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Effects of wire leader use and species-specific distributions on shark catch rates off the southeastern United States

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ABSTRACT

The efficacy of wire and monofilament leaders in retaining captured fishes was assessed to examine the effects of changes in gear used in the commercial longline fishery on the size and catch per unit effort (CPUE) of sharks caught in the western North Atlantic Ocean. For all species examined, with the exception of the shortfin mako (*Isurus oxyrinchus*), size-at-capture was largest when using wire leaders. While mean CPUE was highest for silky sharks (*Carcharhinus falciformis*) when using monofilament leaders, mean CPUE was highest for oceanic whitetip (*C. longimanus*), night (*C. signatus*), and shortfin mako sharks when using wire leaders, and similar for bigeye thresher (*Alopias superciliosus*) and tiger (*Galeocerdo cuvier*) sharks with both leader materials. Examination of monthly trends in the abundance of selected species indicated that catch rates of pelagic sharks vary significantly among months; therefore, CPUE estimates including data collected during all months of the year or corresponding months among years are best suited to examine interannual trends in the abundance of these fishes.

INTRODUCTION

Recently, there has been debate concerning the reported decline in abundance of several shark species in the western North Atlantic Ocean (Baum et al. 2003; Baum and Myers 2004; Baum et al. 2005; Burgess et al. 2005a; Burgess et al. 2005b). Based on generalized linear models applied to data compiled from pelagic longline logbooks, Baum et al. (2003) concluded that populations of thresher (*Alopias* spp.), white (*Carcharodon carcharias*) and hammerhead (*Sphyrna* spp.) sharks have declined by over 75% in the western North Atlantic Ocean, with significant declines also being noted for tiger (*Galeocerdo cuvier*), shortfin mako (*Isurus oxyrinchus*) and blue (*Prionace glauca*) sharks. Using a similar statistical approach, Baum and Myers (2004) compared data collected during exploratory research cruises conducted by the United States Bureau of Commercial Fisheries in the 1950s to pelagic longline fishery observer data collected during the 1990s and determined that oceanic whitetip (*Carcharhinus longimanus*) and silky (*C. falciformis*) shark populations in the Gulf of Mexico have declined by 99.3 and 91.2%, respectively. Burgess et al. (2005a) identified a number of factors that could have affected the conclusions of these studies, including the use of limited data sets, omission of other potentially useful data sets, possible species misidentifications and temporal differences in soak times, fishing depths and gear configuration. Baum et al. (2005) addressed these criticisms and acknowledged that the effects of gear differences, specifically leader material, could have influenced their results.

In 2004 and 2006, the National Marine Fisheries Service, Mississippi Laboratories (NMFS/MSLABS) conducted two pelagic longline pilot studies in the western North Atlantic Ocean. The goal of those studies was to develop sampling protocols and standardized gear for use in future fishery-independent surveys, therefore, because the studies were not intended to be controlled experiments, gear configuration, survey months and the range of bottom depths over which gear was deployed changed between years. Recognizing that several sources of bias could have influenced our results, the purpose of this communication is to report on findings from these two studies which suggest that 1) the change from wire to monofilament leaders in the commercial longline fishery is, at least in part, responsible for the magnitude of the estimated decline of some shark species in the western North Atlantic Ocean and 2) the inclusion of longline catch data collected during periods when certain shark species do not occur in specific regions could have heavily biased the catch per unit effort (CPUE) estimates upon which reported declines were based.

MATERIALS AND METHODS

Pelagic longline pilot studies were conducted in 2004 and 2006 off the east coast of the United States, from approximately Cape Hatteras, NC, to Cape Canaveral, FL, in April-May 2004 and February-March 2006 (Figure 1). In 2004, longline gear consisted of 18.5 km of mainline and 200-300 gangions with monofilament leaders, while the 2006 study had a 9.3 km mainline and used 96-122 gangions with 50-cm long wire leaders on the terminal section of the gear. Wire leaders were multistrand stainless steel cable, 4 mm in diameter. Regardless of year, all gangions were 22 m long and constructed of a snap, 170-kg test monofilament line and a swivel, to which the leader and hook were attached. Hook size (Mustad model # 39960D, #18/0 non-offset circle hook) and bait, Atlantic mackerel (*Scomber scombrus*), remained constant. With few exceptions, soak time was limited to three hours. Fishing depth was approximately 40 m.

In 2004, longline sets were conducted primarily during the night due to disparate vessel objectives during daylight hours. As a result, locations of longline deployment sites were based on proximity to daylight operations rather than a strict sampling scheme. During 2006, longline deployment occurred during light and dark hours at randomly selected locations spatially bounded by proximity to the Gulf Stream (Figure 1). The western edge of the sampling area was in water depths greater than 183 m and eastern edge no more than 93 km east of the current. Bottom depths over which surface longline gear was deployed ranged from 98 – 396 and 114 – 3312 m in 2004 and 2006, respectively.

The fork length (FL) of all captured animals was either measured on a straight line along the axis of the body from the tip of the snout to the posterior notch of the caudal fin or, in a limited number of cases (shark escaped hook while being boarded), was estimated by experienced personnel. Catch per unit effort (CPUE, number per 1000 hook-hours) for sharks caught during the surveys was calculated as:

$$\text{CPUE} = \left(\frac{c}{(h)(t)}\right)(60)(1000)$$

where c is the number of sharks captured, h is the number of hooks deployed and t is soak time in minutes.

Catch data collected during 2004 and 2006 were compared to examine species-specific changes in CPUE and mean size at capture resulting from the use of monofilament and wire leaders. The effect of leader type on mean FL at capture for selected species was assessed by t-test. Kolmogorov-Smirnov and Mann-Whitney U-tests were used to examine differences in the size distribution of the catch between years. Commercial longline CPUE data from Beerkircher et al. (2004) were used to examine trends in monthly and monthly fishing effort and abundance of the selected shark species within our sampling area.

Mean monthly water temperature (T) in the study area was estimated from data collected during 2,506 CTD (conductivity, T and depth) or bathythermograph casts accessed through the World Ocean Database at the National Ocean Data Center (http://www.nodc.noaa.gov). The range of depths utilized in the analyses included those where the surface longline gear was deployed, 0-40 m, during the NMFS/MSLABS surveys. To estimate T associated with the highest abundance of each species, mean monthly T and CPUE data, based on the pelagic longline shark bycatch data, were compared. Species-specific nominal CPUE was calculated from data reported in Beerkircher et al. (2004) by dividing the number of individuals caught each month by the number of hooks deployed within the same month. Monthly CPUE values were then divided by the sum of all monthly CPUE values for each species to provide a weighting factor that was applied to mean monthly T estimates, and T_{opt} was calculated as an annual weighted mean water T. Mean T during the two NMFS/MSLABS surveys, T_{2004} and T_{2006}, was estimated using the aforementioned T data for April-May (156,574 data points) and February-March (292,450 data points), respectively, without weighting by monthly CPUE estimates.

RESULTS

Thirteen longline sets were conducted in 2004 and 54 in 2006. Of the sets conducted in 2006, 23 were within the latitudinal range covered in 2004 and retained for CPUE analysis to minimize spatial bias. Mean CPUE was highest in 2004 for silky sharks, highest in 2006 for oceanic whitetip, night (*C. signatus*), and shortfin mako sharks, and similar in 2004 and 2006 for bigeye thresher (*Alopias superciliosus*) and tiger sharks (Table 1). For all species, with the exception of silky sharks, maximum CPUE was highest when using wire leaders. The expected monthly trends in abundance indicated that all species were approximately equally abundant in the sampling area during the times sampled, with the exception of tiger sharks, which are less abundant during February-March than April-May (Figure 2). In most cases, with the exception of the night shark, sampling did not occur during periods of peak abundance for the selected species in the sampling area (Figure 2). Commercial effort was highest from April to June and then declined from July to January (Figure 3).

With the exception of shortfin mako sharks, the mean size-at-capture of sharks was greater when using wire leaders (Table 1). Due to limited sample sizes of most species captured, comparisons of mean size-at-capture were only undertaken for silky and night sharks. The mean FL of both silky (t-value = -6.27, $p < 0.01$) and night (t-value = -3.34, $p < 0.01$) sharks was significantly higher when using wire leaders. For silky sharks, the mean size-at-capture increased from 1063 mm FL (SD = 185) in 2004 to 1306 mm FL (SD = 287) in 2006. There was also a significant difference in the median length of silky sharks captured in 2004 (1056 mm FL) and 2006 (1320 mm FL) (U = 3704.00, $p < 0.01$). The mean size at capture for night sharks increased from 955 mm FL (SD = 225) in 2004 to 1401 mm FL (SD = 487) in 2006. There was a significant difference in the median size at capture of night sharks between 2004 (960 mm FL) and 2006 (1165 mm FL) (U = 303.50, $p < 0.01$). The length-frequency distributions of both silky (K-S statistic = 2.84, $p < 0.01$) and night (K-S statistic = 1.34, $p = 0.05$) sharks were skewed toward larger sizes in 2006 than in 2004; however, the smallest size classes of each species were approximately equally represented in both years. For all species examined, with the exception of the shortfin mako shark, the mean size captured in the commercial fishery, as reported by Beerkircher et al. (2004), was smaller than the mean sizes collected using wire leaders (Table 1).

Comparison of the catch data presented by Beerkircher et al. (2004) to T data indicated T_{opt} for the selected shark species within the study area ranged from 17.28 to 18.52^{o}C (Table 1). Mean T between 0 and 60 m during the 2004 and 2006 sampling periods was 17.07 (SD = 6.38) and 14.68 (SD = 6.69) ^{o}C, respectively.

DISCUSSION

While the results of this study are not based on a controlled experiment and sources of bias, such as variability in sampling season and surface longline deployment depths, could have influenced our findings, based on our data, the switch from wire to monofilament leaders in the longline fishery operating in U.S. waters could have significantly contributed to reductions in the capture of large pelagic sharks reported by Baum et al. (2003) and Baum and Myers (2004). For example, the mean size of silky sharks increased from 1063 to 1306 mm FL when using wire as opposed to monofilament leaders. Furthermore, CPUE of oceanic whitetip sharks was 0.00 when using monofilament leaders and increased to 0.55 when using wire leaders. Additionally, the mean size of both silky and night sharks reported herein increased significantly when fishing in the same area and holding all gear variables, except leader material, constant. However, it should be noted that CPUE was higher for tiger and, especially, silky sharks when using monofilament leaders during our study. The decrease in silky and tiger shark CPUE in 2006 could be attributed to the mean water temperature of 14.68°C within the sampling area during 2006 being lower than the T_{opt} of 17.88 and 18.08°C for each species, respectively. Additionally, the higher CPUE of silky sharks during 2004 could be related to aggregation behavior frequently exhibited by this species (Driggers, personal observation). Patchy distribution of large numbers of silky sharks is further supported by the maximum observed CPUE of silky sharks during 2004 and 2006 being approximately equal (Table 1).

That larger sharks were caught using wire leaders demonstrates that monofilament leaders are either parted due to the force exerted on the leader or point of hook attachment by a captured shark or are severed due to contact with their teeth. Tooth cusps of most sharks caught on pelagic longline gear are serrated; therefore, it seems likely that monofilament leaders are parted due to contact with their dentition. As both tooth size and dental groove width increase with body size, the probability of the monofilament leader coming into contact with at least one tooth, when hooked in the mouth, increases as individuals get larger. Furthermore, when a shark is hooked in the tongue, esophagus or stomach, the probability of a leader coming in direct contact with teeth is even higher (Watson et al. 2005). Ward et al. (2008) examined the effects of wire and monofilament leaders on the catch of pelagic sharks off the coast of northeastern Australia and determined that catch rates of some shark species, regardless of size, were lower when using monofilament leaders. They also reported that up to half of the sharks captured using monofilament leaders were able to escape by severing the leader material. Branstetter and Musick (1993) also found that pelagic shark catch rates were twice as high using wire leaders when compared to monofilament leaders at bottom depths greater than 100 m.

Despite the constant fishing depth of the gear utilized during this study, it is likely that the differences in CPUE estimates from the surveys were influenced by the greater range of bottom depths over which the gear was deployed in 2006. In 2004, all longline sets were conducted in waters associated with the continental shelf break while in 2006, 19 of the 23 sets were conducted in oceanic waters. During both surveys, silky shark CPUE was highest in waters associated with the continental shelf break. For example, in 2006, the highest CPUE for silky sharks (80.00 individuals per 1000 hook-hours) occurred at 32°04.37’ N and 78°59.23’ W; a location in close proximity to the continental shelf break. Conversely, oceanic whitetip shark catch was 0.00 near the continental shelf break and increased to a mean CPUE of 0.55 individuals per 1000 hook-hours when sampling beyond the shelf in oceanic waters during 2006. Both silky and oceanic whitetip sharks, which are not thought to spatially segregate by size, are known to occur in offshore waters; however, silky sharks are reported to be most abundant near continental shelf breaks, while oceanic whitetip sharks are thought to be most abundant in oceanic waters (Compagno, 1984). Another factor that could have introduced significant bias into our analyses was that longline sets occurred exclusively during dark hours in 2004 and in both light and dark hours during 2006. Recent analyses, using fishery-independent data, indicate that there is a significant relationship between time of day and CPUE for several coastal shark species in the western North Atlantic Ocean (Driggers and Ingram, unpublished data). Due to limited sample sizes, we were not able to model the effects of the various potential sources of bias; however, our results indicate the importance of incorporating leader type as among the most significant variables when modeling catch rates and mean size of pelagic sharks caught in longline fisheries.

Examination of monthly trends in the abundance of the selected species indicated that catch rates of pelagic sharks can vary significantly among months. Monthly differences in commercial CPUE of night and oceanic whitetip sharks provide the most obvious examples of skewed seasonal abundance that could lead to inaccurate estimates of temporal changes in abundance. For example, if oceanic whitetip shark CPUE data collected from January-June during year *X* were compared to CPUE data collected from July-December during a subsequent year *Y*, there could be a perceived increase in the abundance of this species. Conversely, if night shark CPUE data were collected during March of year *X* and compared to CPUE data collected during September of year *Y*, a substantial decline in their abundance could be observed. Peak commercial effort occurred from April to June, but, these months did not correspond to peaks in species abundance. Therefore, as the catchability of each species is not constant throughout the year, CPUE estimates including all months of the year or corresponding months among years are best suited to examine interannual trends in the abundance of highly migratory fishes.

While we are not suggesting that declines in shark populations have not occurred due to anthropogenic influences, based on our data, we conclude that comparisons of shark catch rates using wire and monofilament are inappropriate. Furthermore, changes in fishing methods and market characteristics of fishes caught on pelagic longlines bring the use of fishery-dependent data to monitor shark populations into question, particularly when analyses do not account for these changes. For example, the reduced efficacy of monofilament leaders in retaining sharks has been noted and taken advantage of by the commercial pelagic longline tuna and swordfish fleets to reduce unwanted bycatch of sharks (Ward and Hindmarsh, 2007; Gilman et al. 2008). Thus, changes in fishing methods over the time period analyzed by Baum et al. (2003) and Baum and Myers (2004) likely biased their estimates of declines in shark populations. It will be necessary to incorporate the quantitative effects of these changes and gain a better understanding of spatial distributions of the shark species considered before a reliable assessment of temporal changes in the abundance of these fishes can be conducted.

While the data our analyses are based on were not collected using an experimental design specific to testing the effects of leader type on catch rates, our results underline the importance of including, or at the very least acknowledging, potentially important sources of bias in models when examining long-term catch data from various fishery-dependent sources. Temporal changes in abundance of exploited shark populations are to be expected given the relatively late age at maturity and low fecundity of many species; however, overstating declines in populations could obfuscate successful management measures or inadvertently discount practices that could promote responsibly conservative fishing methods, such as the use of monofilament leaders, in reducing shark bycatch in the longline fishery.

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Table 1. Catch-per-unit effort (number per 1000 hook-hours) (CPUE), size range, mean sizes and optimal temperature (T_{opt}) for pelagic and semi-pelagic sharks caught during NMFS/MSLABS pelagic longline surveys off the east coast of the United States using monofilament (2004) and wire leaders (2006). Also listed is the mean size of each species caught in the commercial pelagic longline shark fishery operating in the region. Sex-specific sizes at maturity are those reported by Beerkircher et al. (2004). Optimal temperature (T_{opt}) for each species was calculated as described in the text and reported in ^{o}C. All sizes reported in mm fork length.

Species	Year	n	Max CPUE	Mean CPUE (SD)	Size range	Mean Size (SD)	Mean size (commercial)	Size at maturity	T_{opt} (SD)
Bigeye thresher	2004	1	1.77	0.14 (0.49)	-	1697	1910	♀ 2080	18.42 (5.13)
	2006	1	3.17	0.14 (0.66)	-	2100		♂ 1720	
Silky	2004	116	82.07	14.31 (23.22)	675 - 1471	1063 (185)	1070	♀ 1920 - 2030	17.88 (5.65)
	2006	43	80	5.34 (16.54)	800 - 1900	1306 (287)		♂ 1860	
Oceanic whitetip	2004	0	-	-	-	-	1000	♀ 1450 - 1530	18.52 (5.55)
	2006	4	9.73	0.55 (2.09)	1700 - 2050	1863 (149)		♂ 1450 - 1530	
Night	2004	15	11.25	1.22 (3.08)	650 - 1300	955 (225)	1120	♀ 1680 - 1730	17.28 (5.68)
	2006	26	32.79	3.25 (7.31)	695 - 2194	1401 (487)		♂ 1560 - 1600	
Tiger	2004	3	2.99	0.36 (0.91)	1739 - 2352	2089 (316)	2045	♀ 2630 - 2670	18.08 (5.60)
	2006	4	3.35	0.29 (0.96)	1739 - 2700	2137 (411)		♂ 2580	
Shortfin mako	2004	1	3.66	0.28 (1.02)	-	1730	1805	♀ 1750	18.36 (5.39)
	2006	4	6.67	0.43 (1.52)	1080 - 1920	1595 (392)		♂ 1860	

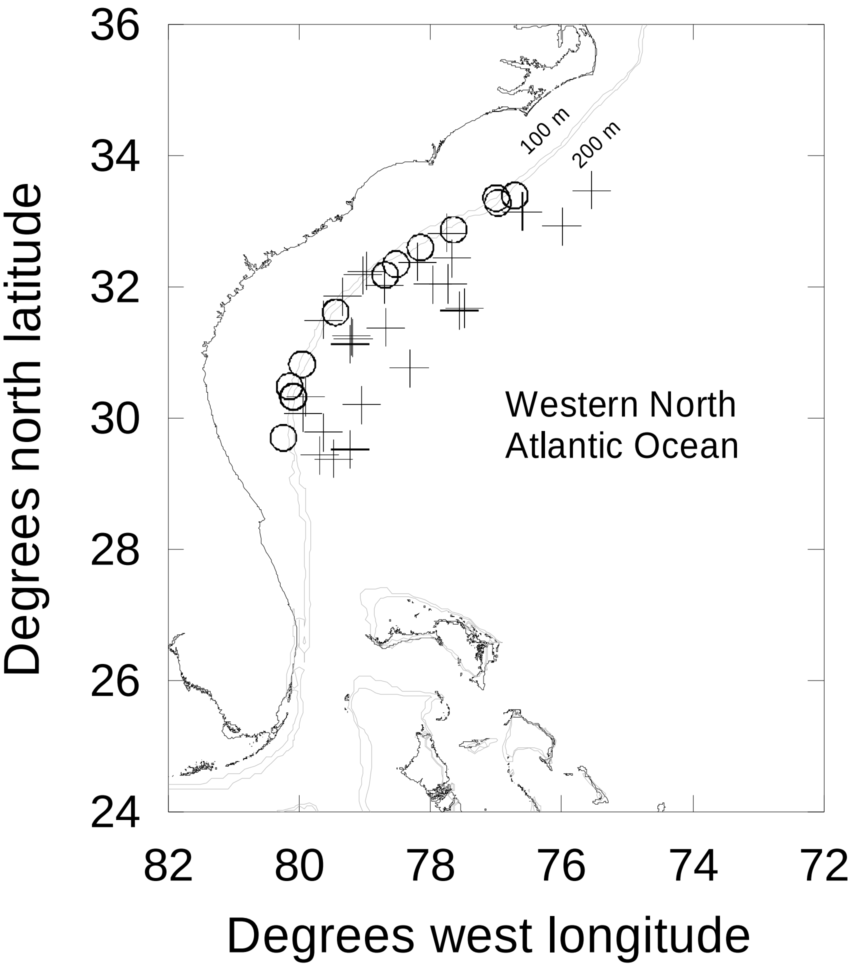

Figure 1. Sampling effort during pelagic longline surveys conducted by NMFS/MSLABS. 2004 and 2006 longline sets are indicated by circles and crosses, respectively. The 100 and 200 m isobaths are indicated.

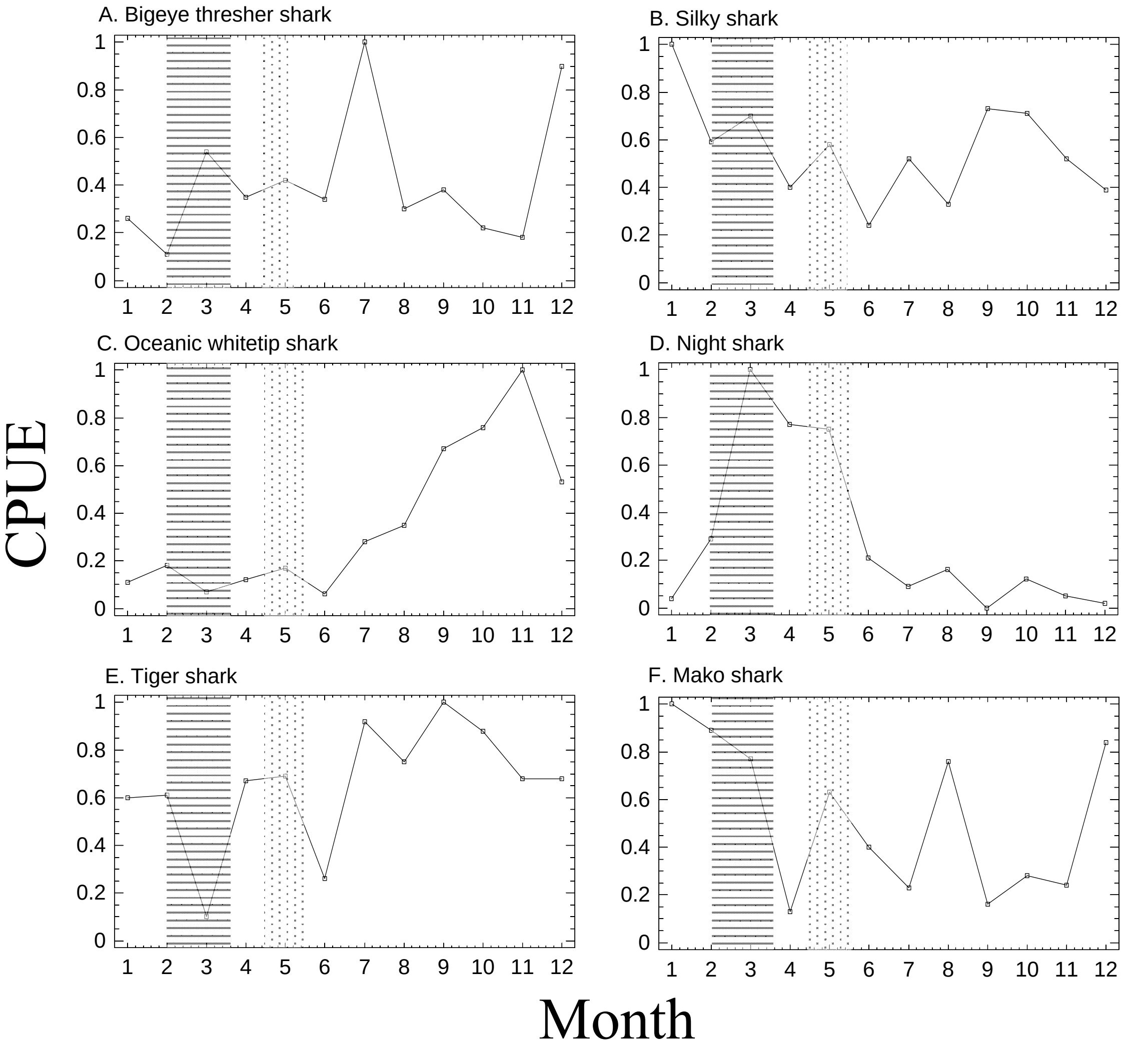

Figure 2. Relative catch per unit effort (CPUE) by month (1 = January) for (A) bigeye thresher, *Alopias superciliosus*, (B) silky, *Carcharhinus falciformis*, (C), oceanic whitetip, *C. longimanus*, (D) night, *C. signatus*, (E) tiger, *Galeocerdo cuvier*, and (F) shortfin mako, *Isurus oxyrinchus*, sharks from Beerkircher et al. (2004) scaled to a maximum value of 1. Dotted and hatched bars represent the 2004 and 2006 sampling periods, respectively.

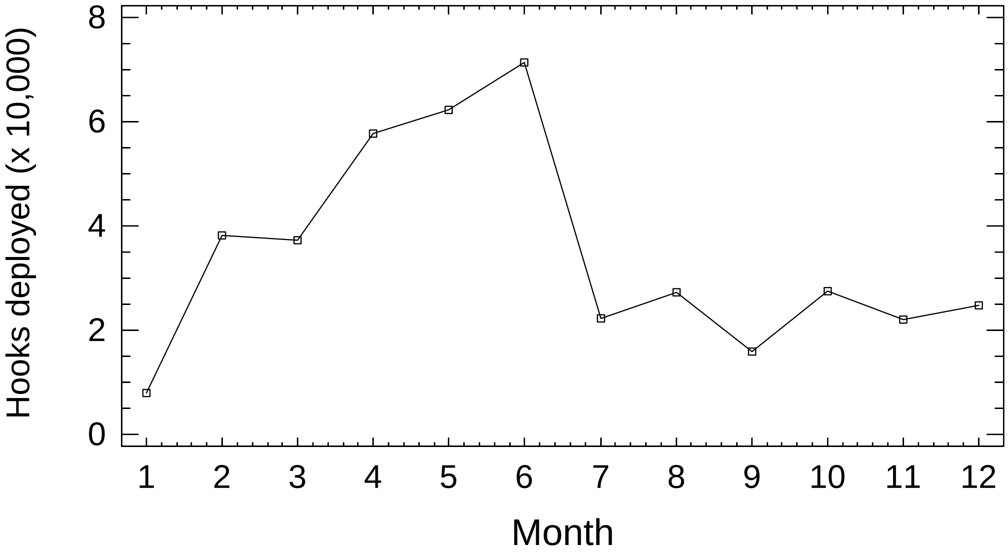

Figure 3. Commercial pelagic longline effort (expressed as number of hooks deployed by month) in the western North Atlantic Ocean, 1992-2000, reported by Beerkircher et al. (2004).