Following the completion of each tow the catch was deposited on-deck and the catch was culled by commercial fishers. To reflect commonplace practices of discarding unwanted catch throughout sorting, monkfish were concurrently sampled up until 30 minutes of aerial exposure (i.e., maximum elapsed time from the dredge leaving the water to catch being discarded). Individuals were sampled according to protocol outlined by Weissman *et al*. (2018), which included testing each monkfish for the presence of a series of reflexes (Table 1) and evaluating the degree of overt physical trauma using an ordinal injury code (Table 1). Monkfish were then measured for total length (TL) and affixed with uniquely coded FLOY dart tags (FT-1-94; FLOY Tag Inc., Seattle, Washington, U.S.A.) in the tail musculature before being released, with the exception of a subsample that were monitored for post-release fate. Upon release under either scenario, the duration of air exposure was recorded with respect to the time of the dredge exposure.

Post-release monitoring

To monitor the post-release vertical movement and fate of the sampled monkfish, a subset of individuals were tagged with .PSATs. (Lotek Wireless Inc., St. John’s, Newfoundland, Canada; Model: PSATLIFE). PSATs were programmed to measure pressure (i.e., depth) and seawater temperature at 10-second intervals for up to either 14 or 28 days during the September and

June/July cruises, respectively. The archived data were then recovered as either Argos transmissions that binned data into five minute bins, or physically recovered and downloaded, which provided access to the higher resolution 10-second data. Tag attachment was accomplished by drilling an attachment point through one of the dorsal spines with a Nemo V2 Divers Edition drill (Nemo Power Tools, Santa Clara, CA) using a 7/64 inch drill bit. Two hundred pound test monofilament with the PSAT attached was threaded through and crimped to secure the attachment (Fig. 2). This attachment site was chosen because it is made of bone that should not break due to stress of the tag or deteriorate within the timeframe of the study. Tag retention trials performed at the University of New England Marine Science Center (Biddeford, Maine, U.S.A.) prior to field trials, with monkfish greater than 45 cm total length, confirmed our attachment method for up to 28 days. In addition, from these trials we determined that the PSAT would be reserved for monkfish greater than 45 cm TL, to avoid altering the behavior of these animals and potentially confounding our results.

Tagged monkfish were selected as a representative subsample of the operational practices (e.g., tow duration and aerial exposure) and various injury conditions, with the later proportioned according to typical variation in injury code reported by Weissman *et al*. (2018). In addition, one monkfish was sacrificed and released with a 14-day PSAT in order to establish the movement signature of a deceased individual that would be used in subsequent analyses (i.e., a negative control).

Survival analysis

To model the probability of monkfish surviving discard in the sea scallop dredge fishery, we followed a four-pronged approach similar to methods described by Knotek *et al*. (2018, 2019).

This included: (1) an examination of depth time-series to identify mortality events; (2) determining the most influential capture-related covariates that are able to predict survival; (3) using this subset of covariates, fit survival mixture models (SMM) developed by Benoit *et al*., 2012, 2015 using this subset of covariates to explain survival and provide mortality rates; and (4) develop best-practice frameworks based upon these results to mitigate monkfish discard mortality. If applicable, statistical significance was accepted at $p < 0.05$, and all analyses were performed with R 3.6.0 (R-Core Team, 2019).

Fate identification

Prior to performing depth-variance survival tests (DVSTs) to determine the fate of individual monkfish post-release, pressure measurements from PSAT tags were converted to depth ("rtide" package in R; Thorley *et al*., 2017) and tidal-noise was removed using local tidal cycle data ("oce" package in R; Kelly and Richards, 2018). Next, depth time-series were evaluated using DVSTs adapted from Capizzano *et al*. (2016) and Knotek *et al*. (2018). The crux of this analysis the compared depth variances of the negative control (i.e., signature of a dead monkfish) and sequential bins of a candidate monkfish, to identify whether or not the movements (or lack thereof) were indicative of a mortality event. However, a necessary component of this analysis was the added clause of characterizing periods of extended live, on-bottom behavior, which would otherwise have been identified as a mortality event signature (Knotek *et al*., 2018). From DVSTs, live-individuals and mortality events were treated as right-censored (i.e., fate is unknown following the monitoring period) and censored observations, respectively, in the subsequent longitudinal survival analysis. DVSTs were also used to estimate the time-of-death if mortality had occurred (Capizzano *et al*., 2016; Knotek *et al*., 2018).

Impact of fishing conditions and practices, biological traits, and health indicators

To determine which covariates had the most significant impact on monkfish survival, we decided to focus on the most relevant capture-related covariates (i.e., fishing conditions and practices, biological traits, and health indicators) that were either commonly known to have an influence on survival, or had potential for being incorporated into best-practices specific to this fishery. Pearson correlation tests were then used to examine the correlation between these covariates and the relevant interactions (i.e., air temperature and exposure, TL and air exposure, and TL and injury code). However, interaction terms were highly collinear with individual covariates ($r > 0.84$) and therefore not considered for the remaining analysis.

Next, the empirical Kaplan-Meier survival function (Cox and Oakes, 1984) was utilized to generate initial graphical presentations of the relationship between individual covariates and the survival function. The semi-parametric Cox proportional-hazards model ((CPHM) Cox, 1972; Therneau and Grambsch, 2000) was then used following methods described by Knotek *et al*.

(2018) to identify which of these covariates were able to predict the survival of discarded monkfish. This model is defined as:

$$\hat{h}(t) = h_0(t)^{(X'\beta + Z'b)} \quad (1)$$

where $\hat{h}(t)$ is the hazard function at time *t* (i.e. the risk of a mortality event occurring at time t) that is based on the non-parametric baseline hazard function $h_0(t)$, the candidate covariates X', and a Gaussian random effect Z'. The latter consisted of the number of each individual tow and was used to account for any within-tow correlations (Benoit *et al*., 2010; Knotek *et al*., 2018). Model parameters were estimated in this approach using partial maximum likelihood (Cox, 1972) and building consisted of a forward selection process similar to the methods described in Knotek *et al*. (2018). This indicated that a fixed-effect modeling approach was appropriate (i.e., the random effect was not significant) and that air temperature was the only significant predictor of survival.

However, this relationship indicated lower survival rates in relatively colder months, contradicting what would be expected from a physiological standpoint (i.e., increased temperatures associated with higher mortality rates; see review by Davis 2002). To this end, we considered other confounding factors that may similarly reflect this air temperature relationship, and concluded that the colder months (as a correlate for temperature) were associated with the monkfish spawning season (Armstrong *et al*., 1992). During this time, fish have been known to exhibit a reduced physiological capacity to deal with additional stressors (i.e., more susceptible to capture-and-handling) because of the chronic allocation of energy to reproduction throughout this timeframe.

Therefore, model building was repeated using month as a substitute for air temperature, and from this analysis we confirmed that month was the sole significant predictor of survival. To determine whether or not any of these months displayed a similar underlying survival function, log-rank tests were utilized, and we considered survival to be similar if the resulting *p*-value was not significant (i.e., $p > 0.05$). Here, we consolidated the months of July and September ($p < 0.54$) for the remainder of the analyses.

Estimating post-release survival

To predict post-release survival we followed methods described by Benoît *et al*. (2012) and Knotek *et al*. (2018). This approach relies upon parametric SMM that are well-suited for longitudinal data because of their ability to predict the time at which the survival function asymptotes (i.e., the survival rate; Benoît *et al*., 2012, 2015). The underlying model for SMM is defined as:

$$\hat{S}(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi) \quad (2)$$

where $\hat{S}(t)$ is the probability of a monkfish surviving to time t. The probability of an individual being adversely affected (i.e., leading to mortality) by the capture event is denoted by π, and the survival function is described using $\exp[-(\alpha \cdot t)^{\gamma}]$. The latter is assumed to follow a Weibull-type distribution with α and γ as scale and shape parameters, respectively. It should be noted that if monkfish were not adversely affected, full-survival can be assumed because of the relatively short monitoring timeframe (14-28 days) in comparison to the lifespan of monkfish (10-13 years of age (Johnson et al. 2008, Richards et al. 2008)). The final component of this model incorporates the effect of covariates on either the survival rate and/or the proportion of adversely affected individuals, using α and π parameters that are manipulated according to several assumptions (Table 2). Based upon these assumptions, SMM were constructed using a maximum likelihood approach, with the final fit (i.e., survival function) evaluated against the 95% confidence bands from month-specific Kaplan-Meier estimates (see Benoît *et al*. 2012 for additional details).

Model-averaging based on Akaike weights (e.g., Knotek *et al*., 2018) of SMMs was then used to generate a survival rate for each month group, which reflected the breadth of month-specific survival assumptions considered in model variants, with their contribution to the survival rate dependent upon Akaike weights. To extrapolate these results onto a fishery-scale, we considered the survival rate a reflection of spawning (June rate) versus non-spawning (July and September rate) seasonality based on the timeframes reported by Armstrong *et al*. (1992), as well as the assumption that catch rates remain equal throughout the months. The average survival rate for all months was then converted into a post-release mortality rate (1 – survival rate), in order to reflect management nomenclature in stock assessments.

Results

General capture characteristics

Overall, 4,961 monkfish (ranging in total length from 15.0 – 92.0 cm) were sampled during scallop dredge cruises that took place in June (n = 1,716), July (n = 2,358), September (n = 841), and October (n = 46) of 2017. Environmental and operational characteristics varied across the cruises and the ranges across the covariates tested by both observation only and PSAT sampled monkfish are shown in Table 3. The majority of these monkfish exhibited little to no overt physical trauma (i.e., injury code 1), while 18.6% of these fish were scored as injury codes 2 or 3, and 10.1% of the monkfish displayed the most physical severe trauma and were either dead or in moribund condition (i.e., injury code 4). In regards to the reflex assessments, 4.1% (n = 180) displayed zero reflexes, 18.1% (n = 795) displayed one reflex, 27.4% (n = 1205) displayed two reflexes, 32.4% (n = 1422) displayed three reflexes, and 18.0% (n = 790) displayed all four reflex responses (Table 4). The September cruise displayed the lowest response across reflexes with 35.7% (n = 250) of monkfish presenting zero or one reflex, while the June cruise displayed the highest number of responses with 58.0% (n = 936) presenting three or four reflexes (Table 4).

The majority of catch composition within dredges consisted of sea scallops (*Placopecten magellanicus*), with an assorted mixture of groundfish (yellowtail flounder - *Pleuronectes ferruginea*; windowpane flounder - *Scopthalmus aquosus*; winter flounder - *Pseudopleuronectes americanus*; red hake - *Urophycis chuss*; and silver hake - *Merluccius bilinearis*), elasmobranchs (little skate - *Leucoraja erinacea*; winter skate - *Leucoraja ocellata*; barndoor skate - *Dipturus laevis*; and spiny dogfish - *Squalus acanthias*), and invertebrates (rock crab - *Cancer spp*., American lobster - *Homarus americanus*; and sand dollar - *Clypeasteroida spp.*).

Post-release monitoring

A total of 60 monkfish (ranging in total length from 45.0 – 92.0 cm) were assessed for injury condition and reflex impairment, and tagged with Lotek PSATLIFE tags over the course of the three cruises. When analyzed by injury condition, 56.7% (n=34) were injury 1, 25.0% (n=15) were injury 2, 13.3% (n=8) were injury 3, and 5.0% (n=3) were injury 4 (Table 4). Of the three tags deployed on dead (injury 4) monkfish, only one transmitted accurate data; therefore, the other two were not included in the analysis. In addition, three tags failed to transmit their data, one tag transmitted inaccurate data, and one tag detached as soon as the fish was released due to poor attachment. Thus, 52 tags deployed on fish coded injury 1, 2, or 3 were included in the post-release mortality analysis and compared to one tag deployed on an injury 4 fish. This provided 253,977 depth observations (64.6 ± 12.5 % of the expected data) from which fate could be determined.

In total, we identified 17 mortality events with the onset of mortality primarily occurring within the first six-hours (n = 13; Fig. 3a), but ranging up 10-days post-release (Fig. 3b). Monkfish that survived throughout the monitoring period were found at an average depth of 49.2 m (± 24.3 m), but exhibited a wide array of off-bottom vertical movement behaviors that ranged upwards of the surface itself (i.e., 0 m depth). These behaviors included extended seafloor resting between off-bottom forays (i.e., maximum resting phase of 112 hours), prolonged bouts of swimming throughout the mid-to-upper portions of the water column, and potentially on/off shelf movement (Fig. 4).

Estimating post-release survival and fishery-scale estimates

All SMM variants fit the 95% confidence bands from the month-specific Kaplan-Meier estimates relatively well (Fig. 5), with Mixture 3 and 4 model variants having the best visible fit as well as accounting for 84% of the information used to derive month-specific survival weights (i.e., based on Akaike weights). Model variants produced various month-specific survival rates according to their assumptions, ranging from nil survival across months in the Weibull 2 model and high survival for July and September months according to Mixture 3 and 4 models (Table 5). However, model averaging based on Akaike weights produced a final estimate wherein monkfish had a higher mortality rate in the month of June (73.9 ± 0.1%), than in July or September (17.6 ± 0.1%; Table 5). Based upon these discard mortality rate estimates and the assumption of their relationship with spawning vs. non-spawning reproductive statuses, if we apply these rates to a consistent catch rate across months, we estimate the fishery-wide discard mortality rate to be 27.0% in the sea scallop dredge fishery.

Discussion

The current study corroborates the Weissman *et al*. (2018) study tat demonstrated that over 80% of monkfish captured by scallop dredge gear remain physically intact or minimally injured, however the vitality of the fish as demonstrated by the presence of reflex responses may indicate a cryptic stress response to capture and handling. Through measuring key physiological markers of stress such as plasma cortisol and lactate via blood sampling, Weissman *et al*. (2018) were able to determine that aerial exposure and injury condition significantly influenced these parameters. However, full recovery or mortality of these fish remains unknown as they were not monitored post-release. The current study is able to further our understanding of the ultimate fate of monkfish after capture by scallop dredge gear and subsequent release to the ocean; thus, allowing a better estimation of how the scallop dredge fishery is affecting the monkfish population.

Similar studies quantifying the effects of capture and handling on benthic fish have also used injury assessments and reflex impairment in conjunction with tags to aid in the prediction of survival post-release. Knotek *et al.* (2018) evaluated vitality and observed post-release mortality through the use of onboard flow-through seawater tanks for three different skate species (*Leucoraja erinacea, Leucoraja ocellata,* and *Dipturus laevis*) caught with scallop dredge gear, reporting discard mortality rates of 45.4, 62.7, and 99.9%, respectively. Compared to these skate species, monkfish seem to be quite resilient to the scallop dredge fishing practices, displaying a discard mortality of 27.0%, despite the evidence that monkfish experience high levels of stress due to capture and handling (Weissman *et al.* 2018).

Monkfish displayed a greater likelihood of survival in July and September compared to June, when the gonadosomatic index of monkfish is at its peak (Armstrong *et al*. 1992). Armstrong *et al*. (1992) concluded that female monkfish tend to spawn in May-June, while male monkfish spawn in May-August. The current study also observed several milting males and females dropping their egg veils during the June cruise. This period of spawning results in a reduced metabolic energy, thus resulting in a greater probability of monkfish mortality due to capture by fishing gear because the monkfish lack the energy reserves to recover from the physical and physiological trauma of capture.

Overall, monkfish appear to be resilient to the long-term negative effects of capture and handling by scallop dredge gear. Although they do exhibit a cryptic stress response as demonstrated by physiological analysis (Weissman *et al.* 2018), they demonstrate high resiliency with over 80% individuals displaying little to no physical trauma, and a 73% post-release survival rate.

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Table 1. Health indictors that were used to evaluate the condition of monkfish post-capture. Reflex responses were adapted from Weissman et al. (2018) and were individually scored on a present-absent scale. The injury code was modified from Mandelman et al. (2013) and Knotek et al. (2018) and was used to evaluate the degree of overt physical trauma post-capture with an ordinal scoring system (1 – 4). Monkfish were assessed by a single-researcher throughout the cruises to reduce subjectivity in scoring between animals.

Health indicator	
Reflexes	**Description**
Mouth	Fish closed jaws when stimulated by insertion of probe into mouth
Back Arch	Fish displayed definitive spinal arch when placed on dorsal side
Eye Fixation	Fish displayed pupil fixation when the body was physically rotated along its longitudinal axis
Thrash	Fish demonstrated resistance to handling by body flexure
Injury	**Description**
1	None to little overt physical trauma • < 10 mm lacerations • No visible hemorrhaging Normal body coloration
2	Moderate degree of overt physical trauma • 11-20 mm lacerations • Minor to moderate hemorrhaging • Buccal cavity filled with moderate amount of sediment or other catch Slight body discoloration
3	Severe physical trauma • > 20 mm lacerations • Extensive hemorrhaging • Buccal cavity completely filled with sediment or other catch Extreme body discoloration
4	Moribund or dead animal

Table 2. Survival mixture model (SMM) variants developed by Benoît et al. (2012) that were used to describe the post-release survival function of monkfish with respect to month. The influence of month on survivorship was incorporated into model variants using the α and π parameters.

Model	**α**	**π**	**Description**
Weibull 2	$f(month)$	1	Monkfish have a common survival function for each month
Mixture 2	$f(month)$	Constant	Monkfish have a common survival function for each month and a fixed proportion of adversely affected animals
Mixture 3	Constant	$f(month)$	Monkfish have a common survival function the proportion of adversely affected animals dependent upon month
Mixture 4	$f(month)$	$f(month)$	Monkfish have a common survival function for each month and the proportion of adversely affected animals is dependent upon month

Table 3. Capture characteristics and individual biological traits for monkfish that were sampled as either observation-only or subsampled with PSAT tags. Values are reported as the mean (minimum – maximum).

Covariate	Observation-only	PSAT tagged
Tows (n)	343	44
Tow duration (min)	49.9 (5.0 – 90.0)	59.0 (13.0 – 86.0)
Depth (m)	73.6 (47.6 – 91.5)	71.5 (58.5 – 84.1)
Air exposure (min)	14.0 (1.4 – 31.4)	6.5 (3.1 – 17.5)
Temperature (°C)		
Air	18.2 (11.3 – 30.7)	18.2 (10.9 – 24.7)
Bottom seawater	11.1 (9.0 - 14.5)	10.0 (9.0 – 12.0)
Total length (cm)	46.1 (15.0 – 92.0)	60.1 (45.0 – 92.0)

Table 4. The proportion of monkfish captured (number of individuals) in scallop dredge gear from June to October 2017 from each injury condition. Injury 1 = uninjured, injury 2 = minor injuries, injury 3 = major physical trauma, injury 4 = dead.

	June	**July**	**September**	**October**	**Total**
Injury 1	72.5% (1243)	71.3% (1682)	70.3% (591)	47.8% (22)	71.3% (3538)
Injury 2	16.3% (280)	14.8% (349)	11.8% (99)	41.3% (19)	15.1% (747)
Injury 3	6.1% (105)	2.3% (54)	1.3% (11)	6.5% (3)	3.5% (173)
Injury 4	5.1% (88)	11.6% (273)	16.6% (140)	4.4% (2)	10.1% (503)

Table 5. The proportion of live monkfish captured in scallop dredge gear from June to October 2017 displaying any number of the four vitality reflex responses. A fish with higher vitality displayed more reflex responses.

	June	July	September	October	Total
Reflex 1	3.0% (49)	0.5% (10)	16.8% (118)	6.8% (3)	4.1% (180)
Reflex 2	13.3% (215)	21.6% (440)	18.8% (132)	18.2% (8)	18.1% (795)
Reflex 3	25.6% (413)	30.3% (616)	23.5% (165)	25.0% (11)	27.4% (1205)
Reflex 4	32.7% (527)	33.5% (682)	28.0% (196)	38.6% (17)	32.4% (1422)
Reflex 5	25.4% (409)	14.1% (286)	12.9% (90)	11.4% (5)	18.0% (790)

Figure Legends

Figure 1. Individual tow locations (indicated with circles) where monkfish were sampled and PSAT tagged from scallop dredge fishing vessels in June, July, and September (2017) on Georges Bank. Circles vary by color with respect to month and the star indicates the port of New Bedford, Massachusetts.

Figure 2. Pop-up satellite archival transmitting (PSAT) tag (Lotek PSATLIFE) attachment method using 400 lb. monofilament line and four crimps to secure the PSAT tag to the bone. A Nemo V2 Divers Underwater Cordless Drill was used to drill the hole into the bone of the monkfish.

Figure 3. Tide-adjusted depth time-series (black line) from pop-up satellite archival transmitting tags that show (A) immediate (~ 6 hours) and (B) delayed (~ 10 days) post-release mortality of monkfish discarded in the scallop dredge fishery. Mortality events were identified using a depth variance survival test and the estimated time of death for each individual is highlighted with a red circle.

Figure 4. Tide-adjusted depth time-series (black line) from pop-up satellite archival transmitting tags that show individual monkfish exhibiting either (A) brief or (B) extended off-bottom forays throughout the monitoring period.

Figure 5. Probability of monthly-specific survival over time (displayed with varying colors) for each model variant. Kaplan-Meier estimates with 95% confidence bands are shown with dashed lines and shaded areas, respectively, and censored observations are shown as "+" symbols located along the dashed lines. Model variant predictions are shown as solid lines.

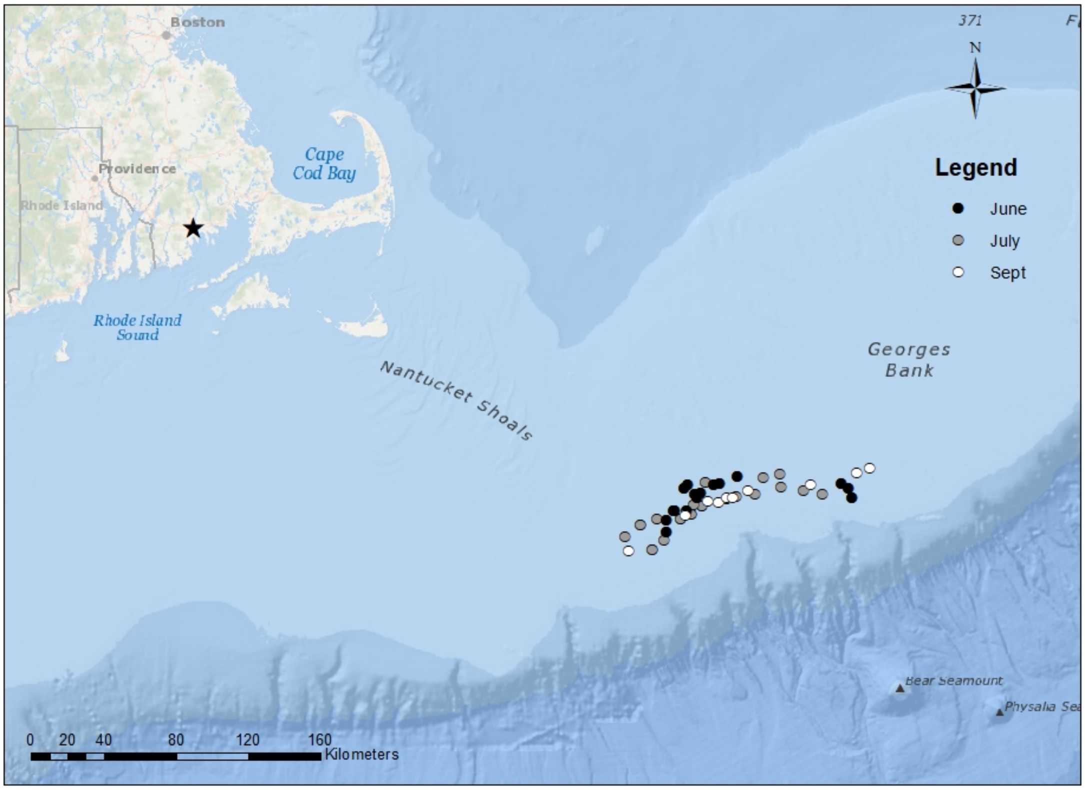

Boston
Providence
Rhode Island
Cape Cod Bay
Rhode Island Sound
Nantucket Shoals
Georges Bank
Bear Seamount
371
N
Legend
June
July
Sept
0 20 40 80 120 160
Kilometers

Figure 1.

Figure 2.

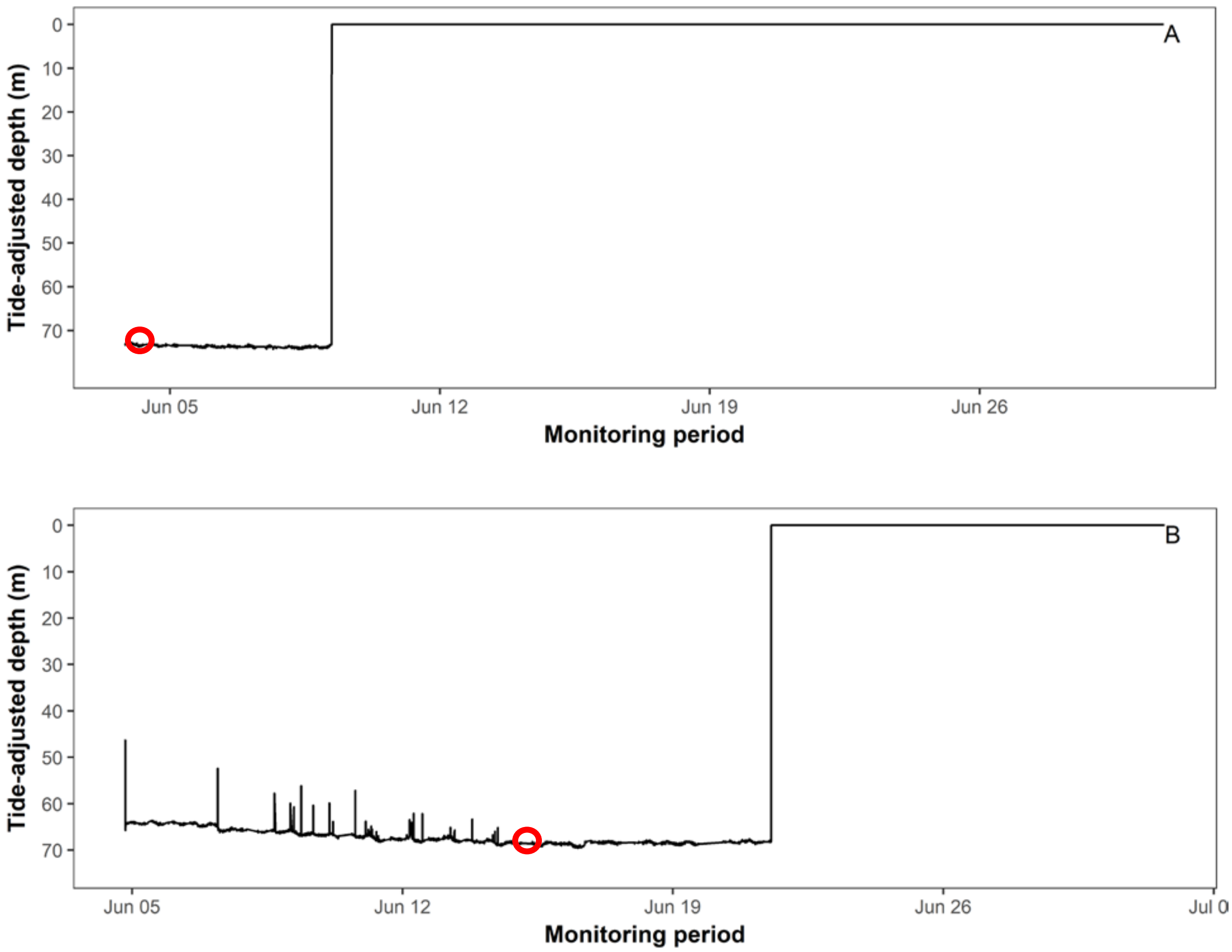
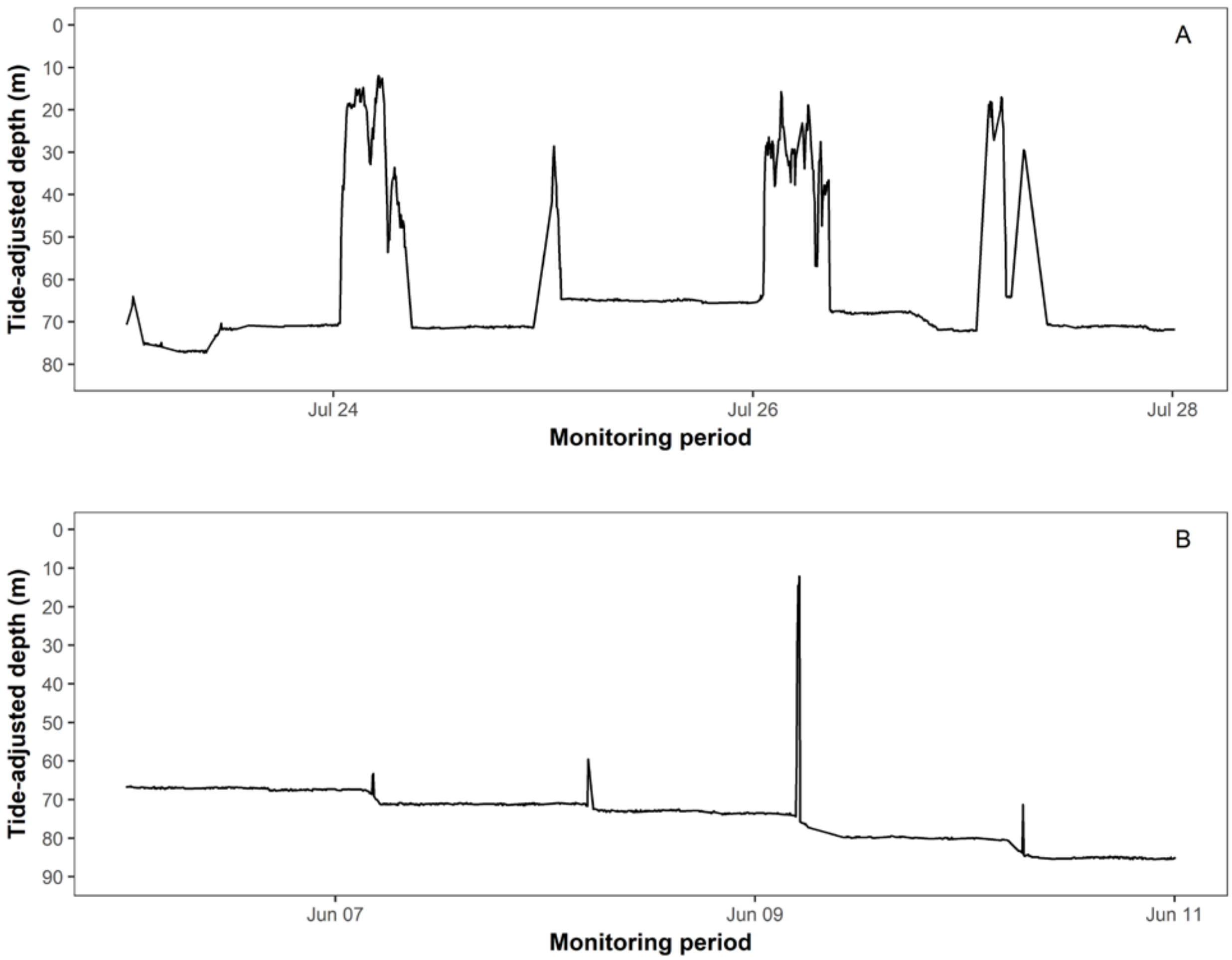

0
10
20
30
40
50
60
70
Tide-adjusted depth (m)
A
Jun 05
Jun 12
Jun 19
Jun 26
Monitoring period
0
10
20
30
40
50
60
70
Tide-adjusted depth (m)
B
Jun 05
Jun 12
Jun 19
Jun 26
Monitoring period

Figure 3.



A
Tide-adjusted depth (m)
0
10
20
30
40
50
60
70
80
Jul 24
Jul 26
Jul 28
Monitoring period
B
Tide-adjusted depth (m)
0
10
20
30
40
50
60
70
80
90
Jun 07
Jun 09
Jun 11
Monitoring period

Figure 4.

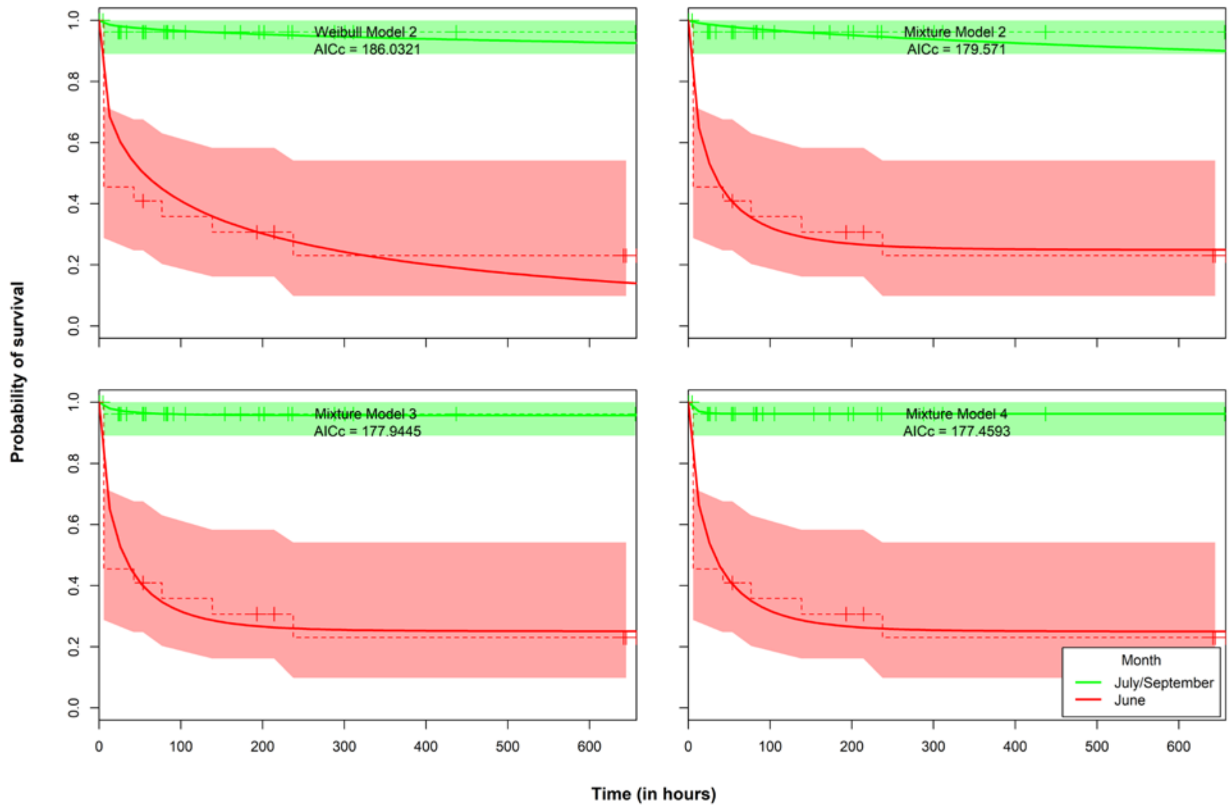

Weibull Model 2
AICc = 186.0321
Mixture Model 2
AICc = 179.571
Mixture Model 3
AICc = 177.9445
Mixture Model 4
AICc = 177.4593
Month
July/September
June
Probability of survival
Time (in hours)
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300
400
500
600

Figure 5.