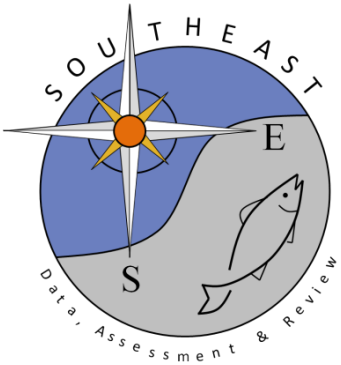
Long-term trends in sandbar shark (*Carcharhinus plumbeus*) CPUE from 2003 – 2023 near Sarasota, Florida

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Long-term trends in sandbar shark (*Carcharhinus plumbeus*) CPUE from 2003 – 2023 near Sarasota, Florida

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1 Introduction

The Mote Large Shark Survey (LSS) was initiated in 2003 to assess population trends in large coastal sharks in the Sarasota, FL, region. It has been maintained since that time with a few gaps occurring due to funding lapses. This paper provides trend information for sandbar sharks (*Carcharhinus plumbeus*) from 2003-2022.

2 Methods

2.1 Study area and survey design

Sarasota (27.3365° N, 82.5310° W) is located along Florida's central Gulf of Mexico coast. Fisheries-independent surveys for large coastal sharks (henceforth referred to as large shark surveys, or LSS) were conducted from 2001 to 2023 primarily using the *R/V Eugenie Clark*, a 50-foot research vessel, but other vessels were used if the primary research vessel was unavailable. LSS were conducted along the Gulf coast from south Tampa Bay to Sanibel Island, though four sampling locations were considered to be the "core" study area (Anna Maria, Longboat Pass, New Pass, Midnight Pass) (Figure 1). Anna Maria, Longboat Pass and New Pass sampling sites were located near passes which connect the Gulf of Mexico to inshore waters; Midnight Pass used to be a pass until it was closed in 1983. LSS occurred each season, with specific months being targeted to reduce variation in seasonal comparisons: winter (December – February, target was December), spring (March – May, target was March). summer (June – August, target was June), and fall (September – November, target was September). If weather in the target month was not conducive for surveys, another month within the season was sampled. December surveys were assigned to the winter of the following calendar year; for example, December 2004 was considered the winter season for 2005, and December 2005 was considered the winter season for 2006, and so on. Sampling was not consistent over years or seasons due to funding constraints. The core Sarasota sampling locations were sampled the most consistently over the time period; thus, the analyses used data collected from these core locations only.

LSS utilized two different gear types: single hook drumlines and longlines, but longlines did not begin until 2003; therefore, the analyses include 2003 to 2023 when both gear types were used (see sampling effort summary in Supplemental 1). Single hook drumlines consisted of a cement block anchor attached to a 20-40 m line (depending on water depth) running to a surface float, and a 30 m heavy monofilament gangion (800 lb test) secured to the bottom anchor by a swivel and terminating with a baited circle hook (18/0). Ten drumlines were deployed primarily between 0.5 nm to 9 nm perpendicular to shore and individual drumlines were set approximately 1 - 1.5 km apart. Drumlines were soaked for 2 to 4 hours (0.65 – 11.83 hrs, median = 3.30 hrs) before being checked for sharks and/or re-baited. Longlines were typically set with a target of 100 hooks (9/0 J or 18/0 circle), but ranged between 45-117 hooks over the study period. Longlines consisted of 3 m gangions with a 1 m leader (stainless steel or monofilament) and an approximately 1.6 km mainline. Similar to the drumlines, the gear was typically soaked for 2 to 4 hours (1.73 – 19.72 hrs, median = 4.83 hrs) before being checked. Longline sets began near the middle of the drumline distribution and extended parallel to shore (Figure 1).

Most sharks were tagged with dart tags before release for external identification. Additional measurements and samples were collected depending on research project needs. All methods were approved by Mote Marine Laboratory's Institutional Animal Care and Use Committee (IACUC).

2.2 Data treatment

Data collected during LSS were filtered to only include sandbar sharks caught in the core sampling area. Using these data, we calculated the total number of sandbar sharks sampled per sampling day per gear type. For each sampling day, we calculated the total number of decimal hook hours in order to standardize the shark catch data by effort. If hook hours were not available for a set, the set (e.g., individual drumline) was dropped from the analysis. To help explain variation in shark counts over time, we also included the following covariates: season (categorical variable with levels: winter, spring, summer, fall), year (continuous variable), red tide presence (categorical variable, 0 = red tide absent, 1 = red tide present – see below for details), and predicted sea surface temperature (SST) average, minimum and maximum (see below for details) to test environmental and temporal variables that may influence shark counts. Data visualizations and preliminary analyses suggested combining summer and fall seasons into one season as the sandbar shark count in these periods was nearly zero. Below are additional processing details pertaining to red tide and temperature data.

1. Red tide: To determine if a *Karenia brevis* harmful algal bloom, or red tide, was present along the coast during sampling days, we downloaded *K. brevis* cell counts from NOAA's National Centers for Environmental Information, Harmful Algal BloomS Observing System (https://habsos.noaa.gov/). The sampling locations were plotted using ArcGIS Pro. Locations ranging from the northern tip of Anna Maria Island (27.5499° N, 82.7555° W) to south of Venice Inlet (27.0944° N, 82.4596° W) and up to approximately 13 nm off the coast were exported for further analysis. Data were transformed to projection NAD 1983 UTM Zone 17N prior to mapping. If *K. brevis* cell counts exceeded 100,000 cells/L, the threshold typically required for fish kills (Quick and Henderson 1975, Landsbert and Steidinger 1998), in at least two samples within 30-days prior to the LSS sampling date, red tide was considered present (red tide = 1), otherwise red tide was considered absent

(red tide = 0). This definition of red tide presence is consistent with previous published work (Gannon et al. 2009). If no samples were collected 30-days prior to the LSS sampling date, red tide was considered absent unless sufficient evidence suggested a bloom was present (this only occurred once during winter 2006 where multiple samples >100,000 cells/L were collected 32-days before LSS survey was conducted, but no samples were collected within 30 days).

2. Temperature: SST data were acquired from NOAA's National Data Buoy Center (ndbc.noaa.gov), station names "VENF1" (27.072° N, 82.453° W) and C10 (27.133° N, 82.924°W). Both stations are located in the Gulf of Mexico and we used SST from both stations to account for changes in SST with distance to shore (VENF1 is approximately 0.2 nm from shore, C10 is approximately 20 nm offshore). Data were provided hourly, which were processed to daily averages, daily minima, and daily maxima. Daily aggregates showed some large periods of missing values (up to 121 consecutive days), especially throughout 2011 to 2013. Long patches of unavailable data cannot be imputed by simple methods, such as averages of neighboring observations, without introducing unrealistic artifacts. Therefore, we opted for a state-space model (SSM), similar to that detailed in Scolardi et al. (2025) to predict these missing values.

2.3 Statistical analyses

Models were built separately for drumline data and longline data as these gear types are not directly comparable. Prior to running statistical analyses, covariates were assessed for multicollinearity. Perhaps not surprisingly, SST and season were highly correlated. Since shark presence in an area can be due to more than just SST effects (e.g., nursery grounds, migration routes, amount of daylight, etc.) we decided to keep season in the model to capture effects that were not measured; we did not include SST min, max or average in the models.

All statistical analyses were completed using program R (v4.4.3, R Core Team 2025). Sandbar shark counts were analyzed using zero-inflated modeling to account for excess zeros in the data, specifically in seasons when sandbar sharks were not frequently caught in the Sarasota area (summer and fall). Both generalized linear models (GLMs) and generalized additive models (GAMs) were evaluated, along with Poisson and negative binomial distributions. Models were fitted using the glmmTMB package (Brooks et al. 2017) and residual diagnostics of each model was assessed using the DHARMa package (v.0.4.7; Hartig, 2024). GAM structures and Poisson distribution did not improve model fit, thus zero-inflated negative binomial GLMs were selected for both gear types.

The conditional count of sandbar sharks was modeled as a function of year, season (reference = winter), red tide presence and an interaction between red tide and season. Effort (log(hook hours)) was included as an offset term to account for unequal sampling over the time period. Zero-inflation was modeled as a function of season, allowing the structural zeros (true absences) to vary seasonally.

3 Results

From 2003-2023, 286 sandbar sharks were sampled (n = 128 drumline; n = 158 longline). More females were sampled than males (n = 206 female, n = 66 male) and sex could not be

identified on 14 individuals (e.g., they may have broken off the line before sex could be confirmed). Average sandbar shark size was 162.44 cm fork length [FL] ± 10.26 SD (range = 137 - 188 cm FL). Distribution of sandbar shark size can be found in Figure 2.

Drumlines. Initial attempts with the default optimizer ("nlminb") for the negative binomial zero-inflated GLM did not converge; therefore, we used the alternative BFGS optimization method. Sandbar shark counts increased over time ($p = 0.009$; Table 1; Figure 3) and sandbar shark counts were lower during the spring and summer/fall seasons as compared to winter ($p = 0.029$ and <0.001, respectively; Table 1; Figure 4). Red tide presence did not have an overall effect on shark counts ($p = 0.788$), but there was marginal evidence ($p = 0.051$) for an interaction between spring and red tide suggesting that sandbar shark abundance may be lower during spring when red tide is present (Figure 4). The interaction between summer/fall was not significant ($p = 0.243$). The probability of structural zeros was higher in spring as compared to the winter (39%; Table 2). Zero-inflation could not be reliably interpreted for the summer/fall season category; however, conditional counts were extremely low during this period (Figure 2; Table 1).

Longlines. The interaction between season and red tide was initially included in the longline model, but was removed due to poor model fit. Sandbar shark counts from longline sampling increased over time ($p = 0.005$; Table 1; Figure 5). Lower shark counts were observed in the spring relative to winter ($p = 0.037$; Table 1; Figure 6). While shark counts during the summer/fall season were not significantly different from winter in the conditional component of the model ($p = 0.673$; Table 1), the probability of structural zeros was high (94.6%; $p = <0.001$), indicating that sandbars were more likely to be absent during this period (Table 2; Figure 6). The probability of zero sandbar sharks was also higher in spring (50.6%) as compared to winter (Table 2). Red tide presence did not affect sandbar shark count ($p = 0.709$; Table 1).

4 Discussion

Both models agree that sandbar shark CPUE has increased over time in the sampling area. There is also a strong seasonal influence on sandbar shark abundance along the Sarasota coast, with the peak occurring in winter, with lower abundance in spring and a near absence in summer and fall. Red tide presence was not a significant factor, though there is some evidence that there may be an effect during spring. Sandbar presence was more variable during red tide periods and local abundance could be dictated by relative severity elsewhere (e.g., when red tide is present in Sarasota but it is not as severe as in other locations local abundance may increase).

Modeling these data did not come without challenges. One difficulty was the large data gap between 2010 and 2019 when only occasional surveys occurred as funding was only periodically available, and sampling did not occur across all seasons (Supplemental 1). Such interrupted time gaps lead to increased uncertainty in both relative abundance estimates (i.e., large confidence intervals) and trends over time (e.g., ability to fit non-linear models or trend direction accuracy; Nuno et al. 2014). Data gaps also reduce statistical power, limiting our ability to detect ecologically important relationships among variables. For example, in the drumline dataset, the zero-inflated component for the combined summer/fall season had high uncertainty, making the estimate uninterpretable despite model diagnostics suggesting there were no

violations of model assumptions. The large time gaps in our data likely also impacted our ability to fit more complex model structures (e.g., GAMs) and reduced our ability to explore complex interactions among explanatory variables (e.g., red tide and seasonality).

5 Conclusion

- Sandbar shark CPUE increased over time in the Sarasota, FL region.
- This species overwinters in this region and moves away during spring.
- Thermal refuge may be more important driver of presence than red tide for sandbar sharks
- Large sampling gaps made modeling difficult.

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7 Tables

Table 1. Conditional model output. Both drumline and longline data were modeled using a zero-inflated generalized linear model with a negative binomial distribution. Effort (log(hook hours)) was included as an offset term. The drumline model included an interaction term between season and red tide presence.

Predictor	Estimate	SE	p-value
Drumline			
Intercept	-83.780	30.758	0.006
Year	0.040	0.015	0.009
Spring	-0.614	0.281	0.029
Summer/Fall	-4.715	0.744	< 0.001
Red Tide	0.062	0.230	0.788
Spring*Red Tide	-1.689	0.866	0.051
Summer/Fall*Red Tide	1.464	1.254	0.243
Longline			
Intercept	-163.680	56.304	0.004
Year	0.079	0.280	0.005
Spring	-1.114	0.534	0.037

Summer/Fall	-0.338	0.800	0.673
Red Tide	-0.175	0.467	0.709

Table 2. Zero-inflation component results of the zero-inflated negative binomial generalized linear model. For both gear types, zero-inflation was modeled as a function of season. *Estimates for the summer/fall combined season in the drumline model had large standard errors and are not interpretable.

Predictor	**Estimate**	**SE**	**p-value**
Drumline			
Intercept	-2.130	0.841	0.011
Spring	1.690	1.003	0.092
Summer/Fall	-4.023	72.108*	0.956
Longline			
Intercept	-1.767	1.093	0.106
Spring	1.792	1.112	0.107
Summer/Fall	4.628	1.195	< 0.001

8 Figures

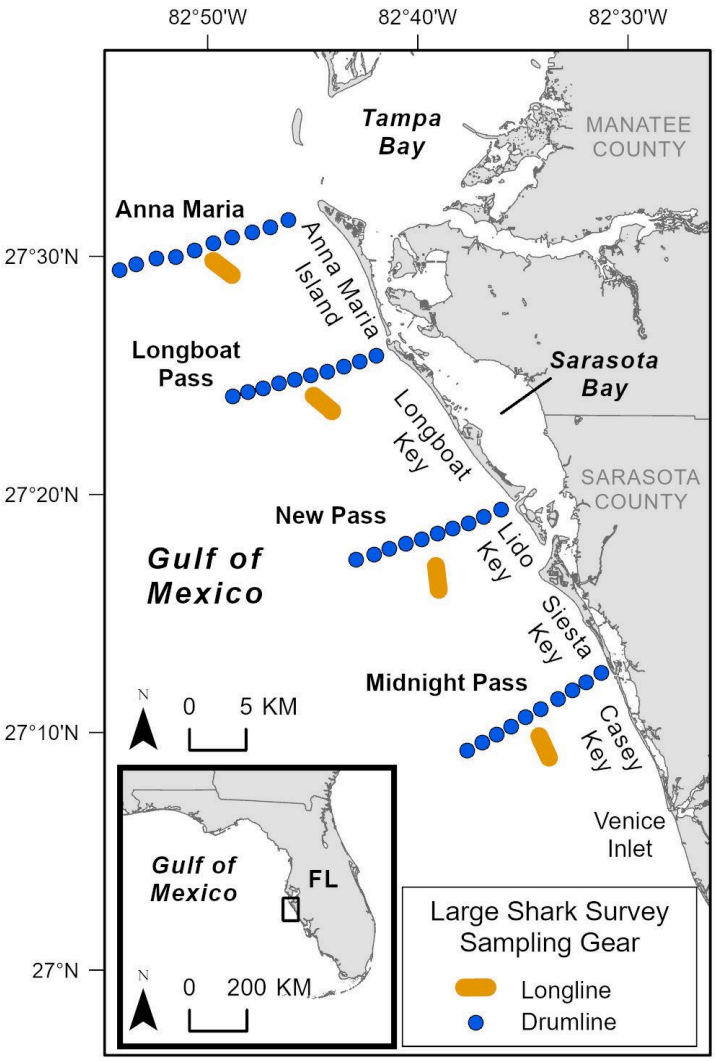


Figure 1. Core Sarasota sampling area with example drumline and longline sets.

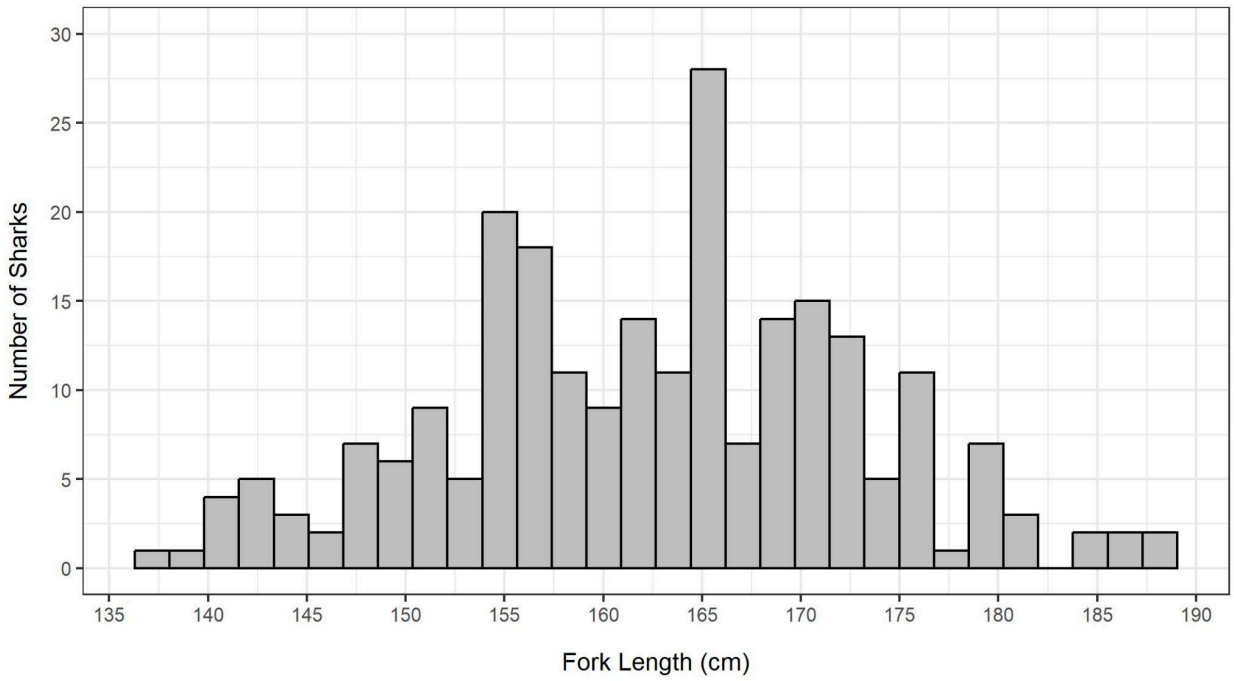


Figure 2. Frequency distribution of sandbar shark fork length (cm) in the core study area, across all years and gear types.

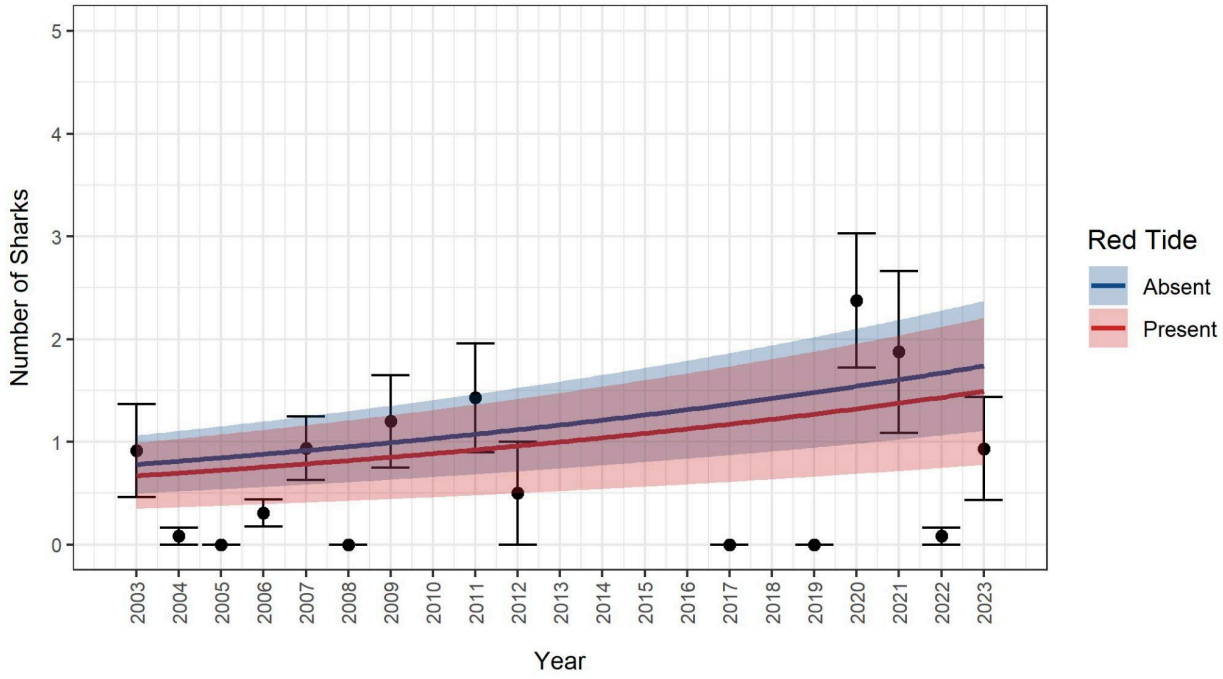


Figure 3. Drumline data. Predicted count of sandbar sharks over time (2003-2023). Effort was held constant at the mean and seasonality was averaged. Observed annual means ± SE (black dots) are shown for reference (lower SE were truncated at zero). Lines show model predictions for years without red tide (blue) and with red tide (red), with 95% confidence intervals (shaded area).

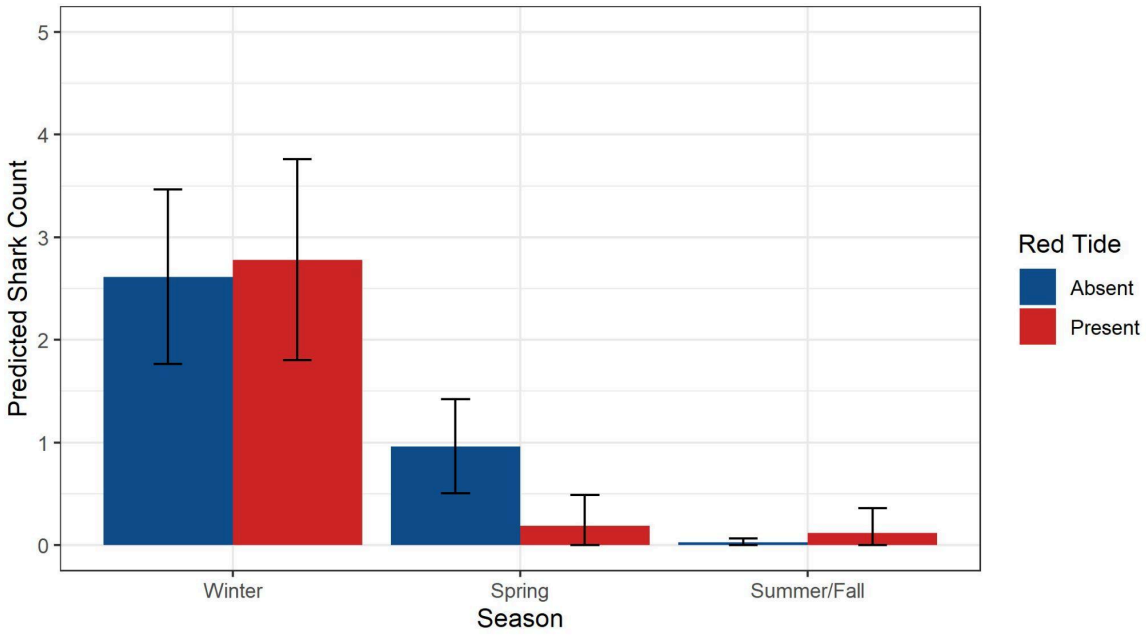


Figure 4. Drumline data. Predicted number of sandbar sharks by season under the presence and absence of red tide. Bars represent the mean predicted shark count across all years (2003-2023), with error bars indicating the 95% confidence intervals on the response scale. Lower confidence intervals were truncated at zero.

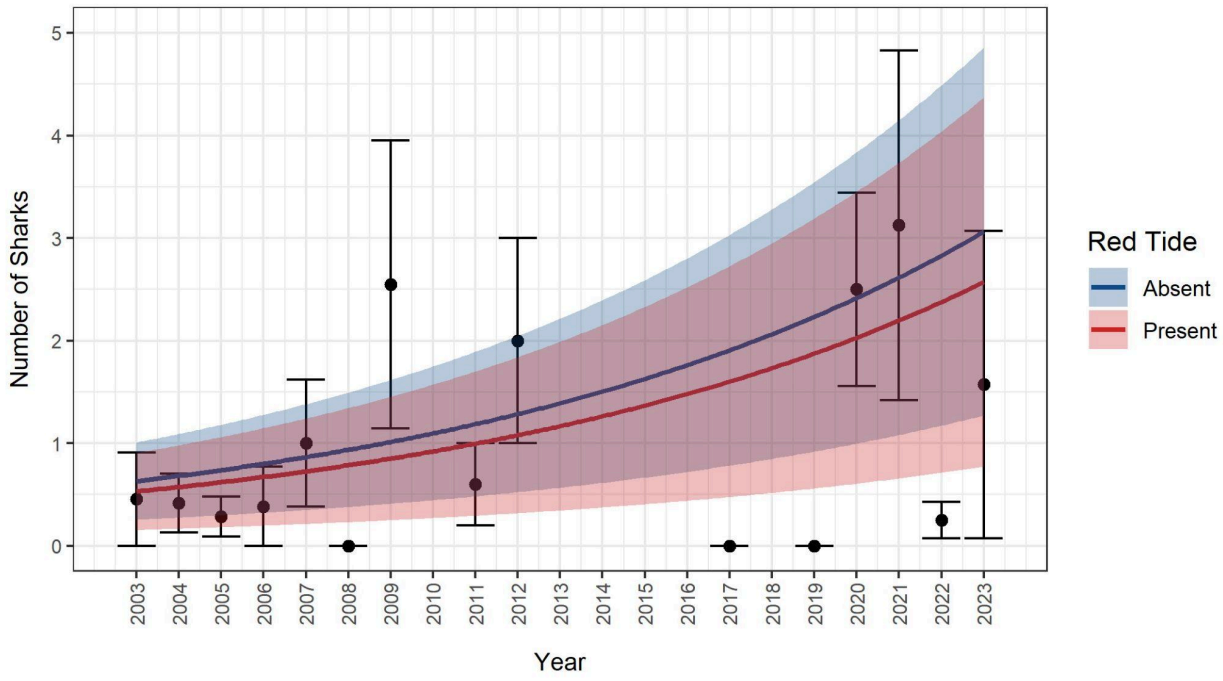


Figure 5. Longline data. Predicted number of sandbar sharks by season under the presence and absence of red tide. Bars represent the mean predicted shark count across all years (2003-2023), with error bars indicating the 95% confidence intervals on the response scale. Lower confidence intervals were truncated at zero.

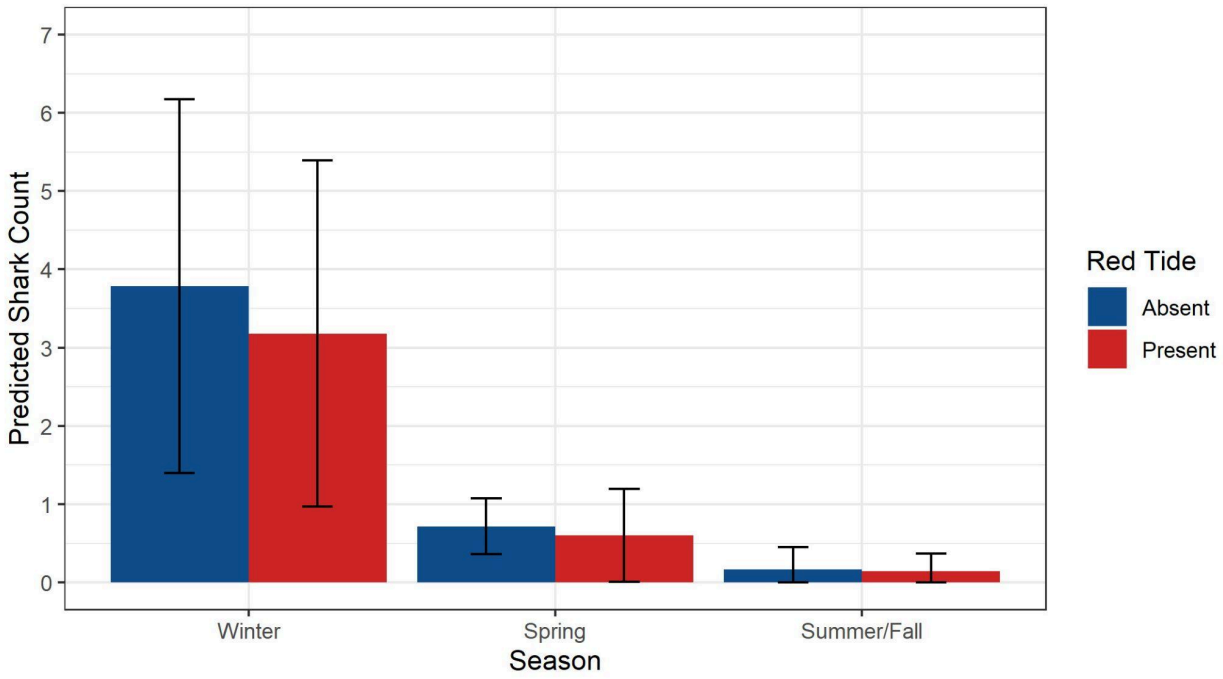


Figure 6. Longline data. Predicted number of sandbar sharks by season under the presence and absence of red tide. Bars represent the mean predicted shark count across all years (2003-2023), with error bars indicating the 95% confidence intervals on the response scale. Lower confidence intervals were truncated at zero.

9 Funding

The LSS was supported by various NOAA grants to REH from 2003-2021, and by the Roe Foundation and Earthwatch International in 2022.

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11 Supplementary Material

Supplemental 1.

Year	Season	Gear Type	Sampling Days
2003	Winter	DL	3
2003	Winter	LL	2
2003	Spring	DL	3
2003	Spring	LL	3
2003	Summer	DL	3
2003	Summer	LL	3
2003	Fall	DL	3
2003	Fall	LL	3
2004	Winter	DL	2
2004	Winter	LL	3
2004	Spring	DL	2
2004	Spring	LL	2
2004	Summer	DL	4
2004	Summer	LL	3
2004	Fall	DL	4
2004	Fall	LL	4
2005	Winter	DL	4
2005	Winter	LL	4
2005	Spring	DL	3
2005	Spring	LL	3
2005	Summer	DL	5
2005	Summer	LL	5
2005	Fall	DL	2
2005	Fall	LL	2
2006	Winter	DL	2
2006	Winter	LL	2
2006	Spring	DL	4
2006	Spring	LL	4
2006	Summer	DL	4
2006	Summer	LL	4
2006	Fall	DL	3
2006	Fall	LL	3
2007	Winter	DL	4
2007	Winter	LL	4
2007	Spring	DL	4
2007	Spring	LL	4
2007	Summer	DL	4
2007	Summer	LL	1

2007	Fall	DL	4
2007	Fall	LL	4
2008	Summer	DL	4
2008	Summer	LL	4
2008	Fall	DL	4
2008	Fall	LL	4
2009	Winter	DL	3
2009	Winter	LL	3
2009	Spring	DL	4
2009	Spring	LL	4
2009	Summer	DL	7
2009	Summer	LL	4
2009	Fall	DL	1
2011	Winter	DL	4
2011	Winter	LL	2
2011	Fall	DL	3
2011	Fall	LL	3
2012	Fall	DL	2
2012	Fall	LL	2
2017	Spring	DL	5
2017	Spring	LL	5
2019	Spring	DL	4
2019	Spring	LL	3
2020	Winter	DL	4
2020	Winter	LL	4
2020	Spring	DL	4
2020	Spring	LL	4
2020	Summer	DL	4
2020	Summer	LL	4
2020	Fall	DL	4
2020	Fall	LL	4
2021	Winter	DL	4
2021	Winter	LL	4
2021	Summer	DL	4
2021	Summer	LL	4
2022	Spring	DL	4
2022	Spring	LL	4
2022	Summer	DL	4
2022	Summer	LL	4
2022	Fall	DL	4
2022	Fall	LL	4
2023	Winter	DL	3
2023	Winter	LL	2
2023	Spring	DL	4
2023	Spring	LL	4

2023	Summer	DL	4
2023	Summer	LL	4
2023	Fall	DL	4
2023	Fall	LL	4

Drumline

Year	Total Hook Hours (Annual Effort)	Standardized CPUE	SE	CV
2003	668.467	0.022	0.007	0.314
2004	1033.833	0.014	0.005	0.378
2005	949.500	0.025	0.007	0.295
2006	871.667	0.025	0.008	0.311
2007	1134.450	0.032	0.009	0.283
2008	592.817	0.001	0.001	0.706
2009	823.567	0.029	0.008	0.280
2011	403.233	0.059	0.013	0.212
2012	72.400	0.005	0.005	1.002
2017	210.900	0.048	0.011	0.236
2019	292.733	0.052	0.012	0.236
2020	1111.467	0.053	0.015	0.279
2021	574.233	0.078	0.018	0.226
2022	760.333	0.021	0.008	0.391
2023	924.183	0.040	0.015	0.372

Longline

Year	Total Hook Hours (Annual Effort)	Standardized CPUE	SE	CV
2003	8080.133	0.002	0.001	0.541
2004	8949.967	0.003	0.002	0.504
2005	6550.733	0.004	0.002	0.476
2006	6646.633	0.003	0.001	0.535
2007	5774.533	0.004	0.002	0.463
2008	3537.467	0.001	0.001	0.798
2009	4981.850	0.005	0.002	0.439
2011	2060.333	0.008	0.003	0.439
2012	597.050	0.001	0.001	0.760
2017	2249.933	0.005	0.001	0.232
2019	798.250	0.006	0.001	0.229
2020	7222.700	0.010	0.005	0.488
2021	4216.667	0.020	0.008	0.396
2022	4762.683	0.004	0.002	0.410
2023	6279.650	0.009	0.005	0.586

Addendum to: Long-term trends in sandbar shark (*Carcharhinus plumbeus*) CPUE from 2003 – 2023 near Sarasota, Florida

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After the SEDAR 101 workshop Mote was asked to provide information for our drumline (Table A1) and longline surveys (Table A2) CPUE by year and the model predicted CPUE with associated uncertainty metrics. Model-predicted CPUE values reflected a model where year is treated as a categorical variable.

Table A1: Requested information for Mote drumlines.

Table A2: Requested information for Mote longlines.