Characterization of the U.S. Gulf of Mexico and South Atlantic Penaeidae and Rock Shrimp (Sicyoniidae) Fisheries through Mandatory Observer Coverage, from 2011 to 2016

ELIZABETH SCOTT-DENTON, PAT F. CRYER, BEN V. DUFFIN, MATT R. DUFFY, JUDITH P. GOCKE, MIKE R. HARRELSON, ANDREW J. WHATLEY, and JO A. WILLIAMS

ABSTRACT—A mandatory Federal observer program was established in July 2007 to characterize the U.S. Gulf of Mexico penaeid shrimp fishery. The program grew in scope in June 2008 to include the South Atlantic Penaeidae and rock (Sicyoniidae) shrimp fisheries. In 2012, following an increase in sea turtle (Chelonioidea) strandings, observer coverage expanded to coastal waters of the northern Gulf of Mexico for skimmer trawl vessels and in 2016 for state-licensed otter trawl vessels. From January 2011 through December 2016, data were collected from 27,116 tows during 11,118 sea days of observations aboard 1,134 trips. For the mandatory component, data from 24,679 tows (10,734 sea days) were analyzed by area and target species. The majority of tows sampled (65%) were off the coasts of Louisiana and Texas. The highest concentrated effort occurred off South Texas, Louisiana, and southwestern Florida. Gear, including net characteristics, bycatch reduction devices (BRD's), and turtle excluder devices (TED's), were fairly consistent for the penaeid and rock shrimp otter trawl fisheries.

By species categories, finfish comprised the majority ($\geq$ 58%) of the catch in the Gulf of Mexico and southern U.S. Atlantic penaeid shrimp fisheries, while in the rock shrimp fishery, finfish and rock shrimp rates were similar. Bycatch to shrimp ratios were comparable to a 2007–10 shrimp assessment but lower than reported in previous studies for the Gulf of Mexico penaeid shrimp fishery. Declining shrimp effort since 2002 combined with higher shrimp catch per unit of effort (CPUE) and several management measures most likely contributed to the lower bycatch ratios seen in more than a decade. Density surface plots for several commercial and recreational species illustrated spatial differences in distribution and CPUE. Hot Spot Analyses depicted areas with significant clustering of high or low CPUE for shrimp and bycatch species. Distribution of protected species interactions is illustrated both spatially and temporally.

Introduction

The southeastern shrimp trawl fishery impacts commercial, recreational, and ecologically important fish stocks (Pellegrin, 1982; Alverson et al., 1994; Nichols et al.[1]; NMFS[2,3]). Declines in several finfish species brought about Federal mandates to identify the reasons for stock declines and management measures necessary for rebuilding affected stocks (Magnuson-Stevens Fishery Conservation and Management Act, Public Law 94-265, as amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479)).

Since the early 1990's, substantial progress has been made in addressing the complex issues associated with finfish bycatch reduction in the southeastern shrimp fishery (NMFS[4]). Bycatch reduction devices (BRD's) developed by industry, scientists, and gear specialists continue to be evaluated through cooperative multi-year efforts among numerous organizations (Scott-Denton and Nance, 1996; Nance and Scott-Denton, 1997; Watson et al., 1999; Scott-Denton, 2007; Scott-Denton et al., 2012; Parsons and Foster, 2015; NMFS[2, 3, 4];Branstetter[5]; Nance et al.[6]; Foster and Scott-Denton[7]; Helies and Jamison[8]). A voluntary component of the observer program continues, to a lesser degree, to assess TED's and BRD's. BRD designs currently required for use in Federal waters of the Gulf of Mexi-

[1]Nichols, S., A. Shah, G. J. Pellegrin, Jr., and K. Mullin. 1987. Estimates of annual shrimp fleet bycatch for thirteen finfish species in the offshore waters of the Gulf of Mexico. Rep. to Gulf Mex. Fish. Manage. Counc. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Pascagoula, Miss., 28 p.

[2]NMFS. 1995. Report to Congress: cooperative research program addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Reg. Off., St. Petersburg, Fla., 68 p.

[3]NMFS. 1998. Report to Congress: southeastern United States shrimp trawl bycatch program. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Galveston Lab., Galveston, Tex., 155 p.

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

doi: https://doi.org/10.7755/MFR.82.1-2.2

[4]NMFS. 2006. Report to Congress: Gulf of Mexico shrimp trawl bycatch reduction. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Miami, Fla., 126 p.

[5]Branstetter, S. 1997. Bycatch and its reduction in the Gulf of Mexico and south Atlantic shrimp fisheries. Gulf South Atl. Fish. Found., Inc., Suite 740, Lincoln Center, 5401 W. Kennedy Blvd. Tampa, Fla., 27 p.

[6]Nance, J., E. Scott-Denton, E. Martinez, J. Watson, A. Shah, and D. Foster. 1997. Bycatch in the southeast shrimp trawl fishery: A data summary report. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Miami, Fla., SFA Task N-10.03, 25 p.

[7]Foster, D. G., and E. Scott-Denton. 2004. Status of bycatch reduction device performance and research in north-central and western Gulf of Mexico. Southeast Data Assessment Rev., South Atl. Fish. Manage. Counc., Charleston, S.C., SEDAR 7-DW-38, 50 p. (avail. at http://www.sefsc.noaa.gov/sedar/)

[8] Helies, F., and J. Jamison. 2009. Reduction rates, species composition, and effort: assessing bycatch within the Gulf of Mexico shrimp trawl fishery. Gulf South Atl. Fish. Found., Inc., Suite 740, Lincoln Cent., 5401 W. Kennedy Blvd. Tampa, Fla., 182 p.

co and South Atlantic include composite panel, extended funnel, fisheye, Jones-Davis, and modified Jones-Davis (NOAA, 2008). The expanded mesh BRD is certified for use in the South Atlantic only. Currently, no TED or BRD requirements are mandated for the skimmer trawl fishery; however, limited tow times apply due to the potential for sea turtle interactions.

Penaeid shrimp species, brown shrimp, *Farfantepenaeus aztecus*; white shrimp, *Litopenaeus setiferus*; and pink shrimp, *Farfantepenaeus duorarum*, have historically comprised the majority of shrimp landed in southeastern U.S. waters. These three species accounted for 97.8 % of annual shrimp landed in the Gulf of Mexico in 2016 (NMFS, 2017). Landings were approximately 206.9 million lb (heads-on) valued at $354.1 million (NMFS, 2017). Penaeid shrimp landings in the South Atlantic were approximately 18.0 million lb (heads-on) valued at $38.6 million. Rock shrimp, *Sicyonia* spp., also primarily targeted in the South Atlantic, accounted for a smaller percentage of landings (1.1 million lb) valued at $1.6 million (NMFS, 2017).

The penaeid otter-trawl shrimp fishery operates year-round in the Gulf of Mexico, with the highest effort occurring May through December (Nance, 1993a). Brown shrimp are primarily caught in offshore waters off the coasts of Texas and Louisiana in depths between 20 and 40 fm, with white shrimp typically captured in waters of about 10 fm in the same areas. Pink shrimp occur in waters of about 35 fm, predominately off southwestern Florida in the winter months (NMFS, 1999). Rock shrimp are targeted in waters primarily off the east coast of Florida in depths between 10-40 fm (Anderson, 1956; Nance, 1993b). In the northern Gulf of Mexico, the skimmer trawl fishery typically captures brown shrimp from May through July and white shrimp from August through December (Pulver et al., 2014).

Currently, there are 1,343 Federally permitted penaeid vessels in the Gulf of Mexico, 481 in the South Atlantic, and 98 rock shrimp vessels recorded as valid (SERO[9]). Observer coverage of the entire southeastern shrimp fishery is approximately 2% based on industry effort (nominal days at sea).

While finfish are the primary bycatch, other species listed under the Endangered Species Act (ESA) of 1973 as amended (16 U.S.C. 1536 et seq.), or other regulatory mandates, have been documented in the southeastern shrimp fishery. These include the following sea turtle species: Kemp's ridley, *Lepidochelys kempii*; leatherback, *Dermochelys coriacea*; hawksbill, *Eretmochelys imbricata*; loggerhead, *Caretta caretta*; and green, *Chelonia mydas*. These sea turtles occur in the Gulf of Mexico and South Atlantic and may be affected by shrimping activities (Magnuson et al., 1990; Epperly et al., 2002; Price and Gearhart, 2011; Scott-Denton et al., 2014; Gray and Kennelly, 2018). All of these species are currently listed as threatened or endangered under the ESA.

While less common, other protected species encountered include smalltooth sawfish, *Pristis pectinata*, listed by National Marine Fisheries Service (NMFS) as endangered under the ESA in April 2003 (50 CFR 224). Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, and Gulf sturgeon, *Acipenser oxyrinchus desotoi*, were listed by NMFS as endangered species in February 2012 (NOAA, 2012). The brown pelican, *Pelecanus occidentalis*, was delisted in November 2009 under ESA, but remains protected under the Migratory Bird Treaty Act (16 U.S.C. §§ 703-712). Lastly, the Marine Mammal Protection Act (MMPA), enacted in 1972 (16 USC Chpt. 31), provides protection for marine mammals.

The continuing goal of the mandatory shrimp observer program is to provide quantitative biological, vessel, and gear-selectivity information for the southeastern shrimp fishery. The primary objectives are to 1) provide general fishery characterization and catch rates for shrimp and bycatch species by area and target species and 2) provide catch rates that managers can use to estimate protected species bycatch levels.

The specific objectives of this manuscript are to 1) provide trip, vessel, environmental, and gear characteristics by gear type, target species, and area; 2) quantify shrimp and bycatch including protected species, by gear type, target species, and area; and 3) estimate catch per unit of effort (CPUE) trends and spatial distribution for target and nontarget species.

Methods

Methods are similar to those as described for the 1992 through mid-2007 voluntary shrimp observer program (Scott-Denton, 2007; NMFS[3]; Foster and Scott-Denton[7]) and, for the most part, the same as the first years of the mandatory program (Scott-Denton et al., 2012). NMFS-approved observers were placed on randomly selected vessels in the Gulf of Mexico based on the previous full year of effort stratified by area, depth, and season. Shrimp landings data were used to allocate sampling effort for the South Atlantic selection proportionally. Triannual selection periods each year were as follows: January through April, May through August, and September through December. For the rock shrimp fishery, one selection occurred for July through November. Selection periods varied for the inshore and nearshore shrimp fisheries due to seasonal closures in state waters.

The authority to place observers falls under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA; 16 USC 1801), ESA, and MMPA. Pursuant to MSFCMA § 303(b)(8), fishery permit holders are required to carry an observer if selected for mandatory coverage. MSFCMA § 303(b)(8) mandates that vessel operators obtain a current Commercial Fishing Vessel Safety Examination decal prior to the selection period for mandatory observer coverage.

[9]SERO. 2016. Fishery permits. Southeast Reg. Off., Natl. Mar. Fish Serv., NOAA, St. Petersburg, Fla. (avail. at http://sero.nmfs.noaa.gov/sf/permits.htm).

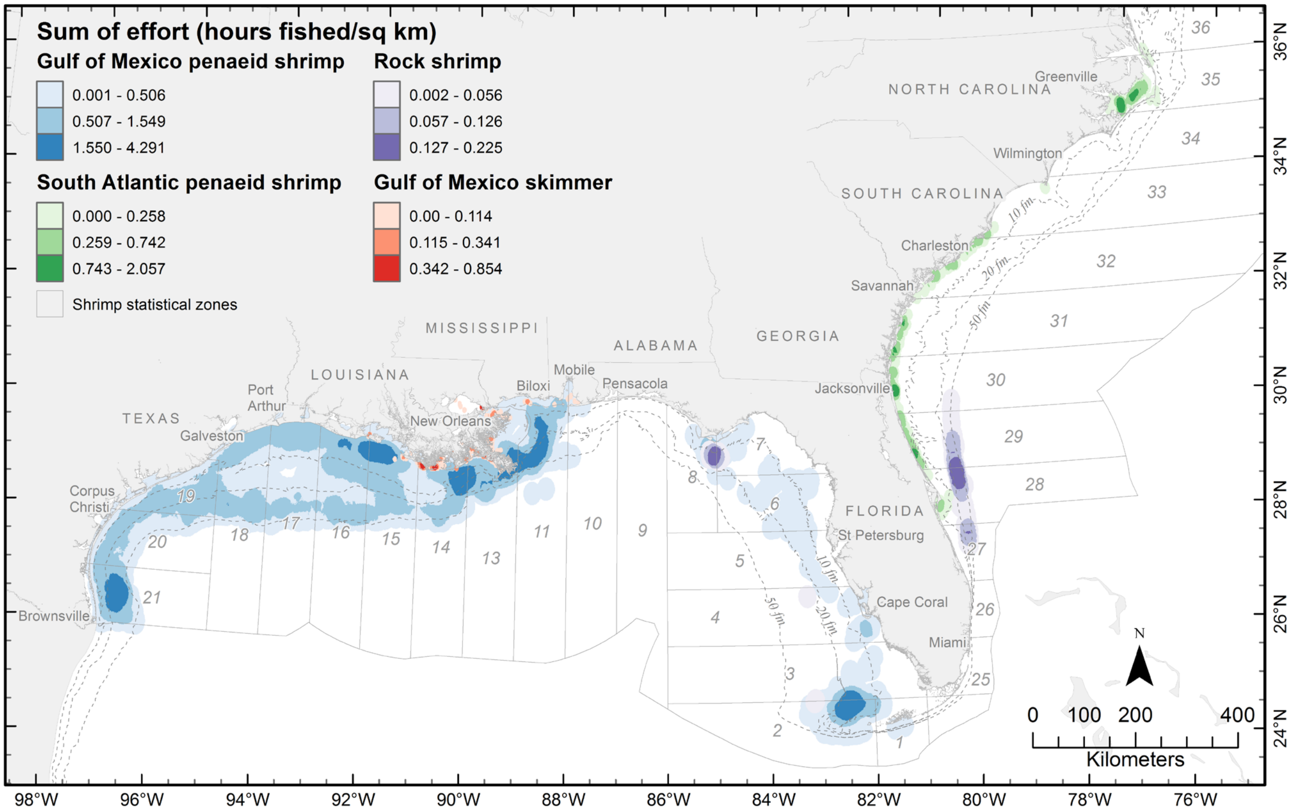

Figure 1.—Distribution of sampling effort (sum of tow times) based on observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

A minimum sea day requirement by permit type was established to prevent early trip termination due to having an observer on board. Gulf of Mexico Federal penaeid shrimp permit holders are required to carry an observer for a minimum of 18 days during a selection period, with 11 and 6 days for rock and South Atlantic penaeid shrimp, respectively. For the state-licensed skimmer trawl and otter-trawl fisheries, the minimum number of days to carry an observer is five and can occur through multiple trips.

Statistical zones (Patella, 1975) were used to delineate area designations in the Gulf of Mexico (Fig. 1). Where statistical areas 1–9 denote areas off the west coast of Florida, areas 10–12 represent Alabama/Mississippi, areas 13–17 depict Louisiana, and areas 18–21 delineate Texas. Depth strata seaward of the beach, or International Regulations for Preventing Collisions at Sea 1972 (COLREGS) line, were categorized as nearshore (≤ 10 fm) or offshore (> 10 fm). For the Atlantic, lat. 24°00’ N – 30°42.5’ N depict the east coast of Florida, > lat. 30°42.5’ N – 32°00’ N denote Georgia, > lat. 32°00’ N – 33°51.6’ N represent South Carolina, and > lat. 33°51.6’ N designate North Carolina.

For each observed trip, vessel length, hull construction material, gross tonnage, engine horsepower, and crew size information were documented. Gear characteristics associated with BRD, TED, net type, and other attributes were recorded at the start of each trip and updated if changes were made during the trip. Bottom time, vessel speed, and operational aspects relative to each net were documented for each tow.

For the otter trawl fisheries, fishery-specific data were collected for each tow from the two outboard nets from vessels equipped with four nets, and one net for vessels equipped with two nets. Total catch and weights of shrimp and red snapper, *Lutjanus campechanus*, were recorded for each net sampled. A subsample (one basket per net; about 32 kg) was processed from each net for bycatch composition by sorting for species, family, or species groupings (now referred to as species). Sampling techniques were slightly modified to accommodate framed nets used in the skimmer trawl fishery (Pulver et al., 2012; Scott-Denton et al., 2014).

Species of commercial, recreational, and ecological importance were recorded. A detailed description of at-sea collection methods by gear type and area, species listings, and data requirements are presented in the NMFS Galveston Laboratory’s observer manual “Characterization of the U.S. Gulf of Mexico and Southeastern Atlantic Otter Trawl and Bottom Reef Fish Fisheries" (NMFS[10]).

All shark species (predominantly family Carcharhinidae) were grouped from 2007 through 2008. Beginning in January 2009, identification of some shark species was implemented.

Biological measurements (weight and length) were recorded in metric units. Vessel, gear, and depth measurements followed current standards for the fisheries (U.S. system equivalents) as related to relevant regulatory mandates.

Catch rates are presented collectively for all years and seasons by area and target species (Gulf of Mexico penaeid otter trawl; South Atlantic penaeid otter trawl; rock shrimp otter trawl; and penaeid skimmer trawl). A minimum of three vessels was required for seasonal and state-specific analyses due to confidentiality restrictions.

Protected species were documented and reported to the NMFS Southeast Regional Office (SERO) and/or the NMFS Southeast Fisheries Science Center (SEFSC), generally within 24 h of capture. Sighting or capture of sea turtles were recorded in accordance with SEFSC protocol (NMFS, 2008). Observer data pertaining to sea turtle interactions and other protected resources were sent to SEFSC for take level estimations.

Statistical Analyses

Species total weights, extrapolated from subsample weight using the total catch weight, were based on all sampled nets (sampling unit) per tow. To depict standard shrimp operations, data from all sampled nets, regardless of operational problems (e.g., torn webbing, hangs, clogging), were included. Total weight extrapolations were derived by multiplying the sample weight of the species of interest by the total weight of the sampled net, divided by the subsample weight for that net. For rare species and red snapper, all specimens were removed from the net. Thus, no extrapolation was required. Ratio estimation was used for analyses of species-specific catch rates (Snedecor and Cochran, 1967; Watson et al., 1999; Scott-Denton et al., 2012).

To standardize discard (bycatch) estimates, the coefficient of variation (CV) was used as a measure of precision for bycatch estimates (NMFS, 2004). The estimated standard error was divided by the estimate of the mean CPUE (kg per hour for selected species) to calculate the CV estimates.

As described in Scott-Denton et al. (2012), a density surface of CPUE for commercial and recreationally important species was created using Fishery Analyst[11,12] to graphically present temporal and spatial trends in fishery statistics (Riolo, 2006). The search radius was based on the average minimum tow length plus the standard deviation for each fishery (20 km for Gulf penaeid and rock shrimp; 10 km for South Atlantic penaeid; 5 km for skimmer trawl). A cell size of 1 km produced the finest resolution. To identify patterns in CPUE for selected species in each fishery, a local spatial statistic, the Getis-Ord Gi* (Gi*), was calculated using the Hot Spot Analysis tool in ArcGIS[13] to locate clusters of features with similarly high or low values and to identify if geographical areas of particularly high levels of bycatch occurred.

Results

Fishing Characteristics

From January 2011 through December 2016, a total of 1,134 trips were observed (Table 1). For the mandatory component, 24,679 tows targeting penaeid, rock, and/or royal red shrimp were sampled during 10,734 sea days of observations. Royal red shrimp were not included in the analyses due to confidentially rules. The highest concentration of effort was in the Gulf of Mexico in statistical areas 2, 11–15, and 21 (Fig. 1). By season, 47% of the tows occurred from May through August; 35% September through December; and 18% January through April (Table 2). The greatest percentage of tows (43%) occurred off Louisiana.

Trip and tow characteristics varied by area and target (Table 3). Trip length averaged 17.2 (± 11.8 s.d.) days in the Gulf, 2.8 (± 3.6 s.d.) days in the South Atlantic penaeid shrimp fishery, 8.8 (± 6.4 s.d.) days for the rock shrimp fishery, and 2.9 (± 1.9 s.d.) in the Gulf skimmer fishery. Average tow times were longer in the Gulf (5.3 h ± 2.1 s.d.) as compared with rock shrimp (3.0 ± 0.8 s.d), South Atlantic penaeid (2.9 h ± 1.2 s.d.) and skimmer trawl (1.0 h ± 0.4 s.d.) shrimp fisheries. Try net (a small net used to intermittently test for shrimp concentrations) tow times were also longer in the Gulf (1.0 h ± 0.5 s.d.) as compared with rock (0.8 h ± 0.3 s.d) and South Atlantic penaeid (0.6 h ± 0.2 s.d) shrimp fisheries. Skimmer trawlers do not utilize try nets. On average, rock shrimp vessels fished greater depths (28.9 fm) than Gulf (15.0 fm), South Atlantic penaeid (4.8 fm), and skimmer trawl (1.8 fm) fisheries. Average vessel trawl speed for all areas and fisheries combined was 2.6 kn.

Vessel characteristics (Table 4) were similar for the Gulf penaeid and rock shrimp fisheries because they often target both penaeid and rock shrimp, though in different areas and times of the year. Gulf penaeid vessels are typically larger ($\bar{X}$ > 75.5 ft), have freezer storage capacity, and are of steel construction. The South Atlantic penaeid fishery has smaller vessels ($\bar{X}$ = 64.9 ft), ice hold storage, and wood construction. Skimmer trawl vessels are smallest ($\bar{X}$ = 42.5 ft), have ice hold storage, and of fiberglass construction.

[10]NMFS. 2010. Characterization of the U.S. Gulf of Mexico and southeastern Atlantic otter trawl and bottom reef fish fisheries. Observer Training Manual. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Galveston Lab., Galveston, Tex. (avail. at https://www.fisheries.noaa.gov/resource/document/southeast-otter-trawl-and-reef-fish-fisheries-observer-materials.

[11]Fishery Analyst, Mappamondo GIS, Via Rubens 3, 43100 Parma(PR) - Italy (avail. at http://www.mappamondogis.it/fisheryanalyst.htm).

[12] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[13]ArcGIS 10.5 Computer Software. 380 New York Street, Redlands, Calif. 92373 (avail. at http://www.esri.com/software/arcgis/index.html).

Table 1.—Trips, tows, and sea days by year and program, based on observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

		Mandatory					Voluntary			
Item	Year	Gulf penaeid	South Atlantic penaeid	Rock	Skimmer	Deepwater Royal red	Experimental skimmer	North Carolina blue crab	Electronic monitoring pink shrimp (sawfish)	Total
Trips by year and project	2011	76	59	2		1	45			183
	2012	80	46		58		34	1		219
	2013	82	54	4	35	2	37			214
	2014	94	16	1	18	1	48		1	179
	2015	97	24	2	23	1	6			153
	2016	118	45	2	15	2	4			186
	Total	547	244	11	149	7	174	1	1	1,134
Tows by year and project	2011	2,677	275	50		43	352			3,397
	2012	2,610	370		765		437	2		4,184
	2013	3,357	322	70	1,075	48	315			5,187
	2014	3,570	177	24	634	51	787		62	5,305
	2015	3,297	202	40	371	19	249			4,178
	2016	3,749	405	43	359	76	233			4,865
	Total	19,260	1,751	227	3,204	237	2,373	2	62	27,116
Sea days by year and project	2011	1,273	102	21		26	72			1,494
	2012	1,413	140		119		63	1		1,736
	2013	1,588	127	30	145	14	51			1,955
	2014	1,731	68	9	82	15	103		33	2,041
	2015	1,555	88	19	44	8	33			1,747
	2016	1,869	164	18	47	19	28			2,145
	Total	9,429	689	97	437	82	350	1	33	11,118

Sea days by year and region	Year	Mandatory	Voluntary	Total	Industry sea days	Industry % cover
Gulf of Mexico	2011	1,320	32	1,352	66,777	2.0
	2012	1,532	42	1,574	70,505	2.2
	2013	1,747	11	1,758	64,788	2.7
	2014	1,856	122	1,978	73,683	2.7
	2015	1,664	33	1,697	66,849	2.5
	2016	2,033	28	2,061	72,609	2.8
	Total	10,152	268	10,420	415,212	2.5
South Atlantic	2011	102	40	142	16,933	0.8
	2012	140	22	162	19,020	0.9
	2013	157	40	197	13,950	1.4
	2014	49	14	63	14,657	0.4
	2015	50		50	15,450	0.3
	2016	84		84	14,919	0.6
	Total	582	116	698	94,929	0.7

Typical gear configurations for the southeastern otter trawl fishery are depicted in Scott-Denton et al. (2012), with Gulf skimmer trawls described in Pulver et al. (2012). Net characteristics by area and target species varied (Table 5). In the otter trawl fisheries, headrope length for the main nets ranged in size with an average of 49.8 ft in the Gulf penaeid to 61.0 ft in the rock shrimp fishery. Try net headrope for all otter trawl fisheries was approximately 12 ft. Several trawl characteristics in the Gulf and South Atlantic fisheries were similar including trawl body and codend material (nylon), door type (wood), trawl extension (none), chaffing gear (mesh), and lazy line rigging (elephant ears).

BRD type and dimensions (Table 6) were examined. The dominant BRD type (fisheye), BRD position (top), and BRD location (behind elephant ears) were recorded most often for the otter-trawl fisheries. Similarly, the dominant TED (Table 7) attributes included TED type and design (hard/curved bar), and TED angle ($\bar{x} \geq 48.5$ degrees).

Catch Composition

Based on actual weight (i.e., nonextrapolated) data, 5.0 million kg of total catch was documented from 30,890 nets (towing for 153,039 h). For nets that had an effort value and an associated total catch and shrimp weight recorded, 4.8 million kg of total catch were documented from 29,853 nets (147,474 h). Penaeid and rock shrimp comprised 1.3 million kg (heads-on) or 27% of the total weight. Average shrimp CPUE was 8.9 kg/h. From 29,587 nets (146,271 h) that had effort, total catch, shrimp and red snapper counts recorded, 269,698 total red snapper were documented in the Gulf of Mexico, yielding an average of 1.8 fish/h.

Extrapolated Species Composition Bycatch Ratios

For the 25,370 nets that contained species characterization data (including nets without effort), 4.4 million kg of total catch was recorded for all years, areas, seasons, and depths. Based on weight extrapolations from species composition samples, bycatch to targeted shrimp (penaeid or rock)

Table 2.—Percentage of tows by season and state, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Area	Jan–April %	May–Aug %	Sept–Dec %	Total %
Texas				
Nearshore	2.8	1.7	1.3	5.7
Offshore	1.5	4.6	10.4	16.5
Subtotal	4.2	6.3	11.7	22.3
Louisiana				
Nearshore	1.9	17.6	8.4	27.9
Offshore	4.8	5.8	4.2	14.8
Subtotal	6.7	23.4	12.6	42.7
Alabama/Mississippi				
Nearshore	0.6	5.9	3.9	10.5
Offshore	1.2	3.6	1.9	6.7
Subtotal	1.8	9.5	5.9	17.2
Florida Gulf				
Nearshore	1.2	0.5	0.4	2.1
Offshore	3.4	2.7	1.7	7.8
Subtotal	4.6	3.2	2.2	10.0
Florida Atlantic				
Nearshore	0.6	1.4	0.5	2.4
Offshore	0.0	0.6	0.2	0.8
Subtotal	0.6	2.0	0.7	3.3
Georgia				
Nearshore	0.1	0.4	0.6	1.1
Subtotal	0.1	0.4	0.6	1.1
South Carolina				
Nearshore	0.0	0.8	0.7	1.4
Subtotal	0.0	0.8	0.7	1.4
North Carolina				
Nearshore	0.0	1.4	0.6	2.0
Subtotal	0.0	1.4	0.6	2.1
Grand total	18.0	47.1	35.0	100.0

Table 3.—Trip characteristics by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Item	Gulf mandatory penaeid	South Atlantic mandatory penaeid	Mandatory rock	Gulf mandatory skimmer
Trip length (days)	*n*=547	*n*=244	*n*=11	*n*=149
Mean	17.2	2.8	8.8	2.9
Range	1.0–61.0	1.0–26.0	1.0–20.0	0–10.0
s.d.	11.8	3.6	6.4	1.9
Main net tow time (h)	*n*=19,198	*n*=1,751	*n*=225	*n*=3,203
Mean	5.3	2.9	3.0	1.0
Range	<0.1–22.2	0.1–8.0	0.2–5.9	<0.1–4.0
s.d.	2.1	1.2	0.8	0.4
Total hs	102,443.1	5,111.0	681.4	3,152.8
Try net towtime (h)	*n*=31,441	*n*=4,342	*n*=284	
Mean	1.0	0.6	0.8	
Range	<0.1–5.6	<0.1–1.9	0.2–1.9	
s.d.	0.5	0.2	0.3	
Water depth (ftm)	*n*=18,977	*n*=1,736	*n*=227	*n*=3,126
Mean	15.0	4.8	28.9	1.8
Range	0.6–100.3	0.8–12.7	11.0–76.3	0.2–20.5
s.d.	11.9	2.5	13.4	1.8
Vessel speed (kt)	*n*=19,126	*n*=1,746	*n*=227	*n*=3,203
Mean	2.9	2.6	2.7	2.2
Range	0.5–4.2	1.4–22.9	2.2–3.1	0.0–5.3
s.d.	0.3	0.6	0.2	0.6

ratios by area and target species (Table 8) were 2.54 in the Gulf penaeid shrimp fishery, 3.50 for the South Atlantic penaeid, 1.68 in rock shrimp, and 1.19 in the Gulf skimmer trawl fishery. Finfish to shrimp ratios for these same fisheries were 2.08, 2.83 and 1.06, and 1.06, respectively.

A total of 166 species were identified (Table 9). For all areas and target species, four species comprised 70% of total catch: grouped finfish species (30.4%), Atlantic croaker, *Micropogonias undulatus* (16.0%), brown shrimp (12.3%), and white shrimp (11.4%).

Extrapolated Species Composition Gulf of Mexico Penaeid Shrimp

Weight extrapolations from species characterization data collected from 25,317 nets that had an associated effort value (134,819 h) were placed into major categories by area and target for all years, seasons, and depths (Fig. 2). In terms of percent composition and CPUE for the Gulf of Mexico penaeid shrimp fishery, finfishes dominated the catch at 59% (18.5 kg/h), followed by penaeid shrimp at 28% (8.9 kg/h), crustaceans at 6% (1.9 kg/h), invertebrates at 5% (1.6 kg/h), and debris at 2% (0.5 kg/h). Overall (total catch) CPUE was 31.5 kg/h.[14]

At the species level, the dominant species by area and target are depicted (Fig. 3–6; Table 9). In the Gulf of Mexico penaeid shrimp fishery, 148 species were identified (Table 9). As to percent composition and CPUE (Fig. 3), grouped finfish accounted for 32% (10.3 kg/h) of the total catch, followed by Atlantic croaker, at 16% (4.9 kg/h), brown shrimp at 13% (4.0 kg/h), white shrimp at 11% (3.6 kg/h), crustaceans at 6% (1.9 kg/h), seatrout, *Cynoscion* spp., at 5% (1.7 kg/h), invertebrates at 5% (1.6 kg/h), pink shrimp at 3% (1.1 kg/h), longspine porgy, *Stenotomus caprinus,* at 3% (1.0 kg/h), and debris at 2% (0.5 kg/h). All other species accounted for 4% of the catch.

CPUE and variance estimates for selected species collected from all sampled nets from January 2011 through December 2016 in the Gulf of Mexico penaeid shrimp fishery depict low (≤0.2) CV estimates (Table 10). The two exceptions were finetooth shark, *Carcharhinus isodon,* and Florida smoothhound shark, *Mustelus norrisi*.

Spatial CPUE density (kg/h) plots for several of these species and areas of high and low CPUE for target and bycatch species are depicted in Fig-

[14]Percentages may not equal 100% due to rounding.

ures 7–23 for all regions and targets. For the Gulf of Mexico region, brown and white shrimp were caught primarily in the western Gulf (statistical areas ≥11), with higher density CPUE for brown shrimp at a greater distance offshore as compared with white shrimp (Fig. 7, 8). Pink shrimp were distributed throughout the Gulf, with highest density CPUE occurring off the west coast of Florida (Fig. 9). Atlantic croaker, a dominant bycatch species, were caught throughout the Gulf region with highest spatial CPUE observed in statistical areas 11–18 (Fig. 10). Red snapper occurred primarily in the western Gulf and to a lesser extent off Florida in statistical areas 1–8 (Fig. 11).

For the Gulf of Mexico, cluster locations of statistically significant high CPUE for penaeid shrimp were most pronounced in relatively small concentrated cells of statistical areas 11–14, 2, and 6 (Fig. 12). For all discard (bycatch) species combined (Fig. 13), clusters of significantly high CPUE were most evident in statistical area 11 in the western Gulf, with relatively lower CPUE detected off south Texas (statistical area 21) and Florida (statistical area 2).

Table 4.—Vessel characteristics by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Item	Gulf mandatory penaeid	South Atlantic mandatory penaeid	Mandatory rock	Gulf mandatory skimmer
Vessel length (ft)	*n*=333	*n*=77	*n*=7	*n*=69
Mean	75.5	64.9	81.0	42.5
Range	34–98	24–88	68–88	26–61
s.d.	11.2	16.0	6.9	9.3
Year built	*n*=332	*n*=76	*n*=7	*n*=69
Mean	1990	1981	1994	1992
Range	1945–2015	1944–2001	1979–2001	1961–2013
s.d.	10.8	13.8	10.2	11.1
Gross tons	*n*=326	*n*=75	*n*=7	*n*=39
Mean	128.5	86.7	147.1	27.4
Range	7–219	1.5–175	114–175	3–49
s.d.	39.8	47.1	21.3	13.6
Horsepower	*n*=287	*n*=63	*n*=7	*n*=62
Mean	628	469.3	665.4	415.7
Range	76–1900	165–1080	360–800	165–1006
s.d.	265.9	211.3	158.6	196.9
Crew size	*n*=536	*n*=244	n=11	n=148
Mean	2	2	3	1
Range	0–4	0–4	2–3	0–3
s.d.	0.9	0.9	0.4	0.7
Cold storage				
Freezer	86.1%	27.3%	100%	3.6%
Ice	11.7%	71.4%		96.4%
Hull construction				
Steel	84.7%	36.4%	85.7%	17.6%
Fiberglass	10.8%	11.7%	14.3%	61.8%
Wood	1.5%	39.2%		6.6%
Fiberglass/Wood	2.5%	10.2%		11.0%

Extrapolated Species Composition South Atlantic Penaeid Shrimp

In the South Atlantic penaeid shrimp fishery, from 1,801 nets (5,521 h), fish species comprised 63% (32.8 kg/h) of the total catch (Fig. 2), followed by penaeid shrimp at 22% (11.6 kg/h), invertebrates at 11% (5.7 kg/h), crustaceans at 3% (1.5 kg/h), and debris at 1% (0.5 kg/h). Overall CPUE was 52.0 kg/h (rounding).

At the species level (Fig 4; Table 9), Atlantic croaker accounted for 25% (12.8 kg/h) of the total catch, followed by white shrimp at 13% (6.8 kg/h), grouped finfish at 12% (6.4 kg/h), spot (flat croaker), *Leiostomus xanthurus*, at 10% (5.4 kg/h), brown shrimp at 9% (4.4 kg/h), cannonball jellyfish, *Stomolophus meleagris,* at 5% (2.5 kg/h), seatrout, (*Cynoscion* spp.) and jellyfish (Family Carybdeidae) at 4% each (2.1 kg/h), star drum, *Stellifer lanceolatus*, at 4% (1.9 kg/h), and southern kingfish, *Menticirrhus americanus,* at 3% (1.5 kg/h). All other species (46) comprised 11% of the total weight.

CPUE and variance estimates for species selected from all sampled nets during the monitoring period in the South Atlantic penaeid shrimp fishery are depicted (Table 11). Relatively higher (≥0.2) CV estimates were observed in the South Atlantic as compared with the Gulf for several species including, but not limited to, sciaenids (Family Sciaenidae), seabasses (Family Serranidae), and sharks (predominantly Family Carcharhinidae).

Spatial CPUE density (kg/h) plots for several of these species are denoted in Figures 7–13. Brown and white shrimp were caught predominantly in statistical areas 28–32, with high CPUE observed in statistical area 35, in Pamlico Sound, North Carolina (Fig. 7, 8). Relatively low-density CPUE was observed for pink shrimp along the southeastern Atlantic coast (Fig. 9); the two exceptions occurred in statistical area 28, and in Pamlico Sound. Atlantic croaker occurred along the southeastern Atlantic coast, with highest CPUE density found in statistical area 35 (Fig. 10). Density surface of CPUE was not detectable for red snapper (Fig. 11). Cluster locations of statistically significant high CPUE for South Atlantic penaeid shrimp were most pronounced in statistical areas 30–32, and 35 (Fig. 12). For discarded species, clusters of significantly high CPUE were detected primarily in the statistical area 35 (Fig. 13).

Extrapolated Species Composition Gulf of Mexico and South Atlantic Rock Shrimp

In the rock shrimp fishery (342 nets; 1,044 h), finfish accounted for 40% (25.2 kg/h) of the total catch (Fig. 2), followed by rock shrimp at 37% (23.7 kg/h), crustaceans at 10% (6.6 kg/h), invertebrates at 8% (4.8 kg/h), penaeid shrimp at 3% (1.9 kg/h), and debris at 2% (1.2 kg/h). Total catch CPUE was 63.5 kg/h.

At the species level (Fig. 5; Table

Table 5.—Net characteristics by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Item	Gulf mandatory penaeid		South Atlantic mandatory penaeid		Mandatory rock		Mandatory skimmer	
Net type (%)	Unknown w/bib	21.2	Mongoose w/bib	57.0	2 seam	34.5	Skimmer trawl	97.1
	Unknown	11.9	4 seam	6.9	2 seam flat	34.5	Butterfly net	2.9
Main net headrope length (ft)		*n*=37,507		*n*=3,431		*n*=452		*n*=6,406
Mean		49.8		53.4		61.0		17.0
Range		16.0–96.7		25.0–89.4		39.1–68.2		11.0–29.6
s.d.		10.6		11.3		5.1		2.2
Main net footrope length (ft)		*n*=37,881		*n*=3,345		*n*=452		*n*=6,386
Mean		56.8		56.3		64.6		28.0
Range		16.0–90.0		24.1–87.5		48.0–72.9		16.0–38.0
s.d.		11.3		11.5		6.5		3.5
Try net headrope length (ft)		*n*=29,714		*n*=4,294		*n*=270		
Mean		12.1		11.9		12.0		
Range		5.0–21.2		6.2–16.5		6.2–16.1		
s.d.		1.4		1.6		1.2		
Try net footrope length (ft)		*n*=29,829		*n*=4,294		*n*=270		
Mean		13.4		12.7		13.4		
Range		5.0–24.0		9.4–16.5		12.0–16.0		
s.d.		2.0		1.4		1.4		
Trawl body (%)	Nylon	50.8	Nylon	38.8	Sapphire	69.5	Poly	65.5
	Sapphire	25.6	Spectra	38.4	Nylon	24.8	Nylon	17.5
Trawl body mesh size (in)		*n*=37,363		*n*=3,307		*n*=452		*n*=6,406
Mean		1.9		1.8		1.9		1.6
Range		1.3–3.0		1.3–2.3		1.5–2.0		1.3–2.4
s.d.		0.2		0.2		0.2		0.2
Cod end (%)	Nylon	63.4	Nylon	38.8	Nylon	65.0	Poly	58.4
	Sapphire	21.3	Poly	29.6	Sapphire	29.2	Nylon	36.5
Cod end mesh size (in)		*n*=36,856		*n*=3,285		*n*=452		*n*=6,264
Mean		1.6		1.6		1.7		1.4
Range		1.0–2.5		1.0–2.0		1.1–2.0		1.2–1.8
s.d.		0.2		0.2		0.3		0.1
Door type (%)	Wood	44.4	Wood	58.3	Aluminum	88.5	None	100.0
	Aluminum	32.8	Aluminum	34.1	Steel	10.6		
Door length (ft)		*n*=37,696		*n*=3,448		*n*=452		
Mean		9.5		8.6		10.6		
Range		3.5–13.3		3.3–12.0		8.9–12.0		
s.d.		2.0		1.8		0.8		
Door height (ft)		*n*=37,696		*n*=3,448		*n*=452		
Mean		3.6		3.4		3.7		
Range		2.5–6.0		2.0–5.0		3.3–4.3		
s.d.		0.3		0.4		0.2		
Dummy door length (ft)		*n*=30,688		*n*=2,656		*n*=452		
Mean		7.7		6.9		8.0		
Range		2.0–11.8		2.8–9.6		5.8–9.0		
s.d.		1.8		1.5		0.5		
Trawl extension type (%)	None	72.3	None	54.0	None	65.5	None	60.1
	Nylon	14.8	Nylon	26.4	Poly	18.1	Poly	24.0
Chaffing gear type (%)	Mesh	95.9	Mesh	86.0	Other	69.9	None	85.3
	None	3.4	None	7.2	Mesh	28.8	Mesh	14.7
Lazy line rigging (%)	Elephant ears	97.7	Elephant ears	90.9	Elephant ears	100.0	Choke	57.1
	Choke	2.0	Choke	8.1			Elephant ears	42.9
Tickler chain length (ft)		*n*=36,810		*n*=3,327		*n*=452		*n*=6,180
Mean		64.7		62.0		71.3		28.9
Range		27.0–100.7		25.0–100.7		50.5–84.1		15.0–46.9
s.d.		12.2		12.2		9.9		3.5

9), rock shrimp comprised 36% (22.7 kg/h) of the total catch, followed by grouped finfish at 22% (14.0 kg/h), invertebrates at 8% (4.8 kg/h), inshore lizardfish, *Synodus foetens,* at 7% (4.5 kg/h), longspine swimming crab, *Portunus spinicarpus*, at 6% (3.7 kg/h), dusky flounder, *Syacium papillosum*, at 6% (3.6 kg/h), crustaceans at 4% (2.5 kg/h), debris at 2% (1.2 kg/h), pink shrimp and rock seabass, *Centropristis philadelphica,* each at 2% (1.1 kg/h). All other species accounted for 7% of the total weight (rounding).

CV estimates for species selected from all sampled nets from July 2011 through December 2016 (Table 12) were higher (≥0.3), and in some instances equal to 1.0, for several species in the rock shrimp fishery.

Highest spatial CPUE density for rock shrimp detected in statistical areas 7 and 8 (Fig. 14). Highest CPUE density for grouped finfish was most evident in statistical areas 4, 29, and 30 (Fig. 15).

Cluster locations of statistically significant high CPUE for rock shrimp were most pronounced in statistical areas 7 and 8 (Fig. 16). The highest clus-

Table 6.—Bycatch reduction device (BRD) characteristics by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Item	Gulf mandatory penaeid		South Atlantic mandatory penaeid		Mandatory rock		Mandatory skimmer	
BRD type (% of nets)	Fish eye	73.6	Fish eye	84.1	Fish eye	78.8	Fish eye	52.3
	Composite panel	18.1	2 fisheye	11.2	Composite panel	21.2	None	47.7
BRD cod end length (meshes)		*n*=35,049		*n*=3,183		*n*=404		*n*=6,112
Mean		136.5		137.1		134.7		117.0
Range		79.0–268.0		50.0–287.0		100.0–167.0		60.0–271.0
s.d.		27.7		32.8		17.9		35.8
BRD circumference (meshes)		*n*=37,601		*n*=3,379		*n*=452		*n*=6,406
Mean		138.8		147.3		146.7		136.6
Range		86.0–210.0		111.0–200.0		109.0–150.0		87.0–200.0
s.d.		16.5		13.6		9.1		20.6
BRD distance to tie-off rings (ft)		*n*=35,999		*n*=3,358		*n*=452		*n*=3,353
Mean		10.8		10.2		11.1		6.5
Range		4.6–30.0		6.0–21.1		6.7–15.1		4.0–9.8
s.d.		3.6		2.3		2.0		1.1
BRD position (%)	Top	78.5	Top	94.2	Top	78.8	None	47.4
	None	10.7	None	4.8	None	21.2	Top	46.0
BRD escape shape (%)	Half moon	38.3	Diamond	65.7	Diamond	67.7	None	47.7
	Oval	36.6	Half moon	13.9	Rectangle	21.2	Oval	20.0
BRD fisheye escape height (in)		*n*=29,835		*n*=3,182		*n*=404		*n*=3,353
Mean		5.9		7.5		12.1		5.8
Range		4.0–26.0		4.0–28.0		5.0–27.0		3.5–9.0
s.d.		2.6		1.9		7.6		1.1
BRD fisheye escape width (in)		*n*=30,339		*n*=3,168		*n*=404		*n*=3,353
Mean		10.6		8.9		9.0		10.8
Range		5.0–32.0		5.0–28.0		8.0–10.0		7.0–18.0
s.d.		2.8		2.1		0.8		1.6
BRD location (%)	Behind	75.5	Behind	71.3	Behind	78.8	Behind	49.8
	Front	21.6	Front	25.1	Front	21.2	None	47.7

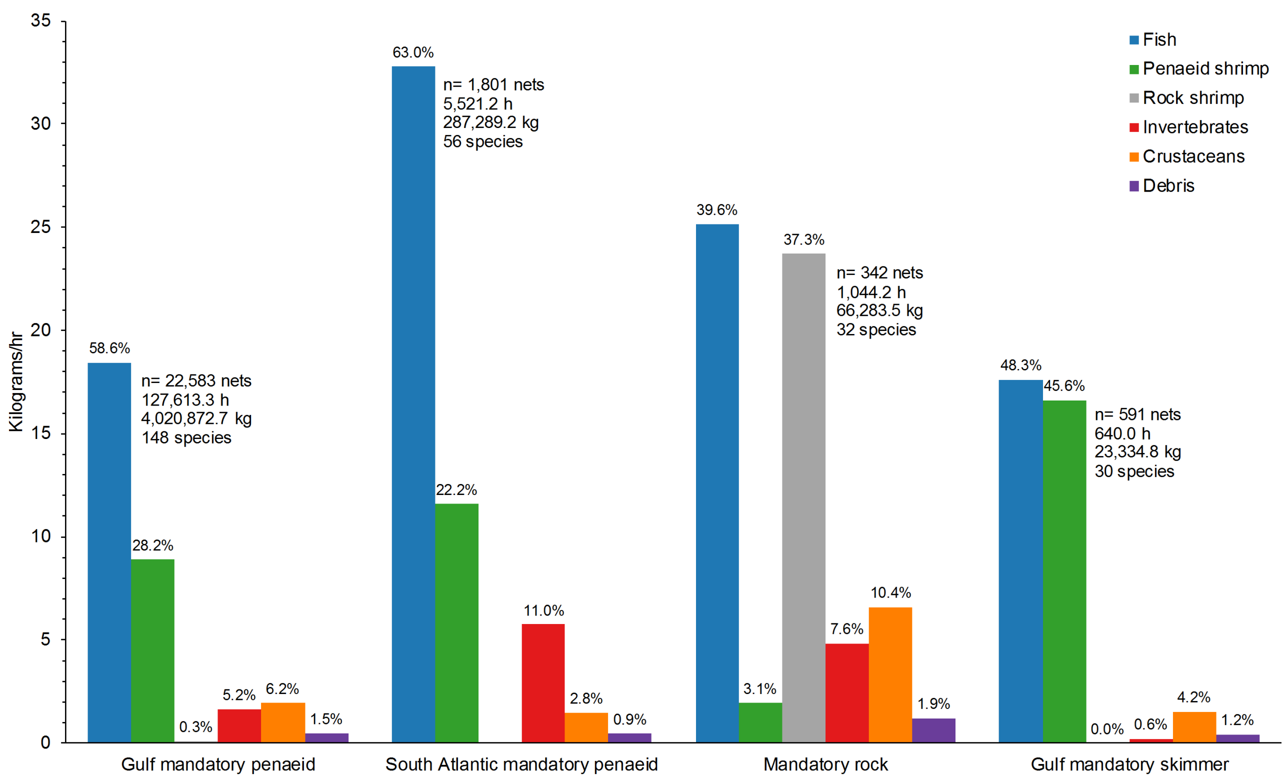

Figure 2.—Major species categories grouped by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Table 7.—Turtle excluder device (TED) characteristics, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Item	Gulf mandatory penaeid		South Atlantic mandatory penaeid		Mandatory rock		Mandatory skimmer	
TED type (%)	Hard	98.7	Hard	99.1	Hard	100.0	None	97.8
	None	1.2	Soft	0.9			Hard	2.2
TED design (%)	Curved bar	58.8	Curved bar	80.5	Curved bar	100.0	None	97.8
	Straight	39.5	Straight	18.6			Straight	2.2
TED opening (%)	Top	50.8	Bottom	80.3	Bottom	100.0	None	97.8
	Bottom	47.4	Top	19.7			Bottom	1.7
TED funnel (%)	No	87.8	No	94.6	Yes	65.0	None	71.1
	Yes	11.1	Yes	4.8	No	34.1	Unknown	23.3
TED flap (%)	Yes	98.1	Yes	97.0	Yes	100.0	None	67.2
	No	1.1	No	2.4			Unknown	23.3
TED material (%)	Aluminum	96.5	Aluminum	94.2	Aluminum	100.0	None	97.8
	Steel	1.3	Steel	3.4			Aluminum	1.7
TED angle (degrees)		*n*=36,721		*n*=3,370		*n*=452		*n*=100
Mean		48.5		51.4		51.9		47.7
Range		22.0–68.0		35.0–66.0		41.0–67.0		46.0–51.0
s.d.		5.4		4.6		5.2		1.8
TED length (in)		*n*=37,372		*n*=3,383		*n*=452		*n*=140
Mean		45.6		45.1		49.7		32.7
Range		30.0–60.0		34.0–64.0		48.0–53.0		32.0–35.0
s.d.		5.2		5.7		2.0		1.3
TED width (in)		*n*=37,469		*n*=3,383		*n*=452		*n*=140
Mean		38.7		36.9		38.8		32.7
Range		23.0–54.0		29.0–52.0		36.0–43.0		31.0–34.0
s.d.		3.5		4.2		2.2		1.3
TED PVC sponge (%)	Foam football	25.3	Foam football	52.6	Foam football	58.2	None	98.8
	Plastic round	24.1	Foam cylinder	13.1	Plastic cylinder	17.7	Foam cylinder	0.6
Number of TED floats		*n*=37,745		*n*=3,437		*n*=452		*n*=140
Mean		2.5		2.2		2.7		0.8
Range		0.0–6.0		0.0–4.0		2.0–3.0		0.0–2.0
s.d.		0.9		0.9		0.4		0.9
Try net TED type (%)	None	100	None	98.1	None	100.0		
			Soft	1.2				

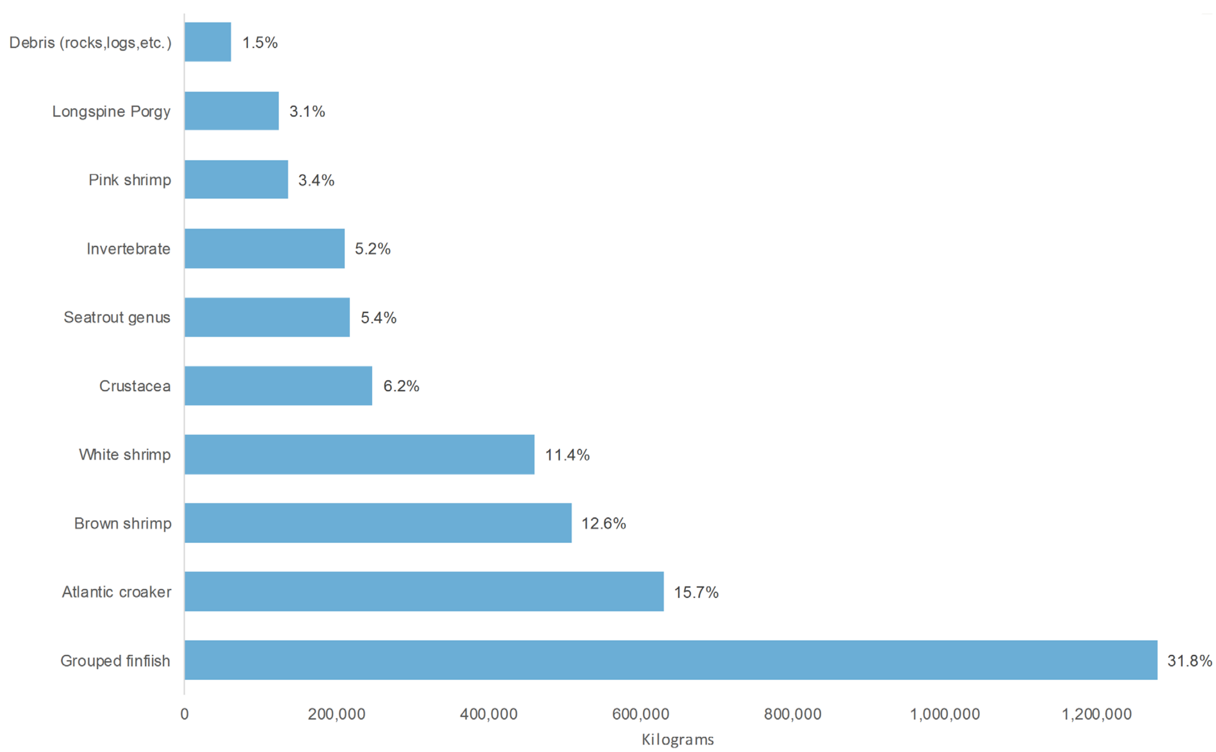

Figure 3.—Species-level characterization in the Gulf of Mexico penaeid shrimp fishery, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

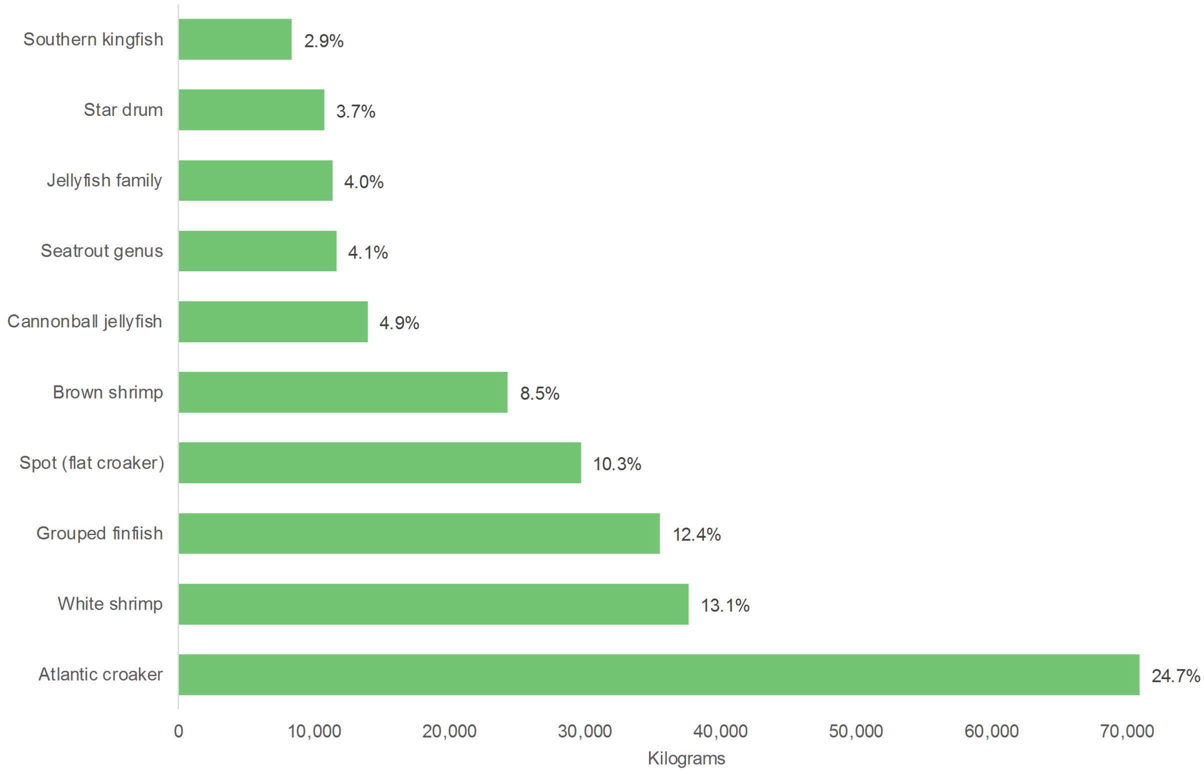

Figure 4.—Species-level characterization in the South Atlantic penaeid shrimp fishery, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

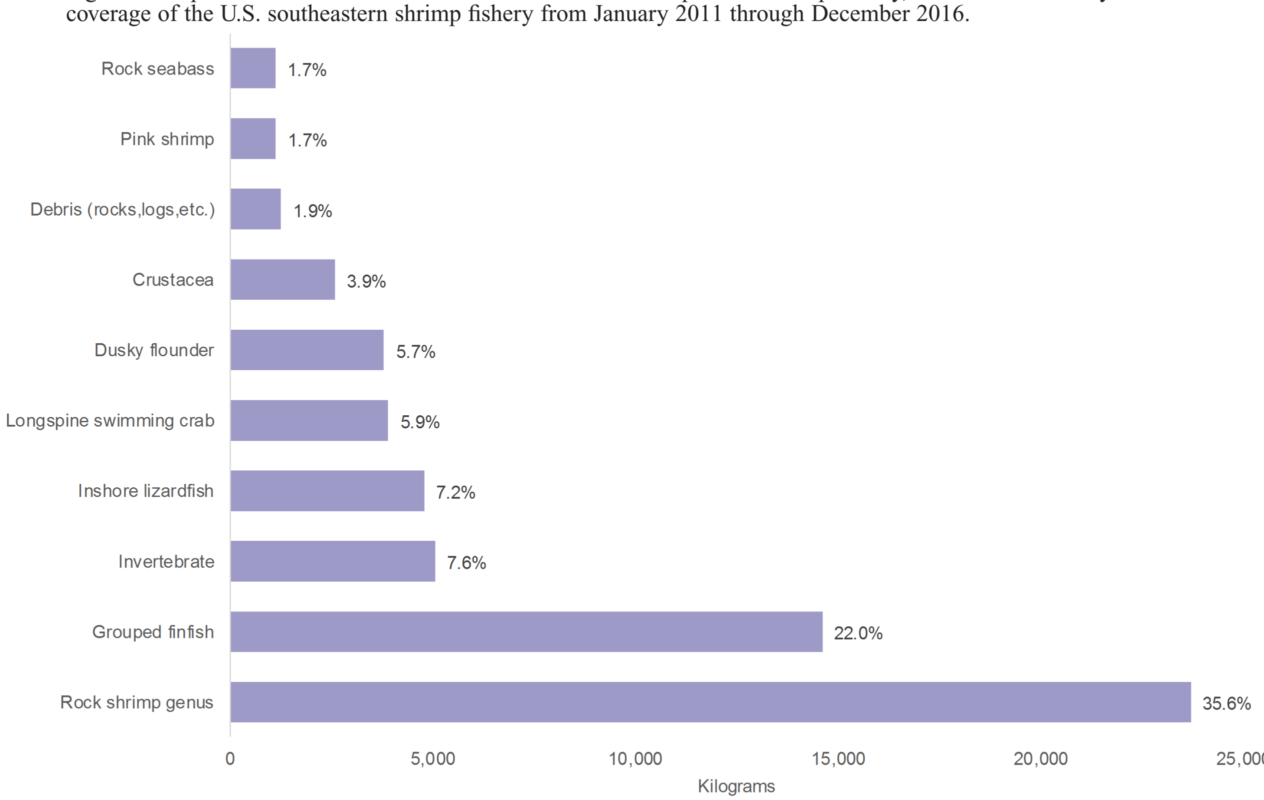

Figure 5.—Species-level characterization in the South Atlantic rock shrimp fishery, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

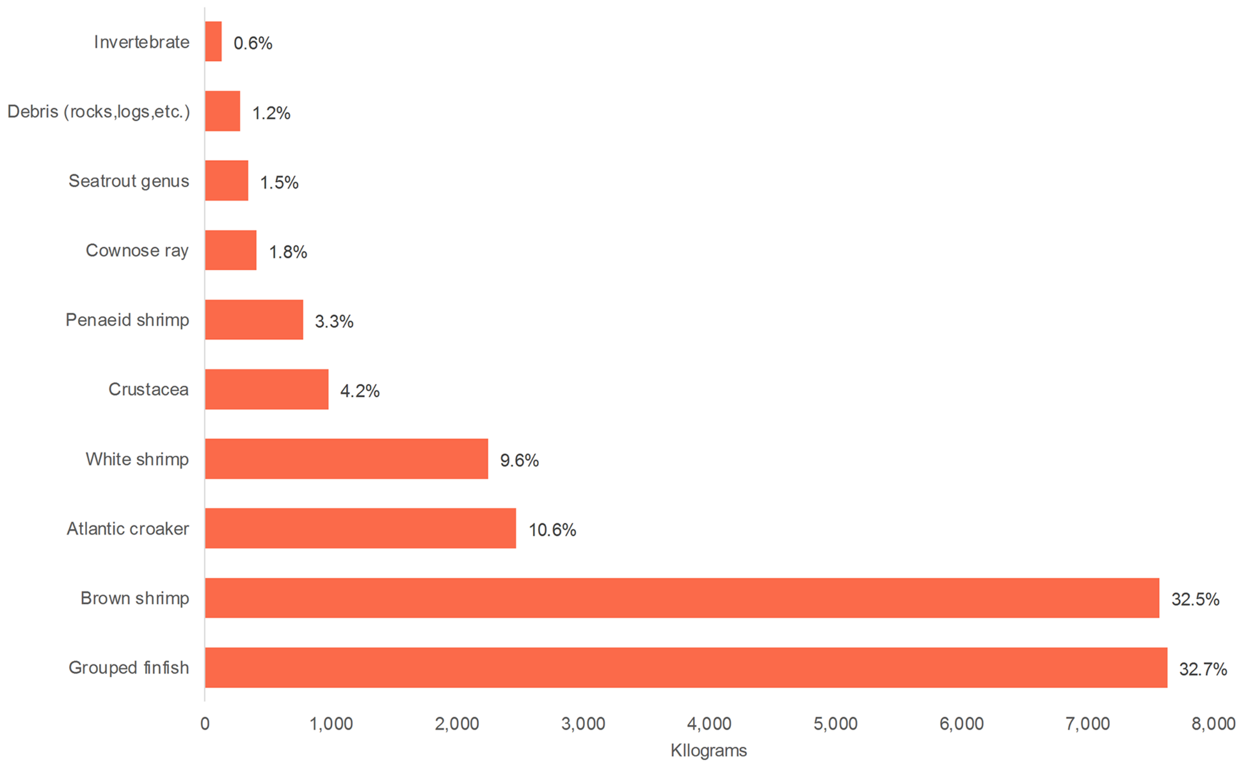

Figure 6.—Species-level characterization in the Gulf of Mexico skimmer shrimp fishery, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

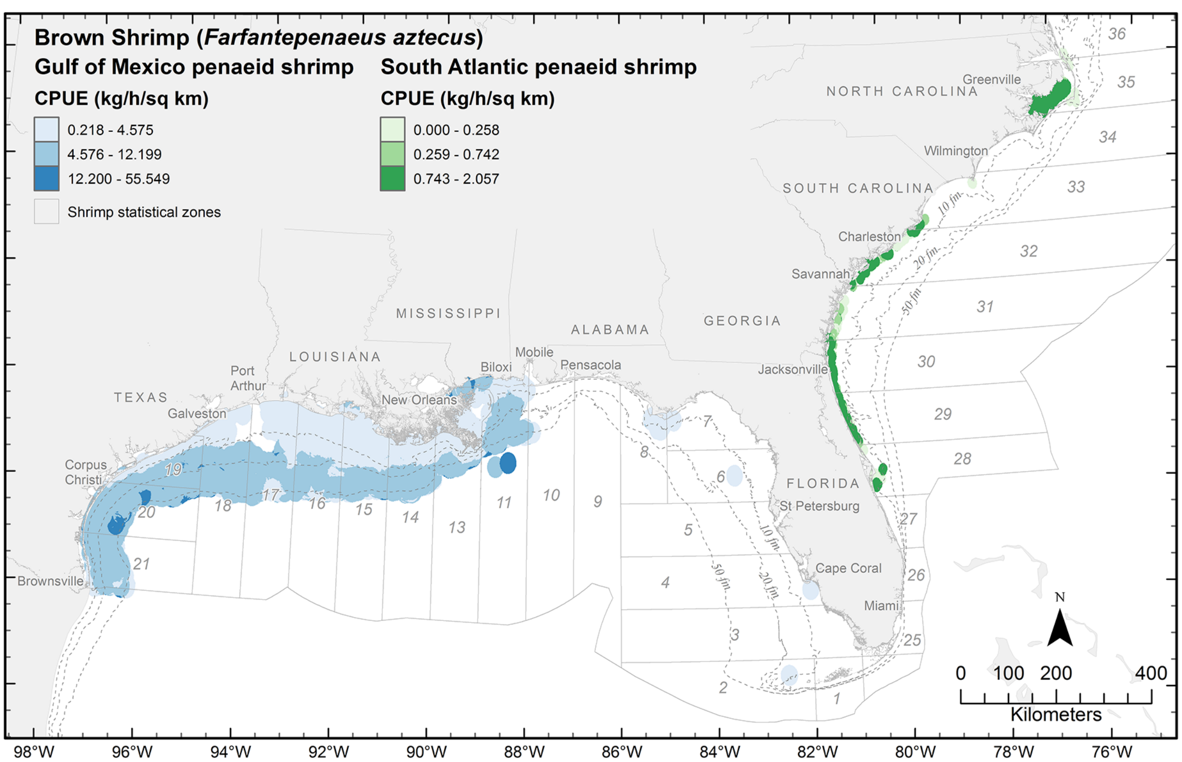

Figure 7.—CPUE density surface for brown shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Table 8.—Bycatch ratios by area and target species, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Project	Total (kg)	All bycatch: penaeid shrimp	Fish: penaeid shrimp	All bycatch: rock shrimp	Fish: rock shrimp
Gulf mandatory penaeid	4,020,872.7	2.54	2.08		
South Atlantic mandatory penaeid	287,289.2	3.50	2.83		
Mandatory rock	66,283.5			1.68	1.06
Gulf mandatory skimmer	23,334.8	1.19	1.06		

Table 9.—Species documented from bycatch characterization samples, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Common name	Scientific name	Gulf mandatory penaeid (kg)	Gulf mandatory penaeid (%)	South Atlantic mandatory penaeid (kg)	South Atlantic mandatory penaeid (%)	Mandatory rock (kg)	Mandatory rock (%)	Gulf mandatory skimmer (kg)	Gulf mandatory skimmer (%)	Total	Percent total
Fish (superclass)	*Pisces*	1,281,387.2	31.8	35,558.6	12.4	14,615.4	22.0	7,635.8	32.7	1,339,197.0	30.4
Atlantic croaker	*Micropogonias undulatus*	630,639.1	15.7	70,947.1	24.7	169.9	0.3	2,473.6	10.6	704,229.7	16.0
Brown shrimp	*Farfantepenaeus aztecus*	509,084.0	12.6	24,340.2	8.5	861.2	1.3	7,575.0	32.5	541,860.4	12.3
White shrimp	*Litopenaeus setiferus*	461,067.8	11.4	37,674.2	13.1	16.2	0.0	2,249.4	9.6	501,007.5	11.4
Arthropod subphylum	Crustacea	248,130.4	6.2	4,916.1	1.7	2,594.5	3.9	985.9	4.2	256,626.9	5.8
Seatrout (genus)	*Cynoscion* spp.	218,008.4	5.4	11,666.5	4.1	43.8	0.1	343.1	1.5	230,061.8	5.2
Invertebrate	Invertebrate	210,182.3	5.2	6,347.3	2.2	5,062.4	7.6	137.7	0.6	221,729.6	5.0
Pink shrimp	*Farfantepenaeus duorarum*	135,793.5	3.4	134.0	0.0	1,139.1	1.7			137,066.6	3.1
Longspine porgy	*Stenotomus caprinus*	124,005.8	3.1							124,005.8	2.8
Debris (rocks,logs,etc.)	Debris	61,360.1	1.5	2,562.1	0.9	1,268.1	1.9	279.7	1.2	65,470.0	1.5
Rock shrimp (genus)	*Sicyonia* spp.	11,305.6	0.3			23,704.6	35.6			35,010.3	0.8
Spot (flat croaker)	*Leiostomus xanthurus*	3,941.7	0.1	29,685.9	10.3	806.7	1.2			34,434.4	0.8
Discarded penaeid shrimp (brown, pink, white)	Penaeus discard	29,471.4	0.7	1,759.2	0.6	15.1	0.0	43.9	0.2	31,289.6	0.7
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	15,354.5	0.4	1,770.8	0.6	80.7	0.1	26.2	0.1	17,232.3	0.4
Red snapper	*Lutjanus campechanus*	13,990.9	0.3	1.2	0.0	0.3	0.0	0.0	0.0	13,992.4	0.3
Cannonball jellyfish	*Stomolophus meleagris*			13,979.9	4.9					13,979.9	0.3
Jellyfish family	Carybdeidae			11,361.6	4.0					11,361.6	0.3
Star drum	*Stellifer lanceolatus*	66.3	0.0	10,750.4	3.7					10,816.6	0.2
Spanish mackerel	*Scomberomorus maculatus*	9,593.9	0.2	471.5	0.2	1.5	0.0	69.4	0.3	10,136.3	0.2
Red drum	*Sciaenops ocellatus*	9,650.8	0.2	8.2	0.0			6.1	0.0	9,665.1	0.2
Southern kingfish	*Menticirrhus americanus*	1,077.4	0.0	8,401.7	2.9					9,479.1	0.2
Inshore lizardfish	*Synodus foetens*	3,720.6	0.1			4,796.2	7.2			8,516.8	0.2
Lane snapper	*Lutjanus synagris*	6,492.6	0.2	0.1	0.0	15.9	0.0	3.8	0.0	6,512.4	0.1
Southern flounder	*Paralichthys lethostigma*	5,487.4	0.1	660.4	0.2	47.2	0.1	48.2	0.2	6,243.2	0.1
Dusky flounder	*Syacium papillosum*	2,359.5	0.1			3,813.7	5.7			6,173.2	0.1
Longspine swimming crab	*Portunus spinicarpus*					3,914.7	5.9			3,914.7	0.1
Bonnethead shark	*Sphyrna tiburo*	2,950.7	0.1	834.3	0.3			1.6	0.0	3,786.6	0.1
Black drum	*Pogonias cromis*	3,737.2	0.1	3.3	0.0			32.5	0.1	3,773.0	0.1
Gulf menhaden	*Brevoortia patronus*	2,951.9	0.1							2,951.9	0.1
Blue crab	*Callinectes sapidus*	0.6	0.0	2,912.9	1.0					2,913.5	0.1
Weakfish	*Cynoscion regalis*			2,780.8	1.0					2,780.8	0.1
Pinfish	*Lagodon rhomboides*	2,725.5	0.1							2,725.5	0.1
Penaeid shrimp genus brown, pink, white)	*Penaeus* spp.	1,800.7	0.0					780.4	3.3	2,581.2	0.1
Blacktip shark	*Carcharhinus limbatus*	2,399.3	0.1	67.9	0.0			48.1	0.2	2,515.3	0.1
Atlantic bumper	*Chloroscombrus chrysurus*	2,488.8	0.1							2,488.8	0.1
Rock seabass	*Centropristis philadelphica*	545.7	0.0	590.8	0.2	1,124.8	1.7			2,261.3	0.1
Atlantic menhaden	*Brevoortia tyrannus*			2,154.0	0.7					2,154.0	0.0
Smooth dogfish shark	*Mustelus canis*	2,108.6	0.1	21.8	0.0					2,130.4	0.0
Atlantic cutlassfish	*Trichiurus lepturus*	2,079.5	0.1							2,079.5	0.0
Silver seatrout	*Cynoscion nothus*			2,040.2	0.7	2.4	0.0			2,042.7	0.0
Rock shrimp discards	Sicyonia discards	414.0	0.0			1,108.0	1.7			1,522.0	0.0
Gulf butterfish	*Peprilus burti*	1,436.1	0.0							1,436.1	0.0
King mackerel	*Scomberomorus cavalla*	1,246.2	0.0	132.8	0.0	2.5	0.0	0.3	0.0	1,381.8	0.0
Cownose ray	*Rhinoptera bonasus*	860.7	0.0					412.2	1.8	1,272.9	0.0
Northern kingfish	*Menticirrhus saxatilis*	1.2	0.0	929.4	0.3	81.5	0.1			1,012.1	0.0
Summer flounder	*Paralichthys dentatus*			856.0	0.3	47.6	0.1			903.6	0.0
Bank seabass	*Centropristis ocyurus*			2.9	0.0	785.6	1.2	0.1	0.0	788.6	0.0
Common crevalle jack	*Caranx hippos*	619.8	0.0					0.2	0.0	620.0	0.0
Sharks grouped	General sharks	552.9	0.0	19.8	0.0					572.7	0.0
Scalloped hammerhead shark	*Sphyrna lewini*	413.1	0.0	146.4	0.1					559.5	0.0
Hake (genus)	*Urophycis* spp.	514.7	0.0							514.7	0.0
Atlantic stingray	*Dasyatis sabina*	510.1	0.0							510.1	0.0
Sand perch	*Diplectrum formosum*	498.3	0.0							498.3	0.0
Sea bob shrimp	*Xiphopenaeus kroyeri*	238.6	0.0	258.2	0.1			1.0	0.0	497.9	0.0
Spinner shark	*Carcharhinus brevipinna*	486.5	0.0							486.5	0.0
Spotted seatrout	*Cynoscion nebulosus*	369.1	0.0	19.7	0.0			65.2	0.3	454.1	0.0
Irridescent swimming crab	*Portunus gibbesii*					422.1	0.6			422.1	0.0
Vermillion snapper	*Rhomboplites aurorubens*	399.4	0.0							399.4	0.0
Bluefish	*Pomatomus saltatrix*	1.2	0.0	370.4	0.1	4.3	0.0			375.8	0.0
Blacknose shark	*Carcharhinus acronotus*	300.2	0.0	7.5	0.0					307.7	0.0
Finetooth shark	*Carcharhinus isodon*	278.8	0.0	2.9	0.0					281.7	0.0

Table continued

Table 9.—*Continued*.

Common name	Scientific name	Gulf mandatory penaeid (kg)	Gulf mandatory penaeid (%)	South Atlantic mandatory penaeid (kg)	South Atlantic mandatory penaeid (%)	Mandatory rock (kg)	Mandatory rock (%)	Gulf mandatory skimmer (kg)	Gulf mandatory skimmer (%)	Total	Percent total
Angel shark	*Squatina dumeril*	279.1	0.0							279.1	0.0
Lefteye flounder family	*Bothidae*	272.7	0.0							272.7	0.0
Pigfish	*Orthopristis chrysoptera*	257.2	0.0							257.2	0.0
Slender mojarra	*Eucinostomus jonesi*	244.7	0.0							244.7	0.0
Cobia (ling)	*Rachycentron canadum*	228.0	0.0	1.0	0.0	11.0	0.0	0.2	0.0	240.1	0.0
Barbfish	*Scorpaena brasiliensis*	210.2	0.0							210.2	0.0
Spotfin mojarra	*Eucinostomus argenteus*	206.1	0.0							206.1	0.0
Rough scad	*Trachurus lathami*	170.4	0.0							170.4	0.0
Blackbelly rosefish	*Helicolenus dactylopterus*	157.6	0.0							157.6	0.0
Gafftopsail catfish	*Bagre marinus*	144.0	0.0							144.0	0.0
Sheepshead	*Archosargus probatocephalus*	79.2	0.0					44.5	0.2	123.7	0.0
Dogfish shark (genus)	*Mustelus* spp.	118.9	0.0	3.3	0.0					122.2	0.0
Mojarra (genus)	*Eucinostomus* spp.	121.4	0.0							121.4	0.0
Southern stingray	*Dasyatis americana*	116.7	0.0							116.7	0.0
Red goatfish	*Mullus auratus*	114.2	0.0							114.2	0.0
Smooth butterfly ray	*Gymnura micrura*	110.3	0.0							110.3	0.0
Brown rock shrimp	*Sicyonia brevirostris*	107.5	0.0							107.5	0.0
Tomtate	*Haemulon aurolineatum*	96.3	0.0							96.3	0.0
Tripletail	*Lobotes surinamensis*	70.1	0.0	17.3	0.0					87.4	0.0
Atlantic thread herring	*Opisthonema oglinum*	81.7	0.0							81.7	0.0
Bullnose ray	*Myliobatis freminvillei*	74.2	0.0							74.2	0.0
Silver jenny	*Eucinostomus gula*	72.4	0.0							72.4	0.0
Bull shark	*Carcharhinus leucas*	62.5	0.0					9.5	0.0	72.0	0.0
Atlantic moonfish	*Selene setapinnis*	57.1	0.0							57.1	0.0
Horseshoe crab	*Limulus polyphemus*			52.8	0.0					52.8	0.0
Silver perch	*Bairdiella chrysoura*	49.4	0.0							49.4	0.0
Roundel skate	*Raja texana*	49.0	0.0							49.0	0.0
Florida pompano	*Trachinotus carolinus*	10.6	0.0	35.9	0.0					46.5	0.0
Snapper (genus)	*Lutjanus* spp.	42.1	0.0							42.1	0.0
Alligator gar	*Atractosteus spatula*							39.8	0.2	39.8	0.0
Cubera snapper	*Lutjanus cyanopterus*	38.2	0.0							38.2	0.0
Southern hake	*Urophycis floridana*	37.1	0.0							37.1	0.0
Devil ray	*Mobula hypostoma*	36.9	0.0							36.9	0.0
Drum, kingfish (genus)	*Menticirrhus* spp.	26.1	0.0	7.6	0.0					33.7	0.0
Sandbar shark	*Carcharhinus plumbeus*	30.2	0.0							30.2	0.0
King snake eel	*Ophicthus rex*	27.2	0.0							27.2	0.0
Stingray (family)	Dasyiatidae	27.2	0.0							27.2	0.0
Black seabass	*Centropristis striata*			3.7	0.0	22.3	0.0			26.0	0.0
Dwarf sand perch	*Diplectrum bivittatum*	25.7	0.0							25.7	0.0
Leopard searobin	*Prionotus scitulus*	23.4	0.0							23.4	0.0
Red lionfish	*Pterois volitans*	23.4	0.0							23.4	0.0
Lefteye flounder (genus)	*Paralichthys* spp.	22.8	0.0	0.5	0.0					23.3	0.0
Longnose gar	*Lepisososteus osseus*	22.0	0.0							22.0	0.0
Hardhead catfish	*Arius felis*	21.8	0.0							21.8	0.0
Paddlefish	*Polyodon spathula*	0.3	0.0					21.2	0.1	21.5	0.0
Atlantic guitarfish	*Rhinobatos lentiginosus*	21.3	0.0							21.3	0.0
Blue catfish	*Ictalurus furcatus*	20.6	0.0							20.6	0.0
Warsaw grouper	*Epinephelus nigritus*	19.9	0.0							19.9	0.0
Gag	*Mycteroperca microlepis*	19.6	0.0							19.6	0.0
Wenchman	*Pristipomoides aquilonaris*	19.3	0.0							19.3	0.0
Tarpon	*Megalops atlanticus*	18.8	0.0							18.8	0.0
Gulf flounder	*Paralichthys albigutta*	16.3	0.0							16.3	0.0
Dusky shark	*Carcharhinus obscurus*	15.6	0.0							15.6	0.0
Tiger shrimp	*Penaeus monodon*	6.2	0.0	5.8	0.0					11.9	0.0
Great hammerhead shark	*Sphyrna mokarran*	11.3	0.0							11.3	0.0
Skate and ray (order)	Rajiformes	11.0	0.0							11.0	0.0
Lesser electric ray	*Narcine brasiliensis*	10.0	0.0							10.0	0.0
Searobin family	Triglidae	9.5	0.0							9.5	0.0
Mackerel (genus)	*Scomberomorus* spp.	8.5	0.0							8.5	0.0
Banded croaker	*Larimus fasciatus*	8.4	0.0							8.4	0.0
Snake eel (family)	Ophichthidae	7.8	0.0							7.8	0.0
Clearnose skate	*Raja eglanteria*	7.8	0.0							7.8	0.0
Twospot flounder	*Bothus robinsi*	7.6	0.0							7.6	0.0
Flounder (genus)	*Cyclopsetta* spp.	7.5	0.0							7.5	0.0
Yellowedge grouper	*Epinephelus flavolimbatus*	6.9	0.0							6.9	0.0
Ray (genus)	*Gymnura* spp.	6.8	0.0							6.8	0.0
Orange filefish	*Aluterus schoepfi*	6.7	0.0							6.7	0.0
Spiny dogfish	*Squalus acanthias*			6.4	0.0					6.4	0.0
Snowy grouper	*Epinephelus niveatus*	6.2	0.0							6.2	0.0
Florida smoothhound shark	*Mustelus norrisi*	6.2	0.0							6.2	0.0
Whitebone porgy	*Calamus leucosteus*	6.0	0.0							6.0	0.0
Striped burrfish	*Chilomycterus schoepfi*	5.5	0.0							5.5	0.0
Gray snapper	*Lutjanus griseus*	4.7	0.0	0.0	0.0					4.8	0.0
Broad flounder	*Paralichthys squamilentus*	4.0	0.0							4.0	0.0
Polkadot batfish	*Ogcocephalus radiatus*	3.9	0.0							3.9	0.0
Gulf bar-eyed tilefish	*Caulolatilus intermedius*	3.8	0.0							3.8	0.0

Table continued

Table 9.—*Continued.*

Common name	Scientific name	Gulf mandatory penaeid (kg)	Gulf mandatory penaeid (%)	South Atlantic mandatory penaeid (kg)	South Atlantic mandatory penaeid (%)	Mandatory rock (kg)	Mandatory rock (%)	Gulf mandatory skimmer (kg)	Gulf mandatory skimmer (%)	Total	Percent total
Jolthead porgy	*Calamus bajonado*	3.1	0.0							3.1	0.0
Swimming crab (genus)	*Callinectes* spp.			3.0	0.0					3.0	0.0
Spotted eagle ray	*Aetobatis narinari*	2.8	0.0							2.8	0.0
Sturgeon (genus)	*Acipenser* spp.			2.3	0.0					2.3	0.0
Atlantic torpedo	*Torpedo nobiliana*	2.1	0.0							2.1	0.0
Lionfish (genus)	*Pterois* spp.	1.8	0.0							1.8	0.0
Lizardfish family	*Synodontidae*	1.7	0.0							1.7	0.0
Streamer searobin	*Bellator egretta*	1.7	0.0							1.7	0.0
Scrawled cowfish	*Lactophrys quadricornis*	1.7	0.0							1.7	0.0
Spotted batfish	*Ogcocephalus pantostictus*	1.5	0.0							1.5	0.0
Honeycomb moray	*Gymnothorax saxicola*	1.4	0.0							1.4	0.0
Blue runner	*Caranx crysos*	1.3	0.0							1.3	0.0
Furcate spider crab	*Stenocionops furcatus*	1.1	0.0							1.1	0.0
Greater Amberjack	*Seriola dumerili*	1.0	0.0							1.0	0.0
Remora	*Remora remora*	1.0	0.0							1.0	0.0
Atlantic midshipman	*Porichthys plectrodon*	0.8	0.0							0.8	0.0
Blackedge moray	*Gymnothorax nigromarginatus*	0.8	0.0							0.8	0.0
Giant hermit crab	*Petrochirus diogenes*	0.7	0.0							0.7	0.0
Bonefish	*Albula vulpes*	0.7	0.0							0.7	0.0
Knobbed porgy	*Calamus nodosus*	0.6	0.0							0.6	0.0
Slipper lobster (genus)	*Scyllarides* spp.	0.6	0.0							0.6	0.0
Lined seahorse	*Hippocampus erectus*	0.3	0.0							0.3	0.0
Yellowtail snapper	*Ocyurus chrysurus*					0.3	0.0			0.3	0.0
Scup	*Stenotomus chrysops*			0.3	0.0					0.3	0.0
Scamp	*Mycteroperca phenax*	0.2	0.0							0.2	0.0
Mutton snapper	*Lutjanus analis*	0.1	0.0							0.1	0.0
Herring (genus)	*Alosa* spp.			0.1	0.0					0.1	0.0
Red grouper	*Epinephelus morio*	0.1	0.0							0.1	0.0
Gray triggerfish,	*Balistes capriscus*	0.0	0.0							0.0	0.0
Total		4,029,401.5	100.0	287,289.1	100.0	66,579.5	100.0	23,334.8	100.0	4,406,604.9	100.0

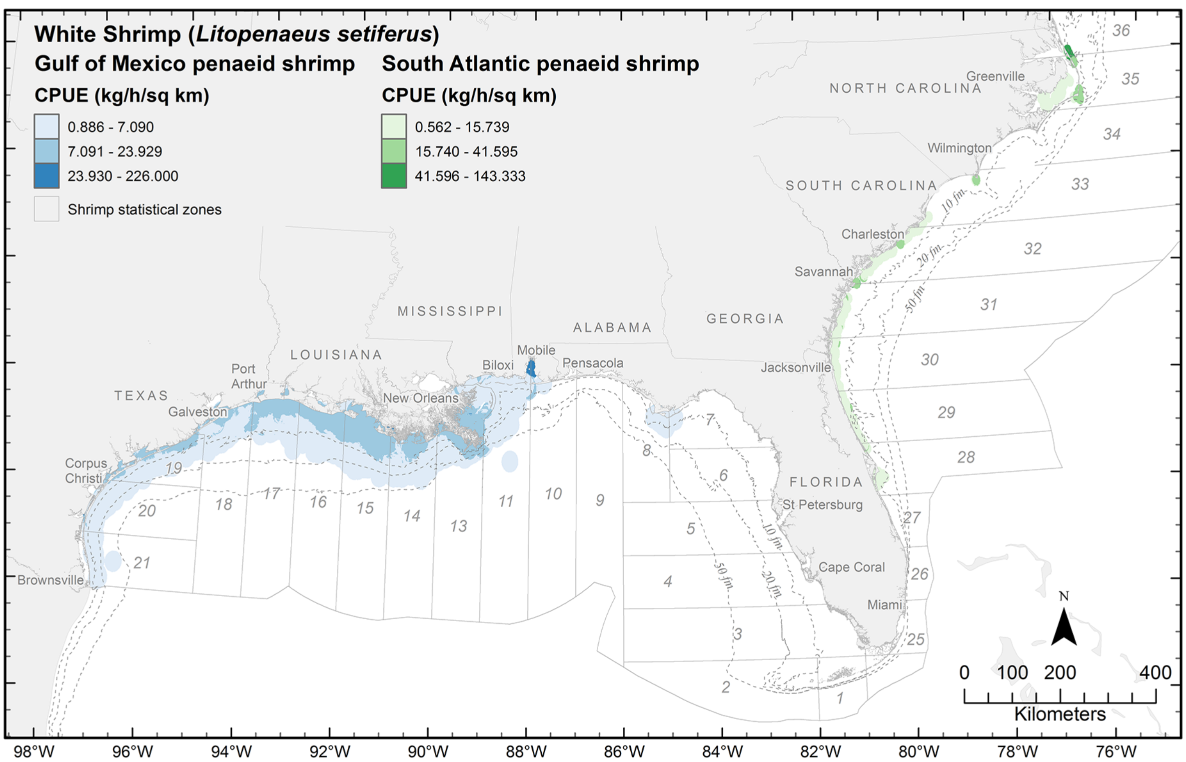

Figure 8.—CPUE density surface for white shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

ters of significantly high CPUE for discarded species were also in these areas and in statistical areas 29 and 30 (Fig. 17).

Extrapolated Species Composition Gulf of Mexico Skimmer Trawl Fishery

In the Gulf of Mexico skimmer trawl fishery, from 591 nets (640 h), fish species comprised 48% (17.6 kg/h) of the total catch (Fig. 2), followed by penaeid shrimp at 46% (16.6 kg/h), crustaceans at 4% (1.5 kg/h), debris at 1% (0.4 kg/h), and invertebrates at 1% (0.2 kg/h). Overall CPUE was 36.5 kg/h.

At the species level (Fig. 6; Table 9), grouped finfish accounted for 33% (11.9 kg/h) of the total catch, followed by brown shrimp at 33% (11.8 kg/h), Atlantic croaker at 11% (3.9 kg/h), white shrimp at 10% (3.5 kg/h), crustaceans at 4% (1.5 kg/h), grouped penaeid shrimp at 3% (1.2 kg/h), cownose ray, *Rhinoptera bonasus,* at 2% (0.6 kg/h), seatrout at 2% (0.5 kg/h),

Table 10.—Selected Gulf of Mexico fish species recorded from all penaeid shrimp nets from bycatch characterization samples, based on mandatory observer coverage from January 2011 through December 2016.

Scientific name	Common name	Extrapolated weight (kg)	Kg/h	CV
Negaprion brevirostris	Lemon shark	0.0	0.0	0.0
Pisces	Fish (superclass)	1,309,967.6	10.3	<0.1
Crustacean	Crustacean	248,077.4	1.9	<0.1
Farfantepenaeus aztecus	Brown shrimp	506,373.2	4.0	<0.1
Litopenaeus setiferus	White shrimp	461,007.8	3.6	<0.1
Micropogonias undulatus	Atlantic croaker	628,606.7	4.9	<0.1
Cynoscion spp.	Seatrout (genus)	217,714.9	1.7	<0.1
Invertebrate	Invertebrate	209,992.9	1.6	<0.1
Stenotomus caprinus	Longspine porgy	123,673.2	1.0	<0.1
Debris	Debris (rocks, logs, etc.)	61,337.3	0.5	<0.1
Farfantepenaeus duorarum	Pink shrimp	135,794.3	1.1	<0.1
Lutjanus campechanus	Red snapper	13,891.9	0.1	<0.1
Penaeus discard	Penaeid shrimp discard (brown,white, pink)	29,471.4	0.2	<0.1
Paralichthys lethostigma	Southern flounder	5,484.3	0.0	<0.1
Scomberomorus maculatus	Spanish mackerel	9,587.8	0.1	<0.1
Rhizoprionodon terraenovae	Atlantic sharpnose shark	15,348.4	0.1	<0.1
Lutjanus synagris	Lane snapper	6,492.6	0.1	<0.1
Sphyrna tiburo	Bonnethead shark	2,945.0	0.0	0.1
Sciaenops ocellatus	Red drum	9,650.8	0.1	0.1
Sicyonia spp.	Rock (genus) shrimp	11,305.7	0.1	0.1
Scomberomorus cavalla	King mackerel	1,244.2	0.0	0.1
Mustelus canis	Smooth dogfish shark	2,108.6	0.0	0.1
Pogonias cromis	Black drum	3,736.6	0.0	0.1
Carcharhinus limbatus	Blacktip shark	2,399.3	0.0	0.1
Sicyonia discards	Rock (discards) shrimp	414.0	0.0	0.1
Rhomboplites aurorubens	Vermilion (B-liner) Snapper	399.4	0.0	0.1
Cynoscion nebulosus	Spotted seatrout	369.1	0.0	0.1
Rachycentron canadum	Ling cobia	228.0	0.0	0.2
Carcharhinus acronotus	Blacknose shark	300.2	0.0	0.2
General sharks	Sharks grouped	229.0	0.0	0.2
Penaeid shrimp (brown,white, pink)	Penaeid shrimp (brown,white, pink)	1,800.7	0.0	0.2
Lutjanus spp.	Snapper (genus)	42.1	0.0	0.2
Sicyonia brevirostris	Brown rock shrimp	106.9	0.0	0.2
Carcharhinus brevipinna	Spinner shark	486.5	0.0	0.2
Carcharhinus isodon	Finetooth shark	278.8	0.0	0.3
Mustelus norrisi	Florida smoothhound shark	6.2	0.0	0.6

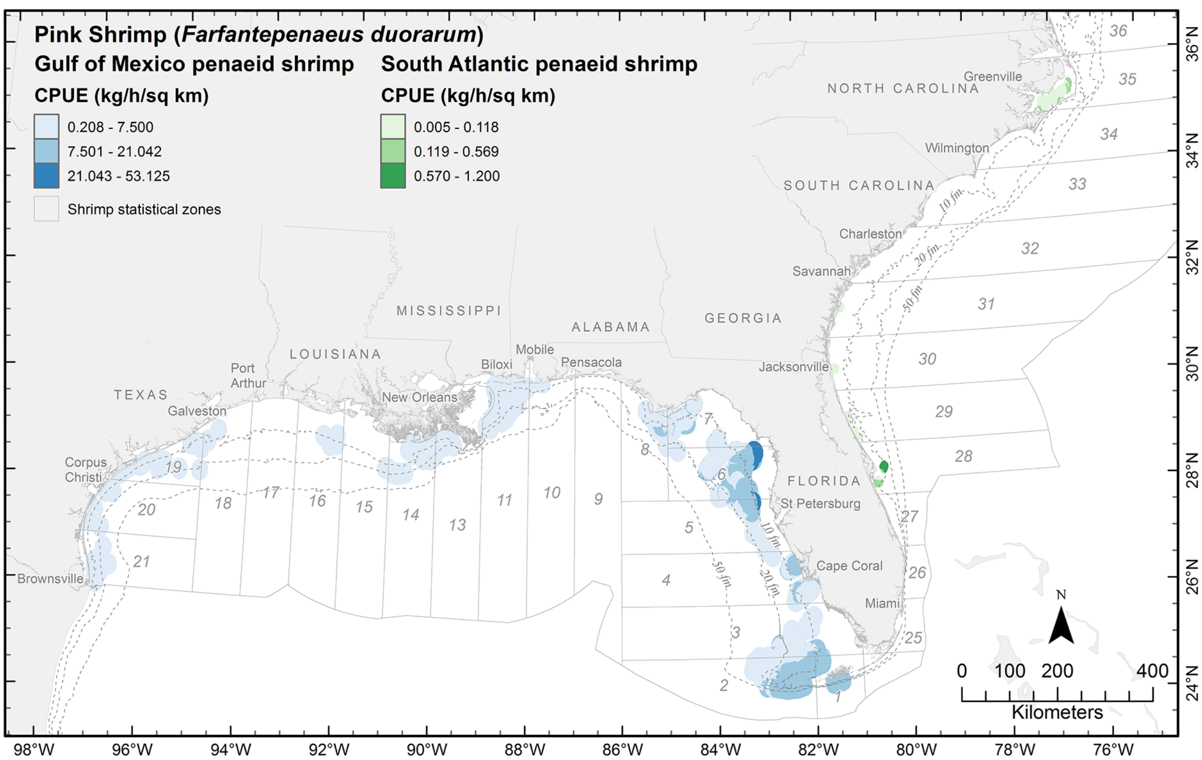

Figure 9.—CPUE density surface for pink shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

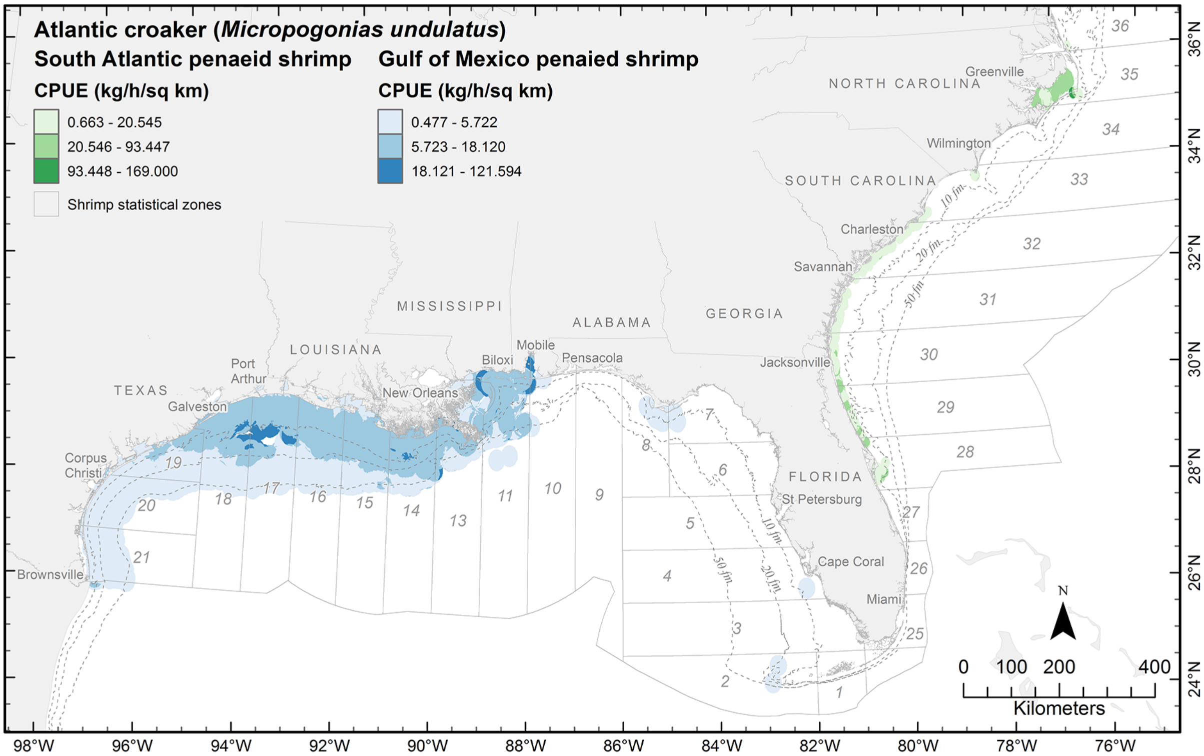

Figure 10.—CPUE density surface for Atlantic croaker by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

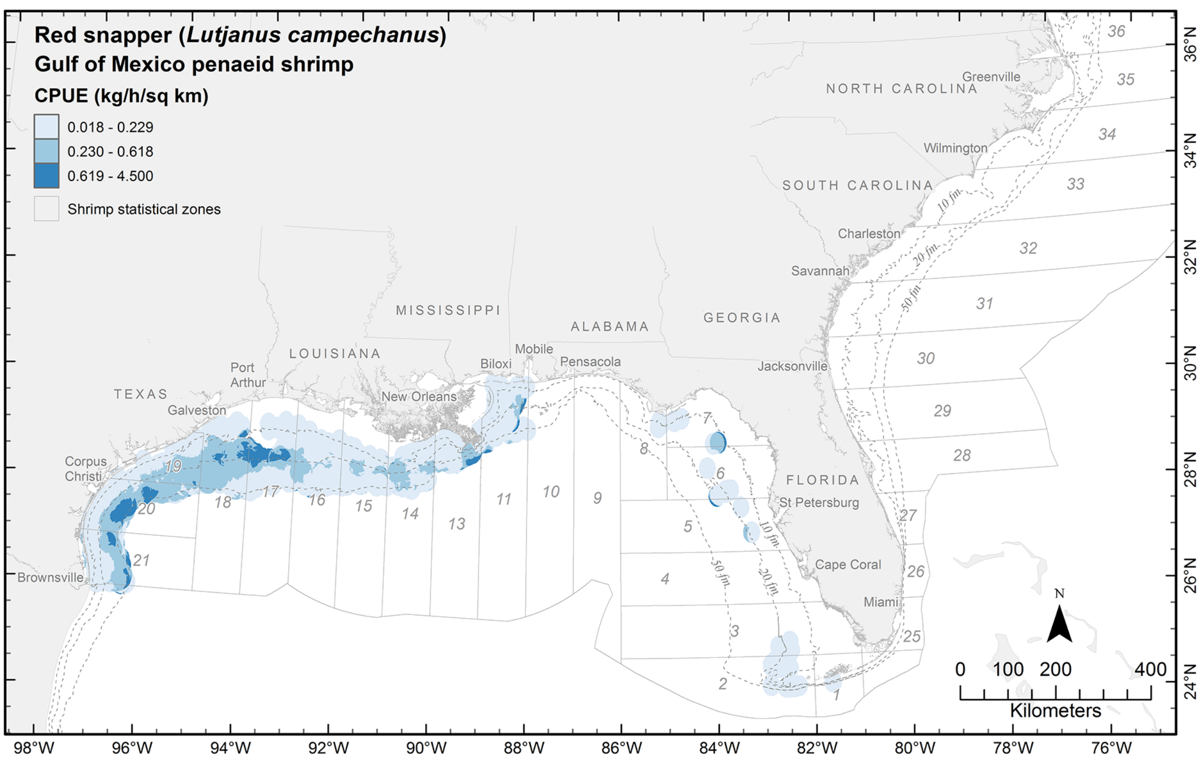

Figure 11.—CPUE density surface for red snapper by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

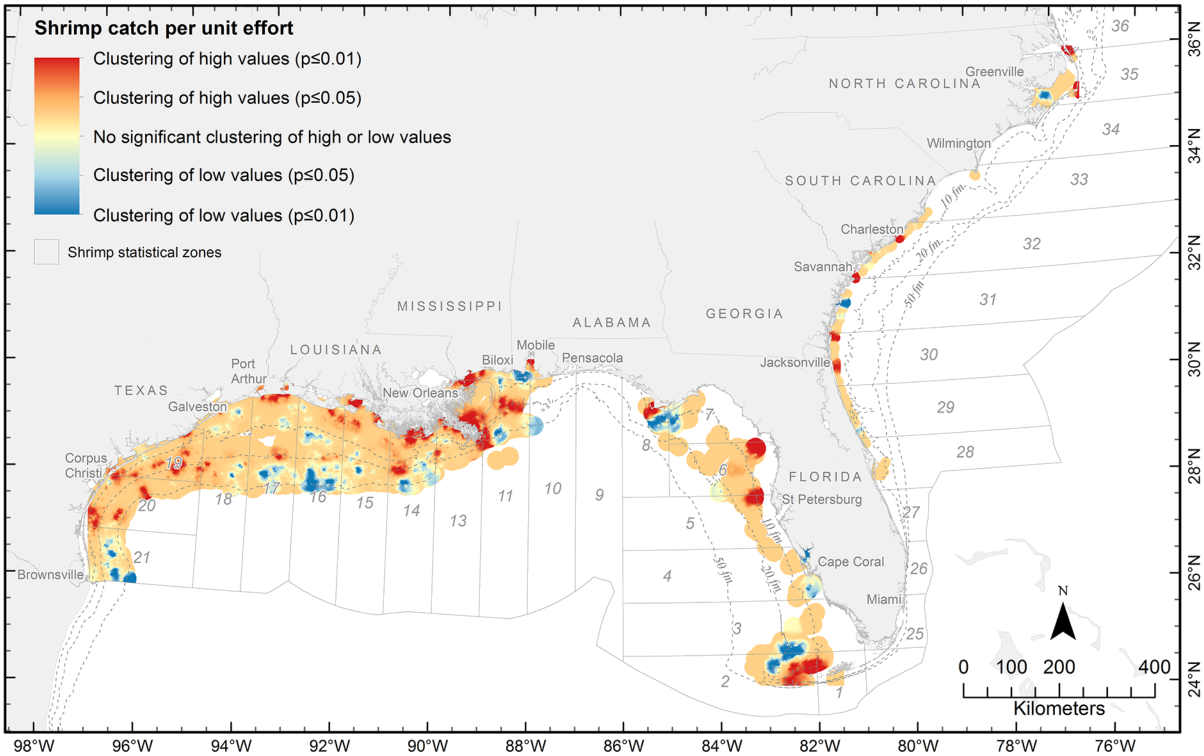

Figure 12.—Hot Spot Analysis for shrimp (penaeid or rock) by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

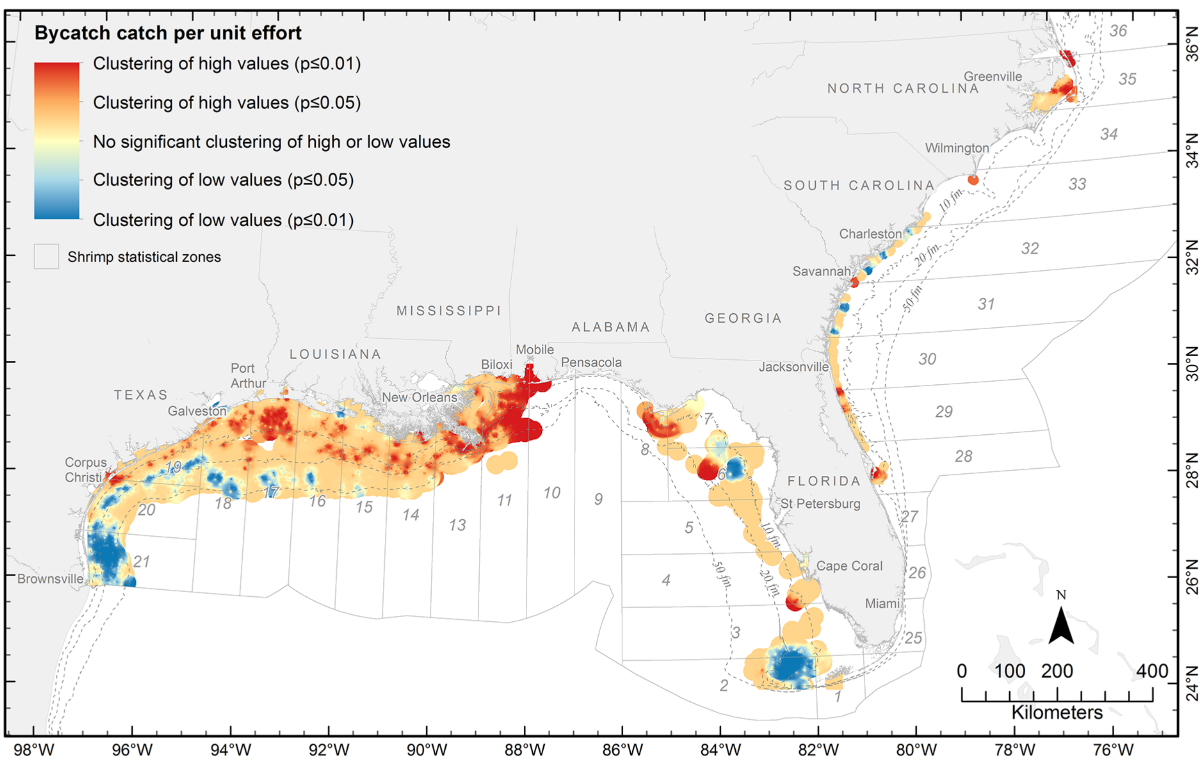

Figure 13.—Hot Spot Analysis for discard (bycatch) species by area and target, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

Table 11.—Selected South Atlantic fish species recorded from all penaeid shrimp nets from bycatch characterization samples, based on mandatory observer coverage from January 2011 through December 2016.

Scientific name	Common name	Extrapolated weight (kg)	Kg/h	CV
Carcharhinus brevipinna	Spinner shark	0.0	0.0	0.0
Carcharhinus falciformis	Silky shark	0.0	0.0	0.0
Mycteroperca microlepis	Gag	0.0	0.0	0.0
Penaeid shrimp (brown,white, pink)	Penaeid shrimp (brown,white, pink)	0.0	0.0	0.0
Litopenaeus setiferus	White shrimp	37,674.2	6.8	<0.1
Pisces	Fish (superclass)	35,601.5	6.4	<0.1
Farfantepenaeus aztecus	Brown shrimp	24,340.3	4.4	<0.1
Micropogonias undulatus	Atlantic croaker	70,947.1	12.8	<0.1
Leiostomus xanthurus	Spot (flat croaker)	29,686.0	5.4	<0.1
Invertebrate	Invertebrate	6,347.3	1.1	<0.1
Cynoscion spp.	Seatrout (genus)	11,666.5	2.1	<0.1
Stellifer lanceolatus	Star drum	10,750.4	1.9	0.1
Carybdeidae	Jellyfish (family)	11,361.6	2.1	0.1
Crustacean	Crustacean	5,235.8	0.9	0.1
Stomolophus meleagris	Cannonball jellyfish	13,979.9	2.5	0.1
Paralichthys dentatus	Summer flounder	856.0	0.2	0.1
Callinectes sapidus	Blue crab	2,912.9	0.5	0.1
Debris	Debris (rocks, logs, etc.)	2,562.1	0.5	0.1
Penaeus discard	Penaeid shrimp discard (brown,white, pink)	1,759.2	0.3	0.1
Brevoortia tyrannus	Atlantic menhaden	2,154.0	0.4	0.1
Rhizoprionodon terraenovae	Atlantic sharpnose shark	1,770.8	0.3	0.1
Centropristis philadelphica	Rock seabass	590.8	0.1	0.1
Cynoscion nothus	Silver seatrout	2,040.2	0.4	0.1
Paralichthys lethostigma	Southern flounder	660.4	0.1	0.1
Scomberomorus maculatus	Spanish mackerel	471.5	0.1	0.1
Menticirrhus saxatilis	Northern kingfish	929.4	0.2	0.1
Sphyrna tiburo	Bonnethead shark	834.3	0.2	0.1
Pomatomus saltatrix	Bluefish	370.4	0.1	0.1
Farfantepenaeus duorarum	Pink shrimp	134.0	0.0	0.1
Cynoscion regalis	Weakfish	2,780.8	0.5	0.1
Menticirrhus americanus	Southern kingfish	8,401.7	1.5	0.1
Scomberomorus cavalla	King mackerel	132.8	0.0	0.2
Sphyrna lewini	Hammerhead scalloped shark	146.4	0.0	0.2
Trachinotus carolinus	Florida pompano	35.9	0.0	0.2
Lutjanus campechanus	Red snapper	1.2	0.0	0.3
Cynoscion nebulosus	Spotted seatrout	19.7	0.0	0.3
Centropristis striata	Black seabass	3.7	0.0	0.4
Carcharhinus limbatus	Blacktip shark	67.9	0.0	0.4
Mustelus canis	Smooth dogfish shark	21.8	0.0	0.4
Centropristis ocyurus	Bank seabass	2.9	0.0	0.5
Stenotomus chrysops	Scup	0.3	0.0	0.5
Pogonias cromis	Black drum	3.3	0.0	0.5
General sharks	Sharks grouped	19.8	0.0	0.6
Carcharhinus isodon	Finetooth shark	2.9	0.0	0.7
Acipenser spp.	Sturgeon (genus)	2.3	0.0	1.0
Rachycentron canadum	Ling cobia	1.0	0.0	1.0
Alosa spp.	Herring (genus)	0.1	0.0	1.0
Sciaenops ocellatus	Red drum	8.2	0.0	1.0

debris at 1% (0.4 kg/h), and invertebrates at 1% (0.2 kg/h). All other species comprised 2% of the total weight (rounding).

CPUE and variance estimates for species selected from all sampled nets during the monitoring period in the Gulf of Mexico skimmer trawl fishery are depicted (Table 13). As expected, CV estimates for commonly caught species were low (≤0.2). Relatively higher CV estimates for several species including, but not limited to, sciaenids and sharks were detected.

Spatial CPUE density (kg/h) plots for several of these species are denoted in Figures 18–23. High-density CPUE for brown shrimp occurred in statistical areas 12 and 13 (Fig. 18), with high CPUE observed in statistical areas 15 and 16 for white shrimp (Fig. 19). High-density CPUE for Atlantic croaker occurred in relatively small concentrated cells throughout statistical areas 10–16 (Fig. 20); seatrout CPUE exhibited a similar pattern as Atlantic croaker although to a lesser degree in density (Fig. 21).

For the Gulf of Mexico skimmer trawl fishery, cluster locations of statistically significant high CPUE for penaeid shrimp were most pronounced in concentrated cells of statistical areas 13–15 (Fig. 22). For all discard (bycatch) species combined (Fig. 23), clusters of significantly high CPUE were most detectable in statistical areas 12–14 in the northwestern Gulf, with significantly lower CPUE occurring in one isolated cell off the coast in statistical area 14.

Protected Species

From January 2011 through December 2016, 158 sea turtles (67 Kemp's Ridley, 47 loggerhead, 22 green, 18 unidentified hardshell, 3 leatherback, and 1 unknown) were captured in otter and skimmer shrimp trawls (Table 14) with most (56%) documented from May to August (Fig. 24). Of the 158 sea turtles, 45 were captured in skimmer trawl nets. The remaining interactions (113) were caught in the otter trawl fishery. Of these, 62% were observed in try nets, 26% in TED-equipped nets (went through the TED grid), and 12% were caught before the TED. Most (82%) of the 158 sea turtles were released alive and conscious.

Other protected species captured aboard shrimp trawlers (Fig. 25) included five Atlantic sturgeon, three of which were released alive. Five smalltooth sawfish were captured, three of the individuals were captured on the same trip and near the same location; two were released alive with one discarded dead. The fate of the remaining two sawfish captured during the study period could not be determined.

Ten sea birds were captured, all of which were discarded dead. Three laughing gulls interacted with skimmer trawl operations. Three brown pelicans and one unidentified pelican were documented in net haul back and retrieval operations aboard shrimp otter trawlers. Two other seabirds and one songbird caught aboard otter trawlers could not be positively identified.

Four bottlenose dolphins, *Tursiops truncatus*, and one unidentified marine mammal (Family Delphinidae) were documented in the Gulf of Mexico shrimp otter trawl fishery. The bottlenose dolphins were entangled in fishing gear, primarily the lazy line, and were all freshly dead at the time of release. The unidentified marine mammal was a previously dead carcass, captured in the try net.

Discussion

Bycatch continues to be one of the most significant and multifaceted issues in fishery management (Hall et al., 2000; Hall and Mainprize, 2005; Gray and Kennelly, 2018). The adverse effects of trawling, on a regional and global scale, in terms of a reduction in biodiversity, shifts in community structure, disruption of the food web, waste, profitability, user conflicts, and mortality of undersized target and nontarget species, inclusive of protected species, have been well documented (Alverson et al., 1994; Hall, 1996; Greenstreet and Rogers, 2000; Hall et al., 2000; Murawski et al., 2000; NRC, 2002; Chuenpagdee et al., 2003; Diamond, 2004; Kumar and Deepthi, 2006). Tropical shrimp trawl fisheries accounted for 27% of global discards as reported by Kelleher (2005). Moreover, an estimated 1.06 million tons of marine fish were discarded in 2002 in U.S. fisheries, ranking the United States one of the highest worldwide relative to discards (Harrington et al., 2005).

Based on findings from the current (2011–16) mandatory observer program, estimated overall CPUE for the shrimp fishery by region was comparable to those reported in Scott-Denton et al. (2012), and similar in some respects to earlier bycatch estimations conducted for the Gulf of Mexico, but markedly different for the South Atlantic (Scott-Denton and Nance, 1996; Nance and Scott-Denton, 1997; Scott-Denton, 2007; NMFS[2,3]; Nance et al.[6]). For the 1992 through 1996 period, overall catch rates were 28.0 kg/h in the Gulf of Mexico, and 27.0 kg/h in the South Atlantic penaeid fisheries (NMFS[3]). Scott-Denton (2007) reported catch rates of 30.8 kg/h in the Gulf of Mexico and 27.7 kg/h in the South Atlantic from 1992 through 2005. Scott Denton et al. (2012) estimated overall CPUE as 34.3 kg/h for the Gulf of Mexico and 51.8 kg/h in the South Atlantic for 2007 through 2010. In this study, CPUE was 31.5 kg/h for the Gulf of Mexico and 52.0 kg/h in the South Atlantic, and relatively consistent with Scott-Denton et al. (2012).

Table 12.—Selected fish species recorded from all rock shrimp nets from bycatch characterization samples, based on mandatory observer coverage from January 2011 through December 2016.

Scientific name	Common name	Extrapolated weight (kg)	Kg/h	CV
Acipenser spp.	Sturgeon (genus)	0.0	0.0	0.0
Alosa spp.	Herring (genus)	0.0	0.0	0.0
General sharks	Sharks grouped	0.0	0.0	0.0
Carcharhinus brevipinna	Spinner shark	0.0	0.0	0.0
Carcharhinus falciformis	Silky shark	0.0	0.0	0.0
Carcharhinus isodon	Finetooth shark	0.0	0.0	0.0
Carcharhinus limbatus	Blacktip shark	0.0	0.0	0.0
Cynoscion nebulosus	Spotted seatrout	0.0	0.0	0.0
Cynoscion regalis	Weakfish	0.0	0.0	0.0
Menticirrhus americanus	Southern kingfish	0.0	0.0	0.0
Mustelus canis	Smooth dogfish shark	0.0	0.0	0.0
Mycteroperca microlepis	Gag	0.0	0.0	0.0
Penaeid shrimp (brown,white, pink)	Penaeid shrimp (brown,white, pink)	0.0	0.0	0.0
Pogonias cromis	Black drum	0.0	0.0	0.0
Rhizoprionodon terraenovae	Atlantic sharpnose shark	0.0	0.0	0.0
Sciaenops ocellatus	Red drum	0.0	0.0	0.0
Sphyrna lewini	Hammerhead scalloped shark	0.0	0.0	0.0
Sphyrna tiburo	Bonnethead shark	0.0	0.0	0.0
Stenotomus chrysops	Scup	0.0	0.0	0.0
Trachinotus carolinus	Florida pompano	0.0	0.0	0.0
Pisces	Fish (superclass)	14,653.9	14.0	<0.1
Sicyonia spp.	Rock (genus) shrimp	23,659.6	22.7	<0.1
Syacium papillosum	Dusky flounder	3,781.6	3.6	0.1
Synodus foetens	Inshore lizardfish	4,685.8	4.5	0.1
Invertebrate	Invertebrate	5,050.6	4.8	0.1
Sicyonia discards	Rock (discards) shrimp	1,097.3	1.1	0.1
Farfantepenaeus aztecus	Brown shrimp	861.2	0.8	0.1
Crustacean	Crustacean	2,592.4	2.5	0.1
Centropristis ocyurus	Bank seabass	785.6	0.8	0.1
Portunus spinicarpus	Longspine swimming crab	3,891.6	3.7	0.1
Centropristis philadelphica	Rock seabass	1,123.7	1.1	0.1
Farfantepenaeus duorarum	Pink shrimp	1,139.1	1.1	0.1
Debris	Debris (rocks, logs, etc.)	1,267.0	1.2	0.1
Portunus gibbesii	Iridescent swimming crab	422.0	0.4	0.2
Penaeus discard	Penaeid shrimp discard (brown,white, pink)	15.1	0.0	0.2
Leiostomus xanthurus	Spot (flat croaker)	806.7	0.8	0.2
Menticirrhus saxatilis	Northern kingfish	81.5	0.1	0.2
Litopenaeus setiferus	White shrimp	16.2	0.0	0.3
Micropogonias undulatus	Atlantic croaker	169.9	0.2	0.3
Paralichthys lethostigma	Southern flounder	47.2	0.0	0.3
Centropristis striata	Black seabass	22.3	0.0	0.3
Paralichthys dentatus	Summer flounder	47.6	0.0	0.4
Cynoscion spp.	Seatrout (genus)	43.8	0.0	0.5
Lutjanus campechanus	Red snapper	0.3	0.0	0.6
Rachycentron canadum	Ling cobia	11.0	0.0	0.7
Pomatomus saltatrix	Bluefish	4.3	0.0	1.0
Scomberomorus cavalla	King mackerel	2.5	0.0	1.0
Scomberomorus maculatus	Spanish mackerel	1.5	0.0	1.0
Cynoscion nothus	Silver seatrout	2.4	0.0	1.0

In comparison to earlier studies on the magnitude of bycatch in southeastern shrimp fishery, more recent years data depict declining trends in the amount of nontarget catch. Alverson et al. (1994) reported a discard to landing ratio of 10.30 and 8.00 for the Gulf of Mexico and South Atlantic shrimp fisheries, respectively. Harrington et al. (2005) and Kelleher (2005) revealed lower ratios in more recent assessments, although estimation methods varied. Scott-Denton (2007) calculated discards to landings ratios of 5.18 and 3.20 for the Gulf of Mexico and South Atlantic, respectively, from 1992 through 2005; slightly higher than estimates of 4.56 and 2.95 reported by Harrington et al. (2005) for 1992 through 1996 for the same areas. Scott-Denton et al. (2012) reported substantially lower bycatch ratios at 2.47 in the Gulf of Mexico and 4.25 in the South Atlantic. In the current study, for these same areas, bycatch ratios were 2.54 and 3.50, respectively. While these ratios are similar to the rates observed during 2007–10, both are considerably lower than the bycatch ratios documented in the pre-TED, pre-BRD, high-effort years (e.g., Alverson et al. (1994) reported bycatch to shrimp ratio for the Gulf penaeid shrimp fishery was 10.3).

Scott-Denton et al. (2012) attribute these differences for the Gulf of Mexico by examining percent composition by species categories that reflect a rise in shrimp CPUE and a substantial decline in shrimp effort (Galla-

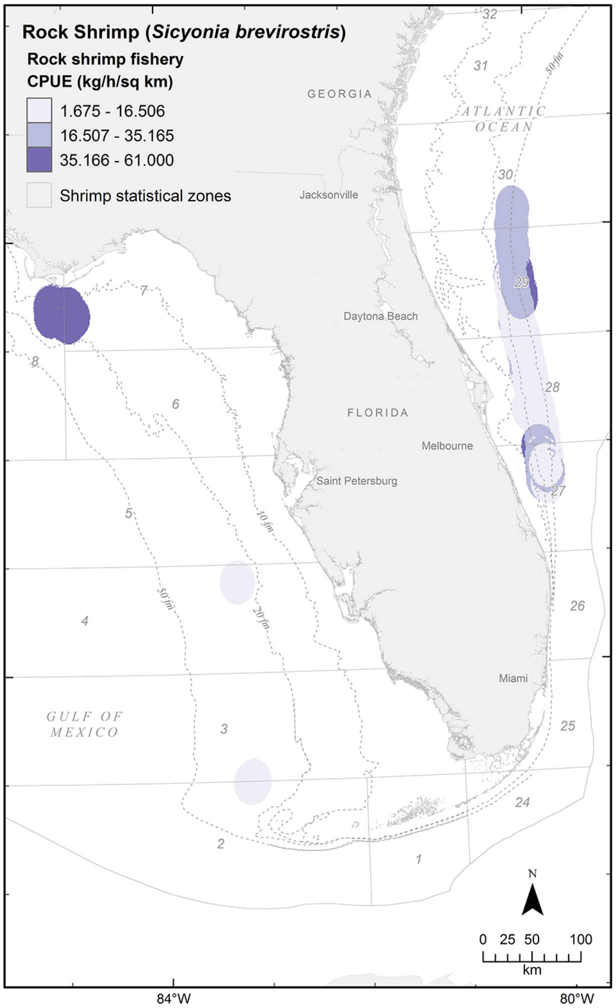

Figure 14.—CPUE density surface for rock shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern rock shrimp fishery from January 2011 through December 2016.

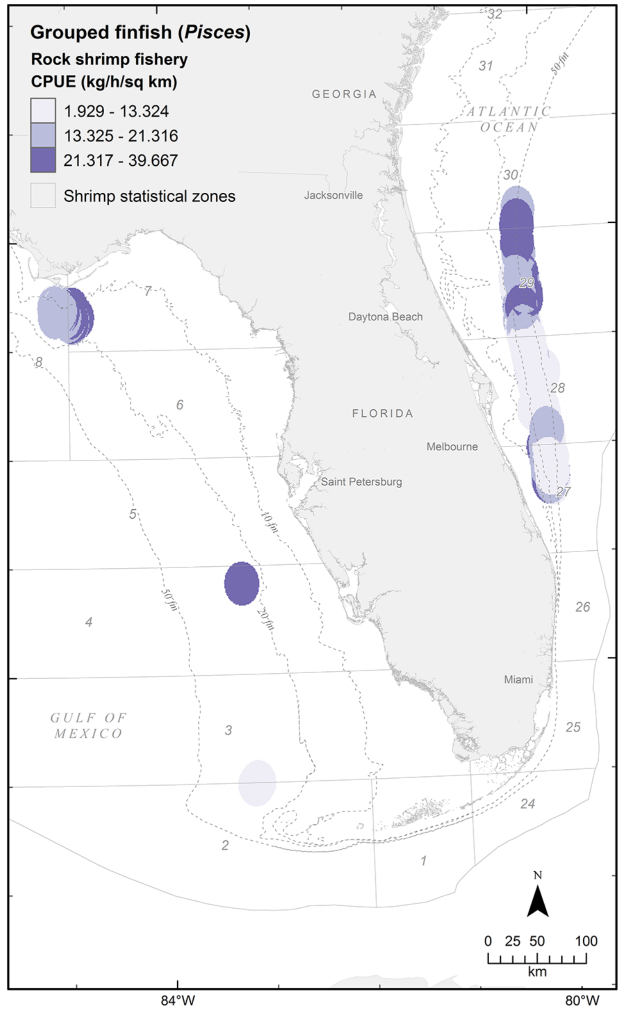

Figure 15.—CPUE density surface for grouped finfish by area and target, based on mandatory observer coverage of the U.S. southeastern rock shrimp fishery from January 2011 through December 2016.

way et al., 2003; Nance et al., 2008). Based on Gulf of Mexico shrimp landings and effort data from 1981 through 2016 (Hart[15]), an increasing trend in shrimp CPUE has been observed since 2002. Conversely, shrimp effort has been decreasing since 2002 as well as the number of federally permitted vessels (SERO[9]). And finally, the mandate for TED's and BRD's over the past decades has reduced primarily large bycatch (e.g., sharks, and many other, but not all, fish and sea turtles).

Helies and Jamison[8] reported that the lower finfish to shrimp ratios in the Gulf of Mexico may be due to basic weight differences between shrimp and fish taken currently in the fishery as compared with earlier years. The authors conclude that an increase abundance in nearshore sciaenids since 2002, resulting from decreases in shrimp fishing effort, combined with more effective exclusion by new BRD designs may have brought about the change in finfish to shrimp ratios in recent years.

In the South Atlantic from 1992 through 1996, estimated percent catch composition for finfish species was at 51%, and 18% for commercial shrimp species (NMFS[3]). Scott-Denton (2007) calculated finfish species at 47% (13.0 kg/h), followed by penaeid shrimp at 24% (6.6 kg/h) for the 1992 through 2005 voluntary observer program. Scott-Denton et al. (2012), in the 2007 through 2010 mandatory observer program, reported that finfish accounted for 60% (31.2 kg/h) of the catch with penaeid shrimp at 19% (9.9 kg/h), which revealed an increase in shrimp CPUE and over a two-fold increase in finfish CPUE. This is similar as in the current study with finfish compris-

[15]Hart, R. 2017. Unpubl. data on file at National Marine Fisheries Service, NOAA, Galveston Laboratory, Galveston, TX 77551

Table 13.—Selected Gulf of Mexico fish species recorded from all skimmer shrimp nets from bycatch characterization samples, based on mandatory observer coverage from January 2011 through December 2016.

Scientific name	Common name	Extrapolated weight (kg)	Kg/h	CV
General sharks	Sharks grouped	0.0	0.0	0.0
Carcharhinus acronotus	Blacknose shark	0.0	0.0	0.0
Carcharhinus brevipinna	Spinner shark	0.0	0.0	0.0
Carcharhinus isodon	Finetooth shark	0.0	0.0	0.0
Farfantepenaeus duorarum	Pink shrimp	0.0	0.0	0.0
Lutjanus campechanus	Red snapper	0.0	0.0	0.0
Lutjanus spp.	Snapper (genus)	0.0	0.0	0.0
Mustelus canis	Smooth dogfish shark	0.0	0.0	0.0
Mustelus norrisi	Florida smoothhound shark	0.0	0.0	0.0
Negaprion brevirostris	Lemon shark	0.0	0.0	0.0
Rhomboplites aurorubens	Vermilion (B-liner) snapper	0.0	0.0	0.0
Sicyonia spp.	Rock (genus) shrimp	0.0	0.0	0.0
Sicyonia brevirostris	Brown rock shrimp	0.0	0.0	0.0
Sicyonia discards	Rock (discards) shrimp	0.0	0.0	0.0
Stenotomus caprinus	Longspine porgy	0.0	0.0	0.0
Farfantepenaeus aztecus	Brown shrimp	7,575.0	11.8	<0.1
Pisces	Fish (superclass)	8,163.3	12.8	<0.1
Micropogonias undulatus	Atlantic croaker	2,473.6	3.9	<0.1
Cynoscion spp.	Seatrout (genus)	343.1	0.5	0.1
Crustacean	Crustacean	986.9	1.5	0.1
Litopenaeus setiferus	White shrimp	2,249.4	3.5	0.1
Cynoscion nebulosus	Spotted seatrout	65.2	0.1	0.1
Paralichthys lethostigma	Southern flounder	48.2	0.1	0.2
Invertebrate	Invertebrate	137.7	0.2	0.2
Penaeid shrimp (brown,white, pink)	Penaeid shrimp (brown,white, pink)	780.4	1.2	0.2
Scomberomorus maculatus	Spanish mackerel	69.4	0.1	0.2
Debris	Debris (rocks, logs, etc.)	279.7	0.4	0.2
Penaeus discard	Penaeid shrimp discard (brown,white, pink)	43.9	0.1	0.3
Carcharhinus limbatus	Blacktip shark	48.1	0.1	0.4
Rhizoprionodon terraenovae	Atlantic sharpnose shark	26.2	0.0	0.4
Pogonias cromis	Black drum	32.5	0.1	0.6
Sciaenops ocellatus	Red drum	6.1	0.0	0.6
Sphyrna tiburo	Bonnethead shark	1.6	0.0	0.7
Scomberomorus cavalla	King mackerel	0.3	0.0	0.8
Rachycentron canadum	Ling cobia	0.2	0.0	0.9
Lutjanus synagris	Lane snapper	3.8	0.0	1.0

ing 63% (32.8 kg/h) of the catch and penaeid shrimp at 22% (11.6 kg/h). A very plausible explanation for the increase in finfish CPUE may be attributable to different fishing patterns between the volunteer and mandatory observer programs resulting in shifts of the dominant species observed.

In the South Atlantic rock shrimp fishery, Scott-Denton et al. (2012) reported an increase in percent composition of rock shrimp at 41% (29.0 kg/h) as compared with the 2001 to 2006 period with rock shrimp comprising 19% (8.7 kg/h) of the catch (SAFMC[16]). During the current study, vessels that fished in both the Gulf and South Atlantic with rock shrimp accounting for 37% (23.7 kg/h), a slight decline and possibly attributed to areas fished.

Scott-Denton et al. (2012) characterized shifts in dominant species and rates for longspine porgy, *Stenotomus caprinus*, and Atlantic croaker during voluntary vs. mandatory programs. In the voluntary program (1992 through 2005), longspine porgy and Atlantic croaker comprised the largest percentage of the overall catch in the Gulf of Mexico with estimated CPUE (kg/h) at 2.8 and 2.1, respectively (Scott-Denton, 2007). Scott-Denton et al. (2012) reported CPUE (kg/h) for Atlantic croaker at 5.4 and 1.4 for longspine porgy in the mandatory program. Scott-Denton et al. (2012) attributed this shift in dominant species and rates to the mandatory nature of vessel selection and areas fished (nearshore vs. offshore). In the voluntary study, a large number of vessel operators who participated fished primarily in offshore waters (Scott-Denton, 2007). Similarly, with respect to the dominant species in South Atlantic from 1992 through 2005, CPUE (kg/h) for Atlantic croaker was 3.6 and 3.4 for spot (Scott-Denton, 2007). In the mandatory program, CPUE (kg/h) was substantially higher for Atlantic croaker at 12.5 and comparable for spot at 3.8 (Scott-Denton et al., 2012). This is similar to the current assessment with CPUE (kg/h) for Atlantic croaker at 12.8 and slightly higher for spot at 5.4

Scott-Denton et al. (2012) reported that while several species listed as overfished or undergoing overfishing did not comprise a large percentage by weight of the total bycatch, the number of individuals discarded combined with the amount of annual shrimp effort exerted may be reason for significant consideration. Analysis of data from three observer programs and federal and state resource surveys was used to provide annual estimates for selected species of finfish bycatch in the commercial Gulf of Mexico shrimp trawl fishery (Nichols et al.[1,17] and Nichols and Pellegrin[18]). The findings revealed that while the magnitude of species common in shrimp trawl bycatch was not unpredicted, the projected estimate for the less frequently encountered species such as red snapper, king mackerel, *Scomberomorus cavalla*, and Spanish mackerel, *Scomberomorus maculatus*, was similar to, or exceeded, the recreational take (Nichols et al.[1]). Red snapper, one of the most high-profile species, accounted for approximately 0.3% of the total catch by weight in the Gulf of Mexico in 1992 through 2005 (Scott-Denton, 2007). This estimate remained the same (0.3%) as reported by both Scott-Denton et al. (2012) and the current study (0.3%). This is further supported by Helies and Jamison[8], who inferred that while there have been increasing trends in the abundance of Atlantic croaker and inshore lizardfish in recent years, abundance levels for longspine porgy and juvenile red

[16]SAFMC. 2008. Observer Coverage of the US Southeastern Atlantic Rock Shrimp Fishery, September 2001 through September 2006 Preliminary Report. South Atl. Fish. Manage. Counc., Charleston, S.C. (avail. at http://www.safmc.net).

[17]Nichols, S., A. Shah, G. J. Pellegrin, and K. Mullin. 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the U.S. Gulf of Mexico. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Pascagoula, Miss., 22 p.

[18]Nichols, S., and G. J. Pellegrin, Jr. 1992. Revi sion and update of estimates of shrimp fleet bycatch 1972–1991. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Pascagoula, Miss., 17 p.

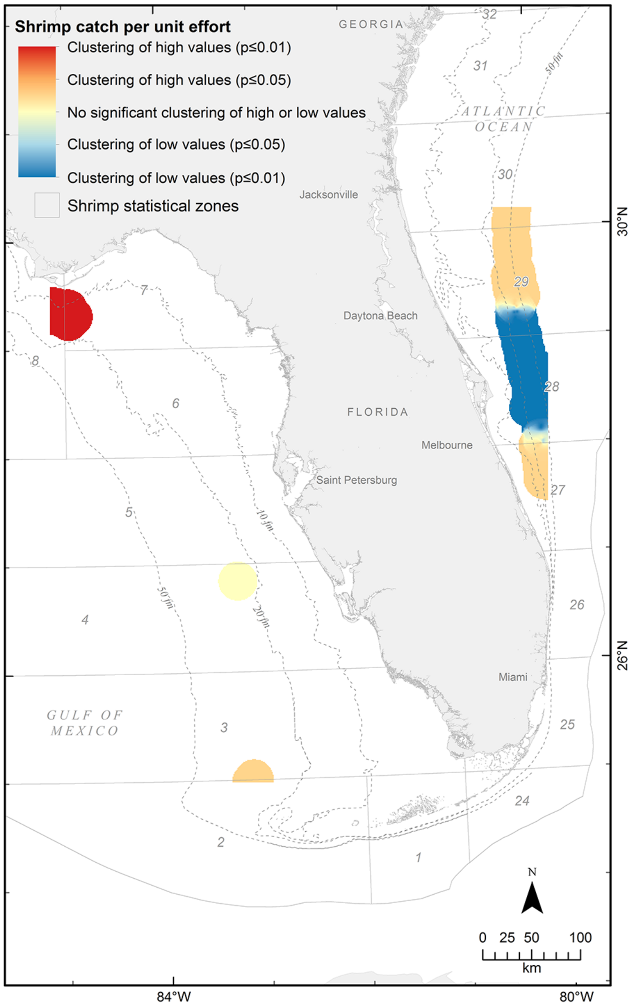

Figure 16.—Hot Spot Analysis for rock shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern rock shrimp fishery from January 2011 through December 2016.

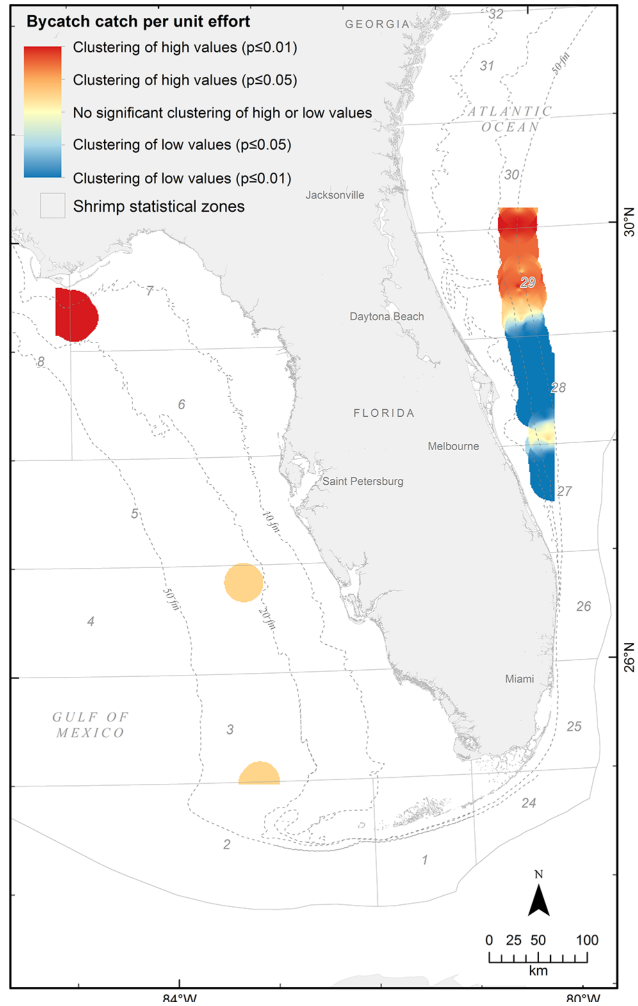

Figure 17.—Hot Spot Analysis for discard (bycatch) species by area and target, based on mandatory observer coverage of the U.S. southeastern rock shrimp fishery from January 2011 through December 2016.

snapper have remained relatively consistent.

Recent literature (Gazey et al., 2008; Gallaway et al., 2009; Gazey et al., 2014; Gallaway et al., 2017; SEDAR 52[19]) addresses current estimates of red snapper life history, mortality, and the effects of trawl mortality on the red snapper stock. These authors agree that shrimp trawl bycatch consists mainly of age 0 and age 1 red snapper, with a minimal number of age 2 fish. Gallaway et al. (2017) concluded that natural mortality of young red snapper is much higher (four times) than was thought to be the case in the late 1980's and early 1990's with bycatch mortality estimated to be only 4%. It was suggested that life history attributes of those species that have not increased in abundance in response to decreased shrimp and bycatch reduction efforts be examined to provide possible explanations.

Mandatory observer coverage for the skimmer trawl fishery began in 2012 (Pulver et al., 2012: Scott-Denton et al., 2014) and has continued at varying levels of coverage to increase the amount of information available on the fishery, particularly to document sea turtle interactions. A total of 45 sea turtles were captured ranging from a high number (24) in 2011 to a low (3) in 2016; however, coverage levels by year have declined primarily due to vessel compliance (Scott-Denton et al., 2014).

Bycatch became a major management issue resulting from the rapid growth in fisheries worldwide, increasing user competition, and the rise of environmental issues and subsequent global efforts to minimize the

[19]SEDAR (Southeast Data, Assessment and Review) 52. 2018. Gulf of Mexico Red Snapper Stock Assessment Report. SEDAR, Charleston, South Carolina.

Table 14.—Sea turtle interactions by net type, species, capture condition, and project for all tows based mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

	Gulf mandatory penaeid			South Atlantic mandatory penaeid			Mandatory rock			Gulf mandatory skimmer			Total		
Project	Total	Condition	Total tow time (h)	Total	Condition	Total tow time (h)	Total	Condition	Total tow time (h)	Total	Condition	Total tow time (h)	Species interactions	Sea turtle condition	Tow time (h)
Standard Net	36		102,443.1	7		5,111.0			681.4	45		3,152.8	88		111,388.4
Green	11			1						4			16		
Alive		2			1						1			4	
Fresh dead/comatose/unresponsive		9									2			11	
Previously dead											1			1	
Kemp's ridley	15			1						36			52		
Alive		5			1						33			39	
Fresh dead/comatose/unresponsive		10									2			12	
Previously dead											1			1	
Leatherback	3												3		
Alive		2												2	
Fresh dead/comatose/unresponsive		1												1	
Loggerhead				1						4			5		
Alive					1						4			5	
Unidentified hardshell	7			4						1			12		
Alive		2			3						1			6	
Fresh dead/comatose/unresponsive		3												3	
Unknown		2			1									3	
Try Net	46		31,441	21		4,342	3		284				70		36,067
Green	5			1									6		
Alive		5			1									6	
Kemp's ridley	9			6									15		
Alive		9			6									15	
Loggerhead	25			14			3						42		
Alive		24			14			3						41	
Fresh dead/comatose/unresponsive		1												1	
Unidentified hardshell	6												6		
Alive		5												5	
Unknown		1												1	
Unknown	1												1		
Unknown		1												1	
Total	82			28			3			45			158		

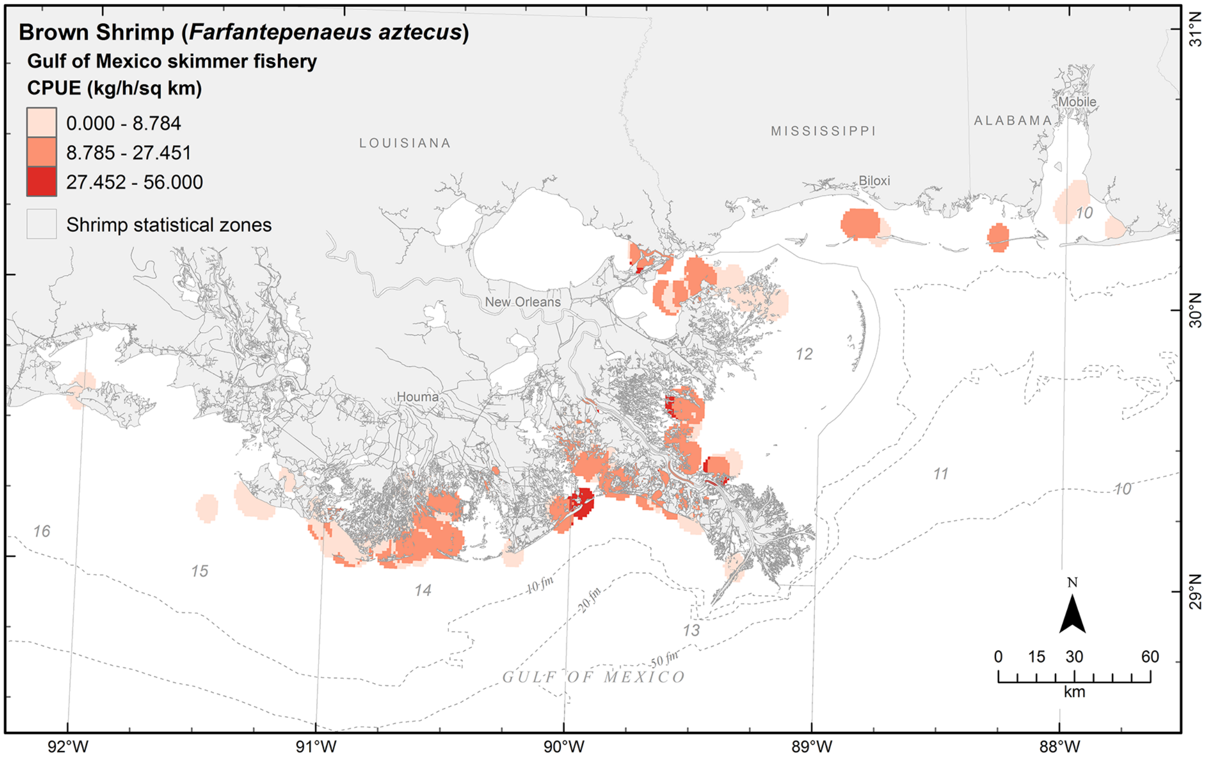

Figure 18.—CPUE density surface for brown shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

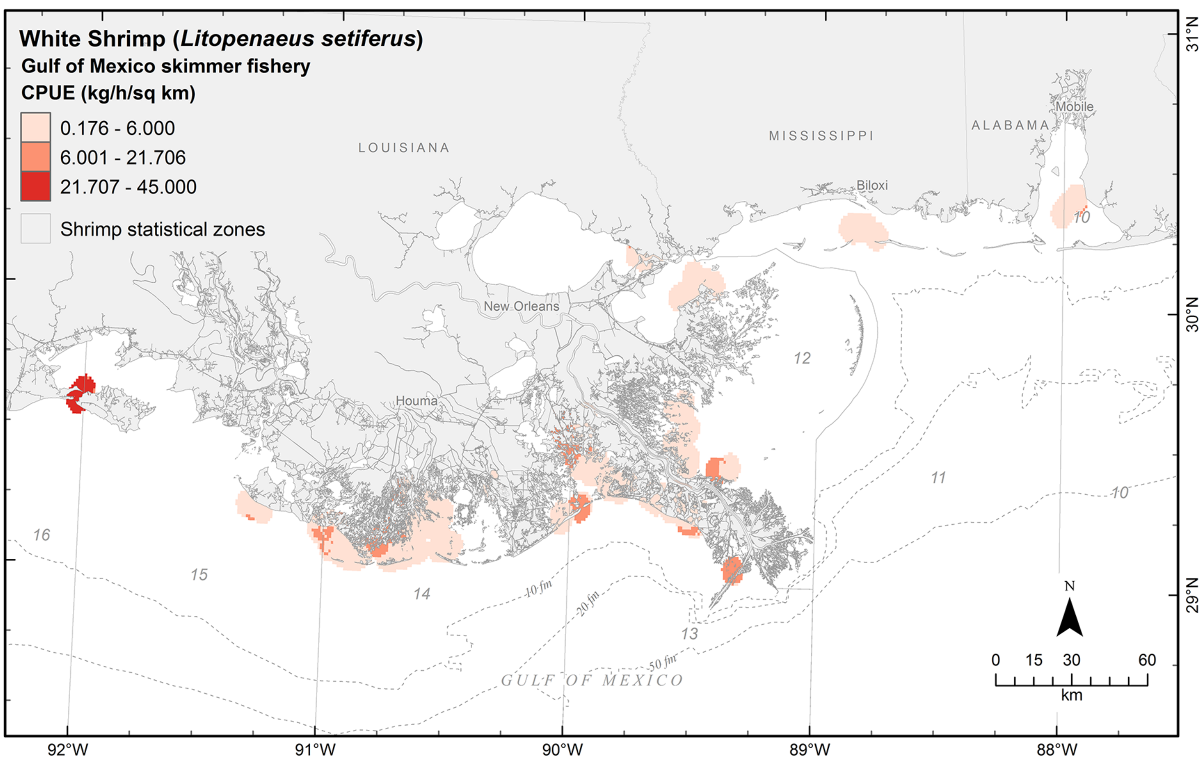

Figure 19.—CPUE density surface for white shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

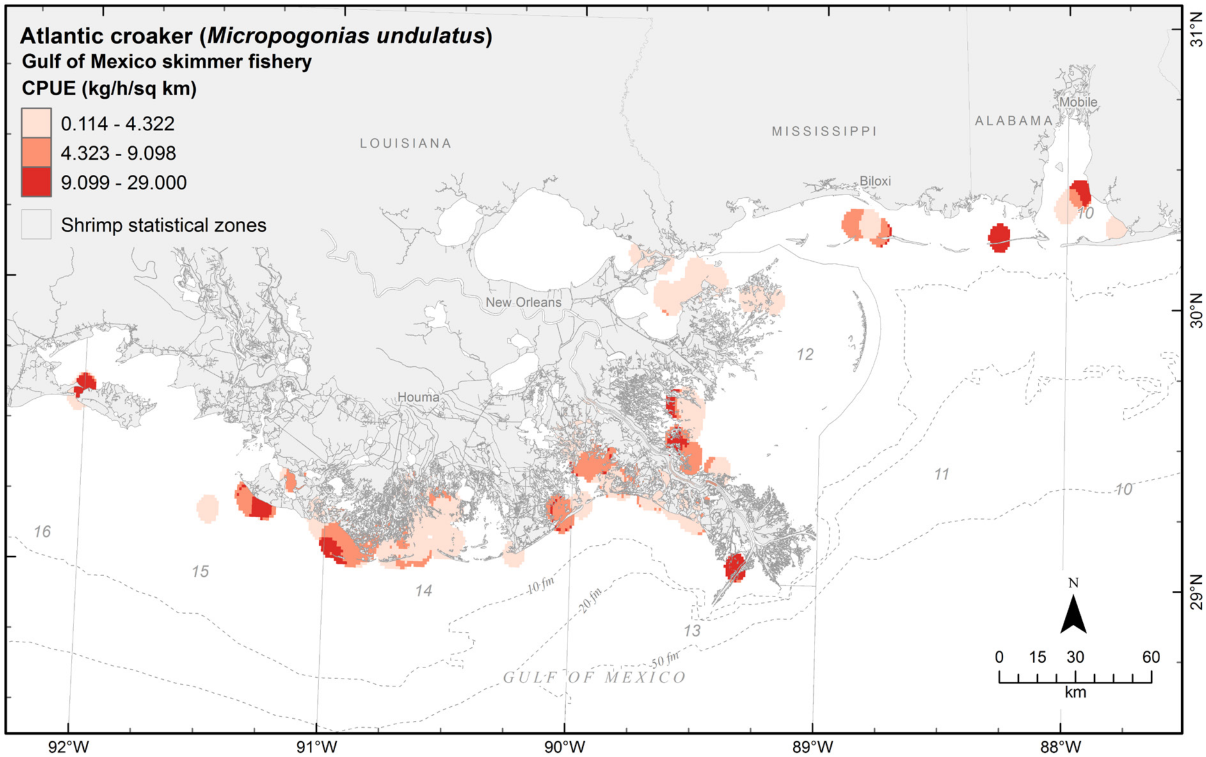

Figure 20.—CPUE density surface for Atlantic croaker by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

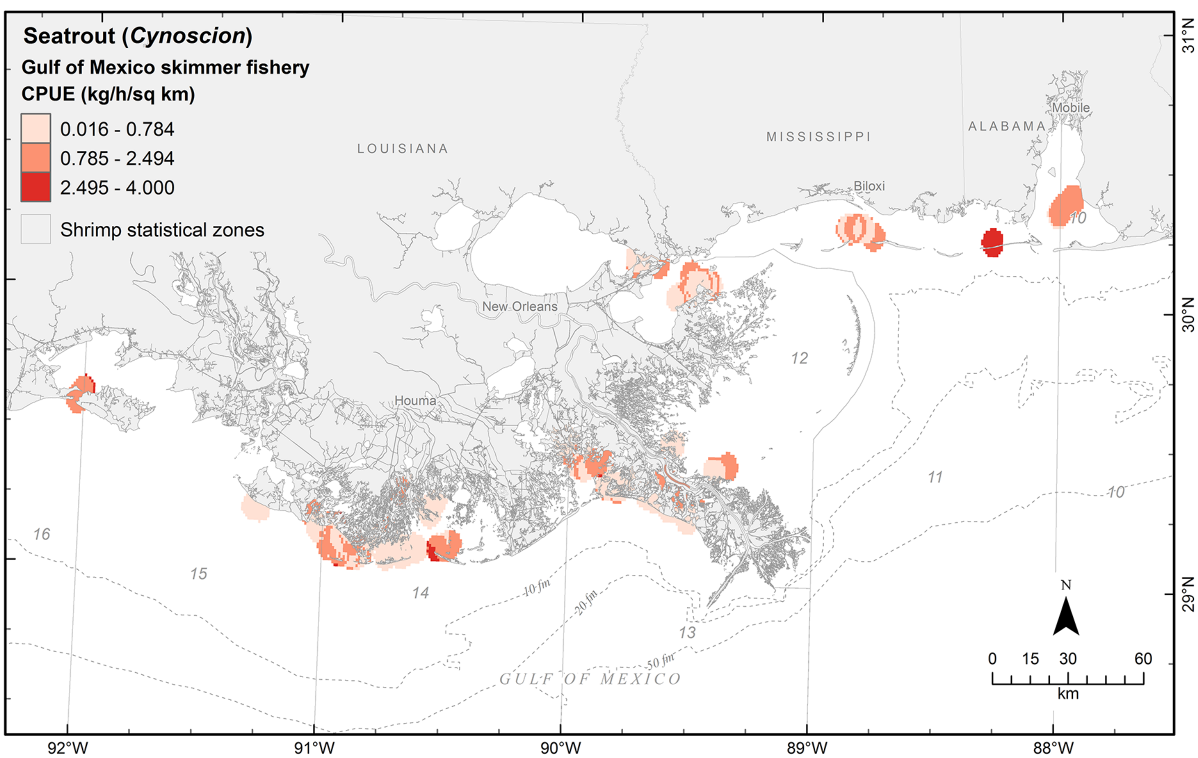

Figure 21.—CPUE density surface for seatrout by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

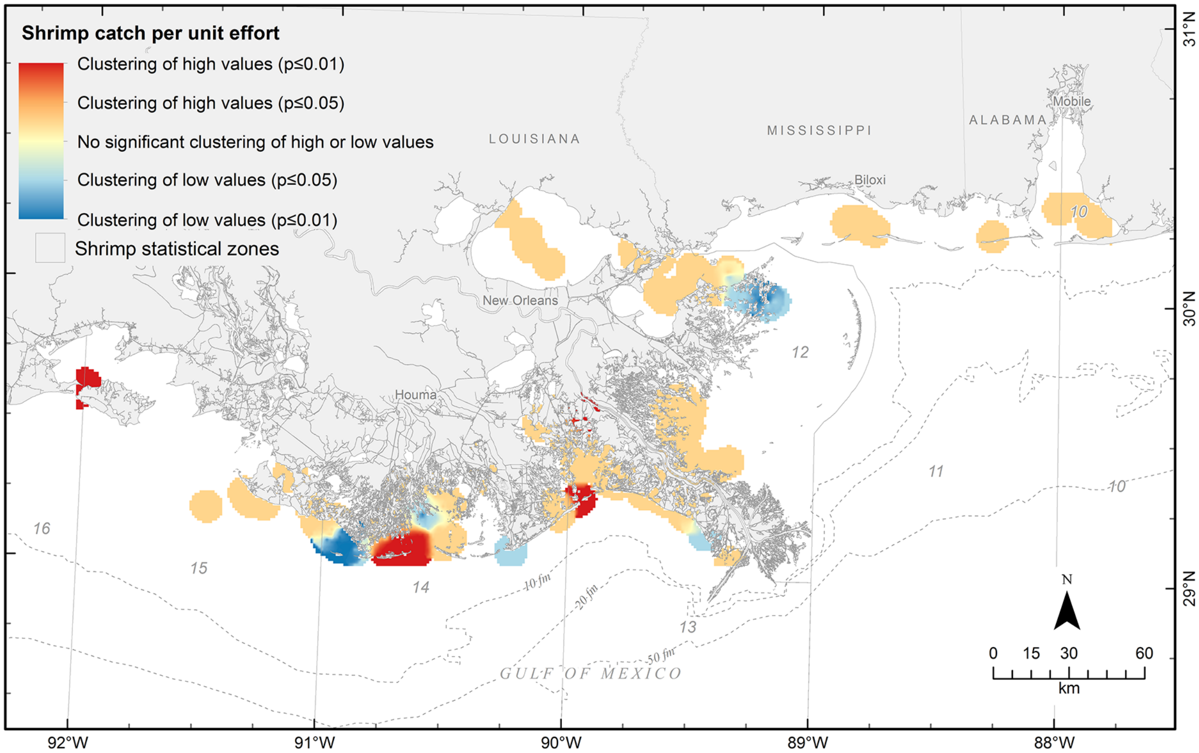

Figure 22.—Hot Spot Analysis for shrimp by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

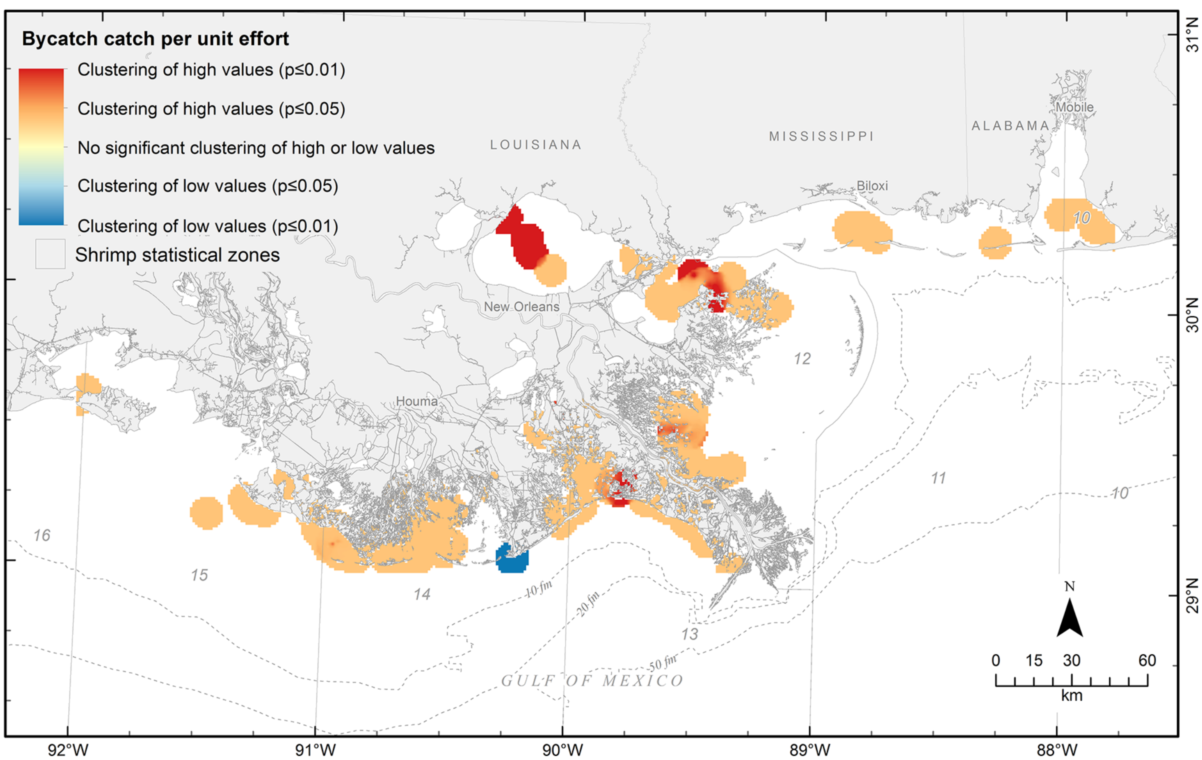

Figure 23.—Hot Spot Analysis for discard (bycatch) species by area and target, based on mandatory observer coverage of the U.S. southeastern skimmer trawl shrimp fishery from January 2011 through December 2016.

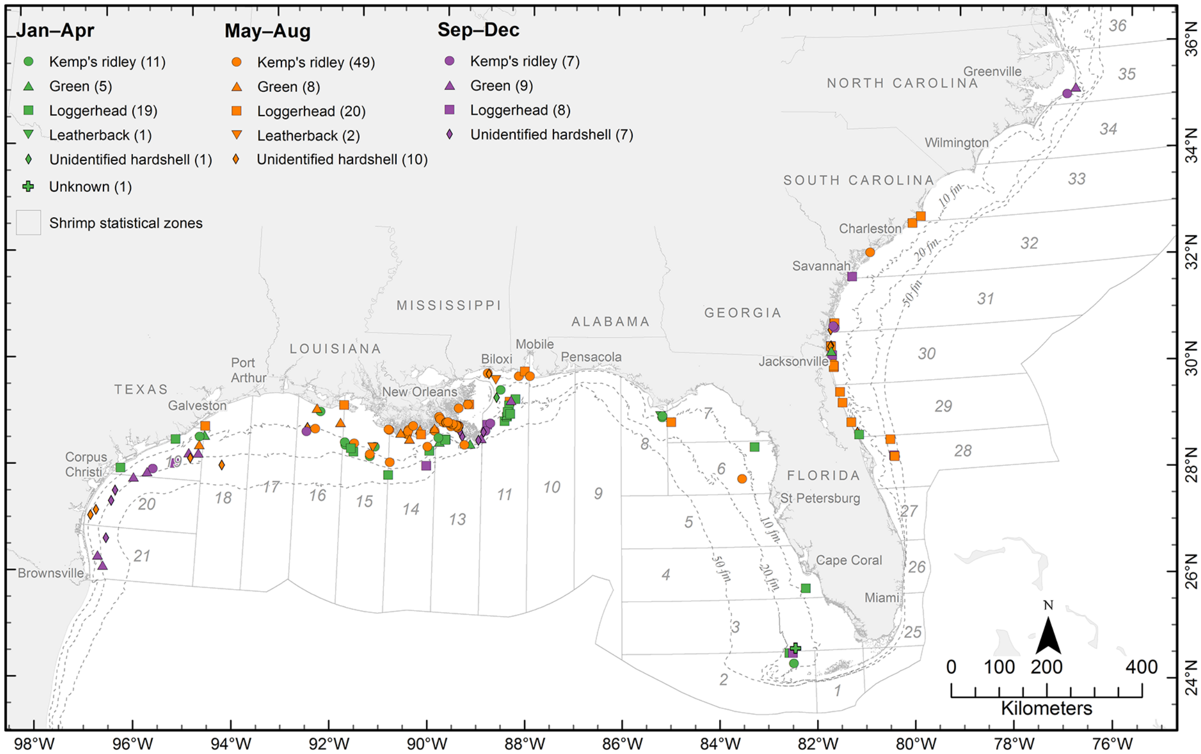

Figure 24.—Locations and dates of sea turtle captures, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

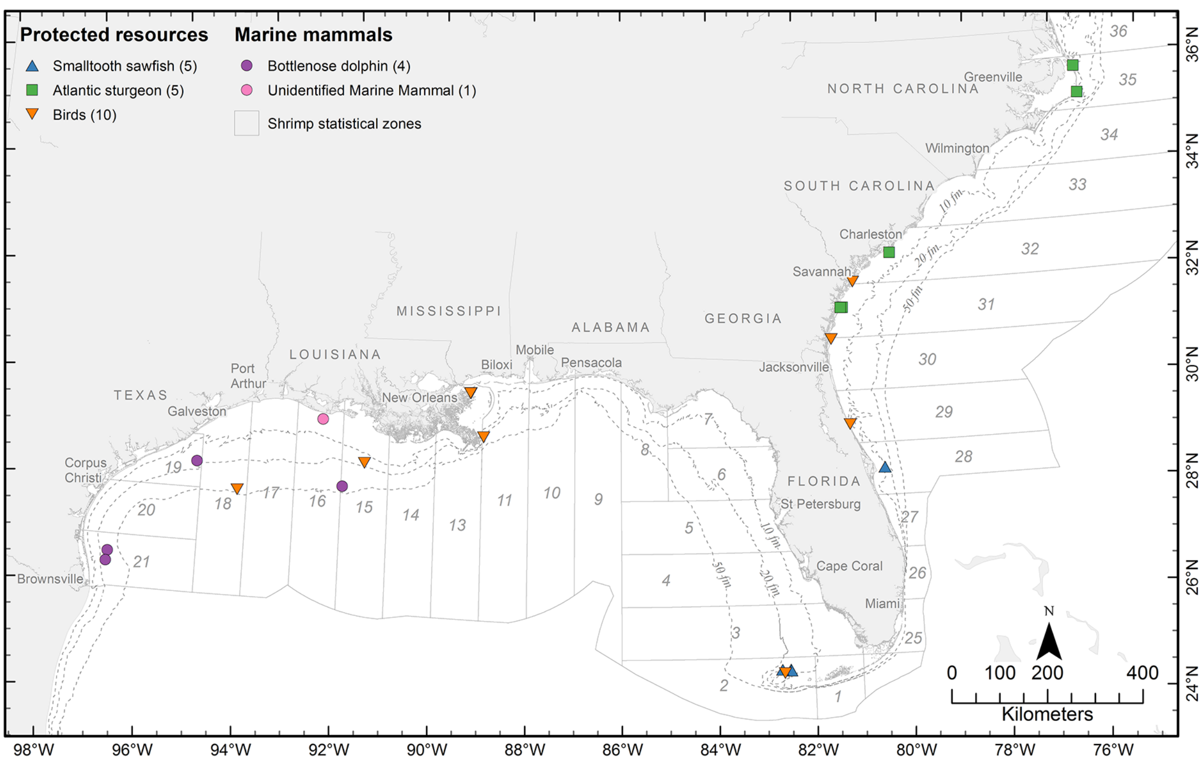

Figure 25.—Locations of protected species captures, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from January 2011 through December 2016.

effects of commercial fishing operations on protected species (Alverson and Hughes, 1996).

In the southeastern United States, the incidental capture of endangered and threatened sea turtles was brought to the forefront primarily by a TED study conducted by Henwood and Stunz (1987) who estimated sea turtle catch rates to be more than 10,000 sea turtles from 1973 to 1984. Sea turtle mortality resulting from trawling operations in the southeastern shrimp fishery was determined to be the major source of man-induced mortality on loggerhead and Kemp's ridley sea turtles, resulting in higher mortality than in all other fisheries combined (Magnuson et al., 1990). Since the 1980's, substantial progress has been made to reduce sea turtle interactions, primarily through the required use of TED's and subsequent modifications (Epperly et al., 2002; Epperly and Teas, 2002) as well as other time and area management strategies. Finkbeiner et al. (2011) examined mean annual sea turtle bycatch and mortality for the U.S. Gulf and South Atlantic shrimp fishery pre-regulation (pre-2003) and post-regulation (post-2003 TED enlargements) and reported 340,500 and 133,400 sea turtles, respectively, acknowledging the reduction was not solely due to TED regulations but in large part due to the decrease in fleet effort.

Advances in TED and BRD research and design as well as management efforts have been, and are being, evaluated for other protected species and finfish stocks as well. TED's exclude large fish such as blacknose sharks, *Carcharhinus acronotus*, (Raborn et al., 2012). While BRD's do not reduce red snapper bycatch to any appreciable degree, they do reduce overall total finfish bycatch by 30% (Helies and Jamison[20]). Further, Amendment 14 to the Gulf of Mexico Fishery Council's (GMFMC) Shrimp Management Plan (GMFMC[21]) reduced red snapper bycatch in the Gulf by a mandatory offshore fisheries effort reduction initially 74% and presently 67%. These beneficial effects of TED's in offshore waters have not been offset by a substantial shrimp loss (~ 6%, Gallaway et al., 2008). These are a few of the major actions that address the negative impacts of trawling in the U.S. southeastern shrimp fisheries.

Observer programs remain the most reliable means for monitoring commercial fisheries to date by providing unbiased, reliable, and high-quality data. Findings from these programs provide insight on finfish and protected species CPUE, as well as life history characteristics for both target and nontarget species. Moreover, they provide a wide array of other variables of interest to fishery managers, the fishing industry, academia, and the public including discard levels, gear effectiveness, temporal and spatial shrimping patterns, socio-economic considerations as related to industry, and individual fishing quota program effectiveness.

[20]Helies, F. C. and J. L. Jamison. 2010. Industry/National Marine Fisheries Service Bycatch Reduction Device Workshop. Final report of the Gulf and South Atlantic Fisheries Foundation prepared under NOAA Award NA08NMF4540398 (avail. at http://www.gulfsouthfoundation.org/research/completed).

[21]GMFMC. 2008. Amendment 14 to the Shrimp Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico. Gulf Mex. Fish Manage. Counc., Tampa, Fla. (avail. at http://www.gulfcouncil.org).

Acknowledgments

We commend the outstanding efforts given by all the fishery observers involved in this research effort for more than two decades and the commercial fishing industry for their continued participation.

Literature Cited

Alverson, D. L., and S. E. Hughes. 1996. Bycatch: from emotion to effective natural resource management. Rev. Fish Biol. Fish. 6(4):443–462 (doi: https://doi.org/10.1007/BF00164325).

__________, M. H. Freeberg, S. A. Murawski, and J. G. Pope. 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Pap. 339, 235 p.

Anderson, W. W. 1956. Observations upon the biology, ecology and life history of the common shrimp, *Penaeus setiferus* (Linnaeus) along the South Atlantic and Gulf Coasts of the United States. Proc. Indo-Pac. Fish. Counc. 6:399–403.

Chuenpagdee, R., L. E. Morgan, S. M. Maxwell, E. A. Norse, and D. Pauly. 2003. Shifting gears: assessing collateral impacts of fishing methods in U.S. waters. Front. Ecol. Environ. 1(10):517–524 (doi: https://doi.org/10.1890/1540-9295(2003)001[0517:SGACIO]2.0.CO;2).

Diamond, S. L. 2004. Bycatch quotas in the Gulf of Mexico shrimp trawl fishery: can they work? Rev. Fish Biol. Fish. 14:207–237 (doi: https://doi.org/10.1007/s11160-004-7121-0).

Epperly, S., L. Avens, L. Garrison, T. Henwood, W. Hoggard, J. Mitchell, J. Nance, J. Poffenberger, C. Sasso, E. Scott-Denton, and C. Yeung. 2002. Analysis of sea turtle bycatch in the commercial shrimp fisheries of southeast U.S. waters and the Gulf of Mexico. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-490, 88 p.

Epperly, S. P., and W. G. Teas. 2002. Turtle excluder devices—are the escape openings large enough? Fish. Bull. 100:466–474.

Finkbeiner, E. M., B. P. Wallace, J. E. Moore, R. L. Lewison, L. B. Crowder, and A. J. Nead. 2011. Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. Biol. Conserv. 144:2,719–2,727 (doi: https://doi.org/10.1016/j.biocon.2011.07.033).

Gallaway, B. J., J. G. Cole, L. R. Martin, J. M. Nance, and M. Longnecker. 2003. An evaluation of an electronic logbook as a more accurate method of estimating spatial patterns of trawling effort and bycatch in the Gulf of Mexico shrimp fishery. N. Am. J. Fish. Manage. 23:787–809 (doi: https://doi.org/10.1577/M02-105).

__________, J. G. Cole, J. M. Nance, R. A. Hart, and G. L. Graham. 2008. Shrimp loss associated with turtle excluder devices: Are historical estimates statistically biased? N. Am. J. Fish. Manage. 28:203–211 (doi: https://doi.org/10.1577/M07-002.1).

__________, S. T. Szedlmayer, and W. J. Gazey. 2009. A life history review for red snapper in the Gulf of Mexico with an evaluation of the importance of offshore petroleum platforms and other artificial reefs. Rev. Fish. 17:1–18 (doi: https://doi.org/10.1080/10641260802160717).

__________, W. J. Gazey, and J. C. Cole. 2017. An updated description of the benefits and consequences of red snapper shrimp trawl bycatch actions in the Gulf of Mexico. N. Am. J. Fish. Manage. (2):414–419 (doi: https://doi.org/10.1080/02755947.2016.1271842).

Gazey, W. J, B. J. Gallaway, J. G. Cole, and D. A. Fournier. 2008. Age composition, growth, and density-dependent mortality in juvenile red snapper estimated from observer data from the Gulf of Mexico penaeid shrimp fishery. N. Am. J. Fish. Manage. 28:1,828–1,842 (doi: https://doi.org/10.1577/M07-216.1).

__________, __________, __________, and __________. 2014. Accounting for fishing mortality when comparing density-dependent with density-independent mortality in Gulf of Mexico red snapper: response to comment. N. Am. J. Fish. Manage. 34(2):352–358 (doi: https://doi.org/10.1080/02755947.2014.880763).

Gray, C. A., and S. J. Kennelly. 2018. Bycatches of endangered, threatened and protected species in marine fisheries. Rev. Fish Biol. Fish. 28:521 (doi: https://doi.org/10.1007/s11160-018-9520-7).

Greenstreet, S. P. R., and S. I. Rogers. 2000. Effects of fishing on non-target fish species. *In* M. J. Kaiser and S. de Groot (Editors), Effects of fishing on non-target species and habitats: biological, conservation and socioeconomic issues, p. 217–234. Blackwell Sci., Oxford.

Hall, M. A. 1996. On bycatches. Rev. Fish Biol. Fish. 6:319–352 (doi: https:/doi.org/10.1007/BF00122585).

Hall, M. H., D. L. Alverson, and K. I. Metuzals. 2000. By-catch: problems and solutions. Mar. Pollut. Bull. 41(1–6):204–219 (doi: https://doi.org/10.1016/S0025-326X(00)00111-9).

Hall, S. J., and B. M. Mainprize. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? Fish Fish. 6:134–155 (doi: https://doi.org/10.1111/j.1467-2979.2005.00183.x).

Harrington, J. M., R. A. Myers, and A. A. Rosenberg. 2005. Wasted fishery resources: discarded by-catch in the USA. Fish Fish. 6:350–361 (doi: https://doi.org/10.1111/j.1467-2979.2005.00201.x).

Henwood, T. A., and W. E. Stunz. 1987. Analysis of sea turtle captures and mortalities during commercial shrimp trawling. Fish. Bull. 85:813–817.

Kelleher, K. 2005. Discards in the world's marine fisheries: an update. FAO Fish. Tech. Pap. 470, 131 p.

Kumar, A. B., and G. R. Deepthi. 2006. Trawling and by-catch: Implications on marine ecosystem. Curr. Sci. India 90(7):992–931.

Magnuson, J. J., K. A. Bjorndal, W. D. DuPaul, G. L. Graham, D. W. Owens, C. H. Peterson, P. C. H. Pritchard, J. I. Richardson, G. E. Saul, and C. W. West. 1990. Decline of the sea turtles: causes and prevention. Natl. Acad. Press, Wash., D.C., 259 p.

Murawski, S., R. Brown, H. Lai, P. Rago, and L. Hendrickson. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bull. Mar. Sci. 66:775–798.

Nance, J. M. 1993a. Effort trends for the Gulf of Mexico shrimp fishery. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-337, 37 p.

__________ . 1993b. Review of the rock shrimp fishery off the east coast of the United States. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-324, 18 p.

__________ , W. Keithly, Jr., C. Caillouet, Jr., J. Cole, W. Gaidry, B. Gallaway, W. Griffin, R. Hart, and M. Travis. 2008. Estimation of effort, maximum sustainable yield, and maximum economic yield in the shrimp fishery of the Gulf of Mexico. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-570, 73 p.

__________ and E. Scott-Denton. 1997. Bycatch in the Gulf of Mexico shrimp fishery. *In* D. A. Hancock, D. C. Smith, A. Grant, and J. P. Beumer (Editors), Developing and sustaining world fisheries resources: the state of science and management, p. 98–102. 2nd World Fish. Congr., CSIRO Publ., Collingwood, Victoria, Aus.

NMFS. 1999. Our living oceans: report on the status of U.S. living marine resources, 1999. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-41, 301 p.

__________. 2004. Evaluating bycatch: a national approach to standardized bycatch monitoring program. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-66, 108 p.

__________. 2008. Sea turtle research techniques manual. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-579, 92 p. [updated 1/2009].

__________. 2017. Fisheries of the United States, 2016. U.S. Dep. Commer., NOAA Curr. Fish. Stat. No. 2016, 147 p. (avail at https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus16/index).

NOAA. 2008. Fisheries of the Caribbean, Gulf of Mexico, and South Atlantic; shrimp fishery of the Gulf of Mexico; revisions to the allowable bycatch reduction devices. Fed. Regist. 73 FR 68355 (18 Nov. 2008), p. 68,355–68,361 (avail. at http://www.gpo.gov/fdsys/pkg/FR-2008-11-18/pdf/E8-27351.pdf).

__________. 2012. Endangered and threatened wildlife and plants; threatened and endangered status for distinct population segments of Atlantic sturgeon in the northeast region. Fed. Regist. 77 FR 5880 (6 Feb. 2012), p. 5,880–5,912 (avail. at http://www.gpo.gov/fdsys/pkg/FR-2012-02-06/pdf/2012-1946.pdf).

NRC (National Research Council). 2002. Effects of trawling and dredging on seafloor habitat. Natl. Acad. Press, Wash., D.C., 136 p.

Parsons, G., and D. Foster. 2015. Reducing bycatch in the United States Gulf of Mexico shrimp trawl fishery with an emphasis on red snapper bycatch reduction. Fish. Res. 167:210–215 (doi: https://doi.org/10.1016/j.fishres.2015.02.009f).

Patella, F. 1975. Water surface area within statistical subareas used in reporting Gulf Coast shrimp data. Mar. Fish. Rev. 37(12):22–24.

Pellegrin, G., Jr. 1982. Fish discards from the southeastern United States shrimp fishery. *In* Fish-bycatch…Bonus from the sea: a report of a technical consultation on shrimp bycatch utilization held in Georgetown, Guyana, 27–30 October 1981, p. 51–54. FAO Int. Dev. Res. Cent., Ottawa, Ont.

Price, A. B., and J. L. Gearhart. 2011. Evaluations of turtle excluder device (TED) performance in the U.S. southeast Atlantic and Gulf of Mexico skimmer trawl fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-615, 15 p.

Pulver, J. R., E. Scott-Denton, and J. A. Williams. 2012. Characterization of the U.S. Gulf of Mexico skimmer trawl fishery based on observer coverage. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-636, 27 p.

__________, E. Scott-Denton, and J. A. Williams. 2014. Observer coverage of the 2013 Gulf of Mexico skimmer trawl fishery. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-654, 25 p.

Raborn, S. W., B. J. Gallaway, J. G. Cole, W. J. Gazey, and K. I. Andrews. 2012. Effects of Turtle Excluder Devices (TEDs) on the bycatch of three small coastal sharks in the Gulf of Mexico penaeid shrimp fishery. N. Am. J. Fish. Manage. 32:333–345 (doi: https://doi.org/10.1080/02755947.2012.678962).

Riolo, F. 2006. A geographic information system for fisheries management in American Samoa. Environ. Modeling Software 21:1,025–1,041.

Scott-Denton, E. 2007. U.S. southeastern shrimp and reef fish resources and their management. Ph.D. Dissert., Texas A&M Univ., Coll. Sta., Tex., 400 p.

__________ and J. M. Nance. 1996. Shrimp trawl bycatch research in the U.S. Gulf of Mexico and southeastern Atlantic. *In* F. Arreguin-Sanchez, J. L. Munro, M. C. Balgos, and D. Pauly (Editors), Biology, fisheries and culture of tropical groupers and snappers, p. 360–362. Proc. EPOMEX/ICLARM Int. Workshop Trop. Snappers Groupers, Univ. Campeche, Campeche, Mex., 26–29 October 1993.

__________, P. F. Cryer, M. R. Duffy, J. P. Gocke, M. R. Harrelson, D. L. Kinsella, J. M. Nance, J. R. Pulver, R. C. Smith, and J. A. Williams. 2012. Characterization of the U.S. Gulf of Mexico and South Atlantic penaeid and rock shrimp fisheries based on observer data. Mar. Fish. Rev. 74(4):1–26.

__________, J. A. Williams, and J. R. Pulver. 2014. Observer coverage of the 2014 Gulf of Mexico skimmer trawl fishery. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-666, 27 p.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods, 6th ed. Iowa State Univ. Press, Ames, 593 p.

Watson, J., D. Foster, A. Shah, E. Scott-Denton, S. Nichols, and J. Nance. 1999. The development of bycatch reduction technology in the southeastern United States shrimp fishery. Mar. Tech. Soc. J. 33(2):51–56 (doi: https://doi.org/10.4031/MTSJ.33.2.8).