Spatiotemporal indices of relative abundance for sandbar shark *Carcharhinus plumbeus* from the NEFSC Coastal Shark Bottom Longline Survey

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Spatiotemporal indices of relative abundance for sandbar shark *Carcharhinus plumbeus* from the NEFSC Coastal Shark Bottom Longline Survey

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Summary

The Northeast Fisheries Science Center (NEFSC) Coastal Shark Bottom Longline Survey (CSBLLS) provides fishery-independent data on coastal shark species along the U.S. Atlantic coast from Florida to Delaware. This data working paper summarizes efforts to develop standardized indices of relative abundance for sandbar shark (*Carcharhinus plumbeus*) using spatiotemporal generalized linear mixed models (GLMMs). Trends in nominal catch-per-hook-hours (CPUE) and standardized indices of relative abundance based on spatiotemporal GLMMs fitted separately to sandbar shark counts and CPUE showed similar patterns from 1996-2024. Both models incorporated spatial and spatiotemporal random effects to account for uneven sampling effort and spatial structure in survey data. Estimated 95% confidence intervals and coefficients of variation (CV) for the standardized indices show good precision. Based on this analysis, it appears that the sandbar shark population has experienced an overall increase in abundance over the past two decades, with relatively stable relative abundance since 2015.

Background

Fisheries-independent surveys provide critical abundance and biological data to support stock assessments and management. For many shark species along the U.S. Atlantic coast, fisheries-independent data are limited, making long-term survey programs particularly important.

The Northeast Fisheries Science Center (NEFSC) Coastal Shark Bottom Longline Survey (CSBLLS) was designed to systematically sample coastal shark populations along the U.S. Atlantic coast. Sampling is conducted using standardized bottom longline gear deployed according to a fixed-station spatial design in continental shelf waters from Florida to Delaware in the Mid-Atlantic, although the spatial extent of sampling, number of samples, and frequency of research cruises have varied over time.

The objective of this working paper was to develop nominal and standardized indices of relative abundance for sandbar shark (*Carcharhinus plumbeus*) from the NEFSC CSBLLS data using a spatiotemporal generalized linear mixed models (GLMMs) framework. These indices are intended to support stock assessment modeling by providing estimates of population trends and spatial trends in stock distribution over time.

Methods

Field Sampling

The 95 sampling sites of the NEFSC CSBLLS are located approximately 30 nm apart except near Cape Hatteras, NC, where the continental shelf narrows (Figure 1). Fishing takes place at all times of the day. Survey gear consists of a 940-lb test monofilament mainline fitted with 3.6-m gangions constructed from 730-lb test monofilament. Each gangion terminates with a 3/0 shark hook baited with chunks of spiny dogfish and is attached to the mainline at approximately 21 m intervals. Weights (2.3 kg) are attached every 15 gangions to maintain bottom contact, and a bullet float paired with a 6.8 kg weight is placed every 50 hooks to stabilize the gear configuration. A 6 m staff buoy (high-flyer), equipped with radar reflectors and flashers during nighttime deployments, is connected to a poly buoy using a 3.6 m line. To ensure that the gear tends to the bottom, 9.1 kg weights are placed at both the beginning and end of the mainline after a length of line approximately two to three times the water depth has been set.

The duration for each longline set is 3 h with approximately 6 h from the beginning of gear deployment to completion of haulback. Data recorded for each longline set includes latitude, longitude, date and time of deployment and retrieval, depth, number of hooks, soak time, and synoptic environmental covariates. Soak time used for CPUE analyses was calculated as time elapsed from the beginning of each longline set to the completion of haulback. All captured sharks are identified to species, sexed and staged when possible, and measured for appropriate length metrics. Research cruises were conducted every 2-3 years from 1996-2024, and catch data are recorded at the individual level and aggregated to the set level for analysis.

Statistical Analysis

Nominal Indices

Effort for each longline set was defined as hook-hours sampled and standardized by dividing by the mean effort across all sets and years. This approach scaled effort to an approximate value of 1.0 for a typical longline set, with values greater than 1.0 representing longer sets and values less than 1.0 representing shorter sets. Year-specific nominal CPUE was calculated as the mean number of individuals captured per standardized unit of effort. Uncertainty for the nominal indices was expressed as 95% confidence intervals.

Standardized Indices

Spatiotemporal GLMMs were fitted to the survey data to develop standardized indices of relative abundance. This modeling framework allows for flexible specification of spatial and spatiotemporal random effects while accommodating non-normal catch distributions commonly observed in longline survey data. The general form of the model was:

$$
\begin{gathered}
\mu_{s,t} = g^{-1}\left(\boldsymbol{X}_{s,t}\boldsymbol{\beta} + \delta_{s,t} + b_{site(s)} + \omega_s + \varepsilon_{s,t}\right) \\
b_{site(s)} \sim N\left(0, \sigma_b^2\right) \\
\omega_s \sim MVN(0, \boldsymbol{\Sigma}_\omega) \\
\varepsilon_{s,t} \sim MVN(0, \boldsymbol{\Sigma}_\varepsilon)
\end{gathered}
\tag{1}
$$

where $\mu_{s,t}$ is expected value of the response variable at location *s* and time *t*, g^{-1} is the inverse link function, $\boldsymbol{X_{s,t}\beta}$ is the linear predictor of fixed effects, $\delta_{s,t}$ is an optional offset term, $b_{site(s)}$ is the random intercept for each sampling site given the fixed station design, ω_s is the spatial random field, and $\varepsilon_{s,t}$ is the spatiotemporal random field. Two complementary model formulations were developed. In the first, the response variable was defined as counts of sandbar sharks captured per longline set and assumed to follow a negative binomial distribution:

$$y_{s,t} \sim NB(\mu_{s,t}, \varphi)$$
$$\delta_{s,t} = \log(\text{effort}_{s,t})$$

where φ is the dispersion parameter. In the second, the response variable was defined as CPUE and assumed to follow a Tweedie distribution to accommodate zeros and continuous observations:

$$y_{s,t} \sim \text{Tweedie}(\mu_{s,t}, \varphi, p)$$

where p is the power parameter (typically $1 < p < 2$).

Fixed effects included year (factor), month (factor), and depth (centered, continuous). Spatial structure was modeled using Gaussian random fields with Matérn covariance, and spatiotemporal variation was modeled using annual random effects.

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.

Model Selection and Diagnostics
A two-phase model selection process was conducted. In the first phase, the fully saturated parameterization of fixed effects and the grouping random intercept was fitted assuming alternative spatial structures, including models with: 1) no spatial or spatiotemporal fields, 2) a spatial field only, 3) both spatial and spatiotemporal fields, and 4) spatiotemporal fields only. Model performance was evaluated using AIC, BIC, and diagnostic assessments. The best-performing spatial structure (of lack thereof) was then retained, and in the second phase, alternative combinations of fixed effects were evaluated. Model diagnostics included quantile-quantile (QQ) plots, residual plots, spatial residual mapping, convergence diagnostics, and sensitivity analyses related to mesh construction. Final models were selected based on diagnostic performance and biological plausibility.

Results & Discussion

A total of 9,886 sandbar sharks were sampled across 649 longline sets from 1996-2024. The proportion of positive longline sets showed an increasing trend over time, ranging from a low of 0.36 in 1996 to a time-series high of 0.93 in 2024 (Figure 2). Across the study period, fork lengths (FL) ranged from 62-213 cm for females and 72-185 cm for males. Year-specific size frequency distributions showed a shift toward larger size classes over time (Figure 3). Consistent with the proportion positive pattern, both nominal CPUE and model-based standardized indices of relative abundance exhibited similar increasing patterns across the study period (Figure 4).

The two modeling approaches - the negative binomial count-based formulation and the Tweedie CPUE formulation - produced similar trends in estimated relative abundance, indicating robustness to alternative distributional assumptions. Model diagnostics indicated adequate fits, with no substantial deviations observed in residuals or QQ plots. Spatial patterns in residuals did not indicate strong systematic structure, and model convergence was achieved across all final model formulations.

Standardized model-based indices of relative abundance showed interannual variability but an increasing trend over the most recent ~17 years of the time series. Earlier portions of the series (the late 1990s through approximately the mid-2000s) were characterized by comparatively lower index values. Confidence intervals CVs indicated generally good in year-specific estimates.

Incorporation of spatial and spatiotemporal random effects and captured fine-scale heterogeneity in catch distribution and indicated an expansion in the spatial footprint of sandbar shark relative abundance throughout the survey domain (Figures 5, 6). In the earliest years of the time series (1996–2004), relatively high catch rates were localized, primarily concentrated in the Mid-Atlantic and near Cape Hatteras, NC. Over time, areas of elevated catch expanded both northward and southward, consistent with the increasing trends observed in the indices of relative abundance.

Figure 1. Map of sampling locations for the NEFSC CSBLLS.

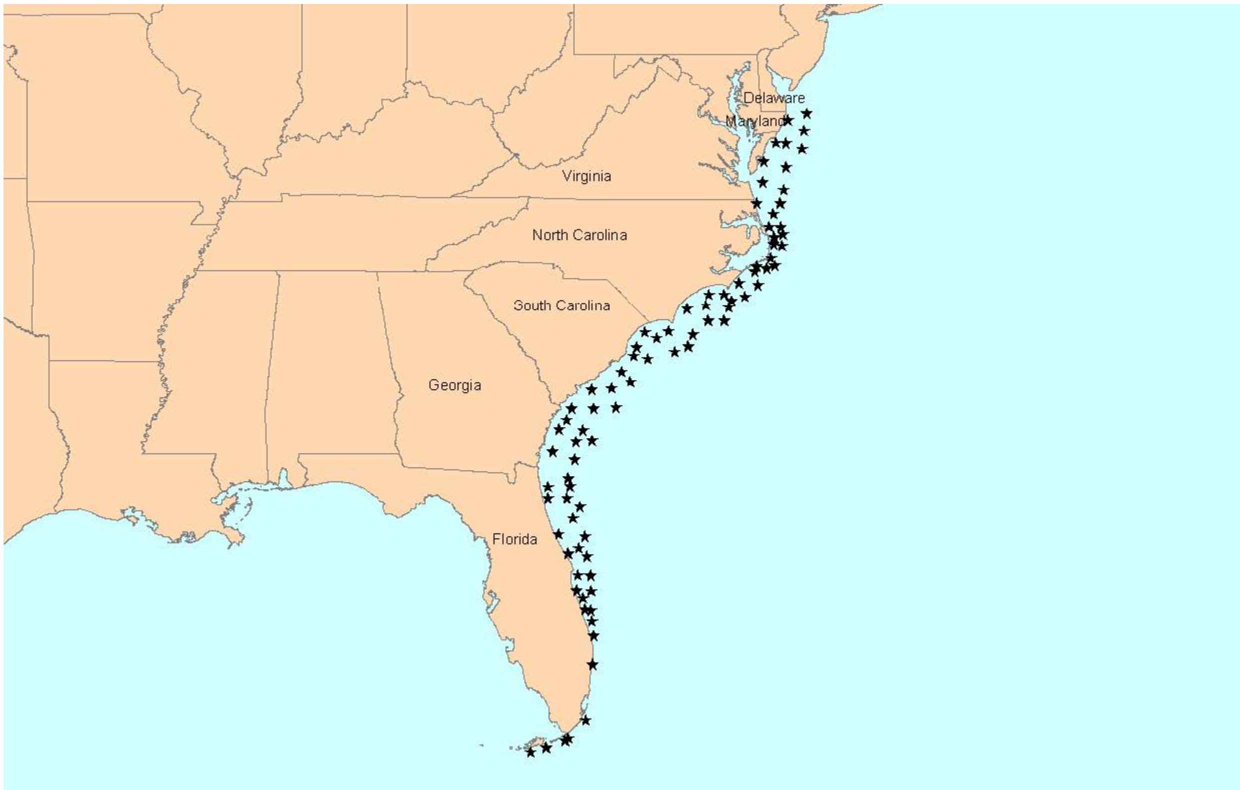

Figure 2. Year-specific proportion of positive longline sets for the NEFSC CSBLLS, 1996-2024. Bars are 95% confidence intervals and numbers next to the points indicate sample totals.

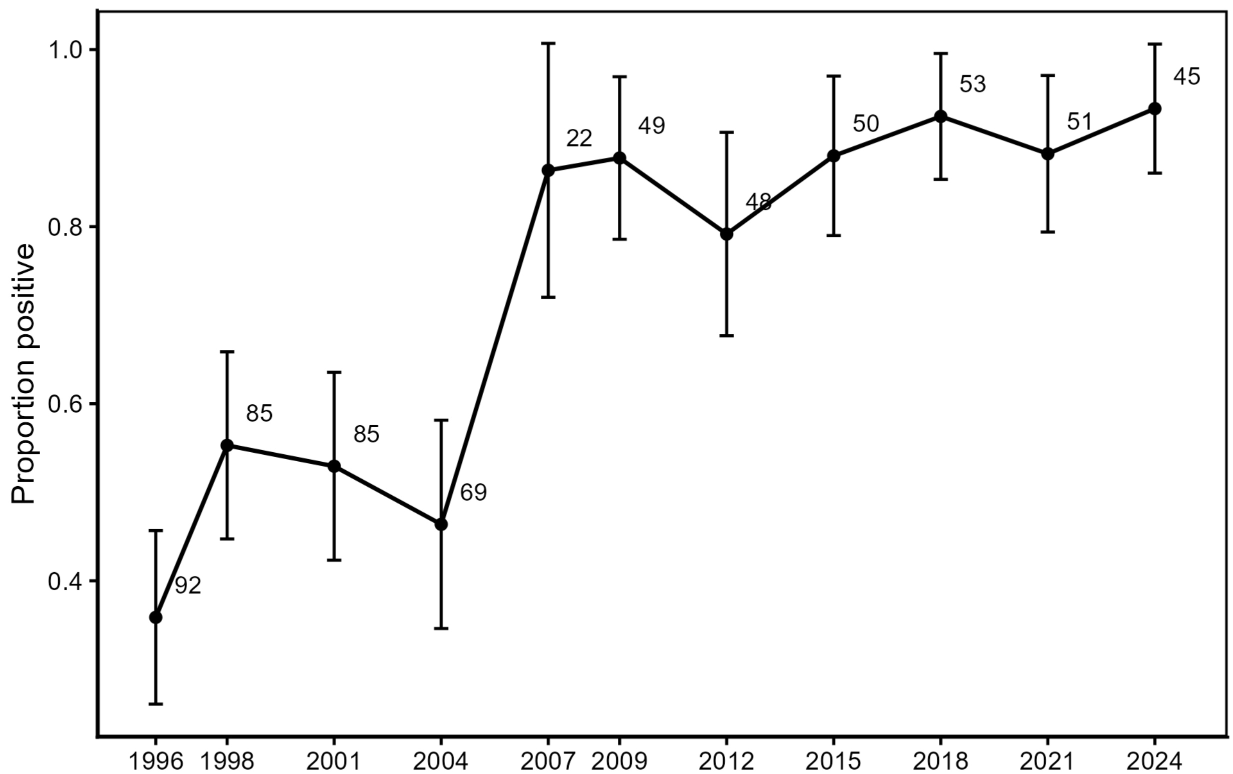

Figure 3. Year-specific fork length frequencies for sandbar sharks collected by the NEFSC CSBLLS, 1996-2024. Bubble sizes correspond to number of individuals in 10 cm fork length bins for females (left) and males (right).

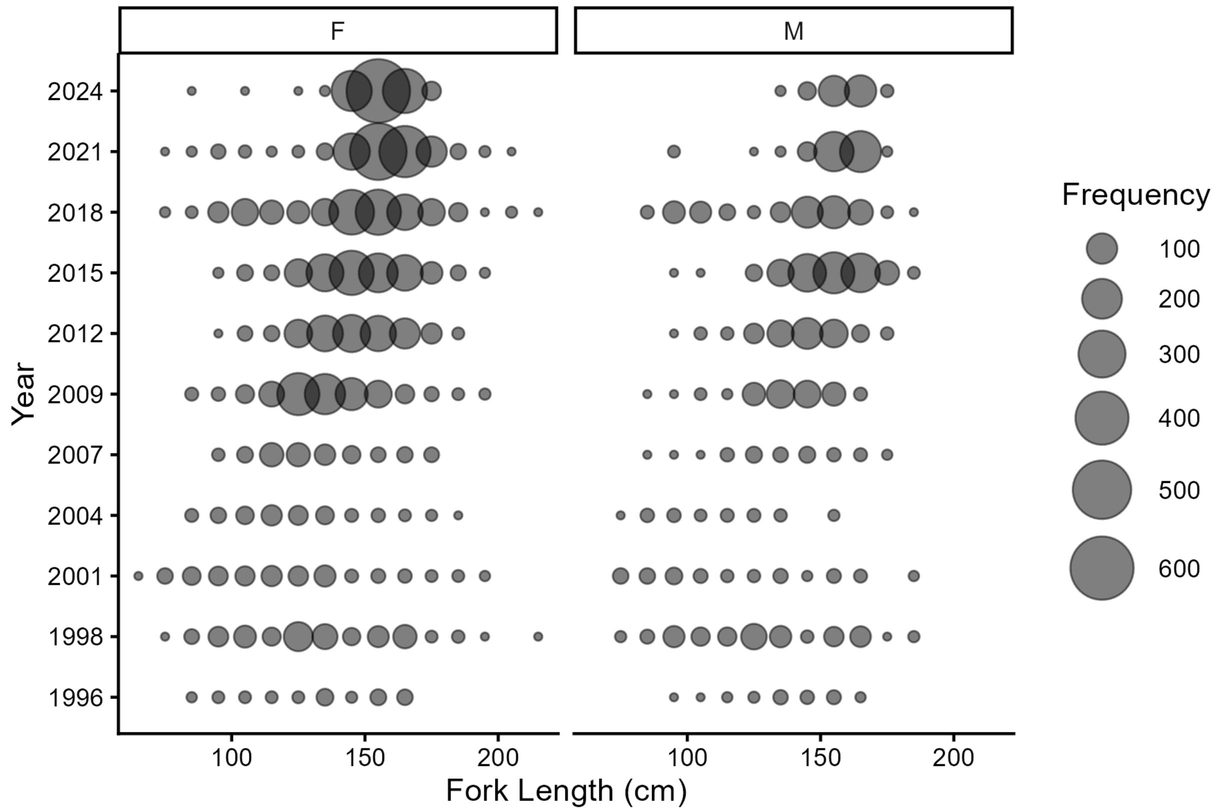

Figure 4. Year-specific mean catch rates for sandbar sharks collected by the NEFSC CSBLLS survey, 1996–2024, estimated using a spatiotemporal count GLMM, a spatiotemporal CPUE GLMM, and nominal CPUE. Error bars represent 95% confidence intervals. Coefficients of variation (CVs) ranged from 0.43-0.47 for the count GLMM, 0.26-0.35 for the CPUE GLMM, and 0.09-0.32 for nominal estimates.

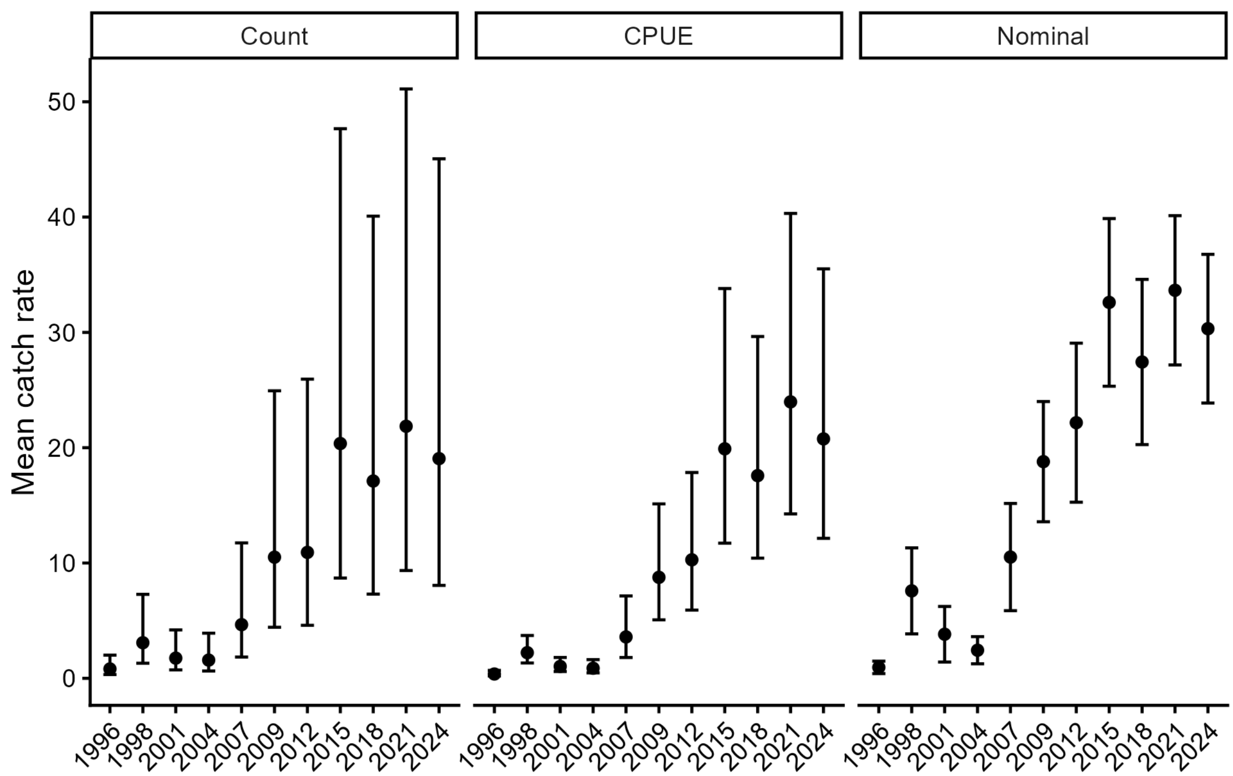

Figure 5. Year-specific spatial plots of mean catch rates for sandbar sharks collected by the NEFSC CSBLLS, 1996-2024, estimated from a spatiotemporal count GLMM.

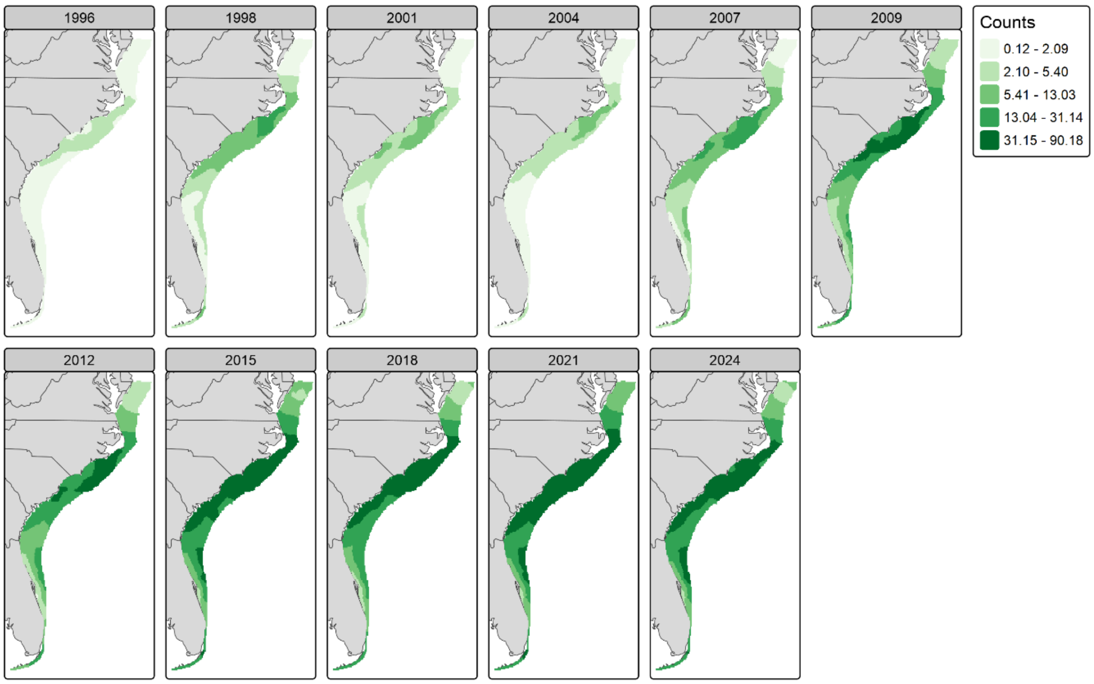

Figure 6. Year-specific spatial plots of mean catch rates for sandbar sharks collected by the NEFSC CSBLLS, 1996-2024, estimated from a spatiotemporal CPUE GLMM.