# Temporal and Spatial Distribution of Finfish Bycatch in the U.S. Atlantic Bottom Longline Shark Fishery

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*ABSTRACT—Bycatch in U.S. fisheries has become an increasingly important issue to both fisheries managers and the public, owing to the wide range of marine resources that can be involved. From 2002 to 2006, the Commercial Shark Fishery Observer Program (CSFOP) and the Shark Bottom Longline Observer Program (SBLOP) collected data on catch and bycatch caught on randomly selected vessels of the U.S. Atlantic shark bottom longline fishery. Three subregions (eastern Gulf of Mexico, South Atlantic, Mid-Atlantic Bight), five years (2002–06), four hook types (small, medium, large, and other), seven depth ranges (<50 m to >300 m), and eight broad taxonomic categories (e.g. Selachimorpha, Batoidea, Serranidae, etc.) were used in the analyses. Results indicated that the majority of bycatch (number) was caught in the eastern Gulf of Mexico and that the Selachimorpha taxon category made up over 90% of the total bycatch. The factors year followed by depth were the most common significant factors affecting bycatch.*

## Introduction

Bycatch in U.S. fisheries has become an increasingly important issue to fisheries managers, fishermen, and the public as there have been a wide range of marine resources taken as bycatch in many fisheries (Crowder and Murawski, 1998). The impact of fisheries bycatch, particularly in longline fisheries, has been under intense scrutiny worldwide. However, most of the current focus has been on pelagic longline bycatch, in particular the effects this fishery has had on endangered sea turtles (e.g. Witzell, 1999; Lewison et al., 2004; Lewison and Crowder, 2007; Crowder and Myers[1]) and sea birds (Brothers et al., 1999; Veran et al., 2007). The effect of bycatch in other longline fisheries has received less attention.

The shark bottom longline fishery is active in the northwest Atlantic Ocean from North Carolina south to Florida and west to Texas. Vessels in the fishery typically average 15 m in length. Longline characteristics vary regionally with gear normally consisting of about 2.9–43.4 km of weighted longline and 500–1,500 hooks. Gear is set at sunset and allowed to soak overnight before hauling back in the morning (Morgan et al., 2009; Hale and Carlson[2]). Historically, there were about 100 active vessels in this fishery out of about 250 vessels that possess directed shark fishing permits. These vessels combined made between 4,000 and 9,000 sets per year (Hale and Carlson[2]). Recent amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan (NMFS[3]) based on updated stock assessments have drastically reduced the major directed shark fishery in the U.S. Atlantic Ocean and Gulf of Mexico. The revised measures cut quotas, drastically reduce retention limits, and modify the authorized species in commercial shark fisheries. Specifically, commercial shark fishermen not participating in a special research fishery are no longer allowed to land sandbar sharks, *Carcharhinus plumbeus*, and are limited to 33 other large coastal shark species (e.g. blacktip, *C. limbatus*) in a trip. Along with large coastal sharks many other fish such as serranids, carangids, and other elasmobranchs are also caught and are either retained or discarded at sea.

Observations by at-sea observers of the Atlantic shark directed bottom longline fishery have been conducted since 1994, and reports of catch and bycatch have been documented (Morgan et al., 2009; Hale and Carlson[2]). While analysis has been made pertaining to

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[1]Crowder, L. R., and R. Myers. 2001. Report to Pew Charitable Trusts: a comprehensive study of the ecological impacts of the worldwide pelagic longline industry. (Available at: http://mory.ml.duke.edu/faculty/crowder/research/crowder_and_myers_Mar_2002.pdf).

[2]Hale, L. F., and J. K. Carlson. 2007. Characterization of the shark bottom longline fishery: 2005–2006. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-554, 28 p.

[3]NMFS. 2007. Amendment 2 to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan. NOAA/NMFS, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, Md., 726 p.

the bycatch of protected sea turtles and smalltooth sawfish, *Pristis pectinata* (Richards[4]), no previous report has attempted to analyze the temporal or spatial distribution of finfish bycatch in this fishery or factors that may influence the rate at which bycatch is caught. These factors could include depth, region, year, or hook type. Our objectives were to identify the spatial and temporal composition of bycatch from the bottom longline vessels. Knowledge of the temporal and spatial distribution of bycatch may prove to be useful in developing approaches to mitigate finfish bycatch such as limiting fishing effort or modifying fishing practices.

## Materials and Methods

The Commercial Shark Fishery Observer Program (CSFOP), was coordinated by the Florida Program for Shark Research at the Florida Museum of Natural History, and the Shark Bottom Longline Observer Program (SBLOP) is coordinated by NOAA's Panama City Laboratory of the National Marine Fisheries Service, Southeast Fisheries Science Center. Trained fishery observers collected data aboard randomly selected commercial bottom longline vessels targeting sharks from New Jersey to Louisiana during a five-year period (Jan. 2002–Dec. 2006). Data were collected prior to 2002, but vessels were not subjected to random selection and thus were not included in this analysis.

Fishery observers were trained in species identification and data collection prior to deployment aboard commercial fishing vessels. Observers recorded geographic positions from a handheld Global Positioning System (GPS) or the vessel's Loran or GPS systems. Loran coordinates were converted to latitude/longitude using the Coast Guard POSAID2 version 2.1a computer program. Fishing sets were allocated to one of three geographical regions based on observed differences in fishing practices (George Burgess, personal observ.): eastern Gulf of Mexico (EGM) (long. >81°W), Southeast Atlantic (SA) (lat. >25°N and long. <81°W) and Mid-Atlantic Bight (MAB) (lat. >31°N) (Fig. 1). Bottom water depth was collected from Stowaway XTI temperature/depth recorders (Onset Computer Corporation[5]) attached to the mainline during the set and subsequently downloaded onto a laboratory computer or was recorded from the vessels depth recorder.

Observers classified the disposition of all catch as carcassed (landed and sold), used for bait, released alive, escaped, tagged, museum specimen, or discarded dead. All animals that were not carcassed were considered bycatch in this study. We used this approach instead of categorizing the species as target, byproduct, and bycatch, because fishermen in this fishery often target groups of fish (i.e groupers, snappers, and sharks) within a single set (Hale and Carlson[2]) and it is not always clear which were targeted species and which were a byproduct but still retained for sale.

Because of the limited observations for many species, bycatch was divided into eight broad taxonomic groups: eels (Anguilliformes), skates and rays (Batoidea), jacks (Carangidae), snappers (Lutjanidae), groupers and seabasses (Serranidae), all other fishes (Other Osteichthyes), invertebrates (Invertebrata), and sharks (Selachimorpha) (Table 1). Hook sizes were categorized into four groups: large (>13/0), medium (10/0–13/0), small (3/0–8/0), and other. The "other" category included sets where multiple hook sizes were used or data were missing or insufficient. The type of hook used (circle or J) was not always recorded and was therefore not included in these analyses, although personal observations (authors) indicate circle hooks are used the majority of the time. Bottom water depth was divided into seven categories: <50 m, 50–100 m, 100–150 m, 150–200 m, 200–250 m, 250–300 m, and >300.

A three-way analysis of covariance (ANCOVA) (Zar, 1984) was performed for each taxonomic group using the number of individuals (total caught by category) as the dependent variable and year, region, hook type, and depth as independent variables and effort as the covariate. Effort (number of animals per 10,000 hook hours) was calculated for each set. Prior to analysis, numbers of individuals were log transformed (log (x+10)) to normalize the data. Factors were considered significant based on F tests of significance ($p$ <0.10). Once all significant factors were included in the model, interactions between factors were investigated and were included in the model when significant at the $p$<0.10 level. Tukey's multiple comparison tests (Zar, 1984) were performed on all significant factors and least squares means adjusted for Tukey's tests were used on significant interaction terms. All statistical analysis was performed in SAS Statistical Software (SAS, vers. 9.1, SAS Inst., Inc., Cary, N.C.).

## Results

Fishery observers monitored from 1.6 to 5.0% (average = 2.5%) of the total number of sets made by the shark longline fleet each year during 2002–06 (2002 = 1.9%; 2003 = 2.2%; 2004 = 1.6%; 2005 = 1.8%; 2006 = 5.0%). Bycatch was primarily caught in the Eastern Gulf of Mexico (45.9%), followed by the Southeast Atlantic (29.7%) and Mid-Atlantic Bight (24.4%). The majority of bycatch was made up of the Selachimorpha (of 94% of all bycatch groups) group (Table 1). Serranidae, Anguilliformes, Other Osteichthyes, and Batoidea each represented approximately 1% of the total bycatch, while Invertebrata and Lutjanidae each represented less than 1% of the total bycatch (Table 1).

Within the Selachimorpha group, Atlantic sharpnose, *Rhizoprionodon terraenovae;* tiger, *Galeocerdo cuvier;* blacktip; sandbar, and blacknose, *Carcharhinus acronotus,* sharks represented the most commonly caught bycatch species (Table 1). The spiny dogfish, *Squalus acanthias,* was the least commonly caught Selachimorpha and was

[4]Richards, P. M. 2006. Estimated takes of protected species in the shark bottom longline fishery 2003, 2004, 2005. U.S. Dep. Commer., NMFS SEFSC Contrib. PRD-05/06-20, 21 p.

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

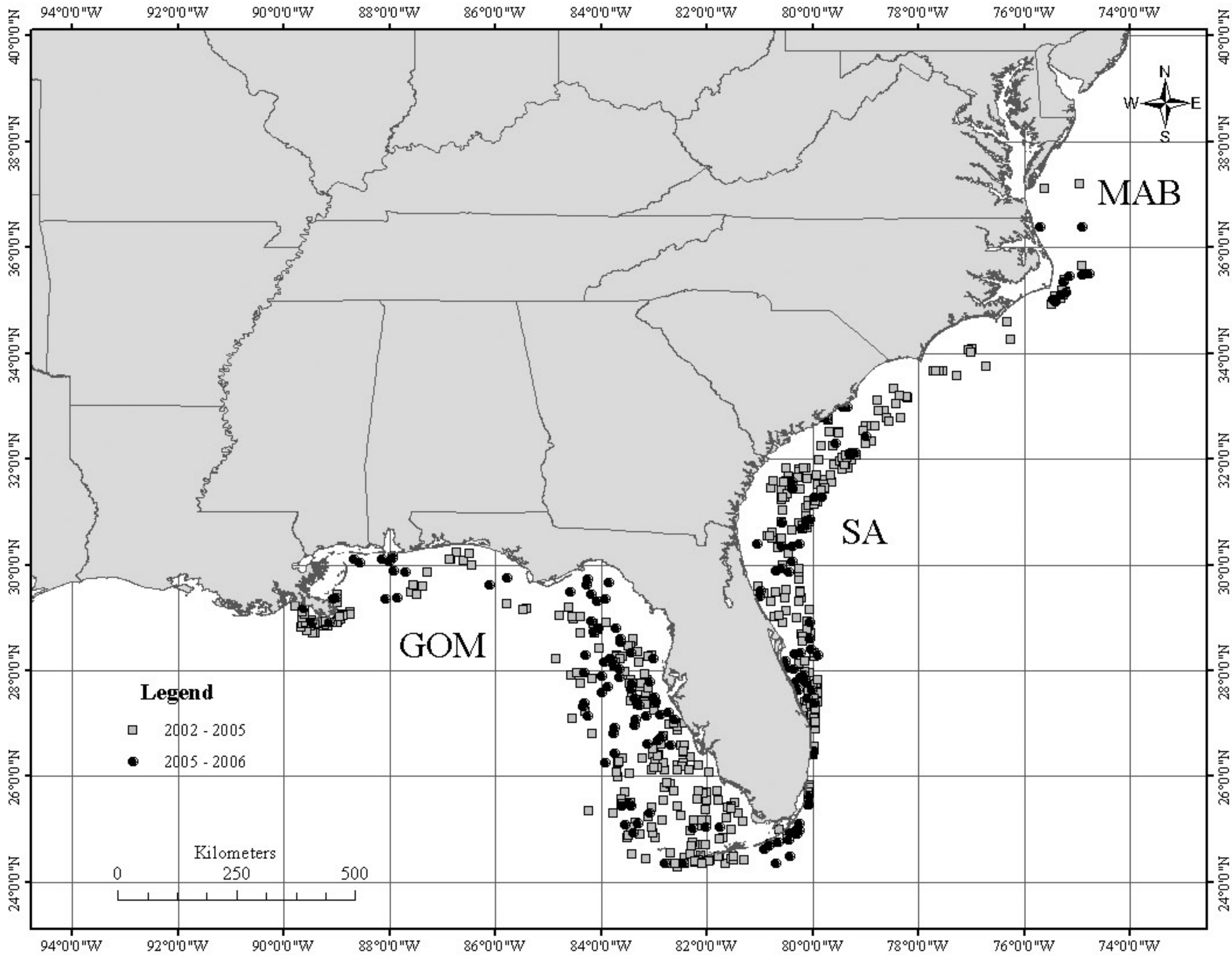


Figure 1.—Individual bottom longline sets observed by the Commercial Shark Fishery Observer Program (Jan. 2002–Apr. 2005) and the Shark Bottom Longline Observer Program (May 2005–Dec. 2006).

only caught in the south Atlantic (Table 1). Close to half (45%) of Selachimorpha were caught in the eastern Gulf of Mexico, a quarter (25%) were caught in the Middle Atlantic Bight, and 30% were caught in the south Atlantic (Table 1).

Three quarters (75%) of the Serranidae, Other Osteichthyes, and Invertebrata were caught in the eastern Gulf of Mexico, while close to 50% of the Batoidea and Lutjanidae were caught in the Middle Atlantic Bight and eastern Gulf of Mexico, respectively (Table 1). There was not a predominant species represented in the Batoidea group, whereas 82% of the Anguilliformes were represented by the king snake eel, *Ophichthus rex* (Table 1). Individual species represented over half of the Serranidae group (red grouper, *Epinephelus morio*), Other Osteichthyes (red drum, *Sciaenops ocellatus*) and Invertebrata (blue crab, *Callinectes sapidus*) (Table 1).

Year was a significant factor for the groups Selachimorpha, Serranidae, Batoidea, and Invertebrata (Table 2). Multiple comparison tests found significantly more bycatch were caught in 2006 compared to 2002 and 2005 for Selachimorpha and Invertebrata, respectively, and in 2005 compared to 2003 for Serranidae (Table 2). Multiple comparison tests for Batoidea did not reveal any significant differences between years (Table 2). In addition to year, the factor depth was also significant for Selachimorpha (Table 2). Results of the multiple comparison tests indicated more bycatch were caught at depths less than 50 m compared to between 100–150 m and 150–200 m and at depths of 50–100 m compared to depths of 150–200 m (Table 2).

The factors region and hook were only significant for Anguilliformes and Lutjanidae, respectively (Table 2). Multiple comparison tests for these two groups indicated that more bycatch were caught in the EGM compared to the SA and with other hooks compared to large and medium hooks (Table 2). Depth was also a significant factor for Lutjanidae and multiple comparison tests showed significantly more bycatch were caught at depths of 100–150 m compared to depth less than 50 m (Table 2).

## Discussion

Over 90% of the total bycatch observed in the bottom longline fishery was made up of sharks (Selachimorpha). High amounts of shark bycatch have also been reported in several pelagic longline fisheries that target the tuna family and swordfish, *Xiphias gladius* (Bailey et al., 1996; Gilman et al., 2008; Herber and McCoy[6]). For example, sharks made up the majority of the total bycatch in the western Pacific (27%) (Bailey et al., 1996), and subtropical (18%) (Herber and McCoy[6]) pelagic longline fisheries and sharks represented 15% of the total catch in the southeastern U.S. pelagic longline fishery that targets tuna and swordfish (Beerkircher et al., 2002). Differences in the total proportion of shark bycatch in these fisheries from that in the shark bottom longline fishery are likely related more to the higher value of tunas and swordfish which are retained and take up most of the hold space, requiring the discard of lesser value shark species.

Different species of sharks are either retained or discarded primarily due to their market value. For example, Atlantic sharpnose shark, the most commonly caught bycatch species, and blacknose shark are small coastal shark species that are typically of less value due to their small body and fin size. Both species are commonly kept and used as bait on longline sets targeting sharks (Morgan et al., 2009; Hale and Carlson[2]) but are still considered bycatch because they are not landed for sale. The tiger shark is not retained because of its poor meat quality and small fin size, but this species is generally released alive (Hale and Carlson[2]). Discards of sandbar and blacktip sharks are likely smaller animals that were released by fishermen because their fins were small or because their flesh was damaged due to long soak times or sand flea infestation (A. Morgan, personal observ.). In addition, trip limits (33 head limit, NMFS[3]), can lead to increased discards if the vessel reaches its quota prior to completion of the haulback.

Fishermen in the bottom longline fleet use different sized hooks to target different species of sharks (Morgan et al.,

**Table 1.—Percentage of the total bycatch composition ($n$ = 21,419) in the U.S. Atlantic bottom longline shark fishery, 2002–06. Species or taxonomic groups (e.g. Carangidae) with less than 10 individual animals caught were not reported. Designated regions are eastern Gulf of Mexico (EGM; $n$ = 9,886), south Atlantic (SA; $n$ = 6,372), Middle Atlantic Bight (MAB; $n$ = 5,176). The three columns, EGM, SA and MAB, are added together to get 100% (for each group). The column "percent caught within group" adds up to 100 percent for each group. The column "percent of total bycatch" equals 100% when the total for each group is added together. T = <0.5**

| Taxonomic group | Percent caught in EGM | Percent caught in SA | Percent caught in MAB | Percent caught within group | Percent of total bycatch |
|---|---|---|---|---|---|
| Selachimorpha ($n$ = 20,242): | | | | | |
| *Rhizoprionodon terraenovae*, sharpnose shark | 42 | 27 | 31 | 31 | 30 |
| *Galeocerdo cuvier*, tiger shark | 13 | 53 | 34 | 20 | 19 |
| *Carcharhinus limbatus*, blacktip shark | 74 | 22 | 4 | 12 | 12 |
| *Carcharhinus plumbeus*, sandbar shark | 31 | 36 | 33 | 12 | 11 |
| *Carcharhinus acronotus*, blacknose shark | 92 | 3 | 5 | 7 | 7 |
| *Ginglymostoma cirratum*, nurse shark | 71 | 28 | 1 | 7 | 7 |
| *Mustelis canis*, smooth dogfish | 15 | 4 | 82 | 2 | 2 |
| *Sphyrna lewini*, scalloped hammerhead | 64 | 29 | 8 | 2 | 2 |
| *Carcharhinus obscurus*, dusky shark | 37 | 10 | 53 | 1 | 1 |
| *Carcharhinus falciformis*, silky shark | 42 | 47 | 11 | 1 | 1 |
| *Carcharhinus leucas*, bull shark | 81 | 17 | 2 | 1 | 1 |
| *Carcharhinus brevipinna*, spinner shark | 84 | 3 | 13 | 1 | 1 |
| *Carcharias taurus*, sand tiger shark | 0 | 4 | 96 | 1 | 1 |
| *Sphyrna mokarran*, great hammerhead | 64 | 21 | 14 | 1 | 1 |
| *Negaprion brevirostris*, lemon shark | 70 | 30 | 0 | T | T |
| *Carcharhinus signatus*, night shark | 26 | 62 | 12 | T | T |
| Carcharhinus sp., shark | 91 | 9 | 0 | T | T |
| *Carcharhinus perezii*, Caribbean reef shark | 19 | 81 | 0 | T | T |
| *Sphyrna tiburo*, bonnethead | 56 | 44 | 0 | T | T |
| *Squalus acanthias*, spiny dogfish | 0 | 100 | 0 | T | T |
| Total percentage Selachimorpha | 45 | 30 | 25 | 100 | 94 |
| Serranidae: ($n$ = 307) | | | | | |
| *Epinephelus morio*, red grouper | 81 | 19 | 0 | 59 | 1 |
| *Epinephelus itajara*, goliath grouper | 91 | 9 | 0 | 18 | T |
| *Mycteroperca microlepis*, gag | 54 | 46 | 0 | 9 | T |
| *Mycteroperca bonaci*, black grouper | 50 | 21 | 29 | 5 | T |
| *Epinephelus niveatus*, snowy grouper | T | 100 | 0 | 3 | T |
| Total percentage Serranidae | 74 | 23 | 4 | 100 | 1 |
| Anguilliformes: ($n$ = 282) | | | | | |
| *Ophichthus rex*, king snake eel | 100 | 0 | 0 | 82 | 1 |
| Congridae, conger eels | 97 | 3 | 0 | 11 | T |
| Total percentage Anguilliformes | 94 | 5 | 1 | 100 | 1 |
| Other Osteichthyes: ($n$ = 275) | | | | | |
| *Sciaenops ocellatus*, red drum | 90 | 4 | 6 | 52 | 1 |
| *Sphyraena barracuda*, great barracuda | 41 | 41 | 19 | 10 | T |
| *Rachycentron canadum*, cobia | 37 | 53 | 11 | 7 | T |
| Echeneis sp. | 71.4 | 46.7 | 6.7 | 0.1 | T |
| Echeneis sp., sharksucker | 62 | 39 | 0 | 5 | T |
| *Megalops atlanticus*, tarpon | 91 | 9 | 0 | 4 | T |
| Total percentage Other Osteichthyes | 72 | 20 | 9 | 100 | 1 |
| Batoidea ($n$ = 222) | | | | | |
| Rajidae | T | 0 | 100 | 17 | T |
| *Raja eglanteria*, clearnose skate | 16 | 0 | 84 | 17 | T |
| *Dasyatis americana*, southern stingray | 12 | 58 | 30 | 15 | T |
| *Dasyatis centroura*, roughtail stingray | 11 | 71 | 18 | 13 | T |
| Dasyatis sp., stingray | 26 | 33 | 41 | 12 | T |
| *Rhinoptera bonasus*, cownose ray | 13 | 83 | 4 | 10 | T |
| *Mobula hypostoma*, devil ray | 94 | 6 | 0 | 7 | T |
| *Aetobatis narinari*, spotted eagle ray | 55 | 27 | 18 | 5 | T |
| Total percentage Batoidea | 20 | 34 | 46 | 100 | 1 |
| Invertebrata: ($n$ = 49) | | | | | |
| Portunidae, swimming crabs | 100 | 0 | 0 | 55 | T |
| Total percentage Invertebrata | 74 | 16 | 10 | 100 | T |
| Lutjanidae: ($n$ = 42) | | | | | |
| *Lutjanus campechanus*, red snapper | 92 | 8 | 0 | 62 | T |
| *Lutjanus analis*, mutton snapper | 0 | 100 | 0 | 36 | T |
| Total percentage Lutjanidae | 57 | 43 | 0 | 100 | T |

[6]Herber, C. F., and M. A. McCoy. 1997. Overview of Pacific fishing agencies and institutions collecting shark catch data. W. Pac. Reg. Fish. Manage. Counc., Honolulu, HI, 128 p.

Table 2.—Results of three-way ANOVA comparisons and post hoc comparisons for main effects from all bycatch groups; only significant (P<0.1) effects are shown. Values in parentheses are back transformed means of the total number caught by category.

| Group | Factors | DF | SS | F-Value | P-Value | Tukey Test of Main Effect Means |
|---|---|---|---|---|---|---|
| Selachimorpha | Year | 4 | 21 | 2 | 0.0719 | 2002 (37) and 2006 (245); |
| | Depth | 5 | 71 | 6 | <0.0001 | < 50 m (99) and 100–150 m (55), 50–100 m (60) and 150–200 m (18), and < 50 m (99) and 150–200 m (18) |
| Serranidae | Year | 4 | 15 | 3 | 0.0632 | 2003 (2) and 2005 (12) |
| Anguilliformes | Region | 2 | 14 | 7 | 0.0102 | EGM (16) and SA (3) |
| Batoidea | Year | 4 | 8 | 3 | 0.0462 | |
| Invertebrata | Year | 2 | 7 | 10 | 0.0180 | 2005 (2) and 2006 (30) |
| Lutjanidae | Hook | 2 | 6 | 85 | 0.0117 | Other (8) and large (2) and other (8) and medium (1) |
| | Depth | 3 | 2 | 26 | 0.0371 | < 50 m (1) and 50–100 m (4) |

2009). Like all fishing gears, longlines are size- and species-specific (Løkkeborg and Bjordal, 1992; Willis and Millar, 2001) and consequently hook size and type used in bottom longline fishing may select for different sizes and species of shark. Previous analysis of the hook types used in this fishery showed that large hooks were most commonly used in all regions but that there was some fluctuation in the use of small hooks over the years (Morgan et al., 2009). Fishermen in the eastern Gulf of Mexico also used the most hooks compared to the other two regions. It is therefore surprising that a significant difference among hook types was not found in bycatch rates for groups other than Lutjanidae. This may have been a result of combining different hook sizes into four large groups.

Significantly higher bycatch of Anguilliformes (primarily snake eels (Ophichthidae)) was noted in the eastern Gulf of Mexico, compared to the South Atlantic. The eastern Gulf of Mexico, which contains the west Florida shelf, is more structurally complex than other areas in this study and includes soft-bottom habitat where snake eels are commonly found (McEachran and Fechhelm, 2005; Lumsden et al., 2007). The differences in bycatch by depth seen in the Selachimorpha and Lutjanidae groups probably reflect differences in depth preference of species within these groupings. It is not unexpected that differences in bycatch were seen between years for most of the groups. There are many factors that likely changed between years (fishing locations within the three regions, number of vessels, observer coverage, etc.) that were not accounted for through the use of effort as a covariate in this analysis.

Bycatch associated with individual fisheries is an important component of fisheries management. While total bycatch estimates from this fishery were not calculated, results suggest that some areas, depths, years, and hook sizes have higher catches of certain bycatch species than others. These results provide an indication of factors that affect bycatch in the bottom longline fishery but further analysis is still needed. For example, a separate analysis looking at individual hook sizes and types (i.e. circle or J) and the effects on bycatch is needed for this fishery. Additionally, further analysis of depth preference by individual species within the groups analyzed in this study is warranted based on our results.

## Acknowledgments

We would like to thank all of the observers who collected data and all of the captains who participated in this program. Alex Chester and Pete Sheridan (NMFS Southeast Fisheries Science Center) provided valuable comments on an earlier version of this manuscript. Funding was provided by the NMFS Marine Fisheries Initiative (MARFIN) Program, the Saltonstall-Kennedy Grant Program, the Gulf and South Atlantic Fisheries Development Foundation, the NMFS Highly Migratory Species Management Division, and the National Observer Program.

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