FINAL REPORT

Characterization of Bycatch for the Menhaden Purse Seine Fishery Occurring off the Coast of Louisiana

Ecological Research Associates, Inc.

FINAL REPORT

Submitted to:

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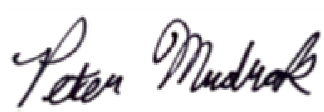

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Table of Contents

Executive Summary

We conducted an intensive, season-long bycatch characterization study covering all fishing vessels within the Gulf menhaden purse seine fleet and monitoring 3.2% of total effort in Louisiana in 2024. Bycatch was characterized by way of an at-sea observer program coupled with electronic monitoring techniques (e.g. on-board cameras) for validating and increasing the robustness of the bycatch estimates produced. In doing so, we characterized all components of bycatch within the fishery (released and retained) and provide estimates (design and model based) by count and weight for all bycatch species encountered. This study thus represents the most comprehensive assessment of bycatch conducted in the menhaden purse seine fishery to date, fulfills key data gaps needed for future management and conservation decisions, and sets the standard for future bycatch characterization studies within the fishery. Key summarized findings are as follows:

- During the 2024 commercial fishing season in Louisiana, we estimate overall bycatch in the fishery (released and retained) comprised 4.57% of total catch by number, 3.59% of total catch by weight and was 3.62% of reported landings by weight (2024 landings for Louisiana were ~346 million kg).

  The retained bycatch (i.e. bycatch retained in the hold) accounted for 4.57% of total catch by number (146 million individuals), 2.96% of total catch by weight (10.3 million kgs) and 2.98% of total landings. The most abundant species in the retained bycatch by number were Atlantic croaker, sand seatrout, spot, white shrimp, hardhead catfish, and gafftopsail catfish. These six species comprised 89% of the estimated total retained catch by number and 74.5% of the estimated total retained catch by weight.

- The rollover bycatch (i.e. bycatch rolled out of the purse nets) accounted for 0.005% of total catch by number (1.4 million individuals), 0.43% of total catch by weight (10.3 million kgs) and was 0.43% of total landings. The most abundant species in the rollover bycatch by number were cownose ray, red drum, black drum, gafftopsail catfish, and crevalle jack. These five species comprised 66.6% of the estimated total rollover catch by number and 52.8% of the estimated total rollover catch by weight. Sharks from the genus *Carcharhinus*, dominated by blacktip shark, bull shark, finetooth shark and spinner shark, comprised an additional 22.3% of estimated total rollover catch by number and 44.1% of the estimated total rollover catch by weight.

- The chute bycatch (i.e. bycatch released via the fish excluder grate) accounted for 0.004% of total catch by number (139 thousand individuals), 0.21% of total catch by weight (729 thousand kgs) and was 0.21% compared to total landings. The most abundant species in the chute bycatch were gafftopsail catfish, cownose ray, red drum, blacktip shark, and black drum. These five species comprised 80.7% of the estimated total chute catch by number and 80% of the estimated total chute catch by weight.

- We estimate total bycatch of 44,593 red drum in the released bycatch (i.e. rollover & chute combined) during the 2024 season. By weight, this equates to a total weight of 412 thousand kgs. Based on survival percentages obtained from our onboard holding study (84% rollover and 2% chute for red drum), we estimate that 22,805 of the 44,593 red drum in the released bycatch are released alive by the fishery. When accounting for the 8,354 estimated red drum mortalities in the retained bycatch (70 thousand kgs), total red drum mortality for the fishery in 2024 equates to 30,142 individuals.

- Spotted seatrout were largely absent in the released bycatch components, comprising of 144 total estimated individuals in the rollover bycatch and 291 total estimated individuals in the chute bycatch. Due to their smaller size, most spotted seatrout were observed in the retained catch, where we estimate total bycatch of 240,368 by number and 45 thousand kg by weight.

- During the 2024 season, we report three sea turtles and one giant manta ray in the rollover bycatch during the 415 sets observed. These encounters would appear to be rare occurrences, and we estimate incidental catch of 60 giant manta ray, 70 Kemp's ridley sea turtle, and 30 loggerhead sea turtle during the 2024 season. In addition, observers were made aware of the incidental capture of bottlenose dolphins (of unknown number) during a single set that was not directly witnessed. For the giant manta ray and sea turtles directly observed, we report that all individuals were released unharmed and appeared to be in excellent condition.

- We observed considerable variation in the dimensions of bycatch excluder devices across the fleet and observed that relatively large fish (e.g. sharks up to ~1.6 meters) could pass through the hose cages. Previous studies note that more optimal hose cage designs likely exist, and we similarly conclude that due to high observed survival rates in the rollover bycatch, modification to industry hose cages represent a promising avenue for reducing bycatch mortality within the fishery.

Objectives

The overreaching goal of this study was to work cooperatively with the LA commercial purse seine fishery to characterize and provide scientifically robust estimates of bycatch (released and retained) across the entire 28-week purse seine season that extended from April 15th through October 31st, 2024. This goal is broken down into six project objectives (as described below).

Objectives 1 through 4 were completed in 2024 and are described in a series of progress reports submitted by LGL to GSMFC (Reports 1-7). A report submitted in early June (Report #8) described the results of the survival study. This Report describes the methods and our findings regarding our bycatch estimation study to satisfy Objective 5. This report is structured so that the methods and results can be reformatted and submitted by LGL for publication in peer-reviewed journals following final revisions and acceptance of this report by GSMFC (e.g., to meet Objective 6). The six project objectives – both completed and in progress – are as follows:

1. Conduct a pilot (i.e., proof-of-concept) study during the 2023 season to refine the sampling techniques and test any necessary modifications that will ensure logistical feasibility of achieving targeted sample sizes during the 2024 season. **Deliverable**: Test every field technique to be implemented and record the workdays required for each; completion of these activities will occur by the end of October 2023. Completed.

2. Evaluate the outcomes of the pilot study, fine-tune methods to incorporate lessons learned, and conduct off-season dock-side vessel visits as necessary. **Deliverable**: A report was provided detailing our findings and recommendations for any changes to the methods proposed. Completed.

3. Carry out a full season of bycatch characterization that covers >2% of the total sets made by the fishery in LA and adjacent federal waters. **Deliverables**: (1) A report midway through the that described progress of the field study. (2) A report at the end of the field season that described the spatiotemporal sampling coverage of the fishery. Completed.

4. Conduct fate studies to estimate the near-term mortality of released bycatch. **Deliverables**: The progress reports for Objective 3 will also include assessments of this objective. Completed.

5. Clearly describe the results of the study, the methods on which they were based, and the implications of our findings. **Deliverable**: A final report will be submitted in June 2025 following analysis of the data collected during the 2024 season. In-progress.

6. Develop a manuscript or series of manuscripts that will be submitted to peer-reviewed fisheries journals. We anticipate this objective will occur simultaneously with Objective 5. **Deliverable:** The resubmission(s) to the chosen journal(s) following peer-review by their respective referees. In-progress

Introduction

Fisheries bycatch (defined as the incidental capture of non-target species; Alverson, 1996), has been a key issue for sustainable fisheries management for at least the past half century (Coe et al., 1984; Lo et al., 1982). As the human population grows and global demand for seafood rises, fishing pressure has intensified, increasing the potential for bycatch across many fisheries (Read et al., 2006). Globally, bycatch can contribute to the decline of vulnerable and protected species (Carlson, 2023), disrupt food webs and ecosystems (Komoroske and Lewison, 2015), result in economic loss for fishers (Patrick and Benaka, 2013), and generate conflicts between marine resource user groups. Solutions for mitigating bycatch exist, but effective bycatch mitigation requires reliable data on its occurrence, composition, and drivers (Lewison et al., 2011). Because a large portion of bycatch is often discarded at sea, such information is often limited.

To address bycatch data gaps, many management authorities have implemented on-board observer programs which place trained personnel aboard vessels to systematically record bycatch events in real-time (Moore et al., 2021). For some fisheries, such as the Gulf of Mexico penaeid shrimp trawl fishery, observer programs have been in place since the early 1990's, and have played a critical role in the development of best practices and bycatch mitigation measures (Scott-Denton, 2014). By quantifying bycatch with high accuracy, observer programs are recognized internationally for playing a central role in advancing sustainable fisheries management for many fisheries (Moore et al., 2021). With the advancement of modern technology, some fisheries observer programs have been replaced or supplemented with electronic monitoring systems (e.g. using onboard cameras or electronic logbooks) that can reduce monitoring costs and increase observer coverage which is often less than 5% of total fishing effort (Brooke, 2012).

The Gulf menhaden (*Brevoortia patronus*) purse seine reduction fishery has existed since the late 1800's and is the largest commercial fishery in the Gulf of Mexico (GoM) and the second largest fishery in the U.S. in terms of total landings (~400,000 metric tons annually over the last decade)(De silva, 1998; Vaughan et al., 2007). As with all fisheries, in addition to target species, Gulf menhaden purse seine boats encounter unwanted bycatch (Condry, 1994; De silva, 1998; Sagarese et al., 2016). Restrictions to bycatch are currently regulated by each Gulf state. In Louisiana, where most of the fishing activity occurs, menhaden fishing vessels may not possess greater than 5% by weight any species other than menhaden and herring-like species. The State of Louisiana also recently implemented a menhaden exclusion zone prohibiting fishing within one half mile from land for much of the coastline (and up to 3 miles in select areas) to minimize the potential for spills of menhaden and bycatch that sometimes occurs in shallow water (LDWF, 2024). The menhaden industry first began efforts to reduce bycatch starting in the 1950s, and continues to support measures to reduce unwanted bycatch (NOAA, 2024; Rester and Condrey, 1999). To minimize bycatch, industry currently deploys two bycatch excluder devices that reduce the take of large bycatch species (~1m or greater in length) by instead discarding them at sea. The menhaden industry also recently achieved certification against the Marine Stewardship Council's (MSC) standard for sustainable fishing (Romito et al., 2023).

Although the Gulf menhaden fishery lacks a mandated annual observer program like that of the Gulf shrimp trawl fishery, periodic bycatch studies have occurred, with one study being carried out roughly every decade (Christmas et al., 1960; Condry, 1994; De Silva et al., 2001; Guillory and Hutton, 1982; Miles and Simmons, 1950; Pulver and Scott-Denton, 2012). While the majority of previous studies have discerned that the Gulf menhaden industry encounters a negligible amount of bycatch with respect to the number of menhaden landed, previous studies are notably sparse (both spatially and temporally) and are often not without limitation. For instance, studies conducted exclusively at the processing plants fail to quantify the number and fate of bycatch released at sea (Guillory and Hutton, 1982) and given the often fast pace of fishing operations, studies utilizing on-board observers have not always had sufficient time and opportunity to identify all portions of the released bycatch (De Silva et al., 2001).

A recent review of the bycatch studies conducted in the gulf menhaden fishery raised concerns over the potential for unaccounted mortalities in the released bycatch component, with the concerns centering around the negative impacts on economically important teleost's such a red drum (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*) (LDWF, 2024; Sagarese et al., 2016), as well as that of Spanish mackerel (*Scomberomorus maculatus*) (Harrington et al., 2005). Some species are likely more susceptible to bycatch in the menhaden fishery, with past estimates approaching ~36,000 sharks and ~28,000 red drum during the 7-month commercial fishing season (De Silva et al., 2001). Given the paucity of studies providing estimates of both the retained and released bycatch components, there is a need for a more comprehensive characterization of bycatch within the Gulf menhaden industry. Similar concerns were raised during the industries' recent sustainability certification that included recommendations for future bycatch studies to be conducted in a more cohesive and standardized manner (Romito et al., 2023). The certification also called for additional evaluation of the bycatch excluder devices following concerns that juvenile sharks or medium fish species could potentially pass through the vessel's pumps if encountered (Romito et al., 2023).

To characterize the magnitude and fate of bycatch during the 2024 Gulf menhaden purse seine fishery occurring off the coast of Louisiana, we conducted an intensive, season-long bycatch characterization study covering all vessels within the Gulf menhaden fleet and monitoring 3.2 % of total effort. Bycatch was characterized by way of an at-sea observer program coupled with electronic monitoring techniques (e.g. on-board cameras) for validating and increasing the robustness of the bycatch estimates produced. In doing so, we characterized all components of bycatch within the fishery (released and retained) and provide estimates (both design and model based) by count and weight for all bycatch species encountered. This study thus represents the most comprehensive assessment of bycatch conducted in the menhaden purse seine fishery to date, fulfills key data gaps needed for future management and conservation decisions, and sets the standard for future bycatch characterization studies within the fishery.

Methods

Sampling Approach

The Gulf menhaden purse seine fishery operates in Mississippi (MS), Louisiana (LA), and to a lesser extent Texas (TX) state waters. The objective of this study was to characterize the fishery in Louisiana waters. Thus, only nets that were fished in Louisiana state waters or adjacent federal waters were sampled during the 2024 commercial fishing season (Figure 1). This fishery operates via multiple vessels owned and operated by the two companies: (1) West Bank Fishing operating out of Empire, LA, and: (2) Omega Protein (Ocean Harvesters) operating out of Abbeville, LA and Moss Point, MS.

Fishing vessels (up to ~195 ft in length) are equipped with a large, refrigerated hold for transporting catch, and twin stern ramps that are used to deploy two, much smaller purse boats (~39 ft in length). A second set of vessels operate as "run boats" that pump catch directly from the nets (or holds) of fishing vessels into their own holds. Run boats reduce the catch burden on fishing vessels by allowing them to remain at sea for longer before transporting their catch back to shore. For this study, all field sampling via our at-sea observers was conducted from run boats which provided additional crew space to allow for full characterization of retained and released bycatch, and the advantage of being able to sample the entire fleet of fishing boats more efficiently. At-sea observers only collected samples when the run boat pumped catch directly out of the purse seine, as catch pumped out of holds consisted of assorted catch and incidental catch from multiple sets. Importantly, the vessel pumps, hoses and the bycatch reduction devices used on the run boats are configured the same as those used by the fishing vessels owned by the same company, and thus all bycatch sampled on run boats experienced replicate conditions to bycatch that is pumped by the fishing vessels.

During sampling operations, the run boats followed the fishing fleet and pumped the catch from the purse seines. At times, there were multiple fishing vessels making net sets within range of the run boat used for sampling. The first available or closest net was pumped by the run boat and thus sampled by observers. This approach was used to prevent captains from intentionally or unintentionally selecting net sets based on the size of the catch, or their expectations of bycatch within the net. Observers attempted to sample every set collected by the run boat while they were onboard. However, if the speed of fishing operations was greater than the speed samples could be worked up, net sets were skipped until the previous net's samples were fully characterized. With a crew of 4-6 observers, skipped sets were generally a rare occurrence, consisting of a total of 15 skipped sets across the fishing season. Each vessel within the menhaden purse seine fishery is currently equipped with two bycatch reduction devices used to release large fish caught in the purse seine (Figure 2). As a result, there are three distinct components of bycatch within the fishery. First, large bycatch is excluded from the pump via a hose cage and remains in the net until the end of the pumping operation. This bycatch is then released from the purse net by a 'rollover' procedure at the end of the set whereby the crew roll the remaining bycatch over the float line (hereafter referred to as "rollover bycatch"). Second, bycatch that passes through the hose cage and pump is then passed over a large fish excluded grate used to release additional bycatch overboard via a bycatch release chute (hereafter referred to as "chute bycatch"). Third, bycatch and catch that passes through the large fish excluder grate enters the hold via the loading chutes and is retained (hereafter referred to as "retained bycatch" (Figure 2). All three of these bycatch components were sampled to fully characterize both the released and retained portions of the bycatch, with each component requiring a unique sampling protocol.

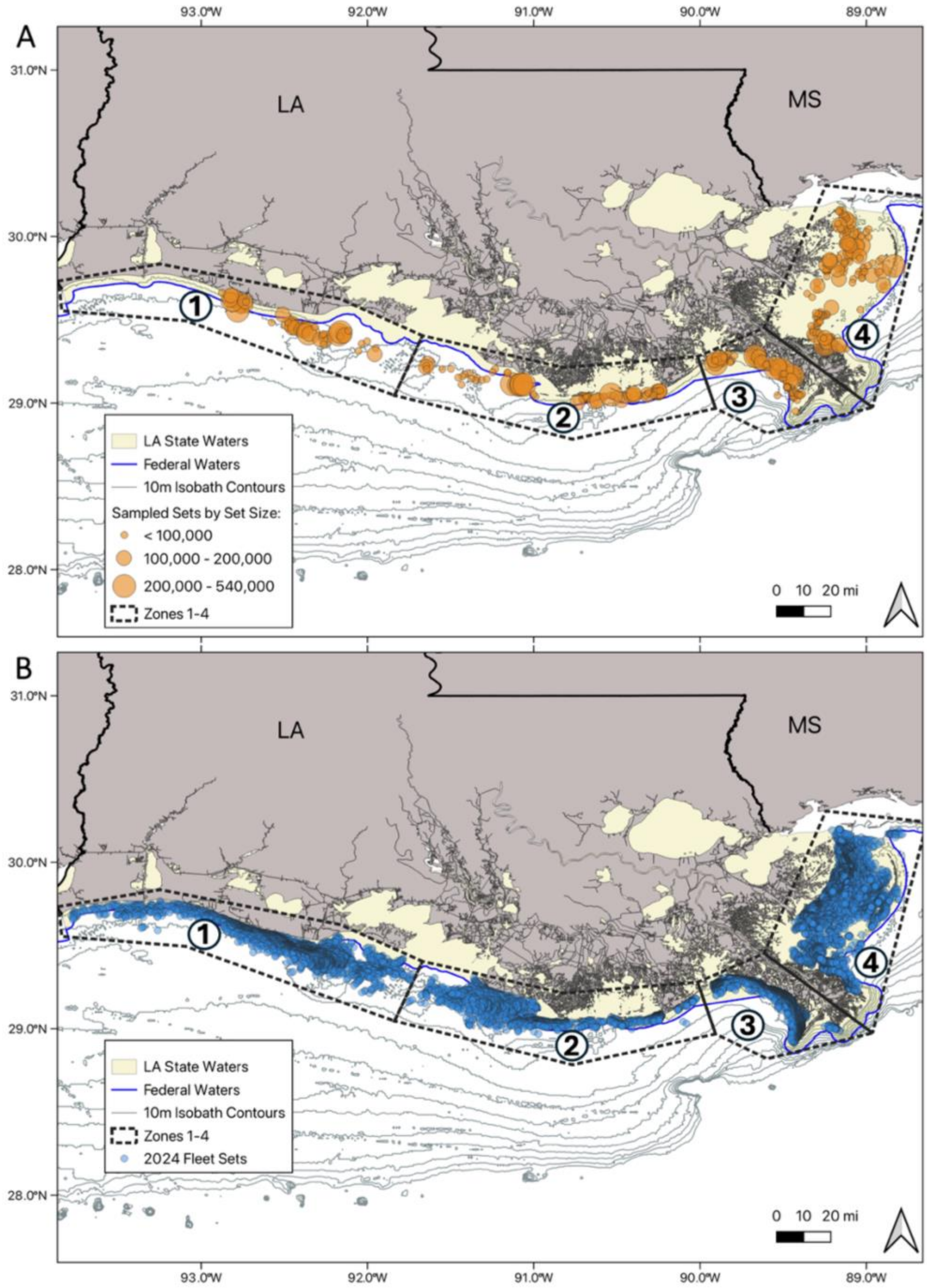

Figure 1. Study area in coastal Louisiana, United States. (A) the locations of the 418 net sets (orange circles) sampled by at-sea observers during the 2024 commercial fishing season, scaled to the size of the set (in terms of # of standard menhaden). (B) Total Louisiana fleet-wide sets (blue circles) from the 2024 purse seine season (n = 13,144). For each panel, we show the zones that were used in model-based estimates of bycatch.

SAMPLING DESIGN

Our target population was all sets made by the fleet in Louisiana and adjacent federal waters during the 2024 season. We used a stratified random survey design with sampling effort apportioned by plant (Abbeville, Empire, and Moss Point) and month (April-October) to facilitate proportionate representation of the fleet's total effort (total number of strata = 21). Month was chosen as a stratum to account for seasonal changes in fleet dynamics. Plant was chosen to accommodate the potential for varying behaviour by plant and spatial patterns in effort. Logistical constraints prevented strict *a priori* spatial stratification. The order that each fleet was visited each month was selected randomly. Our mandate was to sample 2% of the total sets made by the fleet, which we estimated would require sampling ~400 sets. The targeted number of sets to sample for each plant-month stratum in 2024 was based on the maximum fishing effort conducted by the fleets across the years 2020-2022 (2023 data were unavailable at the time of sample allocation).

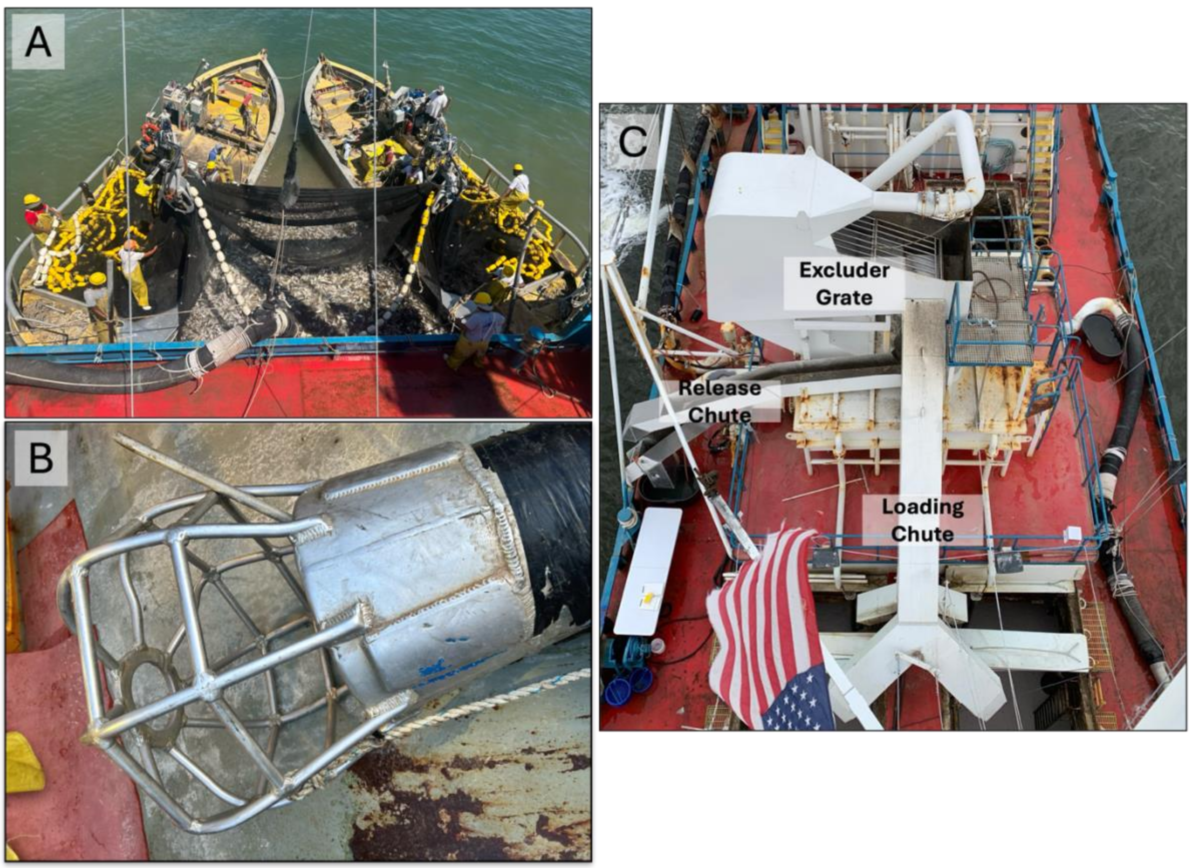

Figure 2. (A) Purse boats alongside the sampling vessel with catch being pumped from the net via the large suction hose. (B) The hose cage used as a bycatch reduction device to prevent large bycatch from being entrained within the hose and pump. (C) Standard vessel layout showing the loading and release chutes and the fish exclude grate used as a secondary bycatch excluder device.

Rollover Bycatch Procedures

To sample bycatch within the rollover component, at-sea observers intercepted and transferred bycatch on board the run boat at the end of the pumping operation. Observers most commonly utilized long-handled landing nets to intercept bycatch directly out of the net as they were rolled out by the crew (Figure 3; frame dimensions 29" w x 40" l; handle: 100"). Beginning in September, at-sea observers utilized a large brailer net (56 x 56") and winch to transfer bycatch individuals onboard more efficiently (Figure 3) and to collect a higher percentage of the rollover bycatch from high bycatch sets (>30 individuals). Observers also obtained bycatch entangled in the hose cage that was transferred on board the run boat when the pump was removed from the net. All bycatch collected were identified to species, weighed, measured (fork length, total length or wingspan for rays), assigned a condition score using the scoring criteria outlined by Benoît et al., (2010) (Appendix 5), and sexed. Observers further recorded whether bycatch was collected directly from the net or from the hose cage following instances of entanglement. All species intercepted from the rollover that were used in the survival study were handled according to the procedures outlined in LGL's Report #8. Sampling of bycatch from the rollover focused on the large bycatch constituents that were excluded from the pump by the hose cage. The menhaden and assorted small bycatch constituents left in the net at the end of pumping operation were too small to be retained by the mesh of the landing nets utilized by observers (1 7/8") and were not quantified in the rollover bycatch. This component of the rollover is minor relative to the amounts retained by the fishery and would be expected to be proportional to the number of menhaden lost in any given set.

At-sea observers attempted to sample the maximum amount of bycatch from each set without overly impacting the efficiency of commercial fishing operations; however, not all rollover bycatch was collected by observers. First, protected species were not collected to avoid any possible harm caused by sampling procedures and were released by the fishing crew using the standard methods employed in the fishery. Second, not all bycatch rolled out by the crew were successfully intercepted in the landing nets or brailer net by observers. Third, sharks and rays too large to safely handle onboard the run boat were intentionally avoided by observers. This caused a truncation of the measured size distributions of these species but will not affect the estimate of total individuals captured. To ensure a complete census of the rollover bycatch, bycatch not brought on board the run boats by observers were quantified using two methods. An observer positioned directly adjacent to the purse net identified and counted all bycatch rolled out of the net that were not sampled by observers. In addition, we deployed multiple cameras systems to record the rollover procedure from multiple viewing angles to allow for counts of bycatch to be produced post hoc and without the time constraints of the commercial fishing operations.

On board observers obtained counts for all rollover sets sampled (n=415) but were not always able to identify individuals that were not collected to species level. In these instances, we used the lowest taxonomic level possible for identification. This resulted in three classifications that were above species level, *Carcharhinus sp.*, Dasyatidae, and blacktip/spinner shark (a clear view of the anal fin is required to distinguish *Carcharhinus limbatus* and *Carcharhinus brevipinna*, and was not always available). This classification system is similar to that used in previous studies on released bycatch in the menhaden reduction fishery (De Silva et al., 2001). In contrast to sharks and rays, bonyfish encountered in the released bycatch (e.g., drum, jacks, etc.) were more easily distinguishable by observers and were identified to species level for all sets sampled.

Video observations of the rollover procedure were conducted using three independent camera systems. Two GoPro Hero 11 cameras filming at 240 Frames Per Second (FPS) were fixed to the port side of the run boat, with one camera mounted forward of the pump on the captain's rear driving station rail, and the other camera mounted on the railing above the engine room above and adjacent to the purse net. In each case, the field of view and magnification were optimized for recording the rollover procedure on each of the three run boats used for sampling. Both fixed cameras were housed within custom shade boxes (10x10x10") equipped with a 120 mm, 120-volt fan to increase airflow (45 cubic feet per minute) and prevent the camera from overheating. A third camera system, a handheld Olympus Tough with 4x optical zoom, was operated by an at-sea observer also positioned above the engine room. This handheld camera provided a third viewing angle of the rollover operation and an opportunity to adaptively zoom and alter imagery depending on the position of the purse boats and crew below. Video observations from the three cameras provided an opportunity to validate counts produced by the onboard observer and the opportunity to improve the level of taxonomic identification.

All rollover videos were analysed blindly by observers unaware of the counts made by the onboard observer. Videos were rewatched in VLC media player which allowed analysers to optimize video playback speeds and magnification and thus the accuracy of bycatch counts and identification. The rollover procedure from each set was recorded from multiple viewing angles, and all available video footage was watched by the video observer. For each set, the video observer recorded how many individuals of each species were counted, the location the bycatch originated from (i.e. was the individual located in the net or stuck in the hose cage), as well as the fate of the bycatch (e.g., collected by observers or released by crew). If the fate could not be determined from the available video, bycatch were assigned an unknown fate. In all cases, the video observer identified bycatch to the lowest possible taxon using the same classification scheme as the onboard observers for sharks and rays that were not identified to species (e.g. *Carcharhinus sp.*, Dasyatidae, and blacktip/spinner shark).

The total counts for the rollover bycatch produced by the two observation methods (onboard observers vs. video observers) generally showed good congruence, especially for low bycatch sets (<30 individuals) (Appendix 7). Under some circumstances (e.g., large bycatch sets with high quality and unobstructed video) video counts resulted in higher counts of released bycatch. During other circumstances (e.g., blurry video footage or obstructed camera views) video counts produced lower counts than those produced by the onboard observer. We thus merged the counts produced by the two methods to ensure a complete census of the rollover bycatch. While species level identification was available for all individuals collected by onboard observers, for individuals that were not collected, the multiple viewing angles and reduced time constraints sometimes allowed video observers to identify released bycatch individuals to a higher taxonomic level than that produced by onboard observers. Thus, encounters of all sea turtles and protected species from the rollover videos were reviewed, and the species identification from the video footage was used rather than the identification by the live observer. For sharks and rays, each set was examined individually, and the identification (onboard or video) with the highest taxonomic accuracy was used.

Because the number and species of rollover bycatch collected by the on-board observers is a known quantity, these species-specific counts were included in the final count, unchanged. Counts of bycatch released from the nets that was not collected by observers were then added to this known quantity, using either the bycatch count produced by the rollover video analysis or the count produced by the onboard observer. The protocol we used for determining the counts used in the final rollover census count involved the following rule-based decision-making process for the non-collected bycatch: (1) The observation method that produced the highest count for each taxonomic group or species was used as the final count. (2) The highest taxonomic resolution was used in the final count. For example, if the live observer reported two unknown sharks and a blacktip shark, and the video reported two finetooth sharks and one unknown shark, the final count would be two finetooth sharks and one blacktip shark; (3) If video observers were unable to discern the fate of fish (e.g. collected or released), the difference between the live and video count of collected individuals was taken. This was then subtracted from the number of individuals of that species whose fate could not be determined in the video count. If the resulting value was negative, the video not collected count remained unchanged, because it is possible the fate of all the unknown individuals was collected. If this value was positive, it was added to the number of individuals that were recorded as not collected in the video count for that species in that set. The video count of individuals not collected was then compared to the live count to see which was larger, as per the normal procedure.

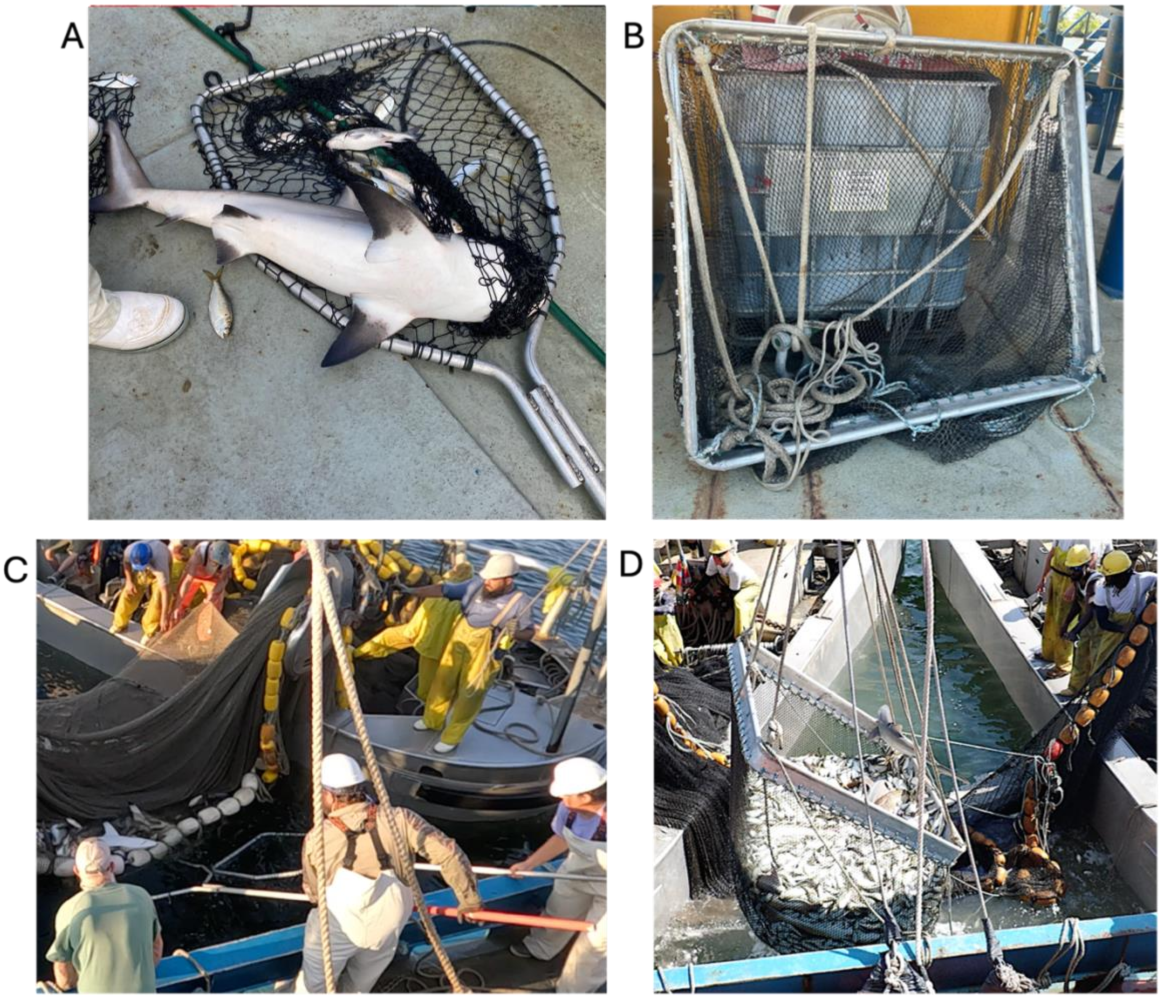

Figure 3. (A) Long-handled landing nets used to subsample the rollover bycatch (frame dimensions 29” w x 40” l; handle: 100”); (B) A brailer net (60” deep) and frame (56 x 56”) used for sampling sets with higher bycatch numbers; (C) Large sharks and rays, as well as a small quantity of leftover menhaden, being rolled over the float line and into the observer’s nets after menhaden have been pumped out of the purse net; (D) For selected high bycatch sets, bycatch and leftover menhaden were rolled into the brailer net and winched onboard the run boat.

Chute Bycatch Procedures

The chute bycatch was sampled by diverting the release chute, which normally shuns fish overboard, back on board the vessel and into a water-filled 100-gallon release tote (Figure 4). During the pumping operation, an at-sea observer monitored the release tote for released bycatch. All bycatch that entered the release tote were removed by observers, identified, weighed, measured (fork length, total length or wingspan for rays), and sexed. When possible, gonads were inspected, and the occurrence of ripe stage ovaries was recorded by observers. Chute bycatch were assigned condition scores using the same scoring criteria utilized for the rollover bycatch (Benoît et al., 2010) (Appendix 5). All species collected in the release tote that were used in the survival study were handled according to the procedures outlined in LGL's Report#8. At the conclusion of the pumping operation, observers inspected the bycatch excluder grate and release chute for fish trapped between the excluder bars or stuck within the release chute. When present, these bycatch individuals were removed by observers and weighed and measured using the same procedures as for fish collected from the release tote. All bycatch collected from the grate and chute were assigned as mortalities given that these individuals were not successfully released during the normal pumping operation. To assess the susceptibility of different species and size classes to entanglement within the fish excluder grate or within the release chute, observers recorded the location at which bycatch was collected (e.g., either from the release tote, chute, or from the excluder grate). Larger species that travelled through the hose cage were frequently dismembered by the pump before release. When faced with dismembered specimens, observers recorded whether the anterior portion (head) or posterior portion (tail) of the specimen remained. All dismembered specimens were excluded from length-weight determinations for the chute bycatch. When calculating bycatch, the number of heads or tails, whichever was greater, for a given species within a set was used to avoid the possibility of counting a single individual twice. During sets when at-sea observers were not sampling, the entrance to the diversion chute was closed and fish were released overboard in the normal fashion. The above approach allowed observers to census all bycatch from the chute bycatch component.

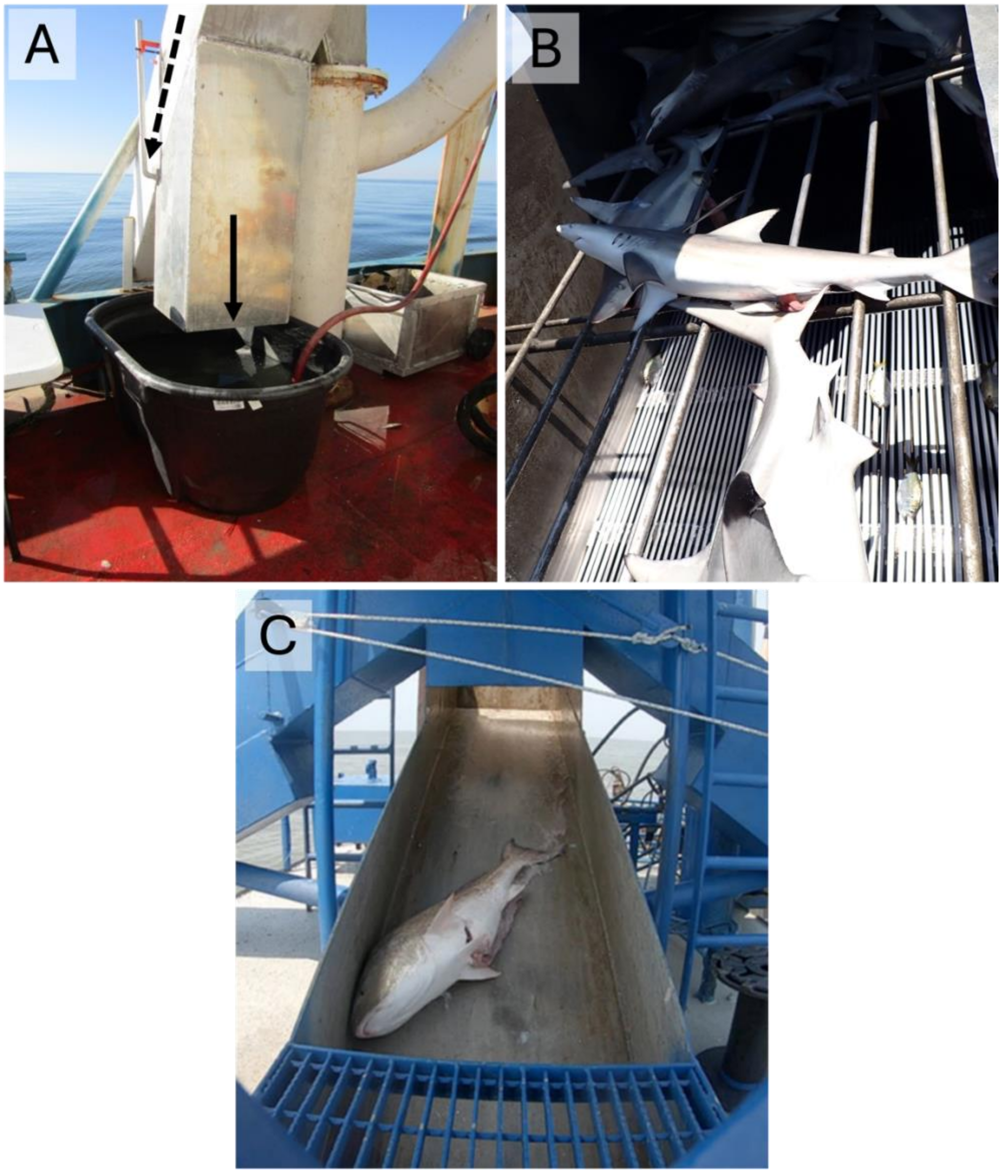

Figure 4. The three chute bycatch sampling locations. (A) The diversion chute (solid arrow) used by at sea observers to divert bycatch normally released by the release chute (dashed arrow) back on board the vessel and into the water-filled release tote. Bycatch that entered the release tote were sampled by observers and assigned condition scores ranging from excellent to mortality. (B) Bycatch entrapped in the fish excluder grate were removed by observers at the end of the set, measured and enumerated, and assigned as mortalities. (C) Bycatch located in the release chute that were not successfully released into the release tote were removed by observers at the end of the set, measured and enumerated, and assigned as mortalities.

Retained Bycatch Procedures

SUBSAMPLING

Sampling of the retained bycatch occurred where the stream of fish entered the vessel's hold. A large rectangular aluminium sampling cage (32 x 20 x 19", L x W x H) was operated by observers using a davit and a 500 lb electric winch (Figure 5). The dimensions of the sampling cage were designed to ensure that the cage sampled over 403 standard menhaden, equivalent to 120 kg of catch (one standard menhaden is 0.3 kg). This threshold was selected to ensure a 90% confidence of being no more than 5% off in a multinomial response (Thompson, 2002). When full, the cage sampled ~126 kg of catch on average, equating to roughly 420 standard menhaden.

At-sea observers signalled captain and crew when catch was to be diverted into the sampling cage. One subsample (e.g., one full sampling cage) was taken for each set, with each sample being haphazardly collected during either the beginning, middle, or the end third of the pumping operation. This sampling design accounted for the potential for a non-homogenous distribution of bycatch across the pumping operation, and followed procedures similar to those deployed during previous bycatch studies (Christmas et al., 1960). All species observed in the sampling cage were recorded. Gulf menhaden were separated from bycatch and placed in commercial shrimp baskets (3/4 bushel). For the first two full shrimp baskets, all menhaden were counted and then weighed in aggregate. All remaining baskets of menhaden were weighed in aggregate but not counted. All incidental catch were sorted by species. While some herring species, such as finescale menhaden (*Bevoortia gunteri*) and Atlantic thread herring (*Opisthonema oglinum*), can be considered legitimate targets of the fishery, we recorded them as bycatch to provide the maximum resolution of species-specific catches as possible. For the first 30 individuals of each bycatch species, we recorded the identity, weight, and length (Fork Length [FL], Total Length [TL], Wingspan for rays). If partial or dismembered specimens were encountered, these were counted and weighed and were not used in the production of length-weight relationships. After 30 individuals of a given bycatch species, the remaining specimens for that set were counted and aggregate weights produced. When time allowed, additional data on the sex and the reproductive state of bycatch was collected with observers noting the occurrence of ripe stage ovaries when encountered while sexing bycatch. Invertebrate bycatch, including jellyfish, shrimp, crabs, and squid, were counted and weighted, but were not measured.

Figure 5. The sampling cage, winch and davit system operated by two at-sea observers to subsample the retained bycatch during each set.

VERIFICATION WITH VIDEO MONITORING

To allow for cross validation of bycatch estimates via two independent methods, subsampling of the retained bycatch via the sampling cage was conducted alongside video monitoring of the retained bycatch entering the hold. Video observations were conducted using four high-speed camera systems. Specifically, four GoPro Hero 11 cameras filming at 240 Frames Per Second (FPS) were fixed in position above the vessel's refrigerated holds, two each above the stern and bow holds. The cameras provided complete coverage of all the loading chutes that transferred menhaden and incidental catch into the hold, with the exact camera locations and configuration optimized for recording on each of the three sampling vessels. All cameras were housed within custom shade boxes (10x10x10") equipped with a 120mm, 120-volt fan to increase airflow (45 cubic feet per minute) and prevent cameras from overheating under hot and humid LA field conditions (Figure 6). An at-sea observer controlled the operation of all four cameras simultaneously using the GoPro Capture App. At the initiation of the pumping operation, the observer began recording on all four cameras. Recording was ceased once the pumping operation had concluded and the purse boats had been untied from the sampling vessel.

Videos recorded of menhaden and incidental catch entering the hold of the sampling vessels were analyzed using Behavioral Observation Research Interactive Software (BORIS, Version 8.25.4) (Friard and Gamba, 2016). BORIS is freely available software that has been used in a range of video review applications, including analyzing bycatch in commercial fisheries (Robert et al., 2020). Point events created in BORIS were used to document the occurrence of bycatch species within the stream of menhaden entering the vessel's hold. Videos were optimized in the BORIS interface to increase the detection of incidental catch during analysis. Playback speeds were 10 times slower, and video magnification was increased as needed to focus imagery on the catch entering the hold. This approach, and the high frame rates recorded, allowed clear observations of larger bycatch such as red drum entering the holds of the vessels (Figure 6), along with the detection of smaller bycatch species when visible. Observers identified and recorded all bycatch (e.g., all non-Brevoortia Sp.) to the highest taxonomic resolution possible, noted whether the specimen was whole or dismembered, and recorded the relative length of each incidental catch event by measuring the length of the bycatch specimen observed in reference to the length of a close by menhaden within the same video frame (Figure 6). The goal of these length determinations was not to accurately determine total lengths of incidental catch, but to determine the size of bycatch in relation to the background stream of menhaden entering the hold. With larger and more conspicuous bycatch expected to have higher detection probabilities, the calculated relative lengths allowed comparison of bycatch estimates based on the relative size, and for better validation between the two methods of estimated bycatch within the retained bycatch component (e.g., onboard subsampling vs. video monitoring). All point events recorded in BORIS were automatically saved and referenced to the video frame of occurrence so that bycatch events and species identifications could be examined by a second reviewer on an ad hoc basis.

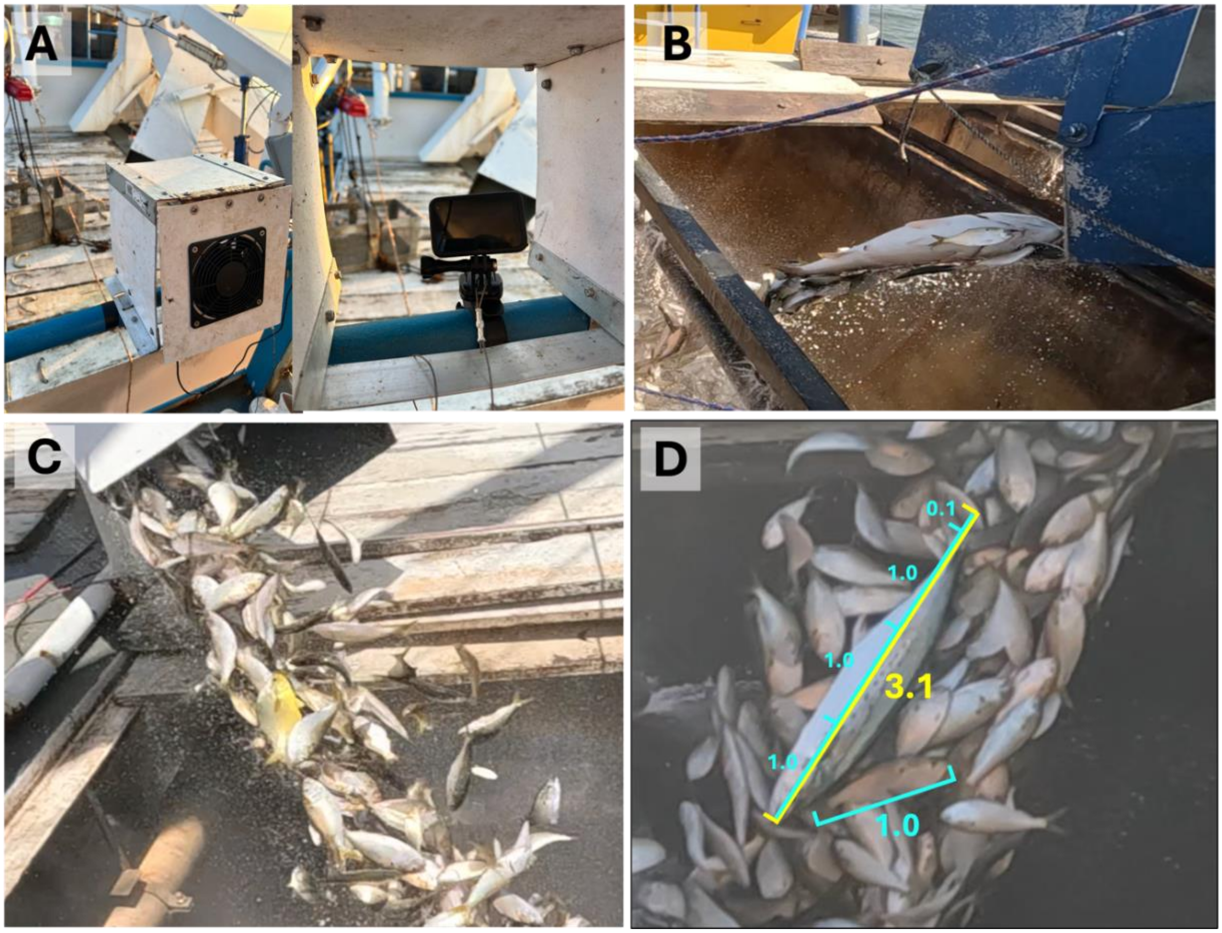

Figure 6. Retain bycatch video monitoring and analysis. (A) The shade boxes and fans (left) housed GoPro Hero 11 cameras (right) for high-speed recording and monitoring of the loading chutes that direct catch into the vessel's hold. (B) Red drum and large bycatch constituents were generally easily identifiable by video monitors. (C) Small bycatch species, like the pictured Florida pompano, were also recorded when observed by video monitors. (D) For all bycatch species observed, video monitors determined the relative length of the bycatch in relation to the length of a nearby menhaden. In the shown example, the Spanish mackerel was calculated as being 3.1 times the length of the reference menhaden.

Additional Data Collection

Set and Trip Metadata

For all net sets sampled, observers recorded the following set-level metadata: set start date and time, set start location (latitude and longitude), set depth (as reported by the Captain's instruments), surface water conditions (described in detail below), fishing vessel, sampling vessel (e.g., run boat), and the captain's total catch estimate/pump time. Captains used the time it takes for catch to be pumped from the net into the vessel's hold to estimate the total catch for each set. Pump speeds were generally in the region of ~15,000 standard menhaden per minute but differed based on vessel-specific pump operation and based on the captain's real-time observation of the flow of catch entering the vessel's hold. During sampling trips, consisting of the duration between when the run boat first left the dock to when it returned to the dock to unload catch, catch estimates were recorded for all sampled and non-sampled sets so that the total catch in the hold of the sampling vessel could be estimated based on the sum of the captain's estimate for all sets pumped during a given trip. The true weight of the total catch in the hold was then obtained when the vessel was offloaded at the processing plant.

Bycatch Reduction Devices

During the 2024 fishing season, at-sea observers quantified the bycatch reduction devices on all 32 vessels within the commercial fleet. For each vessel, dimensions and photographs were taken of the hose cages and large fish excluder grates (Figure 7). Hose cage measurements involved measuring the inner dimensions of the openings on each row of cage bars, measuring the overall length and diameter of the cage, and the measuring the hose opening within the cage. For each cage opening, we measured the length, width and height, so that the area of each opening could be calculated, as well as the total area of the hose cage. Additionally, observers counted the number of rows present, the number of openings per row, the shape of the hose opening, and the presence and number of fender bars surrounding the cage. For the fish excluder grates, the spacing between bars was measured along with the presence or absence of large fish deflectors/gates.

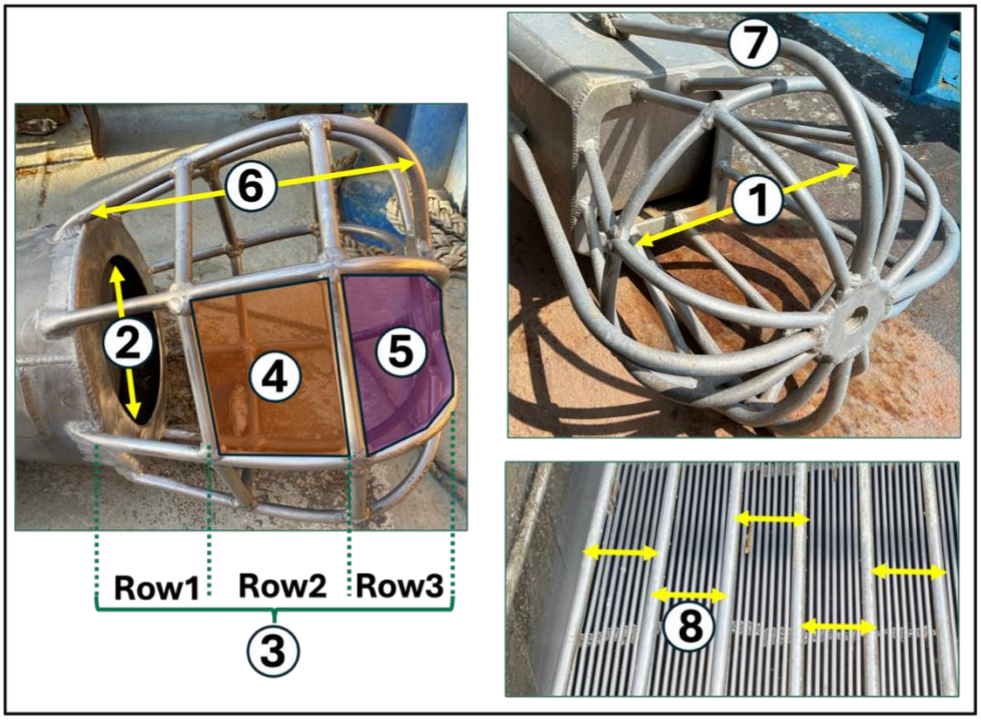

Figure 7. Characterizing bycatch excluder devices. For each hose cage in the fleet we determined: (1) the overall cage diameter, (2) the diameter of the pump opening, (3) the number of hose cage rows, (4) the trapezoid area for the largest opening for the rows on the side of the cage, (5) the largest trapezoid area for openings on the end of the cage, (6) the overall cage length, and (7) the presence or absence of exterior fender bars. The large fish excluder grates were characterized by measuring the spacing between bars (8).

Environmental Data

Observers recorded surface water conditions in the immediate vicinity of all 418 sets sampled during the 2024 season. Vessels were constantly maneuvering and repositioning, thus the preferred method of sampling involved utilizing a two-gallon bucket and rope to obtain a water sample as the run vessel came alongside the purse boats. When possible, care was taken to collect the sample in an area free from the vessel's prop wash so that measured parameters reflected undisturbed in-situ conditions as best as possible. A handheld Yellow Springs Instruments (YSI) multi-parameter sonde (Model: Exo 3) equipped with temperature, conductivity, salinity, and dissolved oxygen sensors was used to record water parameters of the collected water samples.

During August-October, a second YSI sonde was deployed adjacent to the net during 148 sets. Our goal was to better quantify the ambient conditions that rollover bycatch experienced within the nets from the start to finish of the pumping operation and thus draw inference between net conditions and survival estimates produced by the on-board holding study. Once the purse boats were tied to the run vessel, an observer positioned at the stern side of the net lowered a YSI sonde over the port railing of the vessel approximately ~10-20ft from the purse net. The sonde was held ~0.5 ft below the surface and logged conditions at 1 second intervals from the start to finish of the pumping operation, including a ~2-minute baseline reading collected immediately prior to the pumping operation. Upon conclusion of the set, the observer retrieved the sonde. These net-adjacent sonde recordings were the closest proximity conditions observers could safely and practically record during the pumping operation, with heavy machine operation limiting observers from positioning themselves at the stern side of the net. To assess the extent to which sonde readings captured conditions in the net, observers qualitatively assessed each sonde deployment based on visual observations of the sonde position in relation to the high-turbidity plume and oily surface sheen often created down current of the purse net. Sonde readings were categorized into "within plume", "variable", or "outside plume" with readings within the plume best capturing conditions within the net. All YSI sondes utilized in field deployment were calibrated regularly in accordance with YSI standards.

While depth was recorded by the captain at each sampled set, how much each boat drafted varied throughout a trip as the holds filled with catch rendering these readings dubious. Furthermore, bottom depth was not reported for unsampled sets in the fleet (96.8% of sets); however, latitude and longitude were. Therefore, all bottom depths at which sets were fished were extracted from a 3 arc-second Coastal Relief Model for the Gulf of Mexico (available https://geo.gcoos.org/data/topography/CRM.html) based on set locations reported by industry.

DATA ANALYSIS

Principal Component Analysis to Assess Bycatch Reduction Devices

While overall bycatch for a given set—rollover, chute, and retained combined—should not be affected by variation in bycatch reduction devices, how the overall bycatch is apportioned across the three components will be. Which component matters because rollover bycatch survival is relatively high, chute bycatch survival is very low, and retained bycatch survival is of course 0%. As such, we needed to assess how well each run boat's bycatch reduction devices represented the fishing vessels they serviced.

Principal component analyses (PCA) were applied to determine these associations. PCA reduces data dimensionality by converting original measurable variables into new uncorrelated variables called principal components (PCs), which preserve details from the original data (Maćkiewicz and Ratajczak, 1993). The following variables were used to display the bycatch excluder characteristics of each vessel in fewer dimensions: area of largest opening on the side of the hose cage, area of largest opening on the end of the hose cage, total hose cage length, hose cage diameter, overall hose cage area, number of hose cage rows, width of hose cage opening, the presence or absence of fender bars (0 or 1) on the hose cage, and the spacing between bars on the fish excluder grates. The variables were first transformed so that they contributed equally to the PCA. The transformation technique used involved subtracting the mean of the variables from each observation (centering) and dividing each observation by the standard deviation of that variable (scaling). Principal component eigenvalues and eigenvectors were calculated. A total of 8 eigenvalues in 2 dimensions were produced to describe bycatch excluder device characteristics by vessel. PCA results were explored visually to assess and group the data with 99% Confidence Ellipses and to explore the drivers of differences and similarities between vessel hose cage groupings by plant.

Model and Design-Based Inference

Two general frameworks exist for inferring population parameters from estimates based on survey samples—design-based versus model-based inference. The distinction between the two and how sampling design is related to the model specification is routinely omitted by researchers across a range of disciplines. Sterba (2009) reviews these frameworks for the field of psychology; Williams and Brown (2019) expound upon this discussion and tailor it to the field of ecology noting the advantages and disadvantages of each.

If samples are collected at random from the population's universe of units with all possible units having an equal probability of being sampled, then a simple random sample has been obtained. Any statistic derived from this sample, such as an average, is said to be design-unbiased. Sampling probabilities can vary across units when more complex designs are employed—for example stratified random, systematic, or cluster sampling designs—yet the statistics and associated variances they render are still design-unbiased if the selection process controlling these probabilities is accounted for. Thus, the sampling design must be clearly defined and accounted for to ensure unbiased design-based inference (Thompson, 2002).

Not all survey designs are random. This situation can arise when samples are selected for convenience to minimize costs (opportunistic sampling) or intentionally selected from a specific set of conditions to ensure their inclusion for comparison purposes (purposive sampling). Design-unbiased inference is dubious for these datasets as the conditions controlling the unit values are not known to be representative of what the entire population experienced. Nevertheless, model-based inference is still possible if a statistical model can be parameterized to capture the important structural features of the ecological system that control the unit values and of the selection process when it deviates substantially from simple random sampling (Sterba, 2009; Thompson, 2002; Williams and Brown, 2019). If so, then predictions from this model (inference) will represent the infinite population (i.e., be model-unbiased) if they are conditioned on these features.

We attempted to randomly sample in proportion to the spatio-temporal effort exhibited by the fleet throughout the 2024 season. Stratifying and apportioning our samples by plant and month facilitated their representativeness of the entire fleet, and we report design-based estimates of bycatch in this report. However, we must acknowledge that not every set made by the fleet had an equal probability of being sampled. The run boats we sampled from did not have equal access to the entire fleet on any given day during each plant-month combination. This phenomenon could have potentially compromised the unbiased nature of estimates from a purely design-based approach. To guard against this hazard, we parameterized statistical models based on our samples and predicted bycatch for each set made by the entire fleet. We anticipated that a comparison of design-based and model-based estimates of bycatch would be informative. Similar values would suggest that our sampling was in fact representative of the fleet, and that our models were correctly specified and conditioned to yield unbiased predictions. Dissimilarity between the two inferential approaches would suggest that non-representativeness or our samples and/or misspecification of the statistical models. Below we describe our estimation methods for each bycatch component.

Rollover and Chute Bycatch Estimation

Bycatch was estimated for each component (rollover, chute, and retained) independent of the other components. We describe bycatch estimation for both the rollover and chute components in this one section as the statistical methods were the same for both. For each species and component, the stratified mean number of individuals per set was calculated by plant and month. Next these estimates and their variances were expanded to the total number of sets made by the fleet for each stratum and summed across strata to render fleetwide design-based estimates with 95% confidence limits.

Ideally, the endeavor of modeling species abundance metrics (e.g., species distributions or catch and bycatch rates) will account for spatial and temporal autocorrelation and have all relevant processes influencing the responses of interest available. Yet, this ideal modeling scenario requires substantial model complexity that cannot be supported in data-limited situations. Yin et al. (2024) demonstrate how simple models with applicable underlying assumptions can give better predictions than overparameterized models. Furthermore, generalizing a predictive model using covariates from the observed dataset to the entire fleet constrains the available covariates to only those common to both observed and unobserved sets.

We specified our models of bycatch for the rollover and chute components to account for as much variability as possible without overparameterizing and restricted our predictor variables to those available for the entire fleet. Our final model specifications formed generalized additive mixed models (GAMM) for which we estimated parameters using the gam function in the mgcv Package Version 1.9-3 (Wood, 2022) for the R statistical programming language implemented with RStudio (R Development Core Team, 2024); the R code for this model was as follows:

```
Bycatch_Model <- mgcv::gam(Count ~ Plant.fac + Month.fac +
                            s(Lon, Zone.fac, bs="fs",  m=1, k=5) +
                            s(BottomDepth_M, bs="tp", m=1, k=5) +
                            s(DOY.fac, bs = "re"),
                            family = nb(), method = "REML",
                            optimizer = c("outer", "newton"), data=data)
```

where, Count = the number of bycatch individuals for a given species assumed to follow a negative binomial distribution to accommodate overdispersion relative to Poisson. Plant.fac and Month.fac represent categorical factors. s(Lon, Zone.fac, bs="fs", m=1, k=5) fit a separate smooth of longitude for each level of the factor Zone.fac using a thin-plate spline basis by default, and s(BottomDepth_M, bs="tp", m=1, k=5) fit a univariate smooth of water depth. The factor Zone.fac was created to parcel sets by areas wherein line-of-sight was maintained for all sets within each level (area) of this factor (see Figure 1 for their designations). s(DOY.fac, bs = "re") treated the factor day-of-year as a random intercept (one level per day) to capture unexplained daily variability and partially account for spatio-temporal autocorrelation among sets within a given day. The k=5 syntax held the upper limit for the degrees of freedom associated with the smooth to four (k-1), which helped to prevent overparameterization; others have also used this approach (Bolser et al., 2020; Dance and Rooker, 2019; Egerton et al., 2021; Pedersen et al., 2019). The maximum degrees of freedom for each smooth were automatically penalized by minimizing the restricted maximum likelihood (REML; recommended by (Wood, 2022), which results in effective degrees of freedom (the number of coefficients to be estimated). We chose to penalize the squared first derivative for each smooth function as indicated by the syntax m=1. The default is to penalize the second squared derivative (m=2), but low order penalties are recommended when the response can be zero over large areas of covariate space and avoids extreme estimation when the data are uninformative (Wood, 2022). Lower order penalties also help to reduce concurvity (similar to collinearity in linear regression models) among smooth functions (Pedersen et al., 2019).

Retained Bycatch Estimation

For species of most interest (e.g., spotted seatrout and red drum) observed values from the retained bycatch samples did not lend themselves to model parameterization. Low frequency of occurrence caused ~95-98% of the observations to be zeroes, which precluded convergence of even the simplest model specifications. As such, we were only able to estimate bycatch numbers using an intercept-only negative-binomial (NB) model for each plant-month combination. In a sense, this approach was a hybrid form of design- and model-based estimation.

Unlike the rollover and chute bycatch components, which were sampled in total for each set, the retained bycatch component had to be subsampled as described above. Subsampling requires expansion to the total set level, which can be done in several ways. All require knowledge of the set proportions being sampled, which is determined by the total weight of an individual set and the weight of the subsample.

For each set, the captain estimates the total weight. They actually report “number of standard menhaden”, which just a proxy for weight because this number gets multiplied by a standardized individual weight (0.67 lbs or ~0.304 kg). All sets added together from a trip amount to the captain’s estimate of offload weight. The offload weights estimated by the captains were close to the more or less known weights reported by the plants (average percent difference: 2.2%, Appendix 8). Nevertheless, individual set weights for each trip were proportionately adjusted so that their combined weights matched those reported by the respective plants.

The number of bycatch individuals in the subsamples had to be expanded to the set level and then to the entire fleet to get a fleetwide estimate of retained bycatch. As follows:

(1) Weights for each subsample included the combined weight of all menhaden and bycatch in the basket. We estimated the mean subsample multiplier for each plant-month stratum by dividing the total weight of the sets by the total weight of all the baskets sampled per stratum.

(2) We obtained a point estimate for the number of bycatch individuals by species per subsample for each plant-month stratum using an intercept-only negative-binomial (NB) model. This approach yielded more or less the same point estimates as the arithmetic means but allowed for confidence intervals that accounted for overdispersion.

(3) Stratum specific point estimates for subsamples were expanded to the set level through multiplication by their respective stratum subsample multipliers.

(4) Set level point estimates were then expanded to the entire fleet based on the total number of sets per stratum and then totaled across all strata to obtain a fleetwide estimation retained bycatch by species.
(5) Confidence limits were derived via parametric bootstrapping from the negative-binomial model with 10,000 iterations. For each iteration, subsample point estimates were expanded to fleetwide estimates as per steps (3) and (4) above. Then, the 0.025 and 0.975 percentiles from these 10,000 iterations were used as 95% confidence limits for each fleetwide point estimate of total bycatch.

For fish species, we only used observations of whole fish (i.e., heads and tails were not included). Our rationale was that larger fish species were often cut in half with an unknown number of halves winding up in the chute versus being retained. Therefore, there was a potential for an individual to be already accounted for in the chute bycatch based on one half and then be expanded erroneously in the retained bycatch because of the other half. Applying this filter to smaller fish in the retained bycatch had little effect as they were almost always whole. We did not apply this filter to invertebrates because they were not present in the chute bycatch to any substantial degree and were often dismembered in the retained bycatch.

Total Bycatch by Weight

To obtain the weight of bycatch, the estimated number of each species in each component of the bycatch was multiplied by the average weight of individuals of that species collected in that component of the bycatch. When calculating mean weights of taxa not identified to species level, all the collected individuals for all species in the group were pooled together (e.g. the pooled average weight of all individuals in the family Dasyatidae collected in the rollover).

A second estimation of total retained bycatch by weight was obtained by calculating the percent bycatch by weight of each subsample of the 415 sets where the retained bycatch was subsampled. This proportion was then weighted by the size of the set in kg, and a stratified mean percent bycatch was calculated by plant and month.

Results

SAMPLING EFFORT

At-sea observers sampled 418 sets equating to 3.2% of Louisiana fishing effort during the 2024 fishing season. Our field sampling goals (>2% of monthly sets) were met during all months except April (1.88%; Figure 8). With the season starting on April 15th, at-sea observers had only a narrow, two-week window of opportunity to sample in April. Field sampling goals were based on the maximum fishing effort conducted by the fleet across the years 2020-2022. Lower fishing effort in May and June relative to the same months in 2020-2022 facilitated increased sampling effort in 2024, with 4.35% and 4.13% of the total monthly fishing effort being sampled.

Sets were sampled from April 15th to October 15th, 2024, between the hours of 06:30 to 20:45 central standard time, when fishing operations occurred. In 2024 there were 32 vessels operating within the fleet, 5 full-time run boats, 26 full-time fishing vessels, and 1 fishing vessel that operated as a run boat only when observers were onboard. All full-time fishing vessels within the fleet (n=26) were sampled at least four times during the season.

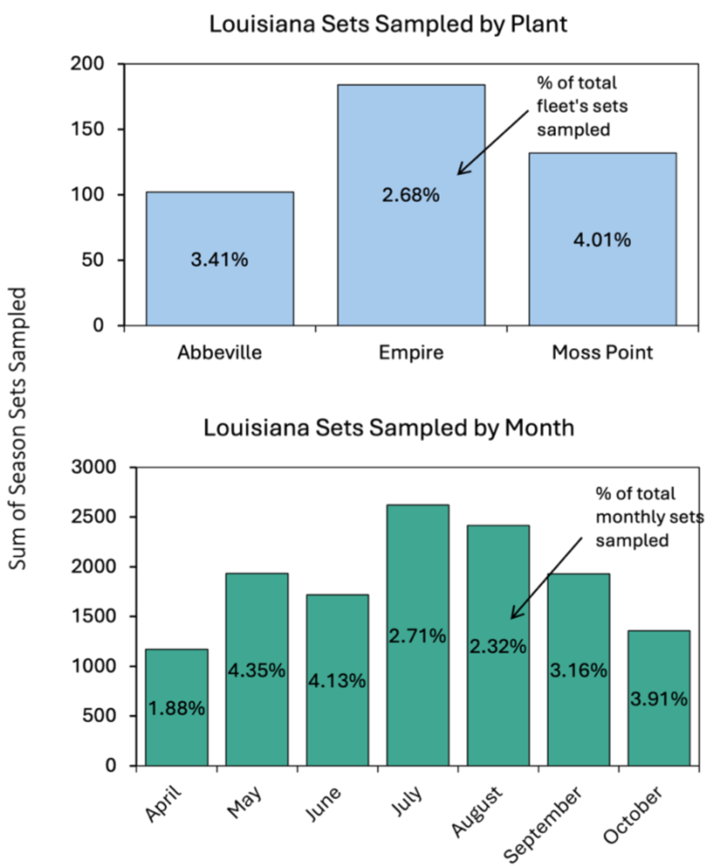

Figure 8. Season sampling effort for sets fished and sampled in Louisiana and adjacent federal waters. (A) Total percentage season sampling effort by plant. (B) Total season sampling effort by month during the 7-month commercial fishing season.

Set Characteristics

A total of 13,144 sets were fished in Louisiana and adjacent federal waters during the 2024 purse seine season, accounting for approximately 93.5% of the total landings in the Gulf of Mexico menhaden reduction fishery. Nearshore areas from the Breton and Chandeleur Sounds in the east to the Texas state line in the west were actively fished from April through October. Sets ranged in size from 0 to 1.15 million standard menhaden, based on the captain's estimate of catch. The depths at which sets were fished ranged from ~0.2 to 17 meters (mean depth: 4.5 m).

At-sea observers sampled a total of 418 sets across the season, ranging in size from 0 to 540 thousand standard menhaden. The size of sets sampled (mean: 75,300 standard menhaden) generally corresponded well with the average size of sets fished during the 2024 season (mean: 85,700 standard menhaden) (Figure 9). Although the largest sets were not represented in our observer data, sets greater than 540,000 menhaden (our largest sampled set) were generally rare, consisting of a total of 49 sets accounting for ~0.4% of the sets fished in 2024. Sets sampled by observers ranged in depth from 0.3 to 13.6 meters (mean depth: 4.7 m) and stretched as far west as Grand Chenier, and as far east as the northern extent of Chandeleur Sound. Surface water temperature showed a minimum of 20.8° C and a maximum of 33.9° C throughout the study, with temperatures peaking in August (mean: 31.8° C). Salinities ranged from 2.99 ppt to 33.6 ppt across the sets sampled (mean: 18.9 ppt). Measured dissolved oxygen at the surface ranged from 3.02 ppm to 15.37 ppm (mean: 7.03 ppm). We acknowledge that unusually high dissolved oxygen values are reported for some of our samples sets (55.6% of sampled sets were supersaturated). Comparison of readings taken by the YSI to that of the additional onboard DO instruments, indicated that sets with high oxygen values were likely not the result of measurement error. Instead, we suspect the high DO values are caused by natural processes such as wave action or photosynthesis, or by artificial aeration from the fishing vessel and during collection of water samples overboard.

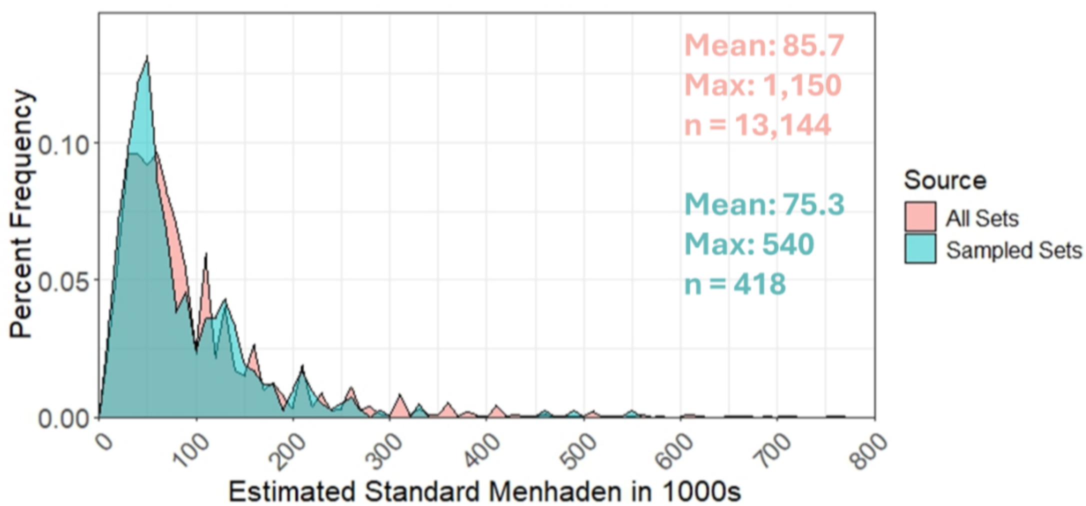

Figure 9. Density plot showing the percent frequency of the captain's estimate of set size in 1,000s of standard menhaden for all 13,144 sets made in Louisiana and adjacent federal waters in 2024. Overlayed is the percent frequency of the set sizes sampled by at-sea observers (n = 418). For clarity, the x-axis is restricted to a maximum set size of 800,000 standard menhaden, resulting in the removal of 4 sets greater than this threshold. Sets of this size were a rare occurrence.

BYCATCH EXCLUDER DEVICES

Considerable variation existed between bycatch excluder devices on vessels in the fleet (Appendix 3). A principal component analysis (PCA) with k-means clustering, separated the fleet into three distinct clusters based on hose cage attributes. Cluster 1 (blue) is characterized by hose cages with fewer cage rows and larger cage openings. Cluster 2 (yellow) represents excluder configurations with smaller openings and a higher number of rows. Cluster 3 (gray) occupies an intermediate position and overlaps both clusters in terms of variance. The first two principal components (PC 1 & PC 2) from the principal component analysis together explained 67.9% of the variance in bycatch excluder characteristics across the 32 fishing vessels and run boats in the fleet (Figure 10). Important to note is that vessels with bycatch excluder devices from each of the three clusters were used by at-sea observers in this study. As a result, bycatch estimates produced are representative of the full suite of excluder device characteristics present within the fishery.

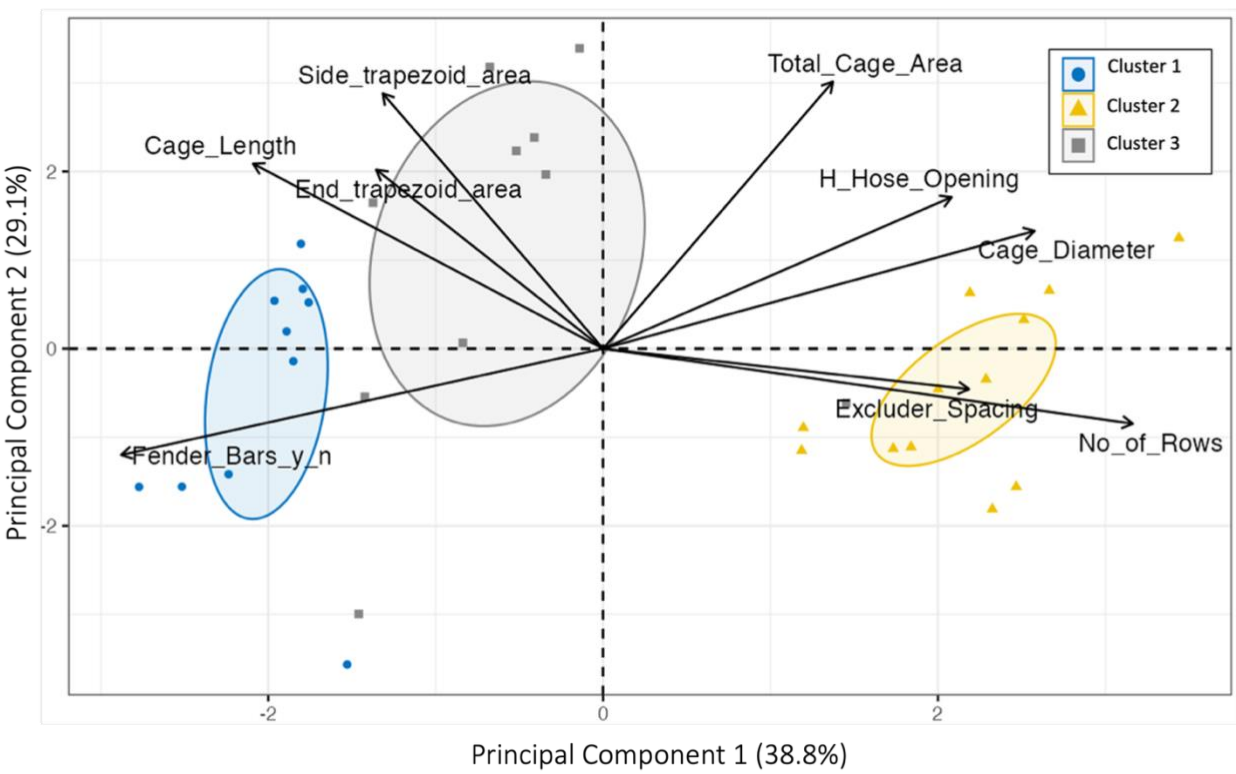

Figure 10. PCA ordination biplots of key bycatch excluder variables for the entire sampled commercial menhaden fleet. Arrows represent the direction of the original variables' contributions to the first two principal components (PC1 and PC2). The length of arrows for each bycatch excluder variable represents the squared cosign with longer arrows denoting higher quality variables. The 99% confidence ellipses denote where the true mean is likely to fall.

DESIGN AND MODEL-BASED ESTIMATES

We generated model-based estimates for the most abundance species in the rollover and chute bycatch components. Model diagnostics indicated no problems with their specifications (Appendix 1) and all models had sample size to parameter ratios that were greater than 10. When comparing model-based and design-based estimates, discrepancies varied by species and bycatch component, but in all the two approaches yielded similar magnitudes of bycatch (Figure 11). Across these species, model-based estimates were lower than design-based estimates by 13% and 17%, respectively. We chose to use the design-based estimates as the worst-case scenario when estimating overall bycatch weight relative to landings.

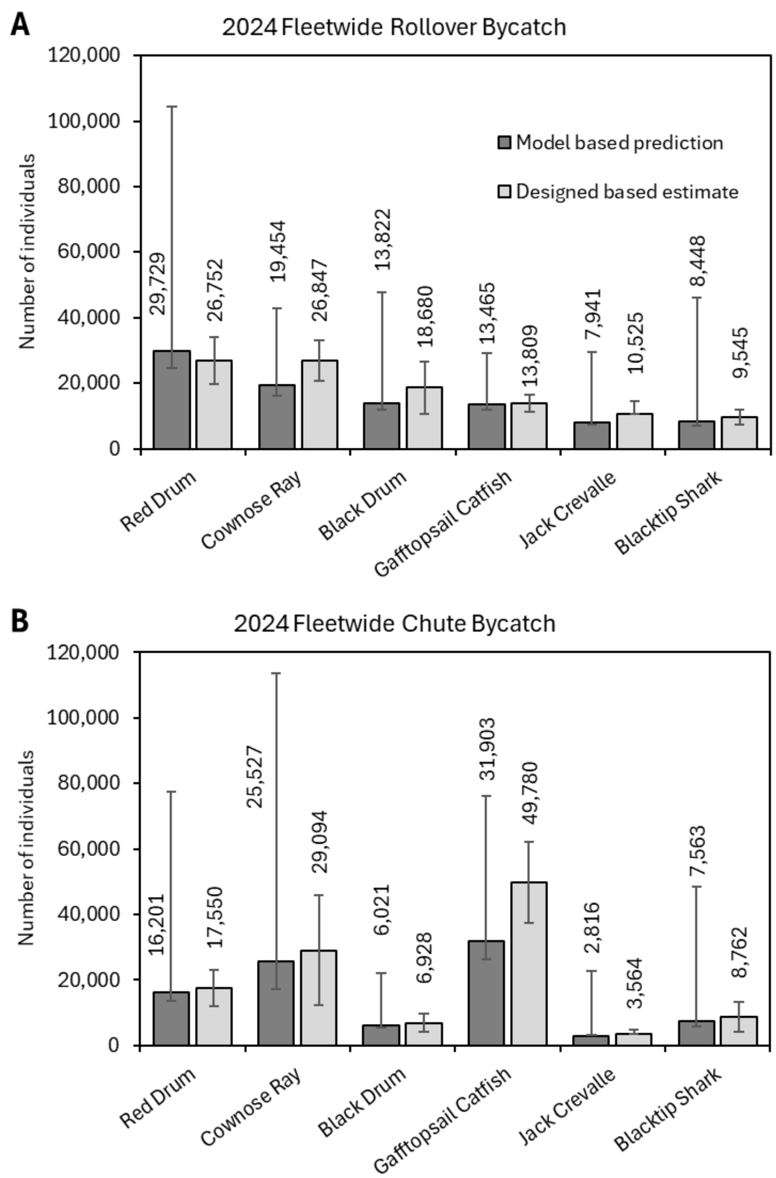

Figure 11. Season estimated bycatch (# individuals) for both design and model-based estimation methods of the six most abundant species in the released bycatch. A) Rollover bycatch. B) Chute bycatch.

BYCATCH ESTIMATION

Rollover Bycatch

The rollover bycatch was successfully sampled from 415 sets. Video was available for verification in all but three of these sets (Appendix 4). The brailer frame was used on a total of six sets, with the remaining 409 sets sampled exclusively with long-handled dip nets. A total of 43 (10.4%) sets had no bycatch in the rollover. Table 1 displays the total number of individuals of each species observed based on the on-board and video counts. In total, 43 species were identified in the rollover bycatch. For each species encountered, we show the maximum number of individuals observed during a single set, the stratified average number of individuals per set, the total estimated catch for the 2024 fishing season by number and weight, and the percent obtained by dividing these total weights by the total landings for the fishery (Table 1). Overall, we estimate the total number of bycatch in the rollover to be 145,095 by number and ~1.48 million kg by weight.

The average number of bycatch observed in the rollover across the 415 sets sampled was 11 individuals, with a maximum of 128 individuals in a single set (for all species grouped). The most abundant species in the rollover bycatch were cownose ray, red drum, black drum, gafftopsail catfish and crevalle jack. These five species comprised 66.6% of the estimated total rollover catch by number and 52.8% of the estimated total catch by weight. Sharks from the genus *Carcharhinus*, dominated by blacktip shark, bull shark, finetooth shark, and spinner shark, comprised an additional 22.3% of estimated total rollover catch by number and 44.1% of the estimated total rollover catch by weight. Not all sharks or rays could be identified to species by on-board observers or during video review. This unidentified portion of the catch, however, is likely comprised of similar species proportions as the identified catch with blacktip sharks constituting most of the unidentified sharks and southern stingray comprising most of Dasyatidae.

The condition of fish in the rollover as assessed by the at-sea observers is shown in Table 2. Across the season, condition scores were assigned to a total of 3,032 individuals. In general, fish released in the rollover bycatch were healthy upon release. For example, 95.9% of red drum and 88.4% of cownose rays were assessed as being in good or excellent condition at the time of release. For blacktip and bull sharks, we report that 77.8% and 66.6% or individuals were assessed as being in good or excellent condition at the time of release. Immediate mortalities for sharks were generally higher than that of bony fish, with 27.9% or blacktip sharks and 19.4% of bull sharks released dead by the fishery. While we do report higher immediate mortalities for some species like Atlantic sharpnose sharks and bluntnose stingray, sample sizes for these species were limited to 1 and 4 individuals, respectively.

The lengths and weights of fish measured by observers in the rollover are shown in Table 3. In total, observers collected morphometric data on a total of 1,684 individuals from the rollover bycatch. The mean total length of bycatch measured in the rollover for all species was 913 mm and ranged from gafftopsail catfish as small as 148 mm to a 2,170 mm long bull shark (2.17 meters). Larger sharks and rays were encountered in the rollover but were not brought onboard by observers for morphometrics. The largest individuals observed were lemon shark, bull shark and giant manta ray. The lengths and weights of all shark and ray species – except for small-bodied species such as Atlantic sharpnose shark, bonnethead shark, cownose ray, and smooth butterfly ray – thus represent an underestimate for the rollover bycatch.

Table. 1. Rollover bycatch in the 2024 Gulf menhaden fishery in terms of numbers and weights based on means stratified by month and plant. Total catch was calculated by summing the stratified means multiplied by the corresponding stratum-specific total sets made in Louisiana and adjacent federal waters. The percent obtained by dividing these total weights by the total weight of landings for the fishery is also displayed. Species lacking total weight estimates consist of species for which individual lengths and weights were not determined. For complete list of scientific names see Appendix 2.

Species	Total # Individuals Observed	Max Observed per Set	Average number per set	Total Catch	Total Weight kg	%W Landings
Cownose Ray	880	44	2.04 (1.57-2.52)	26,847 (20,580-33,115)	244,149 (185,652-302,647)	0.07038 %
Red Drum	865	71	2.04 (1.49-2.58)	26,752 (19,578-33,926)	261,049 (190,905-331,193)	0.07525 %
Black Drum	629	70	1.42 (0.82-2.02)	18,680 (10,745-26,615)	144,668 (83,100-206,236)	0.04170 %
Gafftopsail Catfish	425	33	1.05 (0.85-1.25)	13,809 (11,199-16,420)	18,207 (14,571-21,842)	0.00525 %
Crevalle Jack	353	27	0.80 (0.50-1.10)	10,525 (6,599-14,450)	117,939 (73,841-162,036)	0.03400 %
Blacktip Shark	274	15	0.73 (0.55-0.90)	9,568 (7,261-11,874)	186,032 (139,930-232,133)	0.05362 %
Blacktip/Spinner Shark	274	17	0.66 (0.47-0.85)	8,660 (6,198-11,123)	177,139 (125,584-228,694)	0.05106 %
Carcharhinus sp.	247	19	0.61 (0.40-0.81)	8,004 (5,303-10,705)	160,905 (105,865-215,945)	0.04638 %
Striped Mullet	245	96	0.54 (0.06-1.02)	7,112 (791-13,433)	3,232 (340-6,123)	0.00093 %
Hardhead Catfish	105	16	0.28 (0.15-0.40)	3,629 (1,970-5,289)	1,631 (788-2,475)	0.00047 %
Bull Shark	107	8	0.22 (0.15-0.28)	2,833 (1,966-3,700)	76,657 (51,582-101,732)	0.02210 %
Finetooth Shark	119	8	0.20 (0.13-0.28)	2,692 (1,727-3,656)	35,224 (21,440-49,007)	0.01015 %

Spinner Shark	31	6	0.04 (0.02-0.07)	573 (282-863)	20,303 (9,041-31,565)	0.00585 %
Ladyfish	15	9	0.04 (0.00-0.09)	532 (0-1,216)	525 (0-1,205)	0.00015 %
Dasyatidae	17	3	0.04 (0.02-0.06)	531 (232-829)	10,241 (2,860-17,622)	0.00295 %
Southern Stingray	15	2	0.04 (0.02-0.06)	515 (232-799)	12,552 (2,862-22,243)	0.00362 %
Smooth Butterfly Ray	12	3	0.03 (0.01-0.06)	447 (131-764)	2,007 (465-3,548)	0.00058 %
Devil Ray	9	4	0.03 (0.00-0.05)	329 (0-677)	11,020	0.00318 %
Spanish Mackerel	12	3	0.02 (0.01-0.03)	266 (89-442)	140 (0-287)	0.00004 %
Sheepshead	3	3	0.01 (0.00-0.04)	166 (0-489)	365 (0-1,077)	0.00011 %
Spotted Eagle Ray	5	1	0.01 (0.00-0.02)	140 (0-283)	–	–
Sharksucker	4	1	0.01 (0.00-0.02)	131 (0-278)	6 (0-14)	0.00000 %
Spotted Seatrout	3	1	0.01 (0.00-0.02)	114 (0-239)	40 (0-85)	0.00001 %
Bluntnose Stingray	4	1	0.01 (0.00-0.02)	106 (5-208)	1,210 (51-2,370)	0.00035 %
Atlantic Spadefish	3	1	0.01 (0.00-0.02)	96 (0-203)	–	–
Atlantic Tripletail	3	1	0.01 (0.00-0.02)	95 (0-202)	658 (0-1,405)	0.00019 %
Harvestfish	3	1	0.01 (0.00-0.01)	79 (0-177)	–	–
Alligator Gar	2	2	0.01 (0.00-0.02)	76 (0-223)	–	–
Atlantic Tarpon	2	2	0.00 (0.00-0.01)	61 (0-178)	2,310	0.00067 %
Bonnethead Shark	2	1	0.00 (0.00-0.01)	59 (0-139)	154	0.00004 %
Atlantic Sharpnose Shark	1	1	0.00 (0.00-0.01)	53 (0-157)	37	0.00001 %
Sand Seatrout	1	1	0.00 (0.00-0.01)	51 (0-150)	10	0.00000 %
Lemon Shark	1	1	0.00 (0.00-0.01)	37 (0-108)	–	–
Blue Crab	1	1	0.00 (0.00-0.01)	30 (0-87)	–	–
Roughtail Stingray	1	1	0.00 (0.00-0.01)	30 (0-87)	312	0.00009 %
Bluntnose Jack	1	1	0.00 (0.00-0.00)	8 (0-24)	1	0.00000 %

Scrawled Filefish	1	1	0.00 (0.00-0.00)	8 (0-24)	0	0.00000 %
Shrimp	1	1	0.00 (0.00-0.00)	8 (0-24)	–	–
Total	**4,676**	**–**	**11.04 (0.00-29.31)**	**145,095 (129,586-160,604)**	**1,488,724 (1,337,028-1,640,419)**	**0.42912 %**

Table 2. The condition scores and corresponding sample sizes of rollover bycatch assessed by at-sea observers.

Species	Number of individuals assessed	%Excellent (n)	%Good/Fair (n)	%Poor (n)	%Mortality (n)
Alligator Gar	2	100% (2)	0% (0)	0% (0)	0% (0)
Atlantic Sharpnose Shark	1	0% (0)	0% (0)	0% (0)	100% (1)
Atlantic Spadefish	2	100% (2)	0% (0)	0% (0)	0% (0)
Atlantic Tarpon	2	100% (2)	0% (0)	0% (0)	0% (0)
Atlantic Tripletail	3	100% (3)	0% (0)	0% (0)	0% (0)
Black drum	462	80.7% (373)	14.3% (66)	2.8% (13)	2.2% (10)
Blacktip Shark	201	14.4% (29)	52.2% (105)	5.5% (11)	27.9% (56)
Blacktip/Spinner Shark	12	33.3% (4)	58.3% (7)	0% (0)	8.4% (1)
Bluntnose Jack	1	100% (1)	0% (0)	0% (0)	0% (0)
Bluntnose Stingray	4	25% (1)	25% (1)	25% (1)	25% (1)
Bonnethead Shark	2	50% (1)	0% (0)	50% (1)	0% (0)
Bull Shark	72	33.3% (24)	44.5% (32)	2.8% (2)	19.4% (14)
Carcharhinus sp.	405	19.3% (78)	69.9% (283)	3.2% (13)	7.6% (31)
Cownose Ray	511	61.8% (316)	26.6% (136)	8.4% (43)	3.2% (16)
Crevalle Jack	272	22.1% (60)	48.9% (133)	9.9% (27)	19.1% (52)
Dasyatidae	15	66.7% (10)	20% (3)	0% (0)	33.3% (2)
Devil Ray	4	75.0% (3)	25% (1)	0% (0)	0% (0)
Finetooth Shark	44	36.4% (16)	40.9% (18)	13.6% (6)	9.1% (4)
Gafftopsail Catfish	186	45.7% (85)	42.5% (79)	1.6% (3)	10.2% (19)
Hardhead Catfish	31	74.2% (23)	19.4% (6)	0% (0)	6.4% (2)
Ladyfish	11	27.3% (3)	72.7% (8)	0% (0)	0% (0)
Lemon Shark	1	0% (0)	100% (1)	0% (0)	0% (0)
Red Drum	666	70.4% (469)	25.5% (170)	1.1% (7)	3.0% (20)
Roughtail Stingray	1	0% (0)	100% (1)	0% (0)	0% (0)
Sand Seatrout	1	100% (1)	0% (0)	0% (0)	0% (0)
Scrawled Filefish	1	100% (1)	0% (0)	0% (0)	0% (0)
Sharksucker	2	100% (2)	0% (0)	0% (0)	0% (0)
Sheepshead	2	0% (0)	100% (2)	0% (0)	0% (0)
Smooth Butterfly Ray	9	88.9% (8)	11.1% (1)	0% (0)	0% (0)
Southern Stingray	9	44.4% (4)	55.6% (5)	0% (0)	0% (0)
Spanish Mackerel	9	44.5% (4)	22.2% (2)	0% (0)	33.3% (3)
Spinner Shark	23	13.0% (3)	47.8% (11	4.3% (1)	34.9 (8)
Spotted Eagle Ray	2	100% (2)	0% (0)	0% (0)	0% (0)
Spotted Seatrout	3	33.3% (1)	66.7% (2)	0% (0)	0% (0)
Striped Mullet	60	91.7% (55)	8.3% (5)	0% (0)	0% (0)

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Table 3. The total lengths (or wingspan for rays) and weights of measured fish in the rollover. Note that the lengths and weights of sharks and rays (except for Atlantic sharpnose shark, bonnethead shark, cownose ray and smooth butterfly ray) are an underestimate because the larger individuals could not be safely brought on board the sampling vessel for morphometrics.

Species	Mean TL (mm)	Min TL (mm)	Max TL (mm) (n)	Mean Kg	Min (kg)	Max (kg) (n)
Atlantic Sharpnose Shark	480	480	480 (1)	0.7	0.7	0.7 (1)
Atlantic Tarpon	1,720	1,720	1,720 (1)	38.0	38.0	38.0 (1)
Atlantic Tripletail	687 (673-701)	682	693 (3)	6.9 (5.3-8.6)	6.5	7.7 (3)
Black Drum	791 (784-797)	629	970 (307)	7.7 (7.5-7.9)	3.9	14.0 (306)
Blacktip Shark	1,367 (1,340-1,395)	572	1,815 (196)	19.4 (18.3-20.6)	1.3	45.0 (193)
Bluntnose Jack	268	268	268 (1)	0.2	0.2	0.2 (1)
Bluntnose Stingray	594 (569-618)	577	610 (4)	11.4 (10.2-12.6)	10.5	12.0 (4)
Bonnethead Shark	893	893	893 (1)	2.6	2.6	2.6 (1)
Bull Shark	1,459 (1,373-1,546)	722	2,170 (36)	27.1 (23.8-30.3)	3.0	46.5 (33)
Cownose Ray	800 (787-813)	501	1,015 (218)	9.1 (8.6-9.6)	1.9	20.0 (219)
Crevalle Jack	1,037 (1,027-1,046)	825	1,150 (175)	11.2 (10.9-11.5)	5.9	16.5 (173)
Devil Ray	1,289 (1,244-1,333)	1,285	1,292 (2)	33.5	33.5	33.5 (1)
Finetooth Shark	1,237 (1,159-1,316)	521	1,502 (43)	13.1 (11.0-15.2)	0.7	24.5 (43)
Gafftopsail Catfish	500 (487-512)	148	649 (133)	1.3 (1.2-1.4)	0.1	3.0 (134)
Hardhead Catfish	329 (307-352)	223	463 (28)	0.4 (0.3-0.6)	0.1	1.3 (28)
Ladyfish	560 (546-574)	534	580 (9)	1.0 (0.8-1.2)	0.7	1.3 (9)
Red Drum	944 (939-949)	759	1,067 (427)	9.8 (9.6-9.9)	5.5	15.5 (426)
Roughtail Stingray	606	606	606 (1)	10.5	10.5	10.5 (1)
Sand Seatrout	251	251	251 (1)	0.2	0.2	0.2 (1)
Scrawled Filefish	168	168	168 (1)	0.0	0.0	0.0 (1)
Sharksucker	232 (0-759)	190	273 (2)	0.0 (0.0-0.2)	0.0	0.1 (2)
Sheepshead	489 (482-495)	488	489 (2)	2.2 (2.2-2.2)	2.2	2.2 (2)
Smooth Butterfly Ray	710 (650-770)	646	804 (7)	4.5 (2.8-6.2)	2.7	7.0 (7)

Southern Stingray	782 (536-1,029)	215	1,079 (8)	24.4 (8.4-40.3)	0.3	48.0 (8)
Spanish Mackerel	390 (289-491)	289	568 (7)	0.5 (0.0-1.1)	0.1	1.6 (7)
Spinner Shark	1,735 (1,594-1,876)	835	2,110 (20)	35.5 (26.7-44.3)	3.0	50.0 (13)
Spotted Eagle Ray	1,443 (1,055-1,830)	1,412	1,473 (2)	–	–	–
Spotted Seatrout	281 (160-401)	271	290 (2)	0.4 (0.0-1.0)	0.3	0.4 (2)
Striped Mullet	378 (365-392)	291	450 (45)	0.5 (0.4-0.5)	0.2	0.9 (45)

Chute Bycatch

The chute bycatch was successfully sampled from 414 sets. A total of 117 (28.3%) sets had no bycatch in the release chute; 83.8% of these no bycatch sets occurred on a vessel with the smallest hose cage openings and the widest excluder grate spacing. In total, 41 species were identified in the chute bycatch, these are summarized in Table 4. For each species encountered, we show the total number of individuals encountered, the maximum number of individuals observed during a single set, the stratified average number of individuals per set, the total estimated catch for the 2024 fishing season by number and weight, and the percent obtained by dividing these total weights by the total landings for the fishery (Table 4). Overall, we estimate the total number of bycatch in the chute to be 139,470 by number and 729 thousand kg by weight.

The average number of bycatch observed in the chute across the 414 sets sampled was 10.6 individuals, with a maximum of 220 individuals in a single set (for all species grouped). The most abundant species in the chute bycatch were gafftopsail catfish, cownose ray, red drum, blacktip shark, and black drum. These five species comprised 80.7% of the estimated total catch by number and 80% of the estimated total catch by weight. Striped mullet, crevalle jack, sand seatrout, hardhead catfish, and finetooth sharks accounted for an additional 13.4% of the estimated total catch by number and 10.2% of the estimated total catch by weight. In contrast to the rollover bycatch, observers were able to safely handle all individuals encountered in the chute for morphometrics. However, total lengths or weights could not be obtained from many large-bodied individuals due to damage incurred while transiting through the pump. A small number of sharks (n=15) could not be identified to species by observers either because they fell through the excluder grate while being collected before a complete identification was made, or because identifying characteristics were lost as the fish passed through the pump. All individuals not identified to species level were from the genus *Carcharhinus sp.* and most likely consisted of either blacktip shark, spinner shark, or finetooth shark.

The condition of fish in the chute as assessed by the at-sea observers is shown in Table 5. Across the season, condition scores were assigned to a total of 4,932 individuals. For the most part, fish released in the chute bycatch showed a higher percentage of individuals deemed immediate mortalities, as well as individuals in poor condition. For example, 60.5% of red drum and 82.6% of crevalle jack were assessed as mortalities at the time of release, along with 81.9% of blacktip sharks. For smaller bodied species such as gafftopsail catfish and hardhead catfish, the proportion of immediate mortalities was considerably lower, consisting of 8.3% and 1.8% respectively. While we do report 100% mortalities for some species like alligator gar, sample sizes for these species were limited to 4 individuals.

The lengths and weights of fish measured by observers in the chute are shown in Table 6. In total, observers collected morphometric data on a total of 3,625 individuals from the chute bycatch. The mean total length of bycatch measured in the chute for all species was 676 mm and ranged from Atlantic croaker as small as 109 mm to a 1,623 mm long spinner shark (1.6 meters).

Table. 4. Chute bycatch in the 2024 Gulf menhaden fishery in terms of numbers and weights based on means stratified by month and plant. Total catch was calculated by summing the stratified means multiplied by the corresponding stratum-specific total sets made in Louisiana and adjacent federal waters. The percent obtained by dividing these total weights by the total weight of landings for the fishery is also displayed. Species lacking total weight estimates consist of species that were dismembered by the pump, and for which mean individual lengths and weights could not be determined.

Species	Total #Individuals Observed	Max Observed per Set	Average Number per Set	Total Catch (#)	Total Weight (kg)	%W Landings
Gafftopsail Catfish	1,622	130	3.79 (2.86-4.72)	49,780 (37,534-62,025)	64,432 (48,532-80,331)	0.01857%
Cownose Ray	1,041	166	2.21 (0.93-3.50)	29,094 (12,244-45,945)	196,909 (82,538-311,279)	0.05676%
Red Drum	681	128	1.36 (0.94-1.78)	17,841 (12,315-23,367)	150,769 (104,026-197,511)	0.04346%
Blacktip Shark	287	56	0.67 (0.32-1.02)	8,818 (4,226-13,409)	121,299 (57,790-184,807)	0.03496%
Black Drum	250	28	0.53 (0.32-0.74)	6,957 (4,247-9,667)	50,927 (31,036-70,818)	0.01468%
Striped Mullet	244	99	0.46 (0.08-0.84)	6,033 (997-11,069)	2,789 (458-5,120)	0.00080%
Crevalle Jack	167	18	0.29 (0.16-0.42)	3,816 (2,074-5,559)	40,757 (22,082-59,433)	0.01175%
Sand Seatrout	123	43	0.23 (0.05-0.41)	3,015 (686-5,344)	459 (99-820)	0.00013%
Hardhead Catfish	110	20	0.23 (0.11-0.35)	2,997 (1,458-4,537)	1,095 (522-1,668)	0.00032%
Finetooth Shark	114	7	0.22 (0.16-0.28)	2,888 (2,148-3,627)	29,174 (21,048-37,301)	0.00841%
Atlantic Croaker	114	111	0.20 (0.00-0.57)	2,619 (0-7,480)	80 (0-230)	0.00002%
Spot	52	50	0.09 (0.00-0.26)	1,178 (0-3,367)	87 (0-248)	0.00003%
Harvestfish	26	9	0.07 (0.00-0.13)	910 (56-1,764)	124 (7-242)	0.00004%
Spanish Mackerel	19	3	0.04 (0.02-0.07)	544 (204-884)	237 (57-417)	0.00007%
Carcharhinus sp.	15	9	0.04 (0.00-0.08)	500 (0-1,036)	6,472 (0-13,413)	0.00187%

Bull Shark	16	2	0.03 (0.01-0.05)	420 (179-661)	8,342 (3,331-13,353)	0.00240%
Spinner Shark	13	2	0.03 (0.01-0.05)	410 (155-666)	4,449 (1,151-7,747)	0.00128%
Spotted Seatrout	10	2	0.02 (0.01-0.04)	291 (93-490)	157 (25-288)	0.00005%
Bluefish	8	1	0.02 (0.01-0.03)	253 (66-440)	133 (28-238)	0.00004%
Southern Stingray	4	1	0.01 (0.00-0.02)	115 (0-231)	866 (0-1,848)	0.00025%
Alligator Gar	4	4	0.01 (0.00-0.02)	109 (0-319)	–	–
Smooth Butterfly Ray	4	1	0.01 (0.00-0.02)	108 (4-211)	167 (0-452)	0.00005%
Ladyfish	3	1	0.01 (0.00-0.02)	99 (0-219)	46 (0-109)	0.00001%
Sheepshead	2	1	0.01 (0.00-0.02)	85 (0-207)	191 (0-469)	0.00006%
Bluntnose Jack	3	1	0.01 (0.00-0.01)	83 (0-182)	14 (0-30)	0.00000%
Atlantic Tripletail	2	2	0.01 (0.00-0.02)	76 (0-223)	455 (0-1,360)	0.00013%
Atlantic Stingray	2	1	0.00 (0.00-0.01)	55 (0-127)	104 (0-243)	0.00003%
Florida Pompano	2	1	0.00 (0.00-0.01)	46 (0-120)	26 (0-70)	0.00001%
Bluntnose Stingray	2	1	0.00 (0.00-0.01)	46 (0-106)	524 (0-1,224)	0.00015%
Devil Ray	1	1	0.00 (0.00-0.01)	41 (0-119)	932	0.00027%
Atlantic Cutlassfish	1	1	0.00 (0.00-0.01)	37 (0-109)	2	0.00000%
Blacktip/Spinner Shark	2	2	0.00 (0.00-0.01)	35 (0-101)	475 (0-1,383)	0.00014%
King Mackerel	2	1	0.00 (0.00-0.01)	32 (0-76)	–	–
Spotted Eagle Ray	1	1	0.00 (0.00-0.01)	30 (0-89)	85	0.00002%
Southern Kingfish	1	1	0.00 (0.00-0.01)	27 (0-80)	4	0.00000%

Atlantic Sharpnose Shark	3	3	0.00 (0.00-0.01)	26 (0-74)	–	–
Star Drum	1	1	0.00 (0.00-0.01)	23 (0-67)	0	0.00000%
Blacknose Shark	1	1	0.00 (0.00-0.00)	17 (0-51)	209	0.00006%
Blue Crab	1	1	0.00 (0.00-0.00)	16 (0-46)	3	0.00000%
Total	**4,954**	**–**	**10.61 (2.40-18.82)**	**139,470 (115,816-163,124)**	**729,971 (539,772-825,818)**	**0.21041%**

Table 5. The number of fish assessed for condition by at-sea observers in the chute bycatch.

Species	# of individuals	%Excellent (n)	%Good/Fair (n)	%Poor (n)	%Mortality (n)
Alligator Gar	4	0% (0)	0% (0)	0% (0)	100% (4)
Atlantic Croaker	114	0.9% (1)	99.1% (113)	0% (0)	0% (0)
Atlantic Cutlassfish	1	100% (1)	0% (0)	0% (0)	0% (0)
Atlantic Sharpnose Shark	3	0% (0)	0% (0)	0% (0)	100% (3)
Atlantic Stingray	2	0% (0)	50% (1)	50% (1)	0% (0)
Atlantic Tripletail	2	100% (2)	0% (0)	0% (0)	0% (0)
Black Drum	250	2.8% (7)	29.2% (73)	24.4% (61)	43.6% (109)
Blacknose Shark	1	0% (0)	0% (0)	0% (0)	100% (1)
Blacktip Shark	287	0.3% (1)	7% (20)	10.8% (31)	81.9% (235)
Blacktip/Spinner Shark	2	0% (0)	0% (0)	0% (0)	100% (2)
Blue Crab	1	0% (0)	0% (0)	0% (0)	100% (1)
Bluefish	8	12.5% (1)	75% (6)	0% (0)	12.5% (1)
Bluntnose Jack	3	33.3% (1)	33.4% (1)	0% (0)	33.3% (1)
Bluntnose Stingray	2	0% (0)	50% (1)	50% (1)	0% (0)
Bull Shark	16	0% (0)	0% (0)	18.8% (3)	81.2% (13)
Carcharhinus sp.	15	0% (0)	0% (0)	0% (0)	100% (15)
Cownose Ray	1,019	0.5% (5)	22.9% (233)	47% (479)	29.6% (302)
Crevalle Jack	167	0.6% (1)	4.2% (7)	12.6% (21)	82.6% (138)
Devil Ray	1	0% (0)	0% (0)	0% (0)	100% (1)
Finetooth Shark	114	0.9% (1)	17.5% (20)	20.2% (23)	61.4% (70)
Florida Pompano	2	50% (1)	50% (1)	0% (0)	0% (0)
Gafftopsail Catfish	1,622	6.8% (111)	69.2% (1,122)	15.7% (255)	8.3% (134)
Hardhead Catfish	110	8.2% (9)	81.2% (97)	1.8% (2)	1.8% (2)
Harvestfish	26	3.8% (1)	80.8% (21)	0% (0)	15.4% (4)
King Mackerel	2	0% (0)	0% (0)	0% (0)	100% (2)
Ladyfish	3	0% (0)	100% (3)	0% (0)	0% (0)
Red Drum	681	2.1% (14)	14.5% (99)	22.9% (156)	60.5% (412)
Sand Seatrout	123	3.3% (4)	91.9% (113)	1.6% (2)	3.2% (4)
Sheepshead	2	100% (2)	0% (0)	0% (0)	0% (0)
Smooth Butterfly Ray	4	0% (0)	100% (4)	0% (0)	0% (0)
Southern Kingfish	1	0% (0)	100% (1)	0% (0)	0% (0)
Southern Stingray	4	25% (1)	25% (1)	25% (1)	25% (1)
Spanish Mackerel	19	5.3% (1)	31.6% (6)	26.3% (5)	36.8% (7)
Spinner Shark	13	0% (0)	0% (0)	15.4% (2)	84.6% (11)
Spot	52	36.5% (19)	63.5% (33)	0% (0)	0% (0)
Spotted Eagle Ray	1	0% (0)	100% (1)	0% (0)	0% (0)
Spotted Seatrout	10	0% (0)	80% (8)	0% (0)	20% (2)
Star Drum	1	0% (0)	100% (1)	0% (0)	0% (0)
Striped Mullet	244	1.6% (4)	95.9% (234)	0% (0)	2.5% (6)

Table 6. The total lengths (or wingspan for rays) and weights observed in measured fish in the chute bycatch.

Species	Mean TL (mm)	Min TL (mm)	Max TL (mm) (n)	Weighted Mean Kg	Min Kg	Max Kg (n)
Atlantic Croaker	144 (138-149)	109	195 (36)	0.0 (0.0-0.0)	0.0	0.1 (36)
Atlantic Cutlassfish	472	472	472 (1)	0.1	0.1	0.1 (1)
Atlantic Stingray	352 (205-498)	340	363 (2)	1.9 (0.0-4.4)	1.7	2.1 (2)
Atlantic Tripletail	568 (34-1,102)	526	610 (2)	6.0 (0.0-23.8)	4.6	7.4 (2)
Black Drum	791 (783-799)	585	981 (228)	7.3 (7.1-7.5)	3.2	14.0 (231)
Blacknose Shark	1,177	1,177	1,177 (1)	12.0	12.0	12.0 (1)
Blacktip Shark	1,226 (1,196-1,256)	635	1,590 (257)	13.8 (13.0-14.5)	1.7	28.0 (266)
Blue Crab	159	159	159 (1)	0.2	0.2	0.2 (1)
Bluefish	364 (318-410)	253	412 (8)	0.5 (0.4-0.7)	0.2	0.9 (8)
Bluntnose Jack	274 (226-321)	253	291 (3)	0.2 (0.1-0.2)	0.1	0.2 (3)
Bluntnose Stingray	620 (493-747)	610	630 (2)	11.5 (0.0-24.2)	10.5	12.5 (2)
Bull Shark	1,316 (1,233-1,400)	1025	1,602 (16)	19.9 (16.1-23.7)	9.0	37.0 (16)
Cownose Ray	727 (715-739)	308	1,005 (561)	6.8 (6.5-7.1)	0.5	16.0 (565)
Crevalle Jack	1,002 (978-1,025)	201	1,127 (101)	10.7 (10.3-11.1)	0.2	16.0 (117)
Finetooth Shark	1,142 (1,086-1,197)	480	1,505 (109)	10.1 (9.0-11.2)	0.6	20.5 (109)
Florida Pompano	355 (0-1,022)	302	407 (2)	0.6 (0.0-2.7)	0.4	0.7 (2)
Gafftopsail Catfish	505 (501-508)	251	696 (1,253)	1.3 (1.3-1.3)	0.1	3.3 (1,261)
Hardhead Catfish	322 (314-331)	199	440 (109)	0.4 (0.3-0.4)	0.1	1.1 (109)
Harvestfish	199 (190-208)	137	233 (26)	0.1 (0.1-0.2)	0.0	0.2 (26)
Ladyfish	454 (264-645)	370	520 (3)	0.5 (0.0-1.1)	0.2	0.7 (3)
Red Drum	905 (900-910)	730	1,094 (537)	8.5 (8.3-8.6)	4.5	14.0 (552)
Sand Seatrout	246 (238-253)	185	359 (110)	0.2 (0.1-0.2)	0.1	0.6 (110)
Sheepshead	484 (210-757)	462	505 (2)	2.3 (0.0-5.4)	2.0	2.5 (2)
Smooth Butterfly Ray	452 (124-779)	325	759 (4)	1.6 (0.0-5.1)	0.4	4.9 (4)
Southern Kingfish	264	264	264 (1)	0.2	0.2	0.2 (1)
Southern Stingray	528 (355-701)	412	638 (4)	7.5 (0.9-14.1)	4.0	12.0 (4)
Spanish Mackerel	404 (361-447)	250	633 (19)	0.4 (0.2-0.6)	0.1	2.0 (19)
Spinner Shark	1,177 (994-1,359)	784	1,623 (9)	10.8 (5.7-16.0)	3.4	25.5 (9)
Spot	173 (168-178)	137	198 (33)	0.1 (0.0-0.1)	0.0	0.1 (33)
Spotted Eagle Ray	594	594	594 (1)	2.8	2.8	2.8 (1)
Spotted Seatrout	348 (280-415)	253	465 (10)	0.5 (0.2-0.8)	0.1	1.2 (10)
Star Drum	114	114	114 (1)	0.0	0.0	0.0 (1)
Striped Mullet	378 (372-383)	304	486 (173)	0.5 (0.4-0.5)	0.2	0.8 (173)

Released Bycatch

This section combines bycatch from the rollover and chute to produce estimates for the released bycatch components as a whole. In doing so, more direct comparison to historical bycatch studies conducted in the GoM is possible. The average number of bycatch observed in the released bycatch component was 21.6 individuals. Overall, the most abundant species in the released bycatch were gafftopsail catfish, cownose ray, red drum, black drum, blacktip shark and crevalle jack. These six species comprised 78.2% of the estimated total catch by number and 73.5% of the estimated total catch by weight (Table 7). As observers were unable to obtain morphometrics for the largest sharks and rays encountered in the rollover bycatch, we note that the total weight estimates for the released bycatch component are biased low. Included in our estimates for the released bycatch are spotted eagle rays (*Setobatus narinari*) and devil rays (*Mobula hypostoma*). In total, 4 spotted eagle rays and 9 devil rays were observed in the rollover bycatch and were released from the net in good or excellent condition. In the chute bycatch, one spotted eagle ray was released in good condition and one devil ray was a release mortality.

Table. 7. Released bycatch (e.g. rollover + chute) in the 2024 Gulf menhaden fishery in terms of numbers and weights based on means stratified by month and plant. The percent of sets where each species was present in the released bycatch is shown (% occurrence). Total catch was calculated by summing the stratified means multiplied by the corresponding stratum-specific total sets made in Louisiana and adjacent federal waters. The percent obtained by dividing these total weights by the total weight of landings for the fishery is also displayed. Species lacking total weight estimates consist of species for which individual lengths and weights could not be determined.

Species	% Occurrence	Stratified Mean per Set	Total Catch	Total Weight kg	%W Landings
Gafftopsail Catfish	54.70%	4.84 (3.89-5.79)	63,589 (51,068-76,110)	82,639 (66,329-98,948)	0.02382%
Cownose Ray	43.86%	4.26 (2.89-5.62)	55,941 (37,963-73,920)	441,058 (312,598-569,518)	0.12713%
Red Drum	45.30%	3.39 (2.70-4.08)	44,593 (35,537-53,648)	411,818 (327,528-496,107)	0.11871%
Black Drum	32.29%	1.95 (1.31-2.59)	25,637 (17,252-34,023)	195,595 (130,895-260,295)	0.05638%
Blacktip Shark	32.77%	1.40 (1.01-1.79)	18,385 (13,247-23,524)	307,330 (228,854-385,806)	0.08859%
Crevalle Jack	29.64%	1.09 (0.76-1.42)	14,341 (10,046-18,636)	158,696 (110,808-206,584)	0.04574%
Striped Mullet	5.78%	1.00 (0.39-1.61)	13,145 (5,063-21,227)	6,021 (2,307-9,735)	0.00174%
Blacktip/Spinner Shark	23.13%	0.66 (0.47-0.85)	8,695 (6,232-11,159)	177,615 (126,052-229,177)	0.05120%
Carcharhinus sp.	19.28%	0.65 (0.44-0.86)	8,504 (5,750-11,257)	167,377 (111,902-222,852)	0.04825%

Hardhead Catfish	16.63%	0.50 (0.33-0.68)	6,627 (4,363-8,890)	2,726 (1,706-3,746)	0.00079%
Finetooth Shark	21.45%	0.42 (0.33-0.52)	5,579 (4,364-6,795)	64,398 (48,397-80,398)	0.01856%
Bull Shark	18.07%	0.25 (0.18-0.32)	3,253 (2,353-4,152)	84,999 (59,429-110,570)	0.02450%
Sand Seatrout	6.75%	0.23 (0.06-0.41)	3,066 (735-5,397)	470 (110-830)	0.00014%
Atlantic Croaker	0.72%	0.20 (0.00-0.57)	2,619 (0-7,480)	80 (0-230)	0.00002%
Spot	0.72%	0.09 (0.00-0.26)	1,178 (0-3,367)	87 (0-248)	0.00003%
Harvestfish	2.41%	0.08 (0.01-0.14)	988 (129-1,848)	124 (7-242)	0.00004%
Spinner Shark	5.54%	0.07 (0.05-0.10)	983 (596-1,370)	24,752 (13,017-36,486)	0.00713%
Spanish Mackerel	5.30%	0.06 (0.03-0.09)	809 (426-1,193)	377 (144-610)	0.00011%
Ladyfish	2.17%	0.05 (0.00-0.10)	631 (0-1,325)	572 (0-1,254)	0.00016%
Southern Stingray	4.10%	0.05 (0.02-0.07)	631 (325-937)	13,418 (3,678-23,158)	0.00387%
Smooth Butterfly Ray	2.89%	0.04 (0.02-0.07)	555 (222-888)	2,174 (606-3,741)	0.00063%
Dasyatidae	3.13%	0.04 (0.02-0.06)	531 (232-829)	10,241 (2,860-17,622)	0.00295%
Spotted Seatrout	2.65%	0.03 (0.01-0.05)	405 (170-640)	196 (57-335)	0.00006%
Devil Ray	1.20%	0.03 (0.00-0.06)	369 (12-727)	11,952	0.00345%
Bluefish	1.93%	0.02 (0.01-0.03)	253 (66-440)	133 (28-238)	0.00004%
Sheepshead	0.48%	0.02 (0.00-0.05)	251 (0-597)	557 (0-1,320)	0.00016%
Alligator Gar	0.48%	0.01 (0.00-0.03)	185 (0-441)	–	–
Atlantic Tripletail	0.96%	0.01 (0.00-0.03)	171 (0-353)	1,113 (0-2,287)	0.00032%
Spotted Eagle Ray	1.45%	0.01 (0.00-0.02)	170 (15-325)	85	0.00002%
Bluntnose Stingray	1.45%	0.01 (0.00-0.02)	152 (34-270)	1,734 (379-3,089)	0.00050%
Sharksucker	0.96%	0.01 (0.00-0.02)	131 (0-278)	6 (0-14)	0.00000%
Atlantic Spadefish	0.72%	0.01 (0.00-0.02)	96 (0-203)	–	–
Bluntnose Jack	0.96%	0.01 (0.00-0.01)	91 (0-192)	15 (0-31)	0.00000%
Atlantic Sharpnose Shark	0.48%	0.01 (0.00-0.01)	79 (0-193)	37	0.00001%
Atlantic Tarpon	0.24%	0.00 (0.00-0.01)	61 (0-178)	2,310	0.00067%
Bonnethead Shark	0.48%	0.00 (0.00-0.01)	59 (0-139)	154	0.00004%
Atlantic Stingray	0.48%	0.00 (0.00-0.01)	55 (0-127)	104 (0-243)	0.00003%
Florida Pompano	0.48%	0.00 (0.00-0.01)	46 (0-120)	26 (0-70)	0.00001%
Blue Crab	0.48%	0.00 (0.00-0.01)	46 (0-110)	3	0.00000%
Atlantic Cutlassfish	0.24%	0.00 (0.00-0.01)	37 (0-109)	2	0.00000%
Lemon Shark	0.24%	0.00 (0.00-0.01)	37 (0-108)	–	–
King Mackerel	0.48%	0.00 (0.00-0.01)	32 (0-76)	–	–
Roughtail Stingray	0.24%	0.00 (0.00-0.01)	30 (0-87)	312	0.00009%

Southern Kingfish	0.24%	0.00 (0.00-0.01)	27 (0-80)	4	0.00000%
Star Drum	0.24%	0.00 (0.00-0.01)	23 (0-67)	0	0.00000%
Blacknose Shark	0.24%	0.00 (0.00-0.00)	17 (0-51)	209	0.00006%
Scrawled Filefish	0.24%	0.00 (0.00-0.00)	8 (0-24)	0	0.00000%
Shrimp	0.24%	0.00 (0.00-0.00)	8 (0-24)	–	–
Total	**–**	**21.65 (19.50-23.80)**	**284,565 (256,280-312,850)**	**2,171,519 (1,963,035-2,380,002**	**0.62593%**

Length Frequency Comparison

The length frequency of common species encountered in the rollover and chute are displayed in Figure 12. Visual inspection of the density plots indicated that black drum, red drum, crevalle jack, and gafftopsail catfish appear to show considerable overlap in size distribution between the rollover and chute bycatch. Cownose ray, and the shark species have size distributions large enough to display smaller size classes present in the chute than the rollover bycatch. Only blacktip shark, bull shark, and spinner shark appear to reach sizes large enough (> 1,600 mm) to reliably prevent their inclusion in the chute bycatch.

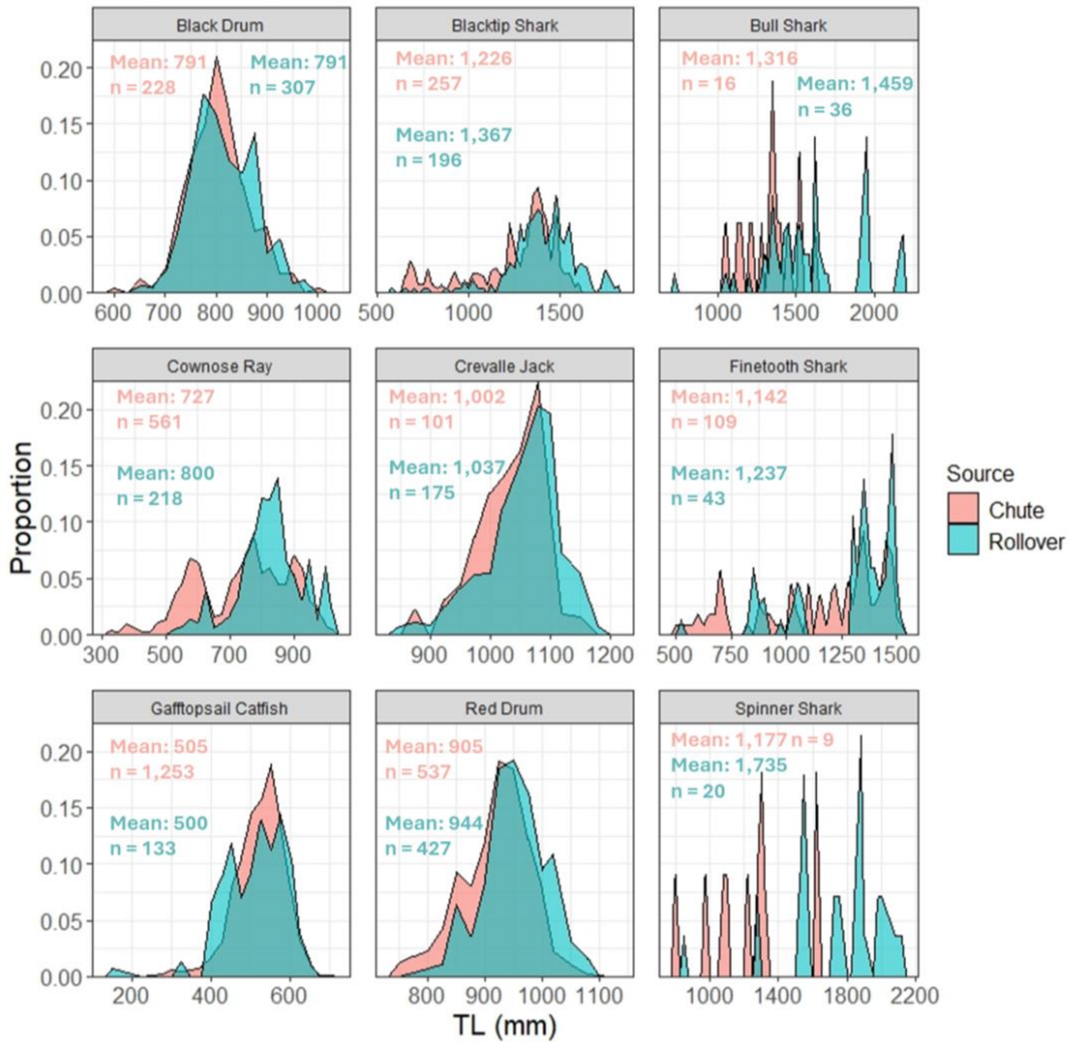

Figure 12. Density plots showing the length frequency of common species observed in the rollover and release chute bycatch. The total lengths (or wingspan for rays) are displayed in 25 mm bins. The length frequency has been weighted to account for individuals that were not measured within individual sets.

Retained Bycatch

The retained bycatch was successfully sampled from 415 sets. Figure 13a illustrates the distribution of sampling effort across the segments subsampled during the pumping operation. Sampling effort was relatively balanced across segments within each plant, with each segment containing at least 22% of the sampled sets. Figure 13b displays the segment composition of individual species captured across all sampled retained sets. Despite variability in species composition and relative abundance, the segment distribution remained consistent across most sampled taxa, suggesting limited segment-driven bias in catch composition. The overall percent similarity index of 83% supports strong consistency in species representation among the three segments, indicating that species composition was largely homogenous regardless of sampling segment.

Bycatch was observed in the retained sampling cage in all sets sampled. In total, 62 species were identified in the retained bycatch. The average number of bycatch observed in our retained subsample was 59.8 individuals, the minimum number of bycatch per set was 1, and the maximum number observed was 1,678 during a set with a high abundance of Atlantic croaker. For each species encountered in the retained bycatch, we show the maximum number of individuals observed in the subsample obtained from a single set, the percent of subsamples where the species was observed, the average total number of individuals per set, the total estimated catch for the 2024 fishing season by number and weight, and the percent (by weight) of total landings for the fishery (Table 8). Overall, we estimate the total amount of retained bycatch to be 145.5 million by number and 10.3 million kg by weight. By number, the most abundant species in the retained bycatch were Atlantic croaker, sand seatrout, spot, and white shrimp. These four species comprised 84.3% of the estimated total catch by number and 51% of the estimated total catch by weight. Gafftopsail catfish accounted for 16.8% of the total retained catch by weight.

The lengths and weights of measured individuals within the retained bycatch is shown in Table 9. Figure 14 shows the total lengths distributions for 16 teleost species captured in the retained subsampling. The most abundant species, including Atlantic croaker, spot, and sand seatrout each displayed relatively narrow length distributions with peaks around 100-200 mm. Species such as Atlantic cutlassfish (mean = 489) and Spanish mackerel (mean = 472) were less abundant but exhibited broader length distributions indicating wider size classes within the retained catch. Several species, such as threadfin shad, gizzard shad, and scaled sardine, exhibited unimodal size distributions, suggesting single cohort dominance or size selective capture. The smallest size ranges were observed in banded drum and star drum, with spotted seatrout demonstrating more variable length distributions.

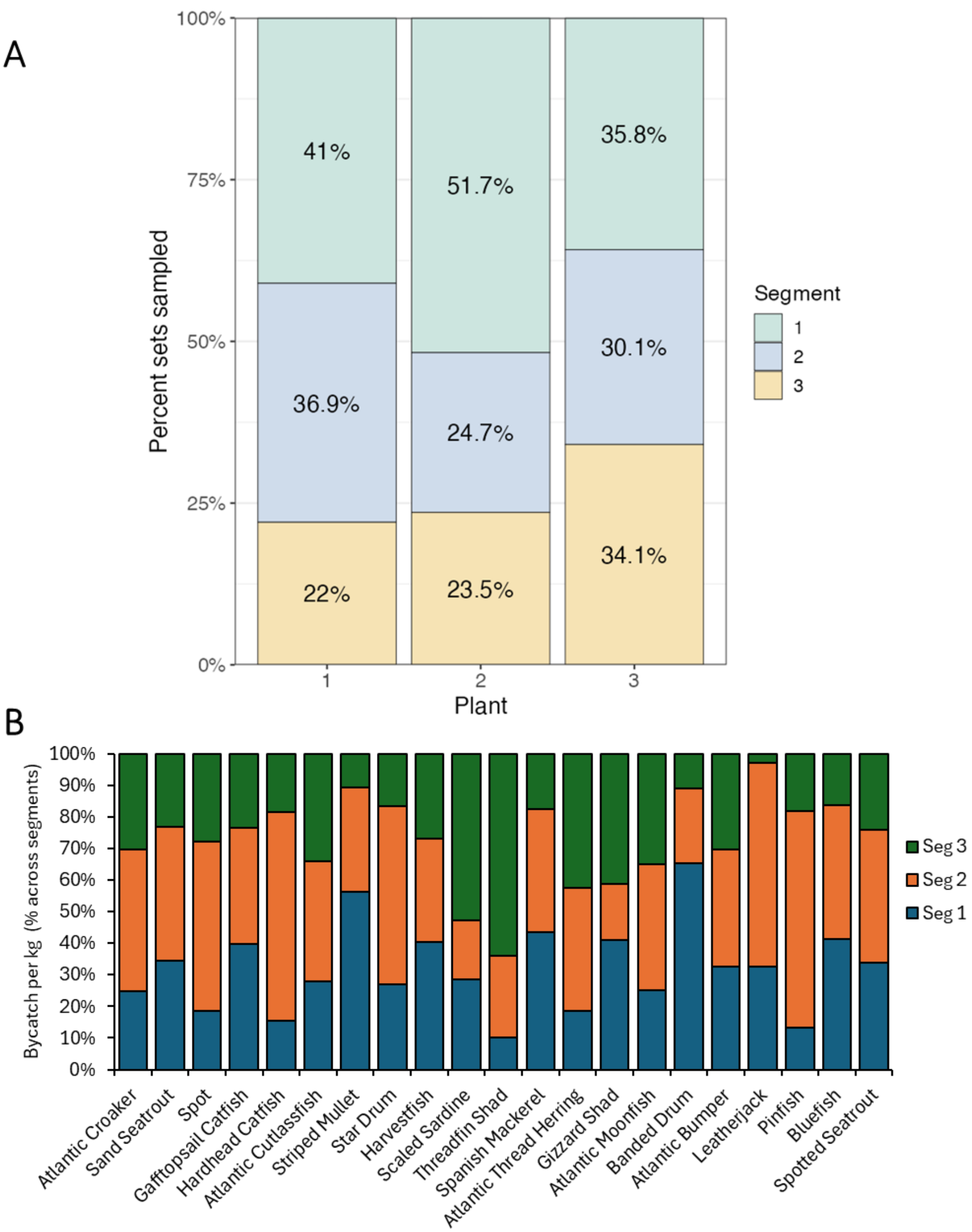

Figure 13. A) Proportion of retained sets sampled within each segment of the pumping operation. Bars represent each of the three plants sampled. Numbers within each bar represent the sampled number of sets per segment. B) Bycatch per kg for each species and segment expressed as a percentage across segments. Segments were 83% similar in their species compositions based on the percent similarity index.

Table. 8. Retained bycatch subsample extrapolation by number and weight based on negative binomial means stratified by month and plant. The percent of sets where each species was present in the retained bycatch subsample is shown (% occurrence), as well as the percent obtained by dividing species total weights by the total weight of landings for the fishery.

Species	Max Number Per Subsample	% Occurrence	Mean Observed Per Set	Total Catch by Number	Total Weight Kg	%W Landings
Atlantic Croaker	1,200	70.84%	6,376 (4,496-8,929)	80,592,690 (57,477,689-110,644,805)	2,484,620 (1,557,623-3,411,616)	0.71618%
Sand Seatrout	206	69.40%	1,741 (1,411-2,152)	24,750,238 (19,411,626-31,524,147)	1,949,187 (1,414,735-2,483,639)	0.56185%
Spot	243	50.12%	951 (687-1,291)	11,685,469 (8,549,694-15,609,587)	680,720 (451,795-909,646)	0.19622%
White Shrimp	83	42.41%	519 (388-665)	5,699,563 (4,112,730-7,449,761)	156,794 (106,021-207,567)	0.04520%
Hardhead Catfish	239	23.13%	276 (108-742)	3,802,183 (1,527,034-9,808,642)	690,749 (0-1,783,403)	0.19911%
Gafftopsail Catfish	50	43.37%	227 (187-275)	2,985,451 (2,393,299-3,702,681)	1,737,206 (1,298,779-2,175,633)	0.50074%
Atlantic Cutlassfish	25	31.57%	166 (119-221)	2,204,329 (1,484,234-3,067,746)	158,401 (95,946-220,856)	0.04566%
Harvestfish	39	26.51%	150 (99-240)	1,903,687 (1,224,533-3,021,111)	175,066 (71,779-278,353)	0.05046%
Striped Mullet	147	6.27%	146 (43-323)	1,843,220 (491,670-4,348,934)	727,743 (0-1,717,781)	0.20977%
Star Drum	68	23.13%	120 (83-178)	1,701,593 (1,115,808-2,581,706)	37,292 (17,898-56,685)	0.01075%
Cnidarian sp.	20	9.88%	69 (39-108)	1,144,930 (584,985-1,993,600)	35,244 (6,241-64,247)	0.01016%
Banded Drum	29	6.02%	49 (21-92)	846,523 (315,178-1,660,221)	16,521 (557-32,486)	0.00476%
Scaled Sardine	27	11.81%	85 (57-116)	656,656 (452,503-876,000)	28,793 (19,083-3,8503)	0.00830%

Spanish Mackerel	20	18.80%	45 (34-58)	573,426 (405,551-778,404)	175,588 (105,580-245,596)	0.05061%
Atlantic Moonfish	8	9.40%	30 (19-44)	476,377 (268,089-737,721)	8,217 (3,347-13,088)	0.00237%
Atlantic Thread Herring	28	7.47%	27 (12-55)	405,097 (169,277-814,607)	47,203 (0-95,086)	0.01361%
Brown Shrimp	14	10.36%	36 (23-53)	385,818 (248,281-559,178)	3,820 (1,938-5,701)	0.00110%
Threadfin Shad	57	6.75%	25 (12-46)	383,697 (173,549-718,925)	12,889 (1,551-24,227)	0.00372%
Pinfish	16	3.37%	26 (9-53)	325,757 (121,436-648,699)	7,568 (40-15,095)	0.00218%
Atlantic Bumper	9	9.88%	23 (14-32)	293,713 (180,998-418,217)	15,120 (8,494-21,746)	0.00436%
Gizzard Shad	25	4.82%	38 (15-73)	290,789 (120,715-540,899)	13,991 (1,847-26,135)	0.00403%
Brief Squid	4	5.30%	15 (7-27)	262,668 (76,767-577,363)	5,706 (0-12,917)	0.00164%
Lookdown	5	1.69%	9 (2-25)	261,134 (35,074-954,089)	3,290 (0-12,059)	0.00095%
Leatherjack	7	7.23%	18 (11-27)	244,629 (125,689-395,464)	13,754 (5,084-22,424)	0.00396%
Spotted Seatrout	3	5.78%	15 (9-24)	240,368 (119,953-413,098)	45,901 (11,461-80,341)	0.01323%
Finescale Menhaden	11	0.48%	4 (0-22)	193,973 (0-1,011,059)	52,021 (0-271,190)	0.01499%
Bluefish	4	6.27%	14 (8-20)	183,235 (91,830-318,433)	31,001 (7,372-54,630)	0.00894%
Sea Nettles	6	0.24%	4 (0-24)	177,367 (0-1,073,411)	2,359	0.00068%
Cownose Ray	22	0.96%	13 (0-58)	166,252 (991-725,244)	388,697 (0-1,696,469)	0.11204%
Southern Kingfish	3	4.82%	10 (5-15)	102,610 (49,310-169,325)	9,093 (2,563-15,624)	0.00262%
Gulf Butterfish	8	2.89%	10 (3-24)	99,830 (39,520-202,954)	8,671 (0-17,799)	0.00250%
Atlantic Spadefish	2	1.93%	4 (1-8)	78,255 (15,828-165,819)	3,467 (0-7,741)	0.00100%
Bluntnose Jack	2	2.17%	5 (2-9)	70,022 (17,156-134,772)	6,491 (140-12,842)	0.00187%
Silver Perch	5	2.41%	6 (2-12)	68,790 (26,506-129,087)	2,509 (288-4,729)	0.00072%

Crevalle Jack	1	2.89%	5 (2-9)	68,249 (29,649-113,099)	6,597 (2,138-11,057)	0.00190%
Black Drum	2	2.17%	4 (1-8)	48,178 (14,502-103,110)	358,661 (0-768,967)	0.10338%
Bay Anchovy	2	1.45%	3 (1-7)	36,039 (8,264-78,928)	138 (0-355)	0.00004%
Blue Crab	1	2.41%	4 (2-7)	32,484 (12,038-58,078)	1,458 (0-3,240)	0.00042%
Blacktip Shark	1	1.69%	3 (1-5)	27,550 (7,095-49,766)	113,468 (0-232,358)	0.03271%
False Silverstripe Halfbeak	1	1.20%	2 (0-4)	24,518 (5,056-51,583)	863 (0-1,839)	0.00025%
Bay Whiff	1	1.45%	2 (1-4)	23,908 (5,056-49,589)	319 (0-695)	0.00009%
Gulf Kingfish	1	0.24%	1 (0-3)	19,896 (0-60,845)	776	0.00022%
Finetooth Shark	1	0.48%	1 (0-2)	16,296 (0-42,549)	27,867 (0-91,005)	0.00803%
Florida Pompano	1	0.96%	1 (0-2)	12,622 (966-34,062)	3,026 (0-9,046)	0.00087%
Sharksucker	1	0.48%	1 (0-2)	11,905 (0-33,608)	333 (0-1,023)	0.00010%
Bigeye Searobin	1	0.72%	1 (0-2)	10,849 (0-26,115)	87 (0-216)	0.00003%
Fringed Flounder	1	0.96%	1 (0-2)	9,307 (1,585-21,220)	130 (0-300)	0.00004%
Striped Anchovy	3	0.24%	1 (0-3)	8,740 (0-41,019)	26 (0-124)	0.00001%
Skipjack Herring	1	0.48%	1 (0-2)	8,367 (0-23,807)	590 (0-1,679)	0.00017%
Red Drum	1	1.45%	1 (0-3)	8,354 (0-22,323)	69,754 (0-186,535)	0.02011%
Hemiramphus balao	1	0.24%	1 (0-2)	7,329 (0-21,705)	183	0.00005%
Ladyfish	1	0.48%	1 (0-2)	6,961 (0-20,224)	4,246 (0-12,338)	0.00122%
Northern Kingfish	3	0.48%	0 (0-1)	6,297 (0-20,602)	420 (0-1,390)	0.00012%
White Mullet	1	0.24%	0 (0-1)	5,162 (0-15,168)	929	0.00027%
Blackcheek Tonguefish	1	0.24%	0 (0-1)	5,157 (0-15,168)	62	0.00002%
Calico Box Crab	1	0.24%	0 (0-1)	4,940 (0-15,168)	25	0.00001%
Hogchoker	1	0.72%	1 (0-2)	4,905 (0-12,846)	90 (0-239)	0.00003%
Blue Runner	1	0.24%	1 (0-2)	4,222 (0-16,474)	629	0.00018%
Pigfish	1	0.24%	0 (0-1)	2,933 (0-8,950)	226	0.00007%
Lesser Blue Crab	1	0.24%	0 (0-0)	1,642 (0-4,754)	7	0.00000%
Squilla empusa mantis	1	0.24%	0 (0-0)	1,593 (0-4,754)	8	0.00000%
Southern Flounder	1	0.24%	0 (0-1)	949 (0-2,973)	171	0.00005%
Total	–		**11,291 (0-31,911,593)**	**145,519,692 (145,519,688-145,519,696)**	**10,326,782 (7,970,802-12,682,763)**	**2.97666%**

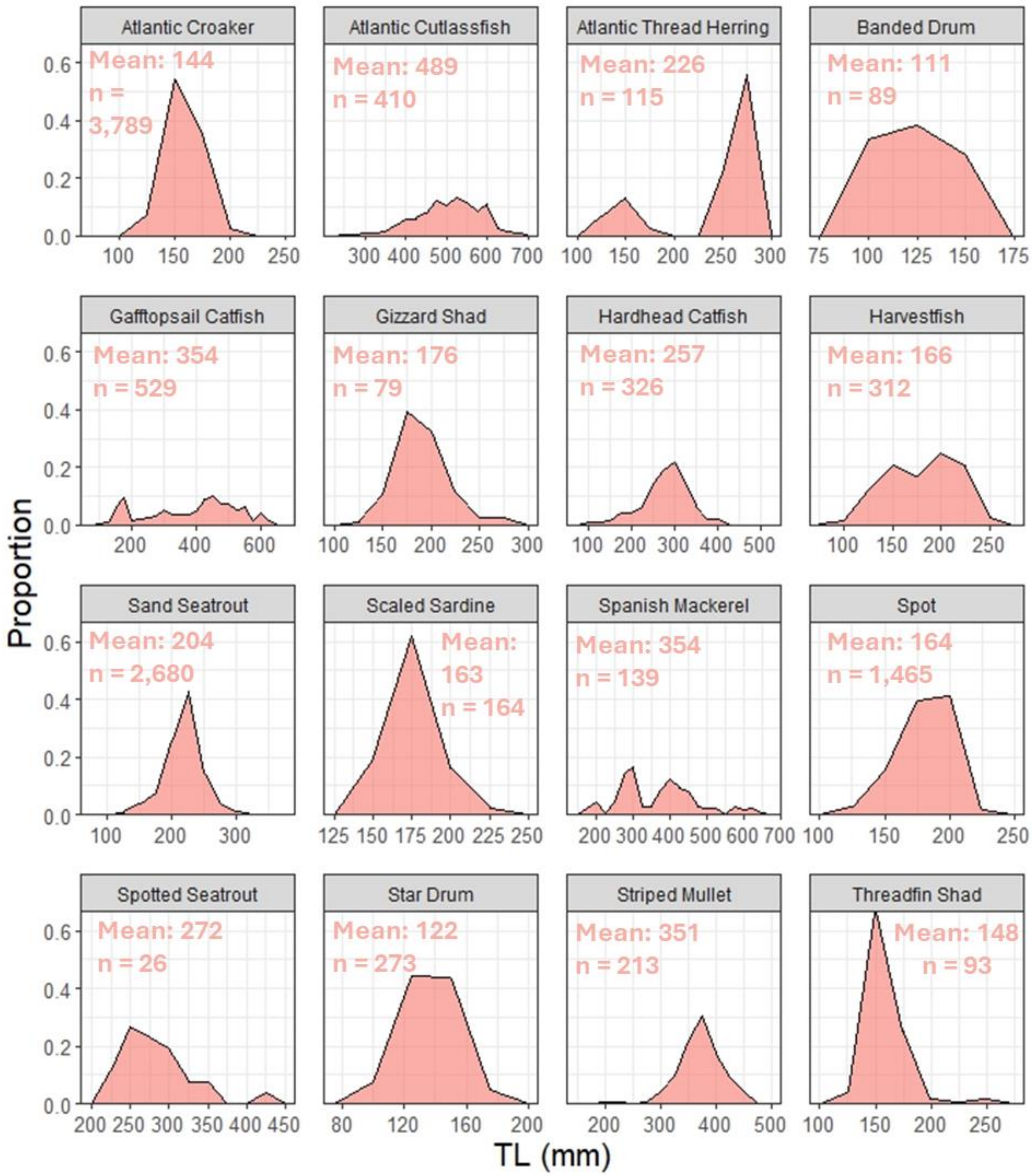

Figure 14. Length frequency distribution of total length (mm) of 16 species observed in the retained bycatch. Only the first 30 individuals encountered within a retained sample were measured, the length frequency has been weighted for individuals not measured within each set.

Table 9. The total lengths (or wingspan for rays) and weights observed in measured fish in the retained bycatch.

Species	Mean TL	Min TL	Max TL (n)	Mean Kg	Min Kg	Max Kg (n)
Atlantic Bumper	178 (168-187)	73	236 (69)	0.051 (0.046-0.057)	0.005	0.100 (69)
Atlantic Croaker	144 (143-144)	90	215 (3,789)	0.031 (0.03-0.031)	0.004	0.113 (3,803)
Atlantic Cutlassfish	489 (481-497)	231	687 (410)	0.072 (0.069-0.075)	0.007	0.192 (412)
Atlantic Moonfish	103 (97-109)	66	225 (76)	0.017 (0.013-0.021)	0.003	0.126 (76)
Atlantic Spadefish	97 (76-119)	55	140 (10)	0.044 (0.018-0.071)	0.008	0.104 (10)
Atlantic Thread Herring	226 (217-236)	104	271 (115)	0.117 (0.107-0.126)	0.011	0.182 (115)
Banded Drum	111 (108-115)	84	146 (89)	0.02 (0.018-0.021)	0.005	0.043 (89)
Bay Anchovy	72 (45-99)	51	123 (6)	0.004 (-0.001-0.009)	0.001	0.013 (6)
Bay Whiff	113 (91-135)	96	140 (5)	0.013 (0.005-0.022)	0.007	0.029 (6)
Bigeye Searobin	86 (68-103)	78	92 (3)	0.008 (-0.001-0.017)	0.006	0.012 (3)
Black Drum	800 (752-847)	697	898 (9)	7.444 (6.626-8.263)	5.500	8.800 (9)
Blackcheek Tonguefish	106	106	106 (1)	0.012	0.012	0.012 (1)
Blacktip Shark	805 (581-1028)	549	1152 (7)	4.119 (0.679-7.559)	0.830	10.500 (7)
Blue Crab	110 (45-175)	52	145 (4)	0.045 (-0.004-0.094)	0.002	0.183 (9)
Blue Runner	242	242	242 (1)	0.149	0.149	0.149 (1)
Bluefish	264 (250-278)	198	373 (32)	0.169 (0.136-0.203)	0.075	0.470 (32)
Bluntnose Jack	214 (181-247)	146	260 (10)	0.093 (0.059-0.127)	0.031	0.167 (10)
Brief Squid	–	–	–	0.022 (0.012-0.031)	0.001	0.071 (18)
Brown Shrimp	–	–	–	0.01 (0.008-0.012)	0.001	0.023 (20)
Calico Box Crab	–	–	–	0.005	0.005	0.005 (1)
Cnidarian sp.	–	–	–	0.031 (0.019-0.042)	0.006	0.112 (23)
Cownose Ray	533 (511-556)	360	650 (25)	2.338 (2.04-2.636)	0.650	4.600 (25)
Crevalle Jack	195 (184-206)	154	213 (11)	0.097 (0.079-0.114)	0.049	0.129 (12)

False Silverstripe Halfbeak	240 (204-276)	197	269 (5)	0.035 (0.023-0.048)	0.019	0.046 (5)
Finescale Menhaden	294 (286-303)	269	321 (16)	0.268 (0.246-0.291)	0.206	0.352 (16)
Finetooth Shark	629 (-2021-3278)	420	837 (2)	1.71 (-15.952-19.372)	0.320	3.100 (2)
Florida Pompano	271 (132-410)	206	400 (4)	0.24 (-0.163-0.643)	0.062	0.615 (4)
Fringed Flounder	103 (80-127)	82	116 (4)	0.014 (0.009-0.019)	0.010	0.017 (4)
Gafftopsail Catfish	354 (342-366)	96	629 (529)	0.582 (0.537-0.627)	0.004	2.300 (531)
Gizzard Shad	176 (171-182)	111	250 (79)	0.048 (0.042-0.054)	0.010	0.142 (79)
Gulf Butterfish	181 (159-202)	60	220 (21)	0.087 (0.068-0.106)	0.003	0.128 (21)
Gulf Kingfish	167	167	167 (1)	0.039	0.039	0.039 (1)
Hardhead Catfish	257 (250-264)	87	488 (326)	0.182 (0.167-0.197)	0.002	0.800 (326)
Harvestfish	166 (162-170)	65	236 (312)	0.092 (0.086-0.097)	0.006	0.234 (312)
Hemiramphus balao	223	223	223 (1)	0.025	0.025	0.025 (1)
Hogchoker	92 (63-121)	79	102 (3)	0.018 (0.004-0.032)	0.012	0.023 (3)
Ladyfish	507 (424-589)	500	513 (2)	0.61 (0.483-0.737)	0.600	0.620 (2)
Leatherjack	204 (196-211)	167	272 (45)	0.056 (0.049-0.064)	0.027	0.148 (45)
Lesser Blue Crab	–	–	–	0.004	0.004	0.004 (1)
Lookdown	97 (86-108)	57	124 (15)	0.013 (0.009-0.016)	0.002	0.022 (15)
Northern Kingfish	162 (126-198)	140	193 (4)	0.067 (0.023-0.11)	0.030	0.096 (4)
Pigfish	194	194	194 (1)	0.077	0.077	0.077 (1)
Pinfish	116 (112-119)	75	151 (39)	0.023 (0.021-0.025)	0.012	0.048 (39)
Red Drum	916 (287-1544)	866	965 (2)	8.35 (3.903-12.797)	8.000	8.700 (2)
Sand Seatrout	204 (202-205)	75	340 (2,680)	0.079 (0.077-0.08)	0.005	0.369 (2,682)
Scaled Sardine	163 (160-165)	127	206 (164)	0.044 (0.042-0.046)	0.024	0.085 (164)

Sharksucker	195 (-313-703)	155	235 (2)	0.028 (-0.15-0.206)	0.014	0.042 (2)
Silver Perch	147 (140-155)	111	171 (15)	0.036 (0.032-0.041)	0.016	0.049 (15)
Skipjack Herring	218 (173-262)	214	221 (2)	0.071 (0.039-0.102)	0.068	0.073 (2)
Southern Flounder	255	255	255 (1)	0.180	0.180	0.180 (1)
Southern Kingfish	196 (176-215)	116	282 (21)	0.089 (0.06-0.117)	0.014	0.253 (21)
Spanish Mackerel	354 (336-371)	167	625 (139)	0.306 (0.252-0.361)	0.029	1.800 (139)
Spot	164 (163-165)	104	212 (1,465)	0.058 (0.057-0.059)	0.007	0.117 (1,467)
Spotted Seatrout	272 (254-290)	204	402 (26)	0.191 (0.148-0.234)	0.073	0.550 (26)
Squilla empusa mantis	–	–	–	0.005	0.005	0.005 (1)
Star Drum	122 (120-124)	76	171 (273)	0.022 (0.021-0.023)	0.005	0.053 (273)
Striped Anchovy	79 (72-85)	76	81 (3)	0.003 (0.001-0.005)	0.002	0.004 (3)
Striped Mullet	351 (345-357)	173	453 (213)	0.395 (0.374-0.416)	0.046	0.900 (213)
Threadfin Shad	148 (145-152)	112	233 (93)	0.034 (0.03-0.037)	0.012	0.119 (93)
White Mullet	284	284	284 (1)	0.180	0.180	0.180 (1)
White Shrimp	–	–	–	0.028 (0.025-0.03)	0.005	0.054 (51)

Retained Bycatch Validation

The retained bycatch was estimated by expansion of subsamples to the set levels as described in the methods. For 241 randomly chosen sets, the retained bycatch was also estimated via video analysis (Table 10). For a given species, the video analysis should have been a complete census of bycatch by set assuming all individuals were visible and counted. Across the 241 sets, the two methods should have rendered similar averages if all assumptions held. In Figure 15 we show the ratio of video averages to subsampling averages for species numerous enough to compare. This ratio clearly declined as the size of bycatch species decreased against the background of menhaden. Red drum yielded the most congruent estimates with the video estimate still the lesser of the two. Size contrast aside, even the largest specimens were probably only visible ~50% of the time given just one side of the stream of fish going into the hold was visible to the cameras. From Figure 6D, it is evident that this mackerel would have been missed by the video if it been on the other side of the menhaden stream. Among the larger bycatch species (shark spp., red drum, and black drum) a ratio of 0.5 seems to be the average, which is as expected if only half were visible in the videos. The take home message is that there was no evidence from the video analyses that the subsampling estimates were biased low.

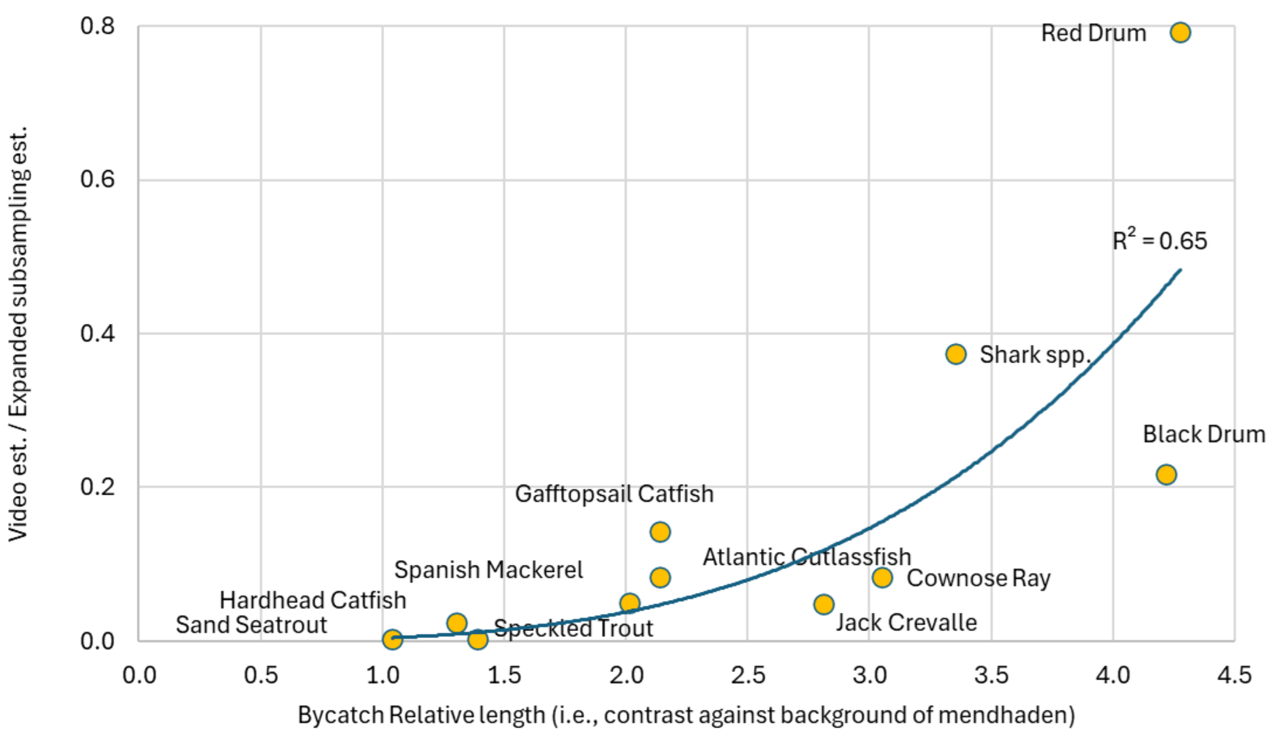

Figure 15. The ratio of the average number of individuals by species as estimated from the videos versus the average based on the expanded subsampling method across the 241 sets analyzed with video.

Table 10. The mean relative length (compared to background menhaden), total number of individuals, maximum number of individuals, and mean number of individuals (95% confidence interval) of each species in 241 sets with video analyzed of the retained bycatch. Only whole individuals were analyzed, and only taxa with species-level identification are shown.

Species	Mean Relative Length	Total # of Individuals Observed	Max Individuals per set	Mean Individuals per Set
Dusky Shark	7	1	1	0 (0-0.01)
King Mackerel	4.9	1	1	0 (0-0.01)
Finetooth Shark	4.4	14	3	0.06 (0.02-0.1)
Bull Shark	4.3	1	1	0 (0-0.01)
Red Drum	4.3	299	60	1.24 (0.66-1.82)
Black Drum	4.2	246	68	1.02 (0.22-1.82)
Blacktip Shark	3.5	18	3	0.07 (0.03-0.12)
Spinner Shark	3.3	1	1	0 (0-0.01)
Cownose Ray	3.1	390	150	1.62 (0.31-2.92)
Crevalle Jack	2.8	63	11	0.26 (0.1-0.42)
Bonnethead Shark	2.5	4	2	0.02 (0-0.04)
Ladyfish	2.5	53	35	0.22 (0-0.51)
Smooth Butterfly Ray	2.4	3	2	0.01 (0-0.03)
Atlantic Cutlassfish	2.1	3,130	254	12.99 (8.9-17.08)
Atlantic Stingray	2.1	7	2	0.03 (0-0.05)
Gafftopsail Catfish	2.1	10,974	665	45.54 (34.86-56.21)
Southern Stingray	2	2	1	0.01 (0-0.02)
Spanish Mackerel	2	875	167	3.63 (2.08-5.18)
Lookdown	1.9	6	2	0.02 (0-0.05)
Atlantic Needlefish	1.7	1	1	0 (0-0.01)
Southern Kingfish	1.7	4	2	0.02 (0-0.04)
Bluefish	1.6	57	7	0.24 (0.13-0.34)
Blue Runner	1.4	7	7	0.03 (0-0.09)
Finescale Menhaden	1.4	19	19	0.08 (0-0.23)
Sheepshead	1.4	5	4	0.02 (0-0.05)
Spotted seatrout	1.4	10	5	0.04 (0-0.09)
Florida Pompano	1.3	62	9	0.26 (0.13-0.39)
Hardhead Catfish	1.3	1,861	1,434	7.72 (0-19.41)
Sharksucker	1.3	2	1	0.01 (0-0.02)

Southern Flounder	1.3	10	5	0.04 (0-0.09)
Bluntnose Jack	1.1	2	1	0.01 (0-0.02)
Gulf Butterfish	1.1	152	71	0.63 (0-1.27)
Atlantic Bumper	1	66	16	0.27 (0.1-0.45)
Atlantic Tripletail	1	1	1	0 (0-0.01)
Leatherjack	1	49	6	0.2 (0.11-0.3)
Sand Seatrout	1	1,036	225	4.3 (1.62-6.98)
Star Drum	1	1	1	0 (0-0.01)
Blue Crab	0.9	7	1	0.03 (0.01-0.05)
Harvestfish	0.9	1,141	133	4.73 (3.06-6.41)
Spot	0.9	538	65	2.23 (1.25-3.21)
Atlantic Croaker	0.7	1,601	155	6.64 (4.32-8.97)
Atlantic Spadefish	0.7	7	3	0.03 (0-0.06)
Pinfish	0.6	8	6	0.03 (0-0.08)
Atlantic Moonfish	0.5	64	21	0.27 (0.04-0.49)
Gizzard Shad	0.4	1	1	0 (0-0.01)

Total Season Bycatch

The mean weight of a gulf menhaden caught in 2024 was 0.11 kg. We estimate total bycatch to equate to 4.57% of the 2024 Louisiana catch by number, and 3.59% of total catch by weight (Table 11). The total bycatch weight (released and retained) is equal to 3.62% of total landings. Bycatch retained with menhaden in the holds of vessels accounted for the bulk of the observed bycatch, with the retained bycatch comprising 4.57% of total catch by number, 2.96% of total catch by weight, and 2.98% of total landings. Rollover and chute bycatch, each making up the released component, accounted for a comparatively smaller proportion of bycatch, estimated at 0.43% and 0.21% by weight, respectively. Compared to bycatch in the retained catch, the released bycatch consisted of fewer, but generally larger-bodied individuals. The proportion of the released bycatch that made up the total season catch was therefore negligible in terms of bycatch numbers. The proportion of retained bycatch in the landings as calculated by the weighted mean percent bycatch in each subsample then stratified by plant and month yielded a similar bycatch estimate of 2.62% (2.15 - 3.09). The total estimated weights of 5 select species of interest, and the proportion of total landings they account for a shown in Table 12.

Table 11. Total fishery bycatch estimates for the 2024 season by total number (N), total weight (W) and total landings (L) for each bycatch component and for overall bycatch.

Component	Number of individuals	Weight (kg)	%N	%W	% L
Roll	145,095	1,488,724	0.005%	0.43%	0.43%
Chute	139,470	729,971	0.004%	0.21%	0.21%
Retained	145,519,692	10,326,782	4.57%	2.96%	2.98%
Total bycatch	145,804,257	12,545,477	4.57%	3.59%	3.62%
Retained bycatch and menhaden catch (i.e. Landings; kg)		346,925,262			
All Bycatch and menhaden catch (kg)		349,143,957			
Menhaden catch (individuals)	3,041,916,145				
All Bycatch and menhaden catch (individuals)	3,187,720,402				

Table 12. The weight of total bycatch (released and retained combined) relative to total reported landings for select bycatch species of interest.

Species	%
Black Drum	0.16%
Cownose Ray	0.24%
Crevalle Jack	0.05%
Gafftopsail Catfish	0.52%
Red Drum	0.14%

Released Bycatch Total Survival Estimates

Using the survival estimates for red drum, black drum, and gafftopsail catfish generated during our onboard holding study (Appendix 6), we estimate the number and weight of the total estimated catch that was released alive for these species. In the released bycatch as a whole, we estimate that ~23,000 of the ~45,000 red drum, ~17,000 of the ~26,000 black drum, and ~29,000 of the ~63,000 gafftopsail catfish are released alive by the fishery (Tables 13-15). As expected, the chute bycatch accounted for the majority of the mortalities in the released bycatch, with 357 of the ~17,000 red drum and 146 of the ~7,000 black drum encountered in the chute estimated being released alive. For gafftopsail catfish, we estimate that ~19,000 of the ~50,000 individuals are released alive.

Table 13. The estimated survival (number and weight) of red drum released in the fishery (rollover and chute). Percent survival estimates are generated based on an onboard holding study conducted during the 2024 season.

Source	Total Estimated Catch	Total Estimated Weight kg	Survival%	Total Released Alive	Total Weight Released Alive kg
Rollover	26,752 (19,578-33,926)	261,049 (190,905-331,193)	83.91% (77.1-89.0)	22,448 (16,221-28,674)	219,046 (158,174-279,919)
Chute	17,841 (12,315-23,367)	150,769 (104,026-197,511)	2.0% (0.0-9.8)	357 (0-1,238)	3,015 (0-10,462)
Total	**44,593 (35,537-53,648)**	**411,818 (327,528-496,107)**	**–**	**22,805 (16,516-29,093)**	**222,061 (160,735-283,388)**

Table 14. The estimated survival (number and weight) of black drum released in the fishery (rollover and chute). Percent survival estimates are generated based on an onboard holding study conducted during the 2024 season.

Source	Total Catch	Total Weight kg	Survival	Total Released Alive	Total Weight Released Alive kg
Rollover	18,680 (10,745-26,615)	144,668 (83,100-206,236)	87.82% (77.5-94.1)	16,405 (9,266-23,544)	127,047 (71,661-182,434)
Chute	6,957 (4,247-9,667)	50,927 (31,036-70,818)	2.1% (0.0-11.1)	146 (0-536)	1,069 (0-3,927)
Total	**25,637 (17,252-34,023)**	**195,595 (130,895-260,295)**	**–**	**16,551 (9,401-23,701)**	**128,116 (72,657-183,577)**

Table 15. The estimated survival (number and weight) of gafftopsail catfish released in the fishery (rollover and chute). Percent survival estimates are generated based on an onboard holding study conducted during the 2024 season.

Source	Total Catch	Total Weight kg	Survival	Total Released Alive	Total Weight Released Alive kg
Rollover	13,809 (11,199-16,420)	18,207 (14,571-21,842)	73.46% (43.3-87.7)	10,144 (6,528-13,760)	13,375 (8,530-18,219)
Chute	49,780 (37,534-62,025)	64,432 (48,532-80,331)	39.1% (26.8-52.1)	19,464 (11,553-27,375)	25,193 (14,942-35,444)
Total	**63,589 (51,068-76,110)**	**82,639 (66,329-98,948)**	**–**	**29,608 (20,910-38,306)**	**38,568 (247,230-49,905)**

SEX RATIOS & REPRODUCTIVE STAGE

The sex ratios of species commonly encountered in the released bycatch and the retained bycatch are shown in Table 16 and Table 17, respectively. Individuals for which the sex could not be determined are classified as unknown, and comprised of a combination of immature individuals, individuals with disfigured reproductive tissue, or species outside of spawning season with inconspicuous reproductive organs. We suspect the unknown category is skewed male as females with developed ovaries were easier to identify than male specimens in most teleost species, especially when not actively spawning. For species with sufficient sample sizes, Figure 16 shows the proportion of female fish for which ripe or late-stage ovaries were present. We use the proportion of fish in ripe condition as a proxy for spawning season, but note that this approach is qualitative and less robust than histology or calculating gonadosomatic index, albeit the most practical approach when sampling consecutive sets.

Table 16. The sex of fish observed in the rollover and chute bycatch during the 2024 commercial season. F = female, M = male, U = unknown

Species	Rollover			Chute			Total	% F	% M	% U
	F	M	U	F	M	U				
Black Drum	57	70	1	92	68	4	292	51.0	47.3	1.7
Blacktip Shark	120	76	0	146	129	1	472	56.4	43.4	0.2
Bull Shark	18	18	0	12	4	0	52	57.7	42.3	0.0
Cownose Ray	99	114	0	265	293	0	771	47.2	52.8	0.0
Finetooth Shark	27	16	0	65	44	0	152	60.5	39.5	0.0
Gafftopsail Catfish	14	8	8	218	108	38	394	58.9	29.4	11.7
Crevalle Jack	38	35	6	36	57	10	182	40.7	50.5	8.8
Red Drum	134	88	1	280	195	40	738	56.1	38.3	5.6
Spinner Shark	16	4	0	6	4	0	30	73.3	26.7	0.0

Table 17. The sex ratios observed in the retained bycatch during the 2024 commercial fishing season for species with samples size >30.

Species	F	M	U	Total	% F	% M	% U
Atlantic Croaker	272	110	82	464	58.6	23.7	17.7
Atlantic Cutlassfish	110	40	9	159	69.2	25.2	5.7
Atlantic Thread Herring	44	24	2	70	62.9	34.3	2.9
Gafftopsail Catfish	67	17	15	99	67.7	17.2	15.2
Hardhead Catfish	18	13	10	41	43.9	31.7	24.4
Harvestfish	37	62	16	115	32.2	53.9	13.9
Sand Seatrout	537	353	45	935	57.4	37.8	4.8
Scaled Sardine	17	8	12	37	45.9	21.6	32.4
Spanish Mackerel	61	31	16	108	56.5	28.7	14.8
Spot	64	37	45	146	43.8	25.3	30.8
Star Drum	55	13	8	76	72.4	17.1	10.5
Striped Mullet	22	8	7	37	59.5	21.6	18.9

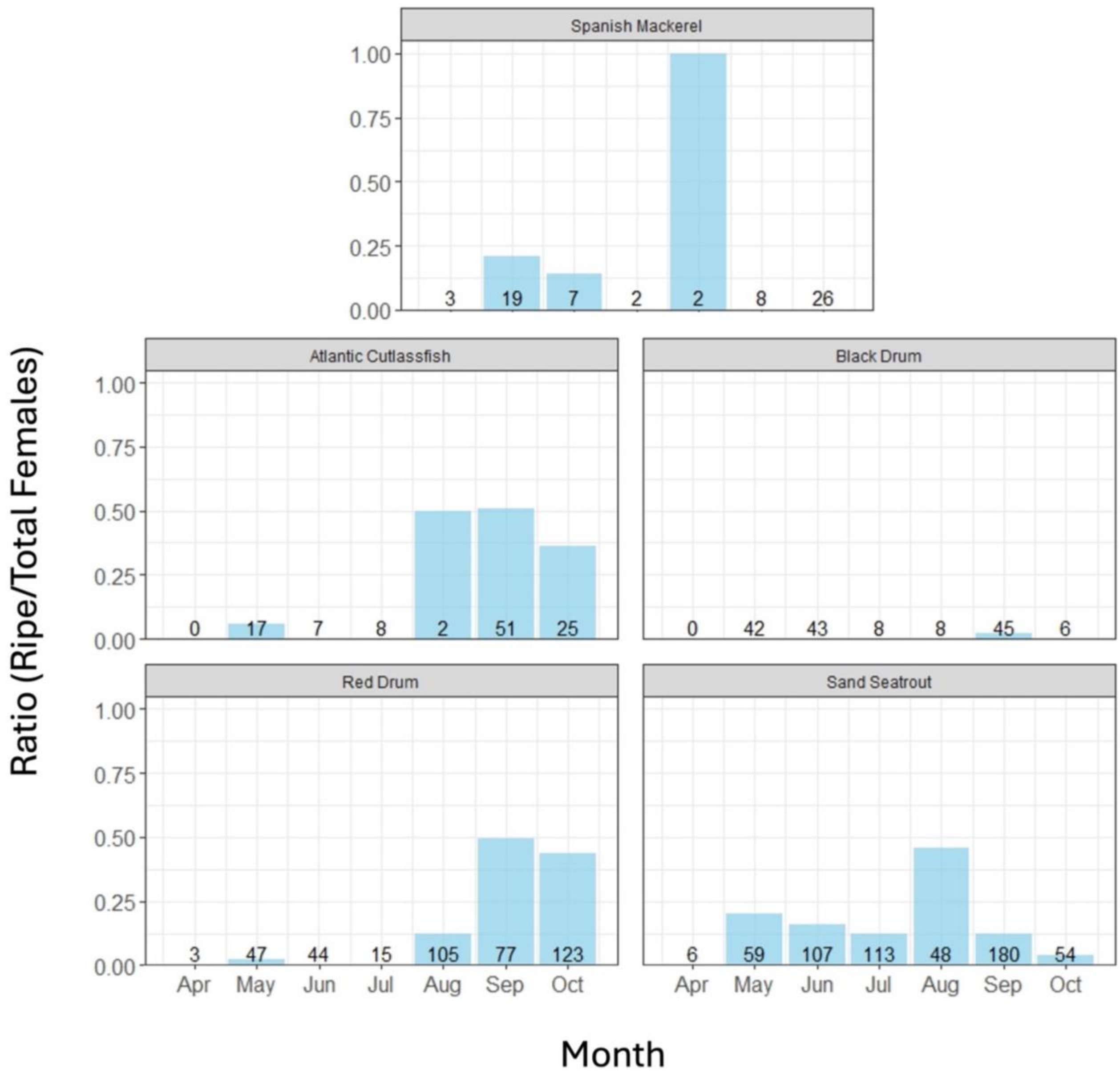

Figure 16. Monthly proportion of ripe females for five teleost species (released and retained bycatch combined). Bars represent the proportion of ripe female by month, and numbers within each bar indicate the total number of female individuals examined that month.

Spatio-Temporal Patterns

Some released bycatch species exhibited strong predicted spatial and seasonal variation across the study area, aligning with seasonal shifts in species distribution and fishing effort (Figures 17-22). Early in the season (April-June), predicted bycatch levels were generally low for most species, with red drum showing moderate activity in a region to the east of the Mississippi River in in May (Figure 17). Counter to the patterns observed for the other five modelled bycatch species, cownose ray expressed high spatial concentrations in early spring, particularly in the vicinity of the Mississippi River delta (Figure 19). By late summer and fall, predictions for cownose ray were uniformly low or absent across most of the Louisiana coastline. For red drum, bycatch intensity increased markedly from July onward, with consistent hotspots emerging along central and western Louisiana coastline, with peak predicted occurrence in August through October. This pattern suggests that Red Drum bycatch risk is highest during late summer and early fall. Unlike the observed patterns for red drum, the spatio-temporal patterns for black drum showed highest predicted bycatch during the month of June with several areas showing elevated bycatch (21-40 individuals per set). Prior to June and for the remainder of the season, GAM predictions indicated that black drum bycatch was generally low or absent across the region (Figure 18). Gafftopsail catfish, the most numerous bycatch constituent in the released bycatch, was widespread across the study area. Low to moderate bycatch predictions were observed in nearly all months and across much of the Louisiana coastline, with elevated bycatch appearing sporadically in June, August, and September (Figure 20).

Predicted bycatch of blacktip sharks exhibited strong seasonal shifts, with the highest intensities concentrated in late summer and fall. In April and May, predicted bycatch was mostly low, with a few localized hotspots in April (Figure 22). By August, pronounced increases were evident in the study area, where several sets showed high predicted values (41–80 individuals per set, red circles). This trend continued in September and October, particularly in the eastern part of the state, where multiple sets predicted high bycatch numbers. Crevalle jack showed scattered predictions, with isolated areas of increased predicted bycatch in September and October, but with noticeably lower catches across most of the west part of coastal Louisiana for most of the fishing season (Figure 21).

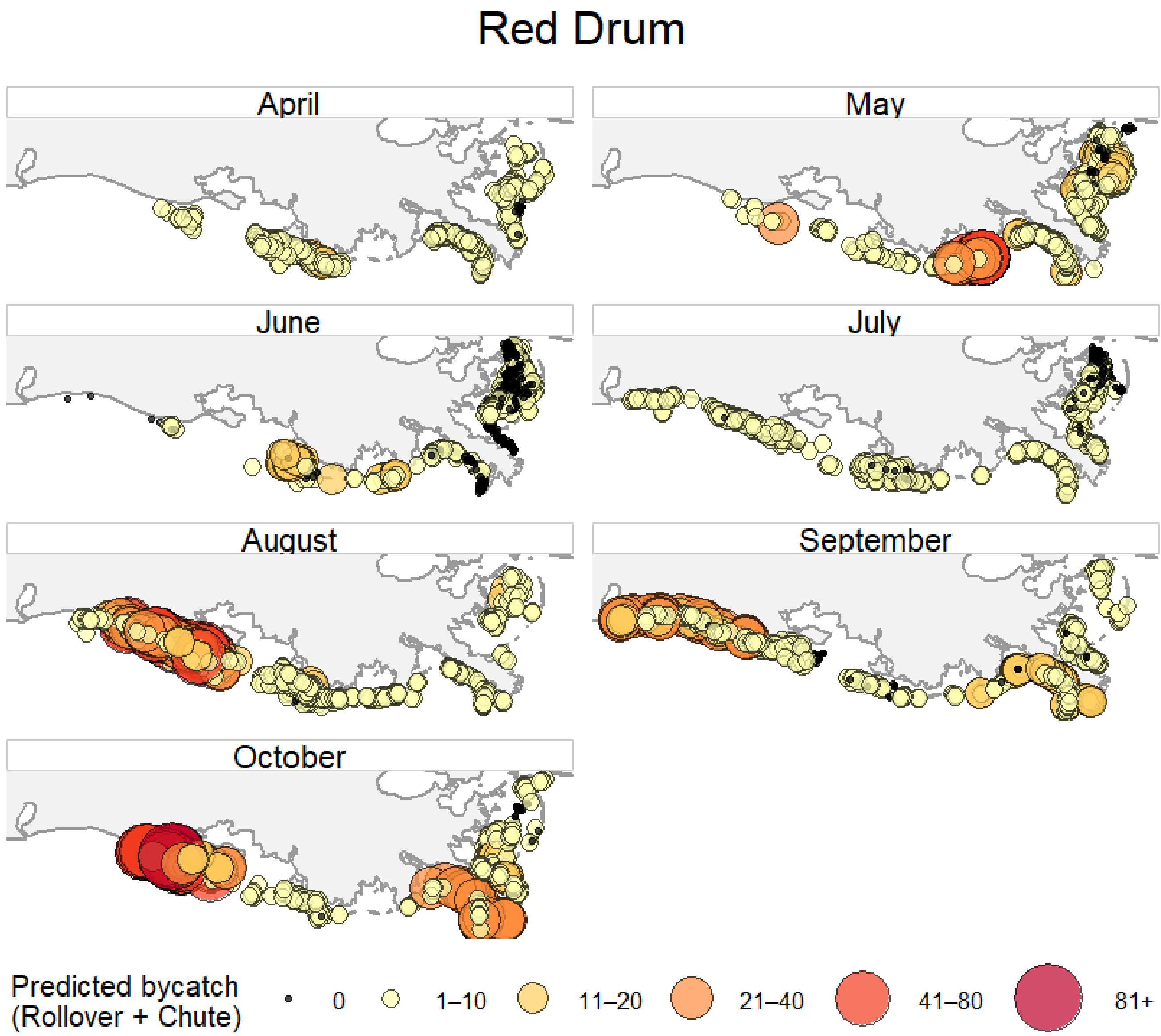

Figure 17. Monthly predicted bycatch of red drum from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

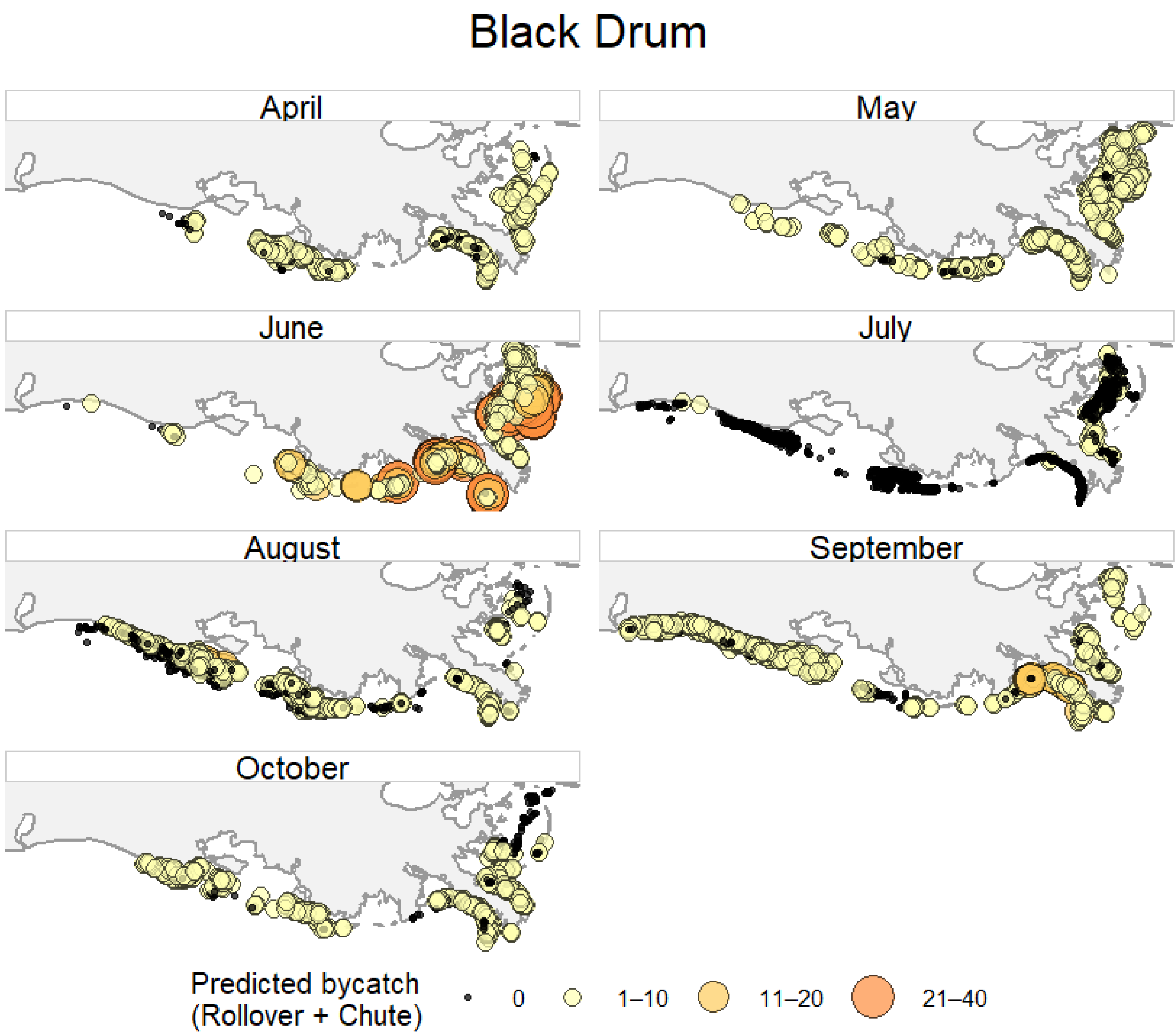

Figure 18. Monthly predicted bycatch of black drum from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

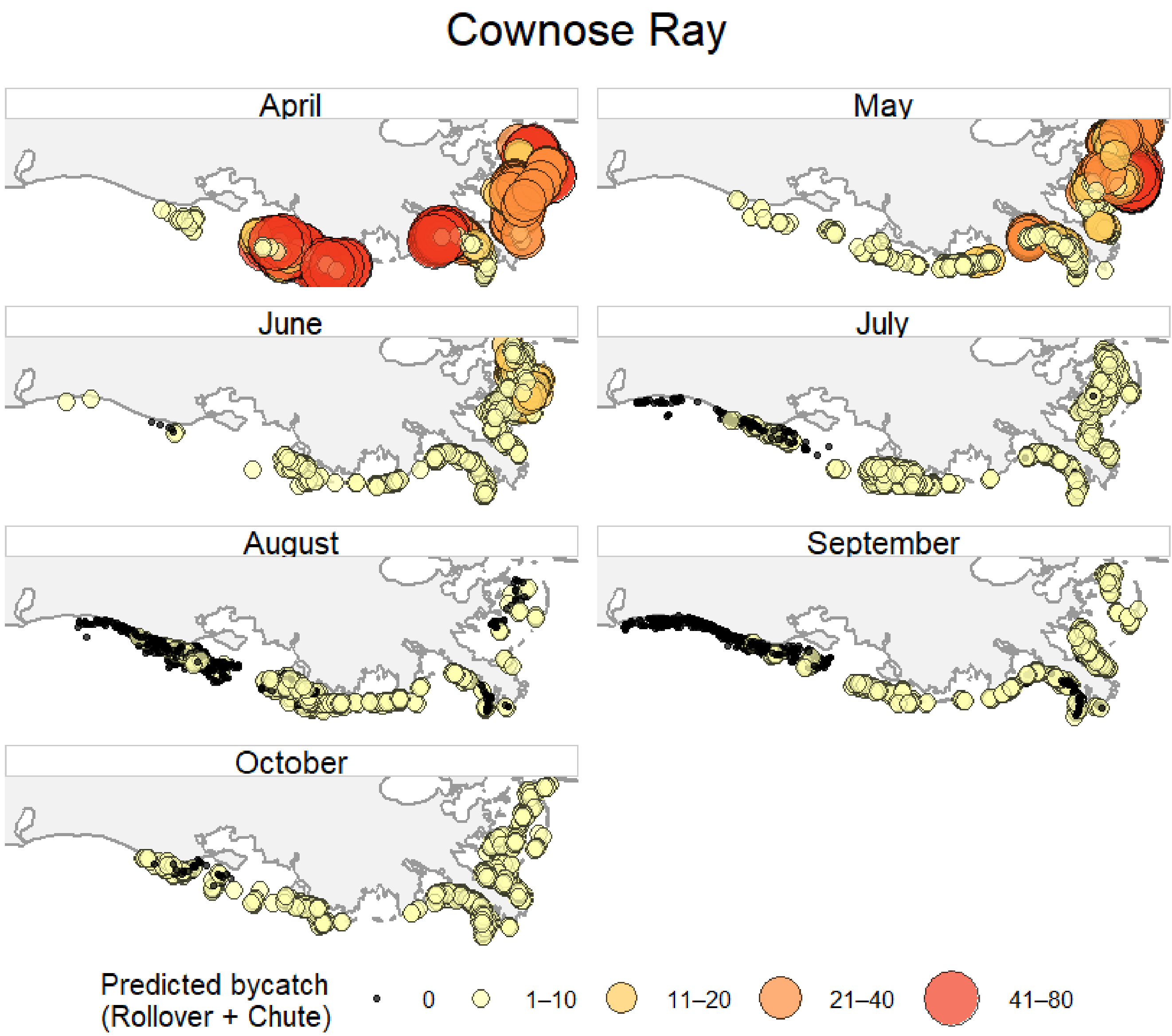

Figure 19. Monthly predicted bycatch of cownose ray from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

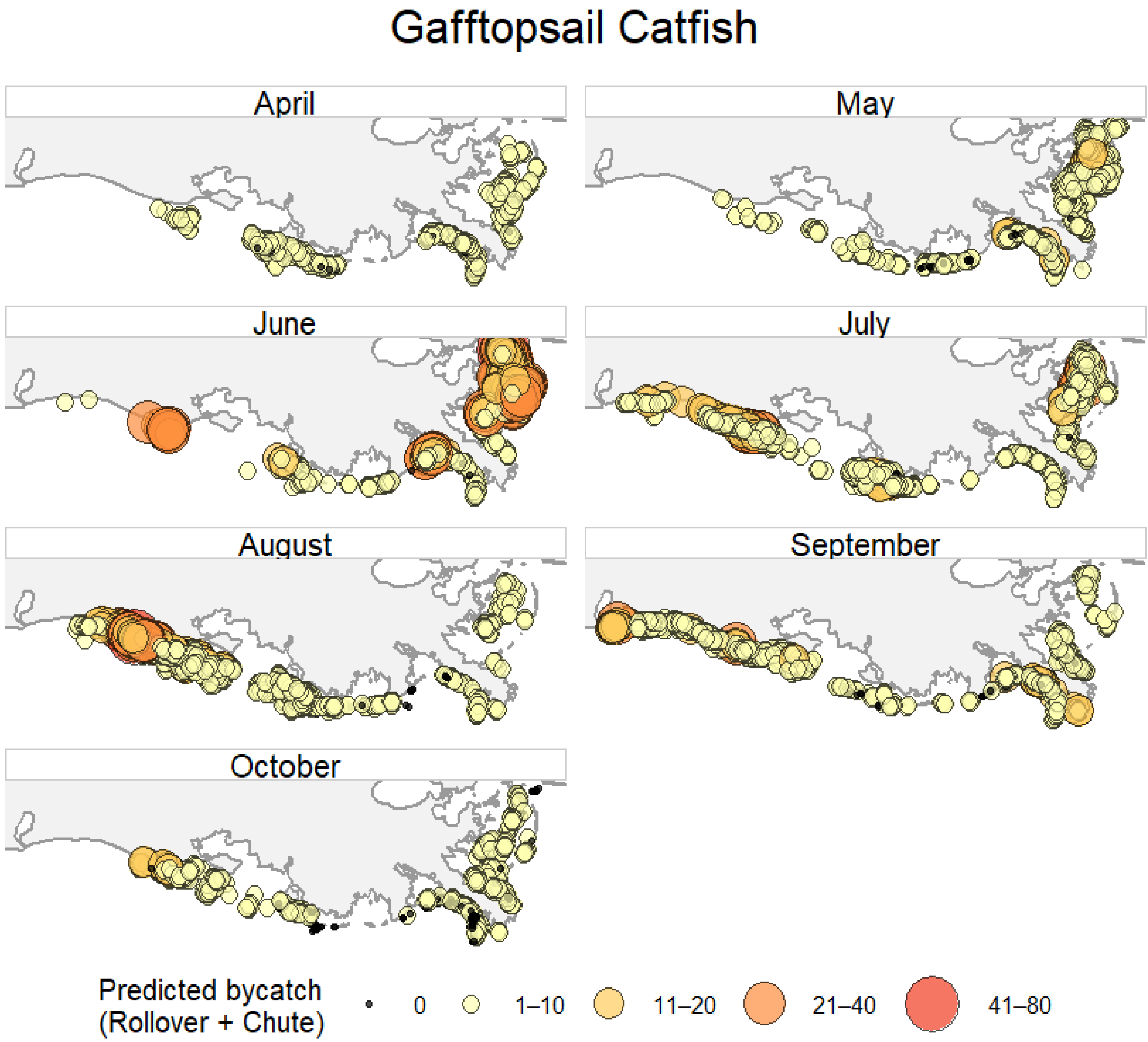

Figure 20. Monthly predicted bycatch of gafftopsail catfish from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

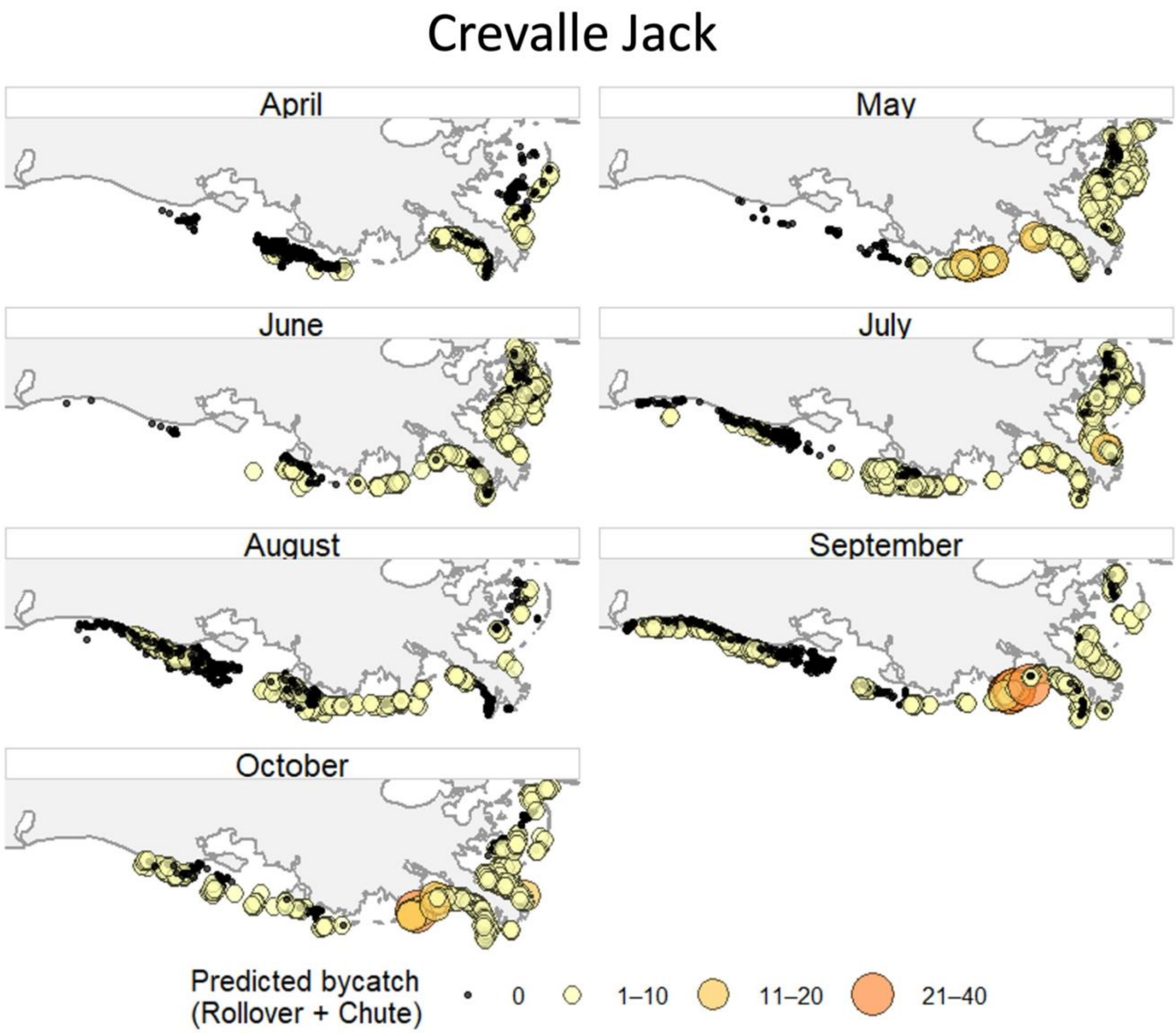

Figure 21. Monthly predicted bycatch of crevalle jack from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

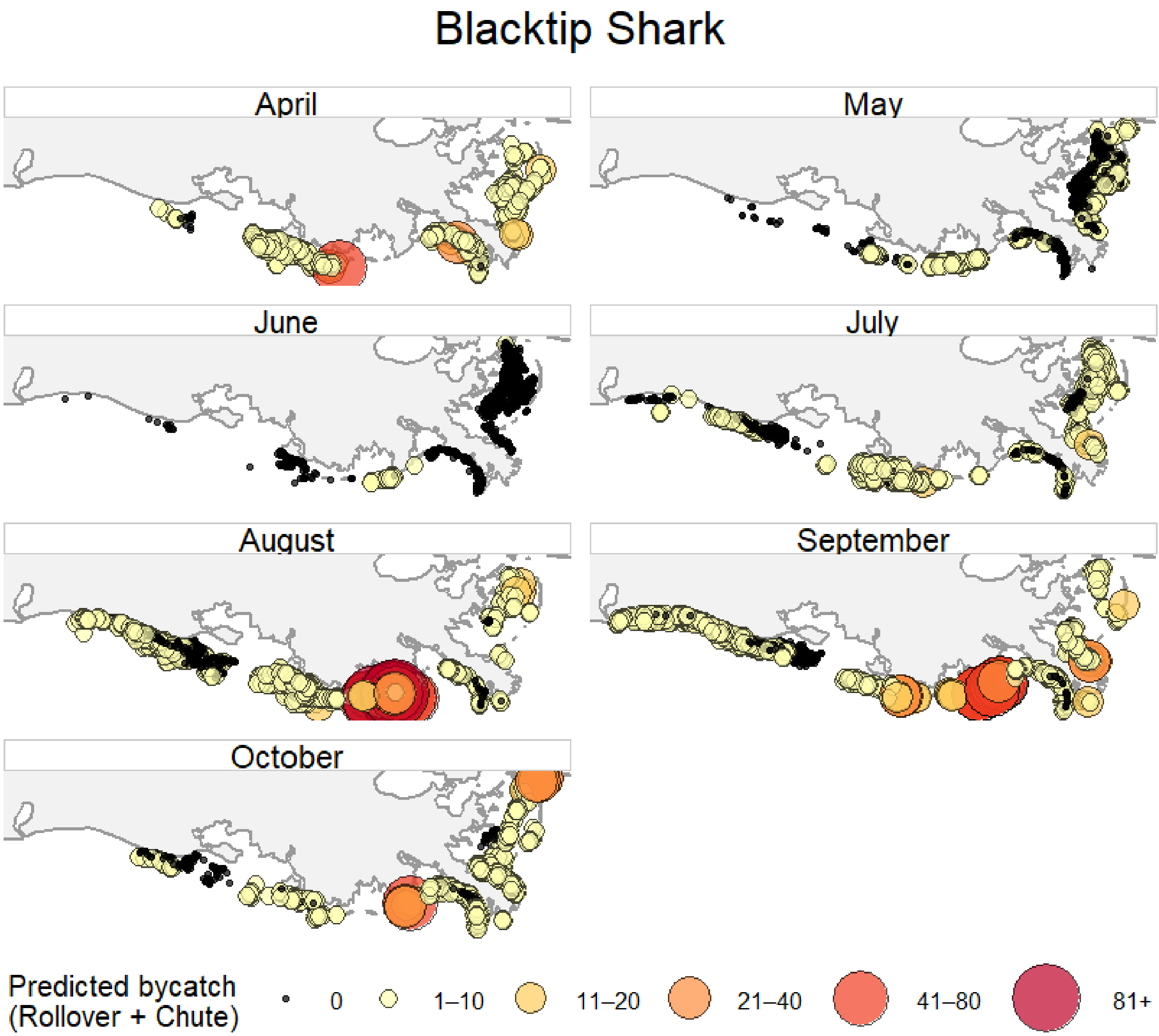

Figure 22. Monthly predicted bycatch of blacktip shark from the released bycatch across the study area. Predictions are derived from a Generalized Additive Model (GAM) incorporating water depth, longitude, plant and a random intercept for day of the year. Each panel represents spatial predictions for a given month (April-October) with point size and color denoting the magnitude of predicted bycatch.

Red drum, black drum, and gafftopsail catfish show a declining trend in predicted catch with increasing depth, suggesting that these species are more associated with shallower waters (< 5 m). By contrast, crevalle jack exhibits a sharp positive association with deeper water. Blacktip shark and cownose ray show a more complex, nonlinear pattern with slightly increasing predicted catches in deeper water for cownose rays, and again for blacktip sharks. These results highlight species-specific habitat preferences along the depth gradient and suggest that segregation by depth may influence catch composition in the fishery (Figure 23).

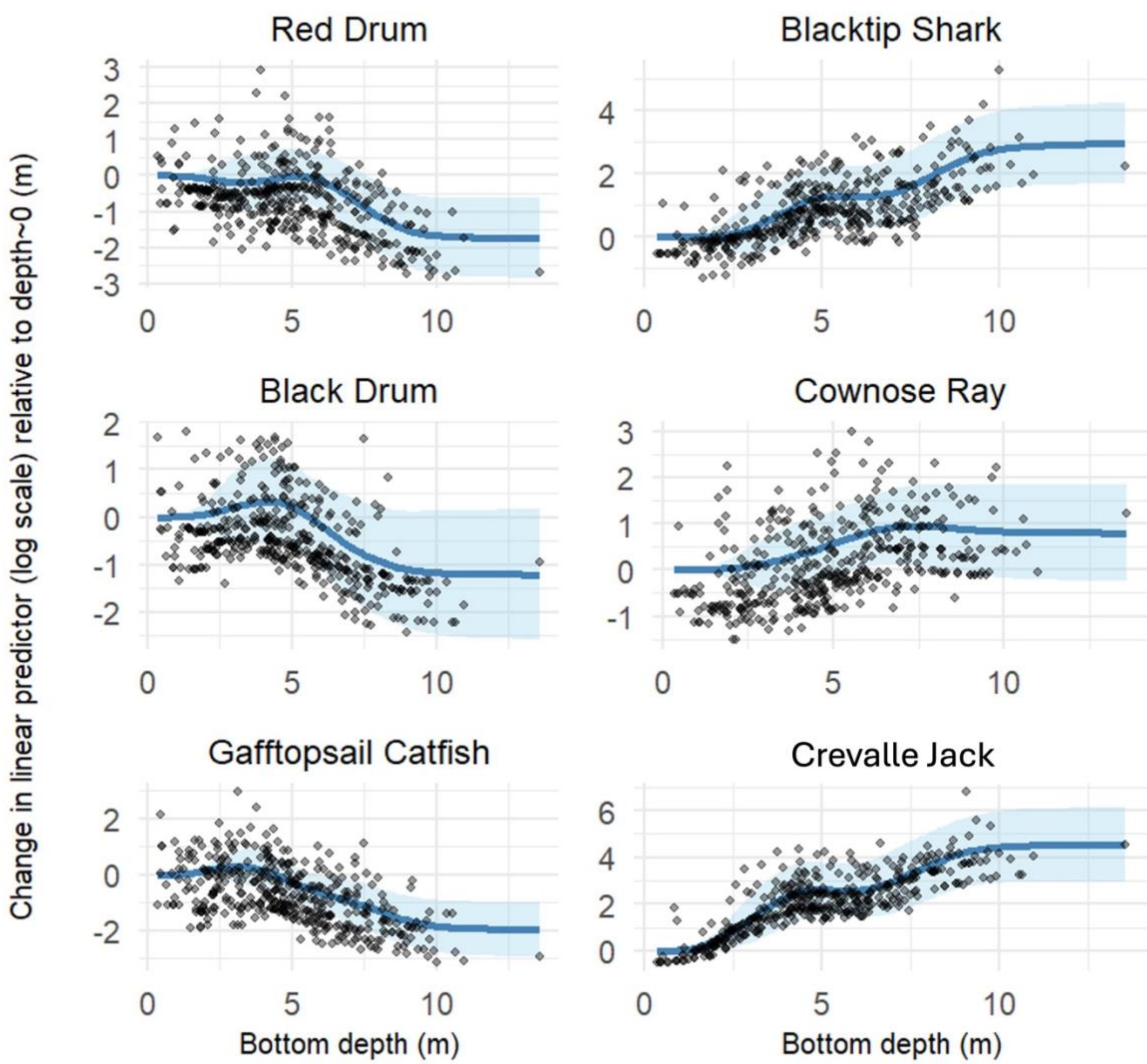

Figure 23. Generalized additive model predictions showing the effect of depth (in meters) on the log transformed probability of capture for six species. Each panel displays the estimated smooth function (solid blue line) with 95% confidence bands (shaded light blue area). Partial residuals are overlayed (black dots).

Protected Species, Marine Mammals, and Seabirds

Protected Species

All protected species observed in the nets when the run boat pulled alongside were identified and counted by at-sea observers and via video monitoring. Protected species were removed from the purse seine by the fishing crew at the first available opportunity, typically via the rollover procedure. As a result, protected species were only recorded in the rollover bycatch. The protected species observed, and their total estimated catch based on the stratified average are displayed in Table 18. Two of the observed species are listed under the endangered species act. The giant manta ray (*Manta birostris*) is listed as threatened, and the Kemp's ridley sea turtle (*Lepidochelys kempii*) is listed as endangered. Observers assigned condition scores to individuals encountered based on visual observations at the time of release. All sea turtles (n= 3) and the giant manta ray appeared to be generally healthy upon release from the net and were assigned vitality scores of excellent (Table 19).

Marine Mammals

No marine mammals were directly observed in the purse nets by observers during the study period. On one occasion, however, a set that would have been sampled was not pumped by the run boat because the captain of the fishing vessel reported the net contained bottlenose dolphins (*Tursiops truncatus*). Releasing the dolphins can be a delicate and time-consuming process, and the respective captains elected for the fishing vessel to pump the set to allow the run boat to continue pumping sets made by other fishing vessels. How regularly marine mammals are encircled within the purse net is not known, but we are aware of no other interactions with marine mammals that occurred during the 2024 commercial fishing season.

Seabirds

Depredation by seabirds as nets are set is a common occurrence in the fishery, with pelicans and gulls flocking to the nets often in high abundance. While most seabirds fly out of the net as it is being pursed, on several occasions we observed pelicans, cormorants, and gulls within the net as the run boat pulled alongside. The individuals reported in Table 18 are those that failed to leave the net before the pursing procedure raised the net far enough out of the water for the birds to fly out without assistance. These individuals within the net were typically removed by crew members using long-handled nets or were rolled over the float line at the end of the pumping operation. While double crested cormorants and brown pelicans were generally assessed in good or excellent condition, 3 brown pelican mortalities were observed (Table 19). Laughing gulls appeared to be more susceptible to injuries within the net, and their smaller size made them less conspicuous to the fishing crew. As a result, most laughing gulls were assessed as being in poor condition in the rollover bycatch, and one mortality was observed. While most seabirds were observed in the rollover bycatch, a single gull (*Laridae*) was also observed entering the hold of the vessel in one of the 241 sets with retained video counts. This would equate to 60 (0-176) gulls entering the retained bycatch over the course of the 2024 fishing season.

Table. 18. Protected species and seabirds observed in the rollover bycatch in the Gulf menhaden reduction fishery in numbers of individuals based on the means of stratified random sampling. The total number of individuals observed, the maximum number of individuals within a single set, and the percent of sets where the species was observed are also shown.

Species	Total #Individuals Observed	Max Observed per Set	% Occurrence	Average number per set	Total Estimated Catch
Brown Pelican	26	7	4.10%	0.04 (0.02 - 0.07)	571 (280 - 862)
Laughing Gull	15	3	2.17%	0.04 (0.01 - 0.06)	487 (124 - 850)
Double-crested Cormorant	8	2	1.45%	0.02 (0.00 - 0.03)	226 (41 - 410)
Kemp's Ridley Sea Turtle	2	1	0.48%	0.01 (0.00 - 0.01)	70 (0 - 168)
Giant Manta Ray	1	1	0.24%	0.00 (0.00 - 0.01)	60 (0 - 176)
Loggerhead Sea Turtle	1	1	0.24%	0.00 (0.00 - 0.01)	30 (0 - 89)

Table 19. The condition scores of protected species and seabirds observed in the rollover bycatch in the Gulf menhaden reduction fishery.

Species	Total Individuals Assessed	Excellent	Good	Poor	Mortality
Brown Pelican	25	10 (40%)	12 (48%)	0 (0%)	3 (12%)
Laughing Gull	12	0 (0%)	5 (42%)	6 (50%)	1 (8%)
Double-crested Cormorant	8	2 (25%)	6 (75%)	0 (0%)	0 (0%)
Kemp's Ridley Sea Turtle	2	2 (100%)	0 (0%)	0 (0%)	0 (0%)
Giant Manta Ray	1	1 (100%)	0 (0%)	0 (0%)	0 (0%)
Loggerhead Sea Turtle	1	1 (100%)	0 (0%)	0 (0%)	0 (0%)

Discussion

This study covered 3.2% of fishing effort, representing the highest observer coverage achieved in the fishery to date. At-sea observers coupled with electronic monitoring systems proved an effective method for characterizing the released and retained bycatch components. Diversion of the chute bycatch onboard the vessel resulted in a complete census of chute bycatch, overcoming limitations of previous studies where the chute bycatch was not always fully observable (Condry, 1994). The addition of on-board cameras for recording and reviewing bycatch in the rollover further increased confidence in bycatch estimates and in species identifications. For the retained bycatch, the large sampling cage used to subsample catch entering the vessel's holds sampled a sufficient volume of retained catch to effectively assess bycatch, on average sampling 126 kg of catch per set.

Studies charactering bycatch in the Gulf menhaden purse seine fishery have, for the most part, characterized bycatch in the fishery as minimal when compared to the billions of menhaden landed. Emphasis has generally been placed on relative bycatch quantities in terms of the percent of bycatch by number. Here, we report that bycatch totaled 4.57% of the total landings by number during the 2024 commercial fishing season. This value is marginally higher than the 3% by number reported by Christmas (1960) and the 2.39-2.96% range reported by Guillory and Hutton (1982). It is important to recognize, however, that key differences exist between methods that render direct comparison with earlier studies difficult. For example, Guillory & Hutton (1982) conducted at-plant sampling across two years and did not quantify released bycatch. Furthermore, we use empirical weights of ~148,000 menhaden sampled during the 2024 season to determine an average menhaden weight of 0.11 kg that we use to estimate the total percent bycatch by number. While this more accurately reflects the average weight of menhaden in the study area, and thus the total landings by number, it is notably lower than the standard menhaden weight of 0.3 kg used by the industry and presumably in prior bycatch studies. Recent studies have emphasized that a more appropriate metric for assessing the magnitude of bycatch in the fishery would be to examine percent bycatch by weight of the catch. When doing so, Condry (1994) reports that the retained catch accounted for an average of 1.2% of the weight of menhaden, Dunham (1972) reports a range of 2-4%, and Guillory and Hutton (1982) report a range of 0.8-2.6%. In the present study, we report that the total bycatch by weight during the 2024 season was 3.59%. Guillory & Hutton (1982) estimated the average annual bycatch across the entire Gulf of Mexico from 1970-1975 was 14.6 million kg. For Louisiana and adjacent federal waters sampled during the 2024 season, we report 12.5 million kg of bycatch, despite lower total landings in 2024 than those reported in the 1970s.

Studies evaluating bycatch in the Gulf menhaden fishery generally group the rollover and chute bycatch into a single category termed the "released" bycatch. Results of our survival study and evaluation of bycatch condition scores demonstrate that released bycatch mortalities are considerably higher for the chute bycatch which travels through the vessel's on-board fish pump. As a result, evaluation of the chute and rollover bycatch separately is needed to most accurately estimate total bycatch mortality in the fishery. We summarize the released bycatch separately and in aggregate to allow for estimates of total bycatch mortality for key species tested in the survival study and to facilitate comparison with previous bycatch studies in the fishery. The rollover bycatch accounted for 1.5 million kg of bycatch, representing 0.43% of the total season landings by weight. By comparison, the chute bycatch accounted for 730 thousand kg of catch and 0.21% of bycatch by weight. Compared to that of the retained catch, the released component of the fishery comprised a small portion of the total bycatch in terms of both number and weight (Table 11).

Gafftopsail catfish were the most frequently encountered single species by number in the chute bycatch, the fourth most common species in the rollover bycatch, and the most frequent species in released bycatch overall (63,589 estimated individuals). In this study, gafftopsail catfish accounted for ~10% of the sampled rollover bycatch and 36% of the sampled chute bycatch by number. This outcome is consistent with previous studies in the Gulf menhaden fishery, with some studies reporting that gafftopsail catfish accounted for 61% of the released bycatch and were the most numerically abundant species overall (Condry, 1994). In this study, gafftopsail catfish were most abundant in the chute component of the released bycatch. The tendency of gafftopsail catfish to end up in the chute bycatch over that of the rollover likely resulted from their smaller average size (505 mm) and thus higher likelihood of travelling through the hose cage excluder. Anecdotally, observers manning the large fish excluder grate observed that their pectoral spines appeared to increase the likelihood that gafftopsail catfish were deflected by the large fish excluder grate. While survival of many species that travel through the onboard fish pump approached 100% mortality, our on-board holding study indicated that 39% of gafftopsail catfish that travel through the chute likely survive capture in the fishery. However, corneal cloudiness was observed in 17% of gafftopsail catfish that survived the chute and could possibly reduce survival over periods longer than 24 hours.

Red drum and black drum were also among the most frequently encountered finfish species in the rollover and chute bycatch components. Although few red drum were reported as bycatch in the fishery during studies in the 1950s-1960s, more recent studies report increased numbers of red drum in the released bycatch. For instance, De Silva and Condry (1997) report an average of 0.95 red drum per set, and Pulver & Scott Denton (2012) report 1.89 red drum per set. In this study, our average number of red drum in the released bycatch was 3.39 per set, equating to an estimated 45 thousand red drum (411 thousand kgs) during the 2024 season. Why red drum catches were higher in our study is not known. Potential explanations include, but are not limited to, spatio-temporal shifts in fishing effort through time, a more robust sampling stratification achieved during this study, as well as higher precision of our estimates through the integration of electronic monitoring technology. Recent red drum stock assessments indicate that the Louisiana stock has been in decline; yet managers acknowledge that key data gaps with regards to the offshore abundance of red drum exist. In light of this, we cannot rule out the possibility that local increases in offshore populations of red drum contributed to the increase bycatch numbers we observed. Of specific relevance to drum in the released bycatch is the survival rate of fish tested in our holding study. We conservatively estimate that 83-92% of red drum and black drum released from the rollover would likely survive, and that survival of drum in the chute approximates ~2%. This equates to ~23 thousand red drum (222 thousand kgs) surviving release.

Sharks and rays were also commonly encountered in the released bycatch component. Previous studies conducting stomach analyses indicate that menhaden schools are an important forage base for coastal sharks in the region and that incidental catch of sharks is tied to this trophic relationship (De silva, 1998). In line with this assessment, sharks were commonly encountered within the rollover bycatch, with blacktip sharks being the most abundant constituent by number (9,568), followed by bull sharks (2,833), finetooth sharks (2,692) and spinner sharks (573). Two additional categories of sharks that were counted but not brought onboard for full identification, included blacktip/spinner shark and *Carcharhinus sp.,* and accounted for an additional 16,664 estimated sharks within the rollover bycatch. Similar observations were made for that of the chute bycatch, whereby blacktip constituted the most abundant shark species (6,957), followed by finetooth sharks (2,888). Not all previous bycatch studies in the Gulf menhaden fishery attempted to classified sharks to species level, making comparisons to some previous studies difficult. Nonetheless, blacktip sharks have previously been reported to account for ~70% of the sharks observed in the fishery, with some studies reporting up to 148 blacktip and spinner sharks in a single set (De Silva et al., 2001). The absence of dusky shark (*Carcharhinus obscurus*), sand tiger shark *(Carcharias taurus),* and scalloped hammerhead shark *(Sphyrna lewini)* in our dataset, species previously reported as bycatch in earlier studies, is consistent with more recent examinations of shark bycatch in the fishery. Although early studies report that species such as hammerhead comprised ~18% of the sharks encountered, recent studies reported values of less than 1% (De Silva et al., 2001). We hypothesize that this outcome may reflect changes in the abundance of shark populations through time, a shift in the spatial extent of the fishery which historically covered a larger region of the Gulf, as well as limitations with the accuracy of species-level identification. Indeed, given the apparent ambiguity over shark identifications in many previous studies, some authors have urged that caution should be exercised when interpreting historical shark bycatch data in the absence of archived specimens (De Silva et al., 2001).

Noteworthy is that cownose rays were the most encountered species in the rollover bycatch (26,847), and the second most encountered species in the chute bycatch (29,094). We estimate total catches of cownose rays of 56 thousand by number and 441 thousand kg by weight for the released bycatch as a whole. Cownose rays are often mixed within menhaden schools in shallow coastal areas in the Northern Gulf of Mexico (Rogers et al., 1990). Despite being opportunistic generalist feeders, evidence for a piscivorous diet in cownose rays is limited, implying that their association with menhaden schools is likely not driven by a predator-prey relationship like that of sharks (Collins et al., 2007). Instead, their schooling tendencies and the preference of adult rays for shallow, low salinity inshore areas that overlap with the fishery may best explain their occurrence and abundance as bycatch (Ajemian and Powers, 2016). Indeed, several previous studies have identified cownose rays in the released bycatch component, albeit in much lower numbers. Christmas et al., (1960) encountered cownose rays in a total of 2 sets of 89 sampled mostly in Mississippi waters and Condry (1994) sampling 127 sets reported that cownose rays accounted for 18% of released bycatch species, with a maximum of 15 individuals encountered in a single set. In this study, cownose rays were observed in the released bycatch of 43.9% sets sampled, with a maximum number of individuals per set of 44 for the rollover and 166 for the chute bycatch. We report that 29% of cownose rays in the chute appeared to suffer mortalities and an additional 47% were released in in poor condition, an outcome similar to the estimated 40% released dead reported by Condry (1994).

One difference between the released bycatch composition reported in this study and that observed in previous studies is the lower relative abundance of Atlantic croaker, sand seatrout and Atlantic cutlassfish in the rollover bycatch component. Differences in methods for quantifying the released bycatch explain this outcome. Due to practical considerations and concerns over sampling bias, we did not attempt to quantify these small-bodied bycatch constituents when observed gilled in the net. Our primary concern stemmed from an inability to discern whether fish gilled in the net originated from the set in question or represented bycatch that was carried over from previous sets conducted that day. This caveat has been acknowledged by previous studies, which likely overestimated these species in the released bycatch component (Condry, 1994). Our observations onboard further indicate that Atlantic croaker, sand seatrout, and Atlantic cutlassfish gilled in the net likely constitute on a small number of total bycatch per set and that gilled species are sufficiently accounted for within the retained bycatch samples.

In comparison to the released bycatch, the retained bycatch accounted for the largest bycatch component in terms of total weight (10 million kgs; 2.96%) and by number (146 million individuals; 4.57%). One striking difference between this study and estimates of the retained catch reported previously, is the lack of sets sampled with no bycatch. Condry (1994) reports that 47% of retained samples, consisting of 1-5 dip nets full of catch, contained no bycatch species. Using an industrial sampling cage to sample on average 126 kg of catch per set, we report bycatch in all 415 sets sampled for the retained bycatch. Such drastic differences raise the question as to whether the volume of previous samples, equating to ~7-32 kg of catch per set, were sufficient for accurately characterizing the retained bycatch. Consistent with this interpretation, we report a total of 63 species in the retained bycatch, compared to just 16 species reported during previous study (Condry, 1994). While we cannot rule out the possibility that increased bycatch reflects increases abundance of some bycatch species in the northern Gulf, it would appear that our sampling design better captured less common bycatch species. Regardless of these differences between the magnitude and richness of bycatch observed in the retained bycatch, similarities do exist with respect to the most frequently encountered species. For instance, previous studies note that of the sampled sets that contained retained bycatch, Atlantic croaker was the most frequently encountered species. We similarly report that Atlantic croaker accounted for 55% of the estimated total bycatch by number in the retained catch, comprising ~2.5 million kgs. Other abundant bycatch species in the retained bycatch included sand seatrout, spot, hardhead catfish, gafftopsail catfish, Atlantic cutlassfish, striped mullet, and star drum. Likewise, these species have been identified as key constituents of the retained bycatch during multiple previous studies sampling both at sea and at the processing plants (Christmas et al., 1960; Condry, 1994; Guillory and Hutton, 1982).

Red drum and spotted seatrout, two species of economic importance in Louisiana, were both encountered within the retained bycatch. Red drum have not been identified within the retained bycatch in any previous studies (Sagarese et al., 2016), though recent studies have failed to examine the retained bycatch entirely (Pulver and Scott-Denton, 2012), and studies conducting at-plant sampling note that large species were often removed prior to unloading (Dunham, 1972). In this study, a total of 2 whole red drum were observed within the sampling cage used to subsample the retained catch. When expanded to the size of the sets sampled and across the season, we estimate by number that 8,356 red drum (69 thousand kgs) are encountered in the retained bycatch, with a mean of 0.93 red drum per set. Bycatch that are infrequent or rare can pose a challenge during estimation (Moore et al., 2021). As such, we deployed high-speed video cameras as a method of validating the estimates produced by the sampling cage. Observers quantified bycatch entering the vessel's hold from start to finish of the pumping operation. Following analysis of 241 sets, observers identified a total of 299 whole red drum entering the holds of vessels, resulting in an estimated mean number of red drum per set of 1.24 in the retained bycatch via our video methods. While we question the reliability of this approach for smaller and less conspicuous bycatch species, detectability increased for larger species like red drum that generally displayed a higher contrast from that of the background menhaden. Of note is that video analysis of the retained catch was ineffective for identifying spotted seatrout given their smaller size and similar appearance to the highly abundant sand seatrout. Nonetheless, spotted seatrout were more abundant than red drum in our sampling cage (n=26) where we estimate total season catches of 240,000 by number (45 thousand kgs) in the retained catch.

Information on interactions with marine mammals, sea turtles and other threatened, endangered, and protected species within the Gulf menhaden purse seine fishery is limited, and incidental capture is generally presumed to be a rare occurrence. During the 2024 season, we report sightings of three sea turtles and one giant manta ray in the rollover bycatch during the 415 sets observed. In addition, observers were made aware of the incidental capture of bottlenose dolphins (unknown number) during a single set that was not directly witnessed. Recent observations using electronic monitoring approaches report similar encounters, with six instances of sea turtles and seven instances of bottlenose dolphins reported within the purse nets, following monitoring of 697 sets in 2022 (Saltwater Inc., 2023). As was the case with previous studies, all sea turtles observed in this study were released alive at the end of the pumping operation and were deemed in excellent condition by observers. We are unaware of the fate of the bottlenose dolphins indirectly encountered, but note that bottlenose dolphins are commonly sighted on the fishing grounds and studies have long reported their association with the fishery, which prior to 2022 was generally deemed to be non-lethal (Christmas et al., 1960; De silva, 1998). The incidental capture of a giant manta ray off the Mississippi River delta in late-April, to the best of our knowledge, represents the first reported encounter of this species in the fishery, although we note that captain and crew acknowledged previous encounters have occurred. Interestingly, recent studies combining sightings and survey data into a distribution modeling framework, predict high giant manta ray distributions near the Mississippi River delta from April to June, with fish capitalizing on the plankton-rich waters (Farmer et al., 2021). Anecdotally, observers also noted that giant manta ray were observed breaching on two separate occasions (unrelated to fishing activities), each within the vicinity of the Mississippi River delta in April. As with any observer program, greater coverage would be required to produce more complete and more accurate estimates of protected species interactions. With ~3% coverage of effort, we can conclude that interactions with protected species is uncommon (~1% of sets).

Summary and Conclusions

The Louisiana purse seine fishery is carried out in shallow coastal areas with the season extending from April to October each year. We characterized all bycatch components during the 2024 commercial fishing season, and report that overall bycatch in the fishery comprised 4.57% of total catch by number and 3.59% by weight. Teleosts and elasmobranchs were the most prominent bycatch in the fishery, with invertebrate bycatch species accounting for only a small proportion of total bycatch, mostly in the retained component. The released bycatch was dominated by larger-bodied species such as red drum, black drum, gafftopsail catfish, and blacktip sharks. Compared to the retained catch, the released bycatch comprised a relatively small amount of total landings by weight (0.64%) and a negligible amount by number. Using an on-board holding study conducted across the entire 7-month season, we report the first post-release survival estimates for key bycatch species in the released bycatch (red drum, black drum, and gafftopsail catfish). Results of the on-board holding study indicate that post-release survival in the rollover bycatch is high (73-88%), and that survival of these same species in the chute bycatch was comparatively lower (2-39%). We observed considerable variation in bycatch excluder designs across the fleet and observed that relatively large fish (shark up to ~1.6 meters) could pass through the hose cages. Previous studies note that more optimal hose cage designs likely exist, and we similarly conclude that given the high survival rates observed in the rollover bycatch, modification to industry hose cages represent a promising avenue for reducing bycatch mortality within the fishery.

Bycatch studies are generally conducted within the fishery once every decade, however, many previous studies have left much to be desired. A major challenge has been designing a study that produces complete and scientifically robust estimates of bycatch (all components) without overly impinging on fishing operations. This study represents a major breakthrough in that endeavour. Working cooperatively with industry partners, vessels were modified to facilitate a full census of the released bycatch during sampled sets, and for expanded subsampling of the retained bycatch. Thus, the methods we present and validate herein represent what we strongly believe is the most comprehensive investigation of bycatch in the Louisiana purse seine fishery to date. Adoption of this approach as standard procedure for characterizing bycatch in the fishery and the implementation of more frequent studies are needed to build a more complete picture of the trends in bycatch composition and relative abundance in the fishery through space and time.

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Appendix

Model Diagnostics

Appendix 1. Summary of generalized additive mixed model (GAMM) diagnostic test results for six modelled species in the chute and rollover bycatch. All species modelled pass the four diagnostics (outlier detection, overdispersion, uniformity, and zero-inflation) and had sample size to effective degrees of freedom ratios >10.

Test	Species	Test statistic	p_value	Passes?
Outliers	Red Drum	0.00	1.000	Yes
	Black Drum	0.00	1.000	Yes
	Gafftopsail Catfish	0.00	1.000	Yes
	Cownose Ray	0.00	1.000	Yes
	Jack Crevalle	0.00	1.000	Yes
	Blacktip Shark	0.00	1.000	Yes
Overdispersion	Red Drum	1.60	0.219	Yes
	Black Drum	1.34	0.373	Yes
	Gafftopsail Catfish	0.71	0.678	Yes
	Cownose Ray	1.44	0.331	Yes
	Jack Crevalle	1.06	0.609	Yes
	Blacktip Shark	1.66	0.191	Yes
Uniformity	Red Drum	0.04	0.634	Yes
	Black Drum	0.04	0.424	Yes
	Gafftopsail Catfish	0.04	0.540	Yes
	Cownose Ray	0.03	0.953	Yes
	Jack Crevalle	0.04	0.479	Yes
	Blacktip Shark	0.04	0.403	Yes
ZeroInflation	Red Drum	0.98	0.568	Yes
	Black Drum	0.97	0.246	Yes
	Gafftopsail Catfish	1.03	0.523	Yes
	Cownose Ray	0.97	0.453	Yes
	Jack Crevalle	0.98	0.475	Yes
	Blacktip Shark	1.00	0.970	Yes

BYCATCH SCIENTIFIC NAMES

Appendix 2. The common and scientific names for all 86 species identified as bycatch during the 2024 commercial fishing season.

Common Name	Latin Name
Alligator Gar	*Atractosteus spatula*
Atlantic Bumper	*Chloroscombrus chrysurus*
Atlantic Croaker	*Micropogonias undulatus*
Atlantic Cutlassfish	*Trichiurus lepturus*
Atlantic Moonfish	*Selene setapinnis*
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*
Atlantic Spadefish	*Chaetodipterus faber*
Atlantic Stingray	*Dasyatis sabina*
Atlantic Tarpon	*Megalops atlanticus*
Atlantic Thread Herring	*Opisthonema oglinum*
Atlantic Tripletail	*Lobotes surinamensis*
Banded Drum	*Larimus fasciatus*
Bay Anchovy	*Anchoa mitchilli*
Bay Whiff	*Citharichthys spilopterus*
Bigeye Searobin	*Prionotus longispinosus*
Black Drum	*Pogonias cromis*
Blackcheek Tonguefish	*Symphurus plagiusa*
Blacknose Shark	*Carcharhinus acronotus*
Blacktip Shark	*Carcharhinus limbatus*
Blue Crab	*Callinectes sapidus*
Blue Runner	*Caranx crysos*
Bluefish	*Pomatomus saltatrix*
Bluntnose Jack	*Hemicaranx amblyrhynchus*
Bluntnose Stingray	*Hypanus say*
Bonnethead Shark	*Sphyrna tiburo*
Brief Squid	*Lolliguncula brevis*
Brown Pelican	*Pelecanus occidentalis*
Brown Shrimp	*Crangon crangon*
Bull Shark	*Carcharhinus leucas*
Calico Box Crab	*Hepatus epheliticus*
Cownose Ray	*Rhinoptera bonasus*
Devil Ray	*Mobula hypostoma*
Double-crested Cormorant	*Phalacrocorax auritus*
False Silverstripe Halfbeak	*Hyporhamphus meeki*
Finescale Menhaden	*Brevoortia gunteri*
Finetooth Shark	*Carcharhinus isodon*
Florida Pompano	*Trachinotus carolinus*
Fringed Flounder	*Etropus crossotus*
Gafftopsail Catfish	*Bagre marinus*
Giant Manta Ray	*Mobula birostris*
Gizzard Shad	*Dorosoma cepedianum*
Gulf Butterfish	*Peprilus burti*
Gulf Kingfish	*Menticirrhus littoralis*

Gulf Menhaden	*Brevoortia patronus*
Hardhead Catfish	*Ariopsis felis*
Harvestfish	*Peprilus paru*
Balao halfbeak	*Hemiramphus balao*
Hogchoker	*Trinectes maculatus*
Crevalle Jack	*Caranx hippos*
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*
King Mackerel	*Scomberomorus cavalla*
Ladyfish	*Elops saurus*
Laughing Gull	*Leucophaeus atricilla*
Leatherjack	*Oligoplites saurus*
Lemon Shark	*Negaprion brevirostris*
Lesser Blue Crab	*Callinectes similis*
Loggerhead Seaturtle	*Caretta caretta*
Lookdown	*Selene vomer*
Northern Kingfish	*Menticirrhus saxatilis*
Pigfish	*Orthopristis chrysoptera*
Pinfish	*Lagodon rhomboides*
Red Drum	*Sciaenops ocellatus*
Roughtail Stingray	*Bathytoshia centroura*
Sand Seatrout	*Cynoscion arenarius*
Scaled Sardine	*Harengula jaguana*
Sea nettle	*Chrysaora quinquecirrha*
Sharksucker	*Echeneis naucrates*
Sheepshead	*Archosargus probatocephalus*
Silver Perch	*Bairdiella chrysoura*
Skipjack Herring	*Alosa chrysochloris*
Smooth Butterfly Ray	*Gymnura micrura*
Southern Flounder	*Paralichthys lethostigma*
Southern Kingfish	*Menticirrhus americanus*
Southern Stingray	*Hypanus americanus*
Spanish Mackerel	*Scomberomorus maculatus*
Spotted Seatrout	*Cynoscion nebulosus*
Spinner Shark	*Carcharhinus brevipinna*
Spot	*Leiostomus xanthurus*
Spotted Eagle Ray	*Aetobatus narinari*
Mantis Shrimp	*Squilla empusa*
Star Drum	*Stellifer lanceolatus*
Striped Anchovy	*Anchoa hepsetus*
Striped Mullet	*Mugil cephalus*
Threadfin Shad	*Dorosoma petenense*
White Mullet	*Mugil curema*
White Shrimp	*Litopenaeus setiferus*

BYCATCH EXCLUSION DEVICES

Appendix 3. Example hose cage excluder devices illustrating the variation in hose cages across the fleet. Hose cages were grouped into three main clusters via a PCA analysis, based on the size, shape, and overall design.

Released Bycatch

Appendix 4. The rollover video coverage for observed sets.

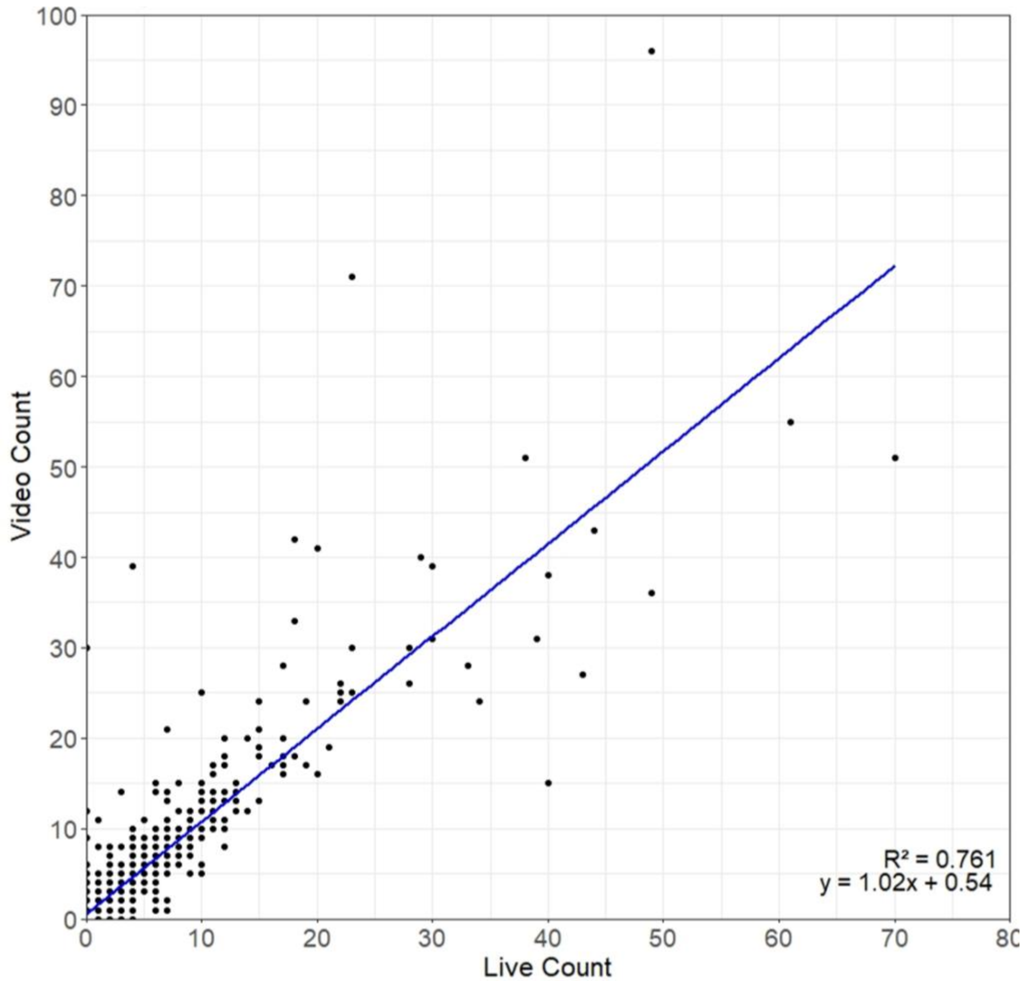
Camera types	Number of Sets
Two stationery and handheld	379
Two stationary and no handheld	10
One stationary and no handheld	4
One stationary and a handheld	13
Handheld only	6
No Video	3
Total	415

Appendix 5. The condition scoring criteria used by at-sea observers to assess released bycatch in the menhaden purse seine fishery (Benoît et al., 2012, 2010).

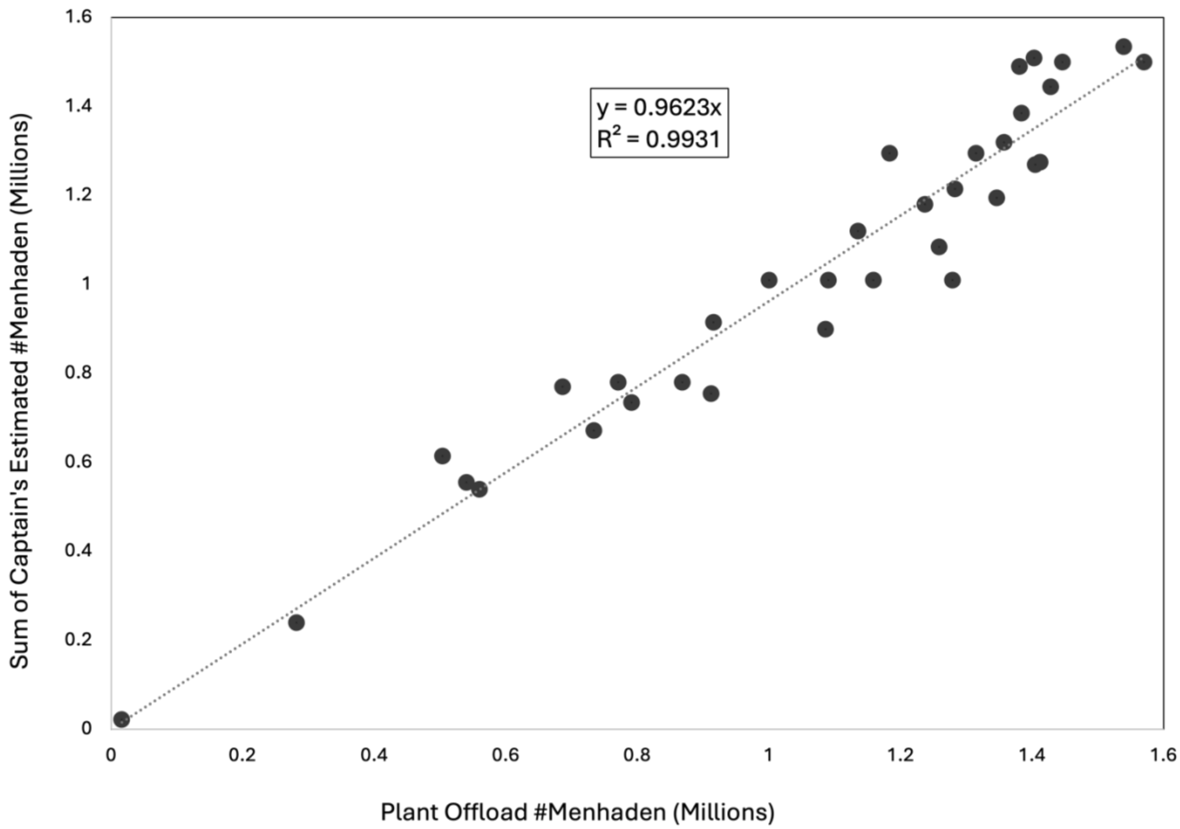
Condition	Code	Description
Excellent	1	Vigorous body movement. No minor[a] external injuries.
Good/fair	2	Weak body movement. Minor[a] external injuries.
Poor	3	No body movement, but opercular movement. Minor[a] or major[b] external injuries.
Mortality	4	No body or opercular movements. Major[b] external injuries or disfigured/decapitated specimen. Dead or moribund.
[a]Minor injuries were defined as minor bleeding or tears, moderate scale loss, or moderate fin damage. [b]Major injuries were defined as major bleeding, major tearing of body parts, damaged operculum, bloated swim bladder, or extensive scale loss (>50% coverage).		

Appendix 6. Final estimated percent survival of bycatch species as reported by the 24 hour holding study. See LGL report #8 for full details.

Source	Species	Survival Rate (%) [A]	Survival Rate (%) [B]
Rollover	Red Drum	83.91% (77.1 – 89.0)	82.76% (75.0 – 88.7)
	Black Drum	87.82% (77.5 – 94.1)	91.93% (81.7 – 96.5)
	Gafftopsail Catfish	73.46% (43.3 – 87.7)	73.46% (43.3 – 87.7)
Chute	Red Drum	2.0% (0.0 – 9.8)	2.3% (0.0 – 11.3)
	Black Drum	2.1% (0.0 – 11.1)	0% (0.0 – 8.3)
	Gafftopsail Catfish	39.1% (26.8 – 52.1)	38.7% (25.4 – 53.0)



Appendix 7. A comparison of live observer counts (x axis) and counts derived from video (y axis) in the rollover. Each point represents the count of an individual species in an individual net set. To avoid differences in counts due to differences in species identification between methods in this comparison, bull shark, blacktip shark, finetooth shark, and spinner shark were all classified as *Charcharinus sp.*, southern stingray, bluntnose stingray, and roughtail stingray were all classified as Dasyatidae, and all sea turtle species were also combined.



Appendix 8. A comparison of the captain's estimated catch within the hold versus the actual offload weight at the plant in millions of standard menhaden.