Title: Abundance and vertical distribution of *Squalus acanthias* at Stellwagen Bank: daily and interannual patterns from 2008-2012

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Abstract:
Squalus acanthias, commonly referred to as Spiny Dogfish, is a small coastal shark with a distribution ranging from Florida to Greenland in the Northwest Atlantic Ocean. It migrates north in the spring and returns to southern offshore waters in the fall. *S. acanthias* stocks are at risk to overfishing because this species matures late in life (6 years male & 12 years female), and has a low fecundity rate. European and Northwestern Atlantic stocks have been severely depleted and overfished, respectively, within the past 10 years. To prevent stock collapse, it is important to understand the species' distributional patterns in relation to its environmental components. From 2008 - 2012, the relationship between internal waves and the distribution of *S. acanthias* was studied on southwestern flank of Stellwagen Bank in Massachusetts Bay, MA. Current and temperature measurements of the water column were made from an anchored vessel (55 m water depth) with an Acoustic Doppler Current Profiler (ADCP), a temperature mooring, Conductivity Temperature Depth (CTD) casts, and echosounders (120 kHz and 200 kHz). The distribution of sharks in the water column was determined from echosounder records of their acoustical traces, and the identity of the traces assessed with an underwater video camera. Here we describe the temporal vertical distribution and abundance patterns (both daily and annually) of *S. acanthias* collected from 2008-2012 in relation to water temperature. We hypothesized that *S. acanthias* abundance would vary with water temperature because as a migratory species, they move north and associate with cooler waters. Previous studies have shown that *S. acanthias* are most likely to be found in water temperatures below 15 °C, but studies have not detailed the local distribution with respect to temperatures at different water depths. Analysis of 1375 shark acoustic traces indicated large interannual variation in abundances of sharks below 25 m. Sharks were relatively abundant during 2008-2010 and rare in 2011-2012. In this study, the average measured abundances of sharks between 25 and 40 m water depth over the past 4 years were negatively correlated with the average measured water temperature at this depth range. Understanding the movement patterns of *S. acanthias* can be vital in fisheries studies and may be useful to fisheries management agencies to improve estimates of *S. acanthias* abundance.

Introduction

Squalus acanthias, commonly referred to as the Spiny Dogfish, is a small slow growing, migratory shark [1-3]. Found in temperate waters from Florida to Greenland and in the Northwest Atlantic Ocean [1, 3]. Due to its late maturation and low reproductive rates, *S. acanthias* is sensitive to fishing pressures and has been extensively overfished in the Northeast Atlantic (NEA). NEA *S. acanthias* landings accounted for around 97% of all landings globally in 1950 – 1972, with 1972 contributing 50,000 mt [4]. In the mid 1980's NEA *S. acanthias* landings began to decrease, with 2004 accounting for 39% of global *S. acanthias* landings [4]. Nevertheless, the NEA species has been listed as Critically Endangered within the IUCN Red List with a decreasing population trend [5]

While a North American *S. acanthias* fishery has existed since the 1930's, landings above 10,000 mt did not exist prior to the 1960's. Greatest North American landings occurred in the 1990's with more than 20,000 mt being caught annually [6]. This eventually lead to the species collapse in 1998 and fisheries closing in 2000 [4]. Recent reports in 2010 indicate that the Northwest Atlantic *S. acanthias* stock has recovered since 1998 [7], however, the NWA subpopulation has been listed as Endangered within the IUCN Red List with a decreasing population trend [8].

Squalus acanthias migrate seasonally, following prey species and cooler waters. Schools of *S. acanthias* normally arrive in Massachusetts by June; however, the period of their stay can vary with water temperature [1]. In 2008, an internal wave observation study began at the southwestern flank of the Stellwagen Bank in Massachusetts Bay. The study's main objective was to observe the relationship between internal waves and fauna of Stellwagen Bank. As a part of this study we examined the temporal vertical distribution and abundance patterns (both daily and annually) of *S. acanthias* collected from 2008-2012. We hypothesized that *S. acanthias* abundance varies with water temperature because as migratory species, they move north and associate with cooler waters.

Methods

Sampling

The southwestern flank of Stellwagen Bank was chosen due to predictable internal wave shoaling, and high humpback whale and prey species abundance. Sampling was conducted 5-7 days a year between the months of June-August at the southwestern flank of Stellwagen Bank. The Stellwagen Bank National Marine Sanctuary NOAA research vessel, the AUK, was used for all sampling. Sampling was conducted at one site while on anchor and consisted of CTD casts, and deployment of two echosounders and a video camera. Vessel movement associated with tidal shifts resulted in occasional bank drifts in which the bottom location rose to depths shallower than 40 meters. Data from these shifts were not considered in our analysis.

CTD casts (RBR 620 and SBE19) were conducted approximately hourly to determine water stratification, temperature, salinity, and chlorophyll *a* concentrations as a function of depth. For each cast, temperature readings were averaged within 1-meter bins of depth at 5-meter intervals until the maximum depth of 50 meters. These values were then averaged across years to determine average annual water temperatures as a function of depth. CTD casts within 15 minutes of the nearest *S. acanthias* trace were used as an estimate of approximate water temperature in relation to *S. acanthias* abundance.

Two BioSonics DT-X Digital Scientific echosounders were used to determine position of fish within Stellwagen Bank. Each echosounder of 120 kHz and 200 kHz frequencies were placed approximately 0.5 m below the surface for the sample duration. Echosounder data were analyzed in the program Visual Acquisition 6. Thin traces with Amplitudes greater than -50 dB were identified via submerged camera to be schooling fish, tuna, and *S. acanthias*. *Squalus acanthias* had very characteristic traces between -40 and -50 dB possibly due to its lack of a swim bladder or bone vertebrae. Organisms with bones and gas bladders (e.g., tuna) exhibited stronger returns greater than -40 db.

To reduce the possibility of repeatedly identifying the same individuals, data files were subsampled at 15-minute intervals within a 2-minute window. Within each 2-minute window *S. acanthias* data were gathered along a vertical line that intersected the most *S. acanthias* traces. The vertical start and end depth of each individual trace, the time elapsed between the two positions, as well as the bottom location, were recorded. This information provided estimates of *S. acanthias* abundance and water column distribution.

<u>Data Analysis</u>

Abundance, total number of *S. acanthias* observed, was calculated by time of day and hours +/- high tide (as determined by the Boston BHBM3 tide station: ID 8443970) in Massachusetts Bay. It was then averaged hourly for each day, taking into account sample duration. These daily values were then averaged to determine annual abundance. The vertical distribution of sharks was determined from the start position (depth) of each individual trace by time of day and hours +/- high tide. These values were then averaged by hour for each day and year.

It was difficult to differentiate individual traces when *S. acanthias* were extremely abundant. In this case, six *S. acanthias* traces were chosen and averaged for width. This width was then used to estimate the number of *individuals* in a school as well as their relative positions.

A one-way analysis of variance (ANOVA) along with a Games-Howell post hoc test was used to investigate annual differences among water temperatures recorded in the depth category where fish were most abundant. To assess whether abundance was related to temperature, annual abundances were ranked on a scale of 1-5 (least to most), as were the average annual temperatures within the identified depth category. A correlation analysis was also used to evaluate the relationship between temperature and annual abundance within the identified depth category.

Results

Over the 27 days of sampling from 2008 - 2012, 1375 individuals were observed with a bottom location below 40 meters. Out of these, 393 *S. acanthias* were within 15 minutes of the nearest CTD cast and, therefore, had an associated water temperature record.

Squalus acanthias were observed in water temperatures as low as 4.48° C and as high as 19.80 °C with an average (± SD) of 8.03 ± 2.89 °C. These temperature values corresponded to a depth range of 1.61- 60 m, with an average depth (± SD) of 33.21± 15.43 m. No daily water temperature patterns were observed for our sample duration (results not presented). However, annual temperatures differed along the depth profile, with 2012 being the warmest year (Figure 1). At depths of maximum *S. acanthias* abundance (25-40 m), average annual temperatures differed significantly (ANOVA: $F = 10.62$, $p < 0.01$), and were greatest for 2012 (Figure 2).

Daily abundances of *S. acanthias* did not exhibit any consistent patterns by tide or time of day (results not presented). Yearly abundance trends were more obvious; the highest hourly abundance occurred in 2010 and the lowest in 2012 (Figure 3).

Rank plots of temperature and abundance suggested a relationship between the two variables (Figure 4). Annual abundances were significantly negatively correlated to average annual temperatures at 25-40 m depth ($r = -0.90$, $p < 0.05$; Figure 5).

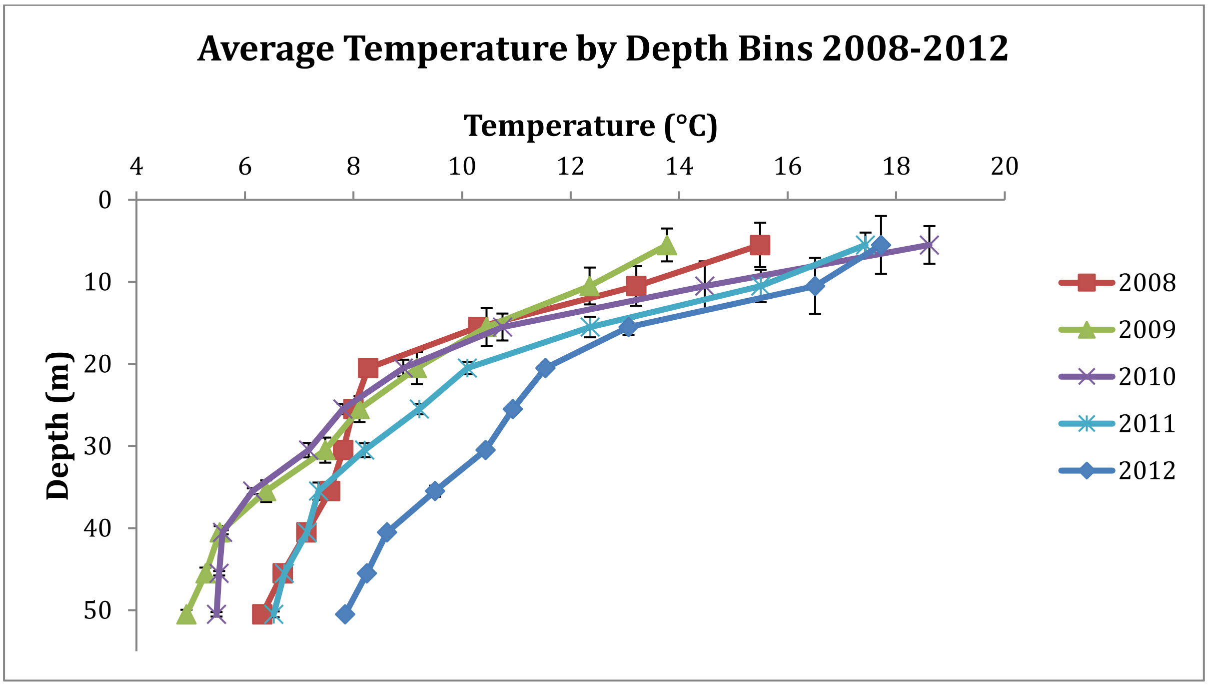

Figure 1. Average annual temperature (± SD) by depth bin for the years 2008-2012.

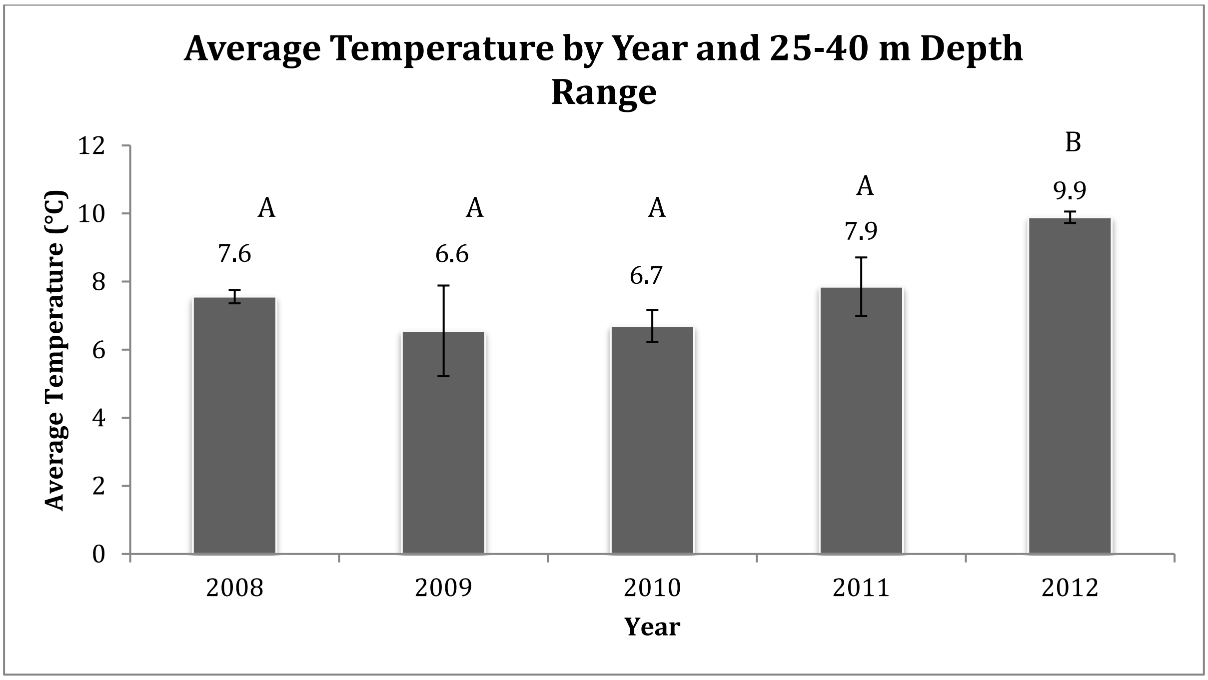

Figure 2. Average water temperatures (± SD) from 25-40 m in the years 2008-2012. Letters indicate significant groups ($p < 0.05$) as determined by Games-Howell post-hoc tests.

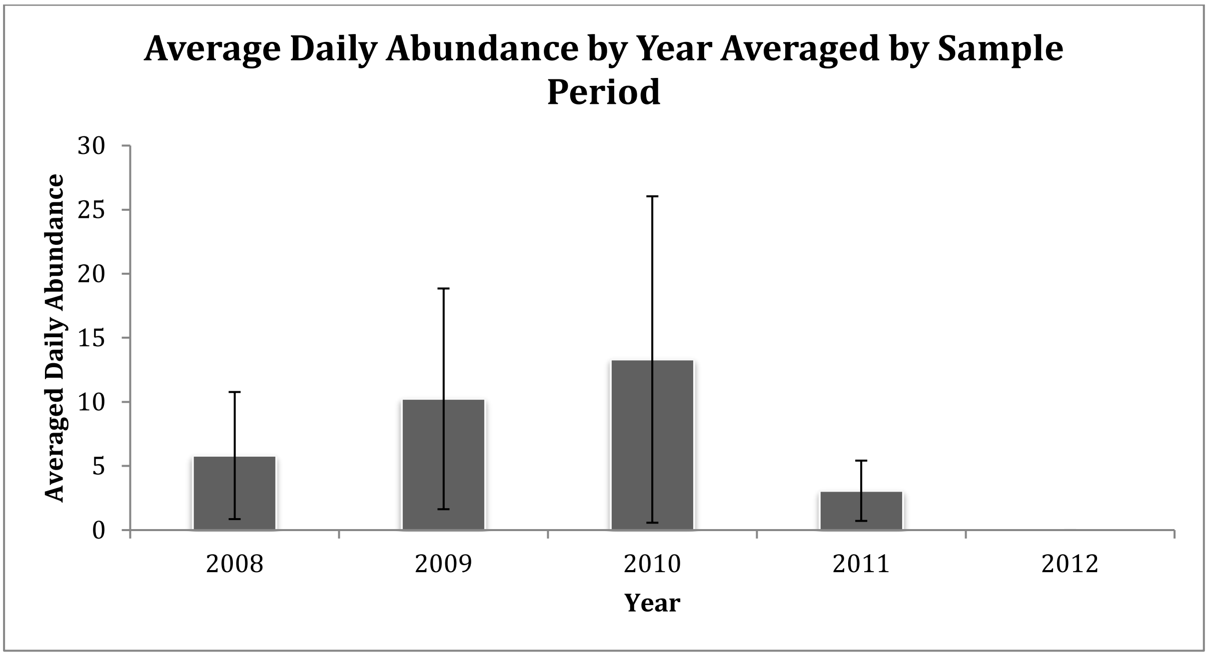

Figure 3. Average Daily Abundance (± SD) averaged by sample period in the years 2008-2012.

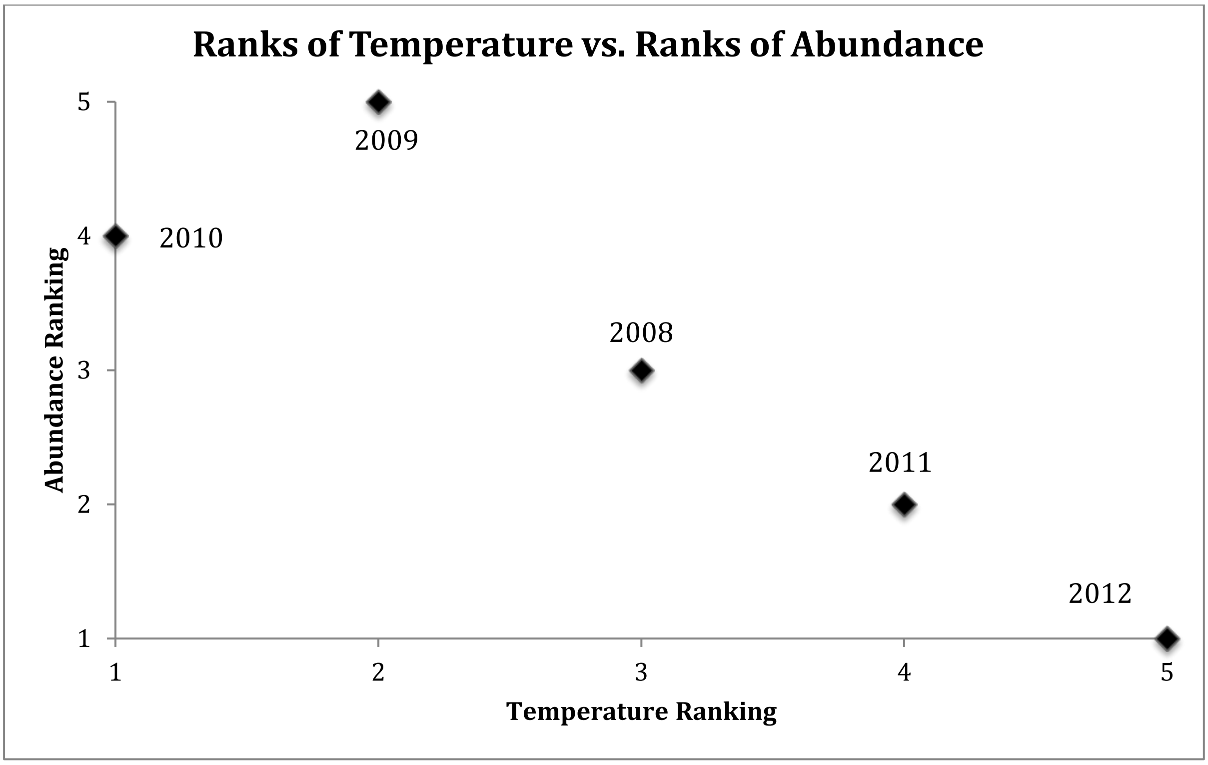

Figure 4. Yearly temperature vs. abundance rank. 1-5 (least to most).

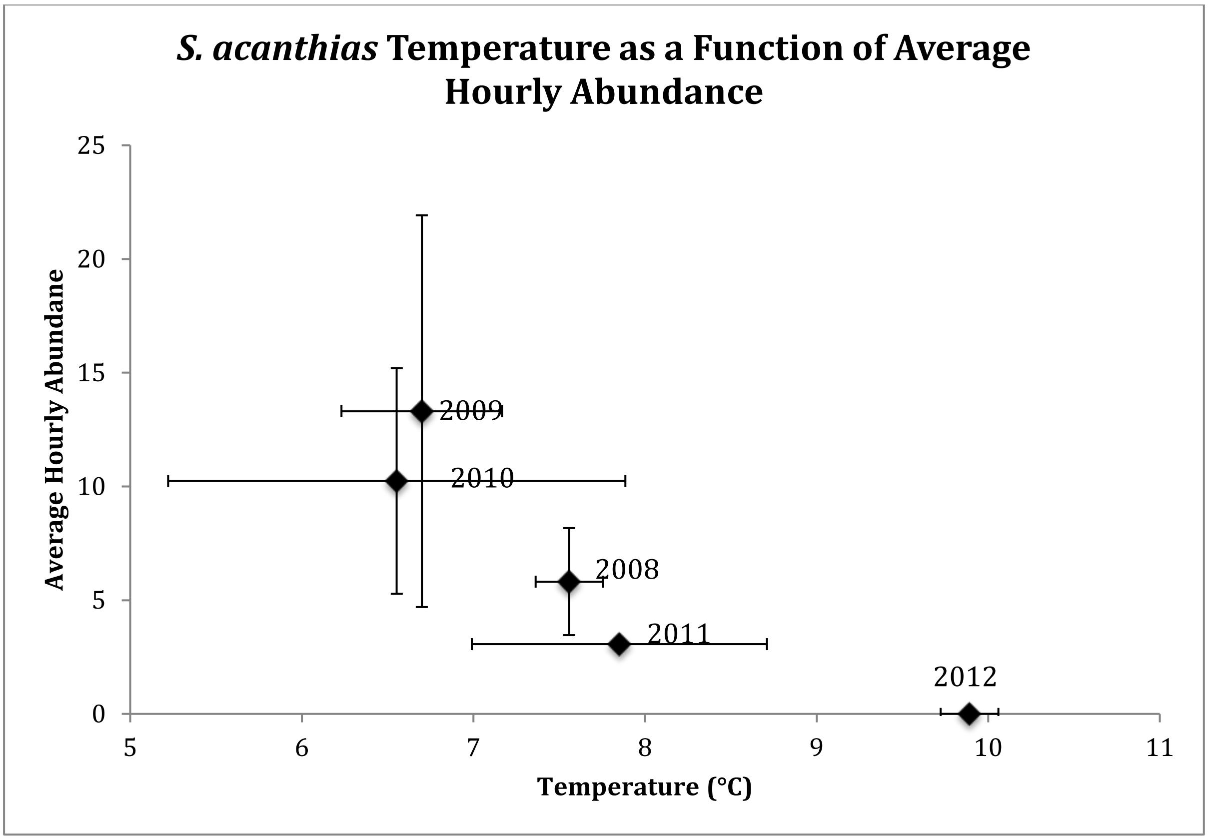

Figure 5. Average hourly abundance (± SD) as a function of water temperature between 25-40 m (± SD) by year.

Discussion

Previous research has indicated that *S. acanthias* are most abundant at temperatures below 12 ºC [6], with some studies observing the species between 4-20 °C with the majority of sharks are found at water temperatures between 1-15 °C [9]. Our study found *S. acanthias* to be in water temperature from 4.4-19.8 ºC with the majority of sharks at 8.0 ± 2.9 ºC. Shark abundance correlated negatively with water temperature with colder waters at depth exhibiting greater *S. acanthias* abundances. Changes in water temperature have been a main explanation for *S. acanthias* migrations and may explain the variation in abundance documented in this study.

Water temperature appears to have an effect water temperature on *S. acanthias* abundance in Stellwagen Bank. High water temperatures in 2012 corresponded to low *S. acanthias* abundance while colder water temperatures in 2009 and 2010 corresponded in high abundance. The low abundance of *S. acanthias* in 2012 might be attributed to a migration to the colder northern or offshore water temperatures than on Stellwagen Bank. Our data is not sufficient to determine whether trends in global warming affects water temperature on Stellwagen Bank and migration patterns or mortality of *S. acanthias*.

Given that the sharks migrate between Canadian and American fisheries, it is important to have accurate estimates of abundance. Our results illustrate that water temperature at depth is related to *S. acanthias* abundance. Understanding the movement patterns of *S. acanthias* can be vital in fisheries studies and may be useful to fisheries management agencies to improve estimates of *S. acanthias* abundance.

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