Final Report

For the Commercial Fisheries Research Foundation
Southern New England Collaborative Research Initiative

Project Title : "Is Cape Cod a Natural Delineation for Migratory Patterns in US and Canadian Spiny Dogfish Stocks?"

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Investigators:
Roger A. Rulifson[1], Michael Pratt[2], Thomas J. Bell[3], and Ian Parente[4]

Jennifer L. Cudney-Burch, Graduate Student Investigator[1]
Andrea Dell'Apa, Graduate Student Investigator[1]

Affiliations:
[1] East Carolina University, Institute for Coastal Science and Policy,
Flanagan 250, East Fifth Street, Greenville, NC 27858-4353

[2] Commercial Fisherman, 4 Charles Street, Canton, MA 02021

[3] Commercial Fisherman, 22 Ridge Hill Rd., Scituate, MA 02066

[4] Commercial Fisherman, 305 Long Highway, Little Compton, RI 02837

Commercial Fisheries Research Foundation
P.O. Box 278, Saunderstown, RI 02874

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Abstract

The spiny dogfish (*Squalus acanthias*) is an important commercial species for the Northwest Atlantic fishery, and the United States and Canada are among the major suppliers for the European market. Spiny dogfish are valued on the European Union (EU) market for their back and belly flaps, and larger animals with more robust fillets are preferred. This inevitably led to North American fishers to target adult females, which are larger and tend to school closer to shore. This fishing strategy resulted in an unsustainable fishery, and the biomass of females declined through the 1990s and early 2000s. The decline and subsequent recovery of the spiny dogfish stock provided an opportunity for the exploration of new viable strategies to better manage the stock.

The US Atlantic spiny dogfish stock is managed through quotas that are allocated by season, region (north versus south), and by state. Alternative management strategies could be based on seasonal availability and migration patterns. Recently, a new paradigm has been proposed that separates the Northwest Atlantic stock into two different stocks: the US, and the Canadian stock. This research evaluates the hypothesis that Cape Cod serves as the natural intermixing between these two potential stocks. In addition, this research attempts to corroborate observations of Cape Cod commercial fishers that the male:female ratio changes in their catches as the day progresses, with a higher number of males in the early morning and more females caught later in the day. Consistency for this diel behaviour may support or refute the development of a male-only spiny dogfish fishery off Cape Cod.

A study employing multi-tagging techniques and fishery-dependent surveys was conducted in the study area providing results supporting both the hypothesis for the presence of two stocks between the US and Canada, and the occurrence of predictable sex ratio changes in an area off the

north-eastern coast of the Cape Cod peninsula. Results also suggest that longline can potentially catch more dogfish of both sexes in the study area, and particularly more males in the South.

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Introduction

The spiny dogfish (*Squalus acanthias*) is a highly commercialized small shark species that schools by sex and size between the coastline and the continental shelf up to 600 m depth (Compagno, 1984). Adult females tend to school inshore and reach a greater averaged size, while adult males prefer deeper offshore waters and are smaller at age (Sheperd et al., 2002; Compagno et al., 2005). The major market demand for its meat is in the European Union (EU), where the species has been overexploited within the last forty years, favouring the development of new fisheries around the world. In 2005, 95% of the US export of spiny dogfish was destined for the EU market (Lack, 2006). Spiny dogfish are valued on the EU market for their backs and belly flaps, and larger animals with more robust fillets are preferred. This inevitably led to North American fishers to target adult females, which are larger and tend to school closer to shore. This fishing strategy resulted in an unsustainable fishery, and the biomass of females declined through the 1990s and early 2000s (NEFSC, 2003).

International concern over the species conservation status has been increasing within the last decade, leading to two different proposals to include the species in the Appendix-II list of the Convention of International Trade in Endangered Species (CITES). An Appendix-II listing does not restrict the species trade, but it must be certified that commercial harvest is not detrimental to stock survival. In light of potentially restrictive measures that could hamstring the US fishery, there is a great demand to explore new management strategies that enhance sustainability in order to provide for the profitability of this fishery in the long run.

Statement of the Problem

The US is actually the only country that has developed a Fishery Management Plan (US-FMP or FMP) to manage the US Northwest Atlantic spiny dogfish fishery, after this stock was declared overfished by the National Marine Fisheries Service (NMFS) in 1998. This assessment triggered the adoption of a federal (3-200 miles offshore) FMP for spiny dogfish (MAFMC, 1999), jointly developed by the Mid-Atlantic and New England Fishery Management Councils (MAFMC-NEFMC) under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) provisions. An interstate FMP was further developed in 2002 (ASMFC, 2002) by the Atlantic States Marine Fisheries Commission (ASMFC) to manage dogfish in state waters (0-3 miles offshore). The adoption of the US-FMP resulted in the US Atlantic spiny dogfish stock to be declared no longer overfished in 2010 by the NMFS, proving the effectiveness of the US fishery management for the species (Dell'Apa et al., 2012).

One important feature of the US-FMP is the catch allocation by region and season, with a different percentage of the annual total allowable catch (TAC) for each state. The annual TAC is based on biomass estimation made on data collected by the NOAA National Marine Fisheries Service-Northeast Fisheries Science Center (NMFS-NEFSC) spring trawl surveys. NMFS currently considers the Northwest Atlantic as a single population for fisheries management purposes (NMFS, 2006). Our tagging data, collected from 16 years of tagging effort off the coasts of North Carolina and Nova Scotia, do not support this single-stock approach (Rulifson, 2010a). Results suggest a seasonal migration of dogfish characterized by overwintering in coastal waters off North Carolina, northward migration to summer off New England, and a return southward migration in the late fall (Rulifson, 2010a). These data, combined with data collected by Dr. Steve Campana of Fisheries and Oceans Canada (Campana et al., 2007; Campana, 2010), strongly suggest that there may be multiple stocks of spiny dogfish along the Northwest Atlantic coast, with possible limited intermixing between the US and Canadian stocks (as much as 10%). At the Transboundary Resource Assessment Committee (TRAC) meeting in Woods Hole in spring 2009, the authors of this study (Campana, 2010; Rulifson, 2010a) jointly presented this new paradigm to the NMFS for spiny dogfish migratory patterns and mixing along the eastern seaboard of North America. This new paradigm suggests that New England, and especially the Cape Cod area, is the natural intermixing ground for the US and Canadian stocks, with also a limited rate for this intermixing. In light of this new paradigm, a more thorough understanding of the spiny dogfish population inhabiting the Northwest Atlantic region is needed. This is of paramount importance especially in the New England area, where extensive multi-tagging effort has being minimal, while an intensive and commercially significant fishing effort for spiny dogfish is present.

Life history parameters make the spiny dogfish particularly vulnerable to the impacts of mortality from human activities. The species is characterized by a long gestation period (~ 2 years), late age of sexual maturation, and slow growth rate. Loss of large reproductive females and changes in sex ratio under exploitation may represent an additional risk factor for the Northwest Atlantic population, eventually making the fishery unsustainable. In the current US fishery management system, sustainability of the spiny dogfish fishery is measured in terms of the Spawning Stock Biomass (SSB), for which adult female stock biomass is used as the only reference point (ASMFC, 2002). The assessment of the US component in the northwest Atlantic indicates a substantial reduction in mean lengths and weights of females taken in surveys over the past two decades, and the ratio of mature males to females in survey catches increased 3-fold from 1993-2000 (NMFS, 2006). These changes in stock structure are consistent with the targeting of large mature females in the US as a consequence of the EU market demand for larger individuals. Therefore, a male-only directed fishery is a desirable management option to reduce pressure on female stocks, which may promote the sustainability of the fishery by enhancing future juvenile recruitment to reach a level sustainable to fishing pressure.

Preliminary support for a male-only directed fishery comes from New England longline fisher observations, and results from surveys with commercial longlines in Cape Cod (Rulifson, 2010b). Sex ratios were observed to change from roughly 1:1 male:female, to mostly female later in the day (Rulifson, 2010b). Consistency of these sex ratio changes through day, season, and location could provide for the possibility of a male-only directed fishery in the Cape Cod and Massachusetts area.

Goal and Objectives

The primary goal for this project was to estimate the amount of mixing between US and Canadian spiny dogfish stocks. The secondary goal was to conduct fishery-dependent surveys in the Cape Cod area to test for the occurrence of changes in the male:female ratio (R) reported by local fishers, and to determine the relationships between R, geographic location, environmental conditions, and local fishery characteristics. The following objectives were designed:

1. To externally tag and release spiny dogfish north and south of Cape Cod using commercial fishing gear and techniques.

2. To surgically implant acoustic tags into spiny dogfish collected both north and south of Cape Cod.

3. To characterize changes in sex ratio and size of spiny dogfish captures through a typical commercial fishing day.

4. To compile tag return information provided by commercial and sport fishers.

5. To analyze tag return data and acoustic detection data.

6. To provide a report of publishable quality to the funding agency.

Methodology and Analysis Techniques

Opportunistic fishery dependent surveys to tag and release a targeted number of spiny dogfish (n_t = 8,000) were conducted with commercial gillnet (10 panels of 6.5 cm stretch mesh size x 91.4 m = 914.4 m line) and commercial longline (4 bundles x 457.2 m = 1828.8 m line. Each bundle was armed with 300 hooks, for a total of 1,200 hooks. Squid – *Loligo* spp., was used as bait) in the fall of 2010 (October), and in the spring (May and June) and summer (August) of 2011. Sets were conducted in the Cape Cod Bay, Massachusetts area, in Rhode Island, and in an area approximately 10 nautical miles northeast off the coast of Chatham, Massachusetts along the eastern portion of the Cape Cod peninsula (Figure 1).

The first experimental survey for this project was conducted between October 7 and 13, 2010. Surveys were conducted north of Cape Cod (Scituate and Green Harbor, MA) from the 7 to 9 of October, and south of Cape Cod (Little Compton, RI, and Chatham, MA) from the 11 to 13 of October. Gillnet sampling in the southern study area was extended for a total of 3 days, as the team was unable to catch enough animals.

The second experimental survey was planned for the period May 9 to 23, 2011, but it was shortened due to one collaborator’s inability to commit to the field days. The research team contacted the CFRF in order to arrange for another fisherman willing to participate in the southern area. Low numbers of dogfish were captured after fieldwork was initiated, likely due to unusually cold bottom water temperature for the spring period in this area (mean = 4.9 °C, range of 4.7-5.8 °C at depths between 40-50 m). The spring survey was extended for another week in June in order to wait for warmer waters, which increased the probability of capturing the targeted number of dogfish necessary to achieve all objectives. Therefore, the spring surveys were conducted on May 9-17, 2011, and June 22-28, 2011.

The third experimental survey was conducted from the 9 to 17 August, 2011. Surveys were conducted in the north area between August 9 and 12 (Scituate and Green Harbor, MA), and in the south area between August 14 and 17, 2011 (Chatham, MA).

Surface water temperature (°C) and salinity (recorded with a handheld YSI model 85), and sea bottom depth (m) from the vessel were collected at the beginning of each sampling. For surveys conducted in the spring and summer, fishing gears were equipped with a mini data logger (STAR-ODDI DST Centi-TD) to collect data on average gear depth (m) and average temperature (°C) at gear depth. Data loggers were set to record environmental parameters at seven minute intervals. The resulting depth and temperature recorded during each set were averaged. For each set, the corresponding latitude and longitude were recorded for mapping position using ArcGIS 9.3.1, and all sharks were sexed and measured for total length (TL in mm). Each shark was equipped with an external yellow tag (FLOY SS-94 single-barb dart tag) attached at the base of the dorsal fin. Each tag had a code number, reward amount and contact information.

For the surgical implant of acoustic tags (n = 120), surgical protocols were developed in collaboration with the East Carolina University Department of Comparative Medicine and Dr. Craig Harms (North Carolina State University). Each shark was inverted to induce tonic immobility on a cushioned surgery pad, and water was continuously flushed across the gills. Sharks were surgically implanted with internal acoustic coded tags (VEMCO V16), and held in on-board recovery tanks until showing clear signs of normal swimming activity. Sharks were then released approximately in the same area of original capture, and latitude and longitude of release location were recorded. All animals subjected to surgery were released alive and in good physical condition. Before release, each shark was equipped with an external single-barb dart tag (FLOY SS-94), and an additional external red button tag (FLOY Oval tag) on the dorsal fin, which indicated the presence of an internal tag and reward information (Figure 2).

In December 2010, 12 receivers (VEMCO VR2W) were deployed in a straight transect perpendicular to shore at approximately 1 nautical mile (1,852 m) intervals in Hatteras Bight just south of Cape Hatteras (Figure 3). During the project the acoustic array was actively recording underwater between February and July of 2011. The acoustic line was redeployed between December 2011 and September 2012. During the period in which the acoustic array was active, receivers were periodically retrieved for maintenance, cleaning, and data downloads. Data on all tagged animals recorded were also provided to the Atlantic Cooperative Telemetry (ACT) Network, whose members use VEMCO receivers along the Northwest Atlantic coast between Canada and North Carolina.

Recapture/redetection data for both external and internal acoustic tags were used to estimate the rate of intermixing of spiny dogfish in the Cape Cod area. For estimating the rate of intermixing (IR) we employed the following equation for external and acoustic tags separately:

$$IR = \frac{\left[\left(\frac{Xrs}{Ntotn}\right)+\left(\frac{Xrn}{Ntots}\right)\right]}{2} \qquad \text{(Eq. 1)}$$

Where x_{rs} was the total number of sharks released in the North and recaptured (external tags) or redetected (acoustic tags) in the South, N_{totn} was the total number of sharks recaptured (external tags) or redetected (acoustic tags) that were released in the North, x_{rn} was the total number of sharks released in the South and recaptured (external tags) or redetected (acoustic tags) in the North, and N_{tots} was the total number of sharks recaptured (external tags) or redetected (acoustic tags) that were released in the South.

The secondary objective of this project was to test for significant changes in the sex ratio (male:female, R) throughout a normal fishing day. The study area was divided into two sampling regions: the North and the South. The 42° N Latitude line from the outer edge of the Cape Cod peninsula was considered the boundary between these two fishing regions (Figure 1), in accordance with the conventionally reported area of activity of local fishers in the North (M. Pratt and T. Bell, pers. comm.).

For each area (North and South), changes in R within sets were correlated to environmental data. All analyses used the $\alpha = 0.05$ level of significance. The presence of sexual segregation in the species affects the possibility for R to show a normal distribution, with a consequential higher chance of recording either value of $R \geq 1$ (higher abundance of males) or value of $R \leq 0$ (higher abundance of females) within each set. Due to the absence of linearity, Spearman's correlation coefficients (ρ) were used to investigate the relationship between each of the independent variables (gear depth, temperature at gear depth, surface water temperature and salinity) with the dependent variable R for each area. Differences in the total number of males and females caught in each set by gear in each area were tested with a Wilcoxon non-parametric test.

For each area, Kruskal-Wallis single factor ANOVA was used to test for differences in R and differences in the total number of males and females caught within sets and across average gear depth and time of deployment. For this analysis, the average gear depth was divided into three strata (stratum 0 = 0-29.9 m; stratum 1 = 30-44.9 m; stratum 2 = >45 m), and time also was divided into three strata (stratum 0 or morning = 600 – 1259; stratum 1 or afternoon = 1300 – 1859; stratum 2 or night = 1900 – 559). In the case of overlap between two time strata, the corresponding set was assigned to the stratum that included more than half of the deployment time duration. For comparison between two strata, a Wilcoxon non-parametric test was used. We used the average sea bottom depth as the value recorded from the fishing vessel for sets that lacked data logger recordings, assuming that both gillnet and longline were operating at the sea bottom. Sets with gillnets conducted in the South in October 2010 were excluded from this analysis as these sets were conducted in a different area by a different fishing vessel with a different setting, potentially biasing comparisons with sets conducted in the North during the same period. The longline and gillnet surveys included in this analysis were conducted by the same vessels (one for longline and one for gillnet, respectively), using the same fishing crew and fishing gear setting for both the North and South study areas, thereby providing a more reliable comparison of results.

For three surveys conducted in the South, a chi-square test, or alternative G-test in case chi-square assumptions were not met, were used to test differences in R and in male and female numbers throughout the fishing day. To test temporal changes in male and female average size across consecutive sets a Kruskal-Wallis single factor ANOVA was used.

Results

Objective 1: To externally tag and release spiny dogfish north and south of Cape Cod using commercial fishing gear and techniques

A total of 89 sets (71 by gillnet and 18 by longline) were conducted in the study area, with 54 sets in the North and 35 in the South. Longline had a greater catching efficiency compared to gillnet, thus requiring less sets to reach the targeted number of dogfish for each seasonal survey (n = 667). A total of 7,745 spiny dogfish were tagged and released, of which 72.3% (5,599) were females and 27.7% (2,146) males. The original target of 8,000 sharks was not reached. Of these sharks, 2,631 were caught during the fall survey in 2010, 2,356 during the spring survey of 2011, and 2,758 during the summer survey of 2011 (Table 1). Considering numbers caught by area, a total of 3,912 dogfish were caught and released in the North (3,531 females and 381 males) and 3,833 in the South (2,068 females and 1,765 males).

Based on size at maturity by sex for North Atlantic spiny dogfish (Nammack et al. 1985), 91.6% (n = 5,121 – 7 missing values) of females captured were considered adult (TL > 800 mm), and 8.4% (n = 471) immature (TL < 800 mm) (Figure 4a). Of these immature females, 67.5% (n = 318) were caught in the North, while 32.5% (n = 153) were caught in the South. For males caught, 99.9% (n = 2,143) were considered of adult size (TL > 600 mm), and 0.1% (n = 3) of immature size (TL < 600 mm) (Figure 4b). Immature males were caught in the South during the fall.

Females had an average size of 864 mm (± 51.2 mm SD, range between 543-1,077 mm), while male average size was 761.7 mm (± 35.6 mm SD, range between 565-990 mm) (Figure 4a and 4b). In the North area, female average size was 862.8 mm (± 50 mm SD, range between 543-1020 mm), while male average size was 768.9 mm (± 39.5 mm SD, range between 639-990 mm) (Figure 5a and 5b). In the South area, females had an average size of 866 mm (± 53 mm SD, range between 543-1077 mm), while male average size was 760.2 mm (± 34.5 mm SD, range between 565-589 mm) (Figure 6a and 6b).

Objective 2: To surgically implant acoustic tags into spiny dogfish collected both north and south of Cape Cod

A total of 120 spiny dogfish (78 females and 42 males) were successfully equipped with internal acoustic coded tags, after surgical implantation (Table 2). One of the dogfish (a female 827 mm TL) tagged and released during the first spring survey in May was recaptured two days later in the same study area by a local fisher. The whole animal was retained by the commercial fisher, enabling the recovery of the acoustic tag for a new surgery, which was successfully conducted on the spring survey in June. Considering the North and South area separately, a total of 42 females and 18 males were released in the North area, and 36 females and 24 males in the South area (Table 2).

Objective 3: To characterize changes in sex ratio and size of spiny dogfish captures through a typical commercial fishing day

A total of 59 sets conducted at different seasons and with both gears (42 by gillnet and 17 by longline) were used for the analysis of sex ratio (R) changes, with 39 sets in the North and 20 in the South areas (Table 3 and Figure 7). Males were caught in 62.7 % (n = 37) of sets (Figure 8), represented by a mean number per set of 32.7 individuals (± SD 85.1; range 0-479). Females were caught in all sets (Figure 8), with a mean number per set of 79.2 individuals (± SD 116.1; range 1-589). Sets characterized by the highest numbers of males caught had a correspondingly low number of females caught, and *vice-versa* (Figure 8). All sets with R>1 (13.6%, n = 8), indicating higher presence of males and lower presence of females, were recorded in the South at different seasons (summer and fall) and with different gears (Figure 9 and Table 3). All sets conducted in the North area were characterized by R<1, due to a higher presence of schools of females caught within sets (Figure 9 and Table 3).

Among the 39 sets in the North, 25.6% (n = 10) were conducted with longline and 74.4% (n = 29) with gillnet. Males were caught in 53.8% (n = 21) of sets with a mean number per set of 4.7 individuals (± SD 5.4; range 0-128). Females were caught in all sets with a mean number per set of 81.1 individuals (± SD 112.3; range 1-589). Among the 20 sets in the South, 35% (n = 7) were conducted with longline and 65% (n = 13) with gillnet. Males were caught in 80% (n = 16) of sets with both gear, while females were caught in all sets. The mean number of males caught per set was 87.1 individuals (± SD 130.1; range 0-479), while the mean number of females per set was 75.6 (± SD 126.2; range 3-584).

Over the study period, the North and South areas did not significantly differ in bottom temperature, sea surface salinity, nor water depth (Table 4), but they did differ significantly in sea surface temperature (Wilcoxon test, $W = 70.5$, $P = 0.003$), with the South on average warmer than the North. Also, the South area has a steep decline in sea bottom depth within approximately 10 miles from shore, which is not a characteristic of the North area (Figure 9 and Table 4).

Results from Spearman's rank correlation (Table 5) show that, for sets conducted in the North, sea surface salinity was positively correlated with R ($\rho = 0.396$, $P < 0.05$, $n = 19$), while no significant relationship was found between R and each of the other variables (n = 39 for average gear depth, and n = 24 for sea surface temperature), although temperature at gear depth is close to significance (ρ = 0.310, P = 0.098, n = 19). Given the positive correlation between sea surface salinity and average temperature at gear depth in this area (ρ = 0.505; P = 0.016, n = 14), and the fact that dogfish were caught at the bottom, it is likely that the temperature at the bottom is the main predictor for changes in the R in the North area, with higher R values as the temperature increases. A simple linear regression between sea surface salinity and average temperature at gear depth confirmed the significance for this association (R^2 = 0.48, P<0.001, n = 14), but more data are needed to support this conclusion. The correlation analysis between R and average temperature at gear depth may be biased by four sets conducted in May in deeper waters (sets 10 to 13 in Table 3). These sets corresponded to 21% of the total sets for which temperature at gear depth was recorded in the North. The recorded temperatures of bottom water were unusually cold for that period (mean = 4.9 °C, range of 4.7-5.8 C° at depths between 40-50 m) and thus not representative of the usual average spring bottom temperature, with a consequential lower abundance of dogfish in the catch. In the South (Table 5), a significant negative correlation was found between R and average gear depth (ρ = -0.810, P < 0.001, n = 20) and a significant positive correlation was found between R and average temperature at gear depth (ρ = 0.774, P < 0.001, n = 16). These two variables are reciprocally negatively correlated (ρ = -0.887, P < 0.001, n = 16) as a natural consequence of a decrease in temperature as the depth increases. This result indicates that, for the South, changes in R were most likely associated with sea bottom depth, as also suggested by the deeper depths present in this area compared to the North area (Figure 9).

In the North, significantly higher numbers of males (Wilcoxon test, W= 84.5; P= 0.04) and females (Wilcoxon test, W= 68; P= 0.014) were caught with longline compared to gillnet; and a higher median R value was recorded in longline sets, although it was not significant (Wilcoxon test, W= 102.5; P= 0.15) (Figures 10a, 10b, 10c).

Kruskal-Wallis test indicated no significant differences in median number of males caught across depth strata ($F_{0.05(2)}$= 3.1; P= 0.2) (Figure 10d). The median number of females caught was higher at depth strata 0 and 1 (Figure 10e), but differences across depth strata were not significant (Kruskal-Wallis test, $F_{0.05(2)}$= 2.3; P= 0.3). Differences for median values of R were not significant (Kruskal-Wallis test, $F_{0.05(2)}$= 3.2; P= 0.2) (Figure 10f).

Differences across time strata (no sets for stratum 2) in median number of sharks caught were not significant for males (Wilcoxon test, W= 185.5; P=0.17) nor for females (Wilcoxon test, W= 162; P= 0.59) (Figures 10g and 10h). No significant difference was found in the median R values across time strata (Wilcoxon test, W= 193; P= 0.1) (Figure 10i).

In the South, significant difference in the median number of males caught across gear was found (Wilcoxon test, W= 14; P= 0.01), with more males caught with longline (Figure 11a). The median number of females caught was higher in gillnets, although difference by gear was not significant (Wilcoxon test, W= 66; P= 0.1) (Figure 11b). The median R values across gear were significantly higher in longline compared to gillnet (Wilcoxon test, W= 12; P= 0.009) (Figure 11c).

Kruskal-Wallis test indicated that the median number of males caught was significantly different across depth strata ($F_{0.05(2)}$= 14.5; P<0.001), and a Bonferroni-corrected pairwise Wilcoxon test detected a significant difference between depth stratum 0 and 2, with higher median number of males caught at the shallower stratum (Figure 11d). Significant difference was found for the median number of females caught across depth strata (Kruskall-Wallis test, $F_{0.05(2)}$= 10.7; P= 0.0048), with higher median numbers found at the deepest stratum compared to the shallowest (Bonferroni-corrected pairwise Wilcoxon test, P<0.05) (Figure 11e). The median R value across depth strata was significantly different (Kruskall-Wallis test, $F_{0.05(2)}$= 13.5; P< 0.001), with higher median values at stratum 0 compared to stratum 2 (Bonferroni-corrected pairwise Wilcoxon test, P<0.05) (Figure 11f).

Kruskal-Wallis test indicated significant difference in the median number of males caught across time strata ($F_{0.05(2)}$= 9.8; P= 0.007), with significantly lower median numbers at depth stratum 1 (moderate depth) compared to shallow and deep strata (Bonferroni-corrected pairwise Wilcoxon test, P<0.05) (Figure 11g). The median number of females caught was not significantly different across time strata (Kruskal-Wallis test, $F_{0.05(2)}$= 4.1; P= 0.1), although more females were caught in deeper waters (Figure 11h). Significant difference in median R values across time strata was found (Kruskal-Wallis test, $F_{0.05(2)}$= 8.6; P= 0.01), with higher values during the morning (stratum 0) compared to other strata (Bonferroni-corrected pairwise Wilcoxon test, P<0.05) (Figure 11i).

Two longline surveys (sets 57 to 59 on October 11, 2010 with average soaking time of 12.3 minutes, and sets 40 to 42 on August 14, 2011 with average soaking time of 14.3 minutes) and one gillnet survey (sets 43 to 46 on August 17, 2011 with average soaking time of 331 minutes) conducted in the South showed significant differences in the R values recorded within consecutive sets conducted in the same area (G = 19.1; P < 0.001 for October 11; χ^2 = 20.3; P < 0.001 for August 14; G = 87; P < 0.001 for August 17), with higher values recorded early in the morning and lower values recorded at night and in late morning (Figures 12 and Table 6). All three surveys were conducted in inshore shallower waters, between 20.7 and 37.8 m deep (Table 3).

For sets conducted with longline (Figures 13a and 13b), significantly higher numbers of males were caught early in the day (χ^2 = 149.6; P < 0.001 for October 11, and χ^2 = 485.6; P < 0.001 for

August 14, respectively). Higher numbers of females were caught in longline sets conducted later in the morning on October 11 (χ^2 = 50.7; P < 0.001), while more females were caught in earlier longline sets on August 14 (G = 6.5; P = 0.038) (Table 6). For the gillnet survey (Figure 13c) differences in abundance across sets were significant for both sexes, with a higher number of females within sets conducted at night (G = 197; P < 0.001) and a clear shift toward higher numbers of males for sets conducted in the morning (χ^2 = 277; P < 0.001) (Table 6).

Considering the average size of sharks caught by sex across sets, significantly larger females were caught in longline sets later in the morning on October 11 (Kruskal-Wallis test, $F_{0.05(2)}$= 10.5; P= 0.005 and Bonferroni-corrected pairwise Wilcoxon test, P < 0.05) (Table 6), concurrent with the decrease in male abundance within the same sets (Figure 14a and 13a). The average size of females caught was also higher for longline sets conducted later in the morning on August 14 (Figure 14b), although differences were not significant (Kruskal-Wallis test, $F_{0.05(2)}$= 1.72; P = 0.4) (Table 6). For the gillnet survey on August 17 significantly differences for the average size of females caught through time were recorded (Kruskal-Wallis test, $F_{0.05(2)}$= 16.5; P < 0.001) (Table 6). Smaller females were caught later in the day (Bonferroni-corrected pairwise Wilcoxon test, P < 0.05), concurrent with a decrease in female numbers and increase in male numbers within the same gillnet sets (Figure 14c and 13c). The average size of males across sets for all three surveys did not change significantly (Figure 14, Table 6).

Although excluded from the R analysis, we report here the results from the gillnet sets (n = 15) conducted in Rhode Island in the Fall of 2010 off Little Compton (Figure 1, and Table 7). These sets were conducted in shallow waters (n = 9; mean = 35.9 m; ± 1.52 SD; range between 34.1 and 38.4 m) in the morning and afternoon. Results indicate the preponderance of females in the catch, with R values close to zero in all sets (Table 7).

<u>Objectives 4-5</u>*: To compile tag return information provided by commercial and sport fishers, and to analyze tag return data and acoustic detection data*

A total of 90 sharks (3 males and 87 females) tagged with external tags (1.2 % recapture rate) were recaptured by commercial and recreational fishers between November 2010 and October 2012 at different locations along the US east coast, between Maine and North Carolina, with no reported recaptures from Canadian waters (Figure 15, 4 missing data for recapture positions). Combined results from 2010 to 2012 indicate the presence of seasonal migration in the stock with higher recaptures in the northern regions, from Maine to Maryland, between spring and summer, and several recaptures occurring in the southern regions, from Virginia to North Carolina, in the winter (Figure 15). Considering the caught-and-released area, 68.9% (n = 62) of these sharks were released in the North, and 31.1% (n = 28) were released in the South. For the sharks released in the North, 79% (n = 49) were recaptured within the North study area range, above the 42° N latitude line, while 21% (n = 13) were recaptured within the South study area below that line (Figure 16a). For sharks released in the South, 64.3% (n = 18) were recaptured within the South study area, while 35.7% (n = 10) were recaptured within the North study area (Figure 16b). These results indicate that the majority of sharks released both in the North and in the South were recaptured in the same area of release, with a lower occurrence of intermixing between the two areas (21% in the North and 35.7% in the South). The occurring average intermixing rate IR, based on external tags recapture data, is estimated at 28.4%.

A total of 58 sharks (12 males and 46 females) tagged with internal acoustic tags (48.3% recapture rate) were redetected between October 2010 and August 2012 by receivers deployed in the Hatteras Bight, NC by the project team and by receivers located along the North Atlantic east coast, which are part of the ACT's acoustic listening arrays (Table 8 and Figure 17). The temporal pattern of these detections confirms the presence of seasonal migration in the stock, with detections in the northern regions occurring from spring to late fall, and several detections in North Carolina occurring in the winter of 2010 (Figure 17). However, no sharks were detected in North Carolina waters in the winter of 2011, while 3 sharks were detected in the northern regions in this same period (Figure 17). Considering the caught-and-released area, 63.8% (n = 37) of these sharks were released in the North, and 36.2% (n = 21) were released in the South. For the sharks released in the North, 94.6% (n = 35) were redetected within the North study area range, while 5.4% (n = 2) were redetected within the South study area (Figure 18a). For sharks released in the South, 28.6% (n = 6) were redetected within the South study area, while 71.4% (n = 15) were redetected within the North study area (Figure 18b). These results further confirm that higher numbers of sharks remained in the original area of release, with lower occurrences of intermixing between the North and the South study areas. The average intermixing rate IR in Cape Cod, based on acoustic tags redetection data, is estimated at 38.4%.

Overall, results from both external and acoustic tags support the hypothesis for the presence of two stocks along the North American Atlantic coast, with Cape Cod as the intermixing ground, and they also suggest the existence of intermixing between these two stocks whose average rate is estimated at between 28.4%-38.4% in the Cape Cod area. Another relevant result is that, based on acoustic redetections, the proportion of female dogfish redetected was significantly higher than the proportion of male dogfish redetected ($\chi^2 = 10.1$; $P = 0.01$), with an odd ratio for sex OR = 3.59. Considering that the majority of redetections came from ACT's acoustic receivers placed in inshore waters, this result suggests that the odds of a female redetection in inshore waters were about 3.6 times higher than the odds of a male being redetected.

Objective 6: To provide a report of publishable quality to the funding agency

As part of the project commitments, the project team presented preliminary results at several national meetings and conferences on elasmobranch and fisheries management. Such presentations included: the 141st Annual Meeting of the American Fishery Society in Seattle, WA, on September 4-8, 2011; the 26th Annual Meeting of the Tidewater Chapter of the American Fisheries Society in Beaufort, NC, on March 8-10, 2012; and the 28th Annual Meeting of the American Elasmobranch Society in Vancouver, Canada, on August 8-14, 2012. In addition, results for objective 3 are under review in the scientific peer reviewed journal *Fisheries Research* for possible publication.

Discussion

Results based on both the external and internal acoustic tags recapture/redetections support the hypothesis for the presence of two main spiny dogfish stocks distributed along the Northwest Atlantic, which can be considered as the US and Canadian stocks, with the Cape Cod and New England area as the natural intermixing ground between them (Figure 16 and 18). The rate of intermixing in this area was previously reported at an estimated 10% (Campana, 2010; Rulifson, 2010a). Our results show an exchange rate for fish north and south of Cape Cod; this exchange rate based on external and acoustic tags combined is about 33.4% (28.4% for external tags recapture and 38.4% for acoustic tags redetections). Our results also indicate that higher recapture rates would be expected with acoustic tags (48.3%) compared to external tags (1.2%). Information about external tags relies on reporting by commercial and recreational fishers. On the other hand, acoustic tags, as they are independent of fishers' observations, provide higher redetections and more detailed information to infer animal behavior, habitat preferences, and temporal migration. However, it should be noted that the actual detection range for tagged animals along the Northwest Atlantic coast is almost entirely limited to inshore coastal waters within state jurisdiction (0-3 nautical miles), with the exception of acoustic receivers placed in the offshore section of the Gulf of Maine and receivers placed and maintained by this project team off Cape Hatteras, NC, which form a line extending 12 miles perpendicular. Therefore, despite a lower recapture rate, results on external tag recaptures might be more useful to infer shark movement patterns in offshore waters, while results on acoustic tags redetections, with the aforementioned exceptions of North Carolina and Gulf of

Maine, are more useful in assessing presence/absence and migratory patterns in inshore coastal waters.

The results for external and acoustic tags both confirm the presence of seasonal migration in the US Atlantic spiny dogfish stock (Figure 15 and 17), which overwinters in North Carolina waters and then migrates northward during the spring to remain in New England waters during summer and until fall, when the stock migrates again southward (Rulifson, 2010a). However, the lack of recaptures/redetections in North Carolina waters during the winter of 2011-12 was unexpected (Figure 15 and 17), based on the knowledge of the migratory pattern for the species (Rulifson, 2010a). The most probable reason is the occurrence in this area of unusual warmer waters during this period, which led the stock of spiny dogfish to remain in the northern regions for a longer period and minimizing the usual large southern seasonal migration in the fall/winter of 2011-12. In support of this conclusion, sampling conducted in February 2012 by members of this same research team for a tagging project on juvenile dogfish off Cape Hatteras, NC (Rulifson, unpublished data – FRG 11-EP-09) saw unexpected low numbers of dogfish, due (we believe) to unusually warmer waters throughout the water column. The average temperature at the surface was about 14 °C, almost 6 °C warmer than usual for the period (C. Hickman, pers. obs.). These results are in accordance with spiny dogfish in the Northwest Atlantic exhibiting water temperature preferences (Sheperd et al. 2002; Sulikowski et al., 2010), and highlight the susceptibility of this stock to specific temperature ranges that, if naturally altered (e.g, climate change), will affect the feasibility of the southern fishery and jeopardize the effectiveness of the TAC allocation system for southern states, such as North Carolina and Virginia. Our acoustic tagging results are also in accordance with other studies reporting a higher occurrence of schools of female dogfish in inshore shallower waters, and a higher occurrence of males in deeper offshore habitats (Shepherd et al., 2002; Methratta and Link, 2007). In particular, in fishery-independent samplings conducted in North Carolina waters, male dogfish were most commonly found in offshore deeper waters along the continental shelf, while female abundance was higher in shallower waters up to a distance of about 50 miles inshore from the continental shelf break (Bangley, 2011). Therefore, these results bring to light the need to extend existing acoustic lines further offshore, possibly to the continental shelf break, in order to increase the chances of redetecting migrating dogfish, particularly adult males. This information will be useful to infer with better confidence migratory patterns and corridors employed by the species for its seasonal migrations.

Results for male:female ratios in fishery-dependent surveys support the idea that the area along the eastern board of the Cape Cod peninsula is characterized by more frequent occurrence of ratio changes as the day progresses, with a higher number of females in late morning and night

(Figure 11h), and a higher number of males occurring at dusk and early in the morning (Figure 11g). It is also important to highlight that these results do not seem to be related to the type of gear and season (Figure 12 and 13). In the North area, our reported sex distribution was consistent with other observed dogfish distributions (Sheperd et al., 2002; Bangley, 2011), with a higher presence of schooling females reported in shallower inshore waters, and similar abundance throughout the day (Figure 10e and 10h). On the contrary, higher numbers of schooling males were caught in the South, where they seem to be more abundant early in the day in inshore shallower waters between spring and late autumn (Figure 11d and 11g).

Results for both external/acoustic tags (Figure 16 and 18) and fishery-dependent catch composition in the study area (Figure 8, 12 and 13) are both in accordance with the reported existence of sexual segregation in spiny dogfish (Ford, 1921). Sexual segregation, which according to Conradt (2005) can be spatial (each sex uses a different distinct area) or temporal (each sex uses the same area but at different times) is a common characteristic in sharks (Springer, 1967). Sexual segregation in sharks can be caused by a variety of factors, such as mating behavior (social avoidance - males are more aggressive than females during copulation) in the small spotted catshark (*Scyliorhinus canicula*) and the nurse shark (*Ginglymostoma cirratum*) (Sims et al., 2001; Pratt and Carrier, 2001), or thermal conditions (females achieve a faster growth rate than males by increasing their body temperature in warmer waters) in the grey reef shark (*Carcharhinus amblyrhynchos*) (Economakis and Lobel, 1998). These studies provide evidence that habitat in sharks may be selected differentially by the sexes for multiple reasons, and further suggest that sexual segregation could be favorably explored for the purpose of commercial exploitation. The possibility for differential exploitation of sharks by sex has not been studied in detail (Mucientes et al., 2009), but could be an important mechanism for enhancing the fishery management and sustainability of important stocks such as the spiny dogfish Northwest Atlantic stock.

We found significant differences in the sex ratio between the North and South study areas. Overall, higher numbers of dogfish were caught with longline, particularly in the South, where a higher male presence seems to occur early in the day in inshore shallower waters between spring and late autumn (Figure 11d, 11g and Table 3). Water depth is the environmental variable most correlated to differences in the sex ratio. Two potential explanations for these differences in sex ratios have been reported in the literature. Shallow waters (North area) can function as a refuge for females to avoid males and energy demanding mating behavior thereby resulting in spatial segregation. In contrast, temporal segregation can occur in deeper areas that cannot provide female refuge to males (South area). In these areas, females likely synchronize their habitat choice to be opposite that of males so to decrease the chance of encountering males, which can be intent in mating and/or feeding behavior (Sims et al., 2001).

The deep area along the eastern seaboard of the Cape Cod peninsula is characterized by a higher presence of schools of males in shallower waters at dusk and early in the morning and a higher number of schools of females encountered between late morning and night in deeper waters (Figure 9, 11d, 11e, 11g, 11h, and Table 3). This behavior is consistent with the social avoidance hypothesis for sexual segregation: as males move toward inshore waters, females move to offshore deeper waters to avoid males and mating behavior. During the spring and summer longline surveys in the South, the majority of males caught had reddened clasper tips indicating the occurrence of a recent mating behavior (Dell'Apa, pers. obs.). Also, within those longline sets the majority of females caught were in an advanced state of pregnancy, likely making them less vulnerable to male courtship (Dell'Apa, pers. obs.). A similar behavior reported by Sims et al. (2001) in the lesser spotted dogfish was interpreted as the result of females choosing to migrate to shallower water refuges as a strategy to reduce energetically demanding mating activity.

Our results are in accordance with available information on the reproductive cycle of spiny dogfish. Females are reported to undergo mating and fertilization right after parturition (Hanchet, 1988). Pups are reported to be born in the fall or early winter, between November to January in the Northwest Atlantic (Nammack et al., 1985). Accordingly, a higher abundance of pregnant females in inshore waters would be predicted in the study area between spring and fall. Although this adult female distribution is shown in the North, it is not apparent in the South, suggesting alternative causes for the presence of sexual segregation in the species.

The occurrence of sexual segregation as observed in the South may be due to forage-related reasons (forage selection), as a consequence of the sexual dimorphism characteristic of the species (Compagno et al., 2005). Dimorphism in body size may result in divergent nutritional and energetic requirements, as larger females likely have higher absolute energy requirements with lower mass-specific costs than smaller males (Schmidt-Nielsen, 1972; Gillooly et al., 2001; Ruckstuhl and Clutton-Brock, 2005). The spiny dogfish is an opportunistic feeder, and the diet of the Northwest Atlantic stock is based primarily on pelagic organisms such as fishes, ctenophores, squid, and secondarily on crustaceans, bivalves, and other invertebrates (Bowman et al., 2000; Link et al., 2002). Studies reporting spiny dogfish feeding habits have rarely discerned between sexes, thus preventing the testing of the forage selection hypothesis to explain the presence of sexual segregation in the species.

In a study investigating the environmental differences in the diet of spiny dogfish off the coast of North Carolina, a distinction between sexes was made and dietary divergence between the sexes was reported, although the sample size of males was small (n=16) (Bangley, 2011). Females were primarily piscivorous (81.01% Index of Relative Importance - IRI), with crustaceans, molluscs and other invertebrates as alternative important prey. In contrast, the diet of males was composed primarily of euphausiid shrimps (66.56% IRI) and secondarily by fish and ctenophores. Interestingly, squid was not found in male stomachs, and Bangley (2011) suggested that the importance of euphausiids and ctenophores in previous studies may have been underestimated due to the rapid digestion of these small soft-bodied prey. These results, although reported from a different area, offer insight into our observed sexual segregation off the South of Cape Cod. Male diurnal vertical movements to inshore shallower waters may be the result of males following their prey, mostly euphausiids. Many species of euphausiids are known to perform diurnal vertical migrations, rising toward the surface at night and descending to deeper waters during the day (Mauchline, 1980). The bathymetry of the area South of Cape Cod (Table 4 and Figure 9) could facilitate the local population of euphausiids to perform diurnal vertical migrations in waters closer to shore, and, in turn, schools of male dogfish can take advantage of this movement toward inshore shallower waters at dusk to feed, as suggested by the higher numbers of males caught with longline (Figures 11a).

During this study, squid was used as bait. Northern shortfin squid (*Illex illecebrosus*) and longfin inshore squid (*Loligo pealeii*) are common prey for spiny dogfish on the Northwest US continental shelf (Bowman et al., 2000; Link et al., 2002). The longfin inshore squid undergoes seasonal offshore migration (MAFMC, 1998), and off Massachusetts larger individuals migrate inshore in April-May while smaller individuals move inshore in the summer (Lange, 1982). Longfin inshore squid are also known to perform diurnal vertical migrations up into the water column at night, then moving to deeper water during the day (MAFMC, 1998; Jacobson, 2005). This squid behavior could also explain the seasonal distribution (June and October) of male dogfish in inshore coastal waters early in the day in the South area, as significantly higher numbers of males were caught with longline compared to gillnet (Figure 11a). Concurrently, females did not show significant differences in catches by gear in the South area, although a higher number was caught with gillnet (Figure 11b). More comprehensive studies on the specific diet composition of spiny dogfish by sex are needed to provide more conclusive findings on the importance of squid in the diet of males, which, in turn, will likely support the conclusion that male movement in the South is due to an opportunistic feeding behavior on local vertically migrating populations of squid.

Local longliners in the North claim to frequently observe higher R values (more males than females) in their catches early in the day with lower value as the day progresses (M. Pratt pers. Comm.). Although this trend was not reflected in our data from the North, our data from the South indicate that changes in R throughout a fishing day do occur (Figures 12), which are caused by the presence of sexual segregation in the species.

Sexual segregation in spiny dogfish in the Cape Cod area is caused by differential behavioral choices by each sex that affect their preferential distribution. Males might move into inshore shallower waters for feeding behavior (forage selection hypothesis) and/or for mating behavior (social factor hypothesis). Concurrently, the presence of males in inshore waters leads to females moving to offshore deeper waters as a male avoidance strategy to avoid energy demanding mating (social factor hypothesis).

The knowledge of this predictable behavior in spiny dogfish could potentially be used to target males in areas where their presence should be predicted as higher due to sexual segregation in the species, although the potential role of sexual segregation for exploiting sharks in relation to fisheries activity has rarely been documented. In a study analyzing the commercial longline catch composition of shortfin mako shark (*Isurus oxyrinchus*) in the South Pacific Ocean (Mucientes et al., 2009), males were found to be more abundant in catches conducted in western waters, whereas adult females where more abundant in eastern catches. The authors concluded with the hypothesis that more intense longlining in the west, occurring over shorter seasonal terms, has the potential for higher catch rates of males and lower catches of females. However, the effect of a male-only directed fishery should be considered cautiously, as selective harvesting can have negative impacts on species fitness and reproductive success (Sato, 2012).

From a management perspective, these results suggest the systematic and predictable presence of schools of male dogfish in an area along the eastern board of the Cape Cod peninsula, as a consequence of temporal sexual segregation in the species. Also, our results suggest that longline gear can potentially catch more dogfish of both sexes in the Cape Cod area, and particularly more males in the South.

Summary of conclusions (bullet form)

- Results with acoustic and conventional external tags suggest the existence of two stocks along the Northwest Atlantic coast, with the Cape Cod and New England area as the natural intermixing ground: the US and Canadian stock, respectively. The estimated average rate of intermixing between these two stocks at the interface is in the range of 28.4-38.4%, and likely decreases quickly with distance from the Cape Cod area.
- Results of acoustic and conventional external tag returns are consistent with the seasonal north-south migration pattern characteristic of the species for the purported US stock.

- There is a consistent and predictable diurnal shift in the male:female ratio within 10 miles of the coastline east of the Cape Cod peninsula, with a higher number of males caught at dusk and early in the day in inshore waters and a higher number of females caught between late morning and night in deeper waters. This sex ratio change seems to be not dependent on season and fishing gear, and suggests the possibility of establishing a male-only directed fishery in the southern study area off the northeast coastal area of the Cape Cod peninsula.
- Results suggest that longline gear can potentially catch more dogfish of both sexes in the Cape Cod area, and particularly more males in the South.

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Table 1: Total numbers of spiny dogfish tagged and released divided by survey, area, fishing gear, and sex.

	Fall 2010		
	Males	Females	Subtotal
North			
Gillnet	33	678	711
Longline	5	660	665
South			
Gillnet	30	558	588
Longline	573	94	667
Subtotal	*641*	*1990*	*2631*
	Spring 2011		
	Males	Females	Subtotal
North			
Gillnet	0	570	570
Longline	4	599	603
South			
Gillnet	30	561	591
Longline	8	584	592
Subtotal	*42*	*2314*	*2356*
	Summer 2011		
	Males	Females	Subtotal
North			
Gillnet	196	473	669
Longline	143	551	694
South			
Gillnet	474	245	719
Longline	650	26	676
Subtotal	*1463*	*1295*	*2758*
Total	**2146**	**5599**	**7745**

Table 2: Total numbers of spiny dogfish tagged with internal acoustic tags and released by area and sex.

	Males	Females	Subtotal
North	18	42	60
South	24	36	60
Total	**42**	**78**	**120**

Table 3: Summary information for all 59 sets included in the male:female ratio changes analysis (NA = data not available): set ID number, date (month/day/year), season, gear, area (N = North, and S = South), deployment time (Settime), retrieval time (Pulltime), average gear depth (m), average temperature (°C) at gear depth, Male:Female Ratio (M:F Ratio), total number of males in the set (Males No), and total number of females in the set (Females No).

Set No	Date	Season	Gear	Area	Settime	Pulltime	Gear Depth (m)	Gear T (°C)	M:F Ratio	Males No	Females No
1	8/9/2011	Summer	Longline	N	6:50	7:04	23.2	9.1	0.37	128	346
2	8/9/2011	Summer	Longline	N	11:22	11:40	17.5	10.3	0.07	15	205
3	6/23/2011	Spring	Gillnet	N	6:50	7:20	38.9	6.8	0	0	137
4	6/23/2011	Spring	Gillnet	N	10:19	10:43	32.9	6.6	0	0	168
5	6/23/2011	Spring	Gillnet	N	11:51	12:09	34.4	6.5	0	0	61
6	6/23/2011	Spring	Gillnet	N	13:07	13:20	39.8	6.7	0	0	21
7	6/23/2011	Spring	Gillnet	N	14:14	14:34	40.7	6.5	0	0	7
8	5/13/2011	Spring	Longline	N	11:55	12:30	28.5	9.1	0.003	2	589
9	5/14/2011	Spring	Longline	N	11:56	13:54	38.4	6.4	0.023	2	8
10	5/17/2011	Spring	Gillnet	N	7:45	8:29	39.4	5.3	0	0	3
11	5/17/2011	Spring	Gillnet	N	8:02	9:10	51.8	4.7	0	0	3
12	5/17/2011	Spring	Gillnet	N	10:54	11:24	50.4	5.7	0	0	21
13	5/17/2011	Spring	Gillnet	N	11:08	12:04	46.7	5.6	0	0	28
14	5/17/2011	Spring	Gillnet	N	14:37	15:42	26.7	9.3	0	0	15
15	10/8/2010	Fall	Gillnet	N	7:05	7:40	20.1	NA	0	0	1
16	10/8/2010	Fall	Gillnet	N	7:10	8:55	20.1	NA	0	0	4
17	10/8/2010	Fall	Gillnet	N	9:35	10:00	29.3	NA	0.1	1	9
18	10/8/2010	Fall	Gillnet	N	9:50	11:00	31.1	NA	0.11	5	45
19	10/8/2010	Fall	Gillnet	N	10:10	11:17	30.2	NA	0	0	10
20	10/8/2010	Fall	Gillnet	N	11:04	11:40	34.7	NA	0.087	2	23
21	10/8/2010	Fall	Gillnet	N	11:28	12:10	40.2	NA	0.25	2	8
22	10/8/2010	Fall	Gillnet	N	12:06	13:08	40.2	NA	0.045	5	111
23	10/8/2010	Fall	Gillnet	N	12:38	14:05	29.3	NA	0.031	5	163
24	10/8/2010	Fall	Gillnet	N	14:41	15:40	38.4	NA	0.049	4	81
25	10/9/2010	Fall	Gillnet	N	7:10	8:24	34.3	NA	0	0	24
26	10/9/2010	Fall	Gillnet	N	7:17	8:52	37.4	NA	0.06	3	51
27	10/9/2010	Fall	Gillnet	N	8:39	10:33	37.4	NA	0.039	3	77
28	10/9/2010	Fall	Gillnet	N	10:52	11:30	35.6	NA	0.04	1	23
29	10/7/2010	Fall	Longline	N	8:04	8:58	37.4	NA	0.006	1	163
30	10/7/2010	Fall	Longline	N	9:03	9:54	38.9	NA	0.004	1	265
31	10/7/2010	Fall	Longline	N	10:00	12:30	38.9	NA	0.009	1	107
32	10/7/2010	Fall	Longline	N	12:35	12:50	43.5	NA	0.019	1	53
33	10/7/2010	Fall	Longline	N	12:55	13:25	43.5	NA	0.019	1	53
34	10/7/2010	Fall	Longline	N	13:30	13:40	43.5	NA	0	0	14
35	8/10/2010	Summer	Gillnet	N	11:33	12:05	17.1	9.9	0.013	1	78
36	8/10/2010	Summer	Gillnet	N	11:46	12:20	15.9	10.1	0.017	1	59
37	8/10/2010	Summer	Gillnet	N	12:47	14:00	12.7	10.8	0	0	51
38	8/10/2010	Summer	Gillnet	N	13:49	15:10	18.6	9.9	0	0	43
39	8/10/2010	Summer	Gillnet	N	14:05	16:02	10.1	10.9	0	0	36
40	8/14/2011	Summer	Longline	S	7:44	8:00	25.4	9.9	39.9	479	12
41	8/14/2011	Summer	Longline	S	10:32	10:49	28.9	8.4	10.63	117	11
42	8/14/2011	Summer	Longline	S	11:34	11:44	24.7	9.1	18,00	54	3
43	8/17/2011	Summer	Gillnet	S	2:56	7:46	27.9	9.6	0.31	19	45
44	8/17/2011	Summer	Gillnet	S	2:34	9:15	37.8	8.5	0.42	47	152
45	8/17/2011	Summer	Gillnet	S	11:31	13:19	25.3	NA	3.73	164	4
46	8/17/2011	Summer	Gillnet	S	8:57	11:45	28.3	10.5	5.55	244	44
47	6/24/2011	Spring	Longline	S	10:26	10:43	33.2	6.6	0.013	8	584
48	6/27/2011	Spring	Gillnet	S	15:07	15:42	71.8	5.9	0	0	48
49	6/27/2011	Spring	Gillnet	S	15:22	16:45	67.9	5.9	0	0	110
50	6/27/2011	Spring	Gillnet	S	16:32	NA	77.7	5.8	0	0	88
51	6/27/2011	Spring	Gillnet	S	17:51	19:10	72	5.9	0.026	2	77
52	6/27/2011	Spring	Gillnet	S	19:00	20:22	69.6	6.2	0.034	1	29
53	6/28/2011	Spring	Gillnet	S	20:05	5:10	66	6	0.34	16	47
54	6/28/2011	Spring	Gillnet	S	21:20	6:23	63.3	6.1	0.27	9	33
55	6/28/2011	Spring	Gillnet	S	7:35	8:06	73.8	6.1	0	0	24
56	6/28/2011	Spring	Gillnet	S	7:47	9:00	75.2	5.9	0.06	9	106
57	10/11/2010	Fall	Longline	S	8:11	8:25	20.7	NA	21.6	194	9
58	10/11/2010	Fall	Longline	S	9:40	9:52	20.7	NA	4.9	309	63
59	10/11/2010	Fall	Longline	S	11:55	12:06	20.7	NA	3.2	70	22

Table 4: Range and mean with ± standard deviation of bottom temperature (°C), surface temperature (°C), water depth (m), and surface salinity for the North and South. Associated statistics (Wicoxon t.test - W and significance – P value). Marked values are significant at 0.05 level.

Environmental parameter	North	South	Statistic
Bottom temperature (°C)	4.7 - 10.9; 7.9 ± 2.1	5.8 - 10.5; 7.3 ± 1.7	W = 185.5; P = 0.27
Surface temperature (°C)	8.9 - 19.2; 14.4 ± 3.5	14.5 - 19.6; 17.4 ± 1.5	W = 70.5; P = 0.003*
Water depth (m)	10.1 - 51.8; 33 ± 10.4	20.7 - 77.7; 46.5 ± 23	W = 308; P = 0.19
Surface salinity	29.4 - 31.4; 30.3 ± 0.7	29.3 - 30.8; 30.2 ± 0.4	W = 162.5; P = 0.74

Table 5: Spearman's correlation (ρ) coefficients between the dependent variable male:female ratio (R) and average gear depth (m), average temperature (°C) at gear depth, surface water temperature (°C) and salinity for each set conducted in the North area, and in the South area. Marked values are significant at 0.05 level.

M:F Ratio	Gear Depth	Gear T	Surface water temperature	Surface water salinity
North	-0.05	0.310	0.092	0.396*
South	-0.810*	0.774*	-0.190	0.308

Table 6: Summary of the Chi-square, G test and F-values of Kruskal-Wallis single factor ANOVA for the distribution of male:female ratio, the total number of males per set, the total number of females per set, the average size (mm) of males per each set, and the average size (mm) of females per each set within consecutive sets conducted on October 11, 2010 (longline), August 14, 2011 (longline) and August 17, 2011 (gillnet) in the South area. Significant results are indicated by an asterisk (*α<0.05, **α<0.001).

	October 11, 2010	August 14, 2011	August 17, 2011
Male:Female Ratio	G=19.1**	χ^2=20.3**	G=87**
Male No per set	χ^2=149.6**	χ^2=485.6**	χ^2=277**
Female No per set	χ^2=50.7**	G=6.5*	G=197**
Male average size per set	F=0.9	F=4.3	F=2.7
Female average size per set	F=10.5**	F=1.72	F=16.5**

Table 7: Summary information for all 15 sets conducted in the Fall of 2010 in Rhode Island (Little Compton) (NA = data not available): set ID number, date (month/day/year), season, gear, area (S = South), deployment time (Settime), retrieval time (Pulltime), Male:Female Ratio (M:F Ratio), total number of males in the set (Males No), and total number of females in the set (Females No).

Set No	Date	Season	Gear	Area	Settime	Pulltime	Depth (m)	M:F Ratio	Males No	Females No
60	10/11/2010	Fall	Gillnet	S	7:30	8:30	34.7	0	0	30
61	10/11/2010	Fall	Gillnet	S	9:15	10:30	36.6	0.2	4	20
62	10/11/2010	Fall	Gillnet	S	11:24	12:30	34.7	0.064	3	47
63	10/11/2010	Fall	Gillnet	S	13:17	14:15	35.3	0.059	3	51
64	10/12/2010	Fall	Gillnet	S	15:00	8:11	38.4	0.014	1	70
65	10/12/2010	Fall	Gillnet	S	7:37	9:40	38.4	0.250	6	24
66	10/12/2010	Fall	Gillnet	S	9:23	10:55	NA	0	0	2
67	10/12/2010	Fall	Gillnet	S	10:07	12:58	NA	0.3	3	10
68	10/12/2010	Fall	Gillnet	S	11:41	12:58	NA	0	0	2
69	10/13/2010	Fall	Gillnet	S	5:22	8:07	NA	0.052	7	135
70	10/13/2010	Fall	Gillnet	S	6:02	9:30	NA	0.043	2	46
71	10/13/2010	Fall	Gillnet	S	9:17	11:27	NA	0	0	11
72	10/13/2010	Fall	Gillnet	S	10:14	12:27	34.1	0	0	51
73	10/13/2010	Fall	Gillnet	S	11:45	14:49	36	0.042	1	24
74	10/13/2010	Fall	Gillnet	S	13:06	15:19	34.7	0	0	35

Table 8: Summary of the spiny dogfish detected in the Hatteras Bight (a) and by the ACT along the US Atlantic coast (b) between October 2010 and August 2012.

a) Cape Hatteras acoustic array

ID No	Sex	Length (mm)	Day released	Release area	Total detections	VR2W Location	Days detected
46339	F	888	10/11/2010	S (Chatham, MA)	61	Site 4	2/16/2011
46351	F	854	10/12/2010	S (Rhode Island)	118	Sites 1-4-5	1/30-31/2011
46359	F	896	10/12/2010	S (Rhode Island)	5	Site 1	2/15/2011
46362	F	854	10/11/2010	S (Chatham, MA)	29	Site 7	1/10/2011
46368	F	850	10/9/2010	N (Cape Cod)	6	Site 1	4/1/2011

b) Atlantic Cooperative Tagging (ACT) acoustic arrays

ID No	Sex	Length (mm)	Day released	Release area	Total detections	Detection area	Days detected
46248	F	744	8/14/2011	S (Cape Cod)	5	Central Maine Shelf, ME	12/20/2011
					117	Central Maine Shelf, ME	12/9-10/2011
46261	F	908	8/9/2011	N (Cape Cod)	112	East Provincetown, MA	9/18/2011
46263	M	701	8/9/2011	N (Cape Cod)	59	East Provincetown, MA	9/13-14-15/2011
					386	East Provincetown, MA	9/20-21/2011
46267	M	766	8/14/2011	S (Chatham, MA)	21	East Provincetown, MA	9/4/2011
					44	North Cape Cod Bay, MA	9/18-19-20/2011
46269	F	929	8/9/2011	N (Cape Cod)	55	North Cape Cod Bay, MA	8/13-14/2011
					87	East Provincetown, MA	9/25-26/2011
					70	North Cape Cod Bay, MA	6/29/2012
					74	North Cape Cod Bay, MA	7/1/2012
					30	Boston Bay, MA	7/2-3/2012
46271	F	831	8/17/2011	S (Chatham, MA)	8	East Provincetown, MA	8/19/2011
46275	M	771	8/10/2011	N (Cape Cod)	18	North Cape Cod Bay, MA	8/13-14/2011
46276	F	819	8/10/2011	N (Cape Cod)	47	North Cape Cod Bay, MA	8/13/2011
46279	M	788	8/10/2011	N (Cape Cod)	24	East Provincetown, MA	10/3/2011
46280	M	774	8/9/2011	N (Cape Cod)	15	East Provincetown, MA	10/21/2011
46282	M	783	8/10/2011	N (Cape Cod)	228	East Provincetown, MA	9/13-14-18-23/2011
46283	F	832	8/10/2011	N (Cape Cod)	156	North Cape Cod Bay, MA	8/13/2011
46284	F	919	8/10/2011	N (Cape Cod)	93	North Cape Cod Bay, MA	8/13-16/2011
46287	F	869	8/14/2011	S (Chatham, MA)	215	East Provincetown, MA	8/19-20-21/2011
46288	M	780	8/14/2011	S (Chatham, MA)	18	East Provincetown, MA	8/21/2011
46292	F	826	8/10/2011	N (Cape Cod)	21	North Cape Cod Bay, MA	7/3/2012
46294	F	941	6/24/2011	S (Chatham, MA)	65	North Cape Cod Bay, MA	7/7/2011
46296	F	890	6/23/2011	N (Cape Cod)	15	North Cape Cod Bay, MA	6/27/2011
46297	F	855	6/23/2011	N (Cape Cod)	7	North Cape Cod Bay, MA	6/29/2011
					136	East Provincetown, MA	8/4-5/2012

Table 8 continues:

ID No	Sex	Length (mm)	Day released	Release area	Total detections	Detection area	Days detected
46299	M	766	6/24/2011	S (Chatham, MA)	124	East Provincetown, MA	9/13-14/2011
46300	F	832	6/27/2011	S (Chahtam, MA)	34	North Cape Cod Bay, MA	7/6-8/2011
46301	F	881	6/27/2011	S (Chahtam, MA)	134	North Cape Cod Bay, MA	7/5-7-8/2011
					8	East Provincetown, MA	7/30/2011
46302	F	922	6/27/2011	S (Chatham, MA)	15	Gloucester, MA	7/5/2011
46303	F	948	6/27/2011	S (Chatham, MA)	9	East Provincetown, MA	7/30/2011
46304	F	880	6/24/2011	S (Chatham, MA)	53	North Cape Cod Bay, MA	7/2-3/2011
46307	F	848	6/27/2011	S (Chatham, MA)	39	North Cape Cod Bay, MA	7/7-8/2011
46308	F	925	6/27/2011	S (Chatham, MA)	12	North Cape Cod Bay, MA	7/7/2011
					9	North Cape Cod Bay, MA	7/2/2012
46309	F	884	6/27/2011	S (Chatham, MA)	58	North Cape Cod Bay, MA	7/7-8/2011
					25	East Provincetown, MA	8/5/2012
46313	F	881	6/23/2011	N (Cape Cod)	26	North Cape Cod Bay, MA	6/26-28/2011
					160	North Cape Cod Bay, MA	7/7-8/2011
46314	F	940	6/23/2011	N (Cape Cod)	37	North Cape Cod Bay, MA	6/28/2011
					29	North Cape Cod Bay, MA	7/2-3/2011
					21	East Provincetown, MA	8/8/2011
					75	East Provincetown, MA	8/4-5/2012
46315	F	795	5/14/2011	N (Cape Cod)	45	North Cape Cod Bay, MA	8/13-17/2011
					7	Central Maine Shelf, ME	12/28/2011
46316	F	800	5/14/2011	N (Cape Cod)	69	North Cape Cod Bay, MA	7/8/2011
46318	F	839	5/14/2011	N (Cape Cod)	86	North Cape Cod Bay, MA	7/2/2011
					22	East Provincetown, MA	7/17/2011
46319	F	857	5/14/2011	N (Cape Cod)	29	North Cape Cod Bay, MA	6/13-20/2011
46320	F	780	5/14/2011	N (Cape Cod)	29	East Provincetown, MA	5/18/2011
					114	North Cape Cod Bay, MA	7/7-8/2011
46322	F	833	5/17/2011	N (Cape Cod)	67	North Cape Cod Bay, MA	6/28-29/2011
					45	East Provincetown, MA	9/18-24/2011
					237	North Cape Cod Bay, MA	6/17-19-24-25/2012
					31	North Cape Cod Bay, MA	7/2/2012
					1269	Boston Bay, MA	7/7-8-9/2012
46323	F	842	5/17/2011	N (Cape Cod)	90	North Cape Cod Bay, MA	7/5-8-30/2011
					92	East Provincetown, MA	9/24/2011
46324	M	768	5/14/2011	N (Cape Cod)	10	Central Maine Shelf, ME	10/15/2011
46325	M	744	5/14/2011	N (Cape Cod)	30	East Provincetown, MA	8/1-25/2011
					644	East Provincetown, MA	9/20-21-22/2011
46326	F	915	5/17/2011	N (Cape Cod)	31	North Cape Cod Bay, MA	6/28/2011
					22	North Cape Cod Bay, MA	8/14/2011
46327	F	884	6/27/2011	S (Chatham, MA)	5	North Cape Cod Bay, MA	7/7/2011
					37	East Provincetown, MA	7/16/2011
46328	F	901	5/17/2011	N (Cape Cod)	16	North Cape Cod Bay, MA	6/26/2011
					14	East Provincetown, MA	8/10/2011
46329	F	915	5/17/2011	N (Cape Cod)	108	East Provincetown, MA	8/6-7-12-21/2011
					57	Boston Bay, MA	6/7/2012
					172	North Cape Cod Bay, MA	6/24-28-29/2012
46331	F	880	6/23/2011	N (Cape Cod)	5	Gloucester, MA	6/25/2011
46332	F	894	6/23/2011	N (Cape Cod)	15	East Provincetown, MA	6/27/2011
46337	F	1004	10/11/2010	S (Chatham, MA)	12	Barletts Reef, CT	6/13/2011
46341	M	731	10/9/2010	N (Cape Cod)	8	Gloucester, MA	9/19/2011
46345	F	815	10/9/2010	N (Cape Cod)	137	Plymouth Bay, MA	9/24/2011
46346	F	870	10/9/2010	N (Cape Cod)	3	North Cape Cod Bay, MA	7/3/2012
46348	F	875	10/9/2010	N (Cape Cod)	134	East Provincetown, MA	7/27-28/2012
					131	East Provincetown, MA	8/4-5/2012
46355	F	937	10/8/2010	N (Cape Cod)	70	Massachusetts Bay, MA	10/29/2010
					126	North Cape Cod Bay, MA	6/23-28-30/2012
46366	F	767	10/8/2010	N (Cape Cod)	108	East Provincetown, MA	8/4-5/2012
46372	F	900	10/8/2010	N (Cape Cod)	3	Gloucester, MA	7/7/2011

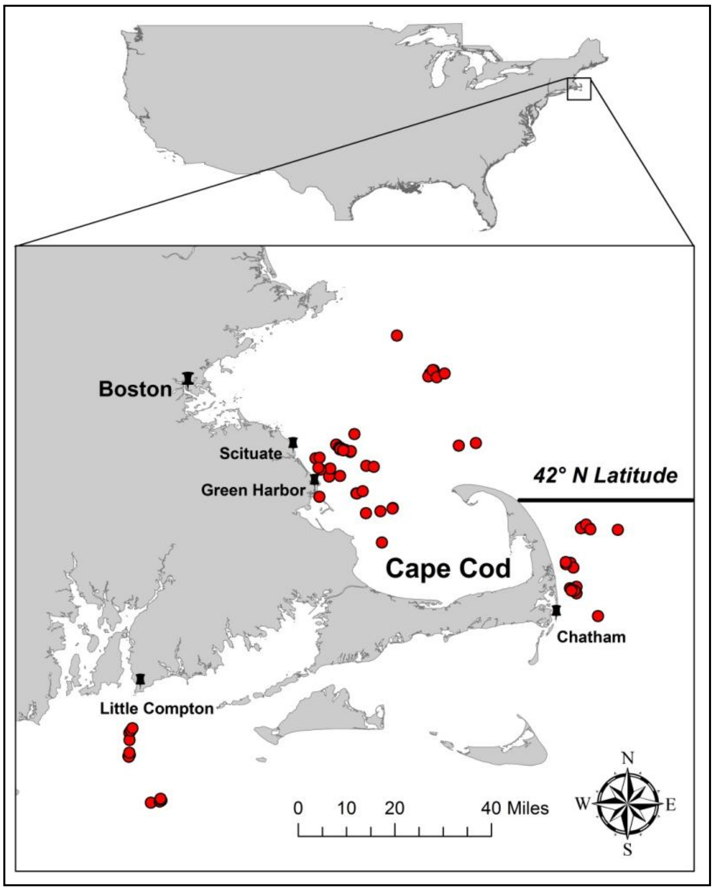

Figure 1: Map of the study area and location (red dots) of all fishery-dependent surveys conducted between October 2010 and August 2011. Black solid horizontal line indicating the 42° N Latitude separating the North and the South study area.

Figure 2: Yellow external tag and red external button tag, with reward information, to indicate the presence of an internal acoustic tag into the shark.

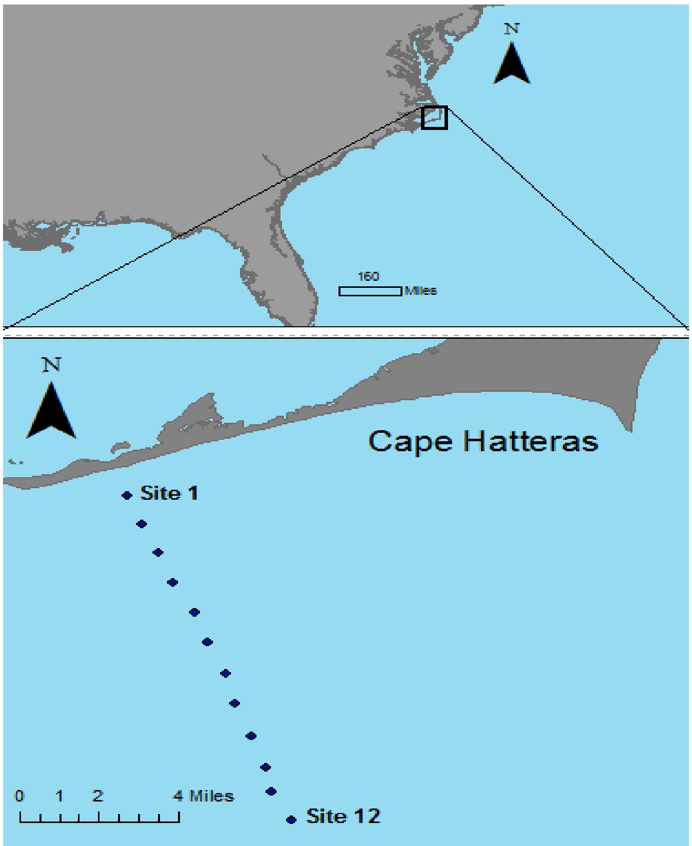

Figure 3: Location sites for the 12 VEMCO VR2W receivers deployed off Cape Hatteras, North Carolina.

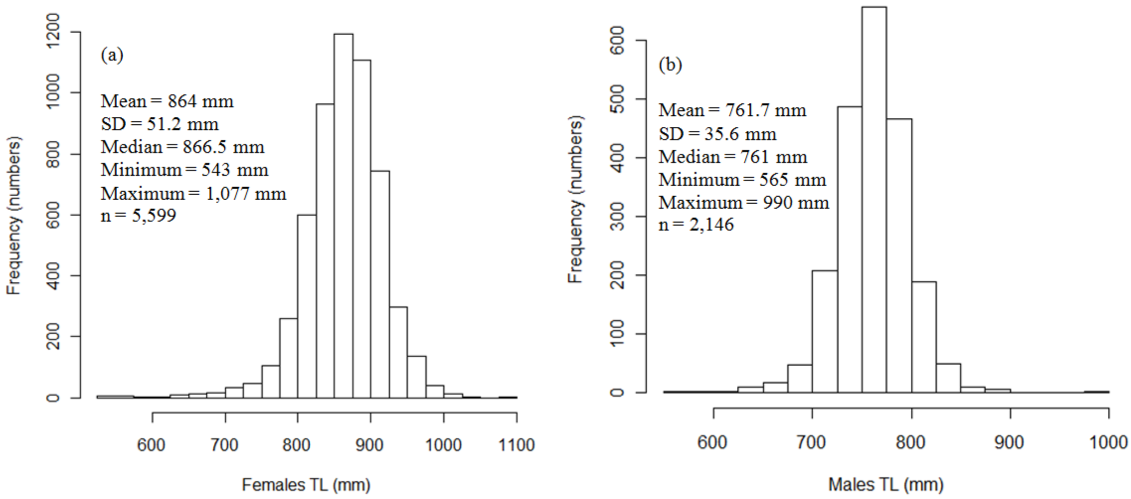

Figure 4: Total length (mm) frequency (numbers of sharks), and summary statistics of females (a) and males (b) caught, tagged, and released in October 2010, May, June, and August 2011.

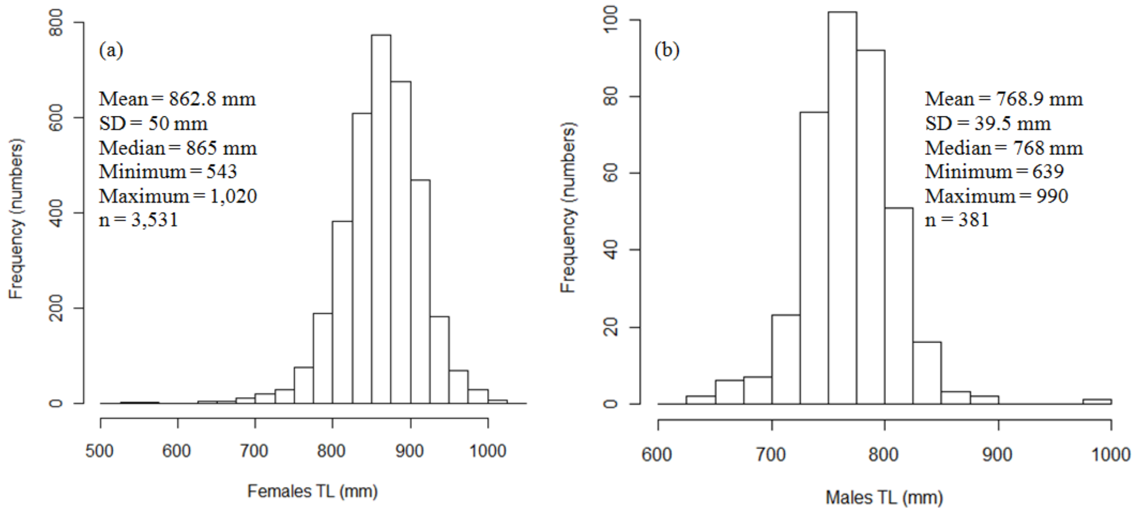

Figure 5: Total length (mm) frequency (numbers of sharks), and summary statistics of females (a) and males (b) caught, tagged, and released in the North study area in October 2010, May, June, and August 2011.

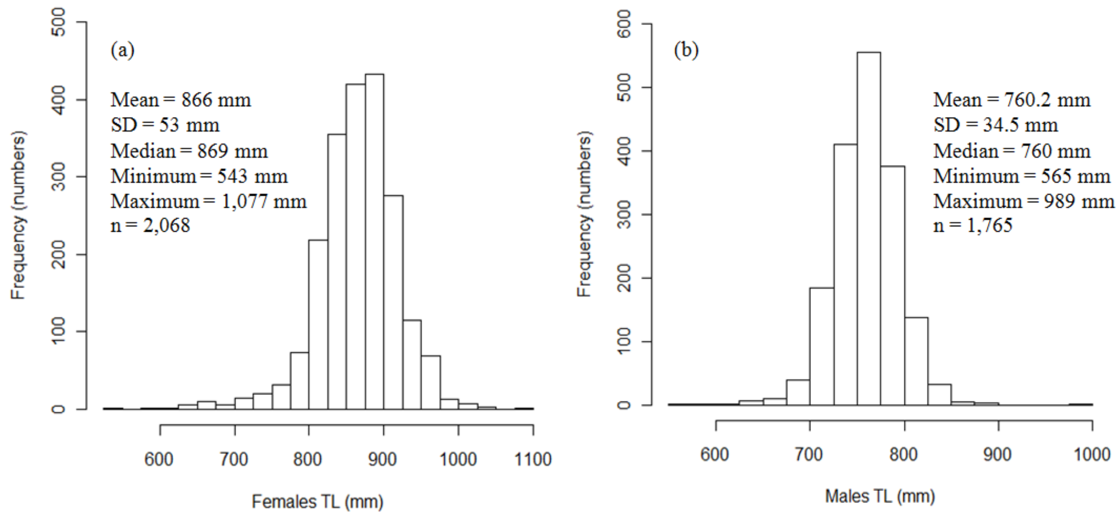

Figure 6: Total length (mm) frequency (numbers of sharks), and summary statistics of females (a) and males (b) caught, tagged, and released in the South study area in October 2010, May, June, and August 2011.

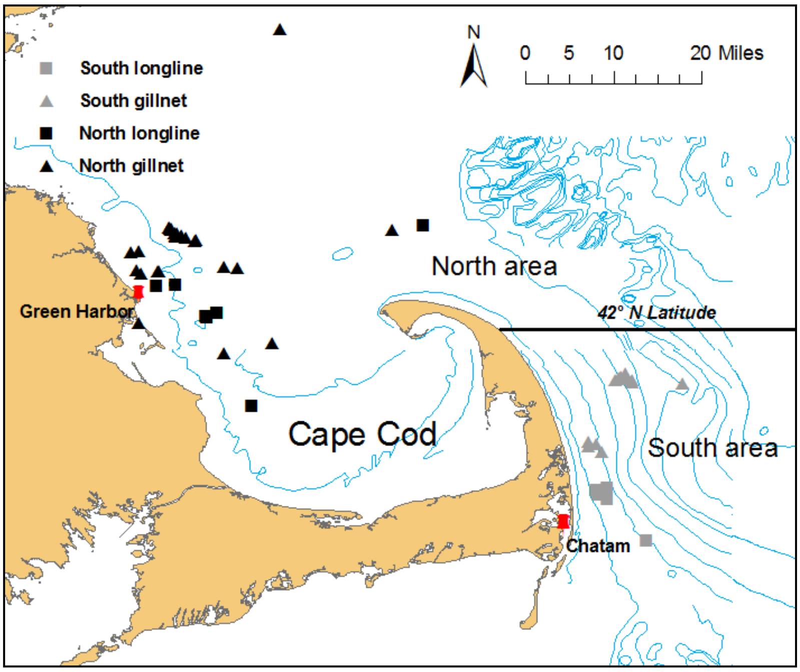

Figure 7: Map of the area and location of all sets (n = 59) included in the male:female ratio (R) changes analysis divided by area (black for North and grey for South) and gear (squares for longline and triangles for gillnet). Black solid horizontal line indicating the 42° N Latitude separating the North and the South study area.

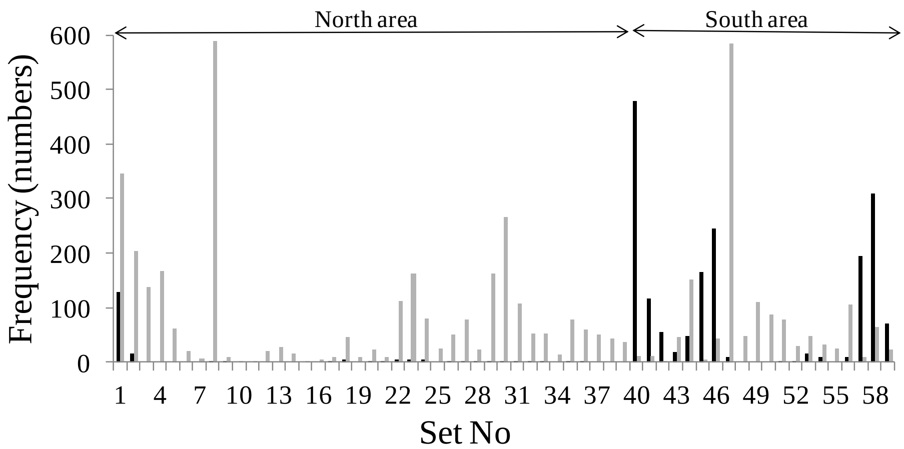

Figure 8: total numbers of males (black bars) and females (grey bars) caught in each set in the North (sets 1 to 39) and in the South (sets 40 to 59).

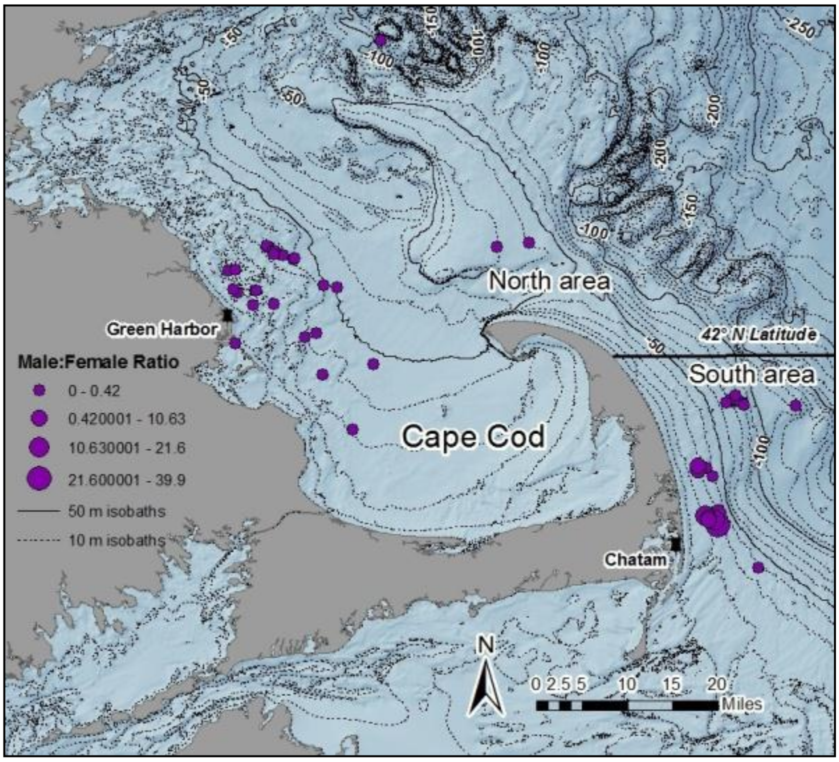

Figure 9: Male:Female Ratio (R) recorded for each set (n = 59) conducted in the North and in the South (purple dots) included in the R changes analysis, with 10 m isobaths (dashed lines) and 50 m isobaths (solid line). Black horizontal solid line indicating the 42° N Latitude separating the North and the South study area. Source for bathymetry: NOAA Geophysical Data Center (NGDC).

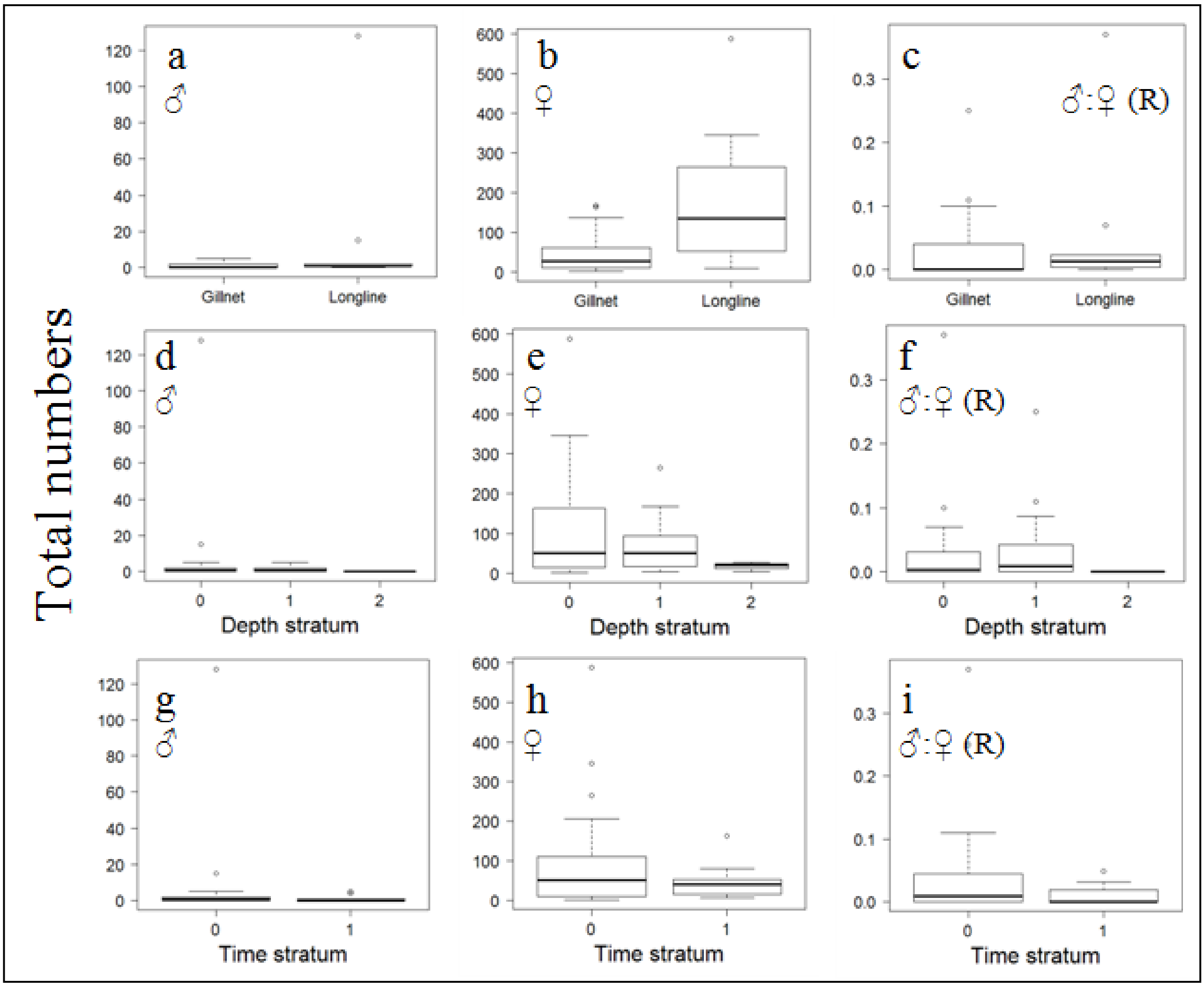

Figure 10: Box (percentiles) and whisker (non-outlier range; outliers denoted by open circles) plots of males (a), females (b), and male:female ratio (c) caught across gear; plots of males (d), females (e), and male:female ratio (f) caught across depth strata (stratum 0 = 0-29.9 m; stratum 1 = 30-44.9 m; stratum 2 = >45 m); plots of males (g), females (h), and male:female ratio (i) caught across time strata stratum (0 = 6:00 – 12:59; stratum 1= 13:00 – 18:59) in the North area.

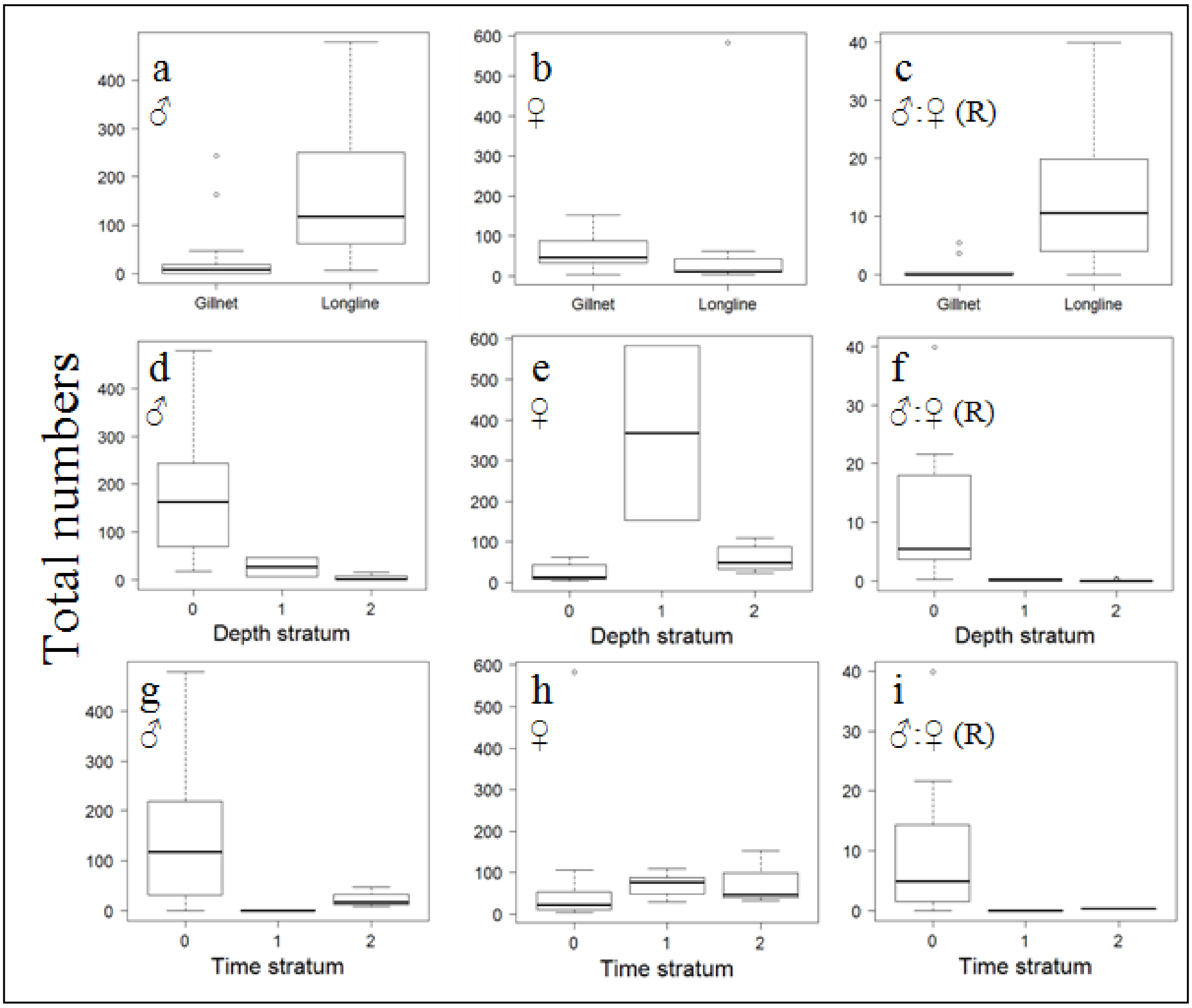

Figure 11: Box (percentiles) and whisker (non-outlier range; outliers denoted by open circles) plots of males (a), females (b), and male:female ratio (c) caught across gear; plots of males (d), females (e), and male:female ratio (f) caught across depth strata (stratum 0 = 0-29.9 m; stratum 1 = 30-44.9 m; stratum 2 = >45 m); plots of males (g), females (h), and male:female ratio (i) caught across time strata stratum (0 = 6:00 – 12:59; stratum 1= 13:00 – 18:59; stratum 2= 19:00 – 5:59) in the South area.

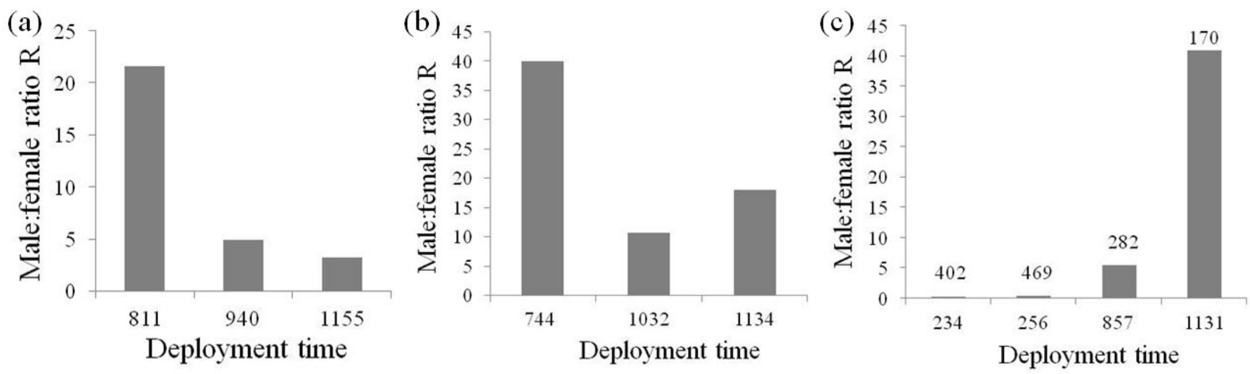

Figure 12: Male:female ratio (R) recorded in consecutive sets conducted in the South on October 11, 2010 with longline (a), on August 14, 2011 with longline (b), and on August 17, 2011 with gillnet, with numbers indicating total soaking time (minutes) for each set (c).

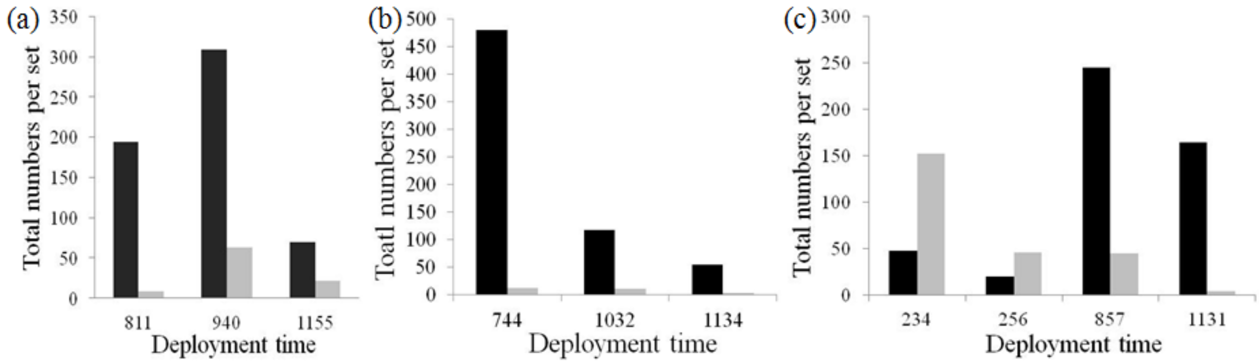

Figure 13: Total numbers of males (black bars) and females (grey bars) caught in consecutive sets conducted in the South on October 11, 2010 with longline (a), on August 14, 2011 with longline (b), and on August 17, 2011 with gillnet (c).

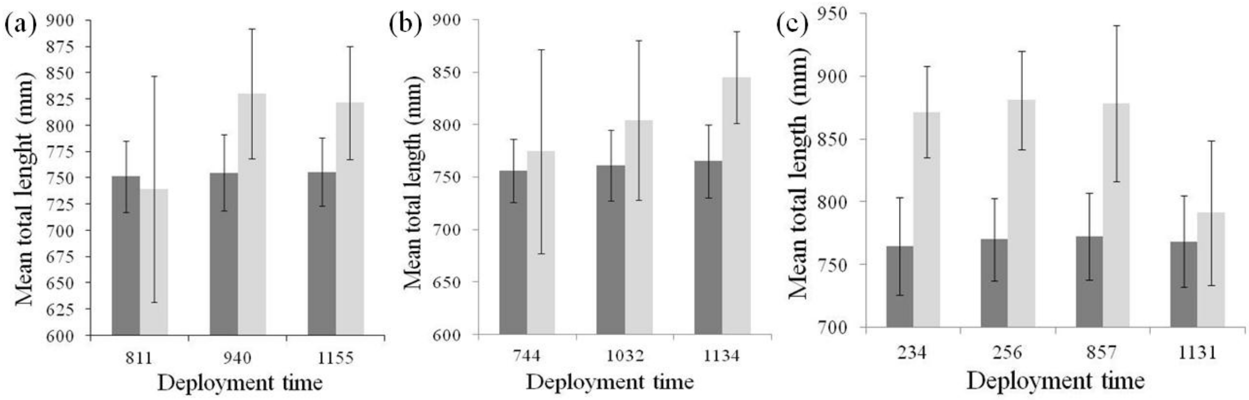

Figure 14: Average male (darker bars) and female (lighter bars) total length (mm, ± SD) for consecutive sets conducted in the South on October 11, 2010 with longline (a), on August 14, 2011 with longline (b), and on August 17, 2011 with gillnet (c).

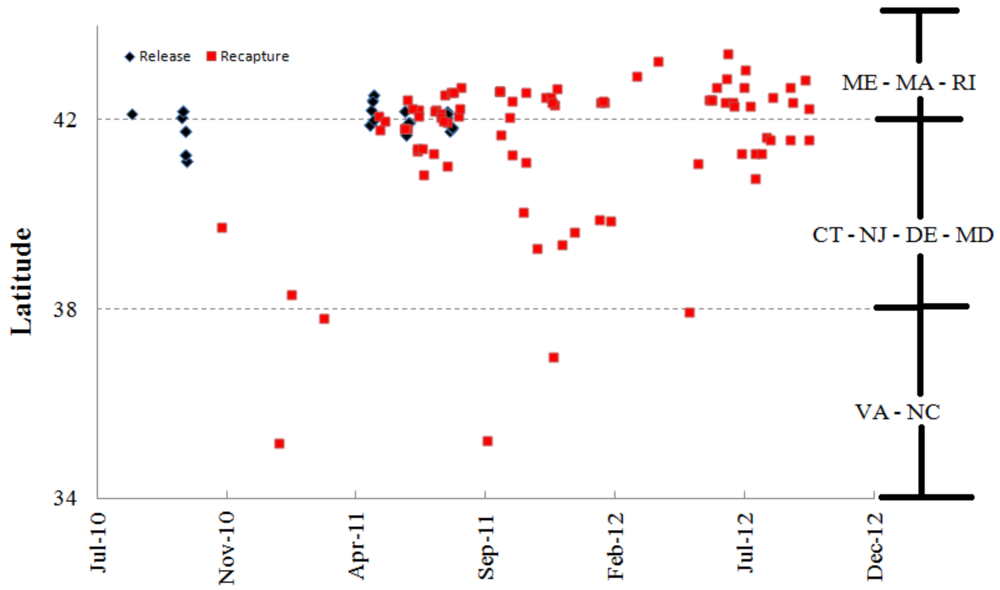

Figure 15: Latitude position (decimal degree) and date (month and year) for releases (black diamonds) and recaptures (red squares) of sharks tagged and released with external tags, with corresponding marine coastal areas along the Northwest Atlantic (n = 86, 4 missing data for recapture positions). ME = Maine, MA = Massachusetts, RI = Rhode Island, CT = Connecticut, NJ = New Jersey, DE = Delaware, MD = Maryland, VA = Virginia, NC = North Carolina.

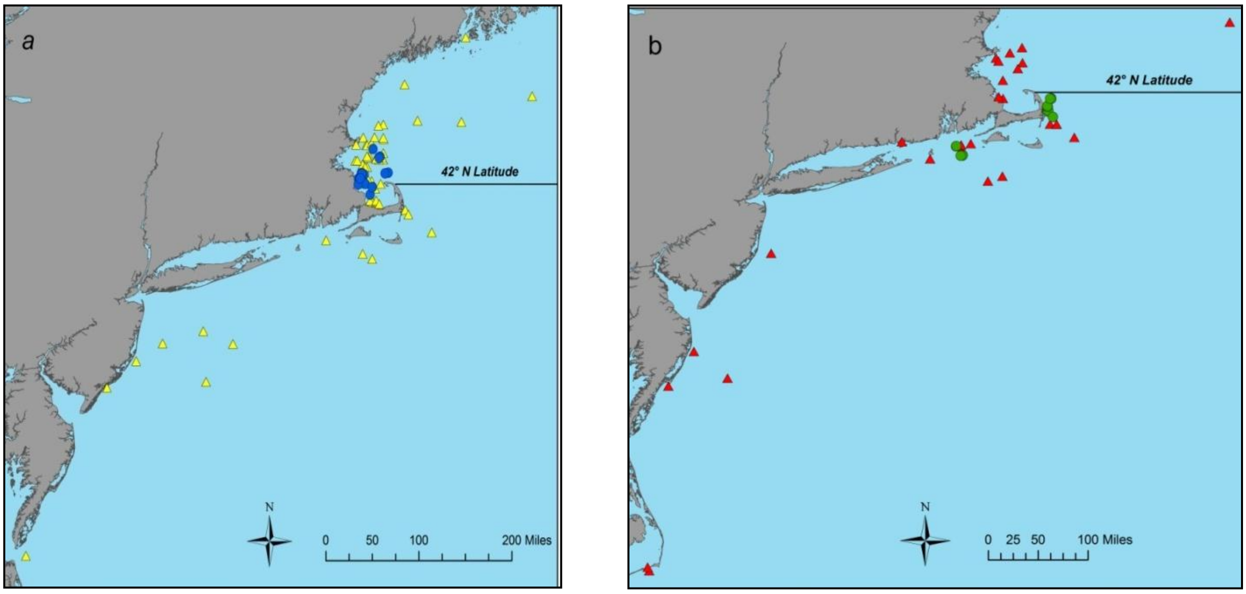

Figure 16: Release (blue dots in the North and green dots in the South) and recapture (yellow triangles in the North and red triangles in the South) sites for sharks tagged with external tags in the North (a) and in the South (b). Black horizontal solid line indicating the 42° N Latitude separating the North and the South study area.

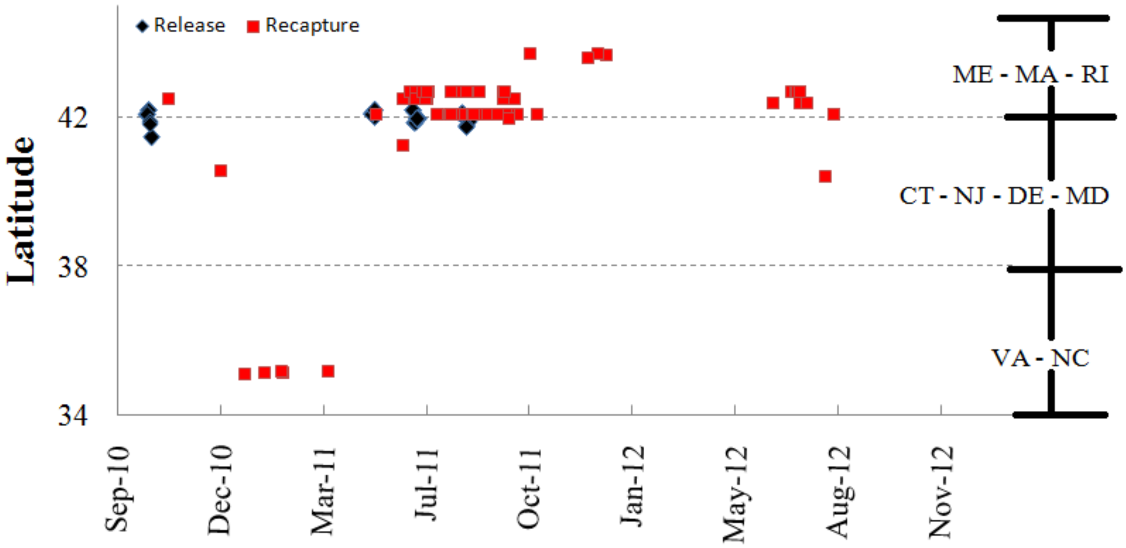

Figure 17: Latitude position (decimal degree) and date (month and year) for releases (black diamonds) and recaptures (red squares) of sharks tagged and released with internal acoustic tags, with corresponding marine coastal areas along the Northwest Atlantic (n = 58). ME = Maine, MA = Massachusetts, RI = Rhode Island, CT = Connecticut, NJ = New Jersey, DE = Delaware, MD = Maryland, VA = Virginia, NC = North Carolina.

Figure 18: Release (blue dots in the North and green dots in the South) and recapture (yellow triangles in the North and red triangles in the South) sites for sharks tagged with internal acoustic tags in the North (a) and in the South (b). Black horizontal solid line indicating the 42° N Latitude separating the North and the South study area.