Estimating Red Snapper, *Lutjanus campechanus*, Release Mortality in the Atlantic Ocean off Northeastern Florida with Three-Dimensional Acoustic Telemetry

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Estimating Red Snapper, *Lutjanus campechanus*, Release Mortality in the Atlantic Ocean off Northeastern Florida with Three-Dimensional Acoustic Telemetry

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Abstract

Discard mortality is a significant management concern for red snapper (*Lutjanus campechanus*) in the U.S. South Atlantic, where regulatory discards in the recreational fishery are estimated to far exceed landings and have precipitated fishery closures. To evaluate the effectiveness of descender devices in mitigating discard mortality, we conducted a three-dimensional acoustic telemetry study for red snapper captured and release at approximately 30 m depths at a 20 km^2 study site off the east coast of central Florida in summer 2024. Red snapper (n = 65) were tagged with external acoustic transmitters and released either at the surface or at depth using a descender device. Spatial patterns, swim speed, and depth of tagged fish were used to infer fate categories (e.g., survival, predation, surface mortality). Bayesian hurdle proportional hazards modeling was used to jointly estimate initial and delayed survival. Overall point estimates of discard mortality for 0–48 hours post-release was significantly lower for descended fish (27.6%) than surface-released fish (46.9%). Factors influencing delayed mortality included smaller fish size and longer times out of water, while release method had a strong effect only on immediate survival. Most mortalities occurred within 24 hours of release due to surface mortalities or predation. These results reinforce that minimizing air exposure and using descender devices can substantially improve post-release survival in Atlantic red snapper, but also highlight that even fish without overt signs of barotrauma can experience post-release mortality. Study results support broader adoption of descending devices and best handling practices to reduce discard mortality and improve management outcomes for Atlantic red snapper.

Introduction

Discard mortality is a symptom of catch-and-release fisheries for numerous species around the globe. However, it is a particularly acute issue for reef fishes in the southeastern U.S. (SEUS), including waters of the Atlantic Ocean and Gulf of Mexico, for which regulatory discards in some fishing sectors are estimated to greatly exceed the landed catch. Barotrauma suffered by these physoclistous species can be severe even at mid-shelf (<40 m) depths, such that acute or chronic effects result in mortality (Bohaboy et al. 2020, 2022; Runde et al. 2019, 2020; Rudershausen et al. 2025). Even moderate (<25 %) release mortality rates can have substantial effects on population biomass and fishery yield when the magnitude of regulatory discards is 5x to 10x higher than landings.

In the case of Atlantic red snapper, the fishing mortality rate due to discards was greater than F_{MSY} for several years in the 2010s, hence there was no open recreational season when landings were permitted (Shertzer et al. 2024). In recent years, the recreational fishery has only been open for a few days each year, again due to the high estimates of dead discards in the fishery. Therefore, several different mitigation measures have been proposed or explored, including size limits, gear modifications or restrictions, seasonal closures of the shelf, and requiring descending devices for all discarded fish. Simulation analysis has demonstrated the utility of several of these proposed management measures, with closure of the reef fish fishery for certain times of the year having the greatest potential conservation benefit (Bohaboy et al. 2020; Shertzer et al. 2024). However, the political expediency of such a solution may be minimal. Therefore, other mitigation measures may hold greater promise in facilitating the recovery of Atlantic red snapper.

Descender devices have been proposed as effective tools for mitigating discard mortality in several reef fish fisheries in the SEUS, including for Atlantic red snapper (Runde et al. 2021; Shertzer et al. 2024; Rudershausen et al. 2025). Reducing the number of dead discards has the potential benefit of shifting some of the total removals in the fishery to landed catch and potentially increasing the number of open days in the recreational fishery (Bohaboy et al. 2020; Shertzer et al. 2024). However, there are limited data available to examine or model the potential effectiveness of descender devices to mitigate the effects of barotrauma, hence reduce the number of dead discards. To address this, we conducted a three-dimensional (3D) acoustic telemetry experiment off the east coast of central Florida to estimate the effectiveness of descender devices to reduce discard mortality in red snapper in this region. Results provide new data with which to evaluate the effectiveness of descender devices to mitigate the effects of barotrauma in red snapper, and highlight the utility of 3D telemetry to effectively assign fate to released reef fishes.

Materials and Methods

Acoustic Telemetry Array

An array of 100 Innovasea VRTx receivers was deployed on the U.S. Atlantic shelf approximately 42 km due east of Ponce Inlet, Florida on April 21 and May 2, 2024 (Fig. 1). The seabed in this area had previously been mapped with multibeam sonar, so all natural reef sites within the array were identified (Fig. 1). The spacing between receivers was 300 m such that the entire array covered an area of approximately 20 km^2. Each receiver was fastened with cable ties to the top of a 2-m PVC riser anchored in 45 kg of concrete (Bohaboy et al. 2020). Once over its deployment coordinates, a receiver base was lowered to the seabed on with an open hook attached to a rope.

Acoustic Tagging

Fish were captured with single 4/0 circle hooks baited with cut fish or squid. Hooks were tied to 2-m, 20-kg test flourocarbon leader which was connected to a barrel swivel and positioned below a 150 to 225 g lead egg sinker. The mainline above the sinker consisted of 80-lb test monofilament. Once a fish was hooked, a stopwatch was started to record fight time. Upon landing the fish, the stopwatch was reset to record the time out of water . Once dehooked, fish were measured to the nearest mm fork length (FL), and any external barotrauma symptoms were noted (e.g., exophthalmia, distended esophagus, or prolapsed intestine). Innovasea VP9H acoustic tags were attached externally through the dorsal musculature via a cinch-up Floy tag following the method of Runde et al. (2022). This method was reported to cause minimal abrasion to reef fish while displaying high tag retention. Each fish was also tagged with a Floy dart tag inserted in the dorsal pterygiophores. Dart tags had the word REWARD and a toll-free number to report tags. Every other acoustically tagged fish was either released at the surface or was released at depth with a Seaqualizer® descender device set to release fish near the seabed at tagging reefs. A GoPro hero 11 camera was attached approximately 1 m above the Seaqualizer descender device to monitor the release and detect predation events during descent.

Innovasea tags were high-output tags (151 dB) thus had the highest detection radius of all V9-sized acoustic tags. Tags were programmed to transmit every 2 min but randomized between 1 and 3 min to avoid tag collisions. The pressure sensor was rated for 34 m with a depth accuracy of ±0.5 m. The spacing of the acoustic array and the pressure sensors in the tags meant fish could be tracked in 3D to estimate the fate of tagged red snapper (Bohaboy et al. 2020).

Bases with receivers were retrieved from the seabed on July 30-31, 2024 using the remotely operated vehicle-based methodology described by Tarnecki and Patterson (2020). All tag detections were downloaded and stored on a solid-state drive. The receiver-specific tag detections were then uploaded to a shared drive accessible by Innovasea personnel who accessed them to estimate the geoposition and depth of each detected tag transmission from acoustically tagged red snapper.

Data Analysis

Detection data were retrieved from acoustic receivers in July 2024 and submitted to Vemco for geolocation processing using the Vemco Positioning System (VPS). Positional estimates for each tagged red snapper were analyzed in R (v4.x). VPS positions with horizontal position error (HPE; Smith 2013) exceeding the 95th percentile were removed to eliminate erroneous detections. Time intervals between consecutive detections were calculated in seconds, and linear distances between consecutive positions were computed using the haversine formula, which estimates great-circle distances based on latitude and longitude coordinates. To estimate swim speed, only position pairs separated by less than 10 minutes (600 seconds) were retained. Average swim speed v in meters per second for movement between two positions—(Lat_1, Lon_1) at time t_1 and (Lat_2, Lon_2) at time t_2, with coordinates converted to radians, was computed as:

$$v = \frac{2r * arcsin\sqrt{\boldsymbol{sin}^2\left(\frac{Lat_2 - Lat_1}{2}\right) + \boldsymbol{cos}(\boldsymbol{Lat_1})\, \boldsymbol{cos}(Lat_2)\, \boldsymbol{sin}^2\left(\frac{Lon_2 - Lon_1}{2}\right)}}{t_2 - t_1}$$

where $r = 6.371\ x\ 10^6\ m$ is the assumed mean radius of the Earth. This metric served as a proxy for fish activity following release. Detection positions were converted to spatial features using the sf package in R (Pebesma 2018), and individual movement trajectories were visualized by plotting detection coordinates overlaid on receiver locations within the array.

Tagged fish were assigned fate based on estimated swim speed, depth, and geographical movements, following criteria outlined in Bohaboy et al. (2020). Days to fate were calculated to categorize fates into three temporal bins: immediate (≤48 hours post-release), short-term (48 hours to 14 days), and long-term (>14 days). The possible assigned fates were predation, emigration, tag loss, surface mortality, harvest, survival, and unknown. Predation was inferred from rapid changes in speed and depth, sustained high speed movements over 0.5 $m \cdot s^{-1}$ and proximity to the surface, or unidirectional movement lacking affinity for reef structures. Predation events were inferred by patterns described in Bohaboy et al. (2020). Tags showing negligible movement or depth variation were considered lost. Surface mortalities were confirmed via visual observation of floating or dead fish post-release. Harvested individuals were identified by sudden disappearance from the center of the array and reports by fishers, while emigrating fish moved toward and then disappeared from the edge of the array. Tagged fish still alive at the end of each time period were classified as alive and present within the array. In instances when position, speed, and depth data were insufficient to distinguish among possible fates, the fate was classified as unknown.

Discard Mortality Estimation

Post-release survival over time for fish released with a descender device, relative to fish released at the surface, was evaluated using a Bayesian hurdle proportional hazards model. This model jointly estimates the probability of survival to first acoustic detection (i.e., overcoming immediate mortality) and the time to fate for individuals that survived beyond the initial detections. This approach allows us to model the influence of covariates on the initial survival in the immediate release period and on the long-term survival after first acoustic detection survival separately. This is necessary as the proportional hazards model baseline survival rate is shared across individuals, thus cannot account for the individual heterogeneity in release condition. Additionally, there is a delay after release before the first acoustic detection that slightly decouples the acoustically assigned fates from the observed survival. For instance, some surface-released individuals may die immediately following release, resulting in survival times that are earlier than the first acoustic detection. The hurdle model facilitates modeling the survival given this delay in the long-term survival observation process (acoustic telemetry).

Factors associated with mortality were used as covariates for the survival analysis. Covariates included release method (descender or surface release), standardized fork length, standardized fight time, and standardized time out of water. A binary indicator for "Descended" was created (1 = descended, 0 = surface), and continuous covariates were mean-centered and standardized. The binary outcome for the hurdle portion modeled whether a fish survived long enough to be detected acoustically ("early mortality" = 0, "survived to detection" = 1). The continuous survival time outcome (in days) was right censored for individuals that did not experience a known fate event.

The first stage of the model estimated whether an individual fish survived long enough to be acoustically detected. Let y_i denote a binary indicator for fish i, where $y_i = 1$ if the fish was detected and $y_i = 0$ if it was not (i.e., early mortality). This was modeled as a Bernoulli process:

$$y_i \sim Bernoulli(\phi_i) \qquad \text{Equation 1}$$

$$\text{logit}(\phi_i) = X_{p,i}\beta_p \qquad \text{Equation 2}$$

where ϕ_i is the probability of survival to first acoustic detection described by a linear model with a vector of hazard covariates describing the individual-level covariates, $X_{p,i}$ and a vector of covariate fixed effects, β_p.

For individuals that survived to the first acoustic detection, a proportional hazard model was implemented where $H(t)$ is the cumulative hazard and equal to integrating the hazard rate, $h(t)$, from time zero to time t_i which can be described as:

$$h(t_i|\theta, \beta, X_{h,i}) = h_0(t_i|\theta)e^{X'_{h,i}\beta_h} \qquad \text{Equation 3}$$

with a baseline hazard function, $h_0(t_i|\theta)$, and proportional hazards described by a linear model with a vector of hazard covariates describing the individual-level hazard covariates, $X_{h,i}$, and a vector of hazard covariate fixed effects, β_h. We set the first covariate within $X_{h,i}$ as the intercept, all values equaling one, facilitating the equivalency of $h_0(t_i|\theta)$ to $e^{\beta_{h,0}}$. Within this framework, the likelihood of the covariates conditioned on the observed survival time, the observed survival (δ_i, right-censorship), and the covariates is:

$$L(\beta_h|t_i, \delta_i, X_{h,i}) = \prod_{i=1}^{n}\left[e^{X'_{h,i}\beta_h}\right]^{\delta_i} \exp\left[-e^{X'_{h,i}\beta_h}\right] \qquad \text{Equation 4}$$

and the expected survival to a given time is equivalent to:

$$\widehat{S}_\iota(t) = \exp\left[-e^{X'_{h,i}\beta_h}\right]^t \qquad \text{Equation 5}$$

and the expected survival times, $\boldsymbol{t_i}$, are equivalent to:

$$\boldsymbol{t_i} = \begin{cases} \delta_i = 0 & e^{X'_{h,i}\beta_h} \\ \delta_i = 1 & -\frac{\log(1-u)}{e^{X'_{h,i}\beta_h}} \end{cases} \qquad \text{Equation 6}$$

with u described by a random draw from a uniform distribution with bounds 0 and T, where T is described as:

$$T = 1 - e^{(X_h' \beta_h)\omega} \qquad \text{Equation 7}$$

which equals the exponential cumulative distribution function evaluated at the upper bound, ω_i, that is equivalent to t_i when $\delta_i = 1$ (censored individuals).

To determine the combined survival to a given time, we multiplied the odds of surviving to the first detection, ϕ_i, by the expected survival at time, $\widehat{S_i}(t)$ within the model to integrate the uncertainty in estimates of β_p and β_h. We then completed a posterior predictive check by estimating predicted survival times of the dead (uncensored) individuals, $\hat{t}_i | \delta_i = 0$, and comparing these predicted survival times to observed survival times (Rubin 1984). All priors were specified using weakly informative priors, such that minor structural information is provided and the inference is weakly regularized (Gelman et al. 2017). Covariate effects, β, were assumed to have normal priors with mean zero and a standard deviation of 5. The Bayesian hurdle proportional hazard model was implemented in *cmdstanr* (Gabry and Češnovar, 2021) using 3,000 iterations for burn-in (discarded), and 2,500 iterations from four chains using the No U-Turn variant of the Hamiltonian sampling algorithm with the adapt delta set to 0.95 and maximum treedepth set to 15. Convergence was assessed visually, using the Gelman-Rubin convergence statistic, $\hat{R}$ (less than 1.1 when chains converged) (Gelman et al. 2013), with effective sample sizes in the bulk and tail distributions above 5000 for all parameters.

We also assessed two versions of the model goodness of fit, R^2, using Equations 9-11.

$$R^2 = 1 - \frac{SS_{pred}}{SS_{tot}} \qquad \text{Equation 9}$$

$$SS_{pred} = \sum_i (t_i - \tilde{\boldsymbol{t}}_{\boldsymbol{i}})^2 \qquad \text{Equation 10}$$

$$SS_{tot} = \sum_i (t_i - \bar{t}_i)^2 \qquad \text{Equation 11}$$

where SS_{pred} is the predicted sum of squares, SS_{tot} is the total sum of squares, $\tilde{\boldsymbol{t}}_{\boldsymbol{i}}$ is the median predicted survival time, and $\bar{t}_i$ is the mean of the observed survival times, t_i. The first version of the model goodness of fit, R_0^2 only used $\tilde{\boldsymbol{t}}_{\boldsymbol{i}}$ values for uncensored individuals. The second version used all the $\tilde{\boldsymbol{t}}_{\boldsymbol{i}}$ values but assumed that the model adequately predicted the individual to survive past the tag deployment period if $\tilde{\boldsymbol{t}}_{\boldsymbol{i}} > t_i$. To do such, $\tilde{t}_i$ values satisfying the condition $\tilde{\boldsymbol{t}}_{\boldsymbol{i}} > t_i$ were set equal to t_i.

Results

Tagging reefs ranged in depth from 22 to 28 m (Table 1). In total, 65 red snapper ranging from 245 to 884 mm TL (mean ± *SD*: 537.7 ± 193.4 mm) were tagged with acoustic transmitters and released into the array (Table 1). Fight times ranged from 14 to 150 s (mean ± SD: 49.7 ± 33.1 s), and out of water times ranged from 25.0 to 181 s (mean ± SD: 87.6 ± 42.1 s). Approximately half of the fish (n = 32) were released at depth using a descender device. Three tagged fish detached from the descender <5 m below the surface. No predation events were observed during descender releases and sharks or dolphins were observed on video recorded during descended releases.

Detection data yielded position estimates for all 65 tagged individuals, with fish tracked for up to 83 d post-release. Fate and time-to-fate (d post-release) were determined for each tagged fish by evaluating its movement patterns, swim speed, and depth in relation to known or inferred behavioral patterns associated with specific fates. Reference data from Bohaboy et al.

(2020) were used to interpret potential predation events. Two tagged bull sharks *(Carcharhinus leucas)* in that study exhibited a mean swim speed of 1.0 $m \cdot s^{-1}$ (and up to 1.54 $m \cdot s^{-1}$), although depth data were unavailable. Their movement patters and speeds served benchmarks for identifying potential predation in the current study. Surface mortalities ($n = 5$), defined as individuals floating at the surface and failing to submerge, were observed. Of these, three fish exhibited post-release swim speeds consistent with predation at the surface (range: 0.38–0.57 $m \cdot s^{-1}$).

Behavior consistent with survival was inferred from movement patterns characteristic of live red snapper, including spatial fidelity to reef structures and typical swim speed and depth profiles. In the absence of harvested or recaptured individuals in this study, behavioral benchmarks were informed by data from Bohaboy et al. (2020), which documented movements of fish prior to recapture (confirmed alive). Red snapper presumed alive had a median swi^{m} ^{s}peed of 0.06 $m \cdot s^{-1}$ (range 0.00 – 1.97 $m \cdot s^{-1}$, based on 103,137 positions). These individuals demonstrated broad variation in depth use, with frequent vertical movements occurring both during the day and at night, including excursions to near-surface depths. Alive fish also exhibited strong site fidelity to reef habitats and did not display the consistent, linear movements characteristic of predation events. Occasional bursts of speeds between 1 $m \cdot s^{-1}$ and 2 $m \cdot s^{-1}$ occurred and were not indicative of predation as subsequent movement patterns returned to baseline behavior, consistent with observations reported for Atlantic red snapper by Rudershausen et al. (2025). Emigration was inferred for individuals that displayed normal movement patterns until detections ceased near the boundary of the array. Prior to the final detection, emigrating individuals had a median swim speed of 0.03 $m \cdot s^{-1}$ (range 0.00 – 1.58 $m \cdot s^{-}$

^{1} , based on 3,396 positions). The frequency distribution of both alive and emigration events was approximately a negative exponential, with a mode between 0.0 and 0.1 m.

Most predation events occurred within 24 hours post-release, with a single outlier detected approximately 135 hours after tagging. In this case, the tagged fish did not appear within the array until that time and exhibited elevated speeds in a straight-line trajectory across the array, suggesting predation had occurred despite the unknown timing of the predation event. Red snapper assumed to be predated on had a median swim speed of 0.24 $m \cdot s^{-1}$ (range 0.00 – 1.12 $m \cdot s^{-1}$). For example, a 295 mm FL red snapper tagged on 08 May 2024 displayed abrupt changes in movement 21 hr post-release, including sustained directional travel and shifts in speed and depth, consistent with a predation event.

Survival Estimation

Point estimates of red snapper discard mortality (0–48 h following release) were lowest for descender-released fish (27.6%, SE = 8.3%) and highest for surface-released fish (46.9%, SE = 8.8%) (Table 3). Overall, red snapper discard mortality for combined surface released and descended fish was 37.7% (SE = 6.2%). Without acoustic telemetry and relying on surface observation alone, estimated release mortality would have been 24.2% (SE = 7.5%).

All chains in the hurdle models computed to test effects on red snapper release mortality converged with Gelman-Rubin statistics less than 1.01 for all parameters and all effective bulk and tail sample sizes greater than 5,000 (minimum was 5,745 tail samples and mean was 7,475 samples). The R^2 value for the uncensored individuals was 0.55 while the R^2 value for all individuals satisfying the constraint $\tilde{\boldsymbol{t}}_{\boldsymbol{i}} > t_i$ was 0.94, with the latter resulting from 90% of individuals having $\tilde{\boldsymbol{t}}_{\boldsymbol{i}} > t_i$. The posterior predictive check indicated observed survival times were on average longer than the median predicted survival time for uncensored individuals, ranging from six min to 12.2 hr longer (Fig. 3).

Ignoring covariate effects (i.e., the intercept, β_0), the shared survival to first detection was 84% (median $\beta_{0,p} = 1.67$) while the baseline hazard was 0.004, which is equivalent to a baseline survival of 99.6% and a baseline survival time to 237 days (median $\beta_{0,h} = -5.5$), which is longer than the acoustic telemetry deployment period. The probability of an individual surviving to first acoustic detection was significantly (*ps* = 0.99) and positively associated $(\beta_{p,desc} = 2.24)$ with descending device use (Table 4, Fig. 2-A). Increasing fight times and FL negatively affected initial survival $(\beta_{p,FL} = -0.31;\ \beta_{p,FT} = -0.55)$, although the uncertainty intervals overlapped zero and the effects were not significant (Table 4). Time out of water had minimal effect on initial survival to first acoustic detection.

Delayed mortality was significantly influenced by fish size (FL) and time out of water. Increasing size decreased the hazard $(\beta_{h,FL} = -1.07)$, among the fish that survived to first acoustic detection (Table 4, Fig. 2-A), thus suggesting smaller fish experienced higher post-release mortality risk. Longer times out of water increased the hazard $(\beta_{h,OWT} = 0.79)$, indicating increased delayed mortality risk with prolonged air exposure. Descending device use and fight time were not significant predictors of post-release hazard (Table 4, Fig. 2-B). The significant negative baseline hazard suggests most of the delayed mortality hazard was influenced by covariates, and in the absence of these covariates, the risk of dying after surviving to first detection was low. These effects are reflected in the survival curves (Fig. 4), where survival declined steeply for smaller fish and individuals with increased time out of water, particularly within the first 20-40 days post-release. The effects of fight time and delayed descending device use were not significant, with overlapping credible intervals suggesting limited or uncertain influence on delayed survival outcomes (Fig. 4).

Discussion

Red snapper release mortality estimates derived from 3D acoustic telemetry indicate mortality during the initial period following release was nearly two-fold greater for fish released at the surface compared to those released using descending devices. This result adds to the growing body of evidence supporting the effectiveness of descending devices in reducing red snapper release mortality. In contrast to previous studies, our results suggest that while descending devices substantially improve acute survival, other factors, such as air exposure time and fish size, had a greater effects on predicting survival after the initial 24 hours following release. Anglers have limited control of the size of fish caught, but our results match those previously reported that minimizing time out of water enhances post-release survival (Bohaboy et al. 2020). Notably, the effect of air exposure on survival was significant even with a maximum time out of water of only 180 s, a duration that is likely shorter than what occurs in many real-world fishing scenarios. This suggests limiting time out of water is an effective strategy to reduce discard mortality, particularly on high-effort fishing trips when multiple fish may be caught at once which may increase time out of water prior to release.

Traumatic hooking has been shown to decrease post-release survival of red snapper (Muoneke and Childress, 1994; Murphy et al. 1995; Bohaboy et al. 2020; Rudershausen et al. 2025), but only circle hooks were used in this study and no traumatic hooking was observed. Fish size is also known to influence the physiological stress response and the severity of barotrauma upon capture and release. In our study, smaller fish exhibited significantly lower survival rates associated with delayed mortality (Table 4, Fig. 4). Theis result was unexpected given previous research has demonstrated that larger body size can negatively affect submergence success due to an increased gas gland surface area, as observed in blue rockfish (*Sebastes mystinus*; Hannah et al. 2008), vermilion snapper (*Rhomboplites aurorubens*), and red grouper (*Epinephelus morio*; Rudershausen et al. 2007).However, it is possible that smaller body size increased the susceptibility of red snapper to post-release predation (Table 2). Further investigation into the relationship between fish size and predation risk could help clarify this dynamic.

Our estimated mortality rate for descended fish falls within the mid-range of values reported in recent acoustic telemetry studies for red snapper, while mortality for surface-released individuals ranks within the upper 25th percentile (Curtis et al. 2015; Stunz et al. 2017; Bohaboy et al. 2020; Runde et al. 2021; Rudershausen 2025). Elevated mortality estimates among surface-released fish may be attributed to gas bladder inflation and associated surface-related mortality, which accounted for one-third of observed mortalities. The presence of predators in the release area could have further contributed to increased post-release mortality, as reported previously as an important contributor to discard mortality (Campbell et al. 2010; Drumhiller et al. 2014; Bohaboy et al. 2020). When comparing surface-release mortality estimates from acoustic telemetry studies on red snapper conducted during the summer, our estimate falls within the mid-range of reported values (Curtis et al. 2015; Stunz et al. 2017; Bohaboy et al. 2020).This suggests seasonal effects, such as elevated water temperature during the summer months, may contribute to the higher surface-release mortality estimates in our study.

This study introduces the use of a hurdle proportional hazards model for disentangling initial and delayed discard mortality. By jointly modeling the probability of survival to first acoustic detection and the subsequent survival of fish that successfully reached detection, we provide a framework for distinguishing acute and chronic sources of mortality, each influenced by distinct covariates. Higher discard mortality rates are often reported in acoustic telemetry studies as compared to surface observation or mark-recapture approaches, making it essential to understand where discrepancies arise. Our results show that nearly all post-release mortality occurred within the first 24 hours following release, suggesting discrepancies between telemetry-based and traditional estimates of discard mortality for red snapper may be attributable to acute, immediate mortality rather than delayed, chronic effects.

Reported discard mortality rates for red snapper remain highly variable across studies despite the growing use of acoustic telemetry to estimate it (Fig. 5). Some of this variation is likely attributed to differences in study design (i.e. gear type, depth of capture, season), but substantial discrepancies exist in results even among studies with similar covariates. These varying estimates highlight the complexity of estimating discard mortality under a wide range of conditions and regions, even for a well-studied species such as red snapper. Broader adoption of high-resolution acoustic telemetry, paired with collaborative data sharing may improve our understanding of factors driving variation in discard mortality estimates and continue towards improving fisheries management.

Our results have important implications for red snapper management and stock assessment in the U.S. Atlantic, a stock where overfishing is largely driven by dead discards in closed and open seasons. Our results highlight that discard mortality can be substantial even in depths less than 30 m and emphasize seasonal differences in release mortality estimates, as greater temperature differences at the surface versus at depth in summer can add stress to discarded fish (Bohaboy et al. 2020). Given the Atlantic recreational fishing season for red snapper occurs primarily during peak summer temperatures in July, differentiating temporal patterns in mortality is crucial for effective management. Collectively, these results reinforce the value of promoting best handling practices, particularly minimizing time out of water to improve long-term survival, and suggest broader adoption of descending devices for red snapper may mitigate discard mortality in the red snapper fishery. However, it should be noted that even fish released at the surface without apparent barotrauma symptoms were estimated to suffer release mortality, and the overall increased survivorship of descended fish was only possible because all fish randomly selected for that category or release were released at depth with a descender device. It is unlikely that all discarded red snapper would be released with a descender device on a given recreational fishing trip, hence the conservation benefits would be less than what we have reported here for only a portion of released fish being descended.

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Table 1. Data for red snapper (n = 65) tagged with externally attached acoustic telemetry tags and released at the surface or at depth with a descender device. Depth, air temperature, and dissolved oxygen (D.O.) parameter ranges apply to all samples. Data reported for release treatments are mean ± standard deviation.

Factors			Fish tagged				
Depth m	Air temp °C	D.O. mg/L	Release method	FL mm	Fight time s	Time out of water s	*n*
22–28	21.6–24.6	7.4–8.4	surface	491.2 ± 193.5	52.0 ± 35.1	84.3 ± 43.1	33
			descended	499.5 ± 162.8	47.2 ± 31.3	91.0 ± 41.5	32

Table 2: Sample sizes of acoustically tagged red snapper in each fate assignment category by three temporal bins following release. Unknown fates (n=3) are not included.

	Time post-release		
Fate	0-24 hr	24-48 hr	>14 d
Surface released			
Predation mortality	10	0	0
Surface mortality	5	0	0
Harvest mortality	0	0	0
Emigration	0	0	1
Tag lost	0	0	1
Alive and present	17	17	15
Descender released			
Predation mortality	6	1	0
Surface mortality	1	0	0
Harvest mortality	0	0	0
Emigration	0	1	0
Tag lost	1	0	3
Alive and present	22	20	17

Table 3: Discard mortality estimates for tagged red snapper across post-release time intervals. The "Treatment" column indicates whether fish were released using a descender device, at the surface, or a pooled estimate across both methods. "Time period" refers to the duration post-release. "n deaths" represents the number of observed mortalities, and "n total" is the number of tagged individuals with known fates (excluding those lost to emigration, tag loss, or unknown outcomes). "D (%)" represents cumulative discard mortality up to each time point with associated standard error SE (%). "D_t (%)" indicates discard mortality specific to each time interval.

Treatment	Time Period	*n* deaths	*n* total	D (%)	D_t (%)	SE (%)
Descender	0-24 hr	7	30	23.0	23.0	7.8
	0-48 hr	8	29	27.6	3.4	8.3
	0-14+ d	8	26	30.8	0.0	9.1
Surface	0-24 hr	15	32	46.9	46.9	8.8
	0-48 hr	15	32	46.9	0.0	8.8
	0-14+ d	15	30	50.0	0.0	9.1
Des + Sur	0-24 hr	22	62	35.5	35.5	6.1
	0-48 hr	23	61	37.7	1.6	6.2
	0-14+ d	23	56	41.2	0.0	6.6

Table 4: Maximum *a posteriori* (MAP), 90% credible intervals, and practical significance (PS)(> 0.9 assessed as significant at an $\alpha = 0.1$, denoted as bold) for the Bayesian hurdle proportional hazard model initial survival (survival to first acoustic detection) and delayed survival (survival to acoustic telemetry assigned fate).

Component	Parameter	MAP	CI	PS
Initial	Intercept	1.68	(0.88 - 2.63)	**1**
	Fork length	-0.31	(-1.43 - 0.61)	0.67
	Fight time	-0.55	(-1.55 - 0.32)	0.81
	Time out of water	0.09	(-0.79 - 1.01)	0.5
	Descended	2.24	(0.66 - 4.81)	**0.99**
Delayed	Baseline	-5.47	(-6.26 - -4.81)	**1**
	Fork length	-1.07	(-1.62 - -0.54)	**1**
	Fight time	0.19	(-0.56 - 0.87)	0.55
	Time out of water	0.79	(0.14 - 1.63)	**0.96**
	Descended	0.04	(-0.95 - 1.02)	0.45

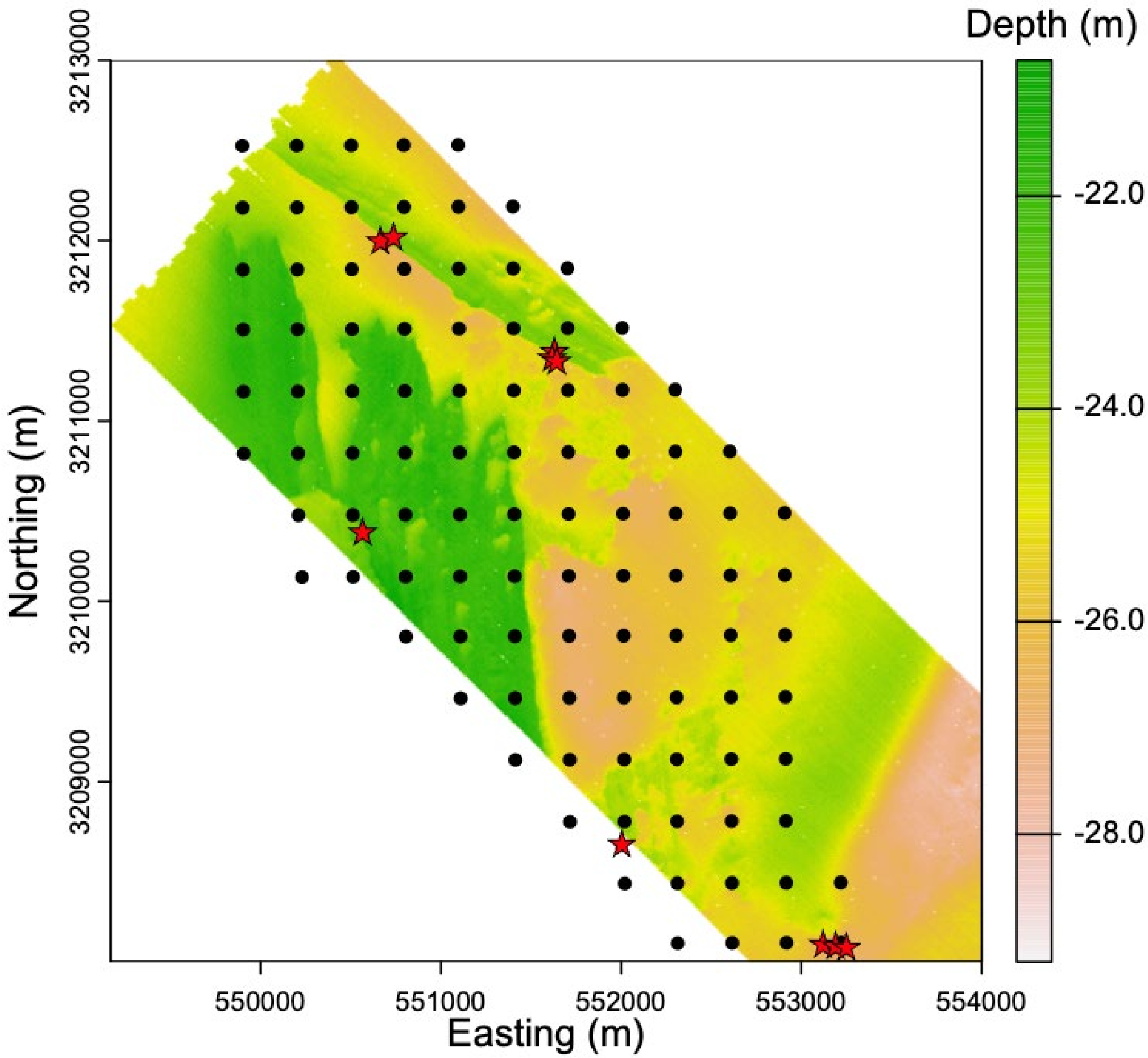

Figure 1. Map of the seabed in the Turtle Mound area approximately 43 km east of Ponce Inlet, Florida where Innovasea VRTx receivers (n = 100) were deployed in April and May 2024. Bathymetry in this region was previously mapped with multibeam sonar. Black circles indicate receiver deployment locations. Red stars indicate red snapper tagging reefs.

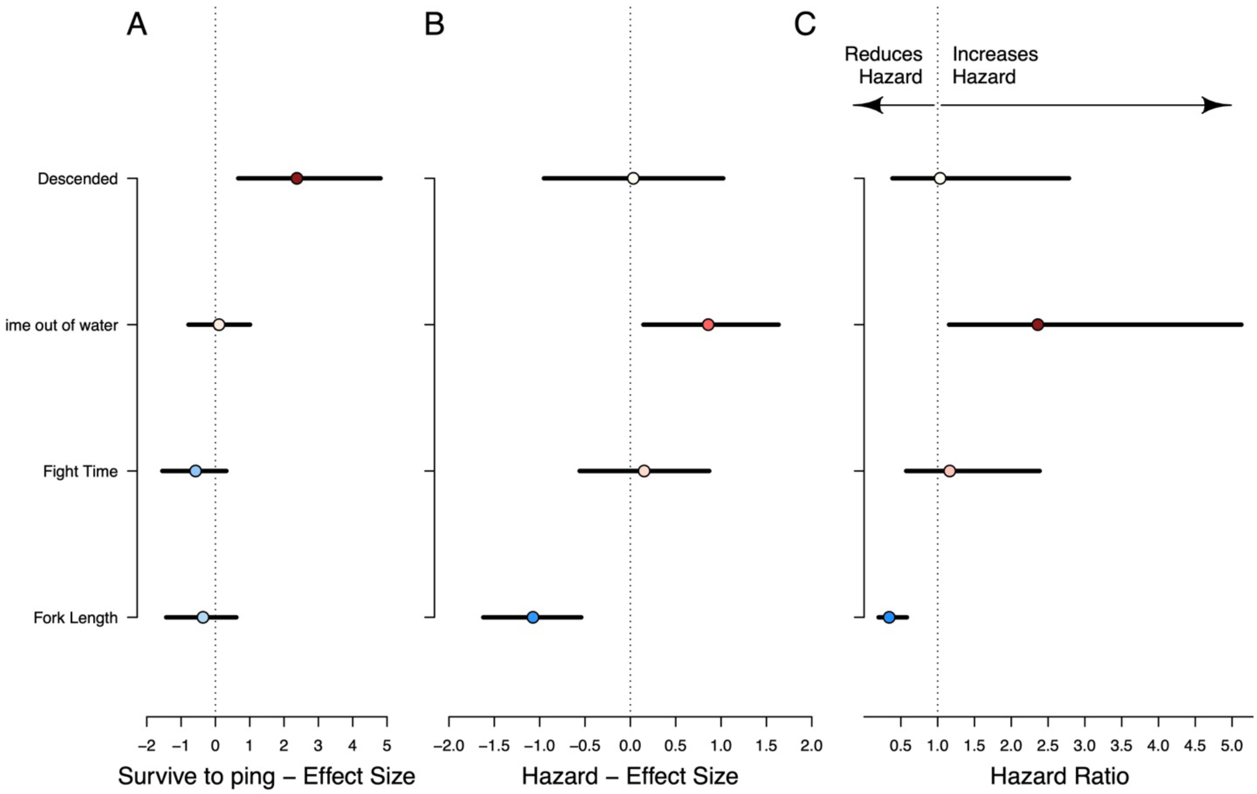

Figure 2. Posterior distributions of effect sizes from Bayesian hurdle proportional hazards model of A) binary component of initial survival to first acoustic detection, B) hazard component of delayed survival among tagged fish that survived to first acoustic detection, and C) hazard ratios. Points represent MAP estimates and horizontal lines represent 90% credible intervals.

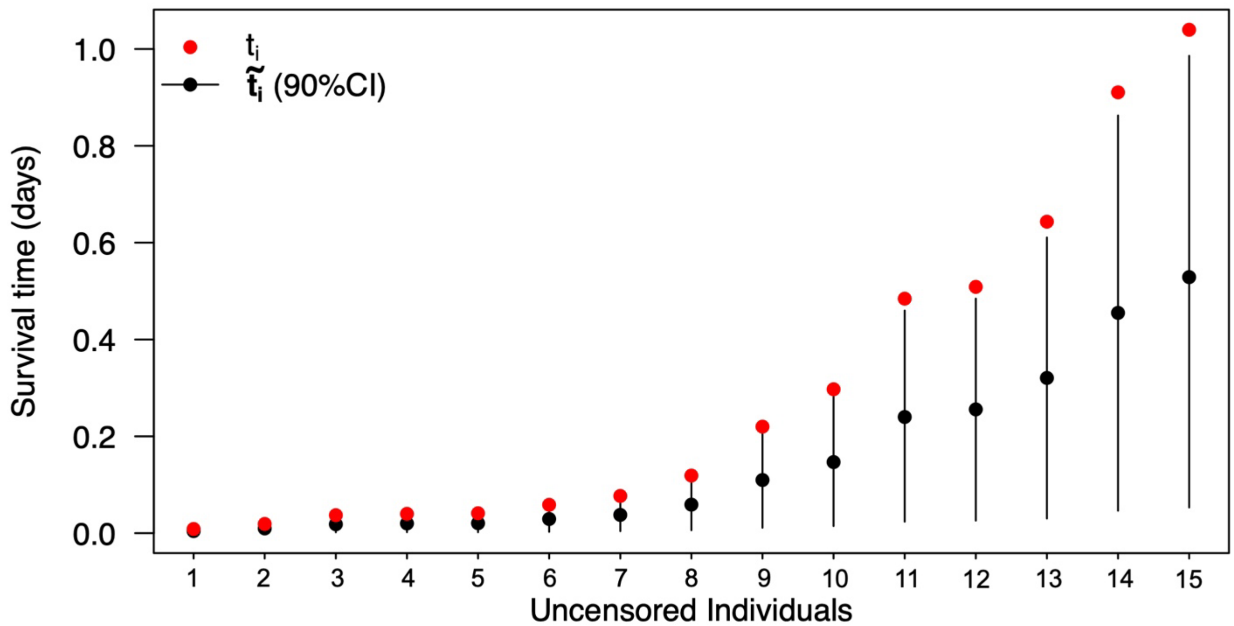

Figure 3. Posterior predictive check for uncensored individuals in the delayed mortality component of the Bayesian hurdle proportional hazards model. Red points indicate the observed survival time t_i while black points indicate the median predicted survival time $\tilde{\boldsymbol{t}}_{\boldsymbol{i}}$ with the black segments indicating the 90% credible interval.

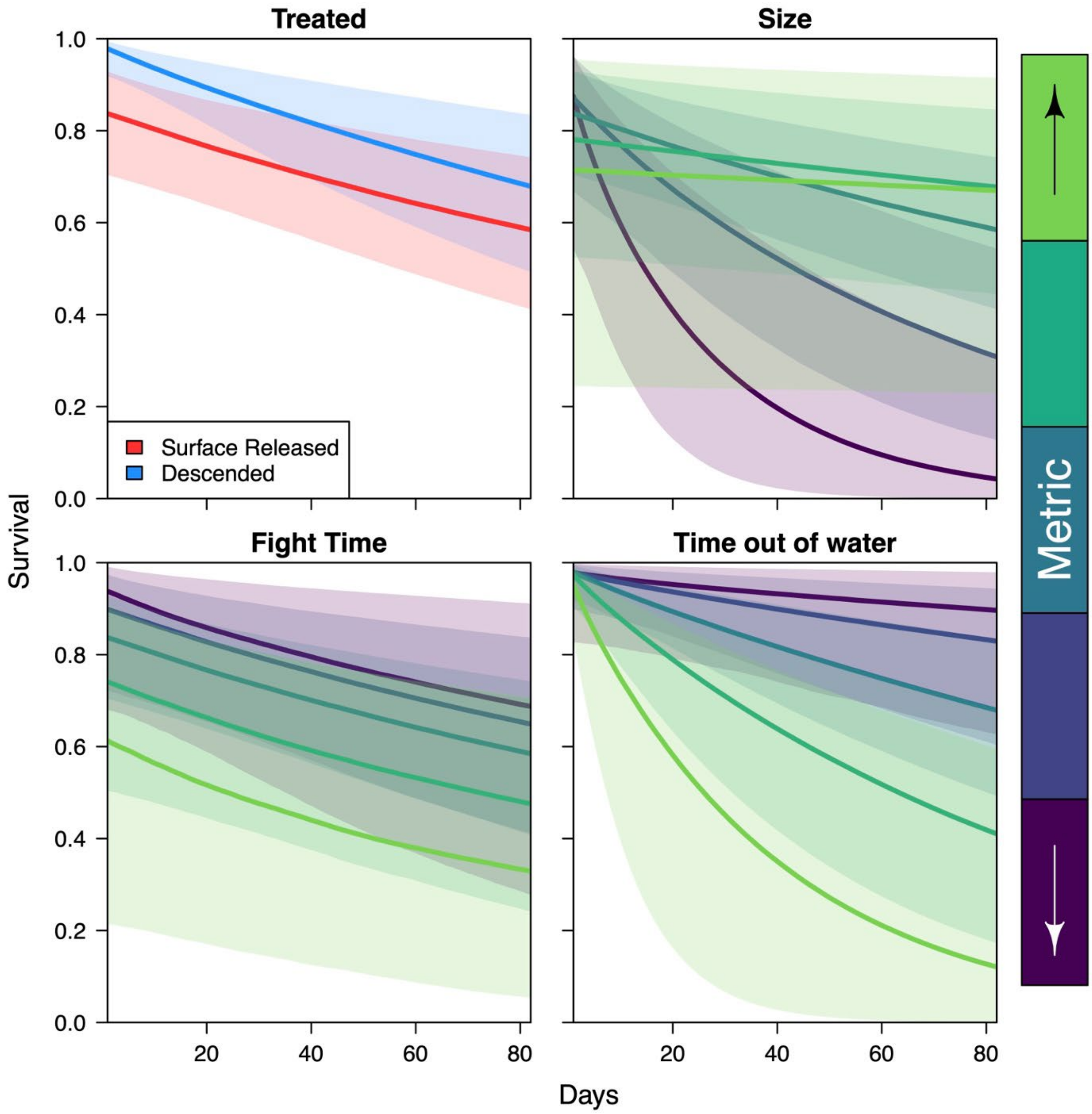

Figure 4. Hurdle model red snapper survival curves of the mean interactions conditions for 1 to 80 days for: (A), treatment condition of descender or surface released, (B), size of tagged fish, (C), fight time of tagged fish, and (D), time out of water of tagged fish.

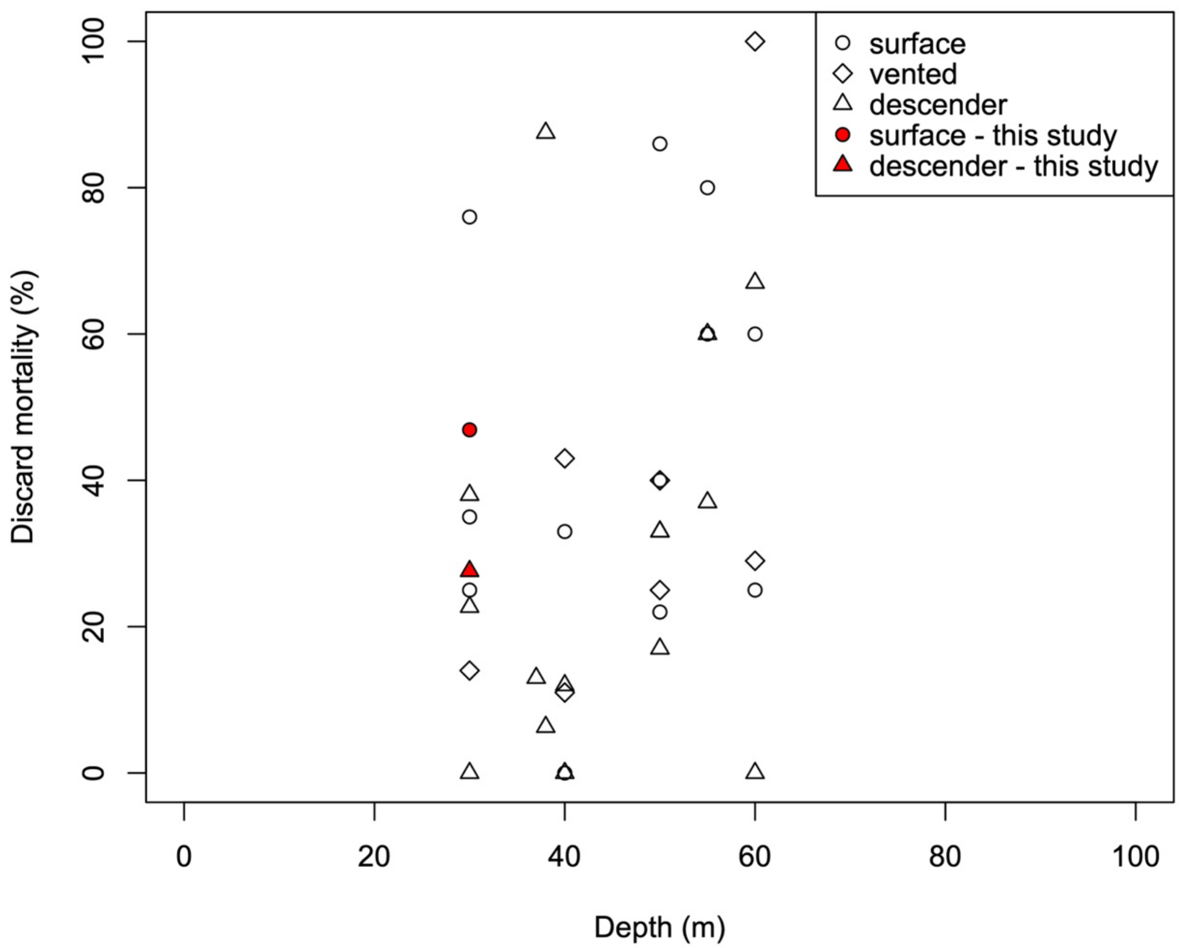

Figure 5. Estimated red snapper discard mortality by release method for the current study and from other acoustic telemetry studies reported by Curtis et al. (2015), Stunz et al. (2017), Bohaboy et al. (2020), Runde et al. (2021), and Rudershausen et al. (2025).