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Relative abundance indices for multiple life stages of sandbar shark (*Carcharhinus plumbeus*) in coastal Virginia waters

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Background

The Virginia Shark Monitoring and Assessment Program (VASMAP), based at the Virginia Institute of Marine Science, is dedicated to monitoring and assessing shark populations in Virginia's coastal waters. The program's field component includes a long-term offshore longline survey (OFF-LL; 1974–present) and a nearshore longline survey (2013–present) conducted in the lower Chesapeake Bay and the coastal lagoons of Virginia's Eastern Shore. The latter survey is part of the regional Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) program and provides important information on the distribution, abundance, and habitat use of neonate and juvenile sandbar sharks (*Carcharhinus plumbeus*) in Virginia's estuarine and nearshore environments.

This objective of this working paper is to summarize the available VASMAP data for sandbar shark in support of ongoing stock assessment activities (SEDAR 101). Data summaries include sex-specific annual length compositions (OFF-LL survey only), annual proportions of positive longline sets, nominal indices of relative abundance, and model-based indices of relative abundance.

Methods

Field sampling

The OFF-LL survey follows a fixed-site sampling design in which a 2,400 m bottom longline, constructed from 4.8-mm-diameter tarred braided nylon mainline and equipped with 100 evenly spaced gangions, is deployed for approximately four hours. During the early years of the survey, some sets were longer in duration and configured with up to 200 hooks. Each gangion consists of a 2 m section of 4.8 mm diameter tarred braided nylon attached via an 8/0 barrel swivel to a 1 m section of 1.6 mm diameter stainless steel leader terminating in a 9/0 Mustad J hook (model 7698B DT). Gangions are attached to the mainline using 8/0 stainless steel longline snaps. Norwegian buoys are placed at 20 hook intervals along the mainline, and both ends of the line are anchored. Atlantic menhaden (*Brevoortia tyrannus*) has been used as standard bait since 1995; prior to that, bait species were selected opportunistically. Sampling cruises are conducted approximately monthly from May through October, although most years include surveys from June through September. Soak time is defined as the elapsed time between the start of gear deployment and the start of haulback. For each longline set, captured sharks are identified to species, counted, sexed, measured (0.5 cm), and released alive when possible.

The COASTSPAN survey follows a stratified random sampling design, with strata defined by geographic region (eastern and western bay) and depth within the lower mainstem Chesapeake Bay and by geographic region within the coastal lagoons of Virginia's Eastern Shore. Sharks are collected using a demersal longline consisting of 305 m of 3.2 mm, 800 lb test monofilament mainline with 50 equally spaced gangions attached via an 8/0 stainless steel longline clip and deployed for a target duration of 0.5

h. Each gangion consists of 50 cm of 1/16 stainless steel cable and 100 cm of 1.8 mm, 300 lb test monofilament, terminating with a 12/0 Mustad circle hook. Soak time is defined as the elapsed time between the start of gear deployment and the start of haulback. Approximately 35 sets are completed during each survey cruise, including 20 in the lower Chesapeake Bay and 15 in the Eastern Shore lagoons. Sampling cruises are conducted monthly from June through August. Atlantic mackerel (*Scomber scombrus*) is used as bait, and all captured sharks are identified to species, counted, sexed, measured (cm TL), and released alive when possible. Sandbar sharks ≤ 71 cm TL are classified as neonates (age 0; Conrath and Musick 2007).

Statistical analyses

Effort for each longline set within the OFF-LL and COASTSPAN datasets was defined as hook-hours (soak-time x hook-count) and standardized to the overall mean across all observations. This approach scaled effort such that a typical longline set had an approximate value of 1.0. Although a small group of 'primary' sites has been sampled relatively consistently throughout the OFF-LL survey, several additional sites have been sampled at varying seasonal and interannual frequencies. Consequently, two modeling approaches were evaluated. The first utilized 'all' available observations (Figures 1a) to maximize the amount of information contributing to the estimation of annual abundance indices, whereas the second was restricted to the 'primary' sites (Figure 1b) to minimize the potential confounding of temporal changes in abundance (as represented by year effects) with changes in the collection of sites sampled among years. For both the 'all' and 'primary' datasets, years with fewer than five observations were excluded from analysis.

Year-specific nominal catch-per-unit-effort (CPUE) for both the OFF-LL and COASTSPAN datasets was calculated as the mean number of individuals captured per effort, rescaled to the survey mean. Uncertainty for the nominal indices was expressed as 95% confidence intervals.

To complement the nominal indices, model-based indices were also estimated. For the OFF-LL survey data, generalized linear mixed-effects models (GLMMs) were used because they are well suited for hierarchical datasets with correlated observations. Because the OFF-LL survey follows a fixed-site design in which sites are repeatedly sampled over time, a random intercept for site was included to account for potential correlation among observations collected from the same location.

GLMMs take the form:

$$g\big(E(\mathbf{y}|\mathbf{b})\big) = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{b} + \boldsymbol{\delta}$$
$$\mathbf{b} \sim \mathrm{N}(\mathbf{0}, \boldsymbol{\Sigma}) \quad (1)$$

where $E(\mathbf{y}|\mathbf{b})$ is the conditional expectation of the response vector $\mathbf{y}$, $\mathbf{X}$ and $\mathbf{Z}$ are the fixed and random effects design matrices, respectively, $\boldsymbol{\beta}$ is the vector of fixed-effect parameters, $\mathbf{b}$ is the vector of normally distributed random effects, $\boldsymbol{\Sigma}$ is the random effects variance-covariance matrix, $\boldsymbol{\delta}$ is the offset vector, and g is the link function.

In contrast, data from the COASTSPAN survey were analyzed using generalized linear models (GLMs) because repeated sampling of individual sites is limited given the stratified random sampling design. GLMs take the form:

$$g\big(E(\mathbf{y})\big) = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\delta} \quad (2)$$

where model terms are defined above. For both surveys, the response variable was the number of sharks captured per set and the offset term was defined as the natural logarithm of sampling effort standardized

to the overall mean across all observations. Model performance was evaluated using quantile-quantile (QQ) plots, residual-versus-fitted plots, convergence diagnostics, and assessments of overdispersion. Predicted indices of relative abundance were computed as marginal means, and standard errors were estimated by applying the delta-method variance approximation. All analyses were conducted using the R software platform, and models were fitted using the sdmTMB package.

Results & Discussion

OFF-LL

A total of 3,585 sandbar sharks were sampled across 1,468 longline sets from 1974-2025. Sex was recorded for 3,396 individuals, with females comprising 71% of the sampled sharks. Total length (TL) and/or pre-caudal length (PCL) but not fork length (FL) were recorded for a 1,133 (33.3%) number of sharks, particularly in the early years of the survey. Accordingly, FL values were estimated using conversions provided by Natanson et al. (2022). Annual length-frequency distributions indicated an expansion in the size composition over time (Figure 2). Early in the time series, catches were dominated by smaller and intermediate-sized sharks, whereas recent years included substantially greater numbers of larger individuals. This pattern was most evident for females, although a similar trend was also apparent for males.

The proportion of positive longline sets was generally high during the 1970s and early 1980s, declined during the mid-1980s to early 1990s, and then remained relatively stable thereafter (Figure 3). Estimates derived from the 'all' site and 'primary' site datasets showed similar temporal patterns, although uncertainty was greater during years with limited sampling.

Nominal CPUE exhibited substantial interannual variability, with relatively high values observed during the 1970s and early 1980s followed by a marked decline during the mid-1980s. From the 1990s onward, nominal CPUE remained comparatively low but fluctuated through time, with periods of moderate increases during the late 2000s and late 2010s (Figure 4). Temporal trends were broadly similar between the 'all' and 'primary' site analyses.

Model-based abundance indices showed patterns consistent with the nominal CPUE series but were generally less variable among years (Figure 5). Abundance was highest during the 1970s and early 1980s, declined sharply by the mid-1980s, and remained at lower levels thereafter. A modest increase was evident during the late 2000s and early 2010s, followed by a subsequent decline and stabilization at relatively low abundance in recent years. Similar trajectories were obtained from both the 'all' and 'primary' site datasets, indicating that annual abundance estimates were largely robust to variation in site occupancy through time.

COASTSPAN

A total of 4,257 sandbar sharks were sampled across 1,342 longline sets from 2013–2025. The proportion of positive longline sets was highest at the beginning of the time series (74% in 2013), declined through 2016, and then fluctuated with a slight decline through the remainder of the study period (Figure 6). Confidence intervals overlapped substantially among years, indicating considerable uncertainty in annual estimates.

Nominal CPUE exhibited substantial interannual variability, with relatively high catch rates observed in 2013 and 2018, lower values during 2015–2016, and moderate fluctuations thereafter (Figure 7). Model-based annual abundance indices showed a broadly similar temporal pattern when compared to the nominal CPUE series. Estimated abundance declined from 2013 to a low in 2015–2016, increased through 2017–2018, and then fluctuated at intermediate levels before declining again during the final

three years of the time series. The widths of confidence intervals for both the nominal and model-based indices were similar in magnitude.

Acknowledgements
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Figures

Figure 1. Maps of sampling locations for the a) OFF-LL all sites, b) OFF-LL primary sites, and c) COASTSPAN survey sites in the lower Chesapeake Bay and Eastern Shore Lagoons. The spatial distribution of the COASTSPAN sites is for a single representative cruise.

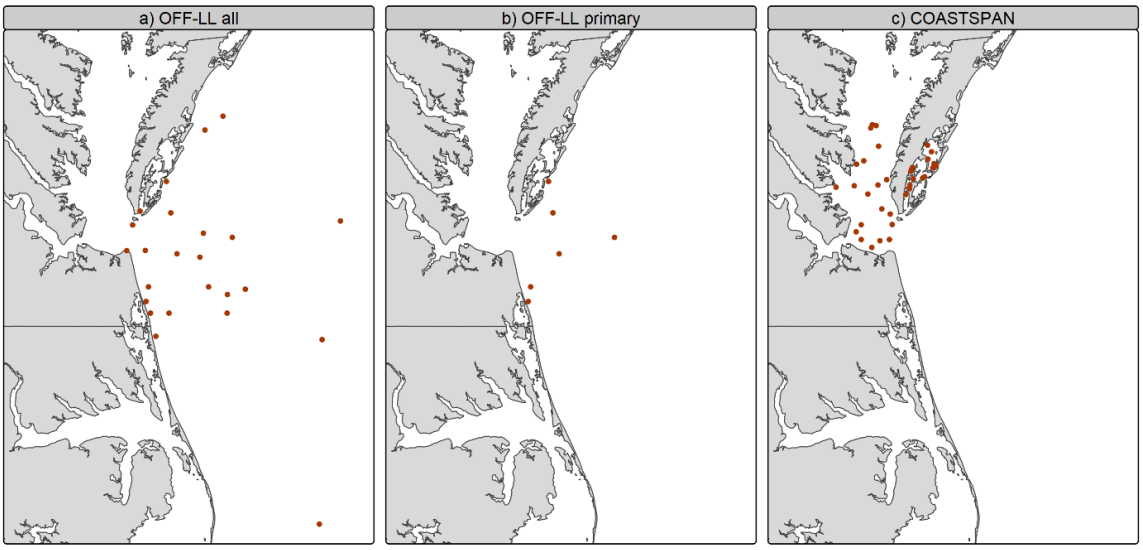

Figure 2. Annual length frequencies for female (left panel) and male (right panel) sandbar sharks collected at all OFF-LL sites, 1974-2025. Missing years indicate either no sampling or less than five total longline sets completed.

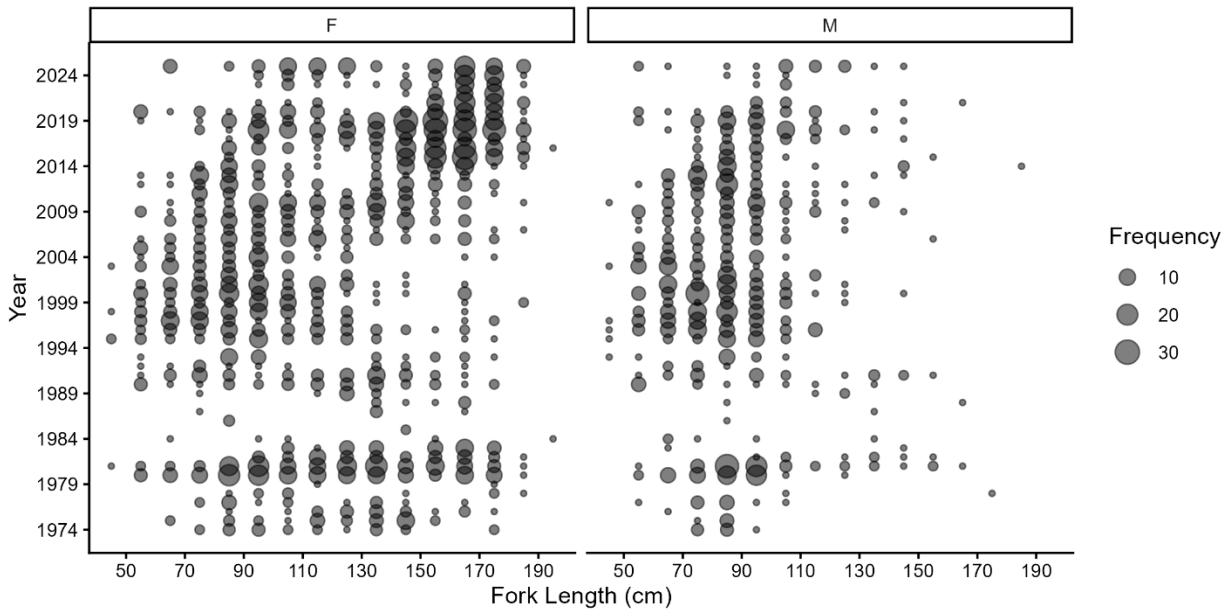

Figure 3. Proportion of positive longline sets (at least on animal captured) for sandbar shark based on all OFF-LL (left panel) and primary OFF-LL (right panel) sites, 1974-2025. Error bars are 95% confidence intervals. Missing years indicate either no sampling or less than five total longline sets completed.

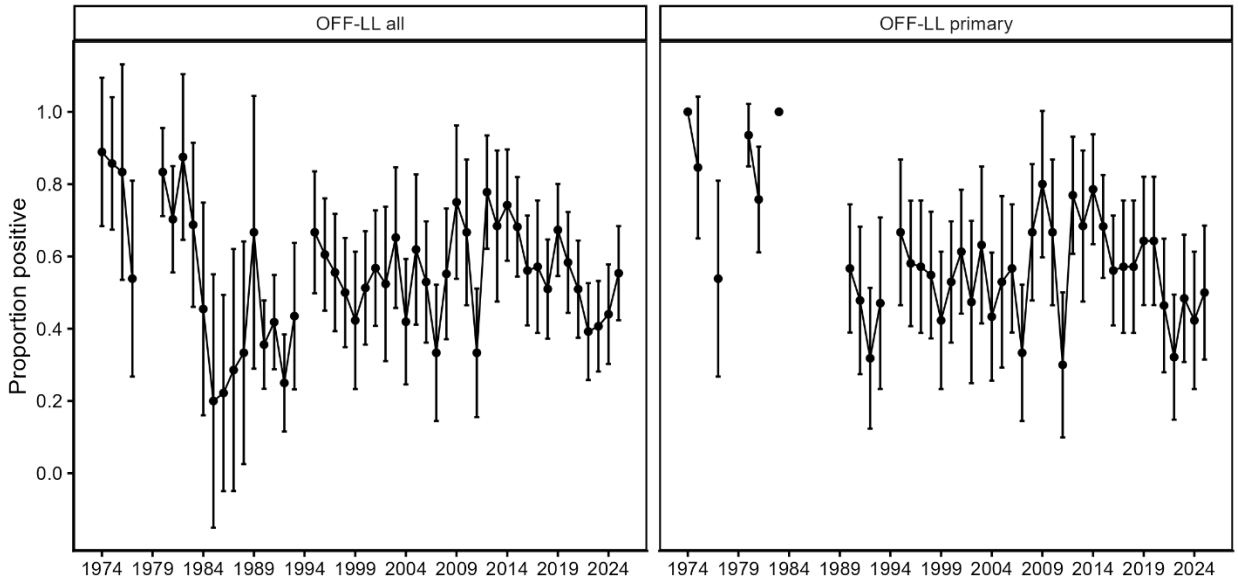

Figure 4. Nominal indices of relative abundance for sandbar shark based on all OFF-LL (left panel) and primary OFF-LL (right panel) sites, 1974-2025. Error bars are 95% confidence intervals. Missing years indicate either no sampling or less than five total longline sets completed.

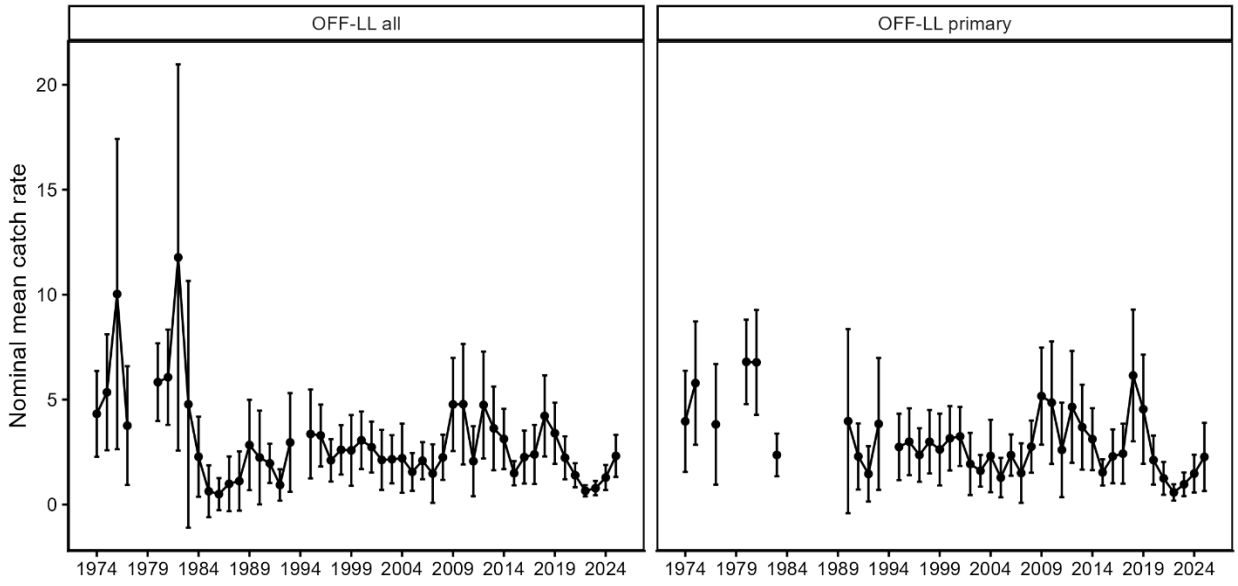

Figure 5. Model-based indices of relative abundance for sandbar shark based on all OFF-LL (left panel) and primary OFF-LL (right panel) sites, 1974-2025. Error bars are 95% confidence intervals. Missing years indicate either no sampling or less than five total longline sets completed.

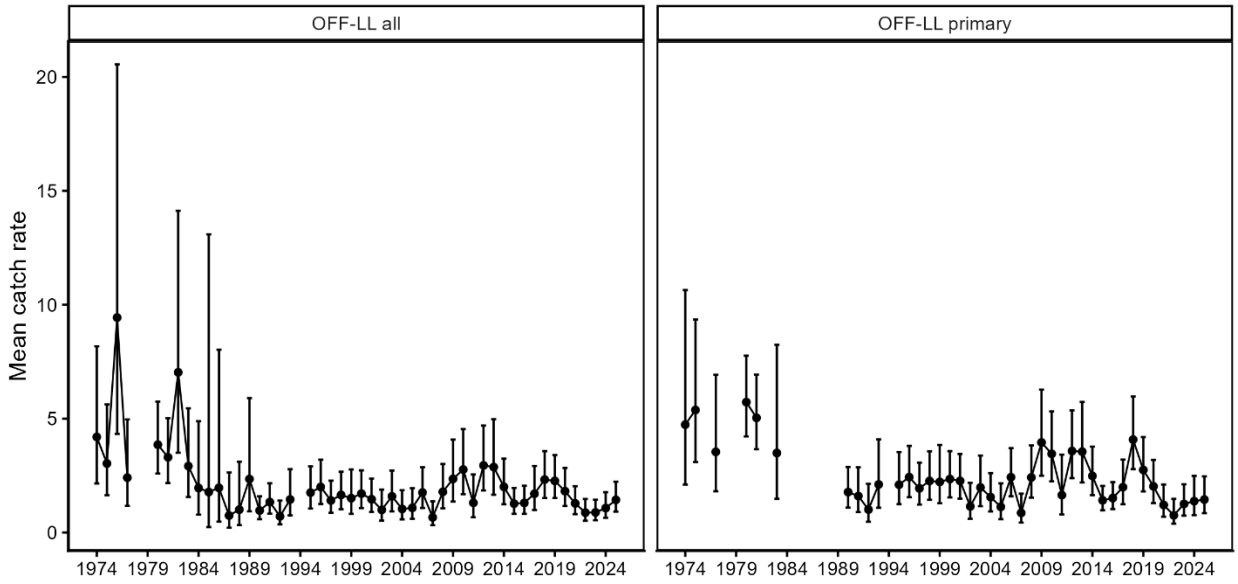

Figure 6. Proportion of positive longline sets (at least on animal captured) for sandbar shark from COASTSPAN, 2013-2025. Error bars are 95% confidence intervals.

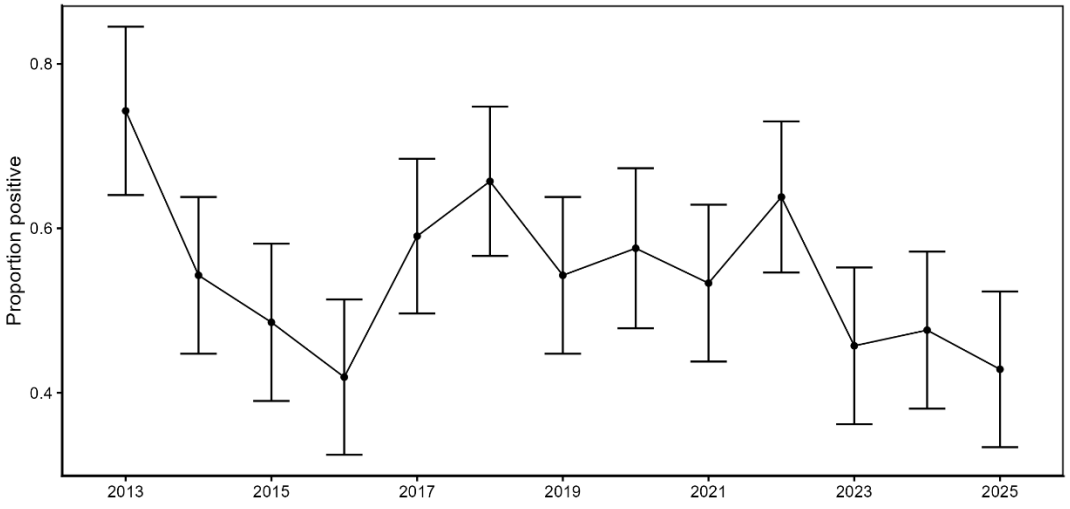

Figure 7. Model based (left panel) and nominal (right panel) indices of relative abundance for sandbar shark from COASTSPAN, 2013-2025. Error bars are 95% confidence intervals.