Standardized catch rates of Sandbar shark (C*archarhinus plumbeus*) surveyed during bottom longline surveys in coastal waters of the northern Gulf of America, 2006-2025

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STANDARDIZED CATCH RATES OF SANDBAR SHARK (*CARCHARHINUS PLUMBEUS*) SURVEYED DURING BOTTOM LONGLINE SURVEYS IN COASTAL WATERS OF THE NORTHERN GULF OF AMERICA, 2006-2025

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SEDAR101

Abstract

*Sandbar sharks (*Carcharhinus plumbeus*) are a wide-ranging, large, coastal shark that occupy waters throughout the Western North Atlantic Ocean and Gulf of America. As the primary target of the U.S. shark bottom longline fishery in the 20th century, they were declared overfished and experiencing overfishing in 2006. Since 2008, they have been a prohibited species under the Atlantic Fishery Management Plan for Highly Migratory Species. At present, knowledge of stock status is limited; however, fishermen claim the population has increased significantly, resulting in increased human-wildlife interactions (i.e., depredation). Here, we generated a standardized index of sandbar shark relative abundance in the northern Gulf of America. Generalized linear models were developed using data from a fishery independent bottom longline survey conducted by the Dauphin Island Sea Lab (2010-2025). These data yielded 875 sandbar sharks captured during 763 sampling sets. The index extends from 2010-2025 and standardized catch rates were ultimately estimated using a two-step delta-lognormal model. Nominal and standardized sandbar shark catch rates varied throughout the survey period, with minimum values observed in 2016 and maximum values observed in 2013. Most individuals sampled were mature (mean =193 cm Total Length).*

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Introduction

Since 2010, the Dauphin Island Sea Laboratory (DISL) has been conducting an annual shark bottom longline (BLL) survey to provide fishery-independent data for coastal shark populations. These data are being provided to SEDAR 101 for consideration to inform the sandbar shark (*Carcharhinus plumbeus*) stock assessment. Specifically, three products are provided: size composition, distribution, and a standardized index of relative abundance for sandbar sharks in the north-central Gulf of America.

Materials and Methods

DISL BLL Survey

Since 2010, the Dauphin Island Sea Laboratory (DISL) has been conducting an annual shark BLL survey. Latitudinal extent of these data ranges from 29.24305 to 30.06605, and longitudinal extent from -88.36282 to -87.53715. The operational methods and materials are identical to those used by NMFS in their Gulf-wide surveys (Powers et al. 2018, Drymon et al. 2020). Bottom longline locations were selected using a stratified-random sampling design in 2 km x 2 km grids (Powers et al. 2018). The longline gear consisted of a 1.6 km (426 kg test) monofilament mainline and 100, 3.7 m gangions of 3 mm monofilament (332 kg test monofilament) outfitted with 15/0 circle hooks and baited with Atlantic mackerel (*Scomber scombrus*). Sets were soaked for one hour. Upon bottom longline retrieval, all sharks that could be safely boated were removed from the main line, unhooked and identified to the species level according to Castro (2010). For each individual shark, length (precaudal, fork, and stretch total in cm) and sex were recorded. For further detail regarding bottom longline methods, see Powers et al. (2018) and Drymon et al. (2020).

Data

All data used in this analysis were obtained from Marcus Drymon as part of the DISL BLL sampling program from the years 2010-2025. A total of 763 stations were sampled during this time (Table 1, Table 2). Both immature and mature individuals were included in the dataset. Proportion of positive captures remained relatively stable between months, and thus all months were retained for analyses (Table 3).

Data Exclusions

The year 2011 was excluded from standardized index development due to its low catch rate (n=6) and missing associated environmental data (bottom temperature, salinity, and dissolved oxygen) for each positive encounter, rendering this year unsuitable for quantifying these impacts on catchability. The final analytical dataset included 739 stations and 869 sandbar shark captures.

Index Development

Model Development

A combination of different generalized linear models (GLM) and generalized linear mixed model (GLMM) were tested using multiple families: negative binomial in which variance is assumed to be a linear function of the mean (GLM), negative binomial in which variance is assumed to be a quadratic function of the mean (GLM), negative binomial in which variance is assumed to be a linear function of the mean and a unique month-year (MMYYYY) label was incorporated as a random intercept (GLMM), a two-part hurdle model using a binomial and a zero-truncated negative binomial distribution (GLM), a delta-lognormal model with a binomial and lognormal distribution (GLM), and a tweedie distribution (GLM). The delta-lognormal model was selected because it had the lowest Akaike's Information Criterion (AIC) and appropriately fit data assumptions (continuous response variable).

Delta-Lognormal Model

Delta-lognormal modeling methods have been used to estimate relative abundance indices for other large, coastal shark species such as the great hammerhead shark (Hoffmayer et al. 2021). The main advantage of using this method is allowance for the probability of zero catch, which tend to comprise much of fisheries-independent survey data (Ortiz et al. 2000). The index computed by this method is a mathematical combination of yearly abundance estimates from two distinct GLMs: a binomial (logistic) model which describes proportion of positive values (i.e. presence/absence) and a lognormal model which describes variability in only the nonzero abundance data (Lo et al. 1992).

The delta-lognormal index of relative abundance (I_y) was estimated as:

(1) $I_y = c_y p_y$

Where c_y is the estimate of mean CPUE for positive catches only for year *y*, and p_y is the estimate of mean probability of occurrence during year *y*. Both c_y and p_y were estimated using GLMs. Data used to estimate abundance for positive catches (*c*) and probability of occurrence (*p*) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $\ln(c) = X\beta + \varepsilon$

and

(3) $p = \frac{e^{X\beta+\varepsilon}}{1+e^{X\beta+\varepsilon}}$,

respectively, where *c* is a vector of the positive catch data, *p* is a vector of the presence/absence data, *X* is the design matrix for main effects, β is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance σ^2. Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE (c_y) and SE (p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated using the delta method approximation β.

(4) $V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y)$

A covariance term is not included in the variance estimator since there is no correlation between the estimator of the proportion positive and the mean CPUE given presence. The two estimators are derived independently and do not covary for a given year.

Submodel Variables

Year: 2010, 2012-2025
Depth: 16.3-114.0 m (continuous)
Bottom Temperature: 14.3-32.0 ℃ (continuous)
Bottom Salinity: 31.9-38.8 ppt (continuous)
Bottom Dissolved Oxygen: 1.2-8.2 mg/L (continuous)

Iterative retrospective analysis of the delta-lognormal model was applied to the data series to generate new indices of relative abundance for time intervals up to 5 years removed from the terminal year. These results yielded indices for the following timeframes: 2010-2024, 2010-2023, 2010-2022, 2010-2021, and 2010-2020.

Results and Discussion

Size, Distribution, and Relative Abundance

From 2010 to 2025, 875 sandbar sharks were captured during the DISL Bottom Longline survey (Table 2). Of these individuals, 846 were either brought on board to measure or left in the water. For sandbar sharks left in the water, stretch total (cm) was estimated using reference measurements alongside the vessel. To reduce handling time, lengths for most sandbar sharks (~77%) were estimated while the fish was left in the water. The mean size of sandbar sharks measured/estimated was 193 cm (Table 4). The length-frequency distribution is shown in Figure 1, with a unimodal distribution at roughly 200 cm. The distribution and catch-per-unit-effort (CPUE; catch/100 hk hrs) of sandbar sharks is shown in Figure 2. The annual number of sandbar sharks captured ranged from 6 to 102.

Index of Relative Abundance

To develop an index of relative abundance, combined estimates of sandbar sharks in the north-central Gulf of America included year, depth, bottom temperature, bottom salinity, and bottom DO. These indices varied interannually with a minimum abundance observed in 2016 and a maximum in 2013 (Figure 3). The AIC for the binomial and lognormal components of the delta-lognormal model were 955.9 and 1100.5 respectively. The diagnostic plots shown in Figure 4a indicate that distribution of residuals is not normal. However, Figure 4b indicates that residuals are appropriately dispersed and Figure 4c indicates no significant presence of outliers. Annual relative abundance indices are presented in Table 5 and Figure 3. Indices developed via retrospective are listed in Table 6.

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Table 1. Number of stations sampled per month per year during DISL bottom longline surveys.

	Month										
Year	3	4	5	6	7	8	9	10	11	12	Total
2010			2			6	7	6	4	3	28
2011	11			4			9				24
2012	7		11			12					30
2013		9	8				10	7			34
2014			28			25	6				59
2015		10	17			21	6				54
2016		18	9			27					54
2017		6	21				27				54
2018		18	9			3	12	8	4		54
2019		20	7				23	4			54
2020			20	7			12	15			54
2021		16	11			13	10	4			54
2022	3	8	14					23			48
2023	3	8	12			11	14				48
2024		9	12	6		21	6				54
2025		13	7	10		6	13	7	4		60
Total	24	135	188	27	0	145	155	74	12	3	763

Table 2. Sandbar shark catches per month per year during DISL bottom longline surveys.

	Month										
Year	3	4	5	6	7	8	9	10	11	12	Total
2010						5	13	7		1	26
2011							6				6
2012	3		18			7					28
2013		16	13				12	12			53
2014			44			52	6				102
2015		4	33			36	5				78
2016		6	8			36					50
2017			20				51				71
2018		19	20			12	7	19	1		78
2019		15	12				32	15			74
2020			28	3			10	12			53
2021		10	17			8	13	5			53
2022		4	11					26			41
2023	2	3	9			18	5				37
2024		2	20	7		30	4				63
2025		4	7	18		16	14	1	2		62
Total	5	83	260	28	0	220	178	97	3	1	875

Table 3. Ratio of positive to zero-catch sampling sets per month.

Month	Proportion of Positive Catches	Mean CPUE
March	0.250	0.312
April	0.333	0.532
May	0.582	1.400
June	0.444	1.040
August	0.653	1.520
September	0.533	1.170
October	0.541	1.310
November	0.167	0.250
December	0.333	0.333

Table 4. Number of stations sampled, number of individual sandbar sharks captured, minimum stretched total length (cm), maximum stretched total length (cm), mean stretched total length (cm), and standard deviation of stretched total length (cm) by year and for 2010-2025.

Survey Year	Number of Stations	Number Collected	Min Total Length (cm)	Max Total Length (cm)	Mean Total Length (cm)	SD (cm)
2010	28	26	164	250	217	20.8
2011	24	6	200	235	219	12.4
2012	30	28	190	225	207	10.9
2013	34	53	165	250	205	24.1
2014	59	102	160	220	195	10.9
2015	54	78	150	250	192	15.5
2016	54	50	167	240	197	15.8
2017	54	71	150	230	196	14.4
2018	54	78	160	220	196	16.6
2019	54	74	140	220	187	18.3
2020	54	53	97	220	179	18.2
2021	54	53	122	230	183	17.2
2022	48	41	150	210	177	15.1
2023	48	37	130	220	186	16.6
2024	54	63	150	210	179	15.6
2025	60	62	130	190	171	11.6
Total Number of Years	**Total Number of Stations**	**Total Number Collected**	**Overall Mean Total Length (cm)**			
16	763	875	193			

Table 5. Nominal predicted frequency (CPUE), number of individual sandbars captured (N), the DL index (catch per 100 hk hr), the DL indices scaled to a mean of predicted values, standard error (SE), and lower and upper confidence limits (LCL an UCL) for the scaled index are listed.

Year	Nominal Frequency	N	DL Index	DL Scaled Index	DL SE	DL UCL	DL LCL	GLM Index	GLM Scaled	GLM SE	GLM LCL	GLM UCL
2010	1.050	26	0.997	0.854	0.367	1.573	0.135	0.914	0.793	0.314	0.177	1.408
2012	1.170	28	1.090	0.930	0.405	1.724	0.136	0.910	0.789	0.324	0.153	1.425
2013	1.710	53	1.820	1.560	0.742	3.014	0.106	1.599	1.388	0.622	0.168	2.607
2014	1.660	102	1.760	1.500	0.264	2.017	0.983	1.703	1.478	0.264	0.960	1.995
2015	1.440	78	1.430	1.230	0.198	1.618	0.842	1.652	1.433	0.255	0.933	1.933
2016	0.720	50	0.727	0.622	0.152	0.920	0.324	0.783	0.680	0.166	0.354	1.006
2017	1.340	71	1.290	1.100	0.231	1.553	0.647	1.291	1.120	0.226	0.677	1.563
2018	1.440	78	1.370	1.170	0.234	1.629	0.711	1.278	1.109	0.213	0.691	1.526
2019	1.370	74	1.290	1.100	0.195	1.482	0.718	1.365	1.185	0.225	0.744	1.625
2020	0.981	53	0.919	0.787	0.184	1.148	0.426	0.879	0.762	0.172	0.425	1.100
2021	0.981	53	1.040	0.892	0.163	1.211	0.573	1.110	0.963	0.188	0.595	1.331
2022	0.872	41	0.907	0.776	0.209	1.186	0.366	0.828	0.718	0.182	0.362	1.074
2023	0.771	37	0.794	0.68	0.159	0.992	0.368	0.872	0.756	0.179	0.405	1.107
2024	1.170	63	1.17	0.998	0.187	1.365	0.631	1.186	1.029	0.199	0.639	1.419
2025	1.030	62	0.93	0.796	0.180	1.149	0.443	0.920	0.798	0.170	0.466	1.131

Table 6. Results of the retrospective analyses of the delta-lognormal model for the years 2021-2025.

	2010-2024			2010-2023			2010-2022			2010-2021			2010-2020		
Year	DL Index	DL Scaled Index	DL SE	DL Index	DL Scaled Index	DL SE	DL Index	DL Scaled Index	DL SE	DL Index	DL Scaled Index	DL SE	DL Index	DL Scaled Index	DL SE
2010	0.994	0.848	0.366	1.050	0.384	1.050	1.020	0.847	0.377	1.000	0.806	0.376	0.974	0.761	0.365
2012	1.050	0.898	0.397	0.996	0.384	0.996	1.060	0.874	0.411	1.080	0.874	0.421	1.090	0.849	0.451
2013	1.740	1.480	0.737	1.730	0.736	1.730	1.710	1.410	0.763	1.710	1.380	0.781	1.860	1.450	0.837
2014	1.750	1.490	0.261	1.740	0.263	1.740	1.770	1.470	0.269	1.760	1.420	0.272	1.790	1.400	0.283
2015	1.430	1.220	0.197	1.450	0.200	1.450	1.450	1.200	0.201	1.450	1.170	0.202	1.430	1.120	0.203
2016	0.727	0.620	0.152	0.722	0.152	0.722	0.726	0.601	0.154	0.728	0.587	0.154	0.731	0.571	0.158
2017	1.280	1.100	0.230	1.300	0.234	1.300	1.310	1.0900	0.236	1.320	1.070	0.239	1.310	1.020	0.238
2018	1.360	1.160	0.233	1.350	0.233	1.350	1.350	1.120	0.237	1.360	1.100	0.240	1.390	1.080	0.249
2019	1.290	1.100	0.194	1.280	0.195	1.280	1.300	1.070	0.198	1.300	1.050	0.199	1.310	1.020	0.205
2020	0.912	0.779	0.183	0.906	0.183	0.906	0.901	0.745	0.185	0.904	0.729	0.187	0.926	0.723	0.194
2021	1.030	0.879	0.162	1.020	0.163	1.020	1.020	0.844	0.166	1.020	0.824	0.169	-	-	-
2022	0.905	0.773	0.209	0.896	0.208	0.896	0.881	0.730	0.209	-	-	-	-	-	-
2023	0.788	0.673	0.158	0.787	0.159	0.787	-	-	-	-	-	-	-	-	-
2024	1.150	0.981	0.185	-	-	-	-	-	-	-	-	-	-	-	-
2025	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

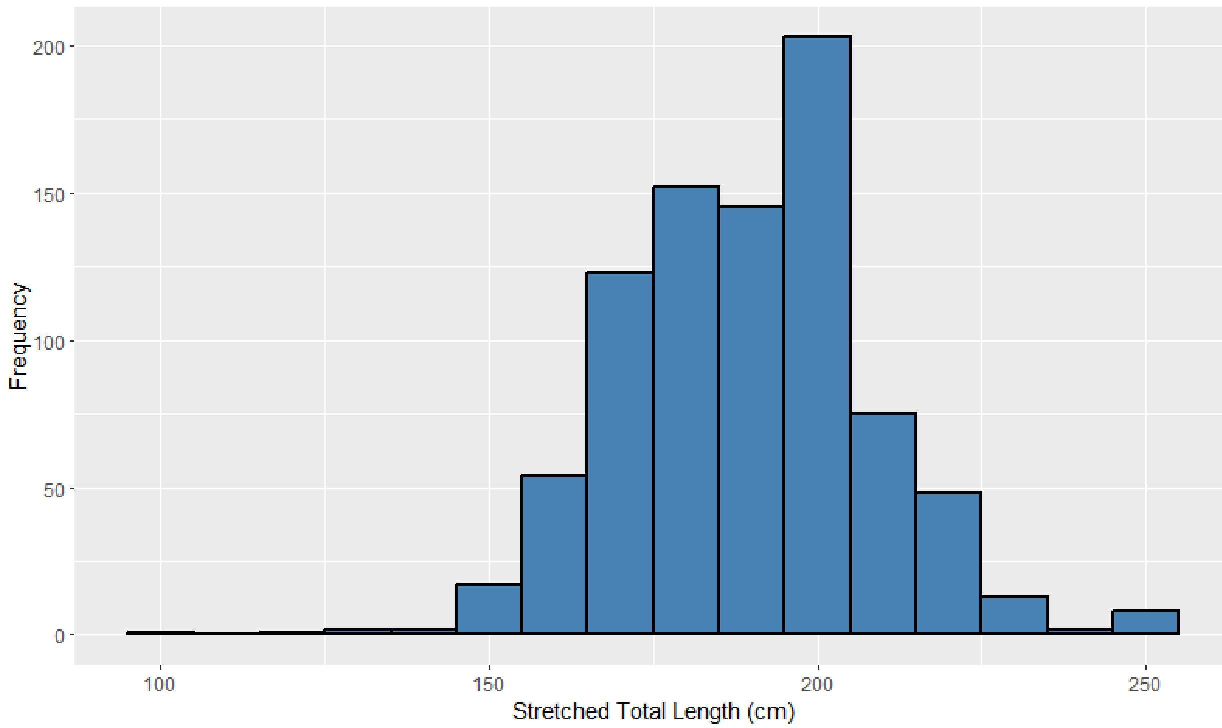

Figure 1. Length frequency histogram of sandbar shark stretched total length (cm) in 100 cm bins.

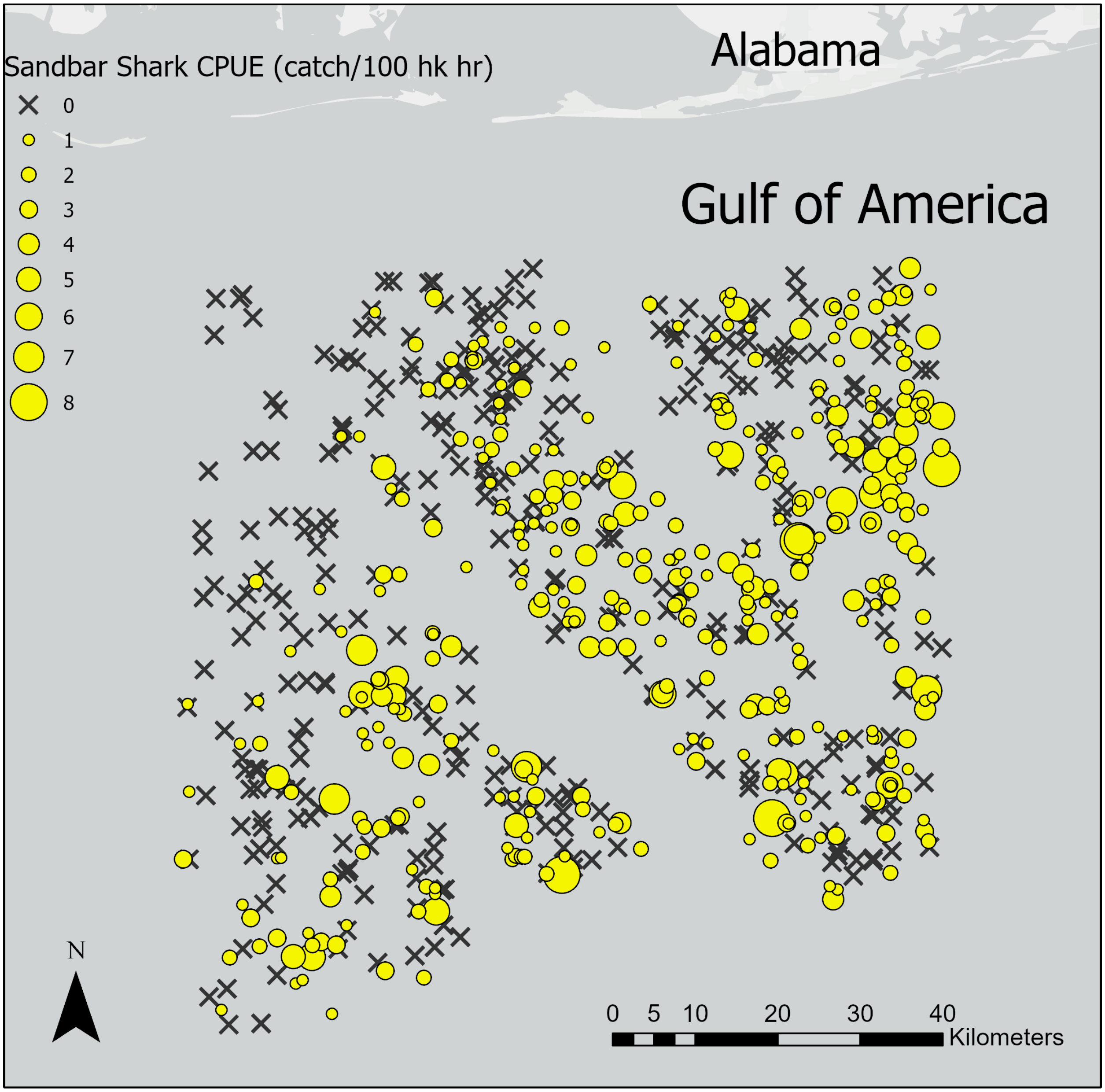

Figure 2. Sandbar shark CPUE (count/100 hook hr) from 2010-2025.

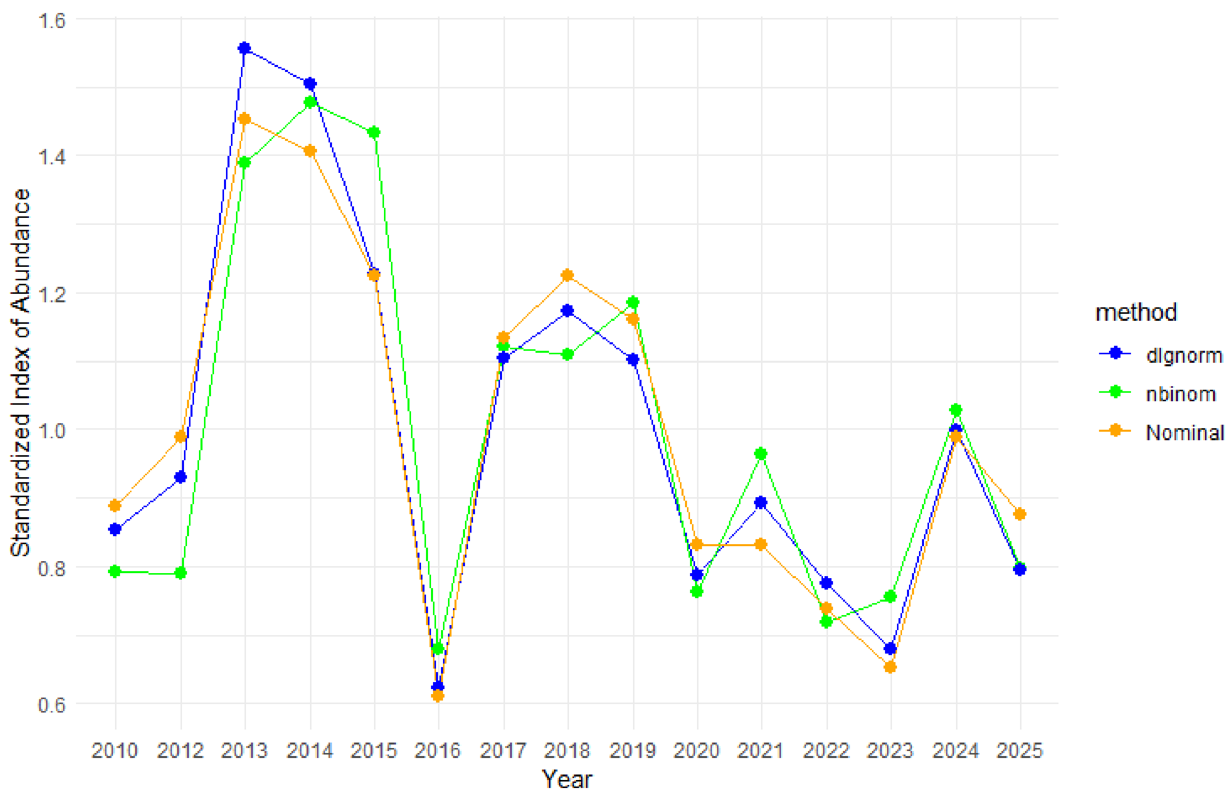

Figure 3. Index of abundance calculated as a nominal index (orange), GLMM with a negative binomial distribution assuming linear variance growth (green, nbinom), and delta-lognormal modeling (blue, dlgnom). The GLMM was the best-performing single-step model and generated comparable outputs to the nominal and delta- lognormal indices.

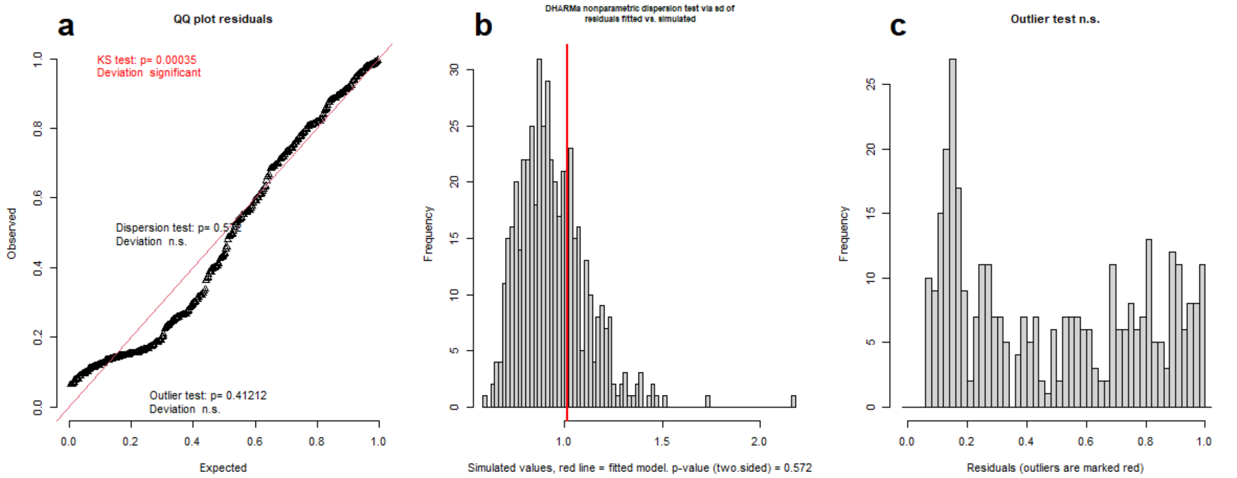

Figure 4. QQ-plot of simulated residuals (a) indicating deviation from normal distribution (Asymptotic one-sample Kolmogorov-Smirnov test, $p<0.05$); non-parametric dispersion test (b) (dispersion=1.0781, p-value=0.572) indicating variation in the data is appropriately expected by the model; and outlier test (c) ($p=0.41$), indicating proportion of outliers is insignificant.