The distribution and direct impacts of marine debris on the commercial shrimping industry

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Abstract

Commercial shrimpers frequently encounter marine debris in their nets, resulting in the loss of time and catch, and added repair costs. Prior to this study, no information existed on the spatial and temporal distribution of marine debris that shrimpers encounter and the subsequent economic impact on commercial shrimping. To characterize the quantity and impacts of marine debris, twenty commercial shrimpers participated in a comprehensive data collection program within the north central Gulf of Mexico, USA. Results showed that derelict crab traps were an overwhelming issue for shrimpers, and the type of fishing gear used (skimmer vs. otter trawls) influenced both the type of marine debris encountered and the subsequent economic impacts. Surveyed shrimpers encountered marine debris on 19% of tows and lost an average of 18.21 minutes, 7.88 kg of catch, and $6.37 (USD) in gear damage per tow with encounters, resulting in losses of $7,683 (USD) per year, per shrimper.

Introduction

Commercial seafood industries have shaped cities and economies along coastlines worldwide. Along the US Gulf Coast, commercial seafood industries have not only established economies, but also have immense cultural significance[1,2]. The shrimping industry is the most economically valuable of fishing industries along the US Gulf Coast and South Atlantic[3]. In Mississippi alone, the entire seafood industry contributed a total of $465.4 (USD) million to the state's economy in 2015 with the shrimping industry accounting for over 46% of that total[4]. Mississippi's shrimping industry contributed a total of $215.4 million (USD), and the total personal income for commercial shrimpers was $88.5 million in 2015[4]. However, this industry is fragile and is exposed to a variety of natural and anthropogenic stressors including lack of stewardship practices, climate change, severe weather, varying and evolving regulations, and ocean pollution[5,6,7], which has led to steady declines in the number of Mississippi shrimpers and associated landings over the last 16 years[8].

One stressor that shrimpers must adapt to is marine debris (MD). MD is defined as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally, or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (33 U.S.C. 1951-1958 (2006)). MD and its impacts can be found on virtually any ocean, seafloor, and beach worldwide. Estimates show that about 6.4 anthropogenic tons of waste is produced each year, most of which primarily plastic and other hard, durable materials[9, 10]. With the continued increasing production of plastics, the generation of MD will likely increase as well[11].

Derelict fishing gear (DFG) is one common type of MD shrimpers encounter[12, 13]; DFG is any recreational or commercial fishing equipment that has been lost, abandoned, or otherwise discarded[3]. Derelict crab traps are a common type of DFG which are found globally and responsible for significant ecological and economic impacts[14]. These crab traps are often lost when the lines attaching the traps to a float are broken by wave action or being run over by propellers, which makes the now unmarked traps difficult to recover. Arthur et al. (2020)[15] estimate that the Mississippi Sound has an estimated 22,000 actively fished crab traps in the state's fishery, and nearly 5,500 derelict crab traps while Louisiana has an estimated 188,000 derelict crab traps and Alabama has over 8,000 derelict crab traps.

Qualitative studies of Mississippi shrimpers have shown they frequently encounter MD, mostly DFG, and it has significant impacts on their operations, indicating that MD has a large impact on the industry[12]. However, no paired quantitative estimate of the distribution and direct economic impact of marine debris on the commercial shrimping industry has occurred. As the amount of MD increases around the world, its impacts are becoming increasingly apparent. The economic state of the Gulf Coast is heavily dependent on the health of fisheries in the Gulf of Mexico. This fragile ecosystem and economy have suffered tremendously in recent decades from natural and anthropogenic disasters. Studying the distribution and effects of marine debris on the commercial shrimping industry is important to understand and potentially manage yet another stressor facing this industry.

Results

a) Distribution of marine debris

The participating fishermen submitted a total of 1,067 tow records. However, 897 tow records were used for data analysis; 170 were excluded because they were either submitted for dates outside of the range of the study, missing information, or not representative of a single tow (> 4 hours). Out of the 897 tows, 218 (24%) reported encountering MD; however, 50 (5.8%) of those encounters were attributed to organic materials, such as vegetation, which was not a focus of this study, and were excluded from the rest of the analyses.

MD encounters varied by location (Kruskal-Wallis Rank Sum Test – $p = 0.010$) with the highest chance of MD encounters occurring in Area 8 (Figure 1). Dunn's post hoc tests indicated that the probability of encountering MD in Area 2 was very low; with Areas 2 and 6 ($p = 0.040$) and Areas 2 and 8 ($p = 0.030$) being significantly different from each other. Nearest neighbor tests showed that the observed clustered pattern in marine debris was not random (nearest neighbor ratio = 0.317; $p < 0.001$), which could indicate overarching anthropogenic and environmental drivers that influence these patterns. MD encounters also varied by month (Kruskal-Wallis Rank Sum Test – $p < 0.001$) with a higher percentage of encounters occurring in November (37%) and lowest occurring in September (12%) than other months (Figure 2). Dunn's post hoc comparison showed that 3 comparisons were significant (e.g., July and September $p = 0.004$, August and November $p = 0.023$, and September and November $p < 0.001$; Figure 2).

Overall, shrimpers reported encountering MD on 19% of tows. The dominant type of debris encountered by shrimpers was reported to be derelict crab traps (79% of the tows with MD encounters) followed by other types of fishing gear (5%), single use plastics (5%), and unknown trash items (4%; Figure 2). Generally, the assemblage of MD encountered was similar in each area (Kruskal- Wallis Rank Sum Test – $p = 0.430$) but varied by month (Kruskal-Wallis Rank Sum Test – $p = 0.007$). However, that monthly result was driven by the difference in MD assemblage between October and November (Dunn's post hoc test- $p = 0.019$) with all other monthly pairwise comparison showing no statistical difference ($p > 0.050$; Figure 2).

The pattern of MD encounters was heavily influenced by type of fishing gear (Kruskal-Wallis Rank Sum Test – $p = 0.002$). The two distinct gear types used were skimmer (29% of all reported tows) and otter trawls (52% of all reported tows). The remaining 19% of tows reported using either both types of gear or other, unidentified gear. The difference in likelihood of MD encounters between these two dominant gear types was significant with over 31% of Skimmer and only 13% of Otter tows reporting encountering MD (Kruskal-Wallis Rank Sum Test – $p < 0.001$). The probability of MD encounters between the two gear types also had a spatial variation (Kruskal Wallis Rank Sum Test- p-value < 0.001; Figures 3 and 4). The use of skimmers resulted in more MD encounters in Area 8 while the use of otter trawls resulted in more MD encounters inshore and mostly in Area 4. Additionally, the types of debris caught by these two gear types were different (Kruskal Wallis Rank Sum Test – $p < 0.001$; Table 1). Skimmers caught both more and a wider variety of MD than otter trawls.

Table 1 Marine debris caught and the probability of occurrence. Amount of each type of marine debris documented by shrimpers and the probability of encountering each type based on the type of gear used.

Types of Marine Debris Caught by Gear Type

	Otter Trawls	Probability of Occurrence	Skimmers	Probability of Occurrence
Derelict Crab Traps	46	10%	64	25%
Wooden Materials	1	0%	0	0%
Other Types of Fishing Gear	2	0%	5	2%
Plastics	2	0%	7	3%
Tires	1	0%	0	0%
Rope	0	0%	1	0%
Clothing	0	0%	2	1%
Glass	0	0%	1	0%
Construction/Housing Materials	4	1%	0	0%
Others/Unknown Materials	3	1%	3	1%
Metal Materials	0	0%	2	1%

b) Direct economic impacts

Of the 897 tows analyzed, shrimpers reported a direct economic impact of MD (i.e., lost fishing time, lost catch, and/or gear damage) for 10% of them. Lost fishing time and catch were more impactful than gear damage (Figure 5; Table 2). Fishermen reported 56% and 54% of all MD encounters resulted in lost time and catch, respectively, whereas gear damage was only reported for about 7%. Overall, shrimpers reported losing between 0 and 240 min, 0 and 68 kg of shrimp catch, and $0 and $200 (USD) in gear damage per tow due to MD (Table 2).

Table 2 Impacts marine debris had on shrimpers. The impact marine debris had on shrimpers per tow including kilograms lost, fishing time lost, total sales lost, and damage costs.

Impacts of Marine Debris at each Percentile

		25%	50%	75%	Mean
Kg Lost	All Tows	0.00	0.00	0.00	2.01
	MD Encounters	0.00	4.54	13.04	7.88
Fishing Time Lost (minutes)	All Tows	0.00	0.00	0.00	4.61
	MD Encounters	0.00	5.00	30.00	18.21
Damage Costs ($)	All Tows	$-	$ -	$ -	$ 1.30
	MD Encounters	$-	$ -	$ -	$ 6.37
Total Sales Lost	All Tows	$-	$ -	$ -	$16.66
	MD Encounters	$-	$29.79	$110.96	$65.63

The length of tows for each gear type was not affected by MD encounter (Figure 6; Kruskal- Wallis Rank Sum Test – $p = 0.221$). However, the impact of MD on lost fishing time (Kruskal-Wallis Rank Sum Test – $p < 0.001$) and lost catch (Kruskal-Wallis Rank Sum Test – $p < 0.001$) was heavily influenced by gear type used (Figure 7). Because gear damage costs did not occur frequently, it did not show an influence of gear type (Kruskal- Wallis Rank Sum Test – $p = 0.466$).

Overall, there were 79 and 56 MD encountering tows reported for skimmer and otter trawls respectively (Table 1). While skimmer trawls were over 2 times more likely to encounter MD than otter trawls (31% vs. 13% encounter rate per tow), otter trawls accounted for the costliest MD encounters. Of those MD encounters with skimmers, only 19% reported lost catch and 24% reported lost fishing time due to MD. Conversely, over 88% and 86% of otter tows with MD encounters reported lost catch and fishing time respectively. Mean catch lost when MD was encountered was nearly 15x greater for otter trawls with MD encounters (14.23 kg per tow) than skimmer trawls (1.61 kg per tow; Figure 7). Time lost showed a nearly identical pattern with reported means of nearly 28 min and 8 min per tow dealing with MD for otter and skimmer trawls respectively (Figure 7).

When analyzing all tows (i.e., with and without marine debris encounters), shrimpers lost an average of 4.61 (± 15.33) minutes removing and disposing of MD and lost an average of 2 (± 6.42) kg of shrimp per tow. These losses lead to an average of $16.67 (± $51.23; USD) lost in direct sales per tow. The cost of damage is considered a labor income loss, and while not as frequent, an average of $1.30 (± $14.35; USD) per tow was lost due to damage to fishing nets due to encounters with MD. When only considering tows with marine debris encounters (MDE), shrimpers lost an average of 18.21 (± 29.13) minutes and 7.88 (± 11.3) kg per tow, increasing the average direct sales lost per tow to $65.67 (± $91.55; USD). The rate of MD causing damage to the fishing nets could result in an average of $6.37 (± $31.76; USD) per tow due to repair costs (Table 2).

Discussion

This study is the first to our knowledge to quantify the distribution and types of MD encountered by commercial shrimpers and its economic impact. Posadas et al. (2021) analyzed the results from the preliminary survey used to select fishermen for this study. Many of the fishermen who participated in the 2018 survey participated in the data collection program for this study. This survey assessed the perceived frequency and impacts caused by MD in 2018. Ninety-eight (98%) of shrimpers reported that they encountered MD during their fishing trips (i.e., round trip of departure and return to harbor) with 85% encountering it frequently, and most shrimpers indicated reduced catch (80%), lost fishing time (82%), and/or vessel repairs (75%) due to MD[12]. Similarly, the shrimpers who participated in this study reported making an average of 7 tows per day, and accurately estimated that 19% of all tows encountered MD. Shrimpers who participated in the qualitative survey, reported the crab traps and other abandoned fishing gear were the most common and most destructive types of MD encountered[12], which agreed with the results of this study. Logbook results showed that derelict crab traps accounted for 79% of MD encounters followed by other types of derelict fishing gear (DFG) in the Mississippi Sound and north-central Gulf of Mexico.

MD encounters also varied by location with the highest chance of MD encounters occurring offshore of Biloxi Bay. The mouth of Biloxi Bay and the offshore waters are located just south of Jackson County, whose shrimpers had the highest participation rates. Additionally, crabbing is also an important industry for the MS Gulf Coast, and there are no regulations restricting where crabbers can drop traps. As of 2018, there were 129 registered crabbers in MS. The highest percentage of the registered crabbers was in Jackson County; with 47 registered crabbers, the county made up 36% of all crabbers in MS with an estimated 2400 traps (44% of traps in MS) lost annually[15]. Therefore, the higher number of crabbers losing traps in this area could explain a higher probability for shrimpers to encounter MD in the waters offshore of Jackson County.

While July through September is generally the peak of the shrimping season[12], the logbook submissions did not peak until October. The onset of “shelter in place” orders due to the COVID-19 pandemic stalled fishing efforts and logbook participation at the beginning of the season which started in June 2020. A general increase in fishing efforts and additional participating fishermen led to a peak of logbook submissions in October. Following the “shelter in place” orders, fishermen dealt with an incredibly busy hurricane season with 8 tropical cyclones making landfall along the Gulf Coast[3,16]. Hurricane Laura made landfall in Louisiana in late August, Hurricane Sally made landfall near Gulf Shores, Alabama in mid-September 2020, and both Hurricane Delta and Zeta made landfall during the month of October in Louisiana with Zeta passing along coastal Mississippi[3]. These hurricanes brought storm surges, winds, and rain that may have moved and/or created MD throughout the study areas. Additionally, the higher tides allowed for shrimpers to fish in areas that were previously too shallow to reach. Peaks in MD encounters during the month of October could be a result of areas fished were that were likely littered with MD that accumulated over long periods of time.

There was little diversity in the type of MD that was encountered throughout the entire study area and a clustered pattern was observed. Crabbers use metal traps that sit on the seafloor with a buoy attached to mark their location. To increase productivity, crabbers typically drop their traps near each other[13, 15]; resulting in the clustered pattern observed with the nearest neighbor analysis. These traps are not extremely mobile except for being dragged by a boat's propellors or strong storm surges affecting the currents and dragging them across the seafloor[13]. Once crab traps are abandoned or lost at sea, they are considered MD[15]. Other types of debris encountered included tires, housing or construction materials, single use plastics, fishing gear, clothing, and rubber material.

Similar to the results of this study, Posadas et al. (2021) indicated that MD has higher impacts on reduced fishing time and catch than gear damage. This study indicated that 56% and 54% of MD encounters reported lost time and catch whereas only 7% of MD encounters reported direct gear damage. However, the impact of MD on lost fishing time and lost catch was heavily influenced by gear type used. The two most common types of trawls used in Mississippi are otter and skimmer trawls. Otter trawls are towed directly behind the boat and must be taken completely out of the water when MD is caught[17]. Skimmers are mounted on a frame and pushed along either side of the boat, fishing the entire water column. Individually, the skimmer nets are about half the width of the otter trawls; however, because two skimmer nets are used at the same time, the two types of gear cover about the same area while fishing[17]. The difference in likelihood of MDE's between these two gear types was significant with over 31% of skimmer and only 13% of otter tows reporting encountering marine debris.

Due to gear types, shrimpers encounter benthic MD, which sits on the seafloor, more often than encountering floating MD[18]. On the Gulf Coast, benthic MD mostly consists of DFG, including crab traps, which our results show is the likely cause of the most impactful MDE's for shrimpers. There was an average loss of 2 (± 6.42) kg of catch, 4.61 (± 15.33) minutes, and $1.30 (± $14.35; USD) costs in gear damage per tow; these collectively corresponded to about $16.66 (± $51.21; USD) per tow in direct losses per tow. When only considering tows with MDE's, shrimpers lost an average of 18.21 (± 29.13) minutes, 7.88 (± 11.3) kg per tow, and $6.37 (± $31.76; USD) in gear damage per tow.

Although the most frequently fished area reported for both types of gear was near the mouth of Biloxi Bay, the probability of MDE's between the two gear types also had a spatial variation. The use of skimmers resulted in more MDE's offshore of the mouth of Biloxi Bay while the use of otter trawls resulted in more MDE's inshore and mostly just off the coast of Harrison County. A possible explanation for these differences is, skimmers fish the entire water column while otter trawls only fish along the seafloor. Coale's (1994) study comparing rates of bycatch between the two types of gear, showed that skimmers were unable to fish in waters with greater depths than 3.7 meters. The more frequent and wider variety of MD encounters with skimmers may be a result of these nets being susceptible to both benthic and floating debris.

Overall, shrimpers submitted an average of 7 tows per day, at the current rate of MDE's (19% of tows) this would equate to $116.69 lost per day. These shrimpers reported fishing an average of 11 days per month[12] during shrimping season (June- December), so these MD impacts can be extrapolated to total $7,701.54 (2020 $USD) lost each season. There were 120 registered shrimpers in the State of Mississippi during 2020, so assuming each shrimper encounters the same level of marine debris as encountered in this study, the total annual negative direct economic impact to the Mississippi shrimping industry is approaching $1,000,000 per year. This impact is significant when considering the total dockside sales of Mississippi commercial shrimpers in 2019 was only $15,000,000[27].

The MD recorded in the data collection is likely an underestimation of the MD in the Mississippi Sound. EPA's Gulf of Mexico Program funded a 2-year collaborative cleanup effort specifically incentivizing commercial shrimpers to remove derelict crab traps from the seafloor. Nearly 2,300 traps were removed from the waters between 2019 and 2020[19], so much of the MD that could have impacted fishing efforts had already been removed. However, as MD inevitably increases in the future and these negative economic impacts could expand significantly.

The expenses caused by MD could become critical for an industry that is already subjected to a variety of stressors such as an aging work force and increasing frequencies of natural and anthropogenic disasters. As development and litter increase worldwide, the MD crisis is expected to escalate as well[10]. For shrimpers, damaging encounters with MD will likely escalate as well. Along with potentially increasing lost sales from lost fishing time and catch and costs of damage caused by MD, shrimpers must also balance rising costs of marine diesel[20] and the falling prices of both dockside and wholesale prices for shrimp[21]. The Gulf States have provided over 86% of commercially caught wild shrimp for the nation[21]. Compared to the other Gulf States, Mississippi's shrimping industry is relatively small, and Mississippi has had the least amount of derelict crab traps. The impacts of MD paired with natural and anthropogenic disasters, rising fuel costs, and falling prices of wild shrimp could be crippling for the industry throughout the region.

Conclusion

This study is the first to quantify the impacts of MD on the commercial shrimping industry. However, Arthur et al. (2020) analyzed the benefits of a derelict crab trap cleanup along the Gulf Coast. This study concluded the removal of these traps would be beneficial for both the blue crab and finfish fisheries with additional benefits for the economy, marine mammals and sea turtles, and boating traffic[15]. Shrimpers and crabbers generally fish in the same areas, so when traps become unmarked or derelict, they are likely to sit on the seafloor until a shrimping trawl picks them up[13].

The higher number of MD occurrences per tow documented in October and November suggest that distribution and patterns of encountering MD could have been influenced by hurricanes in the Gulf of Mexico during the study period. Additionally, the type of gear used influenced the type and magnitude of debris caught as well as the economic impact. To alleviate and prevent these MD encounters, shrimpers may want to consider the type of gear that they choose, and a benthic MD focused cleanup should be done before the start of the hurricane/shrimping seasons each year[15].

Methods

a) Shrimper recruitment

Forty-four (44) shrimpers were surveyed in late 2018 to gather location, vessel and gear characteristics, fishing effort, and to gauge interest in participating in an incentivized data collection program. This survey was approved by the Institutional Review Board in 2019 (MSU IRB-18-533)[12]. From the participants that expressed interest in participating in an incentivized data collection study, we selected twenty (20) that represented a diverse and representative group of shrimpers. They were chosen based on the length of their boat, the type of fishing gear used (e.g., skimmer, otter trawl, and others), which coastal county their boat resides in, and fishing effort (i.e., the number of reported trips in 2018). Shrimpers that successfully completed the data collection procedures for this study were provided a stipend of $300 (USD) per month from July to September 2020 and $500 (USD) per month October to December 2020 (i.e., $2,400 (USD) per shrimper over the shrimping season).

b) Data collection

Shrimpers used logbooks to collect data. In each logbook, they reported data associated with every tow completed over the 2020 shrimping season (e.g., July through December). Specific fields from the logbook are listed below:

• Specific times fishing nets were placed in the water and removed

• General location fished specified by gridded map (Figure 8)

• The types of marine debris encountered (e.g., plastic, fishing gear, metal, etc.)

• The amount of catch lost due to encountering marine debris (pounds)

• The amount of fishing time lost due to encountering marine debris (minutes)

• The damaged caused to fishing gear/vessel by marine debris (e.g., torn net, tangled motor, etc.)

• The estimated cost of the damage that occurred ($)

c) Analyses

Spatial Distribution Analyses

While shrimpers reported location information within individual cells based on the grid map, these cells were grouped into 9 larger fishing areas for spatial analysis (Figure 9). While it was important to group the grid cells as evenly as possible, the fishing areas were grouped by distance from shore, and numbered northwest to southeast. An additional factor that was considered when creating the fishing zones was where the fishermen would logically fish during a single day of fishing. While area of the fishing zone was considered and maintained by grouping 8 grid cells into each zone, the shape of each zone differed from one another. The nearshore study areas (0 to 1.85 KM from shore) include areas 1, 2, 4, and 9 while the offshore (1.86 to 75 KM) study areas include 3, 5, 6, 7, and 8. Some surveys documented multiple areas from the grid map fished. For these, the most northwest quadrant was chosen to use for both spatial and economic impact analyses.

The Shapiro-Wilk normality test was used to assess the assumption of nonparametric data distribution[22]. The Kruskal- Wallis rank sum test [23] was used to determine the probability of encountering marine debris and trends in abundance and diversity of marine debris for each of these 9 study areas. Using the Euclidean Distance, a nearest neighbor analysis[24] was used to evaluate the spatial distribution of MD reported by shrimpers. The default search area was used to encompass all MDE's. Analyses with significant results were then applied to ArcGIS to create a series of choropleth maps showing the probability of MD encounters using base maps derived from ESRI.

Economic Impacts Analyses

The logbooks kept by shrimpers during the 2020 season did not account for weight of shrimp caught per tow; because of this, data from 2019 was used in the formula for sales lost due to fishing time lost due to MDE's. Sales lost due to fishing time lost during MDE's was calculated by multiplying 2020 fishing time lost per tow from the logbooks by the 2019 average catch per minute, 0.364 kg (± 0.395), and the 2019 average dockside price per kilogram ($4.53 (USD))[25].

Due to lack of normality, non-parametric tests were used (e.g., Kruskal-Wallis and Dunn's post hoc test) were used to assess the impacts of MD. To assess the effect of fishing location (n=9) and month (n=6) on the response variables of pounds lost, time lost, damage costs, and cumulative direct economic impact, multiple Kruskal- Wallis Rank Sum tests were conducted following the procedures of Queen and Keough (2002)[26]. Each Kruskal- Wallis test assessed the effect of fishing location and month on an individual response variable (i.e., pounds lost, time lost, and damage costs) across all the records (with and without MD occurrences) and separately for records with MD encounters (i.e., 2 separate ANOVAs for each response variable). If location was significant, but month and the interaction between location and month were not, dates were pooled for Dunn's post hoc comparisons among locations. If a significant interaction between location and month occurred, or location and month were both significant, but the interaction was not, post hoc comparisons were done on each date separately.

Declarations

Data Availability Statement:

All data associated with this project is formatted and ready for upload into the Mississippi State University Institutional Repository. Upon acceptance of publication, all data will be uploaded to the repository and made fully available.

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Author Contributions

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Figures

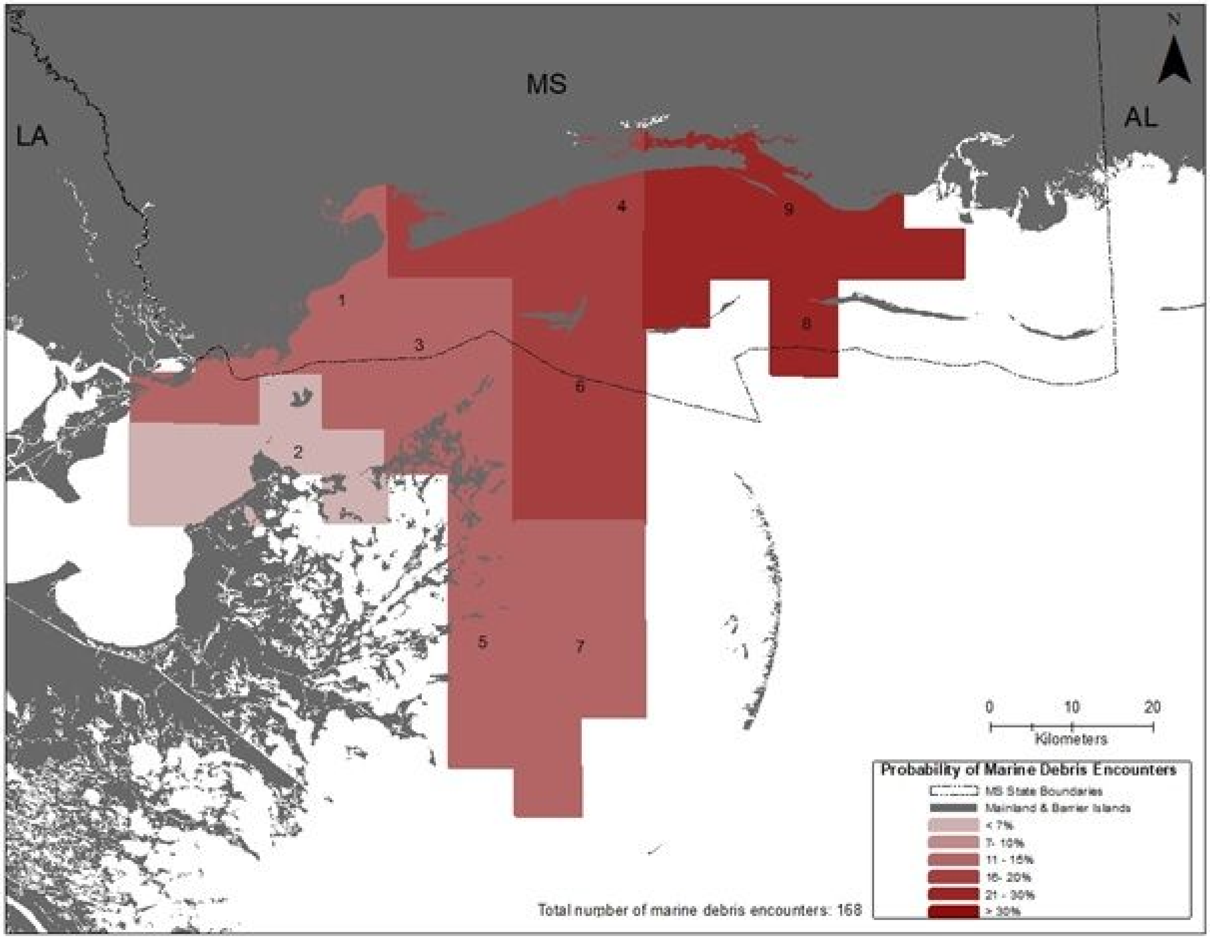

Figure 1

The probability of encountering marine debris reported by shrimpers. Base map sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

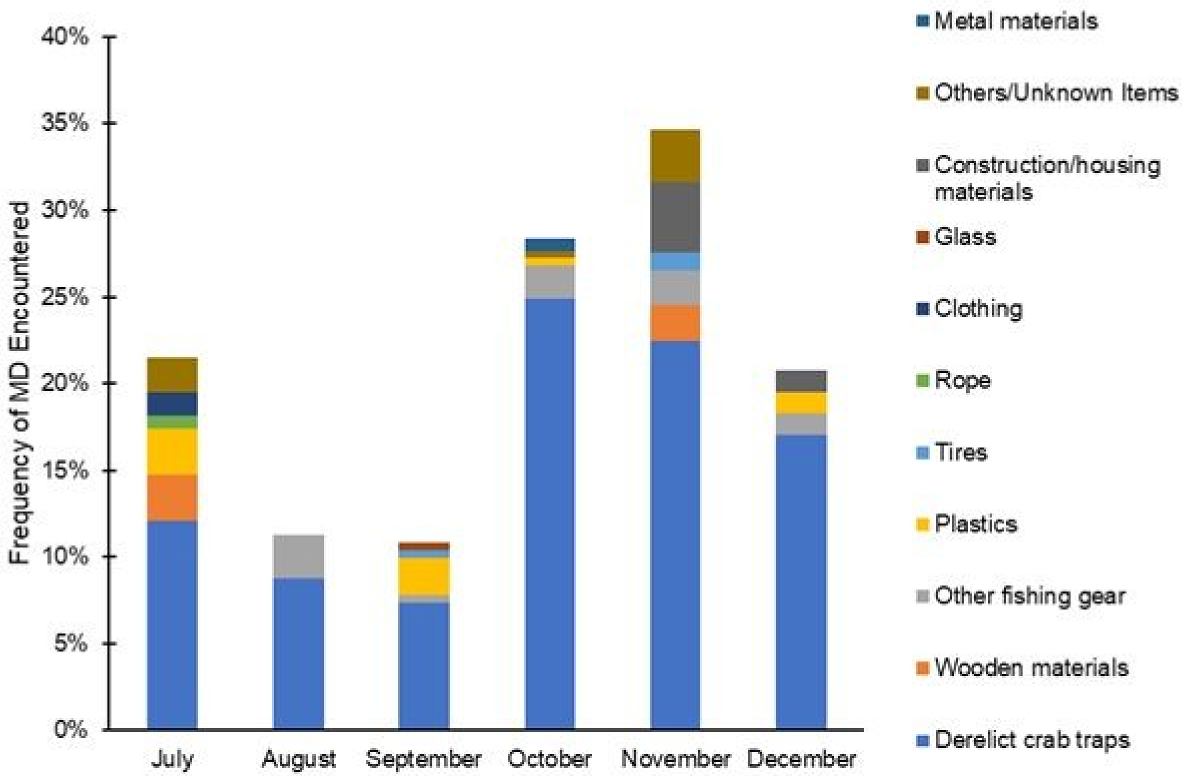

Figure 2

Frequency of marine debris (MD) encounters by MD type on a per tow basis each month.

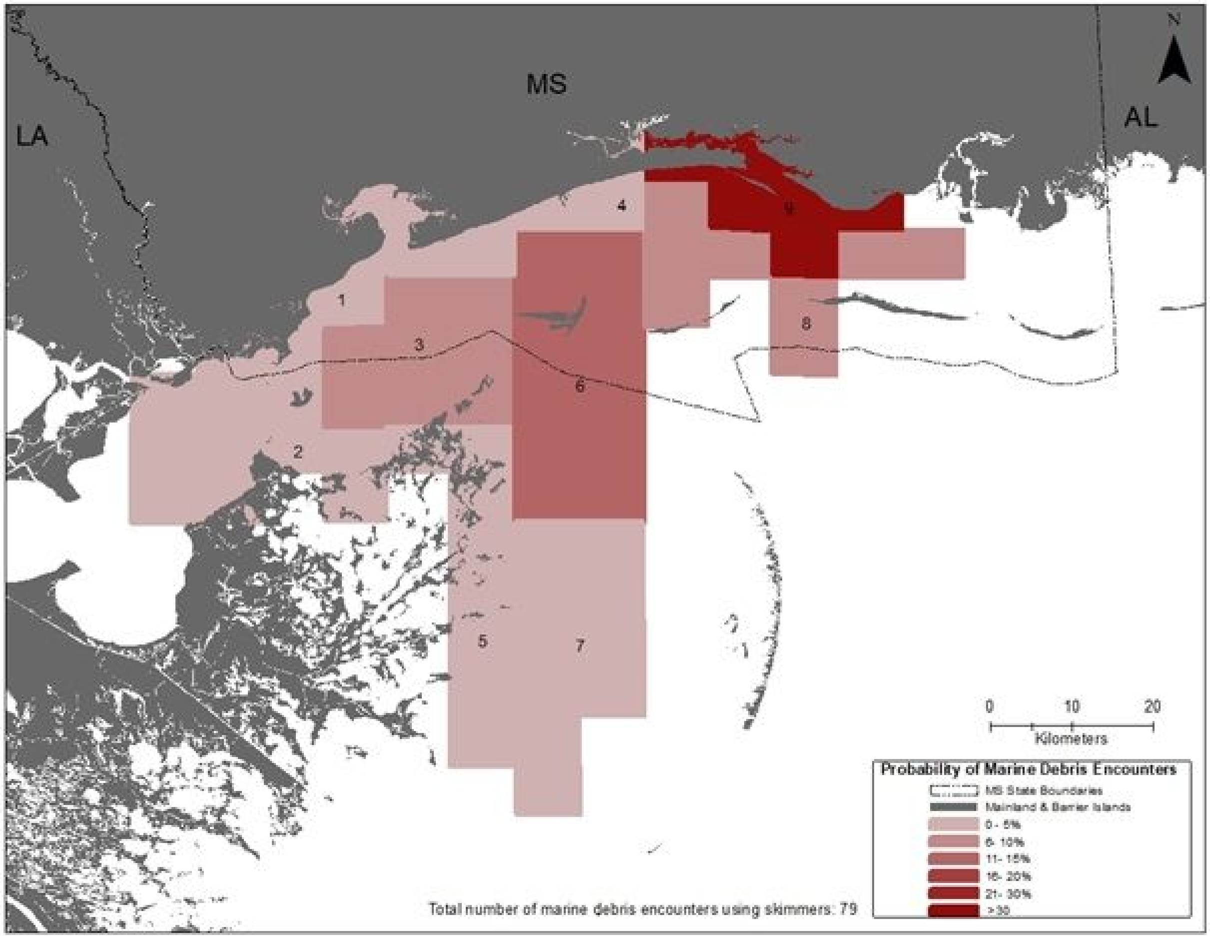

Figure 3

Map of spatial probability of encountering marine debris using a skimmer. Base map sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

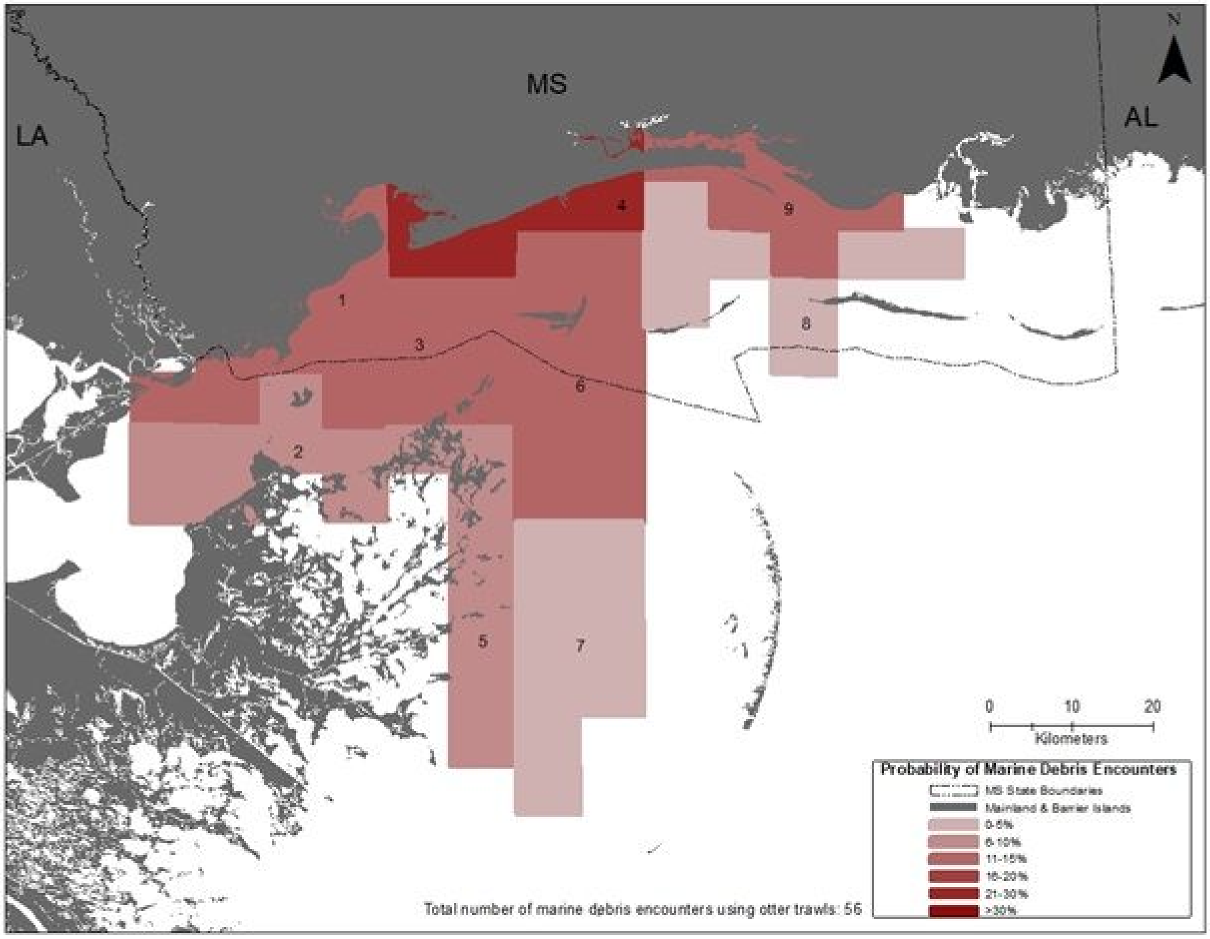

Figure 4

Map of spatial probability of encountering marine debris using an otter trawl. Base map sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

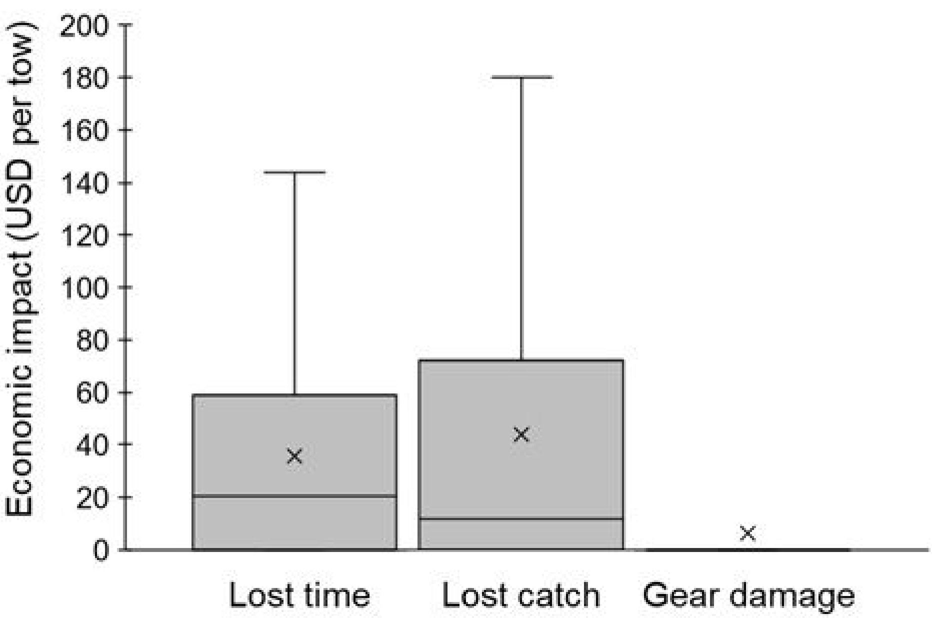

Figure 5

Comparison of the observed impacts when analyzing only marine debris encounters.

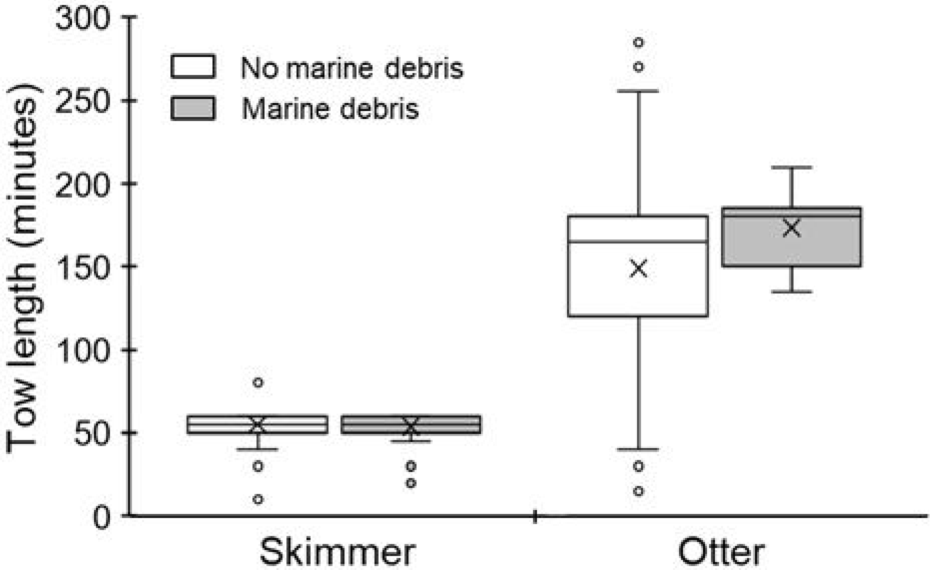

Figure 6

Comparison of the length of tows for each gear type with and without marine debris encounters.

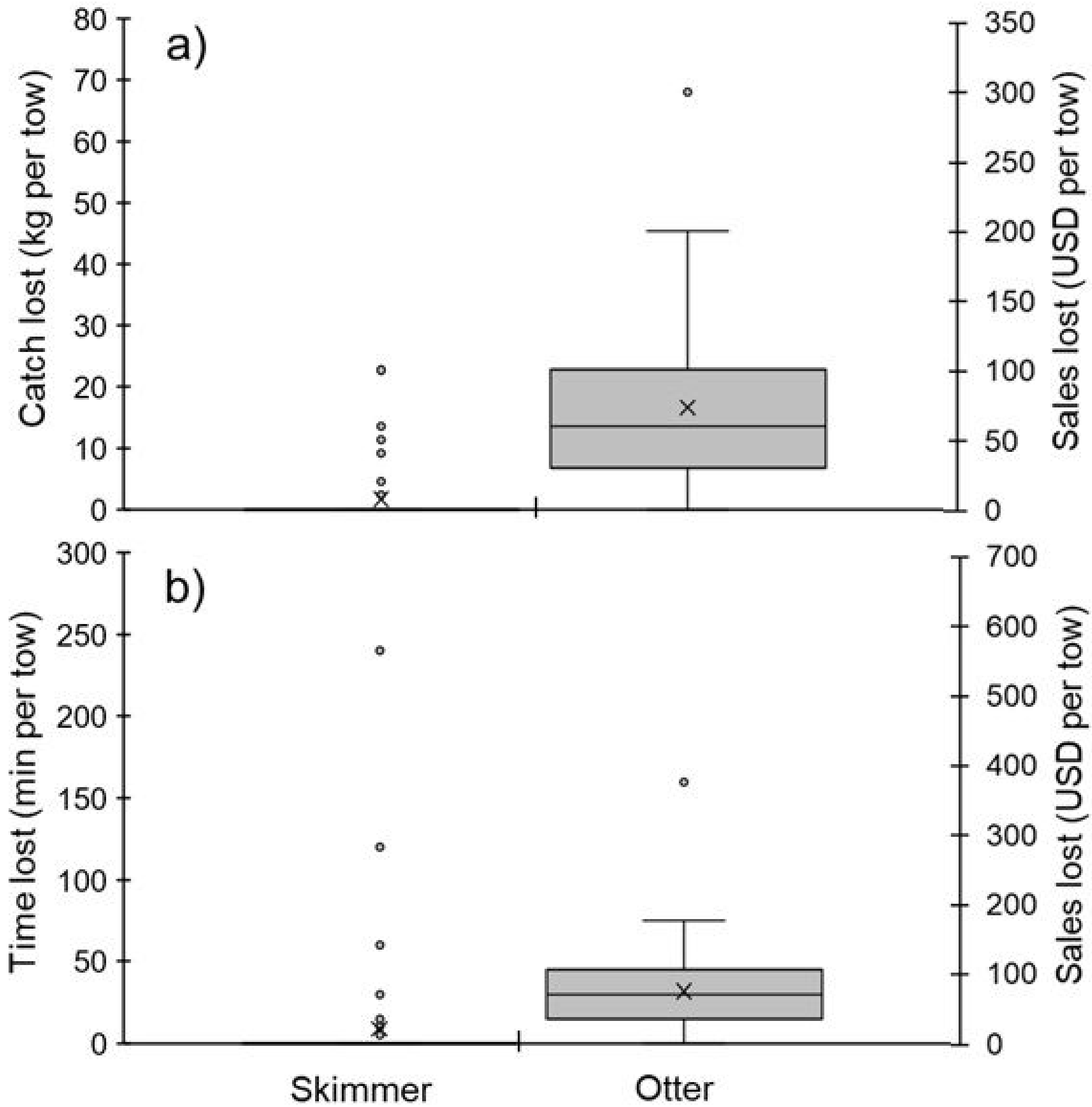

Figure 7

Comparison of impacts caused by marine debris for both gear types (skimmer and otter trawls).

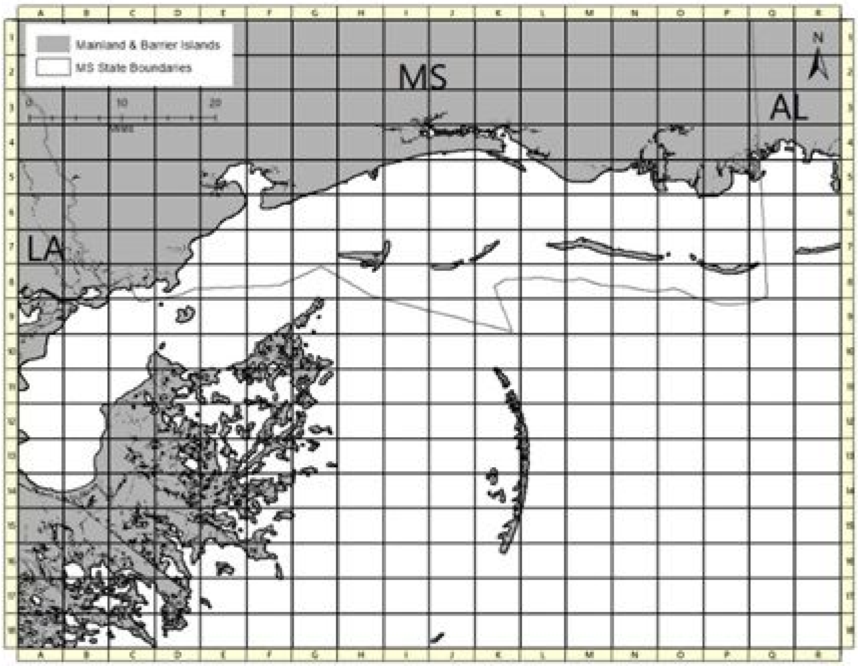

Figure 8

Grid map used by shrimpers to document fishing area. Shrimpers used the map to identify the general location in which they fished for each tow reported. Base map sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

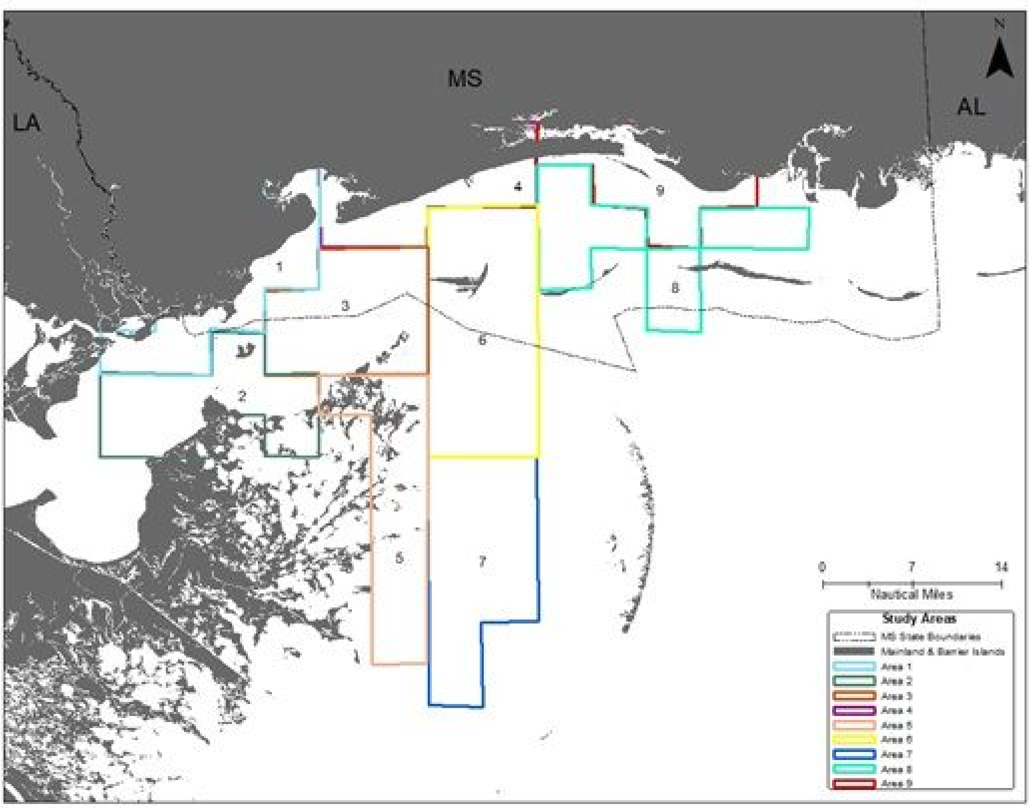

Figure 9

Fishing zones created from the documented grid cells by shrimpers. Nine study areas created for data analysis. Base map sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.