Characterization of Protected Species Bycatch in the U.S. Gulf of Mexico and the Southeastern U.S. Atlantic Penaeid Otter Trawl, Rock Shrimp, and Skimmer Trawl Fisheries Based on Mandatory Observer Coverage from 2007 to 2019

JUDITH P. GOCKE, ELIZABETH SCOTT-DENTON, and JO ANNE WILLIAMS

*ABSTRACT—From 2007 to 2019, the southeastern U.S. shrimp fishery's mandatory observer program has collectively observed 1,766 U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl, rock shrimp, and skimmer trawl trips. During observed shrimp trips, the program documented interactions with sea turtles, marine mammals, sawfish, giant manta rays, sturgeons, and seabirds. Spatial and temporal distribution of sea turtle interactions manifested higher numbers of mortalities off the coasts of Louisiana, Texas, and the southern waters of west Florida. Of the 280 sea turtles captured, 233 were alive at release. Marine mammal interactions, though low in number (*n *=16), resulted in near-total mortality. Habitat range of sawfish overlapped with fishery effort, resulting in captures (*n *=17) off Florida's coast with over 50% being released alive. Documentation of giant manta ray interactions began in 2019 and showed a higher occurrence in the southeastern U.S. Atlantic shrimp fishery relative to Gulf shrimp. The Gulf shrimp fishery off Louisiana and the southeastern U.S. Atlantic shrimp fishery off the coasts of the Carolinas and Georgia reported the capture of 14 sturgeons with close to 80% survival rate at release. Reporting of all captured seabird species was required; however, reports were low totaling 15.*

Introduction

Since its inception, a consequence of the commercial shrimp fishery has been the incidental capture of non-target species, referred to as bycatch. Fisheries bycatch is widely regarded as a wasted resource with adverse effects on stocks' productivity, discarded species, and disruptions to trophic webs and habitats at the ecosystem level (Crowder and Murawski, 1998; Harrington et al., 2005). The majority of shrimp species landed with commercial shrimp gear in the U.S. Gulf of Mexico and southeastern U.S. Atlantic are comprised of three species of penaeid shrimp, including brown shrimp, *Farfantepenaues aztecus*; white shrimp, *Litopenaeus setiferus*; and pink shrimp, *Farfantepenaeus duorarum*; and to a lesser degree, rock shrimp, *Sicyonia brevirostris*.

The capture, also referred to as interactions, of non-target species included the incidental take of threatened, endangered, and other marine protected species in commercial fishing gear. Captures or interactions are regulated by the National Marine Fisheries Service (NMFS), an agency of the National Oceanic and Atmospheric Administration (NOAA). NMFS management efforts include, but are not limited to, seasonal, temporal, and in-season area closures as well as gear modifications and restrictions. We will characterize interactions with sea turtles, marine mammals, sawfish, sturgeons, giant manta rays, and seabirds; emphasizing sea turtle interactions, documented by observers within the U.S. Gulf of Mexico and U.S. southeast Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries.

Within these four fisheries, the NMFS Southeast Fisheries Science Center (SEFSC) observer program has documented interactions with the following sea turtle species: Kemp's ridley, *Lepidochelys kempii*; loggerhead, *Caretta caretta*; green, *Chelonia mydas*; hawksbill, *Eretmochelys imbricate*; and leatherback, *Dermochelys coriacea*. Captures of the following protected species are also documented: sawfish, *Pristis* spp.; smalltooth sawfish, *Pristis pectinate*; bottlenose dolphins, *Tursiops truncates*; unidentified marine mammals, Family Delphinidae; Atlantic sturgeon, *Acipenser oxyrinchus*; Gulf sturgeon, *Acipenser oxyrinchus desotoi*; giant manta ray, *Manta birostris*; and all seabirds.

The specific objectives of this paper are to 1) document interactions with protected species during commercial shrimp operations based on gear within the U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries; and 2) quantify protected species interactions within the U.S. Gulf of Mexico and south U.S. Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries by area and season using hot spot analyses to depict areas with significant clustering of high or low catch-per-unit-effort (CPUE) for sea turtles.

Background

In December of 1973 the Endangered Species Act (ESA) was passed in an effort to conserve protected species. The ESA was designed not only to prevent extinction but also to recover species. In the 1980's, a decline in finfish species of the U.S. Gulf of Mexico and southeastern U.S. Atlantic brought about federal management measures to determine the cause of the decline and develop ways to rebuild the affected stocks.

Concerns over bycatch in the 1990's prompted the Sustainable Fisheries Act

The authors are with the Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77551 (corresponding author: judy.gocke@noaa.gov).

doi: https://doi.org/10.7755/MFR.84.3-4.2

amendment to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA [16 USC 1801]). The SEFSC observer program, based in Galveston Texas, was provided authority to place observers on commercial fishing vessels operating within federally managed fisheries by MSFCMA, the Marine Mammal Protection Act (MMPA), and the ESA. These acts required the government to collect data and report on activities that affect marine resources. All data discussed here were collected by the above referenced observer program. The data collected by the observer program has, in turn, been used to provide data to promote fisheries management efforts to conserve and recover affected species.

In 1992, in response to the congressional mandates, the NMFS Southeast Fisheries Science Center, in cooperation with the Gulf and South Atlantic Fisheries Foundation, Inc. (Foundation), implemented a cooperative research plan to identify, develop, and evaluate gear options to reduce bycatch in the Gulf of Mexico and southeastern U.S. Atlantic shrimp fisheries (NMFS, 1991; Hoar et al., 1992). The goal was to evaluate bycatch species catch rates collected by shrimp trawlers and reduce finfish and protected species bycatch with the aid of bycatch reduction devices (BRD). Numerous BRD styles were developed by industry, scientists, and gear specialists and evaluated through cooperative multiyear efforts (NMFS, 1995; Scott-Denton and Nance, 1996; Branstetter, 1997; Nance and Scott-Denton, 1997; Nance et al., 1997; NMFS, 1998; Watson et al., 1999; Foster and Scott-Denton, 2004; NMFS, 2006; Scott-Denton, 2007; Helies and Jamison, 2009; Scott-Denton et al., 2012).

Through voluntary observer coverage, from 1992 to mid-July 2007, species-specific bycatch data from the U.S. Gulf of Mexico and southeastern U.S. Atlantic commercial shrimp fisheries were collected (Scott-Denton et al., 2007). The Texas Shrimp Association (TSA), North Carolina Division of Marine Fisheries (NCDMF), and the Georgia Department of Natural Resources (GDNR) have also collected observer data from commercial shrimp vessels and contributed to the shrimp trawl observer database. A voluntary component of the observer program continues for TED and BRD development and evaluation (Scott-Denton et al., 2012).

Joint voluntary observer coverage from 1992 to mid-July 2007 resulted in 158 observed trips with protected species interactions. Trips were designed to evaluate turtle excluder devices (TED's), naked nets (TED alternative-nets not equipped with TED's), BRD certifications, effort, and bycatch characterizations. NOAA observers completed 77 trips; 69 were observed by the Foundation, 6 by North Carolina Sea Grant, and 6 by the Georgia Department of Natural Resources. All combined, 525 sea turtles were captured (360 loggerheads, 115 Kemp's ridleys, 19 unidentified hardshell species, 18 greens, 9 leatherbacks, and 4 unknown species). In addition to sea turtles, voluntary observer coverage documented individual interactions with 7 marine mammals, 2 sturgeons, and 1 smalltooth sawfish.

To improve the statistical validity of data for the voluntary observer program, including bycatch, fishing effort, and fishery performance metrics, the Gulf of Mexico Fishery Management Council (GMFMC), through Amendment 13 to the Shrimp Fishery Management Plan (GMFMC, 2005), mandated observer coverage of federally permitted vessels; which required all vessels with federally regulated fishing permits to carry observers during fishing operation when selected by the observer program. Implementation of the mandatory observer program for the commercial shrimp fishery operating in the U.S. Gulf of Mexico began in 2007. Observer coverage was expanded in June 2008 to include the southeastern U.S. Atlantic penaeid and rock shrimp fisheries through Amendment 6 to the Shrimp Fishery Management Plan for the South Atlantic Region (SAFMC, 2005).

Increased interest in sea turtle mortality, within the SEFSC, prompted further expansion of the program, and NMFS observers were deployed off Louisiana's coast on inshore commercial skimmer vessels from 2004 to 2005. The skimmer trawl fishery is limited geographically; the nets are designed for fishing during shallow water, limiting the fleet's size to vessels with shallow drafts. Skimmer nets are pushed rather than pulled through the water, fished in nearshore surface waters, and not outfitted with turtle excluder devices (TED's). Fisheries observers provided coverage for a voluntary skimmer trawl fishery component (Scott-Denton et al., 2007); this was done through voluntary agreements with individual vessels. From 2004 to 2005, no protected species interactions were documented.

Further expansion occurred in 2008 and continued through 2010 to include coverage of North Carolina to evaluate TED's. In 2012, observer coverage of the skimmer trawl fishery off the coasts of Louisiana, Alabama, and Mississippi was made mandatory for vessels selected by the observer program. Voluntary coverage continued in addition to a mandatory component that began in May of 2012 (Pulver et al., 2012; 2014, Scott-Denton et al., 2014). From 2010 to 2015, the voluntary coverage resulted in 28 observed sea turtle interactions (16 Kemp's ridleys, 10 greens, and 2 loggerheads) and 12 seabird interactions.

Methods

Methods used in this investigation are those described by the current mandatory observer program operating in the U.S. Gulf of Mexico and along the southeastern U.S. Atlantic (Scott-Denton et al., 2012), as well as coastal Louisiana and North Carolina skimmer trawl observer programs (Scott-Denton et al., 2007). Observers were placed on otter trawl vessels from 2007 to 2019, targeting either penaeid or rock shrimp. Selections for placing observers on skimmer trawl vessels began in May 2012, targeting penaeid shrimp. The observer program operated in state and federal waters within the exclusive eco-

nomic zone (EEZ). The EEZ comprises an area that extends either from the coast or, in federal systems, from the seaward boundaries of state waters (3–12 n.mi., in most cases) to 200 n.mi. off the coast.

Vessels were selected to carry an observer from the current NMFS Southeast Regional Office (SERO) vessel permit lists (SERO, 2020). Skimmer trawl vessels were selected from state license holder lists. The number of vessels selected for each selection was dependent on funding availability, coverage needs, and varied based on the fishery and season. Selection letters were sent to owners of selected vessels via certified mail. Vessel owners were instructed to contact the observer program within 24 h upon receipt of the certified letter. Moreover, as a safety requirement, vessel operators were required to contact the United States Coast Guard (USCG) to obtain a current safety decal. The decal provided proof the vessel successfully passed a USCG dockside safety exam in compliance with the Commercial Fishing Industry Safety Act (Craig, 2014) prior to placing an observer onboard a vessel.

Shrimp vessels were selected based on the previous year's reported catch (landings/effort), stratified by area fished, water depth fished, and season. Similarly, the skimmer trawl fishery was stratified by area and season, with the assumption of depth as inshore or nearshore due to the nature of the fishery. Depth strata were classified as inshore (the area from the beach seaward inside the International Regulations for Preventing Collisions at Sea 1972 [72 COLREGS] line), nearshore (the water outside the inshore lines, ≤ 10 fm), and offshore (> 10 fm). Fishing areas were delineated by statistical zones (Patella, 1975; Fig. 1). The statistical zones were broken down into 34 areas: 1–9 west coast of Florida, 10–11 Alabama/Mississippi, 12–17 Louisiana, 18–21 Texas, 24–30 east coast of Florida, 31 Georgia, 32–33 South Carolina, and 34–36 North Carolina. Similarly, for the Atlantic, lat. 24°00'N–30°42.5'N denote the east coast of Florida, > lat. 30°42.5'N–32°00'N depict Georgia, > lat. 32°00'N–33°51.6'N represent South Carolina, and > lat. 33°51.6'N delineate North Carolina (Scott-Denton et al., 2012).

Seasons were fishery specific; the U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl fisheries were broken down into three seasons per year (January–April, May–August, and September–December). The rock shrimp fishery was covered during one season (July–November), and inshore commercial shrimp skimmer trawl and North Carolina TED testing consisted of one season (May–August); if coverage and/or vessel compliance were not met and funding was available, seasonal coverage was extended (September–December).

Selected vessels were required to carry observers for a specific number of sea days, within the season for which they were selected, to satisfy permit obligations. A sea day was defined as any part of a day spent at sea, in transit, on anchor, or fishing without a return to port. The number of sea days a vessel was required to fulfill varied by fishery. The two fisheries that received the highest observer coverage, U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl fisheries (Gulf shrimp and southeastern U.S. Atlantic shrimp), were required to carry an observer for 18 and 6 sea days, respectively, with fishery coverage year-round. Rock shrimp fishery required vessels to carry an observer for 11 sea days, and the skimmer trawl fishery required 5 sea days.

Fishing gear and biological sampling procedures were fisheries specific. Detailed descriptions for all sampling procedures can be found in the NMFS Characterization of the U.S. Gulf of Mexico and Southeastern Atlantic Otter Trawl and Bottom Reef Fish Fisheries Observer Training Manual (NMFS, 2020). Vessel information was recorded, including, but not limited to, the following: vessel length, hull material, gross tonnage, engine horsepower, and crew size. Net type and associated gear information (TED and BRD type) were recorded, as well as changes to gear throughout a trip. Tow specific information (beginning and end) included: date, time, Global Positioning System (GPS) coordinates, vessel speed, and water depth. Net information, per tow, included sample weight (kg), total catch weight (kg), total shrimp weight (kg), and status of BRD (open or closed). Sample weight was calculated by separating one basket from each sampled net (approximately 32 kg). Catch from the sample weight basket provided the species-specific information, collected per net, consisting of the scientific name, number of individuals, and sample or select weights (kg). Select weight referred to a particular species of commercial importance that was separated out of the total catch and was not included in the sample weight. No extrapolation was required for select species like red snapper, which were measured and counted separately.

Protected species interactions or captures were recorded as they occurred during both sampled and unsampled tows. Sampled tows were tows that occurred when the vessel was actively fishing with the main nets and the observer collected biological data. Unsampled tows were tows when the vessel was actively fishing and the observer was not collecting biological data. Sightings of protected species were recorded but not used in this analysis; sightings were not caught as bycatch and had no interaction with the vessel or gear. Protocols for the scientific sampling of protected species captured as bycatch followed the SEFSC permitted requirements and Observer Training Manual (NMFS, 2008; 2020). Data collected for sea turtles consisted of condition at the time of capture and release, injury status as a result of capture, biological information (measurements, scute counts and orientation, dorsal coloration), biological samples (skin tissue biopsies or carcass retention), gear interaction details, and tag application (flipper, passive integrated transponders [PIT] tags, and survival pop-up archival transmitting tags [sPAT]). Details of sea turtle interactions, includ-

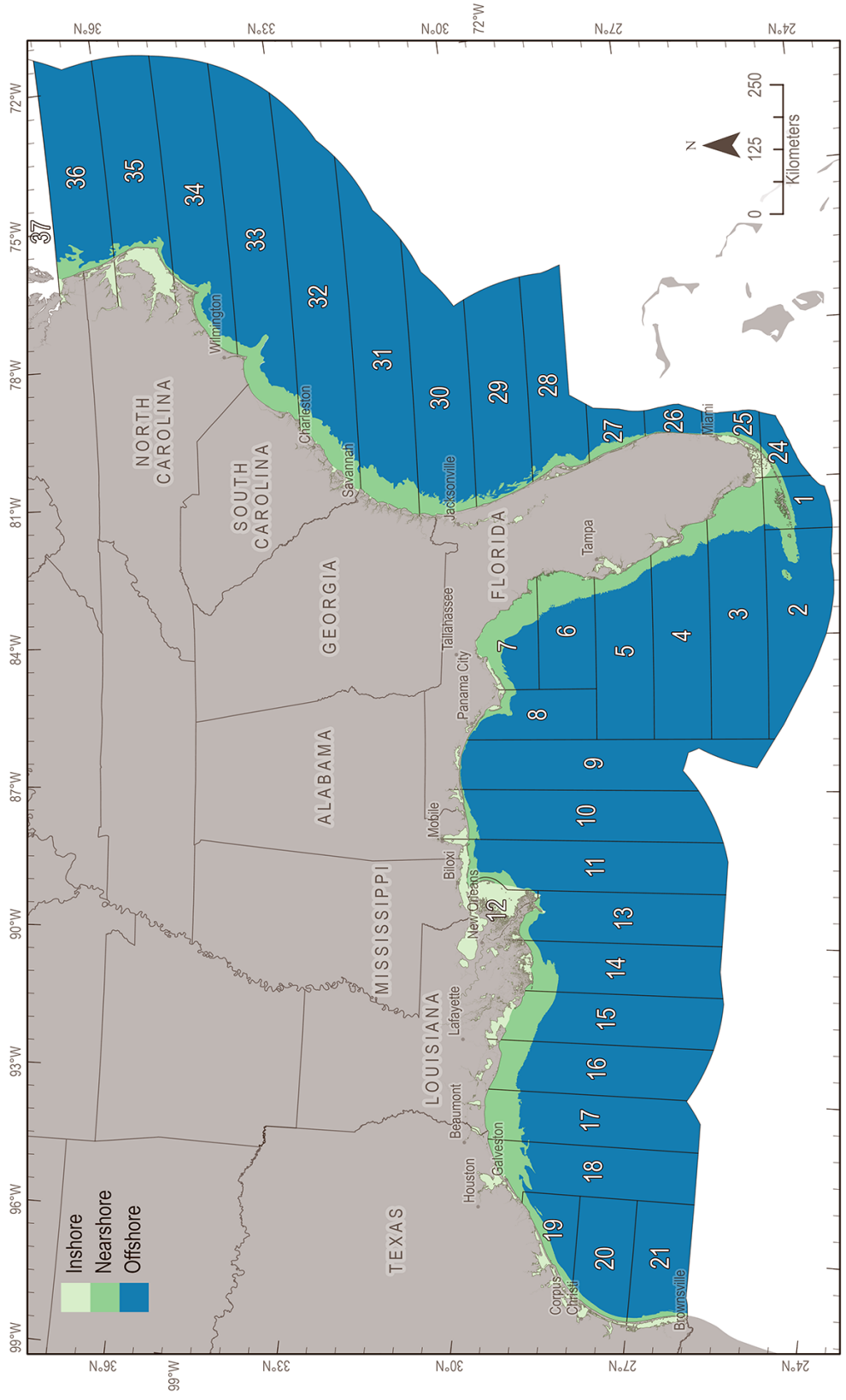

Figure 1.—Fishing area map delineated by statistical zones (Patella, 1975).

ing species and condition at the time of capture and release (i.e., alive, fresh dead/unresponsive, previously dead, unknown, or other), were reported to the SEFSC for scientific and management purposes, including annual sea turtle mortality assessments. Age and sex determinations were not made.

Marine mammal interactions were reported to the SEFSC; captures were categorized by species and condition of the marine mammal at the time of release (alive/swam away normally, alive/swam away abnormally, or dead). The Protected Resource Capture Report was completed for the capture of sawfish, sturgeon, giant manta ray, and seabirds and categorized by species and final disposition (alive, discarded dead/unresponsive carcass, or unknown) (Gocke, 2019). All interaction data was reported to the SEFSC generally within 24 h of capture.

Statistical Methods

All protected species results reported are non-extrapolated and based on the total number of interactions. Data for all interactions, regardless of operations problems (e.g., torn nets, hangs, clogging, and faulty gear), were included to represent standard commercial operations experienced by the fishery. If required, all nets used were consistent with current BRD regulations. Two to four nets were towed during standard fishing operation; effort metrics are based on the single net where protected species interaction occurred.

The surface density of fishing effort was created using the ArcGIS Pro Kernel Density[1] tool (Esri Inc, 2020). This tool calculated the density of feature values within a specified search radius around the feature and created a smooth surface of the magnitude per unit area. The search radius was based on the average minimum tow length plus the standard deviation for each fishery (20 km for Gulf and rock shrimp; 10 km for southeastern U.S. Atlantic shrimp; 5 km for skimmer trawl).

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

CPUE of sea turtle interactions were calculated using tow hours (calculated per tow hour based on a single net in which interaction occurred, regardless of the total number of nets towed). For try net interactions, try net tow times were used, if available. To identify statistically significant spatial clusters of high or low sea turtle CPUE, a local spatial statistic, the Getis-Ord Gi* (Gi*), was calculated using the Optimized Hot Spot Analysis tool in ArcGIS Pro. This tool analyzed the value (sea turtle CPUE) of each feature (tow location) in relation to the value of its neighboring features and compared each neighborhood to the value for all features within the dataset. Having a high value alone does not mean that a feature is a "hot spot" (or "cold spot" for low values)—it must be surrounded by features with similarly high (or low) values as well.

The tool used three strategies to determine the appropriate scale of analysis. The Incremental Spatial Autocorrelation tool was used to measure spatial autocorrelation at increasing distance increments. The distance associated with a statistically significant peak was used for the scale of analysis. This method was used for the Gulf shrimp fishery (peak clustering found at 6,720.07 m) and the skimmer fishery (peak clustering found at 4.583.73 m).

If no peak distance was found, the tool computed the average distance that would yield K neighbors for each feature (where K = 0.05 * N, the number of features in the dataset) and used it as the scale of analysis. If the average distance that would yield K neighbors exceeded one standard distance, then the third method was used and the scale of analysis was set to one standard distance. The K neighbor average distance method was used to determine the scale of analysis for the southeastern U.S. Atlantic shrimp fishery (optimal fixed distance band of 5,731.0 m was based on the average distance to 30 nearest neighbors) and the rock shrimp fishery (the optimal fixed distance band of 1,5237.0 m was based on the average distance to 25 nearest neighbors).

These values for the scale of analysis determined which features were analyzed together in order to assess local clustering. The local sum for a feature and its neighbors was compared proportionally to the sum of all features. The tool generated a z-score, p-value, and the number of neighbors for each feature. When the local sum was very different from the expected local sum, and when that difference was too large to be the result of random chance, a statistically significant z-score resulted.

For statistically significant positive z-scores, the larger the z-score was, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score was, the more intense the clustering of low values (cold spot). The p-value was a measure of probability. The lower the p-value, the more likely it was that the pattern of high or low values was a statistically significant cluster and was not due to random chance but rather the result of some underlying spatial process.

A False Discovery Rate (FDR) correction was applied to adjust the statistical significance to account for multiple testing and spatial dependency. Based on an FDR correction, the Gulf shrimp fishery had 1,302 tow locations with statistically significant high or low turtle CPUE's. The southeast U.S. Atlantic had 130; the rock shrimp fishery had no statistically significant clusters of high or low sea turtle CPUE values. The skimmer fishery had 384 tow locations with statistically significant clusters of high or low sea turtle CPUE values. To effectively visualize the hot spot analysis results, an inverse distance weighted technique (ArcGIS Pro IDW Spatial Analyst tool) was used to create a continuous surface.

Results

The mandatory shrimp trips observed, by the program, from July 2007 through December 2019 totaled 1,766 (Table 1). In July 2007, 100% of the observer program's coverage was concentrated in the Gulf shrimp

fishery. As the observer program progressed, fishing effort was distributed across four mandatory fisheries (Gulf shrimp, southeastern U.S. Atlantic shrimp, rock shrimp, and skimmer trawl); however, the highest concentration of effort remained in the Gulf shrimp fishery. Of the 1,766 trips completed, shrimp catch from 46,098 tows was sampled targeting penaeid and rock shrimp during 20,813 sea days of operation.

Observed Gulf shrimp fishery trips consisted of 38,186 tows (18,642 sea days), comprising 83% of the observed tows by year and fishery across all fisheries from 2007 to 2019 (Table 1). As fishing effort was distributed throughout the different fisheries, the Gulf shrimp fishery produced the highest sea days by year and fishery at 90%. When the years were combined and evaluated spatially, fishing effort spanned the entire U.S. Gulf of Mexico. The highest concentration of fishing effort was completed in statistical zones 11–17 off Louisiana and Mississippi's coasts. Statistical zone 21 off the coast of Texas and zone 2 off the west Florida coast also exhibited high concentrations of effort (Fig. 2). When broken down by season, the highest concentration of h fished (> 1.484 h fished/km^2) occurred from May through August off the coast of Louisiana in statistical zones 11–16 (Fig 3–5).

A total of 3,567 tows (1,411 sea days) were sampled in the southeastern U.S. Atlantic shrimp fishery resulting in 8% of the completed tows for the whole observer program encompassing the years 2007–19 (Table 1). Percent coverage by sea days in the southeastern U.S. Atlantic shrimp fishery did not exceed 12% during this period. The highest concentration of effort in the combined years was located in North Carolina (statistical zone 35); small pockets of fishing effort were also situated off the coast of eastern Florida and Georgia in zone 29–31 (Fig. 6). May through August produced the highest concentration of fishing effort off the coast of North Carolina in statistical zone 35 (>1.143 h fished/km^2) with slightly lower concentrations (> 0.417 h fished/km^2) off the coasts of South Carolina, Georgia, and eastern Florida in statistical zones 28–33. Effort was concentrated in the same locations during season three, September through December, with slightly lower effort (> 0.417 to ≤ 1.143 h fished/km^2) (Fig. 7–9).

The rock shrimp fishery off Florida's eastern coast consisted of 502 tows by year and fishery (226 sea days) totaling 1% of the overall tows sampled by the observer program during 2007–19 (Table 1). Percent coverage by sea days was at its highest point in 2008 at 3%. Florida's east coast received the highest concentration of effort in statistical zones 29–27 with maximum effort in zone 28. Effort occurred, to a lesser degree, in zones 7 and 8 off the coast of west Florida south of Apalachicola and in statistical zones 2–4 (Fig. 10). The highest concentration of effort occurred at the beginning of the season >0.211 h fished/km^2 (May–August) and continued at lower concentrations (>0.077 to ≤ 0.211 h fished/km^2) to the end of the season in November (Fig. 11–13).

Observed mandatory coverage of the skimmer trawl fishery, which began in 2012, completed 3,843 tows (534 sea days) off Louisiana, Missis-

Table 1.—Trips, tows, sea days, and percent distribution of observer coverage across projects by year and program, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Item	Year	Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Trips by year and fishery	2007	31 (100%)				31
	2008	107 (78%)	27 (20%)	3 (2%)		137
	2009	105 (60%)	68 (39%)	2 (1%)		175
	2010	104 (78%)	29 (22%)	1 (1%)		134
	2011	76 (55%)	59 (43%)	2 (1%)		137
	2012	80 (43%)	46 (25%)		58 (32%)	184
	2013	82 (47%)	54 (31%)	4 (2%)	35 (20%)	175
	2014	94 (73%)	16 (12%)	1 (1%)	18 (14%)	129
	2015	97 (66%)	24 (16%)	2 (1%)	23 (16%)	146
	2016	118 (66%)	45 (25%)	2 (1%)	15 (8%)	180
	2017	106 (80%)	18 (14%)	3 (2%)	5 (4%)	132
	2018	81 (69%)	24 (21%)	1 (1%)	11 (9%)	117
	2019	62 (70%)	19 (21%)	3 (3%)	5 (6%)	89
	Total	1,143 (65%)	429 (24%)	24 (1%)	170 (10%)	1,766
Tows by year and fishery	2007	1,242 (100%)				1,242
	2008	2,797 (90%)	202 (7%)	97 (3%)		3,096
	2009	2,918 (86%)	441 (13%)	16 (0%)		3,375
	2010	2,307 (93%)	145 (6%)	41 (2%)		2,493
	2011	2,677 (89%)	275 (9%)	50 (2%)		3,002
	2012	2,610 (70%)	370 (10%)		765 (20%)	3,745
	2013	3,357 (70%)	322 (7%)	70 (1%)	1,075 (22%)	4,824
	2014	3,570 (81%)	177 (4%)	24 (1%)	634 (14%)	4,405
	2015	3,297 (84%)	202 (5%)	40 (1%)	371 (9%)	3,910
	2016	3,749 (82%)	405 (9%)	43 (1%)	359 (8%)	4,556
	2017	4,282 (88%)	378 (8%)	77 (2%)	131 (3%)	4,868
	2018	3,306 (80%)	417 (10%)	6 (0%)	381 (9%)	4,110
	2019	2,074 (84%)	233 (9%)	38 (2%)	127 (5%)	2,472
	Total	38,186 (83%)	3,567 (8%)	502 (1%)	3,843 (8%)	46,098
Sea days by year and fishery	2007	639 (100%)				639
	2008	1,435 (91%)	86 (5%)	53 (3%)	(0%)	1,574
	2009	1,559 (88%)	206 (12%)	7 (0%)	(0%)	1,772
	2010	1,130 (93%)	68 (6%)	14 (1%)	(0%)	1,212
	2011	1,273 (91%)	102 (7%)	21 (2%)	(0%)	1,396
	2012	1,413 (85%)	140 (8%)		119 (7%)	1,672
	2013	1,588 (84%)	127 (7%)	30 (2%)	145 (8%)	1,890
	2014	1,731 (92%)	68 (4%)	9 (0%)	82 (4%)	1,890
	2015	1,555 (91%)	88 (5%)	19 (1%)	44 (3%)	1,706
	2016	1,869 (89%)	164 (8%)	18 (1%)	47 (2%)	2,098
	2017	1,840 (91%)	126 (6%)	34 (2%)	16 (1%)	2,016
	2018	1,580 (89%)	139 (8%)	1 (0%)	57 (3%)	1,777
	2019	1,030 (88%)	97 (8%)	20 (2%)	24 (2%)	1,171
	Total	18,642 (90%)	1,411 (7%)	226 (1%)	534 (3%)	20,813

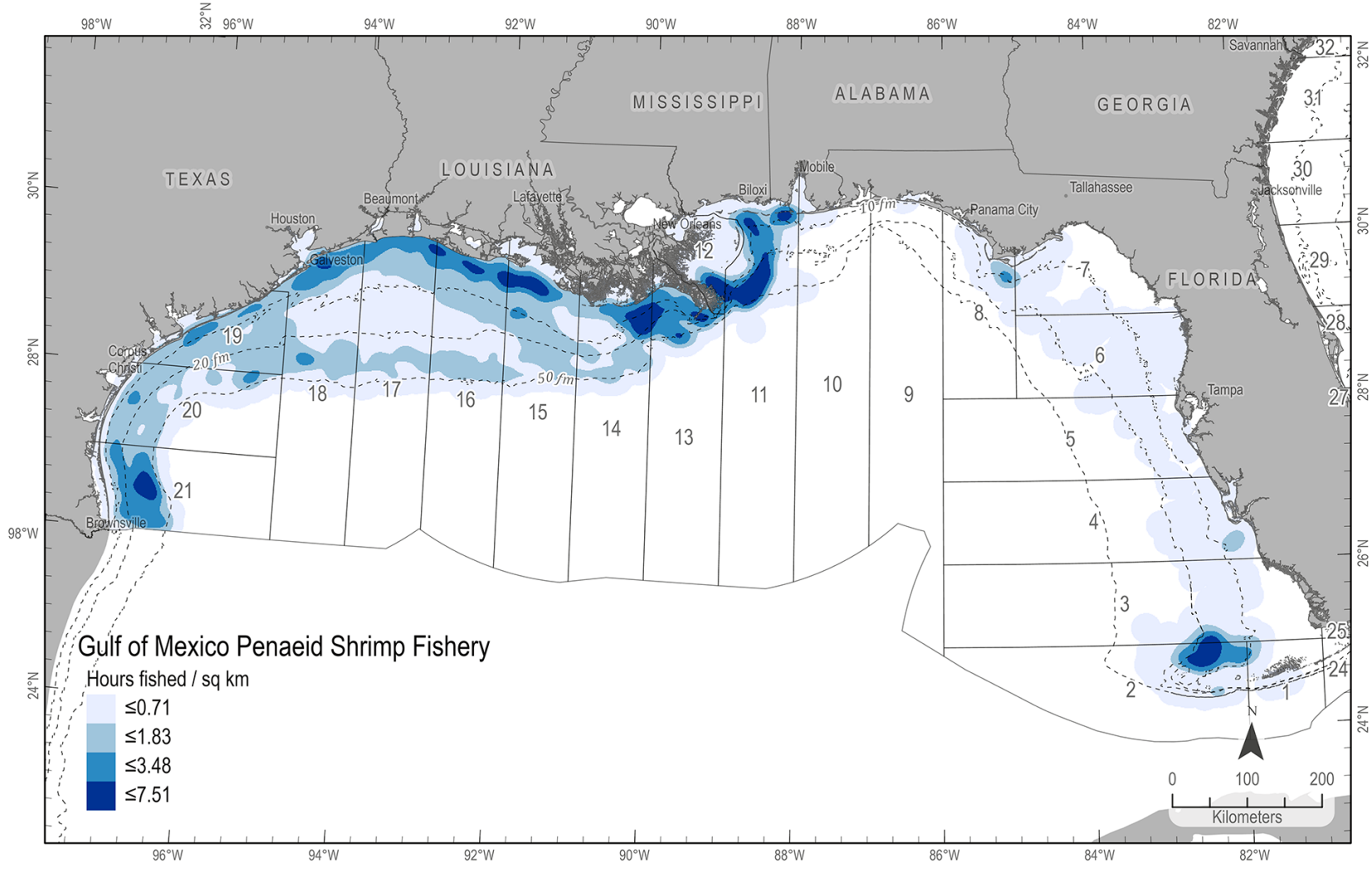

Figure 2.—Density of hours fished for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

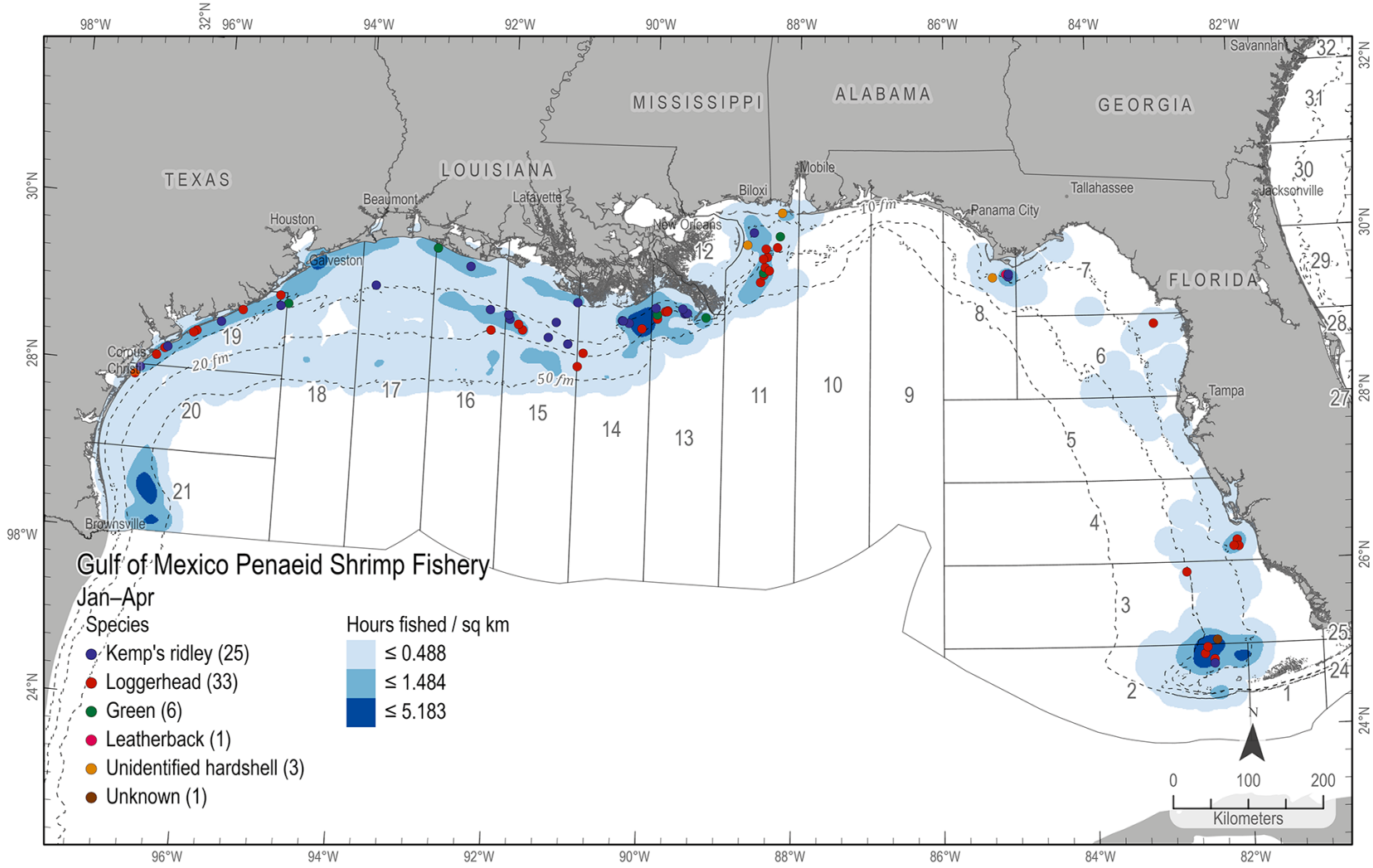

Figure 3.—Density of hours fished and sea turtle captures (n = 69), January through April, for the Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

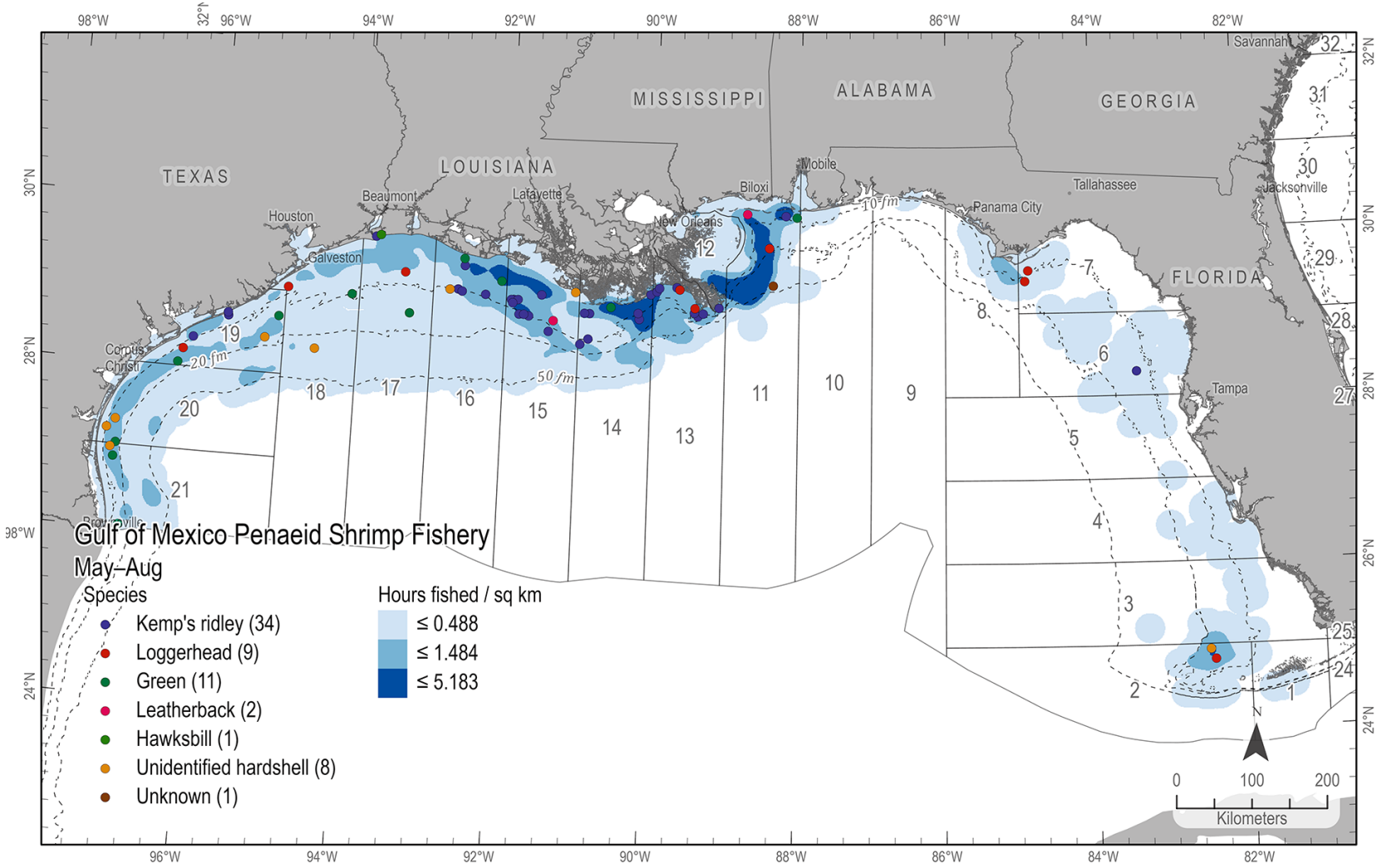

Figure 4.—Density of hours fished and sea turtle captures (n = 66), May through August, for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

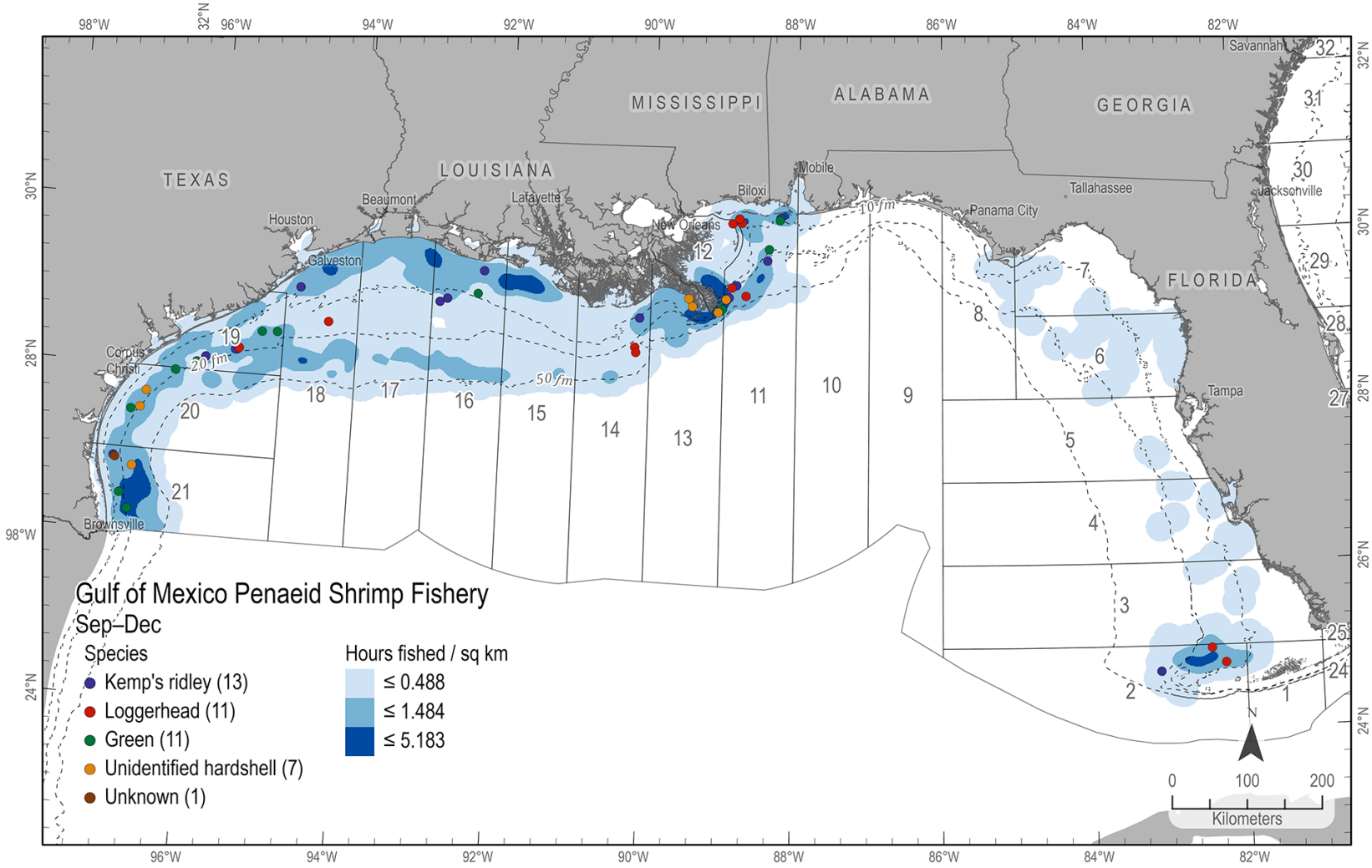

Figure 5.—Density of hours fished and sea turtle captures (n = 43), September through December, for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

sippi, and Alabama for 8% coverage of the total completed tows during 2007–19 (Table 1). Percent coverage by sea day was highest in 2013 at 8% and lowest in 2017 with 1% coverage. The largest concentration of effort was collected in the shallow water of Caillou Bay and Lake Pelto in statistical zone 14 with concentrations of effort near Marsh Island (statistical zones 15–16), in Black Bay (zone 12), and Barataria Bay (zone 13; Fig. 14). The skimmer trawl fishery generally began in May and was broken down into two seasons. The highest concentration of effort >1.709 h fished/km^2 occurred in May through August and tapered off during September through December with effort peaking at ≤1.709 h fished/km^2 (Fig. 15–17).

Protected Species Observations During Mandatory Observer Coverage

Turtle Characterization

From July 2007 through December 2019, 280 sea turtle captures were documented. Species and quantities of each varied over time with the following species recorded: Kemp's ridley, loggerhead, green, unidentified hardshell, leatherback, unknown/unidentified, and hawksbill (Table 2). The majority (n = 178) of the captures, occurred in the Gulf shrimp fishery. The second-highest concentration occurred in the skimmer trawl fishery with 58 captures. This was followed by the southeastern U.S. Atlantic fishery with a total of 39. The fewest number of captures occurred in the rock shrimp fishery, with a total of 5 loggerheads.

Tagging of captured turtles relied on the vessels' ability to board the turtle, size of the turtle, observer being given access to work up the turtle, and the availability of supplies while at sea. During mandatory coverage, 141 sea turtles were flipper tagged within the four fisheries, and 160 turtles were PIT tagged. Discrepancies between number of flipper and PIT tag application was predominantly due to collection regulations, as sea turtles must be of adequate size to safely flipper or PIT tag. Turtles greater than 30 cm straight carapace length (SCL) can be PIT and flipper tagged (NMFS, 2009). In cooperation with the SEFSC, Miami sea turtle researchers, sPAT tags were applied to 3 Kemp's ridleys and 3 loggerheads to augment a post-interaction mortality study. When boarded, every attempt was made by observers to collect biological information, biopsy samples, and apply tags (flipper, PIT, and sPAT tags).

Gulf Shrimp Fishery The largest numbers of turtles were captured between January and April (season 1), followed by May–August (season 2), with lowest concentration of captures in September–December (the final, sea-

Table 2.—Sea turtle capture and release status based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Species Capture condition Disposition	Fishery Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Kemp's ridley	72	11		48	131
Alive	45	11		43	99
Released alive	45	11		43	99
Fresh dead/unresponsive	26			4	30
Released alive	14			3	17
Salvaged carcass	3				3
Discarded carcass	9			1	10
Previously dead	1			1	2
Discarded carcass	1			1	2
Loggerhead	53	21	5	4	83
Alive	50	21	5	4	80
Released alive	49	21	5	4	79
Unknown	1				1
Fresh dead/unresponsive	2				2
Released alive	1				1
Discarded carcass	1				1
Previously dead	1				1
Discarded carcass	1				1
Green	28	2		4	34
Alive	10	2		1	13
Released alive	10	2		1	13
Fresh dead/unresponsive	18			2	20
Released alive	2				2
Salvaged carcass	6				6
Discarded carcass	9			2	11
Unknown	1				1
Previously dead				1	1
Discarded carcass				1	1
Unidentified hardshell	18	5		2	25
Alive	11	4		2	17
Released alive	11	4		2	17
Fresh dead/unresponsive	4				4
Discarded carcass	3				3
Unknown	1				1
Unknown	3	1			4
Unknown	3	1			4
Leatherback	3				3
Alive	2				2
Released alive	2				2
Fresh dead/unresponsive	1				1
Discarded carcass	1				1
Hawksbill	1				1
Alive	1				1
Released alive	1				1
Unknown	3				3
Unknown	3				3
Released alive	2				2
Unknown	1				1
Total	178	39	5	58	280

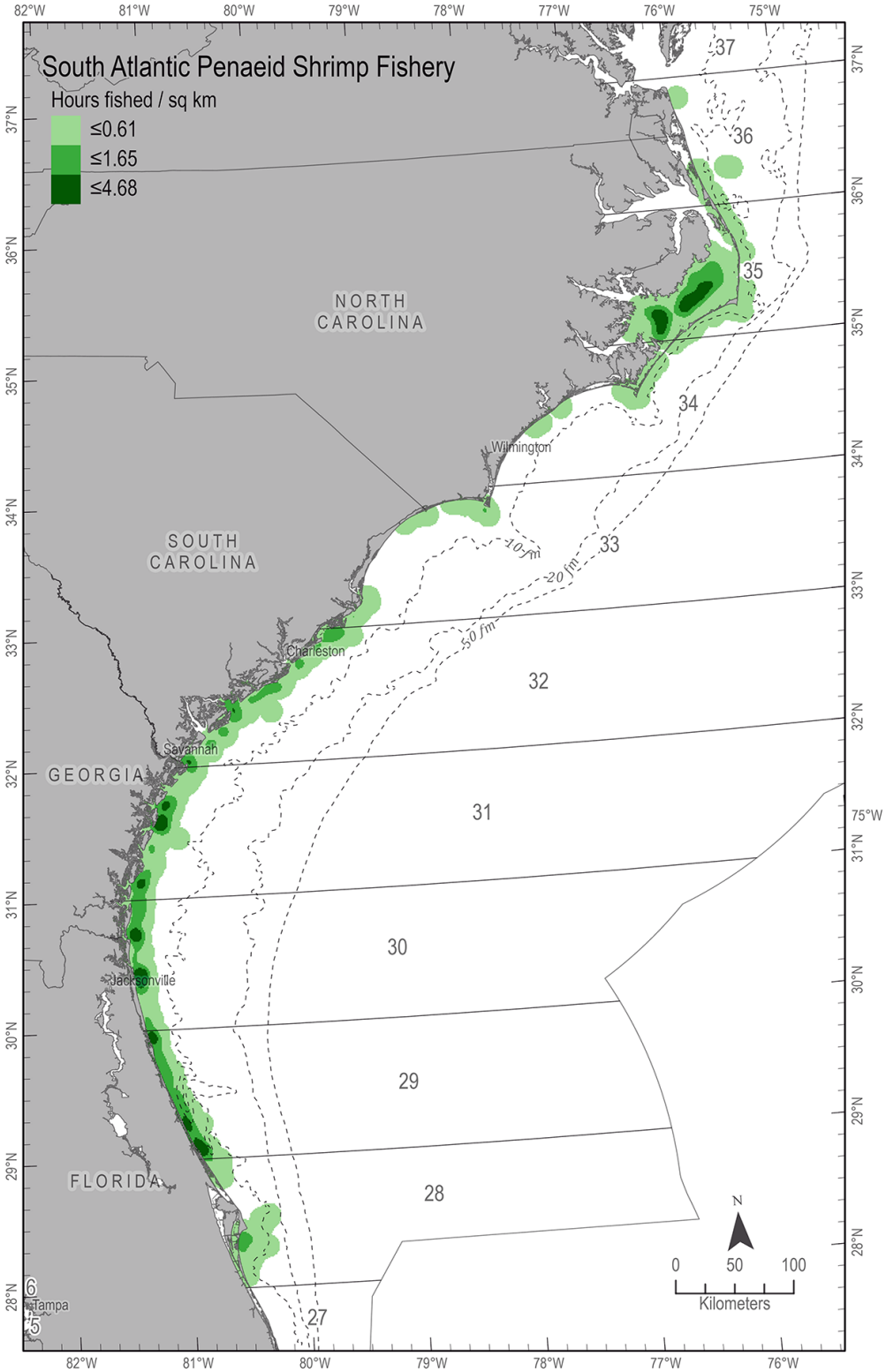

Figure 6.—Density of hours fished for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

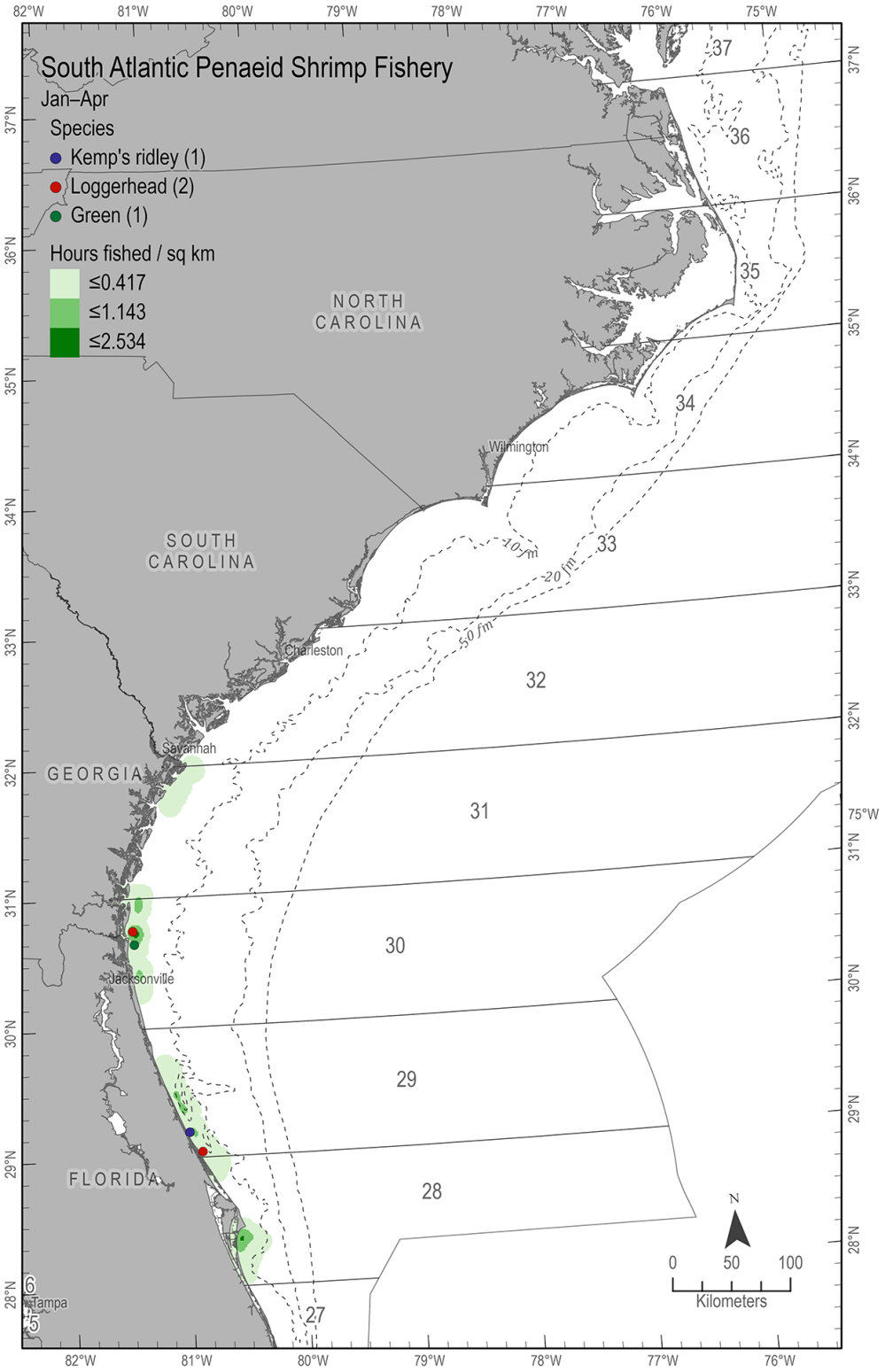

Figure 7.—Density of hours fished and sea turtle captures (n = 4), January through April, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

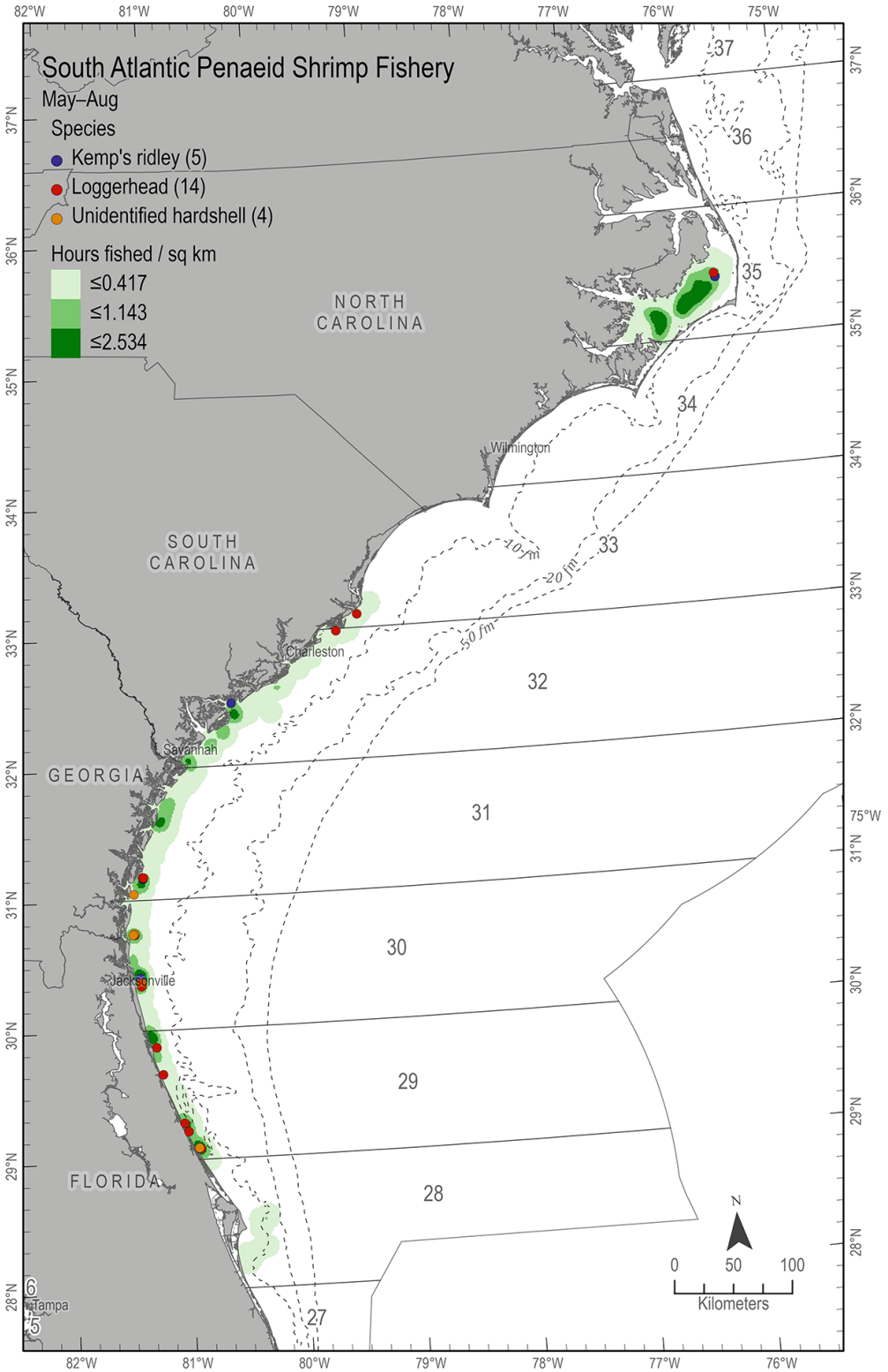

Figure 8.—Density of hours fished and sea turtle captures (n = 23), May through August, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

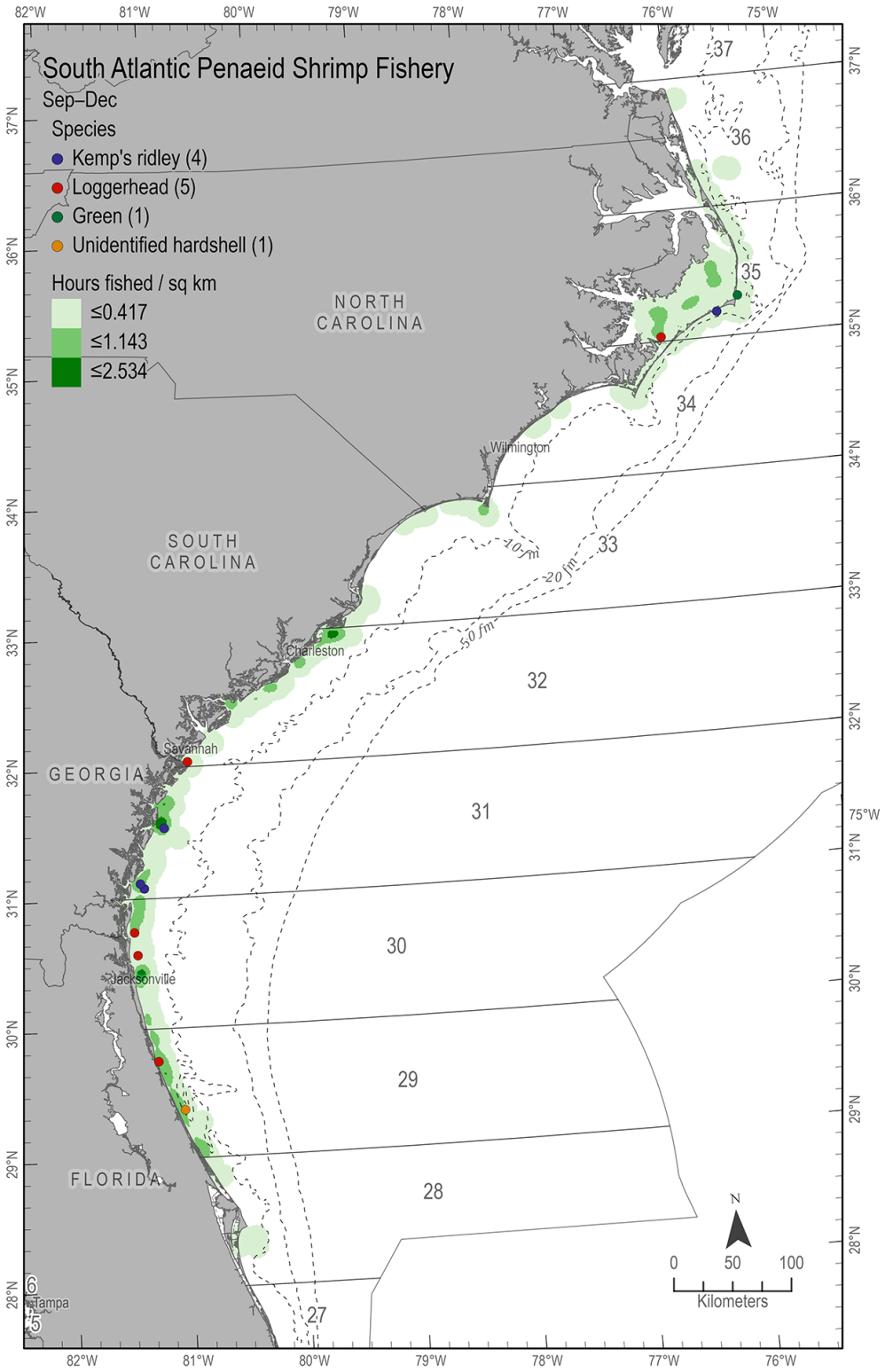

Figure 9.—Density of hours fished and sea turtle captures (n = 11), September through December, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

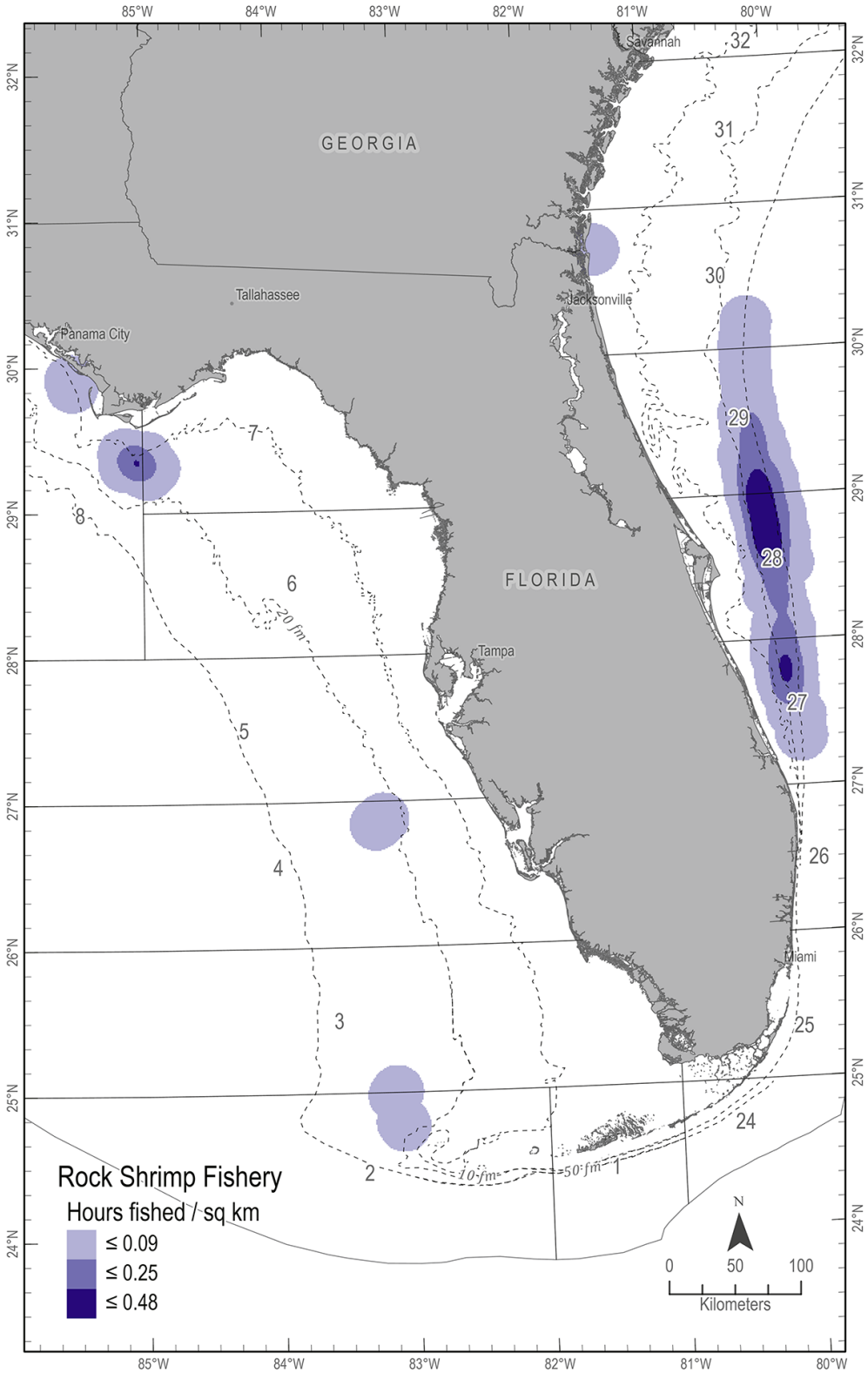

Figure 10.—Density of hours fished for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

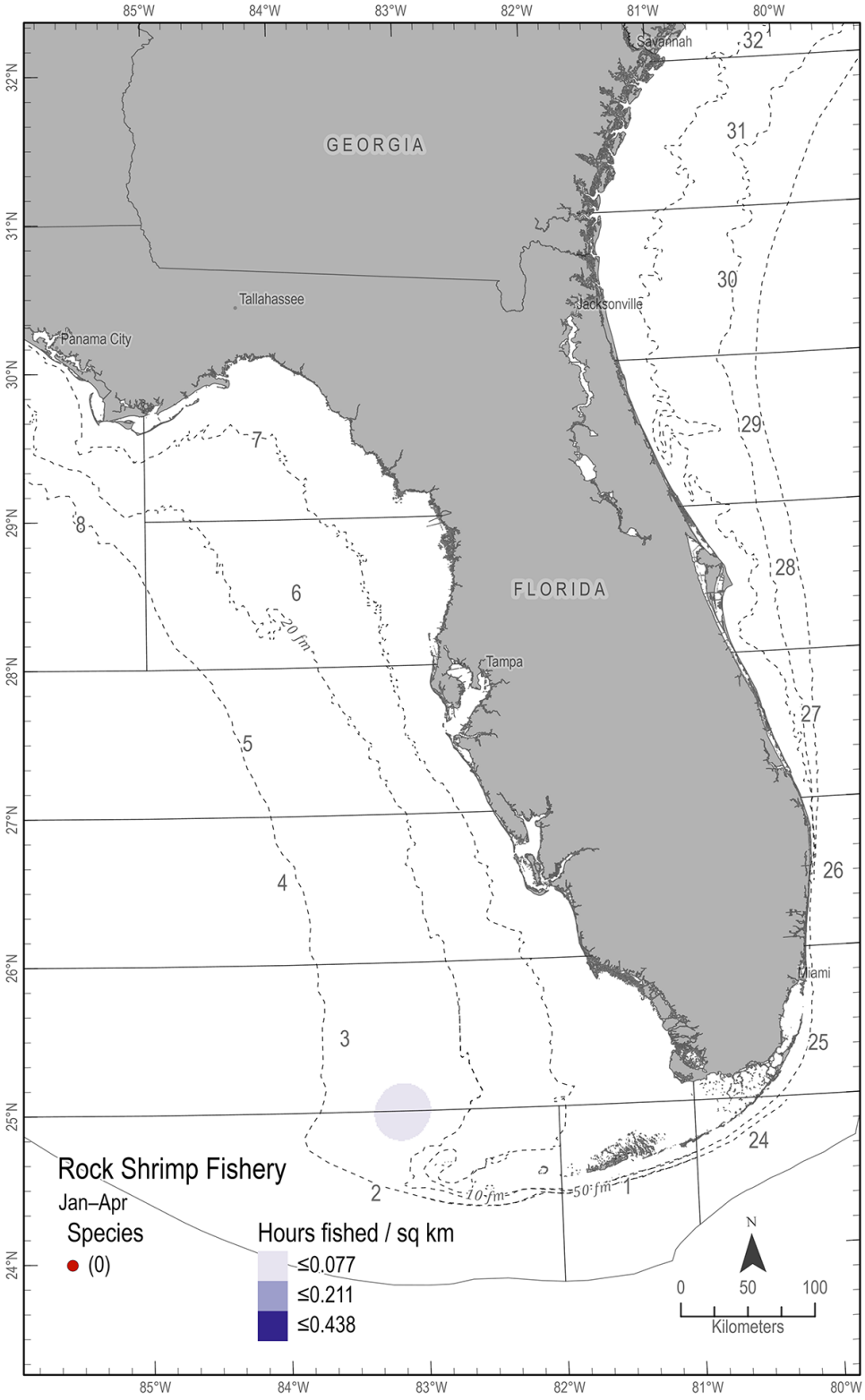

Figure 11.—Density of hours fished and sea turtle captures (n = 0), January through April, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

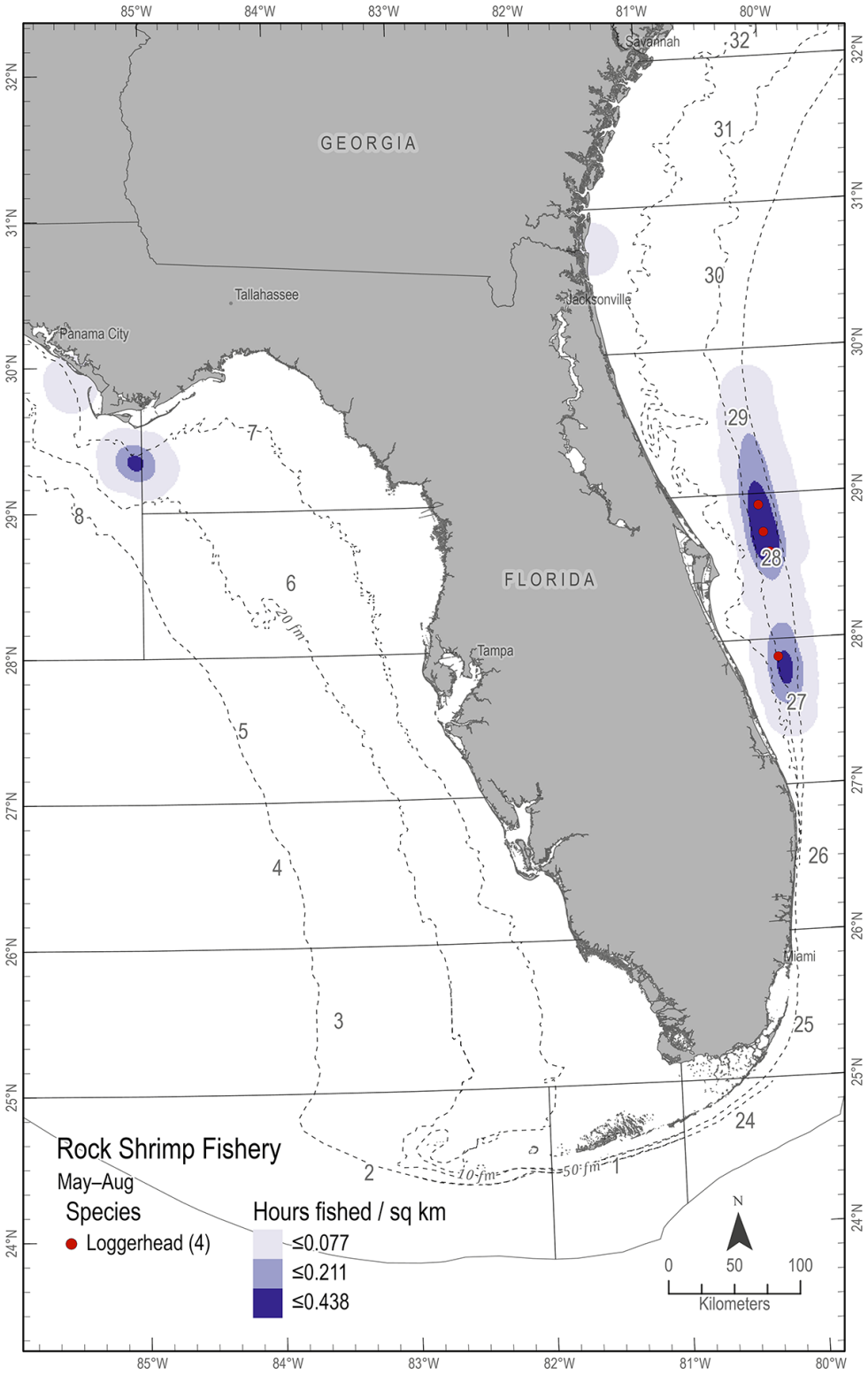

Figure 12.—Density of hours fished and sea turtle captures (n = 4), May through August, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

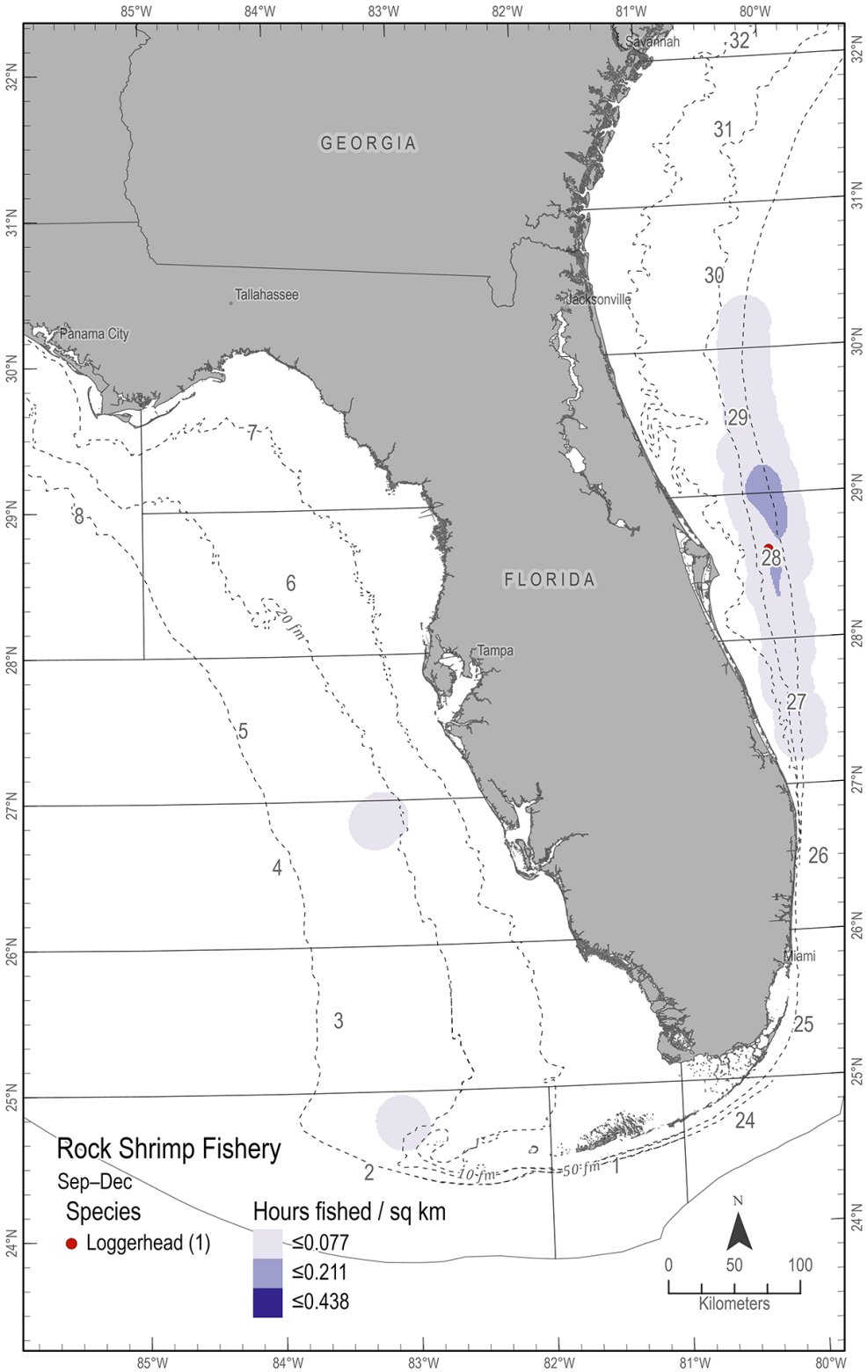

Figure 13.—Density of hours fished and sea turtle captures (n = 1), September through December, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

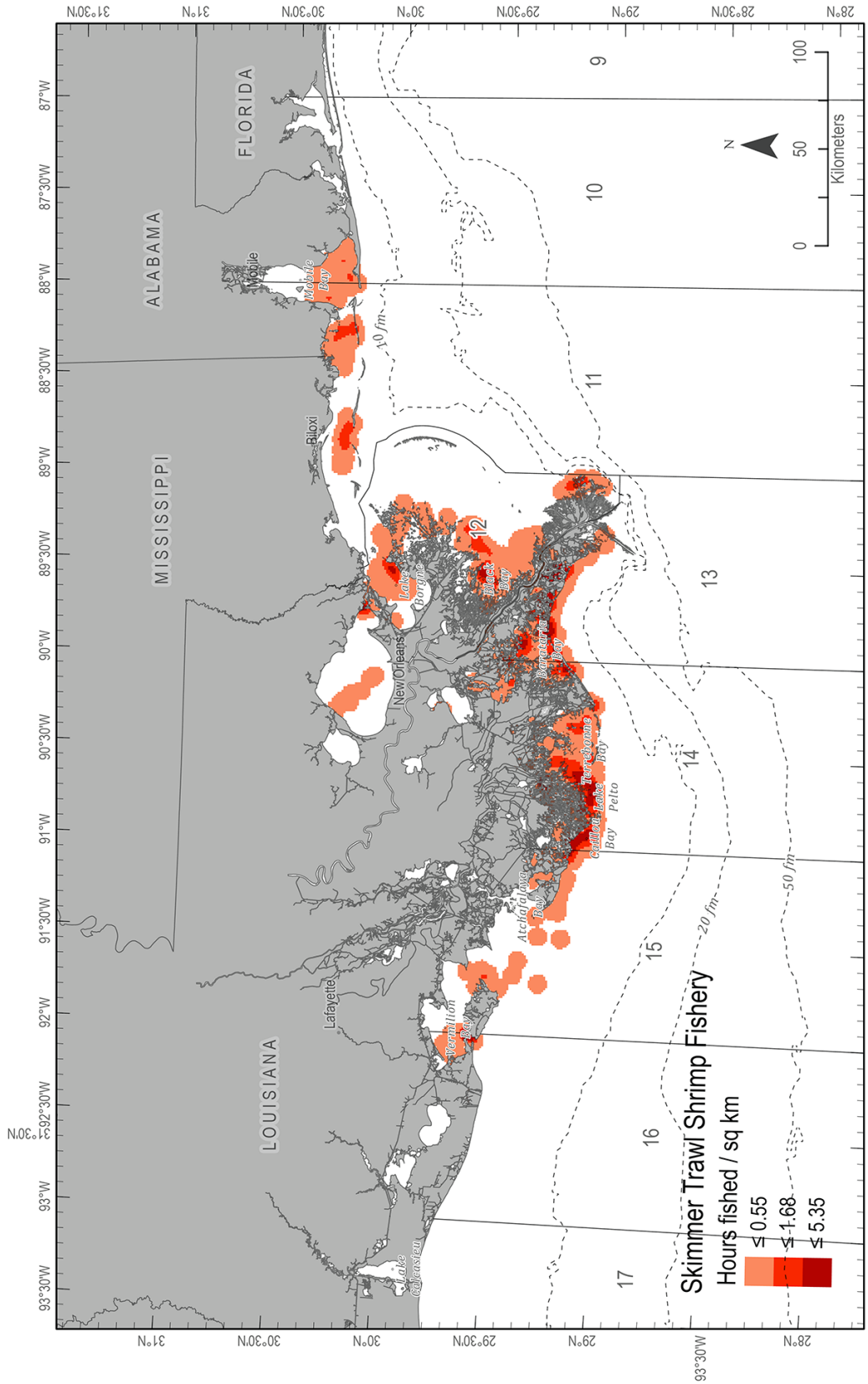

Figure 14.—Density of hours fished for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

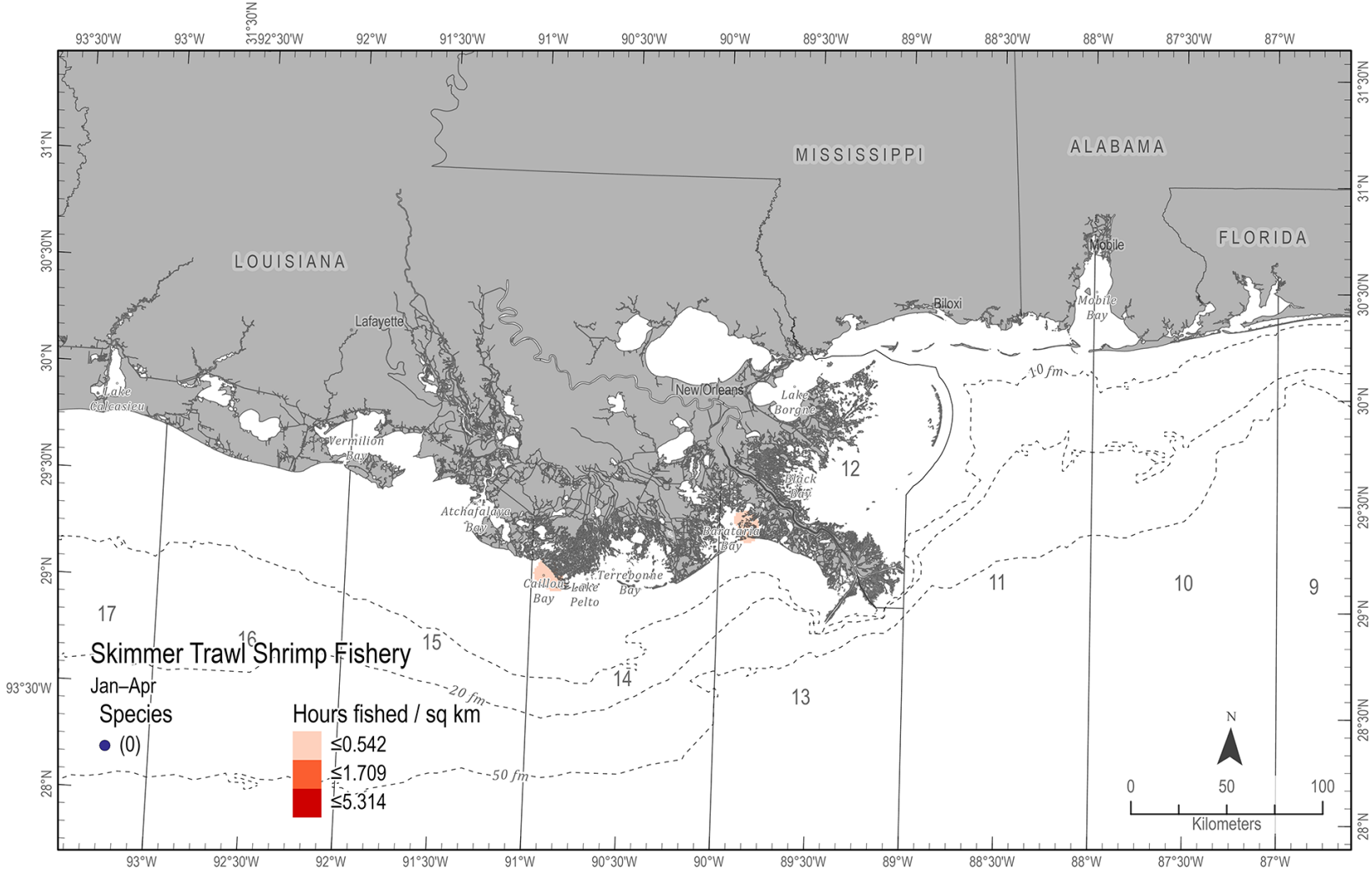

Figure 15.—Density of hours fished and sea turtle captures (n = 0), January through April, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

son 3) (Fig. 3–5). Most sea turtle captures occurred off Louisiana, Texas, and the southern waters of west Florida. This was consistent with areas of high fishing effort and confirmed based on the optimized Hot Spot Analysis with clusters of significantly high sea turtle CPUE ($p<0.01$; Fig. 18). The predominate species of turtles captured during January–April, and May–August, were Kemp's ridleys and loggerheads. Interactions with green sea turtles were relatively consistent across the three seasons, with the largest number of captures in Texas waters.

Of the 178 turtles captured by the Gulf shrimp fishery, 77% (n = 137) were released alive after being worked up for biological samples. One hundred and nineteen turtles had a capture condition of alive, 51 were captured as fresh dead/unresponsive, of these, 135 or 79% were released alive (Table 2). Kemp's ridleys made up the majority of the species captured for a total of 72 followed by loggerheads at 53. Of the 52 loggerheads captured alive or fresh dead/unresponsive, 50 were released alive. Kemp's ridleys had a successful release rate of 83%. Of the 71 Kemp's ridley turtles captured alive or fresh dead/unresponsive 59 were released alive. A total of 28 greens were captured alive or fresh dead/unresponsive, of those, 12 (43%) were released alive; the lowest percentage of all the species.

Under field conditions, it was difficult to discern between unresponsive and dead turtles. Twenty-three turtles were released discarded dead/unresponsive. To decrease the chances of double reporting, discarded carcasses were marked with metal flipper tags and orange spray paint applied to the carapace in the shape of an X. In cooperation with the NMFS Office of Protected Resources (OPR), the carcasses of 9 additional turtles captured dead (6 greens and 3 Kemp's ridleys) were retained and returned to port to be examined for decompression sickness (see García-Párraga et al., 2014). Unknown status at capture and release was the result of the observer being unable to determine or observe the condition of the specimen.

Southeastern U.S. Atlantic Shrimp Fishery The southeastern U.S. Atlantic shrimp fishery generated 39 captures of the following species: loggerhead, Kemp's ridley, unidentified hardshell, and green. Thirty-eight of those were captured and released alive (Table 2). The fishery's final capture was an unidentified hardshell that was captured and released with an unknown status. The highest concentration of captures occurred in season 2 (May–August) off the coast of eastern Florida and Georgia, followed by season 3 (September–December). The lowest concentration of captures occurred in season 1 (Fig. 7–9). Loggerheads were the predominant species involved in interactions with the fishery, followed by Kemp's ridley. A cluster of significantly high ($p<0.01$) sea turtle CPUE was evident off the Georgia coast in the lower portion of statistical zone 31 (Fig. 19).

Rock Shrimp Fishery Five loggerhead sea turtles were captured and released alive in the rock shrimp fishery (Table 2). At the beginning of the season, between May and August off the coast of eastern Florida, 4 loggerheads were captured. The final loggerhead was captured between September–December in the same location (Fig. 11–13). There was no significant clustering of high or low sea turtle CPUE values (Fig. 20).

Skimmer Trawl Fishery The skimmer trawl fishery captured 58 sea turtles; 56 had a capture status of alive or fresh dead/unresponsive and 53 of those were released alive (Table 2). There were also two reports of previously dead (rotting flesh and crushed shell), specimens that died not as a result of current fishing (1 Kemp's Ridley, 1 green). Kemp's ridleys comprised the largest number of captures for this fishery at a total of 48; 46 of the 47 with a capture status of alive or fresh dead/unresponsive were released alive. Seasonal coverage of the skimmer trawl fishery generally begins in May. The peak season, between the months of May and August, resulted in the highest number of captures. Kemp's ridley was the predominate species captured in shallow waters of coastal Louisiana. No interactions were reported between January and April. (Fig. 15–16). Based on optimized Hot Spot Analysis, clusters of significantly high values of sea turtle CPUE ($p<0.01$) were found in the shallow waters just south of the Mississippi River Delta (Fig. 21).

Marine Mammal Characterization

Sixteen marine mammal interactions occurred, during mandatory coverage, 11 bottlenose dolphins, 3 unidentified dolphins, and 2 decomposed unidentified marine mammals (Table 3). All interactions with marine mammals occurred in the Gulf shrimp fishery, resulting from entanglement during trawling operations. Three bottlenose dolphins and 1 unidentified marine mammal were captured in the body of the shrimp net. The remaining 8 bottlenose dolphins were captured in various portions of the shrimp net configuration, 7 in the lazy line, and one in the leg line. The final unidentified marine mammal was entangled in a try net; it was decomposing prior to capture and showed evidence of bite marks on the carcass. Two unidentified dolphins were captured in the lazy line, and one decomposing carcass was captured in the tickler chain. The majority of marine mammals were captured off the coasts of Texas and Louisiana and one west of the Straits of Florida (Fig. 22). All but two of the marine mammals were released dead after being removed from the gear. Of the two that swam away after release, one dolphin captured in the body of the net swam away abnormally. The second, an unidentified dolphin, was tangled in the lazy line and swam away normally at release.

Sawfish Characterization

Seventeen sawfish were captured off Florida's coast, 12 were identified to the species level, smalltooth sawfish. The Gulf shrimp fishery captured 14, the southeastern U.S. Atlantic shrimp fishery captured 2, and 1 was captured by the rock shrimp fishery. All but one was captured in standard

Table 3.—Protected species capture and release status based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Type Species Disposition	Fishery Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Birds	9	3		3	15
Brown pelican	3	2			5
Discarded dead/unresponsive carcass	3	2			5
Laughing gull				3	3
Discarded dead/unresponsive carcass				3	3
Pelican	1				1
Discarded dead/unresponsive carcass	1				1
Unidentified songbird	1				1
Discarded dead/unresponsive carcass	1				1
Unknown bird	4	1			5
Discarded dead/unresponsive carcass	4	1			5
Giant manta ray	2	6			8
Released alive		4			4
Unknown	2	2			4
Sawfish	14	2	1		17
Smalltooth sawfish	11	1			12
Discarded dead/unresponsive carcass	1				1
Released alive	6				6
Unknown	4	1			5
Sawfish spp.	3	1	1		5
Discarded dead/unresponsive carcass	1		1		2
Released alive	2	1			3
Sturgeon	2	12			14
Atlantic sturgeon		9			9
Discarded dead/unresponsive carcass		3			3
Released alive		6			6
Gulf sturgeon	1				1
Released alive	1				1
Sturgeon spp.	1	3			4
Released alive	1	3			4
Marine mammals	16				16
Bottlenose dolphin	11				11
Alive, swam away abnormally	1				1
Dead	10				10
Unidentified dolphin	3				3
Alive, swam away normally	1				1
Dead	2				2
Unidentified marine mammal	2				2

shrimp nets; the final capture was in a Gulf shrimp vessel's try net. Of the captured sawfish in the Gulf of Mexico fishery, 11 were smalltooth sawfish, and 6 were released alive, 1 was released dead/unresponsive, and 4 were released with unknown status (including the specimen captured in the try net; Table 3). The majority of the Gulf shrimp captures occurred in statistical zones 1 and 2 off the Florida Keys, and the final capture occurred in statistical zone 4 (Fig. 23). Of the two sawfish captured in the southeastern U.S. Atlantic shrimp fishery, one sawfish was released alive, and one smalltooth sawfish was released with an unknown status off the coast of Port Canaveral in statistical zone 28. The sawfish captured by the rock shrimp fishery occurred in statistical zone 29 and was discarded as a dead/unresponsive carcass.

Giant Manta Ray Characterization

In 2019, the observer program began recording giant manta ray capture data, and during that year, eight were captured; two were caught in the Gulf shrimp fishery and six in the southeastern U.S. Atlantic shrimp fishery. The two caught in the Gulf shrimp fishery were released with an unknown status off Louisiana's coast, statistical zone 13 (Table 3, Fig. 23). The six captured in the southeastern U.S. Atlantic shrimp fishery were caught off Georgia's coast; four were released alive and two with unknown status. Exact GPS coordinates were not available for giant manta rays captured off the coast of Georgia; however, all specimens were captured during the same trip. Based on that trip's general location, it was determined the captures occurred in Georgia waters at depths of 24–31 ft in statistical zone 31.

Sturgeon Characterization

Fourteen sturgeons, *Acipenser* spp., were captured throughout the observer program, two by the Gulf shrimp fishery and twelve by the southeastern U.S. Atlantic shrimp fishery (Table 3). Nine of the specimens caught by the southeastern U.S. Atlantic shrimp fishery were released alive; the remaining three were discarded/dead unresponsive. All twelve were captured off the east coast ranging from statistical zones 31 to 35 (Fig. 23). The two specimens caught by the Gulf shrimp fishery were captured in statistical zones 11 and 12; both were released alive.

Seabird Characterization

The incidental capture of 15 individual birds were reported; 9 from the Gulf shrimp fishery, 3 from the southeastern U.S. Atlantic fishery, and 3 from the skimmer trawl fishery (Table 3). The following species were reported, 5 brown pelicans, *Pelecanus occidentalis*, 3 laughing gulls, *Leucopaeus atricilla*, 1 pelican, *Pelecanus* spp., 1 unidentified songbird, and 5 unknown bird species. Brown pelicans were captured by both the Gulf shrimp and southeastern U.S. Atlantic shrimp fisheries. The three captured by the Gulf shrimp fishery were caught in statistical zones 11, 14, and 15 (Fig. 23). Captures by the southeastern U.S. Atlantic shrimp fishery occurred in statistical zones 29 and 32. Three laughing gulls were captured by the skim-

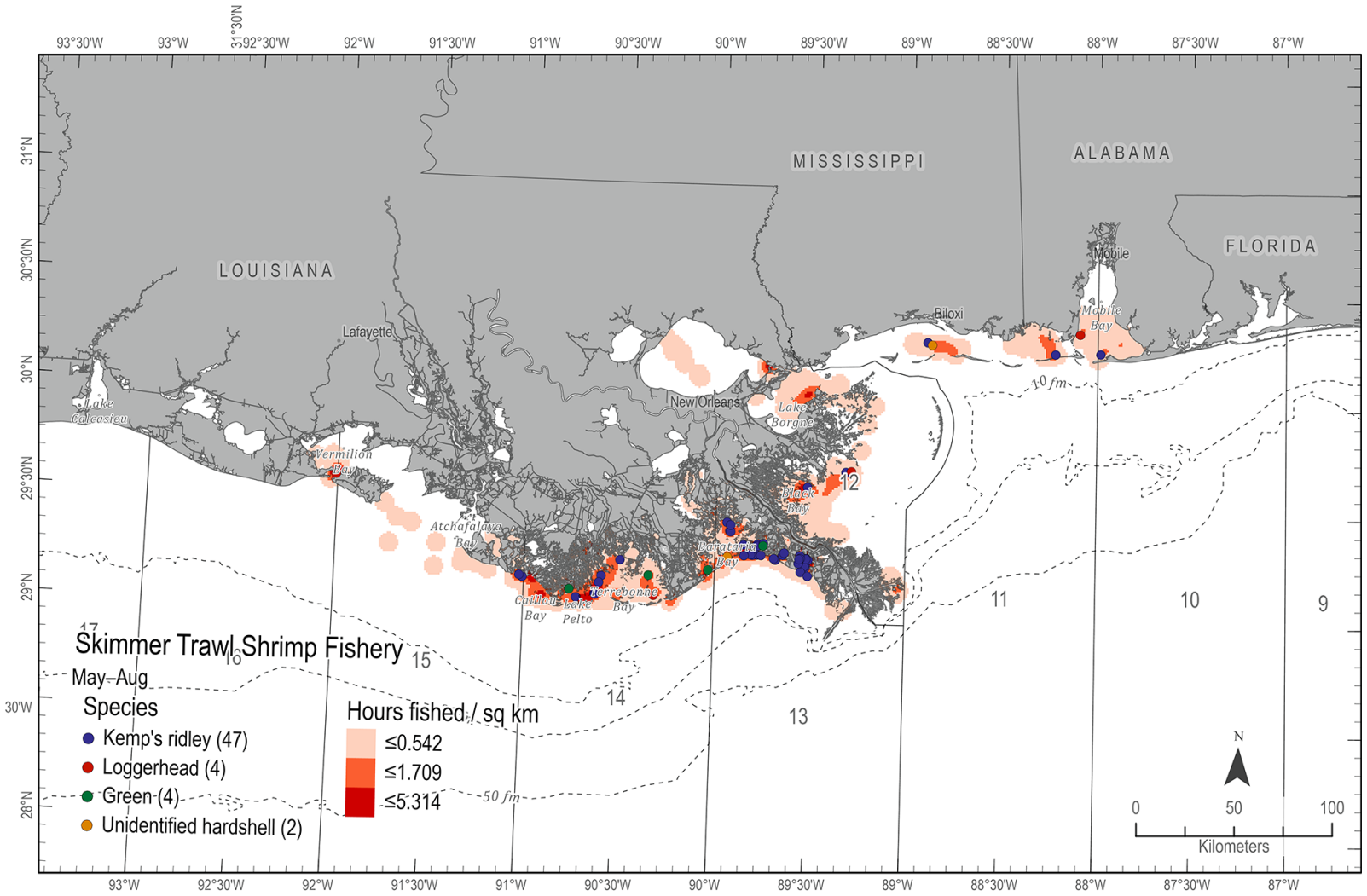

Figure 16.—Density of hours fished and sea turtle captures (n = 57), May through August, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

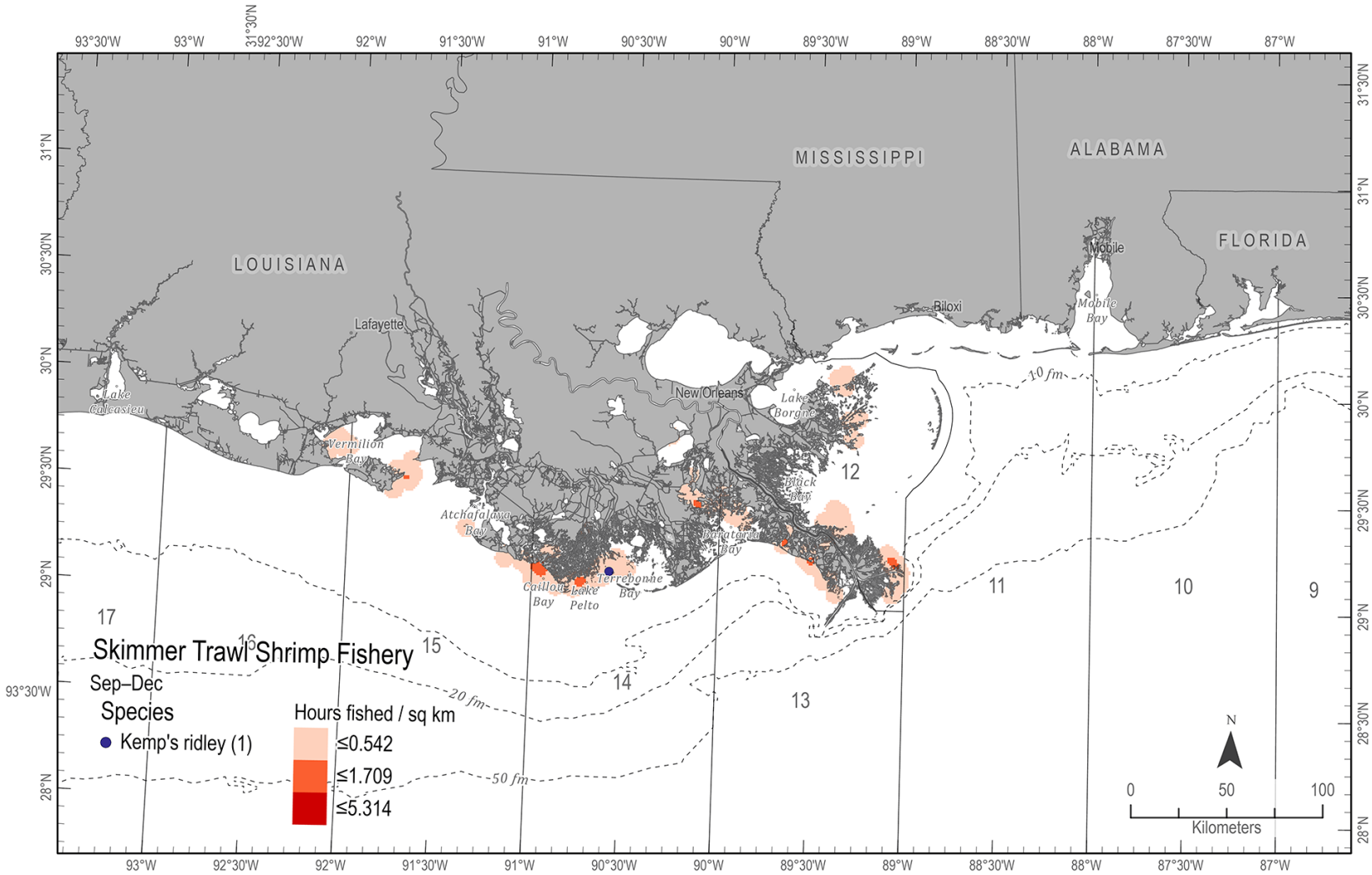

Figure 17.—Density of hours fished and sea turtle captures (n = 1), September through December, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

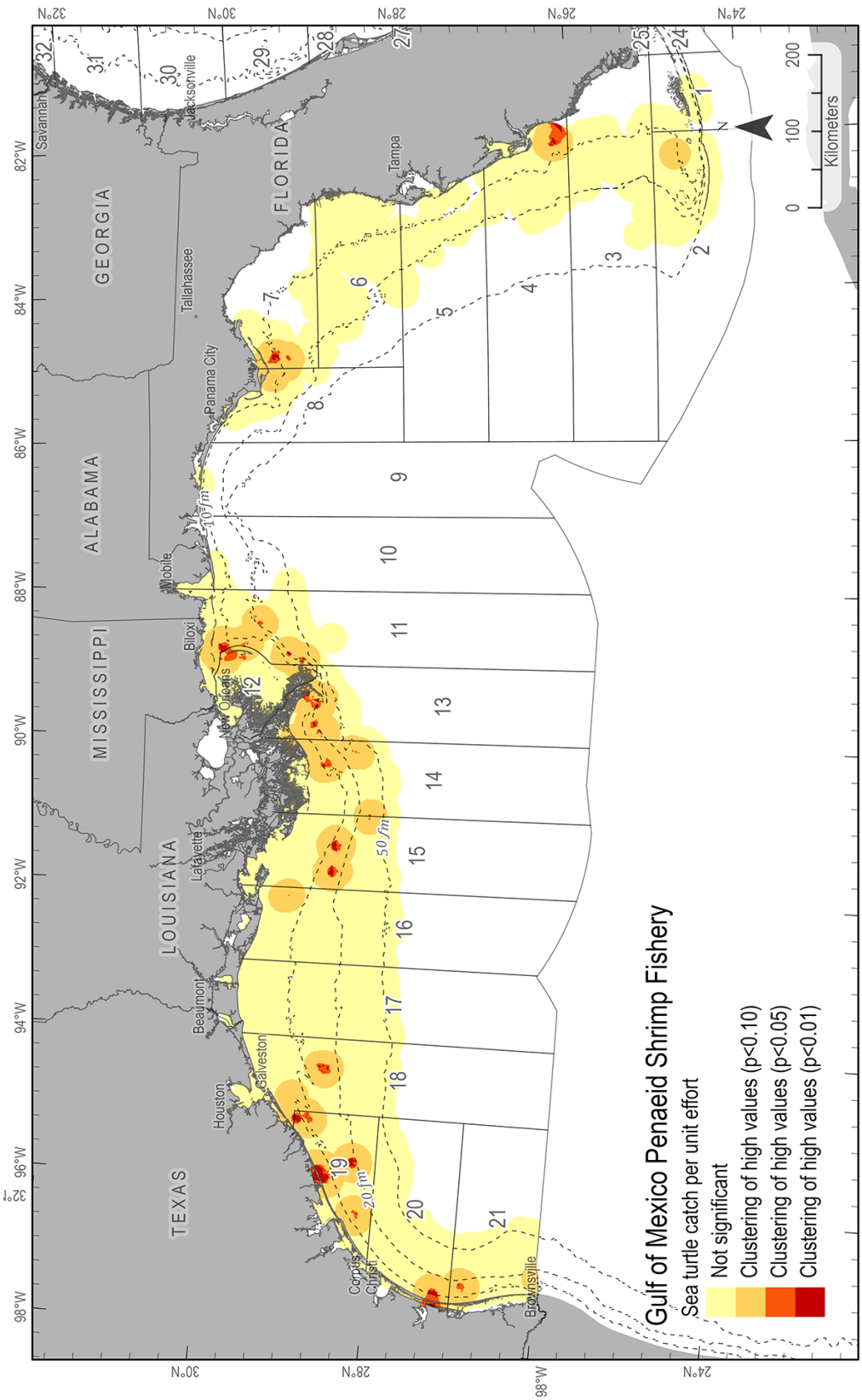

Figure 18.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

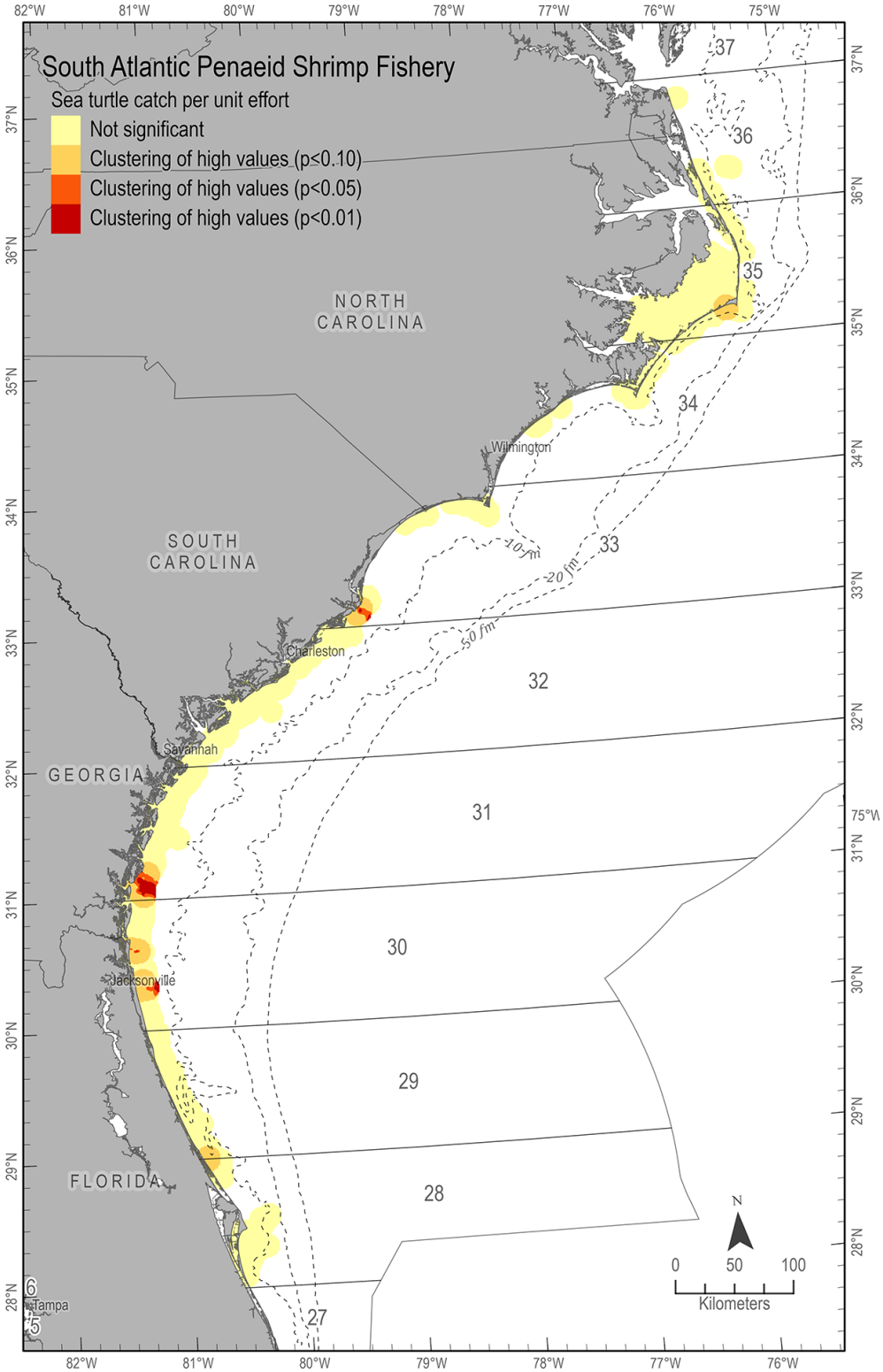

Figure 19.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the U.S. south Atlantic penaeid shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

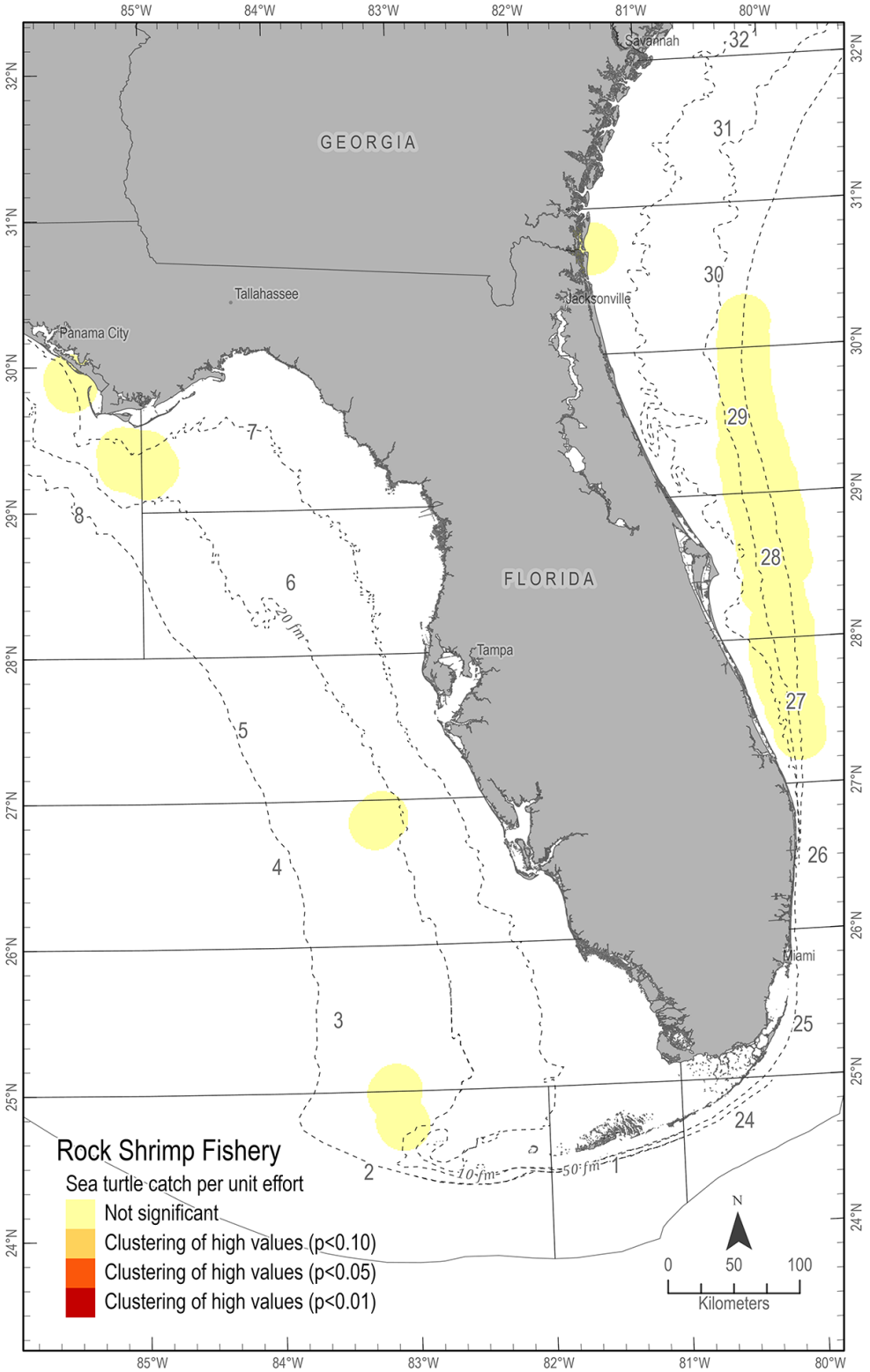

Figure 20.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

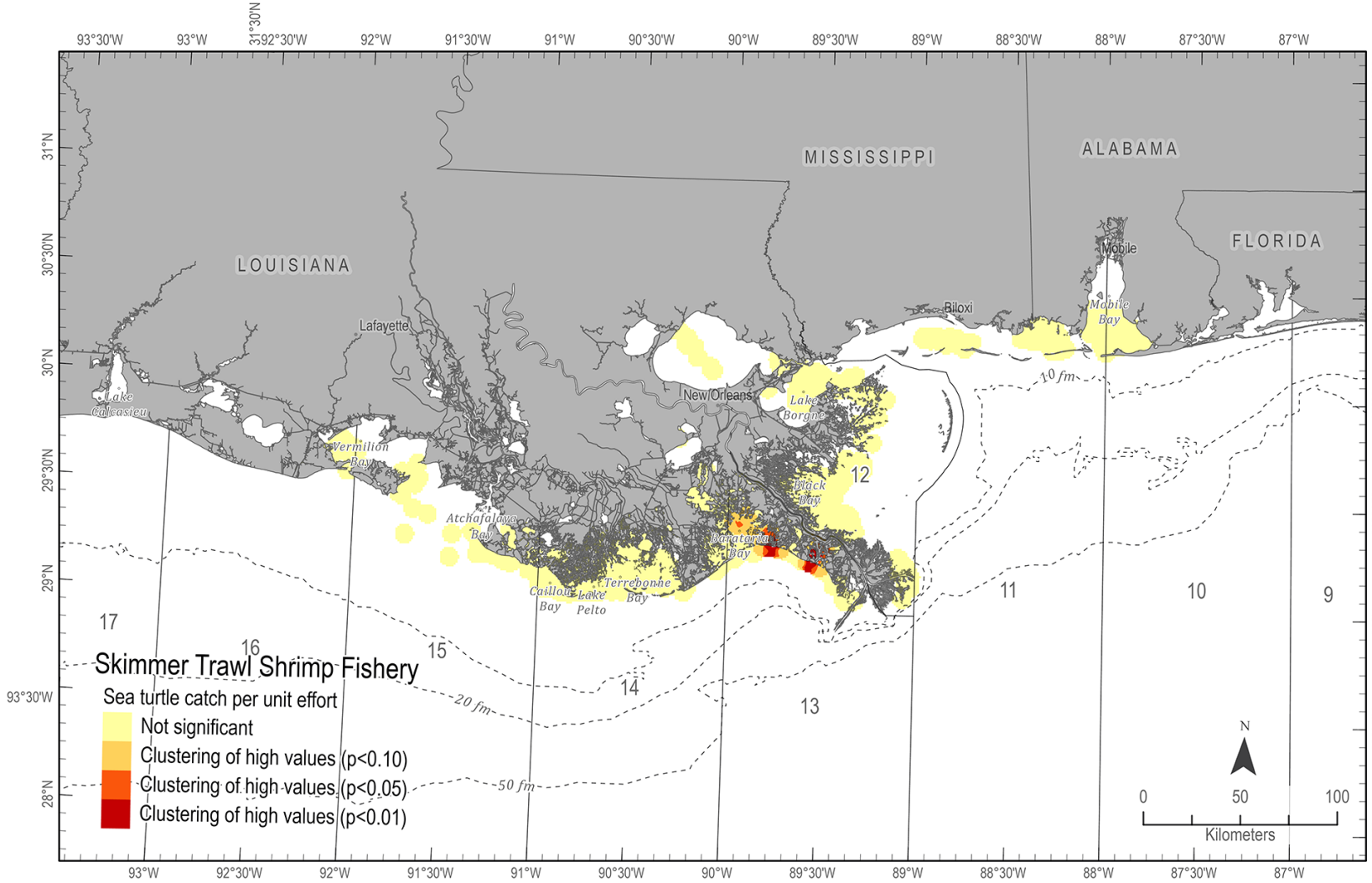

Figure 21.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

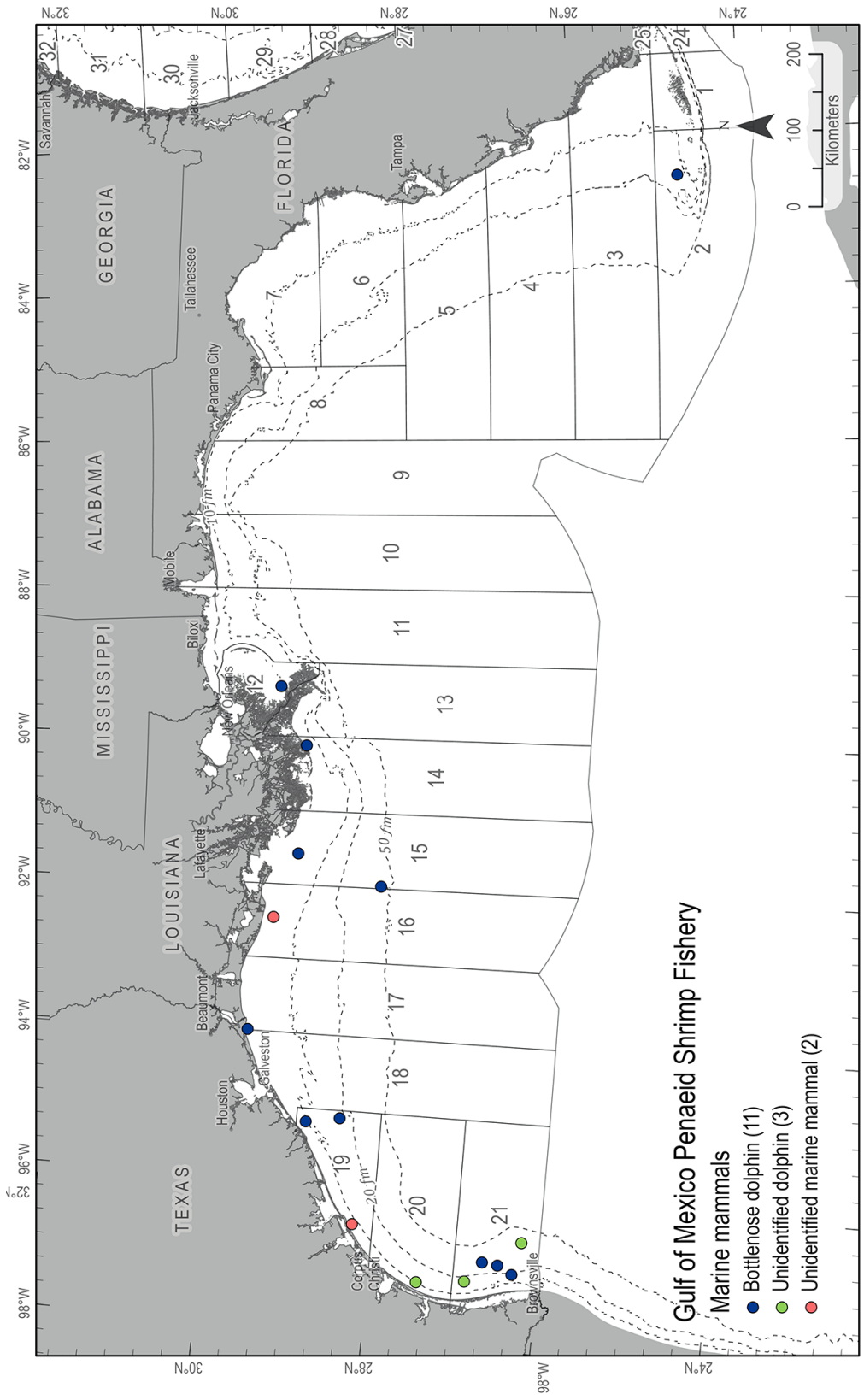

Figure 22.—Locations of marine mammal captures (n = 16), based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

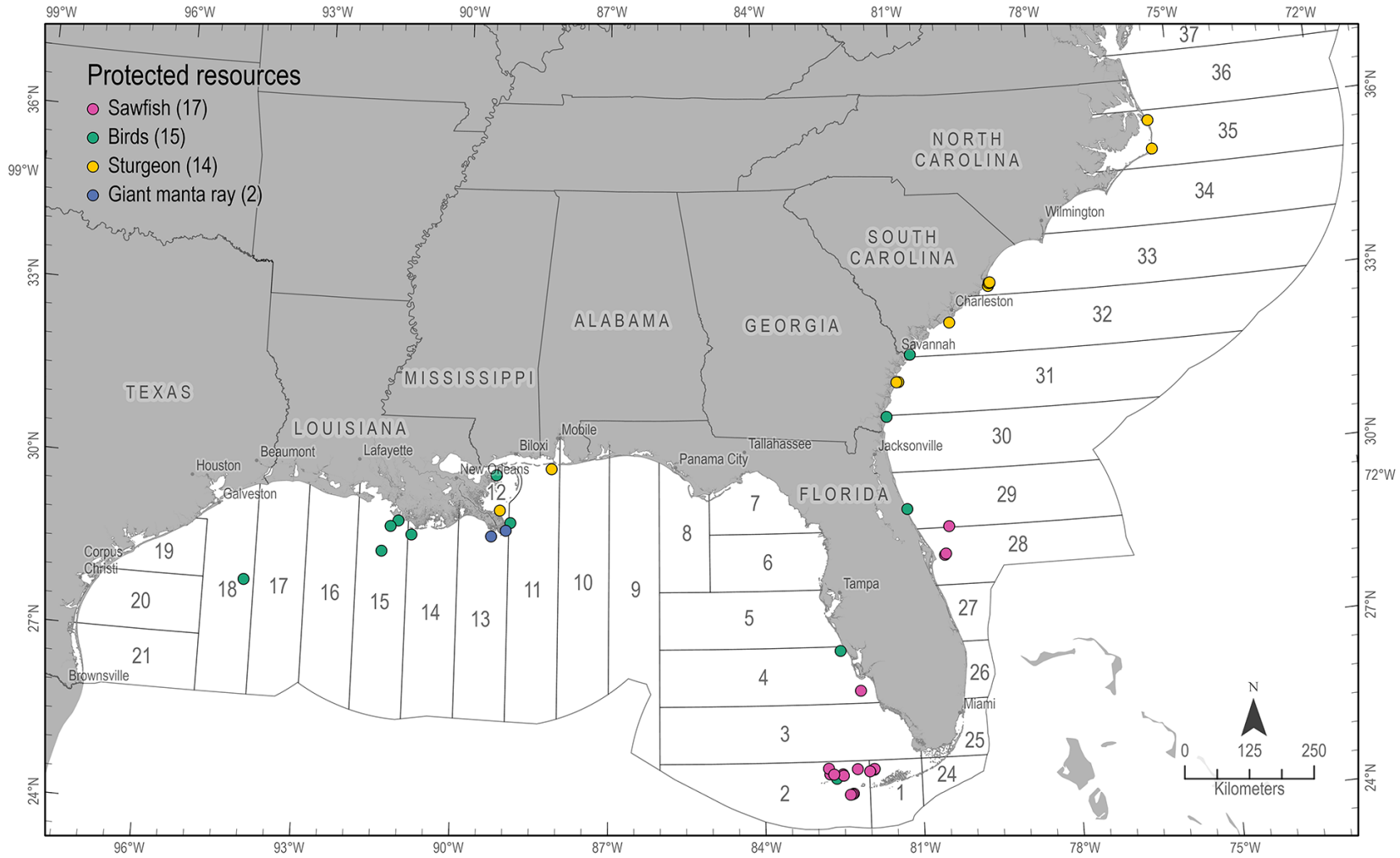

Figure 23.—Locations of protected species captures (n = 48), based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

mer trawl fishery off Louisiana's coast in statistical zone 12 during one trip. A bird identified as pelican, *Pelecanus* spp., was captured by the Gulf shrimp fishery in statistical zone 2 off west Florida and an unidentified songbird in statistical zone 18. The remaining five unknown species were split between the Gulf and southeastern U.S. Atlantic shrimp fisheries, with three captures in statistical zone 15 off the coast of Louisiana, 1 in statistical zone 4 off the west coast of Florida, and 1 off Georgia's coast in statistical zone 30.

Discussion

Observer coverage, fishing effort, and protected species interactions fluctuated from 2007 to 2019; this was primarily due to funding and additional fisheries that split observer coverage over time. During the observer program's mandatory coverage of 1,766 shrimp trips, a total of 280 sea turtles, 16 marine mammals, 8 giant manta rays, 17 sawfish, 14 sturgeons, and 15 seabird interactions were documented. Captures were divided between four mandatory coverage fisheries: Gulf shrimp, southeastern U.S. Atlantic shrimp, rock shrimp, and skimmer trawl. Approximately 90% of observer coverage, by sea days, occurred in the Gulf shrimp fishery (Table 1). The spatial distribution of incidental captures was consistent with fishing effort and fishery distribution. Further research will be needed to determine if species-specific rate of capture is influenced by spatial and seasonal distribution of fishing effort.

Fishing effort in the Gulf shrimp fishery was concentrated off Texas and Louisiana's coasts, coinciding with the largest quantity of sea turtle interactions in those zones (Fig. 2). Interactions with sea turtles (Fig. 3–5) were highest during season 1 from January to April, with a slight decrease in season 2 from May to August. Of those, 137 sea turtles were released alive (Table 2). Fishing grounds in both state and federal waters off the Texas coast are closed yearly for an approximate 60-day period during May–July to allow shrimp to reach an economically valuable size and to decrease bycatch of immature shrimp. Research has determined the closure of Texas waters plays a positive role by temporarily decreasing sea turtle interactions during May–August (Crowder et al., 1995; Caillouet et al., 1996; Shaver and Caillouett, 1998; Lewison et al., 2003).

The southeastern U.S. Atlantic shrimp fishery showed spatial distribution of fishing effort from North Carolina down the coast to Cape Canaveral, Fla., with high concentrations in North Carolina off Pamlico Sound. Sporadic clusters of concentration from north Florida to Charleston, S.C. (Fig. 6) were evident. Season 2, from May to August, resulted in the highest sea turtle interactions (n = 23) (Fig. 7–9), consistent with the distribution of fishing effort. A total of 39 sea turtle interactions occurred, all but one was released alive (Table 2).

One percent of the observer program's effort was dedicated to the rock shrimp fishery (Table 1); however, the positive spatial distribution of sea turtle interaction, fishing effort, and fishing seasonality was evident (Fig. 11–13). The low percent coverage was a direct reflection of the small size of the fishing fleet, short fishing season, and geographic limitations due to species habitat. All five of the loggerhead turtles captured in the fishery were released alive (Table 2).

Coverage of the skimmer trawl fishery, 2012–19, made up 3% of the sea days by year and fishery for the combined years of coverage across all four fisheries (Table 1). Fishing effort was highly concentrated in the shallow waters off Louisiana and around the Mississippi River Delta (Fig. 14). Fishing seasons began in May, the largest volume of effort occurred during May through August (Fig. 15–17). The observer program's percent coverage was low at 3%; however, the fishery exhibited a large volume of sea turtle interactions, a total of 58 captures, when compared to the number of captures in relation to sea days by year and fishery for the other fisheries (Table 2). The areas fished also presented a possible species richness during the fishing season with 48 Kemp's ridley captures. Survival rates were also high; 53 of the 58 interactions were released alive, possibly a direct result of the fisheries' short tow times. The shorter tow times and frequent tail bag retrieval may result in higher survival rates (Coale et al., 1994). At the time of this research, skimmer trawls were not required to have TED's. Beginning 1 Aug. 2021, skimmer trawl vessels of 40 feet and greater in length that are rigged for fishing were required to install TED's (NOAA, 2019).

Concerning observed survival rates, marine mammals are the most adversely affected. Dolphins are known to forage and inhabit areas around active shrimp trawls, resulting in gear entanglement and death if captured (Fertl, 1994; Fertl and Leatherwood, 1997; Kovacs and Cox, 2014; Siegel, et al., 2015; Moreno and Mathews, 2018). The incidental capture of marine mammals was low, 16 over a 13-yr period; however, 14 of those interactions resulted in death (Table 3), with forced submergence due to entanglement in fishing gear being the likely cause of death.

Birds, also highly common around shrimp vessels, are unlikely to survive an interaction. Various species of birds are common around active shrimp trawlers, attracted to fishing operations to feed on discarded bycatch as it is dumped overboard (Wickliffe and Jodice, 2010; Jodice, et al., 2011). Fifteen captures of no significant spatial distribution were reported over the 13-yr period. The number of bird captures reported here were low; observers were required to report all bird captures. A bird's ability to fly away from active fishing gear may be a contributing factor to the low numbers.

Giant manta rays, a recent addition to the observer program's reporting requirements, showed higher rates of interaction in the southeastern U.S. Atlantic shrimp fishery than the Gulf shrimp fishery. Of the eight reported interactions, four were released alive (Table 3). These numbers are likely to increase as reporting continues; reported captures to date were the re-

sult of two independent fishing trips in 2019.

The spatial distribution of sturgeon interaction was limited by habitat ranges. Gulf and Atlantic sturgeon hatch in freshwater streams, they migrate out to sea as juveniles and return as breeding adults. Of the fourteen reported interactions, eleven were released alive (Table 3). Observed recorded interaction with these species were low in number, with a favorable survival. Increased fishing and reporting efforts in and around their natural habitat, over time, may exhibit higher results.

Interactions with sawfish in the Gulf shrimp fishery occurred exclusively off the west coast of Florida; southeastern U.S. Atlantic shrimp fishery interactions were located off Port Canaveral, Fla.; rock shrimp captures occurred in statistical zone 29 off the east coast of Florida. This was consistent with habitat ranges for this species. Of the seventeen specimens captured, nine were released alive, five were released with unknown status (due to poor water visibility at time of release), and three were discarded dead.

The shrimp fishery produces high quantities of bycatch; the federal government works to regulate and sustain the fishery for future generations of consumers and fishermen. To further decrease bycatch, continued research is necessary to evaluate the effects of fishing on the environment and develop gear and methods to improve it. To date, success is evident with the development of BRD's, TED's, tow time restrictions, and area and fishery closures (Crowder et al., 1994; Crowder et al., 1995; Watson et al., 1999; Hall et al., 2000; Harrington et al., 2005; Keledjian et al., 2014; Scott-Denton et al., 2020). BRD's and TED's have reduced bycatch and interactions with sea turtles, aiding escape from active fishing. Length of forced submergence in shrimp gear has been decreased through tow time restrictions. Fishery closures allows stocks to mature and temporarily stop interaction with protected species.

Currently, given the non-selective nature of the shrimp fishery gear, interactions with protected species are inevitable. To conserve fish stocks and protected species for the future, continued efforts must be made to limit interactions and reduce mortality as a result of fishing efforts. The incidental mortality of long-lived marine species and the reduction of bycatch are topics of grave concern. Due to the low percentage of observer coverage, in terms of fishing effort and geographic distribution, protected species interactions are likely underreported; however, attempts are made to utilize available data (Epperly and Teas, 2002; Epperly et al., 2002; Scott-Denton et al., 2012; Wallace et al., 2013; Babcock et al., 2018). Moreover, advanced technology, notably electronic monitoring (EM), machine learning (ML), and artificial intelligence (AI) are being evaluated for use in Gulf of Mexico commercial fisheries to augment observer coverage levels.

The observer program's fluidity allows for expansion and the incorporation of outside research needs to aid in scientific research. Recent incorporations to the observer program include decompression sickness studies, post-interaction mortality research, and constant development of bycatch mitigation techniques. This also holds true for informing research needs resulting from natural disasters such as hurricanes and human-made disasters like the Deepwater Horizon Oil Spill.

Protected species mortality estimates are used to determine annual potential biological removal from various stocks. The observer program educates the industry regarding proper protected species handling and resuscitation techniques as well as the need to limit tow times and advance gear development. The advancement of gear development aids in increasing catch rates of target species while decreasing the capture of and/or increasing the survival rates of incidental catch. In addition, the presence of observers aboard the vessel may increase sea turtle survival rates through resuscitation effort prior to release.

Observer programs remain the most reliable means for monitoring commercial fisheries by providing unbiased, reliable, and high-quality data. Human observer coverage of the shrimp fisheries is minimal (approximately 2–3%); however, 100% coverage is not fiscally possible. Technological advancements in the form of EM and effort monitoring tools (vessel monitoring systems, electronic logbooks, and navigational vessel programs) will aid in increased coverage and assessment in the future. Collectively, these efforts will provide important insight on shrimp species and protected species CPUE, and life history characteristics for both target and non-target species.

Acknowledgments

We commend the outstanding efforts in this research effort performed by the Galveston Observer Program staff, fishery observers involved, and the commercial fishing industry for their continued participation.

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