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ABSTRACT— Integration of electronic monitoring on commercial bottom longline vessels has been successfully conducted through several pilot studies in the U.S. Gulf of Mexico reef fish fishery. Collaborative work conducted from 2016 through 2021 by the Mote Marine Laboratory Center for Fisheries Electronic Monitoring at Mote (CFEMM) and 13 volunteer eastern Gulf fishing vessels resulted in observations of 82,936 individual fish from 131 unique species or species groups from 306 trips covering 2,822 sea days of fishing effort. The fishing area covered 114,268 km^2 *with capture depths ranging from 35 m to 360 m. The most predominantly caught species were red grouper,* Epinephelus morio *(65%); red snapper,* Lutjanus campechanus *(9%); and yellowedge grouper,* Epinephelus flavolimbatus *(5%). Of these species, 48%, 23%, and 2%, were discarded, respectively. Important bycatch species included blueline tilefish,* Caulolatilus microps*; scamp,* Mycteroperca phenax*; and gag grouper,* Mycteroperca microlepis*. Notably, sea turtle and sea bird interactions were minimal. Discards included undersized and depredated reef fish, along with a variety of shark species. Statistically significant spatial clusters of high catch per unit of effort (CPUE) hotspots, low CPUE cold spots, and random distributions are presented spatially joined to 10.0 min grids for primary targeted and bycatch species, grouped shark bycatch, and specifically for sandbar sharks,* Carcharhinus plumbeus*, a species that is prohibited from harvest, except under a NMFS research permit. This project demonstrates that electronic monitoring is an effective method for collecting catch and bycatch data from the commercial eastern Gulf of Mexico reef fish fishery. Increasing trip coverage and providing additional EM-derived data that complements observer reports would contribute to enriching the data available for supporting stock assessments and promoting sustainable fishing practices.*

Introduction

The U.S. Gulf of Mexico (hereafter referred to as "Gulf") commercial reef fish fishery involves more than 800 federally permitted vessels (Stephen[1]) using primarily bottom longline (BLL) and vertical hook-and-line (VL) gear (Scott-Denton et al., 2011; Pulver and Stephen, 2019). In the Gulf, off Florida's west coast, about 62 vessels have an eastern Gulf reef fish BLL endorsement (Stephen[1]). These vessels primarily target red grouper, *Epinephelus morio*, in shallow waters, and yellowedge grouper, *Epinephelus flavolimbatus*; tilefish (Malacanthidae); and snappers, *Lutjanus* spp., in deeper water (Scott-Denton et al., 2011).

Thirty-one of the reef fish within this multi-species complex in federal waters are managed by the Gulf of Mexico Fishery Management Council (GMFMC[2]) who implement plans or regulations based on quantitative scientific information provided through fish stock assessments to determine stock status and set annual catch limits to prevent overfishing (Mace et al., 2001). The Gulf reef fish industry and management agencies have an increased urgency to provide reliable data with the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006[3] requiring implementation of annual catch limits (ACL's) and accountability measures (AM's) to curtail overfishing (Farmer et al., 2016). Unfortunately, for many of the reef fish stocks there is limited data available for input into stock assessments (Farmer et al., 2016) and to inform management actions in support of sustainable fisheries (Lynch et al., 2018). Resulting uncertainty in a stock's status makes it difficult to be confident that overfishing is not occurring and the stock is not overfished (Methot, 2015)**.** Ultimately, robust, timely, and accurate catch, effort, and discard data is needed to support species-specific stock assessments and science-based management (Michelin et al., 2018).

The Gulf commercial reef fish fishery has relied on multiple sources for fishery-dependent data contributions, including onboard observers, dealer reports, port sampling, trip interviews, vessel monitoring systems (VMS), and captains' self-reported logbooks, all of which have their own data limitations. The National Marine Fisheries Service (NMFS) reef fish observer program, an important source for fishery-dependent data, is limited to sampling approximately 2% of the commercial reef fish trips annually, due to bud-

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[1] Stephen, J., Ph.D., personal commun., 1 April 2022. LAPP/DM Branch Chief, NOAA, NMFS Southeast Regional Office, 263 13th Ave South, St. Petersburg, FL 33701.

[2] GMFMC (Gulf of Mexico Fisheries Management Council. NOAA, Natl. Mar. Fish. Serv. Federally Managed Gulf of Mexico Reef Fish. (https://www.fisheries.noaa.gov/species/federally-managed-gulf-mexico-reef-fish).

[3] Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (https://www.govinfo.gov/content/pkg/CHRG-112shrg67219/html/CHRG-112shrg67219.htm).

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get constraints (Scott-Denton[4]). While data is plentiful on landed commercial catches (Stephen and Harris, 2010), these data do not reflect all of the fish that were caught, as discards can represent a large proportion of the total catch (van Helmond et al., 2014). This can be attributed to the fishery's high species diversity in combination with multiple fishing gear types and methods, which often results in the incidental captures of non-target (bycatch) or undersized species (Pulver and Stephen, 2019). Of fundamental concern to fishery managers is the contribution of discards to the overexploitation of stocks (Sissenwine et al., 2014, as cited in Pulver and Stephen, 2019). The fishermen have the opportunity to provide bycatch and corresponding discard information in voluntary self-reported discard logbooks, but historically these have been incomplete or questionable with reports of trips with "no discards," which is highly unlikely in a multispecies fishery where size and harvest limits necessitate regulatory discards (GMFMC[5]). Pulver and Stephen (2019) reported that biases associated with the commercial fishermen logbooks primarily result from inaccurate reporting of species that are caught in large numbers, are of little economic interest, and/or are from low compliance rates.

To supplement the collection of fishery-dependent data, electronic monitoring (EM) video technology has gained prominence over the last two decades as an additional approach for documenting catches in fisheries (Ames et al., 2007; Michelin et al., 2018; Bradley et al., 2019; Emery et al., 2018; van Helmond et al., 2020; Fujita et al.[6]). These systems typically include video cameras, a global positioning system (GPS), and gear sensors to record fishing activity. Similar to at-sea observers, EM offers advantages over gathering data on a particular fishery solely through monitoring portside landings (Ames et al., 2007), as it enables observations of fishing location coordinates, catch location and quantity, composition of the catch, and discarded fish. The permanent documentation of this information through video and sensors for subsequent review contributes to reducing data uncertainty (Ames et al., 2007; Michelin et al., 2018). Numerous studies have concluded that EM technology whether designed to augment onboard human observer programs or serve as a stand-alone application can effectively function as a data collection platform to broaden monitoring coverage of fishing activities (McElderry et al., 2003; Ames et al., 2007; Michelin et al., 2018; Bradley et al., 2019; Gilman et al., 2019; Wozniak et al., 2020). These findings have increasingly led to the integration of EM technology on commercial fishing vessels across various global fisheries, particularly in those where human observer coverage did not exist or where it is limited (Michelin et al., 2018; Bradley et al., 2019; Gilman et al., 2019; van Helmond et al., 2020).

In the Gulf region, EM systems have proven effective on commercial reef fish vessels in several pilot studies. These studies, notably those first conducted by Archipelago Marine Research (AMR), Ltd., Victoria, Canada, demonstrated the reliability of EM in documenting fishing effort and retained catch on BLL vessels (Pria et al.[7]). However, some limitations were noted that EM was less reliable for determining catch discards or species identification, which were mostly attributed to camera obstructions or dirty lenses (Pria et al.[7]; NOAA[8]). During a subsequent study in 2012–13, a collaborative effort led by the Ocean Conservancy, St. Petersburg, FL, with partners AMR, Gulf of Mexico Shareholders' Alliance, Galveston, TX, and Mote Marine Laboratory (Mote), Sarasota, FL, engaged both commercial BLL and VL vessels to further assess EM's suitability for capturing fishery data and validating captains' self-reported data. This initiative, eventually led Mote to spearhead the expansion of EM with a focus on the eastern Gulf starting in 2014. This expansion involved collaborations with various organizations, including AMR, Waterinterface Ltd., Wimauma, FL; Sustainable Fisheries Partnership Foundation, San Francisco, CA; Environmental Defense Fund, New York, NY; and the Gulf of Mexico Reef Fish Shareholders' Alliance, Galveston, TX. The expansion efforts not only included the addition of vessels, but also aimed to effectively address the limitations observed in the previous pilot studies. This encompassed improvements in camera coverage, refinement of documentation processes, addition of species for selection, and categorization of catch, non-targeted species of bycatch, and discards.

In 2016, Mote initiated a significant change by transitioning to a new EM hardware and software provider, Saltwater Inc., based in Anchorage, AK. This transition was driven by a National Marine Fisheries Service request for Mote to incorporate non-proprietary review and vessel software. The shift of adopting the non-proprietary EM vessel and review software brought several advantages, including reduced software costs and increased user flexibility, transparency, and accessibility.

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[4] Scott-Denton, E., Ph.D., personal commun. 16 June 2020. Fishery Observer Program Manager, NOAA Southeast Fishery Science Center, Galveston Laboratory, 4700 Avenue U, Galveston, TX 77551, USA.

[5] Gulf of Mexico Fishery Management Council (GMFMC), Sustainable Fisheries Committee. January 26, 2022. (Webinar Transcript) (https://gulfcouncil.org/wp-content/uploads/E-2-GMFMC-Sustainable-Fisheries-Minutes-January-2022.pdf).

[6] Fujita, R., C. Cusack, R. Karasik, H. Takade-Heumacher, and C. Baker. 2018. Technologies for improving fisheries monitoring. Environmental Defense Fund, San Francisco. 71. (https://fisherysolutionscenter.edf.org/sites/default/files/Technology_for_Improving_Fisheries_Monitoring.pdf).

[7] Pria, M. J., H. McElderry, M. Dyas, and P. Wesley. Using electronic monitoring to estimate reef fish catch on bottom longline vessels in the Gulf of Mexico: a pilot study. Unpublished report prepared for the National Marine Fisheries Service by Archipelago Marine Research Ltd., Victoria, British Columbia, Canada, 42 p. (https://www.yumpu.com/en/document/read/11507510/using-electronic-monitoring-to-estimate-reef-fish-catch).

[8] National Oceanic and Atmospheric Administration (NOAA). 2015. Electronic monitoring and reporting implementation plan - Southeast Region. January 8. (https://gulfcouncil.org/wp-content/uploads/E%20-%205%20EM%20ER%20Implementation%20Plan.pdf).

In addition to the non-proprietary software, Saltwater Inc. provided a more compact EM processor system that was particularly useful for vessels with limited space. This, coupled with the availability of in-state technical service staff, improved convenience, and lowered costs for installations and support for vessels utilizing the system.

In 2020, the Center for Fisheries Electronic Monitoring at Mote (CFEMM) was established with the goal of further enhancing fishery-dependent monitoring in the reef fish fishery utilizing EM as a tool. This initiative sought to augment traditional observer reporting by providing a complementary and supplementary method for data collection. The overarching objective of the CFEMM was to provide EM data products to inform industry stakeholders and Gulf management, assisting them in their efforts to enhance fisheries management practices.

This paper aims to demonstrate that EM technology applied in the eastern Gulf commercial reef fish BLL fishery is a valuable tool, capable of providing accurate, detailed characteristics of catch, bycatch, and discards. It highlights the significant contributions of volunteer industry stakeholders in generating a substantial amount of EM data on fishing operational metrics. Through general additive models, it examines temporal catch patterns and the spatial distribution of primary target and prominent bycatch species through hotspot/coldspot analysis. Additionally, the paper reports incidental sea turtle and sea bird catches, along with instances of catch depredation (damage) by sharks and/or marine mammals, documented by EM from July 2016 through December 2021. These findings contribute to a more comprehensive understanding of the fishery's spatial dynamics and serves to inform management for their consideration in efforts aimed to promote sustainable fishing practices for the long-term health of this fishery.

Methods

Through established industry partnerships, 13 BLL vessels from Madeira Beach, Redington Shores, and Cortez, Florida, voluntarily participated in pilot projects requiring the onboard installation of an EM system. Saltwater Inc. EM systems included an electronic monitoring unit (EMU) consisting of a Lanner control center computer processor (Model 5770-7D; Lanner Electronics, Inc, Fremont, CA) housed in a protective weather resistant and non-jarring case mount. The processor held two exchangeable 1-terabyte data hard drives, and stored data was encrypted through the EMU Linux operating system (OS). Each vessel was equipped with three or four closed-circuit, fixed-focal-length digital Internet Protocol (IP) cameras with light emitting diodes of one type or a combination of GeoVision Inc., Taiwan (Models GV-EVD3100 [3MP H.264, 1/2.8" progressive scan, low lux], and/or (GV-TDR2700 [2MP, 2.8, H.265, 2.8mm, low lux]), and or Vivotek Inc., Taiwan (Model FD8134V [1MP, H.264 IP66]).

Cameras were mounted using custom stainless steel brackets or a camera base plate based on captain and crew input; initial onboard testing confirmed that camera locations provided optimum coverage of fishing operations, including where catch was processed or discarded. Most vessels were also installed with custom aluminum retractable or stationary roof mounted vertical or horizontal booms to position one or more cameras overhead and/or extended over the rail to improve coverage of haul and discard areas. A multi-port power over Ethernet (POE) switch connected marine Category 5 Enhanced (CAT5e) camera cables to the EMU. An inline hydraulic sensor and a set of two magnetic reverse polarity rotation sensors installed on a mainline drum served to document when the vessel was setting and hauling gear and triggered video recording of gear retrievals. Video recording with no sound was activated at the start of the mainline being hauled and continued to approximately 30 min post-haul, based on software settings to allow for complete coverage of fish processing. A rooftop or cabin window mounted GPS receiver logged the vessel position, speed, and heading. The sensors and GPS recorded data continuously when the processor was powered on. A wheelhouse monitor displaying all camera views was used by the captain to watch deck activities in real time and for confirming EM system functionality.

Captains and crew were requested to power on their EMU prior to leaving port and to keep the system on during their fishing efforts. Systems could be powered down when the vessel wasn't fishing or if there were concerns of power limitations during their night fishing activities. Upon trip completion, hard drives were retrieved and replaced with reformatted hard drives. During vessel hard drive collections, captains and crew members provided additional trip and or system performance information.

At the CFEMM, vessel data was downloaded from the hard drives using an Intel Next Unit of Computing (NUC) processor with Saltwater Inc. software for conversion of the Linux encrypted data to a more user-friendly Microsoft Windows OS format. The resulting imagery and sensor data was subsequently stored on a dedicated server for retrieval to individual computer stations for review and backed up both pre- and post-review on a series of secure Synology Networked Attached System (NAS) units.

Imagery review was conducted using Saltwater Inc. non-proprietary review software modified specifically for this fishery. A preliminary review of the recorded sensor and video footage was made to identify which set-haul events (SHE's) were acceptable for full review and analysis. If a SHE was deemed not reviewable due to incomplete imagery or sensor information, it was removed from the individual trip dataset, reducing the total selectable events. Only reviewable SHE's remained in the trip data pool, from which 25% were randomly sampled from each trip using a "random-sampling-without-replacement" method.

Data associated with fishing activities represented trip, SHE, and catch-level information. Trip details recorded by the system included the trip duration, time, and location of sets and hauls. In the review software the video reviewers selections were keyed into a custom template from a series of drop-down menus. Trip level entries included the offload port, whether an observer was onboard, and specific gear characteristics, including longline leader material and hook type. Confirmation of hook sizes used were documented during vessel visits, and provided captain questionnaires. Bait types were also selected at the overall trip level based on reviewed hauls. Information collected at the SHE level included the timing and location of the gear set and haul. Each caught fish was identified to the lowest taxonomic level possible, with more than 200 individual species or species grouping options available for selection. An "unidentified" code was available when identification could not be discerned. For sharks that could not confidently be identified to species level, particularly those released at the rail while underwater, three classification groupings were available for selection including, shark unidentified, carcharhinid unidentified, and hammerhead unidentified. Individual fish catch characteristics, including handling, condition upon capture, and fate selection options included 1) Handling: brought onboard, not handled (dropped off), cutoff at rail (no entanglement), cutoff at rail (entanglement), or unknown handling; 2) Condition: live healthy, live stomach and/or eyes protruding, live damaged, dead (damaged), dead (undamaged), or unknown condition; and 3) Fate: retained, retained as bait, discarded live healthy (vented), discarded live healthy (not vented), discarded live damaged (vented), discarded live damaged (not vented), discarded dead, discarded unknown, or unknown fate. Specific to shark bycatch, juvenile or adult status was selected and an estimated size category of small (< 1 m), medium (1 to 2 m), or large (> 2 m) was assigned. If possible, sex was recorded based on the presence or absence of claspers. Unknown maturity and sex were recorded when neither could be determined.

A series of manual and automated quality control steps were taken with the resulting species detailed recorded information, referred to as annotations, prior to export into a Microsoft Access database, including confirmation of species identification, accuracy of assigned condition, and fate. Trip dataset annotations were aggregated using an R statistical software routine[9], which enacted 75 explicit error checks. Aggregated data underwent thorough checks for missing information and inconsistencies, such as handling codes that did not align with fish fate. Any identified issues were automatically detailed in a report, allowing the opportunity to resolve any problems prior to importing the dataset into the final database. Finalized data were then spatially joined using R code to link metadata including bathymetry information to enable depth estimation for catch events.

For the presented work, effort was calculated as the product of hook number and soak time in hook-hours. Soak time was defined as the start of the longline (mainline) deployment through the recovery of the last hook (McCarthy[10]). The standard regulatory hook count for this fishery was 750 hooks per longline (NMFS[11]). This number was used as the estimated amount of hooks utilized per set to calculate effort. Catch rates were calculated by number of fish (both species-specific and total number) per hook-hour scaled by 1,000 hooks to standardize the CPUE calculations, following a protocol used by Scott-Denton et al. (2011).

Generalized Additive Model (GAM) Methods

Inter-annual patterns in CPUE estimates using GAM's were depicted (Hastie and Tibshirani, 1987). For each species of interest, the GAM applied a nonparametric smoothing function for data and was fitted using the GAM function in R[9]. The degrees of freedom associated with fitting each smoothing function (k) were chosen by identifying local minima in generalized cross validation scores; the smallest k value associated with a local minima was selected for each GAM.

Geographic Information System (GIS) Methods and Spatial Analysis

Spatial analysis was based on a stepwise procedure using geospatial statistics that leveraged spatial heterogeneity inherent in fishing activities. The uniquely precise locations of individual fish annotations provided by EM systems functioned as proxies for catch location and covariate responses for assessment of spatial distributions including global spatial autocorrelation (Global Moran's l), local indicators of spatial association (LISA's), and response variable density maps. Therefore, areas of concentrated fishing effort and fine-scale aggregations of target and non-target fishes were identified and used to describe particular areas of fishing activity in terms of localized fish density.

Fishing activity was quantified by use of a convex polygon to define the fishing area encompassing all annotated catch, and kernel density was used to illustrate fishing effort intensity. Fishing effort for all species, all vessels, and all years reported was defined and mapped using simple point density analysis, with raster cell size and search radius determined following the methods of Scott-Denton, et al. (2011), executed in ArcGIS Pro 2.8[12]. To derive point density rasters, the analysis em-

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[9] R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria (https://www.R-project.org/)

[10] McCarthy, K. J., Ph.D., personal commun. 2017 April 11. Branch Chief, NOAA Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

[11] National Marine Fisheries Service (NMFS). Final rule modifies the number of unrigged hooks carried on board bottom longline vessels in the Gulf of Mexico (https://www.fisheries.noaa.gov/bulletin/final-rule-modifies-number-unrigged-hooks-carried-board-bottom-longline-vessels-gulf).

[12] ESRI. 2020. ArcGIS Pro Desktop. Release 2.8. Environmental Systems Research Institute, 380 New York Street, Redlands, CA. 92373 (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

ployed a search radius of 25 km and an isotropic circular cell size of 5,000 m, with results reported as hook-hours/km^2. The Jenks Natural Breaks Classification (Jenks, 1967) was used for raster maps to minimize the average deviation from the class mean while maximizing the deviation from the means of all other groups. Annotated catch and initial set locations were mapped using the World Geographic Coordinate System GCS_WGS_1984. Specific locations and distances were mathematically projected using a transformation from spherical coordinates (latitude and longitude) to an XY (planar coordinate system) known as WGS_1984_World_Mercator, WKID-3395 Authority-EPSG. Additionally, LISA's, referenced as "hot spot" and "cold spot" analyses, were primarily analyzed using the local spatial statistic Optimized Hot Spot Analysis, executed in ArcGIS Pro 2.8[12] following Getis and Ord (1992) and Ord and Getis (1995) for species-specific CPUE, all sharks CPUE, and red grouper discard proportion. False positives were evaluated by the statistic during execution and false discovery executed if optimal. Z-score, p-value, and confidence level bin (Gi_Bin) were the final results of the analysis. Features in the ±3 bins reflect statistical significance with a 99% confidence level; features in the ±2 bins reflect a 95% confidence level; features in the ±1 bins reflect a 90% confidence level; and the clustering for features in bin 0 were not statistically significant. A 0.05 significance level was selected for spatial hot spot identification. Hot spot and cold spot centroids were averaged, aggregated, and spatially joined to 10 min grid cells (10.0 min x 10.0 min; 18.5 km x 20.4 km; 377.4 km^2) as areal features using a one to one operation; match option = within; merge rule = mean, final CPUE Gi bins were aggregated to grids as mean bin probability and were symbolized accordingly.

Results

Vessel Participation and Sampling Effort

From July 2016 through December 2021, 13 eastern Gulf commercial BLL reef fish vessels provided EM video from 306 trips covering 2,822 sea days. Most vessels fished for periods of 10–14 days with a crew of 2–4. Vessel lengths ranged from 37.2–48.4 ft (11.34–14.75 m) and each used a single drum and one mainline made of either braided stainless steel or monofilament averaging 4.95 nmi (9.2 km). Monofilament gangions (250–300 lb test) of 3–6 ft (1–2 m) in length were set with up to 750 baited non-stainless steel circle hooks as per NMFS regulations (GMFMC[13]). The participating reef fish vessels generally used Mustad, Miami, FL, offset circle hooks from a size of 12/0 to a larger size of 15/0, with 13/0 being the most commonly used option. The frequency of longline deployments ranged from two to four per day, with most occurring during daylight hours. Typical soak times were 3–4 h, from the beginning of the set to the end of the haul.

The area of fishing activity encompassed 114,268 km^2 and spanned the northern Gulf from near the Madison Swanson marine protected area to south, proximate to the Dry Tortugas. This region reflects the U.S. Gulf statistical zones 2–6 and 8–9, with depths ranging from 34 m to 360 m at the edge of the Florida Escarpment (Fig. 1). The cumulative fishing effort amounted to 5,159,933 hook-hours. Predominantly, the fishing effort occurred in zones 4 and 5, constituting 31% (1,584,151 hook-hours) and 38% (1,939,577 hook-hours) of the total effort, respectively. Notably, these zones represent only 39% of the total fishing area defined by the fishing polygon in Figure 1.

In zones 4 and 5, fishing effort was generally located proximal to the vessel's home ports, centered in three high density areas, including lat. 27°30'N long. 83°30'W, lat. 26°30'N long. 83°20'W, and lat. 27°0'W long. 83°20'N. Highest density fishing effort kernels of approximately 16,000–19,000 hook-hours/km^2, encompassed large areas in zone 5, approximately 149.0 km^2 and 413.6 km^2, respectively (Fig. 1). In zone 4 the fishing effort covered approximately 43.8 km^2. No fishing events were recorded in zone 7.

Fishery-dependent data presented here resulted from the review of 1,796 hauls representing the established 25% of all potentially analyzable SHE's. The remaining 75% of SHE's were archived. Annual video sampling rates are shown in Figure 2. Subsequent event review resulted in 82,936 individual annotated fish (Fig. 3) from 131 unique species or species groups.

Bait

Bait types used during the recorded trips, though not necessarily each haul, mirrored the typical selection used in this fishery during the specified time period. The choice of bait varied based on a captain's preference, availability, and opportunities presented by bycatch. On most trips there was a mix of different baits used, with herring being the most common, utilized in 65% of the trips. Eels, remoras, and grouper stomachs made up the majority of the caught bait category, accounting for 63% of trips. Assorted fish scraps, known as trim, were presented on 21% of trips and included scraps such as bloodlines brought on the trip from fish processing, consisting of a variety of fresh and saltwater species. Squid was used on 14% of trips, exhibiting a decrease over time compared to earlier periods. Salted shark belly meat acquired from the commercial shark fishery was used on 4% of the trips.

Catch Composition and Characterization

All BLL catches recorded through EM are presented in Table 1, with the most predominant species being red grouper (*n* = 53,740), constituting 65% of the total recorded catch. The average capture depth for this species was 52 m, with minimum and maximum depths of 36 m and 130 m, respectively. Red grouper were recorded with physical attributes of barotrauma 42% of the time (Table 2), and fish-

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[13] Gulf of Mexico Fishery Management Council (GMFMC). 2019. Commercial fishing regulation for Gulf of Mexico federal waters. Tampa, FL, 52 p. (https://gulfcouncil.org/wp-content/uploads/commercial-regulations.pdf).

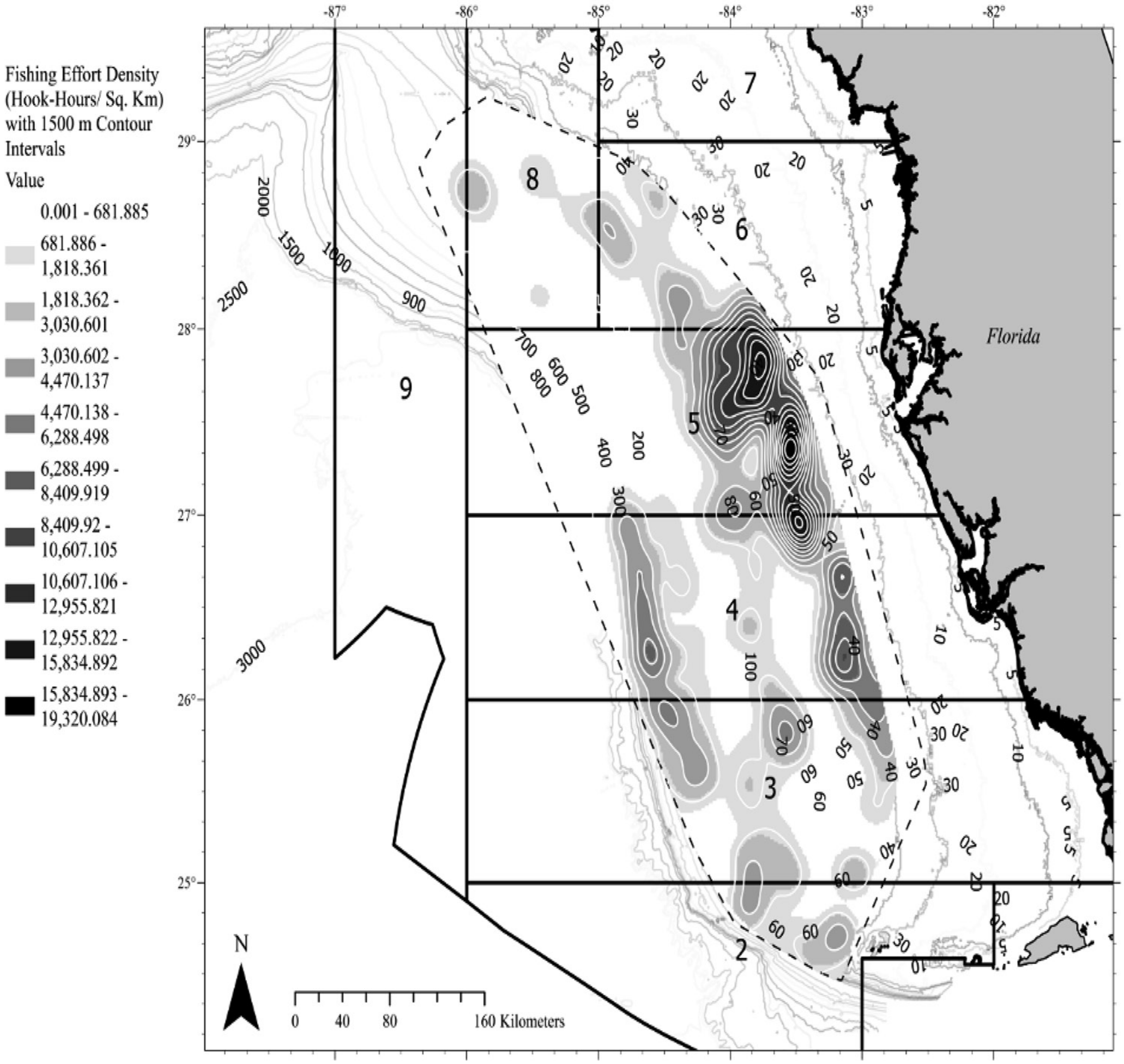

Figure 1.—Fishing area (dashed line convex polygon) with kernel density raster partitioned by 1,500 m contours overlaying NMFS statistical zones 2-9 to define participating electronic monitoring vessels fishing areas and kernels of most intense fishing effort with bathymetry from July 2016 through December 2021.

ermen were twice as likely to vent the fish prior to release than not (Table 3). This primary target species was documented as damaged by predators, evidenced by a partial carcass or distinct rake marks, at a rate of 1%. Nearly half of red grouper (48%) were discarded, although rates varied across the fishing area with higher discard rates in shallower depths shoreward of 50 m (Fig. 4). The largest aggregations of high confidence (≥ 95%) CPUE hot spots occurred in 19 grid cells, centered at lat. 27°57'N, long. 83°73'W, comprising an area of 7,163 km^2 (Fig. 5). This area of highly efficient fishing also approximates the same general locations where fishing effort was the highest (Fig. 1). High confidence CPUE hot spots included an additional 17 grid cells from approximately lat. 26°93'N, long. 83°57'W to lat. 25°60'N, long. 82°74'W, running northwest to southeast, which generally approximated the 50 m isobath, and comprised approximately 6,416 km^2. An additional grouping of three cells was also pres-

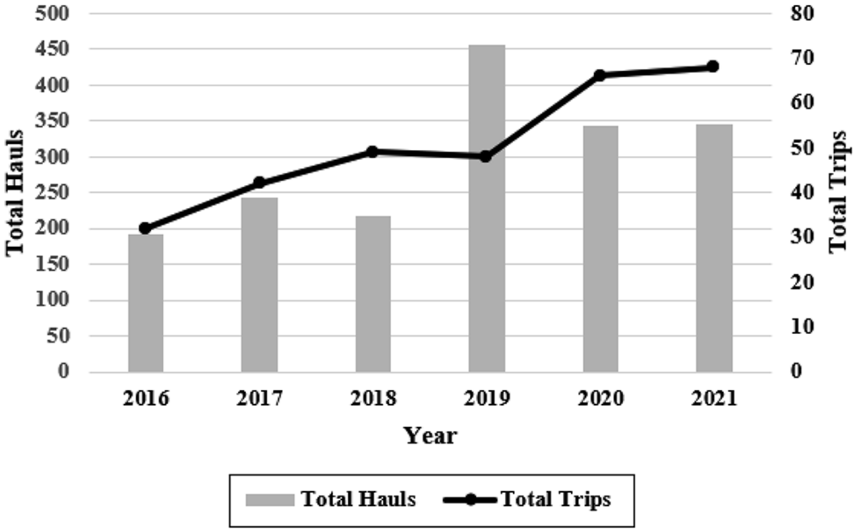

Figure 2.—Total hauls reviewed and total trips recorded from participating eastern Gulf of Mexico bottom longline vessels.

ent in the northern most area adjacent to the Florida Middle Grounds at lat. 28°45’N, long. 84°20’W. Red grouper CPUE was generally low (cold spots) seaward of the 60 m isobath. Peaks of CPUE for this species occurred annually between October and March throughout the study period (Fig. 6), straddling the June through September BLL closure inside 35 fathoms interannually (Fig. 7).

Similar observations were seen for red snapper (Fig. 6), which made up 9% of the catch (*n* = 7,154). Approximately one quarter were discarded and venting was recorded during half of the discard events. Predation was recorded for 2% of the individuals (Table 3). Capture depth ranged from 36 m to 168 m with an average of 64 m. The CPUE hot spots were located in two main groupings (Fig. 8). The largest aggregation of high confidence CPUE hot spots occurred in nine grid cells centered at lat. 27°66’N, long. 84°06’W and comprised an area of 3,397 km^2. A northern group centered at lat. 28°53’N, long. 84°86’W comprised five grid cells and an area of 1,887 km^2. There were two additional red snapper hot spot grid cells located in the south central and southern part of the fishing area, centered at lat. 29°17’N, long. 88°62’W and lat. 24°85’N, long. 83°26’W, respectively. A conspicuous area of red snapper cold spots was located inshore between 30 and 40 m isobaths centered at lat. 27°50’N, long. 83°54’W and located in an area of intense red grouper fishing with high catch efficiency. The CPUE rates for this species were relatively stable, with the exception of elevated CPUE in 2018 (Fig. 6).

Yellowedge grouper was the most targeted reef fish species on trips that focused on the deepwater grouper and tilefish complex, resulting in the third highest number of annotations (*n* = 4,237; 5% of the catch). Average capture depth was 213 m, with the shallowest at 69 m, and the deepest from 301 m. Due to a lack of size limits, total discards for this species were minimal (2%), with most of the discards attributed specifically to observed physical predator damage (1%), or juvenile individuals. The CPUE hot spots were aggregated in grid cells approximating the 100–300 m isobaths in northern and southern groups centered near lat. 28°84’N, long. 85°73’W and lat. 26°21’N, long. 84°21’W, respectively (Fig. 9). There were 6 complete high confidence grid cells and 2 partial cells in the northern group while the southern grouping contained 12 cells and 1 partial cell. Widespread cold spots were found adjacent to these hotspot groupings. The CPUE for this species was highest in 2017 (Fig. 6), and during times of the year where red grouper were targeted less (Fig. 7).

Blueline tilefish, *Caulolatilus microps*, were most often caught (*n* = 3,077) while fishermen targeted yellowedge grouper in similar average depths of 213 m. Despite the absence of a regulatory size limit for this species, the reluctance of the fishermen to utilize quota for retaining them led to high grading. This involved discarding them (17%) or using them as bait (5%), allowing for the retention of species with higher market value. Their CPUE hot spots were mainly aggregated between the 100–300 m isobaths in two distinct groupings centered near lat. 26°70’N, long. 84°46’W (three grid cells) and at lat. 25°92’N, long. 84°47’W with two partial and one full grid cell (Fig. 10). The CPUE for this species generally increased over the period and was the highest in late 2020 (Fig. 6).

Scamp, *Mycteroperca phenax*, catches ranged in depths from 44 m to 178 m with 1,127 individuals recorded. Discards were minimal (3%) with few undersized or damaged individuals. Their hotspots were typically further offshore than those of red grouper, with an average depth of capture of 83 m. A large northern group of six high confidence cells was centered near lat. 27°91’N, long. 84°44’W, comprising an area of 2,264 km^2. A single hot spot cell occurred along the same isobath near lat. 27°26’N, long. 84°06’W, and a rather deep partial hotspot cell was located at the 200 m isobath near lat. 25°44’N, long. 84°39’W (Fig. 11). The CPUE for this species was nearly twice as high when this study was initiated in late 2016 than in following years, though relatively elevated CPUE was seen during spring 2018 and fall 2021 (Fig. 12).

Similarly, gag grouper, *Mycteroperca microlepis*, capture (*n* = 960) depth ranged from 37 m to 163 m with an average depth of 78 m. Overall discards were also low (8%) when compared to red grouper and red snapper, as under-

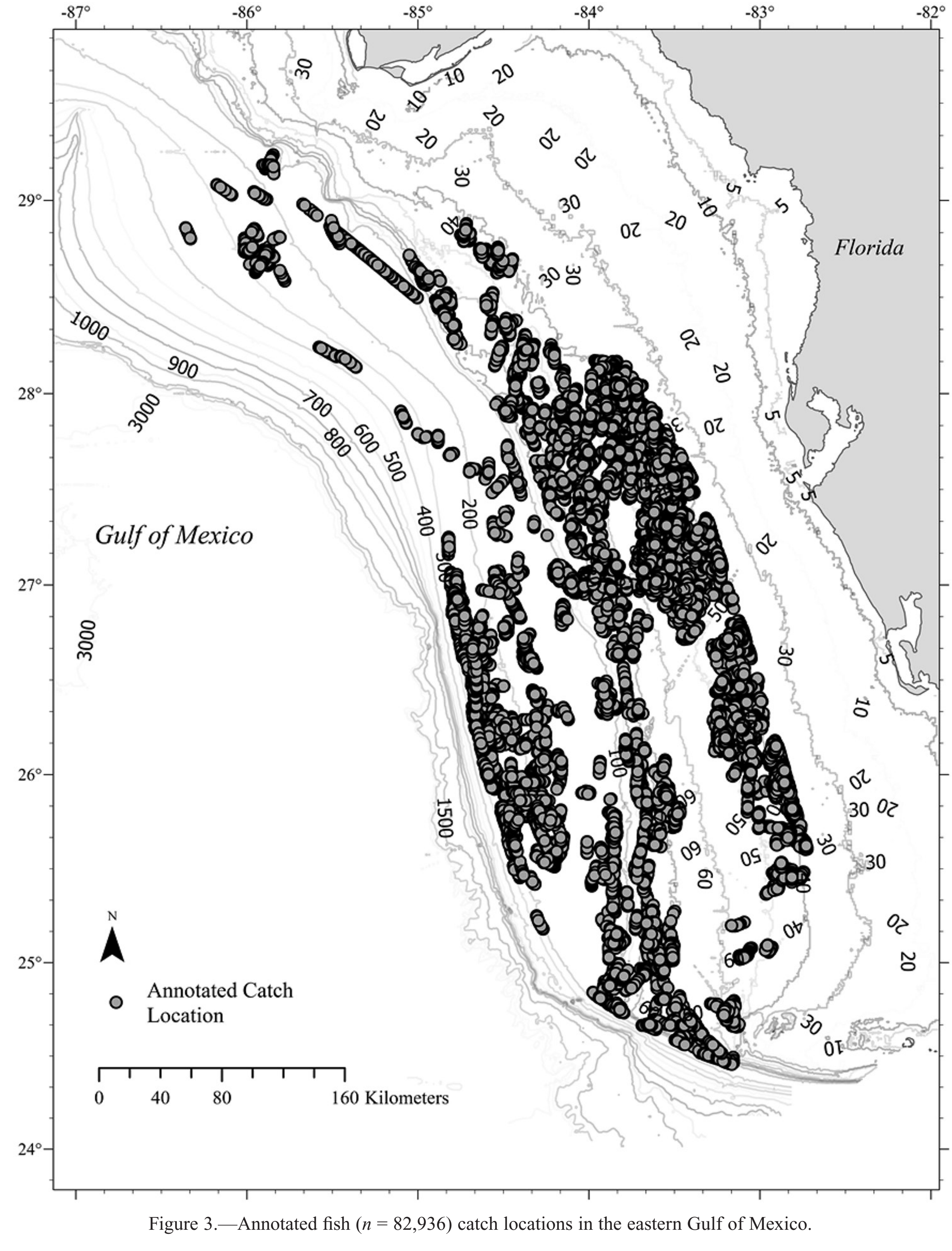

Figure 3.—Annotated fish (*n* = 82,936) catch locations in the eastern Gulf of Mexico.

sized individuals were infrequently encountered. Discounting individuals of this species that were lost at the surface (broke leader or fish dropped off) and those with predator damage, gag grouper generated a discard rate of 2%. Their catch rates did not indicate significant clustering between 28°N and 24°N. A single group of 12 adjacent cells (Fig. 13) were located around a center point at lat. 28°57'N, long. 84°91'W, covering 4,529 km^2. The CPUE for gag grouper nearly mirrored trends seen in scamp during 2017–21, with the exception of comparatively lower CPUE in 2016 (Fig. 12).

Shark Bycatch

Twenty species of sharks were caught (Table 1), totaling 5% of all annotated catch (n = 3,973). When comparing sharks separately from the rest of the catch, the Atlantic sharpnose shark, *Rhizoprionodon terraenovae* (23%), and sandbar shark, *Carcharhinus plumbeus* (15%), were the most commonly caught, followed by the blacknose shark, *Carcharhinus acronotus* (13%), smooth dogfish, *Mustelus* spp. (11%), and spiny dogfish, *Squalidae* (9%). Smooth dogfish (n = 428) were grouped, potentially representing three species of *Mustelus* present in the region (Giresi et al., 2015). The spiny dogfish category (n = 378) consisted of a variety of deepwater dogfish species, including Cuban, *Squalus cubensis*; shortspine, *Squalus mitsukurii*; and roughskin, *Cirrhigaleus asper*, but primarily consisted of the smaller Cuban and shortspine dogfish. The larger roughskin dogfish were rarely encountered. Cuban and shortspine dogfish in particular were difficult for reviewers to differentiate and recent discoveries of new dogfish species in the region complicated identification (Pfleger et al., 2018). Of the sharks recorded, 18% were species that were prohibited to harvest both commercially and recreationally in state and federal waters. These included sandbar, night, *Carcharhinus signatus*; dusky, *C. obscurus*; sixgill, *Hexanchus* spp.; sharpnose sevengill, *Heptranchias perlo*; and angel sharks, *Squatina dumeril*.

Table 1.—Species in descending frequency of occurrence for participating bottom longline vessels fishing the eastern Gulf of Mexico from July 2016 through December 2021.

Common name	Scientific name	Number caught	Relative frequency (%)
Red Grouper	*Epinephelus morio*	53,740	64.80
Red Snapper	*Lutjanus campechanus*	7,154	8.63
Yellowedge Grouper	*Epinephelus flavolimbatus*	4,237	5.11
Blueline Tilefish	*Caulolatilus microps*	3,077	3.71
Scamp	*Mycteroperca phenax*	1,127	1.36
Gag Grouper	*Mycteroperca microlepis*	960	1.16
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	912	1.10
Mutton Snapper	*Lutjanus analis*	776	0.94
Snowy Grouper	*Epinephelus niveatus*	683	0.82
Jolthead Porgy	*Calamus bajonada*	612	0.74
Sandbar Shark	*Carcharhinus plumbeus*	597	0.72
Blacknose Shark	*Carcharhinus acronotus*	514	0.62
Tilefish, Golden	*Lopholatilus chamaelonticeps*	459	0.55
Speckled Hind	*Epinephelus drummondhayi*	430	0.52
Dogfish, Smooth	*Mustelus* spp.	428	0.52
Moray Eel, Unidentified	*Muraenidae*	419	0.51
Lane Snapper	*Lutjanus synagris*	406	0.49
Dogfish, Spiny	*Squalidae*	378	0.46
Eel, Unidentified	*Anguilliformes*	375	0.45
Red Porgy	*Pagrus pagrus*	345	0.42
Gray Snapper	*Lutjanus griseus*	325	0.39
Tiger Shark	*Galeocerdo cuvier*	316	0.38
Remora	*Echeneidae*	307	0.37
Great Barracuda	*Sphyraena barracuda*	271	0.33
Nurse Shark	*Ginglymostoma cirratum*	237	0.29
Almaco Jack	*Seriola rivoliana*	227	0.27
Vermilion Snapper	*Rhomboplities aurorubens*	206	0.25
Pufferfish	*Tetraodontidae*	202	0.24
Gray Triggerfish	*Balistes capriscus*	194	0.23
Greater Amberjack	*Seriola dumerili*	190	0.23
Lizardfish	*Synodus* spp.	183	0.22
Shark, Unidentified	*Selachimorpha*	183	0.22
Hake, Unidentified	*Gadiformes*	176	0.21
Blackfin Tuna	*Thunnus atlanticus*	165	0.20
Silky Shark	*Carcharhinus falciformis*	148	0.18
Little Tunny	*Euthynnus alletteratus*	146	0.18
Toadfish	*Opsanus* spp.	132	0.16
Silk Snapper	*Lutjanus vivanus*	100	0.12
Night Shark	*Carcharhinus signatus*	74	0.09
Snakefish	*Trachinocephalus myops*	72	0.09
Crab, Unidentified	*Brachyura*	71	0.09
Coral	*Anthozoa*	64	0.08
Lionfish	*Pterois* spp.	60	0.07
Unidentified Bottom Debris	Unidentified Bottom Debris	60	0.07
Banded Rudderfish	*Seriola zonata*	56	0.07
Dolphin Fish (Mahi mahi)	*Coryphaena hippurus*	56	0.07
Queen Snapper	*Etelis oculatus*	56	0.07
Scalloped Hammerhead	*Sphyrna lewini*	54	0.07
Black Grouper	*Mycteroperca bonaci*	53	0.06
Sponge	*Porifera*	51	0.06
Blackfin Snapper	*Lutjanus buccanella*	48	0.06
Scorpionfish, Spiny Cheek	*Neomerinthe hemingwayi*	48	0.06
Carcharhinid, Unidentified	*Carcharhinus* spp.	42	0.05
Knobbed Porgy	*Calamus nadosus*	40	0.05
Sand Perch	*Diplectrum formosum*	37	0.04
Finfish, Unidentified	Unidentified Teleost	36	0.04
Cobia	*Rachycentron canadum*	35	0.04
King Snake Eel	*Ophichthus rex*	33	0.04
Yellowtail Snapper	*Ocyurus chrysurus*	32	0.04
Flatfish	*Pleuronectiformes*	26	0.03
Amberjack, Unidentified	*Seriola* spp.	24	0.03
Squirrelfish	*Holocentrus adscensionis*	24	0.03
Wahoo	*Acanthocybius solanderi*	24	0.03
Tilefish, Sand	*Malacanthus plumieri*	23	0.03
King Mackerel	*Scomberomorus cavalla*	22	0.03
Spinner Shark	*Carcharhinus brevipinna*	21	0.03
Starfish	*Asteroidea*	21	0.03
Sixgill Shark	*Hexanchus* spp.	18	0.02
Bank Sea Bass	*Centropristis ocyurus*	17	0.02

Table continued

Table 1.—*Continued.*

Common name	Scientific name	Number caught	Relative frequency (%)
Invertebrate, Unidentified	Invertebrate	17	0.02
Margate	*Haemulon album*	17	0.02
Blackbelly Rosefish	*Helicolenus dactylopterus*	15	0.02
Skates or Rays, Unidentified	*Batoidea*	15	0.02
Grouper, Unidentified	*Epinephelinae*	14	0.02
Great Hammerhead	*Sphyrna makarran*	11	0.01
Jack Crevalle	*Caranx hippos*	11	0.01
Lemon Shark	*Negaprion breirostris*	11	0.01
Unidentified	Unidentified	10	0.01
Warsaw Grouper	*Epinephelus nigritus*	10	0.01
Tilefish, Blackline	*Caulolatilus cyanops*	9	0.01
Bearded Brotula	*Brotula barbata*	7	0.01
Blacktip Shark	*Carcharhinus limbatus*	7	0.01
Conger Eel	*Conger oceanica*	7	0.01
Dusky Shark	*Carcharhinus obscurus*	7	0.01
Snapper, Unidentified	*Lutjanidae*	7	0.01
Swordfish	*Xiphias gladius*	7	0.01
Barrelfish	*Hyperoglyphe perciformis*	6	0.01
Common Octopus	*Octopus vulgaris*	6	0.01
Hammerhead, Unidentified	*Sphyrna* spp.	6	0.01
Goliath Grouper	*Epinephelus itajara*	5	0.01
Littlehead Porgy	*Calamus proridens*	5	0.01
Loggerhead Sea Turtle	*Caretta caretta*	5	0.01
Porgy, Unidentified	*Sparidae*	5	0.01
Rock Hind	*Epinephelus adscensionis*	5	0.01
Brown Pelican	*Pelecanus occidentalis*	4	<0.01
Cubera Snapper	*Lutjanus cyanopterus*	4	<0.01
Scorpionfish, Longspine	*Pontinus longispinis*	4	<0.01
Wenchman	*Pristipomoides aquilonaris*	4	<0.01
African Pompano	*Alectis ciliaris*	3	<0.01
Bull Shark	*Carcharhinus leucas*	3	<0.01
Chain Catshark	*Scyliorhinus retifer*	3	<0.01
Gull, Unidentified	*Laridae*	3	<0.01
Lobster, Unidentified	*Achelata*	3	<0.01
Scorpionfish, Spotted	*Scorpaena plumieri*	3	<0.01
Short Bigeye	*Pristigenys alta*	3	<0.01
Yellowfin Tuna	*Thunnus albacares*	3	<0.01
Sharpnose Sevengill Shark	*Heptranchias perlo*	2	<0.01
Billfish, Unidentified	*Istiophoriformes*	2	<0.01
Cornetfish, Red	*Fistularia petimba*	2	<0.01
Grunt, Unidentified	*Haemulidae*	2	<0.01
Herring Gull	*Larus argentatus*	2	<0.01
Sailfish, Atlantic	*Istiophorus albicans*	2	<0.01
Skipjack Tuna	*Katsuwonus pelamis*	2	<0.01
Whitebone Porgy	*Calamus leucosteus*	2	<0.01
Yellowmouth Grouper	*Mycteroperca interstitialis*	2	<0.01
Angel Shark	*Squatina dumeril*	1	<0.01
Atlantic Bonito	*Sarda sarda*	1	<0.01
Bigeye	*Priacanthus arenatus*	1	<0.01
Bluefish	*Pomatomus saltatrix*	1	<0.01
Clearnose Skate	*Raja eglanteria*	1	<0.01
Coney Grouper	*Cephalopholis fulva*	1	<0.01
Crustacean, Unidentified	Crustacean	1	<0.01
Dog Snapper	*Lutjanus jocu*	1	<0.01
Gannet	*Morus bassanus*	1	<0.01
Goosefish	*Lophius americanus*	1	<0.01
Graysby Grouper	*Epinephelus cruentatus*	1	<0.01
Laughing Gull	*Leucophaeus atricilla*	1	<0.01
Longtail Bass	*Hemanthias leptus*	1	<0.01
Seabird, Unidentified	*Aves*	1	<0.01
Sheepshead	*Archosargus probatocephalus*	1	<0.01
Triggerfish, Unidentified	*Balistidae*	1	<0.01

In total, unidentified sharks accounted for a low percentage (6%).of the total shark catch.

Nearly 94% of the sharks arrived at the vessels alive, but some shark species were more adept at surviving on commercial BLL fishing gear than others, as reflected in Table 4. Notable shark species with high survival included blacknose (97%), sandbar (100%), and tiger, *Galeocerdo cuvier* (100%). In comparison, silky sharks, *Carcharhinus falciformis*, arrived at vessels dead 34% of the time, while the scalloped hammerhead, *Sphyrna lewini*, had an at-vessel mortality rate of 39%. Dusky sharks were the most likely to succumb from capture with a 43% mortality rate. Of the sharks that arrived at a vessel, only 8% were removed from the population by being discarded dead or retained as bait. Small coastal sharks, including the Atlantic sharpnose and blacknose, represented the majority of those retained as bait, as well as juvenile silky sharks. A total of 1% of all sharks were recorded as having an “unknown condition” at capture, and 0.5% that had an “unknown fate.”

Among the shark bycatch, 56% had biological information documented through EM review, providing valuable data for further analysis. This included 30% whose sex was determined by the presence or absence of claspers, resulting in 755 females and 423 males. Based on size range, there were 405 juveniles and 645 identified as an adult. Sharks classified as small (<1 m) included juveniles, deepwater sharks, and small coastal species, comprising 42% of the shark catch. Large sharks (>2 m) were mainly adults and accounted for 18% of all recorded sharks.

Examining all shark species collectively, hotspots of CPUE were identified in the extreme northwest and southeastern corners of the fishing area (Fig. 14). However, extensive clustering patterns were not observed for most of the entire fishing area, resulting in no cold spots being observed and indicating a predominantly random distribution. Two complete and one partial hotspot occurred at greater depths in the northwestern area centered near lat. 28°94’N and long. 86°00’W, driven by dogfish shark species catches, with one additional cell occurring due east in shallower depths. The southeastern cluster of two grid cells was centered near lat. 24°78’N, long. 83°12’W encompassing 755 km^2, and represented a variety of different species encountered. When all shark species were grouped, CPUE remained relatively stable, ranging from approximately 1.0 to 1.3 indi-

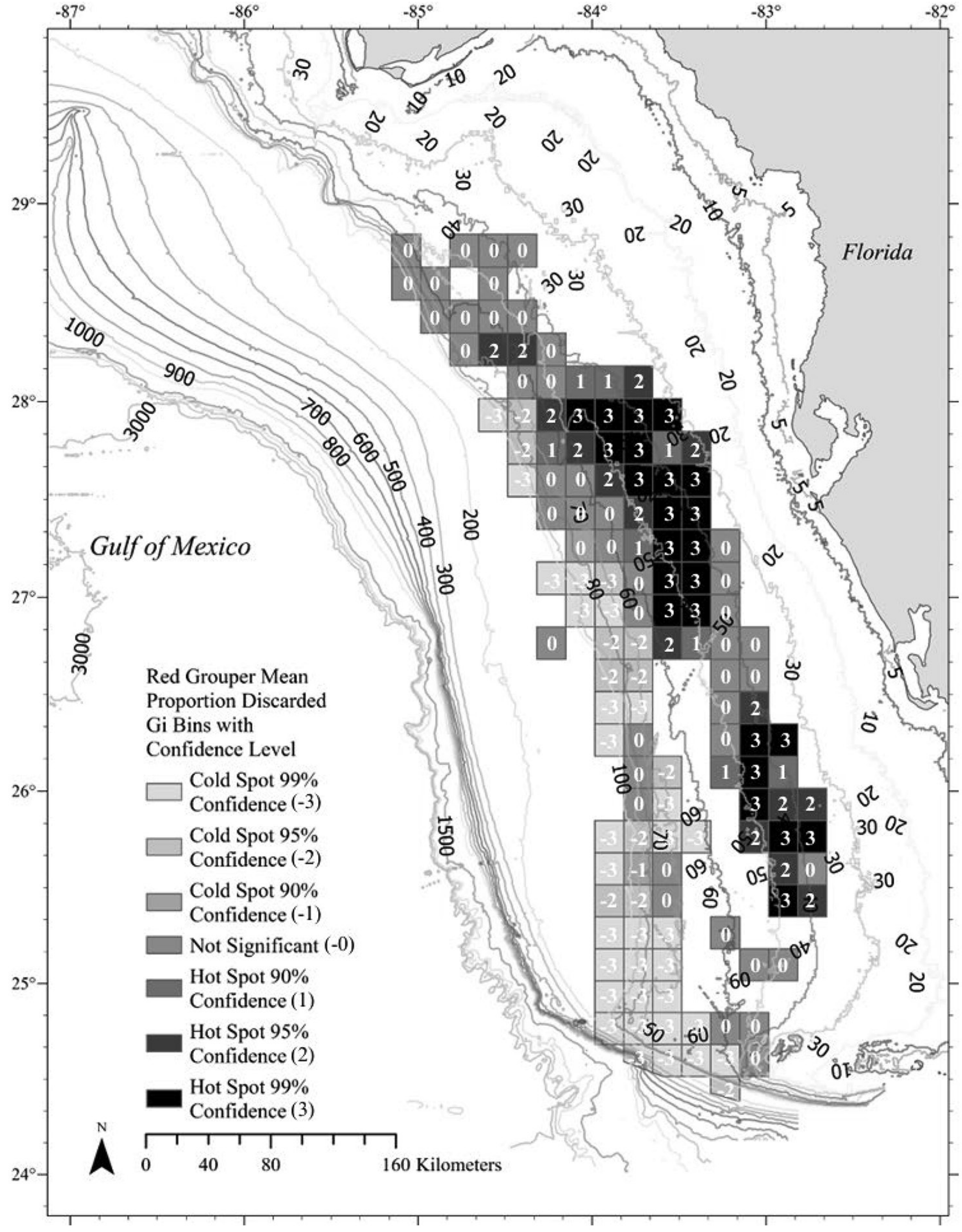

Figure 4.—Spatial clusters of mean high value (hotspot), low value (coldspot), and random distributions of the proportion of landed red grouper discarded at sea spatially joined to 10.0-min grids from bottom longline vessels fishing the eastern Gulf of Mexico from July 2016 through December 2021. Isobaths are shown in meters.

Table 2.—Condition on arrival of red grouper, red snapper, and other bony fishes caught by participating bottom longline vessels.

Condition	No. of red grouper	% of red grouper	No. of red snapper	% of red snapper	No. of other bony fishes	% of other bony fishes
Dead - damaged	406	0.76	158	2.21	317	1.79
Dead - undamaged	516	0.96	403	5.63	655	3.69
Live - damaged	134	0.25	13	0.18	49	0.28
Live - healthy	29,887	55.61	5,099	71.27	9,945	56.04
Live - stomach and/or eyes protruding	22,635	42.12	1,473	20.59	6,643	37.43
Unknown condition	162	0.30	8	0.11	137	0.77

Table 3.—Fate (disposition) of red grouper, red snapper, and other bony fishes caught by participating bottom longline vessels.

	Red grouper		Red snapper		Other bony fishes	
Catch and fate	Number	%	Number	%	Number	%
Discarded – dead	956	1.78	461	6.44	708	3.99
Discarded – live and damaged (not vented)	97	0.18	16	0.22	25	0.14
Discarded – live and damaged (vented)	132	0.25	6	0.08	3	0.02
Discarded – live and healthy (not vented)	7,510	13.97	592	8.28	1,045	5.89
Discarded – live and healthy (vented)	17,004	31.64	579	8.09	232	1.31
Discarded – unknown	120	0.22	6	0.08	77	0.43
Retained	27,814	51.76	5,486	76.68	13,526	76.22
Retained as bait	3	0.01	1	0.01	1,940	10.93
Unknown fate	104	0.19	7	0.10	190	1.07

Table 4.—Condition of shark catch by species based on percentage arriving to the vessels dead as identified through electronic monitoring.

Common name	Scientific name	Number caught	Number dead	% Dead on arrival
Dusky Shark	*Carcharhinus obscurus*	7	3	42.86
Scalloped Hammerhead	*Sphyrna lewini*	54	21	38.89
Silky Shark	*Carcharhinus falciformis*	148	51	34.46
Great Hammerhead	*Sphyrna makarran*	11	3	27.27
Spinner Shark	*Carcharhinus brevipinna*	21	3	14.29
Night Shark	*Carcharhinus signatus*	74	9	12.16
Carcharhinid, Unidentified	*Carcharhinus* spp.	42	4	9.52
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	912	64	7.02
Shark, Unidentified	*Selachimorpha* spp.	183	11	6.01
Blacknose Shark	*Carcharhinus acronotus*	514	16	3.11
Dogfish, Smooth	*Mustelus* spp.	428	4	0.93
Dogfish, Spiny	*Squalidae* spp.	378	2	0.53
Sandbar Shark	*Carcharhinus plumbeus*	597	2	0.34
Sharpnose Sevengill Shark	*Heptranchias perlo*	2	0	0.00
Angel Shark	*Squatina dumeril*	1	0	0.00
Blacktip Shark	*Carcharhinus limbatus*	7	0	0.00
Bull Shark	*Carcharhinus leucas*	3	0	0.00
Chain Catshark	*Scyliorhinus retifer*	3	0	0.00
Hammerhead, Unidentified	*Sphyrna* spp.	6	0	0.00
Lemon Shark	*Negaprion breirostris*	11	0	0.00
Nurse Shark	*Ginglymostoma cirratum*	237	0	0.00
Sixgill Shark	*Hexanchus* spp.	18	0	0.00
Tiger Shark	*Galeocerdo cuvier*	316	0	0.00
Total		3,973	193	

viduals per 1,000 hook hours (Fig. 15); small-bodied shark species contributed disproportionately to CPUE during the earlier half of the study.

Sandbar sharks were the most predominant large coastal shark and were caught at depths between 37 m and 243 m, and an average depth of 66 m. High confidence CPUE hotspots were aggregated into two groups, one group of three highly significant grid cells occurred in the northwest end of the fishing area centered near lat. 28°43’N, long 84°68’W, and three cells totaling 1,132 km^2, with a proximal cell located further northwest. The second group was at the extreme southwestern end of the fishing area, proximal to the Dry Tortugas and Pulley Ridge Marine Protected Areas, and was centered around lat. 24°68’N, long. 83°45’W with four complete and three partial cells (Fig. 16). Though no seasonal trends were apparent, sandbar sharks were the only shark species that showed an increase in CPUE, approximately 66% from 2016 to 2021 (Fig. 15). In comparing sandbar shark hotspots CPUE (Fig. 16) and those of recorded depredated fish species (Fig. 17), the hotspots did not align to validate if this was the primary shark species driving depredation.

Sea Turtle and Seabird Interactions

Sea turtles and seabirds represented a small portion of the incidental bycatch. Among the five loggerhead turtles, *Caretta caretta,* encountered, two mortalities were recorded. Interestingly, there were no recorded encounters in the years 2019 and 2020. Seasonally, two sea turtles were captured in winter months (January–March), two in the spring (April–June), and one in the fall (October–December), with no captures recorded during the summer months (July–September). The incidental cap-

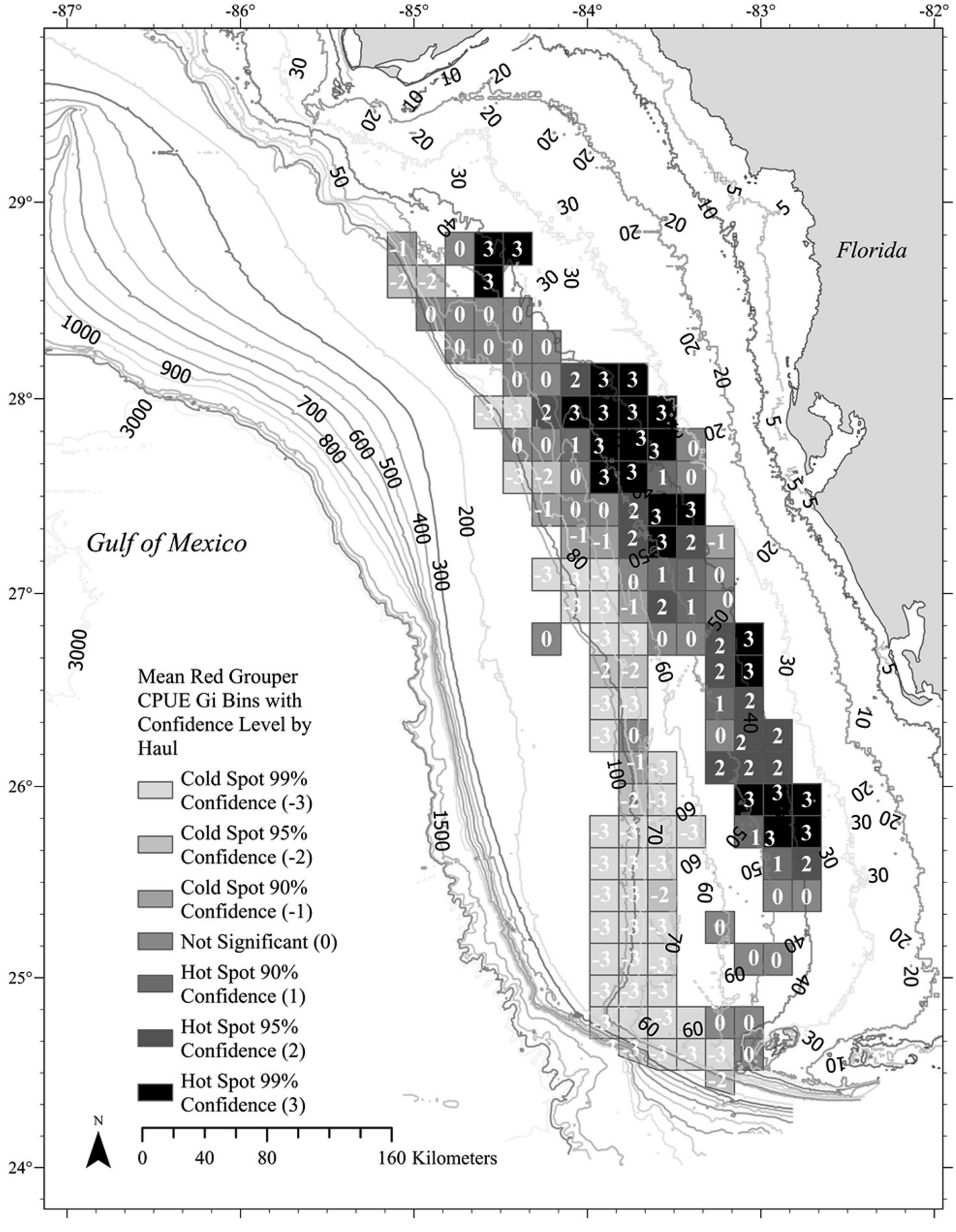

Figure 5.—Spatial clusters of red grouper catch depicted as mean high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

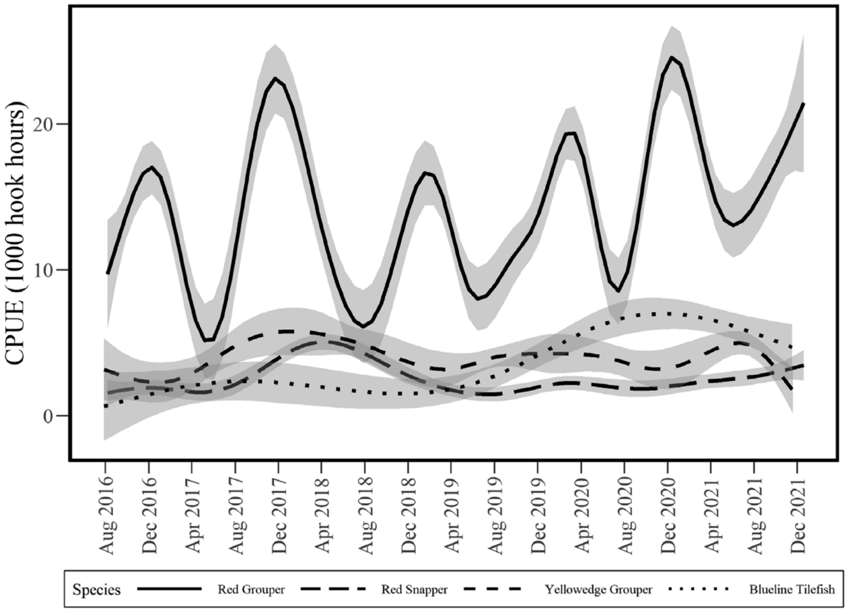

Figure 6.—Catch per unit effort (CPUE) trends for red grouper, red snapper, yellowedge grouper, and blueline tilefish catch.

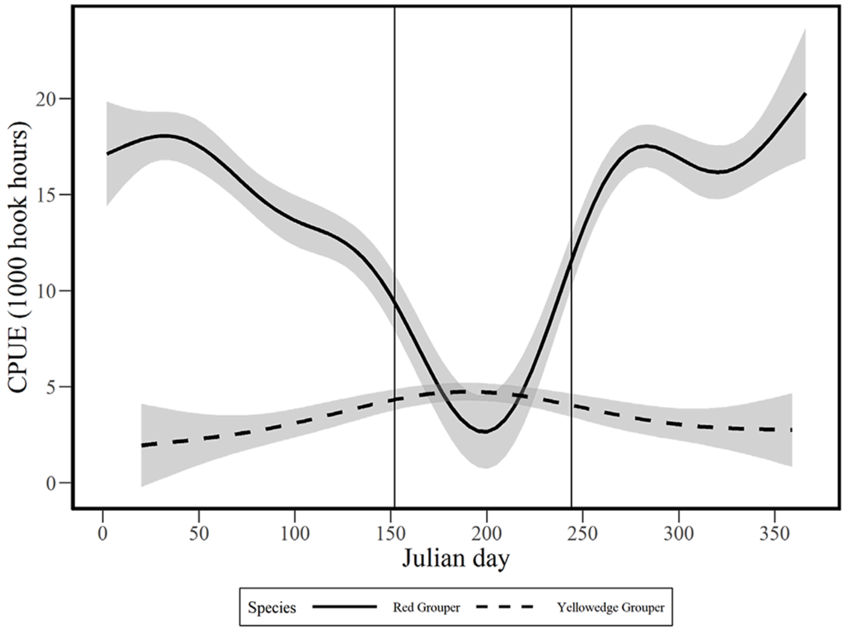

Figure 7.—Catch per unit effort (CPUE) for red grouper and yellowedge grouper catch by day of year relative to the June through September closure inside 35 fathoms (vertical lines).

ture of birds resulted in a high mortality rate of 90%, with various gulls, *Laridae* being the most affected species (*n* = 6), followed by brown pelicans, *Pelecanus occidentalis* (*n* = 4), and one gannet, *Morus bassanus*.

Discussion

The application of EM over a span of five years in partnership with the eastern U.S. Gulf BLL reef fish fishery, utilizing Saltwater Inc, EM hardware and software, yielded promising results. This initiative facilitated the collection of detailed fishing activity observations and comprehensive documentation of catch, bycatch, and particularly discard species, along with their quantity, location, and subsequent disposition. Through the voluntary efforts of the fishing industry, a significant milestone of over 20% of the eastern Gulf BLL fleet was participating in EM coverage as of 2021. During the study period from the summer of 2016 through 2020, EM systems documented 306 BLL trips, nearly three times the number of trips covered by the regulatory reef fish observer program (105) for all Gulf BLL vessels (Atkinson[14]). This additional stream of data is particularly important for management consideration, given this area's high species diversity (Pulver and Stephen, 2019), limited (~2%) at-sea observer coverage (Scott-Denton[4]), and challenges associated with the unreliable self-reported discard data by fishermen (GMFMC[5]). Gaining a better understanding and accurately documenting discarded unintentional or non-targeted catch is especially critical in fisheries management. These discards, often comprising a significant proportion of the catch (Harrington et al., 2005), are characterized by high release mortality rates, influenced by various factors (Shertzer et al., 2021). Therefore,

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[14] Atkinson, S, S. G. Smith, and G. Decossas. 2023. CPUE Expansion estimation for commercial discards of Gulf of Mexico yellowedge grouper (*Hyporthodus flavolimbatus*). SEDAR85-WP-06. SEDAR, North Charleston, SC, 28 p. (https://sedarweb.org/documents/sedar-85-wp-06-cpue-expansion-estimation-for-commercial-discards-of-gulf-of-mexico-yellowedge-grouper-hyporthodus-flavolimbatus/).

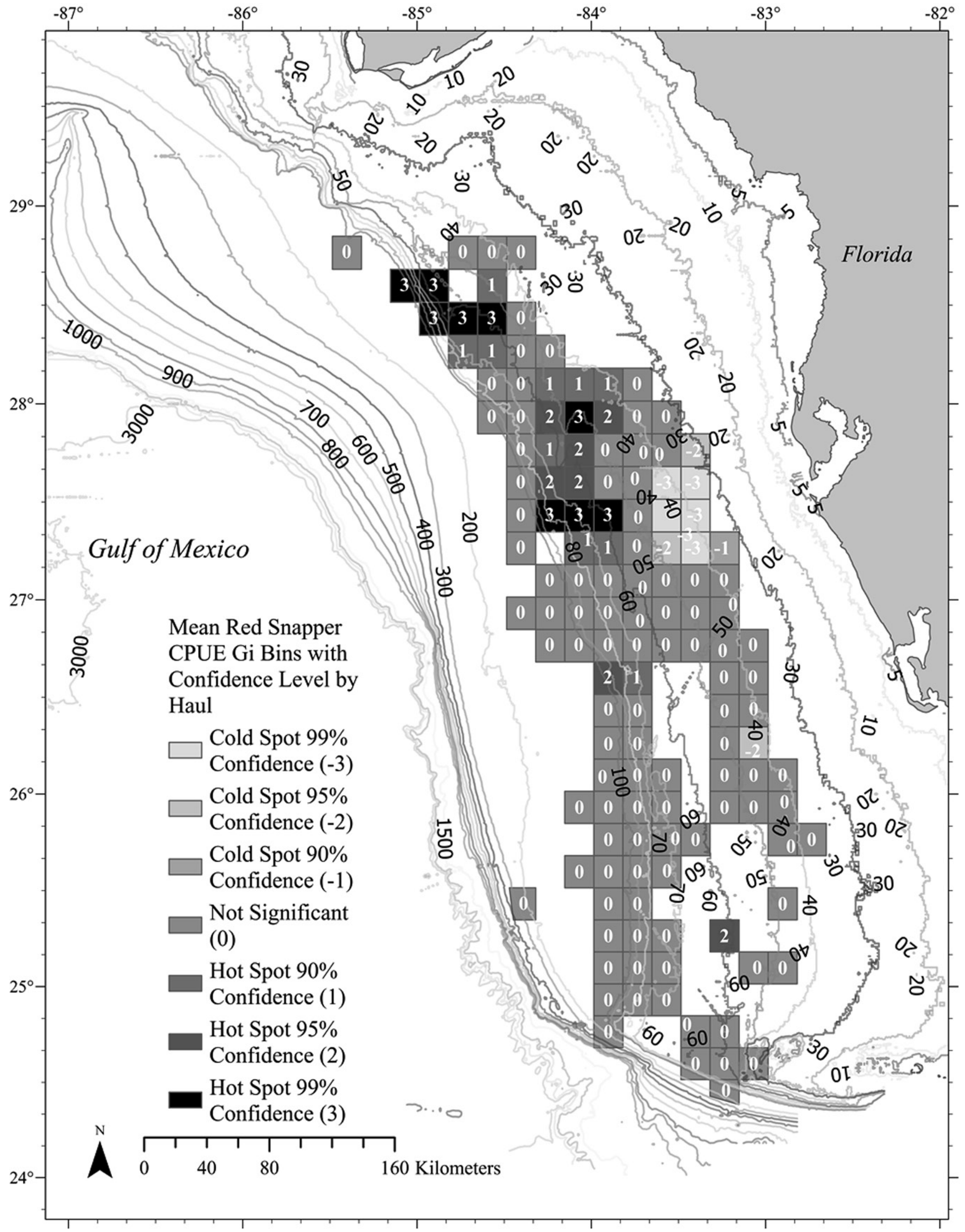

Figure 8.—Spatial clusters of red snapper catch depicted as mean high value (hotspot), low value (cold spot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

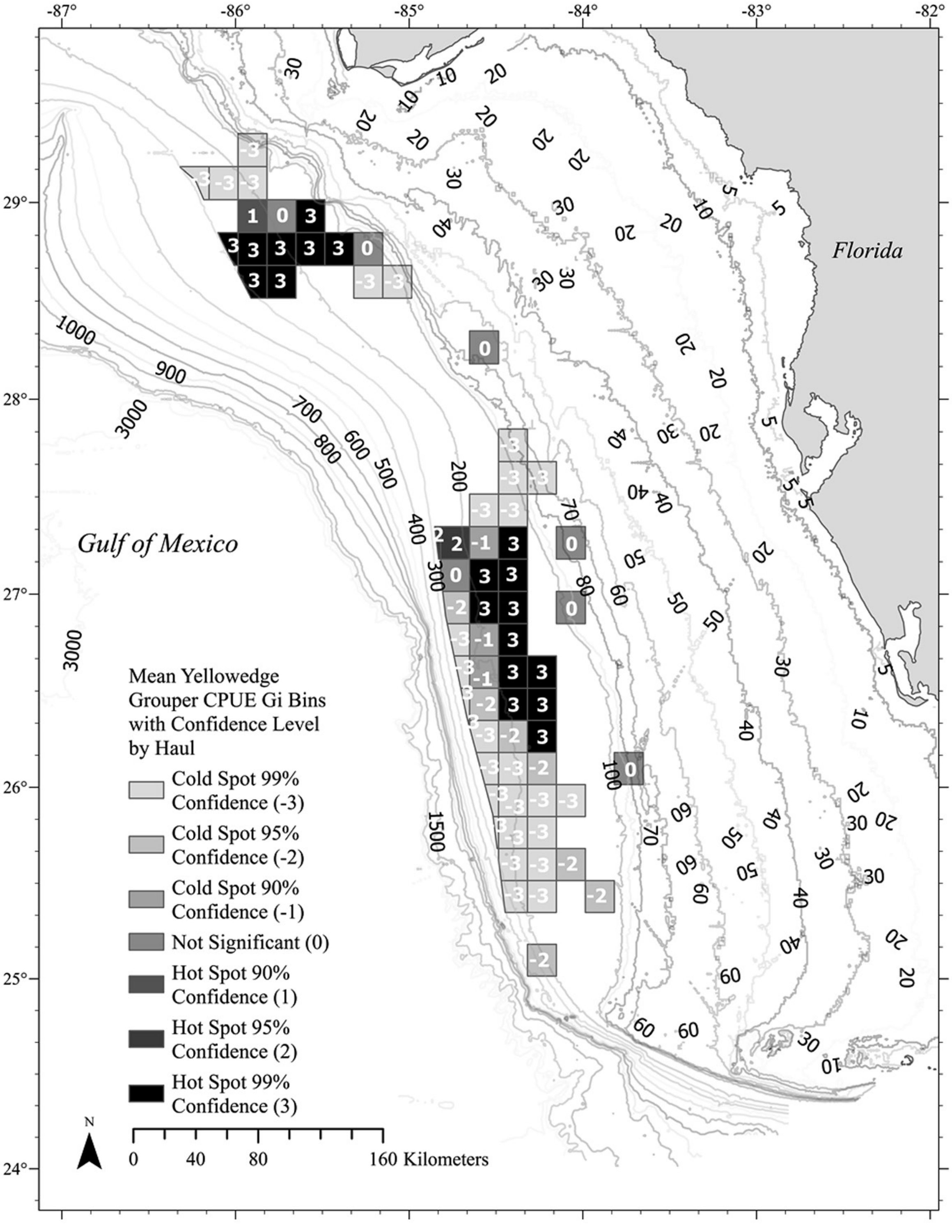

Figure 9.—Spatial clusters of yellowedge grouper catch depicted as mean high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

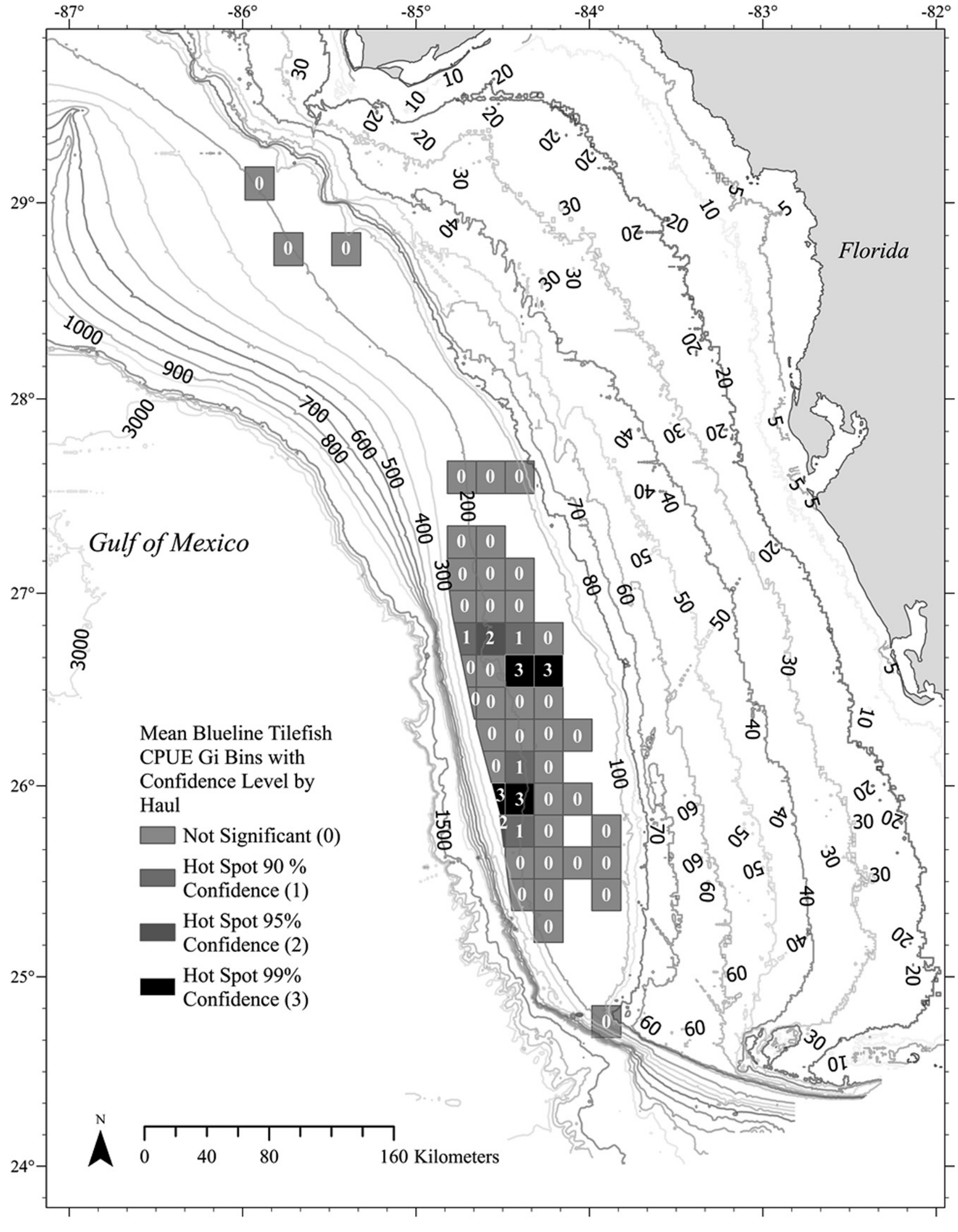

Figure 10.—Spatial clusters of blueline tilefish catch are depicted as mean high value (hotspot), low value (cold spot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

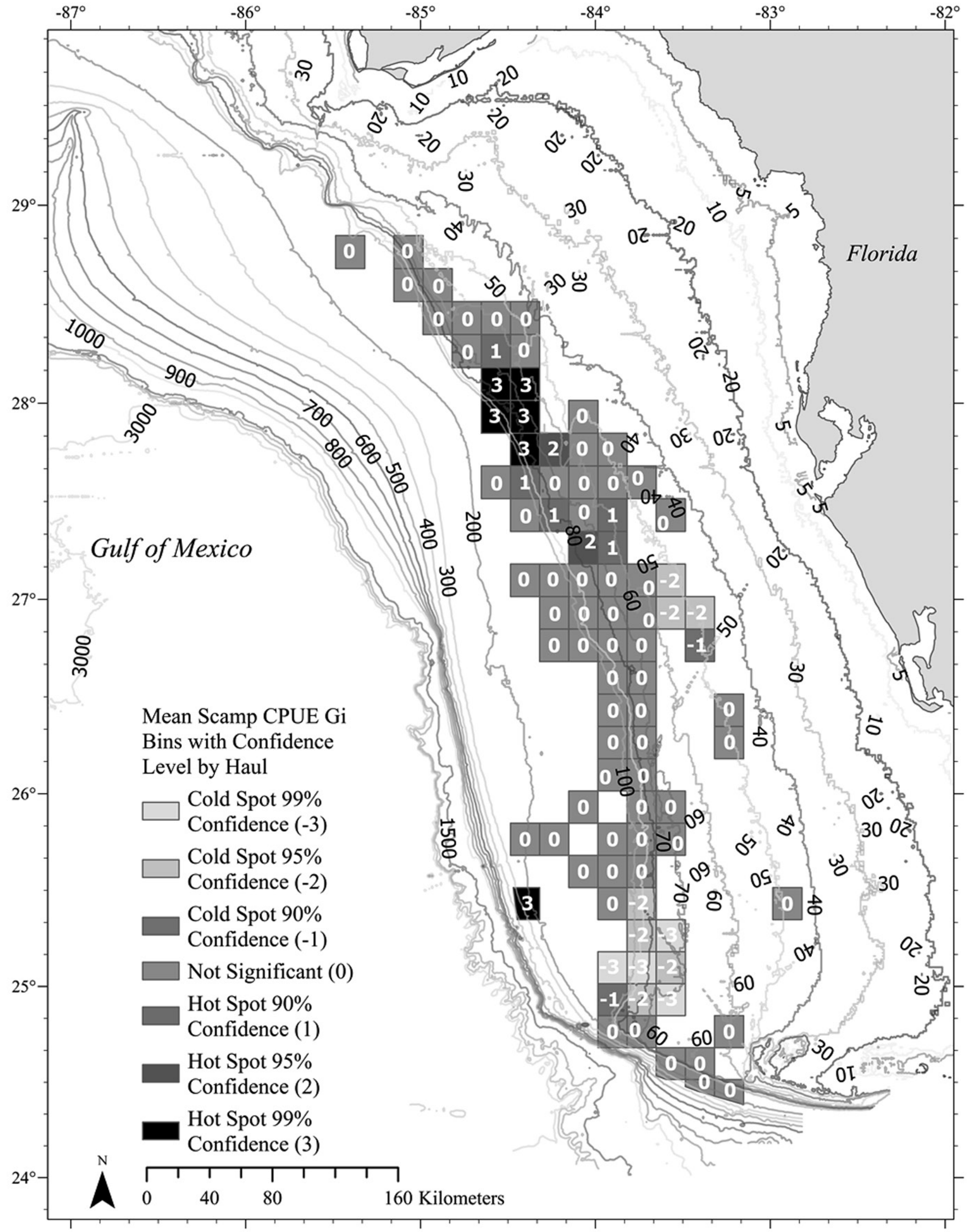

Figure 11.—Spatial clusters of scamp catch depicted as mean high value (hotspot), low value (cold spot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

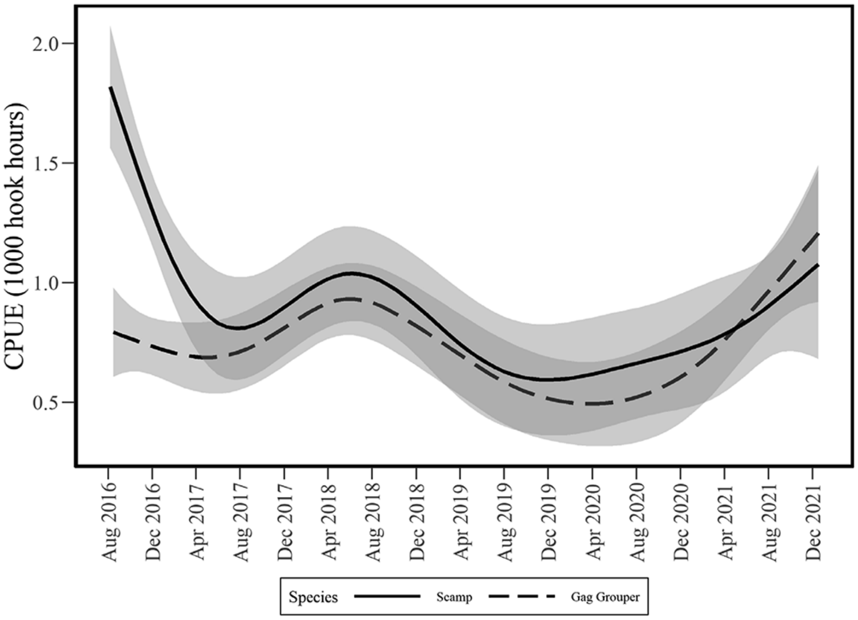

Figure 12.—Catch per unit effort (CPUE) as related to 1,000 hook hours for scamp and gag grouper catch from bottom longline vessels.

implementing solutions to enhance and augment the accuracy of discard documentation is essential for generating reliable stock assessments (Suuronen and Gilman, 2020) and informing management practices.

Our findings align with previous research that has assessed the efficacy of video monitoring, and affirms that EM can serve as a reliable and accurate method to estimate catch (McElderry et al., 2003; Ames et al., 2007; Stanley et al., 2011; van Helmond et al., 2014, 2020). This is especially notable in fisheries challenged by low observer coverage, as acknowledged in studies by Michelin et al. (2018), Bradley et al. (2019), and Gilman et al. (2019). Following these investigations, our study emphasized improving views through camera positioning, including use of boom mounts, to view catches in a way that allowed individual fish to be tracked from their arrival to their disposition. This level of monitoring was also achieved through ongoing communications with the vessel captains and crew to ensure technical issues with the EM systems and any changes in fish processing locations were addressed quickly.

The use of EM technology is rapidly gathering momentum, and can perform some functions at a higher level than human observers, though there can be challenges such as poor lighting or dirty camera domes, fish handled out of frame, high volume of fish across the camera frame (Ruiz et al., 2015; van Helmond et al., 2020; Sylvia[15]; NMFS[16]), fish released while underwater, and/or EM system malfunction. This technology has demonstrated suitability for use across a wide range of vessels, providing the capability to review video for data verification, increase scalability, and engage industry in the self-reporting processes (van Helmond et al., 2020). Relative to human observers, EM programs are typically lower in cost, and this advantage is expected to expand with ongoing advancements in technology (Michelin et al., 2018). Although EM programs traditionally do not evaluate the size structure and gear specificity like traditional observer programs, integrating EM with clearly established standards (Stanley et al., 2011, 2015) into fishery-dependent monitoring programs can contribute to assessments of exploited stocks (ICES, 2019). It can also aid in the quantification of impacts on species, particularly endangered, threatened, and protected species (Gray and Kennelly, 2018). Furthermore, EM integrated as new data stream can contribute valuable insights into vessel and fleet operations, fishing effort, and information concerning discards and discarding practices (Bradley et al., 2019; van Helmond et al., 2020; Suuronen and Gilman, 2020).

Gulf reef fish fishery vessel owners and captains voluntarily participated in this work due to their expressed interest to have the permanent video documentation and the resulting data analysis. They aimed to leverage this data to improve their fishing operations, demonstrate to fisheries managers that they were applying sustainable fishing practices, and to contribute additional accurate information for managers to consider in making more informed decisions regarding regulations for this fishery. Similar motivations for enhancing stock assessments and promoting sustainability were also reported in studies by van Helmond (2020) and Plet-Hansen et al. (2017). Many participants expressed a preference for applying EM full-time over occasional at sea-observer coverage. During the period of 2016 through 2021, observers were present on roughly 3% of the EM trips. Interestingly, some captains expressed a willingness to adopt EM systems if NMFS granted an observer waiver. This suggests a potential interest for applying EM technology as an alternative for traditional at-sea observer coverage. However, effectively implementing EM as an alternative for these exemptions would necessitate coordination with both management and the vessel captains to ensure compliance.

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[15] Sylvia, G., M. Harte, and C. Cusack. 2016. Challenges, opportunities, and costs of electronic fisheries monitoring. The Environmental Defense Fund, San Francisco, CA,. 34 p. (https://www.edf.org/sites/default/files/electronic_monitoring_for_fisheries_report_-_september_2016.pdf).

[16] NMFS Office of Policy and Electronic Monitoring Working Group. 2013. Electronic monitoring and electronic reporting: guidance and best practices for federally-managed fisheries (http://www.nmfs.noaa.gov/op/snippets/em_er_discussion_draft_august_2013.pdf)

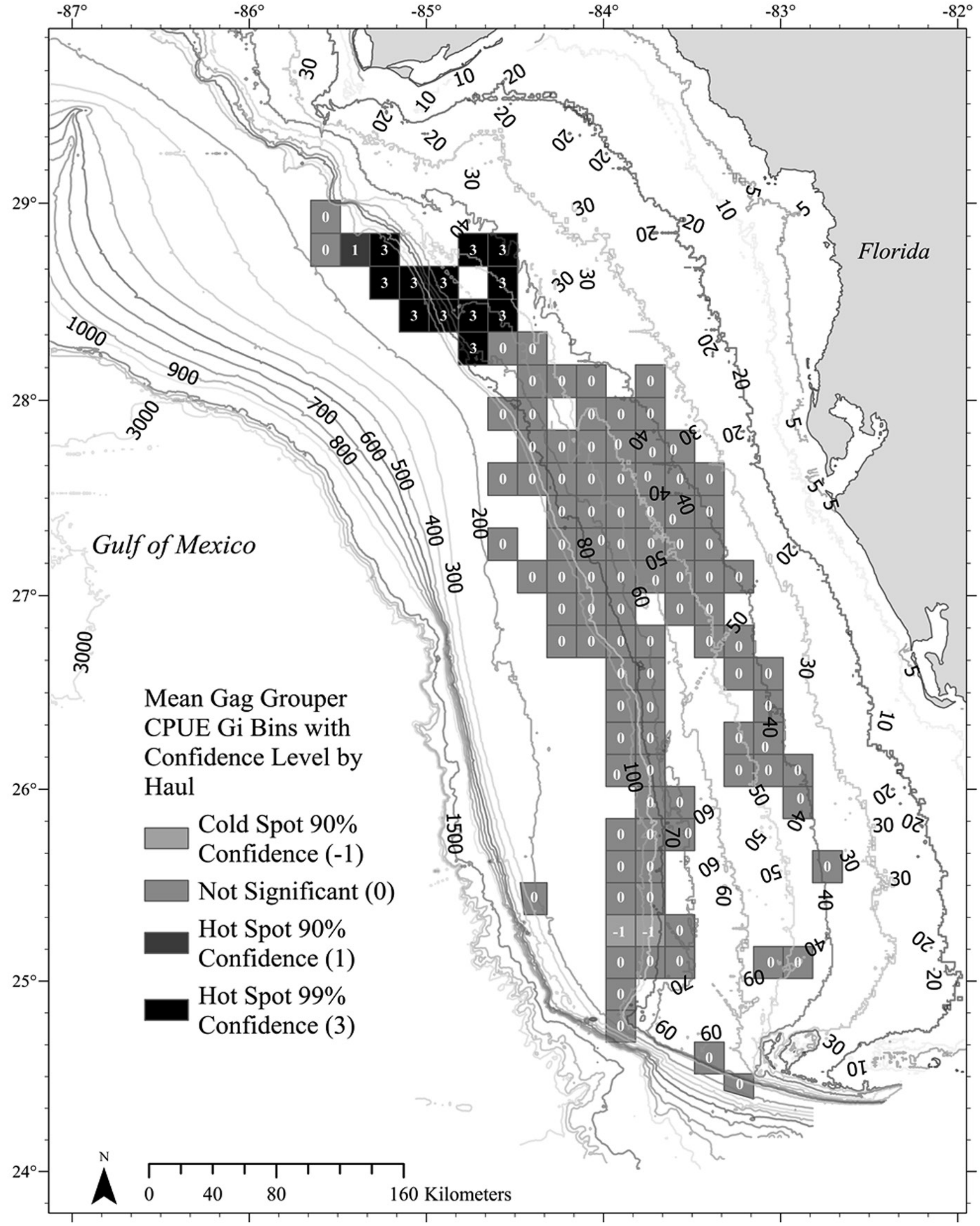

Figure 13.—Spatial clusters of gag grouper catch depicted as mean high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

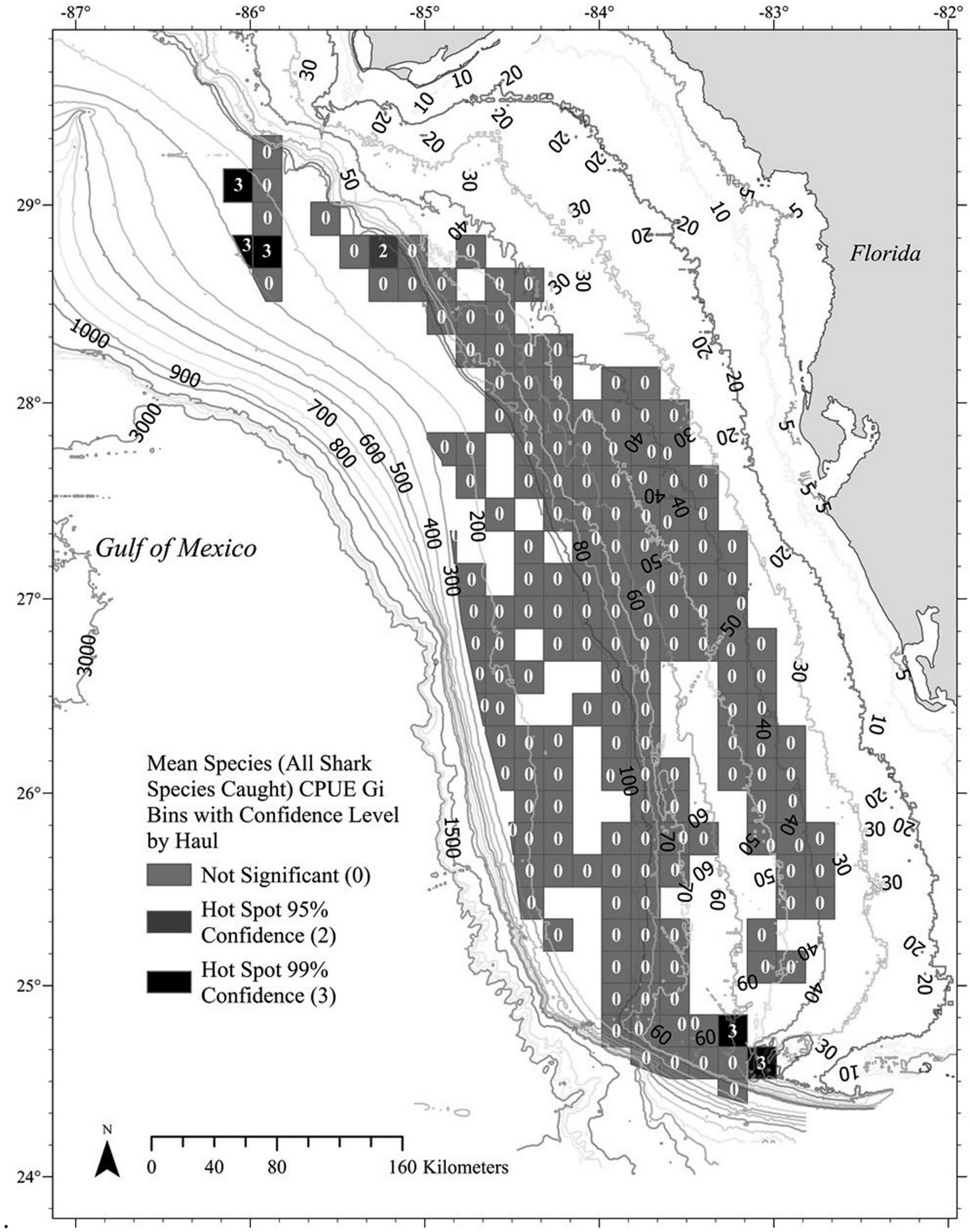

Figure 14.—Spatial clusters of catch of all shark species depicted as mean high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

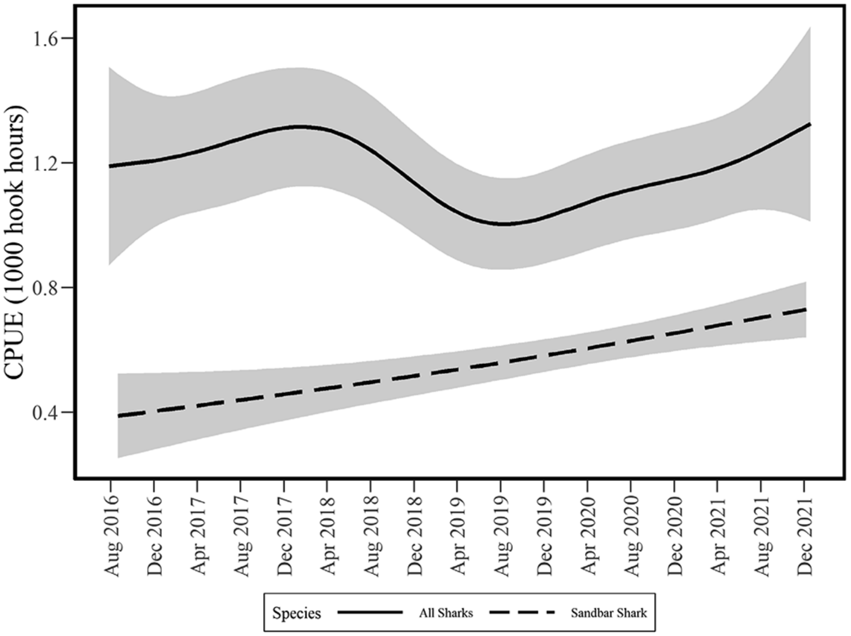

Figure 15.—Catch per unit effort (CPUE) as related to 1,000 hook hours for all sharks and sandbar shark catches from bottom longline vessels.

Several vessel owners and captains who expressed their willingness to participate in EM data collection, cited their trust in the work being carried out by a non-governmental and non-enforcement organization. However, there were also fishermen who declined to take part, citing concerns over potential privacy intrusion. In addition, several captains expressed a general distrust in any form of monitoring, and voiced concerns that broader data collection efforts might result in further restrictions being imposed. Efforts were made to address these concerns to the best of our ability, emphasizing the potential benefits of more informed management for the fishery, which would ultimately serve the interests of the fishermen. Similar sentiments, highlighting concerns among some fishermen regarding potential changes in data collection and management practices in fisheries, were reported by Mangi et al. (2013), Eayrs et al. (2015), and Plet-Hansen et al. (2017) in their on-water camera surveillance research studies and in fishery compliance applications.

There were some challenges in maintaining consistency with vessels due to unexpected extended periods in port for major repairs, sales, or relocations to distant ports. These challenges required persistent and constant communications with industry representatives to make every effort to maintain consistent and reliable data collection. While there were several captains who worked the same vessel for the full duration, turnover among captains and particularly crew members was common across vessels. In several instances, vessels experienced turnover with more than five different captains during the project period. These situations provided the opportunity to gather data on the variability in effort and catch on individual vessels across multiple captains over time, a task that a limited number of human observers may not have been able to accomplish.

Many vessels, which had been actively fishing for decades, exhibited ongoing power-related issues stemming from inadequate wiring or the use of aged marine batteries. While captains were assured of the low amperage draw of the EM system, some expressed concerns that they might exhaust their battery power after dusk, as their battery draw increased with multiple deck lights illuminating fishing activities. In some cases, an integrated battery backup or replacement marine battery was provided. Few vessels used generators, which supplied a more reliable power source. Reliance on volunteer captains and aged vessels did not detract from the program's ability to gather fairly consistent catch, bycatch, and discard data for producing data products in support of industry and management goals.

The Saltwater Inc. EM vessel monitoring systems, including the two camera models, were found to be durable and long-lasting under the adverse conditions presented by the Gulf climate. The only irreparable damage occurred to one processor due to saltwater intrusion during a severe storm. Replacement of components, such as monitors, system power packs, and drum sensor hardware, was typically due to wear and tear over time. The preferred camera model was the GeoVision Model GV-EVD3100, due to simply removing the outer face plate to make minor vertical or horizontal adjustments to the lens to improve views. In contrast, making minor lens positioning adjustments on the Vivotek model was challenging, as it required unmounting the camera from the vessel to access the internal components through the base plate and then remounting to confirm the lens adjustment was correct. Additionally, a point of concern with the Vivotek camera model was the use of an external rather than internal cable coupler. This was a concern for possible moisture intrusion or the camera cable becoming disconnected. As a preventive measure, cable connections were bound with marine grade tape and secured to make a drip loop. Regardless of the camera brand, occasional poor image quality was observed due to dried salt spray, clinging heavy dew or rain drops, or fish slime. Minor scratches sometimes occurred on the domes, but they were typically not problematic unless they were directly in front of the lens. Captains and their crew were encouraged to clean

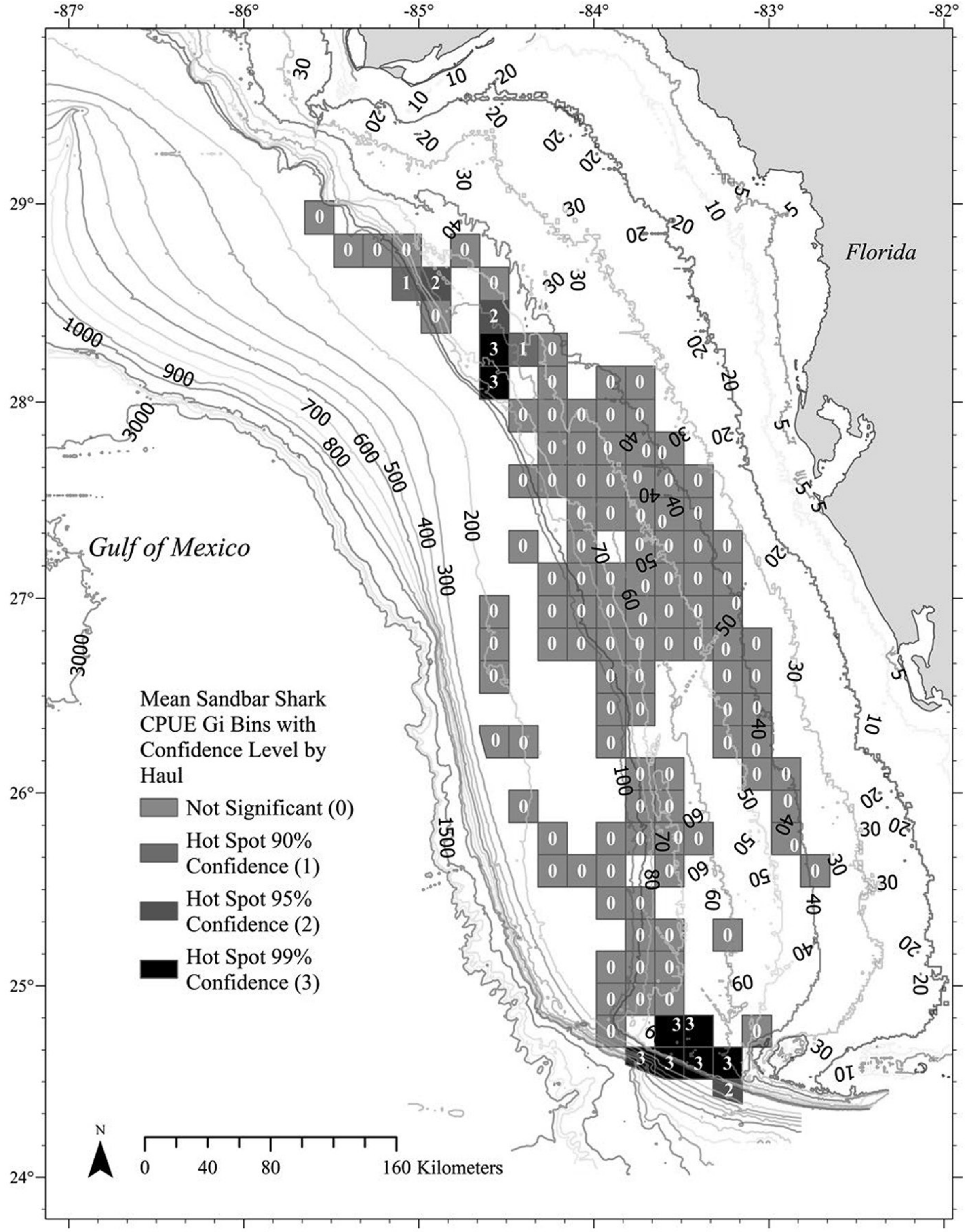

Figure 16.—Spatial clusters of sandbar sharks mean depicted as high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

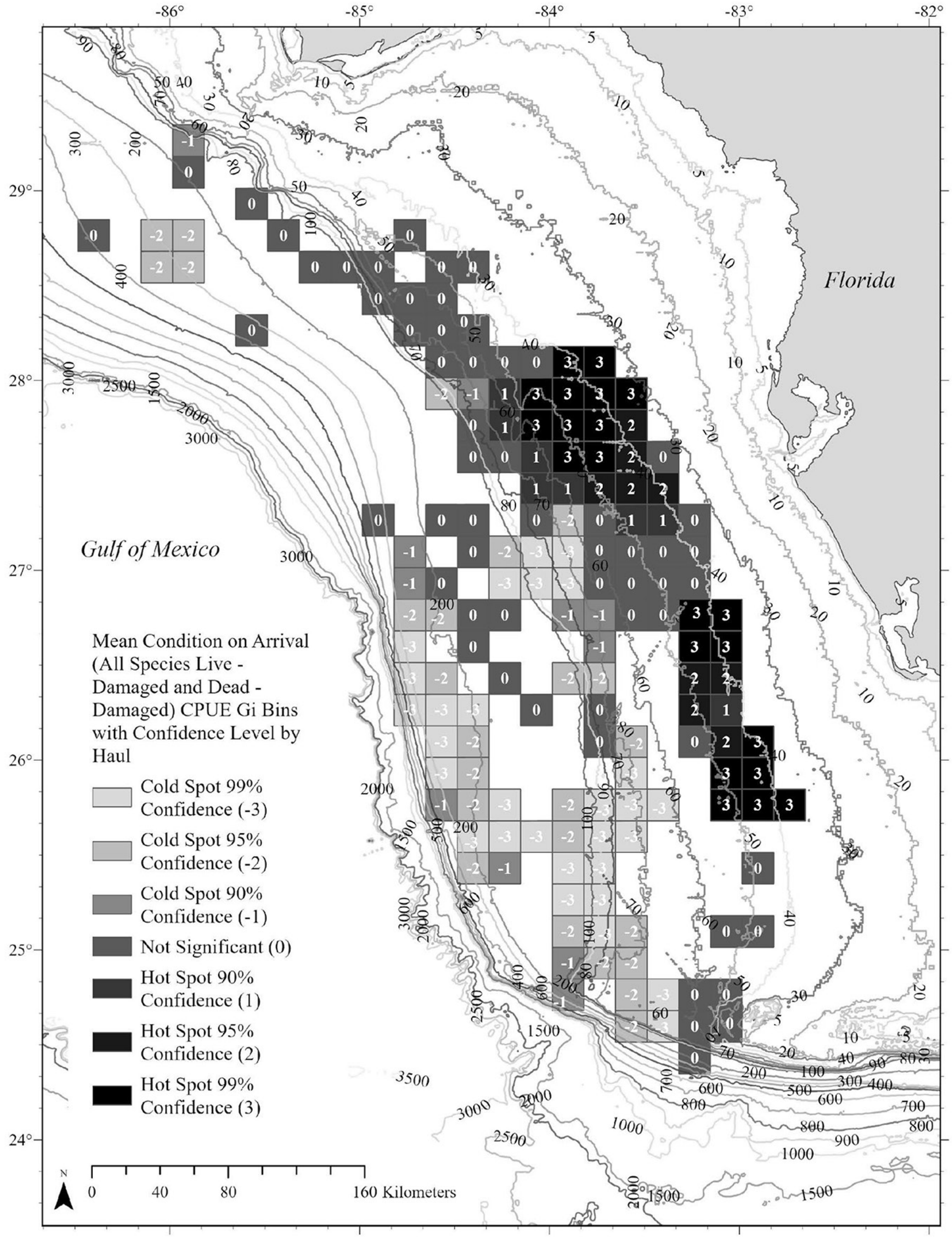

Figure 17.—Spatial clusters of depredated fish mean depicted as high value (hotspot), low value (coldspot), and random distributions of species-specific catch per unit effort (set-haul hook-hours x 1,000) spatially joined to 10.0-min grids. Isobaths are shown in meters.

dirty camera domes and were provided with cleaning supplies.

Cameras mounted on vessel specific aluminum booms were integrated early during this work and made a significant improvement in views of the longline gear and fish as they were hauled and brought onboard or were released in close proximity to the vessel. Booms also improved views for the identification of large sharks that were discarded at the rail while underwater near the vessels and for documenting at-surface predation of discards by sharks or marine mammals.

Camera placement to maintain unobstructed views of the deck processing areas was critical for not only optimizing the documentation of individual fish from haul to discard, but also for reviewers to make detailed observations on fish condition and handling procedures, notably the presence of barotrauma and venting. It was noted that most crew members were aware of the benefits of venting and more often than not took the extra effort to do so; however, the vast majority of observed venting efforts were not performed correctly. This may have been attributed to crew turnover and a lack of hands-on training. During early monitoring, only a few fishermen used NMFS recommended hollow sharp cannula venting tools, with reviewers observing that filet knives and kill picks were most often the tools of choice. Unfortunately, these tools were often applied incorrectly, potentially causing internal damage. As reported by Drumhiller et al. (2014), improper venting techniques can decrease the survival odds for fish released with barotrauma.

In fisheries electronic monitoring, there is evidence to suggest that fishermen may adjust their discard behavior in response to the presence of monitoring systems, leading to changes in fishing practices, sorting techniques, or even avoidance of monitored areas or species. However, the extent of these adjustments can depend on factors such as the level of enforcement, the effectiveness of monitoring systems, and if economic incentives are involved. Interestingly, in this study, discard behavior did not seem markedly influenced across participating volunteer vessels. As we reported in this study, there were observed instances where bycatch, which should have been discarded, were repurposed as bait, in addition to instances of improper venting.

The most recent comparable fishery-dependent data for the Gulf BLL reef fish fishery is from the region’s fisheries observer program, where 90% of the fishing effort recorded from 2006 to 2009 occurred specifically in the eastern Gulf (Scott-Denton et al., 2011). The observer and EM BLL vessel data results were reasonably consistent in identifying areas with high fishing effort. Based on EM data, the majority of effort, 61%, was recorded in zones 4 and 5 (Fig. 1), while information based on observer data reported zone 4 as having the highest fishing effort (35%) among zones 3 through 5. Red grouper was the predominant catch in the eastern Gulf. According to EM data, fishing effort in statistical zones 4 and 5 produced more than 80% of the total catch, which consisted of red grouper (65%) and red snapper (9%), followed by yellowedge grouper (5%), and blueline tilefish (4%) (Table 1). However, observer data from Scott-Denton et al. (2011) showed a lower contribution (56%) of red grouper, with red snapper catches accounting for only 3% of their observed harvest. It was reported that yellowedge grouper used to be the second most common species and comprised 10% of the catch, followed by blueline tilefish (5%), other tilefish, and Atlantic sharpnose sharks, which were each 3%.

Generally, the EM systems were able to generate some of the same types of data as an onboard observer, including fishing activity and catch and discard composition and disposition, and at times surpassed the capability of a human observer. For instance, in the case of shark identification, EM data showed 6% of sharks were recorded as “unknown” or “unknown carcharhinid,” while early observer reports (Scott-Denton et al., 2011) for unknown shark groupings were higher (16%). This could potentially be due to various factors, including observers biological sampling workload, inexperience, not being able to observe crew releasing sharks while underwater, and possibly obstructed views.

Applying EM in this fishery not only was useful for documenting retained catch, but more importantly for documenting discarded species and their disposition (dead or live). Usually, fishing pressure has been monitored using only estimates of the portion of the catch that fishermen retain (Gilman et al., 2019). Because discards can be substantial, optimal camera coverage in this study was beneficial for monitoring and accounting for individual fish and their disposition. As emphasized by Cook (2019), Gilman et al. (2019), and Suuronen and Gilman (2020), comprehensive data is essential for estimating total fishing mortality to support more robust stock assessments and improved fisheries management.

High discard rates observed in the Gulf commercial reef fish fishery are attributed to regulations based on size limits, quota restrictions, and marketability (Pulver and Stephen, 2019). According to EM collected data, nearly half of all of the red grouper caught were discarded, primarily due to size limit restrictions. Minimal yellowedge discards were attributed to fishermen who had sufficient quota when targeting deepwater species, which promoted management related discarding. Conversely, according to the captains, red snapper discards were primarily attributed to quota related issues or fishermen’s concern over the quality and marketability of those fish that arrived at the vessel dead with discolored gills, rather than size limits. Marketability was also a driver of blueline tilefish discards, as they have no size limit, but low prices leave fishermen with limited profits after paying for leased quota compared to other reef fish species (Pulver and Stephen, 2019). Management or market-based solutions are needed to improve blueline tilefish sustainability, as discard mortality studies show an estimate of post-release mortality of 90%, with the potential for discard mortality to be 100% (SEDAR[17]). Limited discards observed for the other economically important reef fish species, including scamp and gag grouper, were attributed to no size limit restriction, or that they were generally a larger size class of fish caught by this gear type. As reported by Suuronen and Gilman (2020), at-sea human observer programs produce accurate discard data. However, the potential of EM as a highly effective method is highlighted due to its ability to overcome most sources of statistical sampling bias in conventional human onboard observer programs. Our study showed that EM is capable of providing extensive discard data. Moving forward, it is important to take steps towards constructing a management framework that integrates EM into the larger data collection process. Through the adoption of an integrated approach, the full potential of EM technology can enhance the effectiveness and reliability of discard data acquisition for fisheries management.

Collection of spatial information on fisheries catch and effort is essential to understanding the spatial processes of exploited population dynamics and to manage heterogeneously distributed resources and uses (Léopold et al., 2014). For this work, more than five years of EM data analyzed for hotspots and coldspots revealed that CPUE's for primary target species were not distributed similarly across the study area (Fig. 5, 8, 9, 10, 11, 13, and 15). Shallow water species, such as red grouper, showed large expanses of highly productive fishing areas (15,851 km^2), whereas deepwater species, like blueline tilefish, showed smaller areas (2,264 km^2), which lends this species to localized overfishing. Negative impacts of the recent reduction in commercial red grouper quota (NMFS[18]) and drastic cuts in gag grouper quota that industry expects to be enacted in 2023 could drive efforts offshore to these areas. Additional effort in these offshore areas could create increased interactions with Highly Migratory Species (HMS) such as scalloped hammerheads and silky sharks that show some of the highest mortality of the shark species caught on BLL gear (Table 4).

Sharks caught in this fishery are unintentional catches, with many incidents going unreported (Drymon et al.[19]), a recognized problem in many fisheries (Molina and Cooke, 2012). However, during this study, the fishermen frequently reported that shark interactions, particularly with sandbar sharks, were significantly increasing, which aligns with commercial fishermen reports included in SEDAR74-DW-32 (Drymon et al.[19]). As noted by Brewster-Geisz and Miller (2000), sandbar sharks are the most commonly observed shark species in the Gulf, despite a drastic decline from overfishing (Romine, 2008). They are prohibited from commercial or recreational harvest except through a federal research fisheries commercial harvest program (Mathers et al., 2018; SEDAR[20]). Although EM data did not show an increase in overall shark catches, a steady annual increase in sandbar shark abundance was observed (Fig. 15), validating the assertions made by participating fishermen and various sectors of the reef fish fishery (Drymon[19]; Brewster-Geisz[21]).

Fishermen's reports of an increase in sandbar shark interactions included identifying them as a primary predator causing significant depredation of catch. Depredated catch, as described in Mitchell et al. (2018) by Gilman et al. (2008), and MacNeil et al. (2009) involves catch being partially or completely consumed by an animal before it can be retrieved to the vessel. Concerns regarding the impacts of depredation, particularly from sandbar sharks, have been documented in various forums, including NMFS HMS Advisory Panel Meetings (Brewster-Geisz[21]), GMFMC meeting by NMFS HMS staff[22], public GMFMC open testimony[23], and in a report by Drymon et al.[19]. In our review of over 80,000 species-specific records of EM catch events, we found that more than 900 reef fish exhibited clear physical evidence of depredation due most likely to sharks or marine mammals. However, the exact number of depredated fish completely removed from hooks is unknown, making observed depredation rates minimum estimates. An analysis of sandbar hotspots CPUE (Fig. 16) and those of our recorded depredated species (Fig. 17) did not align to validate if this particular species of shark was driving depredation. Unfortunately, as reported by NMFS[24] the nature, extent, frequency, and geographic locations of shark and dolphin interactions in the Gulf commercial reef fish fish-

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[17] SEDAR. 2017. SEDAR 50 – Atlantic blueline tilefish assessment report. SEDAR, North Charleston, SC, 542 p. (http://sedarweb.org/sedar-50).

[18] National Marine Fisheries Service (NMFS). 2022. Fisheries of the Caribbean, Gulf of Mexico, and South Atlantic; reef fish fishery of the Gulf of Mexico; Amendment 5. 87(84) (https://www.govinfo.gov/content/pkg/FR-2022-05-02/pdf/2022-09300.pdf).

[19] Drymon, M., A. Osowski, A. Jefferson, A. Anderson, D. McAree, S. Scyphers, E. Prasky, S. Swinea, S. Gibbs, M. Karnauskas, and C. Gervasi. 2022. Co-Producing a shared characterization of depredation in the Gulf of Mexico reef fish fishery: 2022 Workshop summary report. SEDAR74-DW-32. SEDAR, North Charleston, SC. 25 p., (https://sedarweb.org/documents/sedar-74-dw-32-co-producing-a-shared-characterization-of-depredation-in-the-gulf-of-mexico-reef-fish-fishery-2022-workshop-summary-report/).

[20] Southeast Data, Assessment, and Review (SEDAR). 2010. SEDAR21, Stock assessment report: HMS sandbar shark. SEDAR, North Charleston, SC, 459 p. (https://sedarweb.org/documents/sedar-21-final-stock-assessment-report-hms-sandbar-shark/).

[21] Brewster-Geisz, K. 2019. NOAA Atlantic HMS Management Division. Shark depredation, Presentation, Tab M, No. 4 (https://gulfcouncil.org/wp-content/uploads/M-4-Depredation_slides_Councils_wide.20200116.pdf).

[22] National Marine Fisheries Service (NMFS). 2022. HMS Advisory Panel Meeting. Days 1-3 Transcripts. 18-20 May 2022 (https://www.fisheries.noaa.gov/event/may-2022-hms-advisory-panel-meeting).

[23] Gulf of Mexico Fishery Management Council (GMFMC). 2022. Public testimony, 23 June 2022, 15 and 24 August 2022, and 5 October 2022 (https://docs.google.com/spreadsheets/u/3/d/e/2PACX-1vQVPwRXQn06iM-6fx44XhuB9YtIx8dsrUzuOBIhMhDgtye_1VwaMY9wtO6B4OgsZ4Bgypxmhnbjhh7x/pubhtml?gid=265588419&single=true).

[24] National Marine Fisheries Service (NMFS). 2022. Interactions between bottlenose dolphins and sharks and commercial, for-hire, and private recreational fisheries in the Gulf of Mexico and South Atlantic. Report to Congress. 29 August 2022, 49 p. (https://media.fisheries.noaa.gov/2022-08/NMFS-Assessment-Fishing-Interference-RTC-08_29_22.pdf).

ery are not fully understood. Therefore, improved data collection coverage are warranted to quantify depredation events over time and track their monetary impact. Additionally, DNA testing of depredated catch could be an asset in identifying predators, whether shark, marine mammal, or others, which can then be correlated with damage traits, including those viewed on species documented through EM. With further refined genetic techniques, it becomes feasible to identify the specific species responsible for depredation, thereby providing valuable insights to effectively inform mitigation strategies.

Additionally, there are significant management concerns regarding the observed high at-vessel mortality for hammerhead, *Sphyrna* spp., and dusky sharks, attributed to handling stress (Gulak et al., 2015; Sulikowski et al., 2020). Even though a small number of hammerhead (*n* = 54) and dusky shark (*n* = 7) interactions were documented in our study, these resulted in at-vessel mortality rates of 39% and 43%, respectively. Therefore, it is crucial to regularly obtain data on key variables associated with these capture events, including gear configuration, bait type, environmental parameters, and biology of the species of interest (Carruthers et al., 2009). Data derived from EM documenting vessel interactions with all species of hammerhead sharks were provided to SEDAR 77 by the CFEMM (Lee et al.[25]) in 2021 for consideration in the cooperative stock assessment process. Although the scalloped hammerheads are not considered endangered in the U.S. Atlantic, distinct population segments exist that NMFS considers to be endangered or threatened in other Atlantic areas (NOAA[26]). Regarding dusky sharks, the most recent stock assessment suggests this species has been so depleted in the U.S. Atlantic (including the Gulf), that the recommended rebuilding schedule may take 100 years or more to reach sustainability (NOAA, 2016; Candless et al.[27]). Due to the low numbers of these shark species encountered in the eastern Gulf BLL fishery, it is critical to maximize the documentation of these encounters to inform current and future stock assessments.

Addressing the management challenges posed by sharks, integrating EM as an additional tool to complement at-sea observer coverage to document incidental shark catches and their subsequent fate is a valuable contribution for both reef fish and HMS management. While this study has made efforts to accurately identify shark catches, with additional expertise provided by outside shark experts, it is important to note that sharks in the genus *Carcharhinus*, such as silky and dusky sharks, are difficult to discern **(**Beerkircher et al., 2002). Consequently, unconfirmed interactions of these species, labeled by EM reviewers under an unidentified shark grouping likely exist in the dataset. However, an advantage of EM review is that the captured video of these species events serves as permanent documentation, allowing questionable annotations to be referred to additional experts for species verification or reexamined if artificial intelligence identification tools become available in the future.

Accounting for non-target species such as sea turtles, aquatic marine mammals, and seabirds caught as bycatch during commercial fishing is a priority in fisheries management (Burgess et al., 2018; Michelin et al., 2018; van Helmond et al., 2020), with appropriate camera placement, EM has been proven to provide accurate coverage for these encounters (Michelin et al., 2018). In our studies, five sea turtles were documented, with two brought in dead and three released. No bottlenose dolphins, *Tursiops truncatus*, were observed as caught or entangled in gear, although their presence was recorded when they were observed in close proximity to a vessel. Seabirds were frequently observed actively targeting bait and discarded floating scraps from processed fish. Ten individual seabirds recorded as caught were incidental captures, often hooked during the set, resulting in a high mortality rate.

The presented work showcases the effectiveness of EM in collaboration with voluntary participants from the eastern Gulf reef fish fishery resulting in the collection of a significant amount of data on vessel operations, targeted catch, bycatch, discarded species, and interactions with protected species. Despite its limitations, EM emerges as a robust monitoring tool with solid strengths, demonstrating its potential as a valuable asset in fisheries monitoring efforts. Furthermore, this study emphasizes advantages that EM can provide if integrated into fishery dependent monitoring programs, especially in regions like the Gulf where coverage is limited. By integrating EM alongside traditional methods and integrating additional data tools as necessary within the EM platform, we can effectively address critical data gaps and bolster the overall efficacy of monitoring initiatives. However, transitioning EM from a demonstration project to an integral component of comprehensive management programs requires a distinct approach. Collaboration with management is essential to expand monitoring efforts beyond voluntary participation and ensure the acquisition of representative data. This collaborative approach is crucial for broadening the scope and depth of monitoring coverage, ultimately leading to more informed decision-making in fisheries management. In conclusion, while this work effectively showcases the capabilities of EM and

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[25] Lee, M., G. Patrick, C. Neidig, and R. Schloesser. 2021. Hammerhead shark (*Sphyrna* spp.) electronic monitoring data review from the Gulf of Mexico bottom longline reef fish fishery. SEDAR77-DW05. SEDAR, North Charleston, SC, 9 p. (https://sedarweb.org/documents/sedar-77-dw05-hammerhead-shark-sphyrna-spp-electronic-monitoring-data-review-from-the-gulf-of-mexico-bottom-longline-reef-fish-fishery/).

[26] National Marine Fisheries Service (NMFS). 2020. Scalloped hammerhead shark (*Sphyrna lewini*) 5-Year Review: Summary and Evaluation. U.S. Dep. Commer., NOAA, NMFS, Off. Prot. Resour,, Silver Springs, MD, 43 p. (https://media.fisheries.noaa.gov/dam-migration/scalloped_hammerhead_5-year_review.pdf).

[27] McCandless, C. T., P. Conn, P. Cooper, E. Cortés, S. W. Laporte, and M. Nammack. 2014. Status review report: northwest Atlantic dusky shark (*Carcharhinus obscurus*). Report to National Marine Fisheries Service, Office of Protected Resources. October 2014. 72 p. (https://repository.library.noaa.gov/view/noaa/17711).

the success of industry collaboration, the next crucial step involves partnering with management to fully integrate EM into broader management frameworks, thereby maximizing its potential to enhance sustainable fisheries management practices in the Gulf reef fish fishery.

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