Indices of Abundance for the Gulf Tilefish Complex (*Caulolatilus chrysops*, *Caulolatilus microps*) from the Gulf Fishery Independent Survey of Habitat and Ecosystem Resources

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Indices of abundance for the Gulf Tilefish Complex (*Caulolatilus chrysops*, *Caulolatilus microps*) from the Gulf Fishery Independent Survey of Habitat and Ecosystem Resources

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1. Background

Historically, fishery-independent stationary video surveys across the northern Gulf of America (Gulf), specifically the SEAMAP Reef Fish Video (SRFV) survey, the NMFS Panama City (PC) Laboratory survey, and the Florida Fish and Wildlife Research Institute (FWRI) survey, featured differing spatial footprints, operational boundaries, varying sampling intensities, and some lab-specific variations in video reading annotation. These spatial and historical design imbalances presented challenges for indexing relative abundance for two species in the Tilefish Complex: goldface tilefish, *Caulolatilus chrysops* and blueline tilefish *Caulolatilus microps*.

Unlike many shallow-water grouper or snapper species that span inshore-to-offshore gradients across their life histories, many species within the *Caulolatilus* genus, specifically *C. chrysops* and *C. microps* exhibit restrictive physiological boundaries and specific habitat requirements (Dooley 1978; GMFMC 2016). They are strongly obligate to deep benthic environments, targeting habitats that typically exceed depths of 75 m, although they can be found as shallow as 30 m (GMFMC 2016).

Prior to 2020, a compounding challenge when evaluating the historical data for the Tilefish Complex is the limitation in annual sample sizes during the early years of the time series. This scarcity was not necessarily reflective of true stock declines, but rather a potential artifact of limited deepwater sampling effort across the historical programs. Because the PC and FWRI surveys were operationally optimized for predominately shallower, nearshore shelf matrices in earlier years, the number of annual stations that actually met the necessary $\geq$ 30 m bathymetric threshold was low and highly variable. Shifting spatial footprints introduces a high risk of tracking localized sampling artifacts rather than true stock abundance, inflating the variance around annual estimates.

To resolve these historical design challenges, the integrated Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (G-FISHER) program was established in 2020. Consequently, this working paper presents a model-based index of relative abundance for the Tilefish Complex utilizing solely integrated G-FISHER data spanning 2020 through 2024.

2. Methods

Survey Design

Beginning in 2020, Gulf-wide video survey efforts were integrated under a unified, standardized survey design under the G-FISHER program (Thompson et al. 2022, Switzer et al. 2023). A stratified-random design structure was adopted incorporating both spatial and habitat stratification to subdivide the survey domain into homogeneous strata and efficiently partition population variance (Smith et al. 2011).

Spatially, the G-FISHER survey domain is subdivided into three depth strata (10 – 25 m, > 25 – 50 m, and > 50 – 180 m) and six regional strata (Texas, west Louisiana, east Louisiana, north-central Gulf, Big Bend, and southwest Florida). For both natural and artificial reefs, habitat strata are delineated based on relative relief (low, medium, high) and the size of the individual reef feature. Under this design, approximately 2,000 reef fish stations are sampled annually with stereo baited remote underwater video (SBRUV) camera arrays designed to characterize benthic habitats and provide data on abundance and size composition of observed reef fishes.

Data Filtering and Reduction:

Prior to index standardization, the raw video dataset was filtered using three primary criteria to ensure the analyzed data representative of the Tilefish Complex's biological distribution and to prevent numerical estimation issues during model fitting:

1. Temporal Truncation: The time series was restricted to the combined G-FISHER program years (2020 – 2024) to eliminate multi-vessel sampling footprint imbalances inherent to the historical pre-integration era.
2. Bathymetric Truncation: A depth restriction was applied to the data, subsetting to stations with depths ≥ 30 m. This filter dropped shallow-water sampling stations where the Tilefish Complex presence is near zero, this assists with artificial inflation of zero-catch data cells.
3. Habitat and Quality Exclusions: All data collected on artificial reefs were excluded from subsequent analyses to focus strictly on natural benthic habitats. Additionally, video reads were excluded if they were unreadable due to high turbidity or camera deployment errors.

Due to constraints during the 2020 sampling season, G-FISHER sampling effort was restricted exclusively to the Eastern Gulf of Mexico (East of -89° Longitude). Sampling resumed its full standardized, Gulf-wide footprint from 2021 through 2024. The 2020 data were retained in the final index calculation because the fixed-effect spatial stratification variable ($INDEX_REGION$) implemented within the GLM framework mathematically controls for regional footprint variations, predicting a unified trend based on the baseline regional density ratios calculated across fully-sampled calendar years.

The final filtered dataset comprised a total sample size of 3,748 stations across the 5-year time series (Figure 1). The same data reduction procedures were applied to the video length data set such that annual size composition vectors were generated solely from stations used to generate standardized indices. Individual measurements were subsequently assigned to 20 mm size bins. The corresponding length-frequency dataset yielded a total of 99 individual fish measurements available for length-composition analysis.

Video Processing and Length Measurements

Paired stereo-imaging cameras were used at each site. All videos are read to identify the maximum number of individuals of each species viewed in a single frame within a 20-minute time frame, often referred to as MaxN or MinCount. Habitat characteristics on video are also noted with the percentage or presence/absence of abiotic and biotic habitat types that may contribute to fish biomass (e.g. sponge, algae, and corals). All length measurements are obtained from the SeaGIS software (SeaGIS Pty. Ltd.). Length measurements are typically taken at the point in the video where the greatest number of fish are measurable, and often there are some individuals observed that are not measurable.

Index Model:

Standardized indices of relative abundance (MaxN) were modeled using a generalized linear model (GLM) framework implemented via the glmmTMB package in R (R Core Team 2025). Given the characteristic overdispersion and high proportion of zero counts typical of reef fish video data, a Negative Binomial Type-II (nbinom2) error distribution with a log-link function was selected:

$$\boldsymbol{E(MaxN) = \mu}$$

$$\boldsymbol{Var(MaxN) = \mu + \frac{\mu^2}{k}}$$

where k is the overdispersion parameter. Rather than utilizing a year-and-laboratory configuration, which introduces severe spatial-temporal confounding due to changing annual survey regions among vessels, a spatial stratification variable ($INDEX\ REGION$; East vs. West Gulf separated at -89° Longitude) was incorporated. This spatial term accounts for baseline structural differences in tilefish abundance between the dominant habitat types between the Western Gulf and Eastern Gulf.

To determine the optimal covariate structure, a forward-selection pool of 16 distinct model configurations was evaluated (Table 1). This testing suite crossed candidate environmental and localized habitat covariates against two alternative bathymetric profiles: a simple linear depth

term ($DEPTH$) and a second-order polynomial profile ($poly(DEPTH, 2)$). The global model structure is generalized as

$$\mathbf{ln}(\boldsymbol{MaxN}) = \boldsymbol{YEAR} + \boldsymbol{INDEX\ REGION} + \boldsymbol{f}(\boldsymbol{DEPTH}) + \boldsymbol{COVARIATE}$$

where $f(DEPTH)$ represents either the linear or quadratic formulation, and COVARIATE represents the specific habitat or environmental driver under evaluation. Final model fits were evaluated using the DHARMa package (Hartig 2024) to test for deviations from the expected distribution, under/overdispersion, and outliers.

3. Results and Discussion

Model Selection and Diagnostics

Model selection was guided by a simultaneous evaluation of Information Criteria (AIC) and numerical optimization stability. The complete model testing matrix and diagnostic scorecard are detailed in Table 1.

Initial screening revealed that models incorporating fine-scale, higher complexity classifications (specifically $GENHAB$ and $COMBO_MAX_RELIEF$) produced the lowest nominal AIC values. However, closer inspection of the variance-covariance structures revealed that the inclusion of complex categorical habitat covariates introduced numerical instability into the model(s). Due to a total absence of tilefish detections within specific rare habitat treatments, the optimization algorithm attempted to estimate infinite coefficients on the log-link scale, leading to a singular Hessian matrix and undefined standard errors. These models were mathematically rejected as over-fitting artifacts.

Among the structurally sound candidates that maintained stability and successful convergence (Convergence Code = 0, Separation Count = 0), the model configured with **Region + Polynomial Depth + Relief Presence/Absence** (m7_poly; Table 1**),** was the most definitive and parsimonious, outperforming its linear depth counterpart by 32.4 AIC points.

The inclusion of the second-order polynomial for depth was further justified by empirical data density screening. While raw G-FISHER sampling effort peaks heavily in shallow waters (< 50 m), positive tilefish catches are strictly confined to a deepwater corridor, peaking between 120 m and 160 m before tapering deeper (Figure 2). The quadratic structure successfully mapped this parabolic depth preference, preventing model misspecification. Residual diagnostics evaluated via simulated standardized residuals (DHARMa package; Hartig 2024) confirmed excellent model fit, showing no significant signs of remaining overdispersion, residual patterning, or outlier inflation (Figure 3).

Annual Index and Size Composition

Annual standardized index values were generated by extracting marginal means from the selected model across years using the emmeans package (Figure 4, Table 2). Standardized index values tracking relative abundance show a drop from a time series peak in 2020 (1.85) down to a minimum in 2022 (0.43), followed by a steady rebuilding trend through 2024 (0.99; Figure 4, Table 2). The nominal CPUE closely tracks the standardized index trend. Following standard regional protocols, annual 95% confidence intervals were constructed using a linear Wald framework scaled to the grand mean, calculated as the standardized index value ±2 standard errors.

Annual length frequencies were aggregated into standardized 20 mm size bins ranging from 240 to 760 mm FL (Figure 5 – 6). Proportions-at-length were calculated natively within the filtered survey footprint, preserving between the index trends and the size compositions available.

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Table 1. Model performance and diagnostic matrix with models sorted by AIC value. The selected model is bolded.

Model Name	Conv Code	Max Gradient	Separation Count	Max SE	AIC	Δ AIC
m3_poly (Region + GenHab [Poly])	0	0.00015	31	-Inf	908.17	0
m7_poly (Region + Relief PA [Poly])	0	0.00002	0	14.55	913.26	5.09
m4_poly (Region + Complexity [Poly])	0	0.0001	0	14.76	918.74	10.57
m2_poly (Region + Habitat Relief [Poly])	1	0.00117	42	-Inf	924.19	16.02
m6_poly (Region + Latitude [Poly])	0	0.00254	0	17.1	925.65	17.48
m3_lin (Region + GenHab [Linear])	1	0.01377	30	-Inf	935.74	27.57
m5_poly (Region + Longitude [Poly])	0	0.00155	0	17.39	940.14	31.97
m7_lin (Region + Relief PA [Linear])	0	0.00669	0	0.49	945.69	37.52
m2_lin (Region + Habitat Relief [Linear])	1	0.01048	41	-Inf	947.16	38.99
m1_poly (Base [Poly Depth])	0	0.00012	0	14.92	948.99	40.82
m8_poly (Region + HabStrat [Poly])	0	0.00004	0	14.71	955.56	47.39
m4_lin (Region + Complexity [Linear])	0	0.00111	0	0.5	955.74	47.56
m6_lin (Region + Latitude [Linear])	0	0.00293	0	3.41	968.63	60.46
m5_lin (Region + Longitude [Linear])	0	0.00721	0	8.47	982.73	74.56
m1_lin (Base [Linear Depth])	0	0.00138	0	0.39	990.96	82.79
m8_lin (Region + HabStrat [Linear])	0	0.00022	0	0.48	992.27	84.10

Table 2. Number of stations sampled (N Sites), number of sites with positive occurrence of Tilefish Complex (N Sites Pos), number of Tilefish Complex (N Fish) by year, proportion of positive sets (PPOS), standardized index (Index), nominal index (Nominal CPUE), upper and lower 95% confidence level (LCL, UCL, respectively), and CV for the annual Tilefish Complex G-FISHER index Gulf-wide.

Year	N Sites	N Sites Pos	N Fish	PPOS	Nominal CPUE	Index	UCL	LCL	CV
2020	417	24	44	0.05755396	1.903924345	1.84567015	0.51923203	3.17210827	0.359
2021	862	40	48	0.04640371	1.004770873	0.968700209	0.32096526	1.61643516	0.334
2022	804	13	15	0.01616915	0.336641983	0.425204576	0.09235291	0.75805624	0.391
2023	831	25	28	0.03008424	0.607981092	0.766968599	0.231175	1.3027622	0.349
2024	834	40	53	0.04796163	1.146681708	0.993456467	0.33083758	1.65607535	0.333

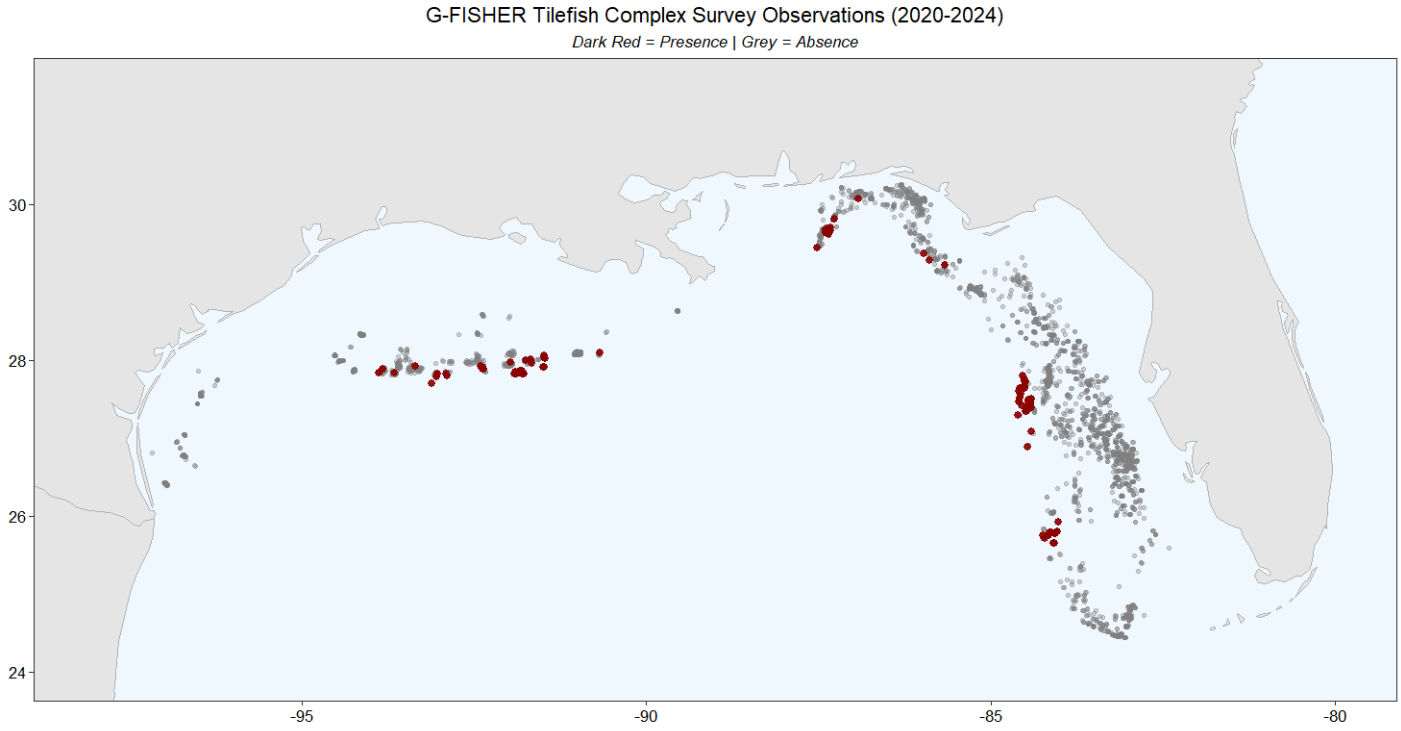

Figure 1. Spatial distribution of the Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (G-FISHER) sampling stations evaluated for the Tilefish Complex (2020 – 2024). Grey points indicate stations with $n = 0$ Tilefish Complex observations (Absence); dark red points denote confirmed $n \geq 1$ (Presence).

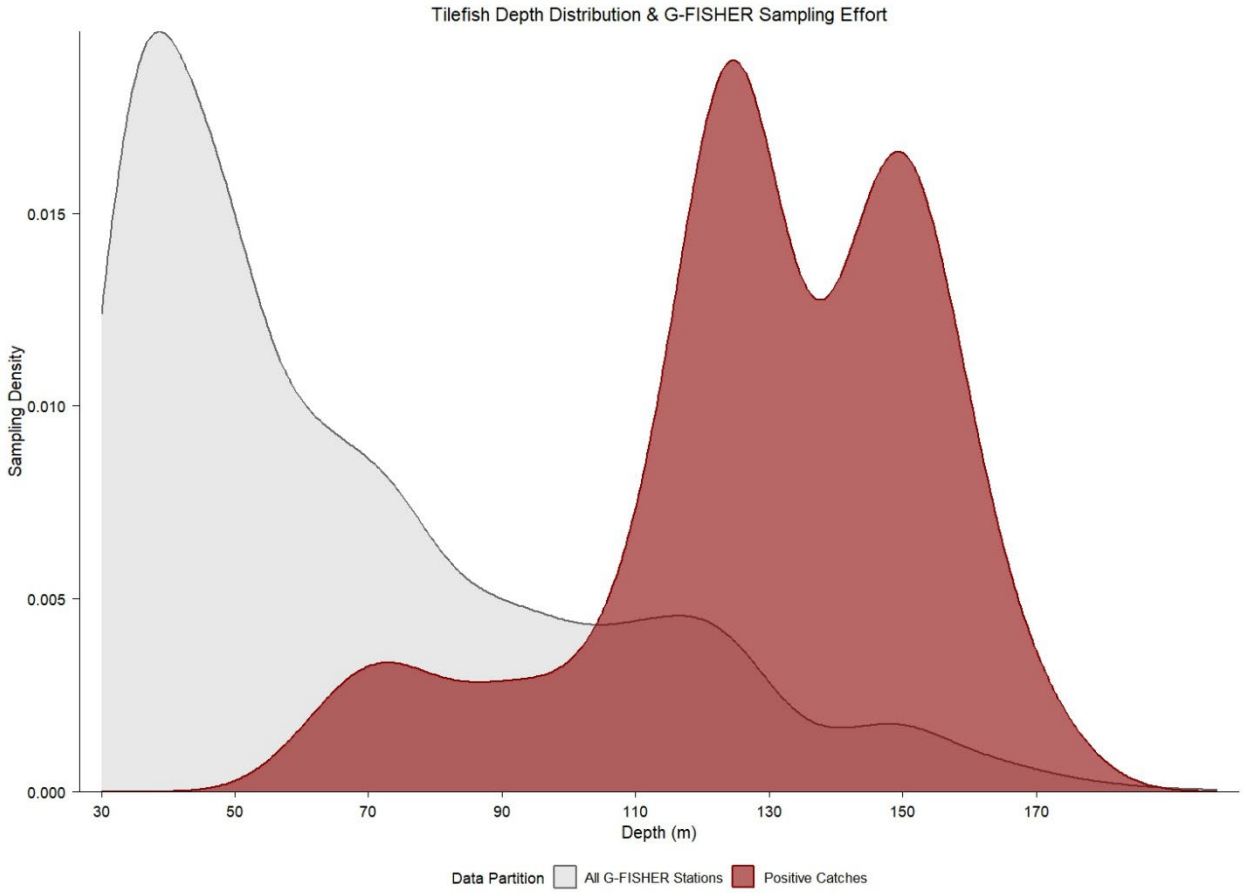

Figure 2. Bathymetric distribution density profiles overlaying total G-FISHER sampling effort (light grey) against positive habitat selections where Tilefish Complex species were present (dark red) across the truncated survey domain (≥ 30 m).

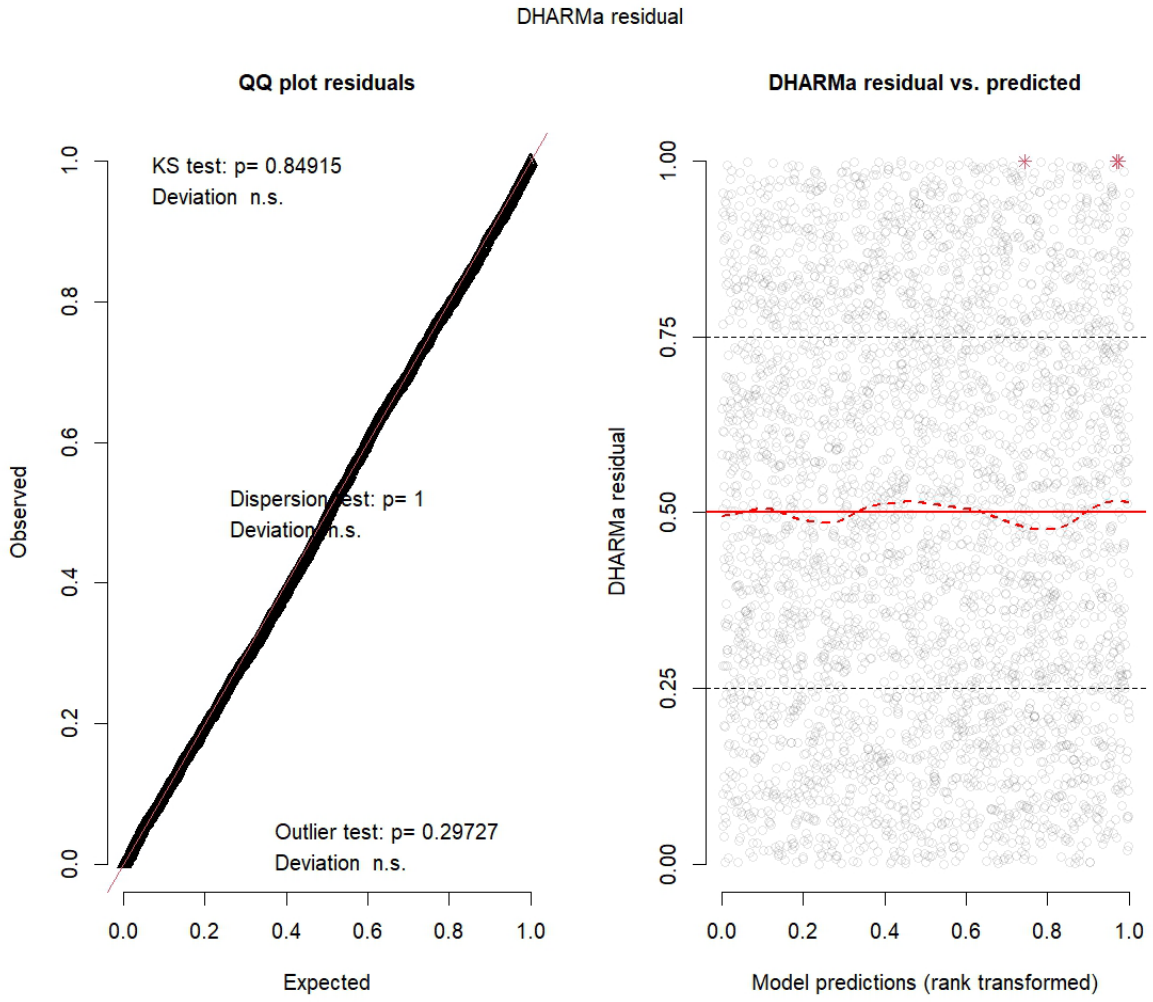

Figure 3. Standardized diagnostic panel generated via residual simulation (DHARMa package) for the selected index model, showing the quantile-quantile (Q-Q) plot (left) and residuals plotted against rank-transformed model predictions (right).

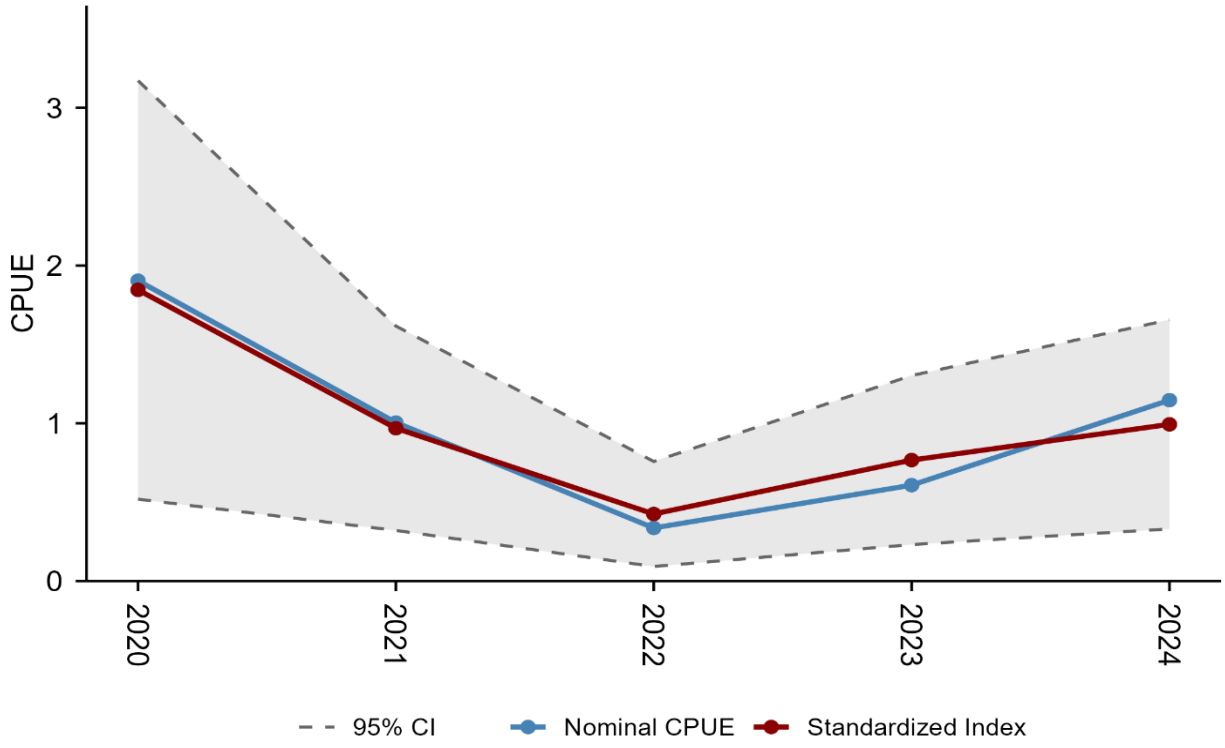

Figure 4. Standardized relative abundance index (dark red line) compared against the nominal CPUE trend (blue line) for the Gulf Tilefish Complex (2020 – 2024). The shaded area and dashed lines represent the corresponding linear scaled 95% confidence intervals (±2SE).

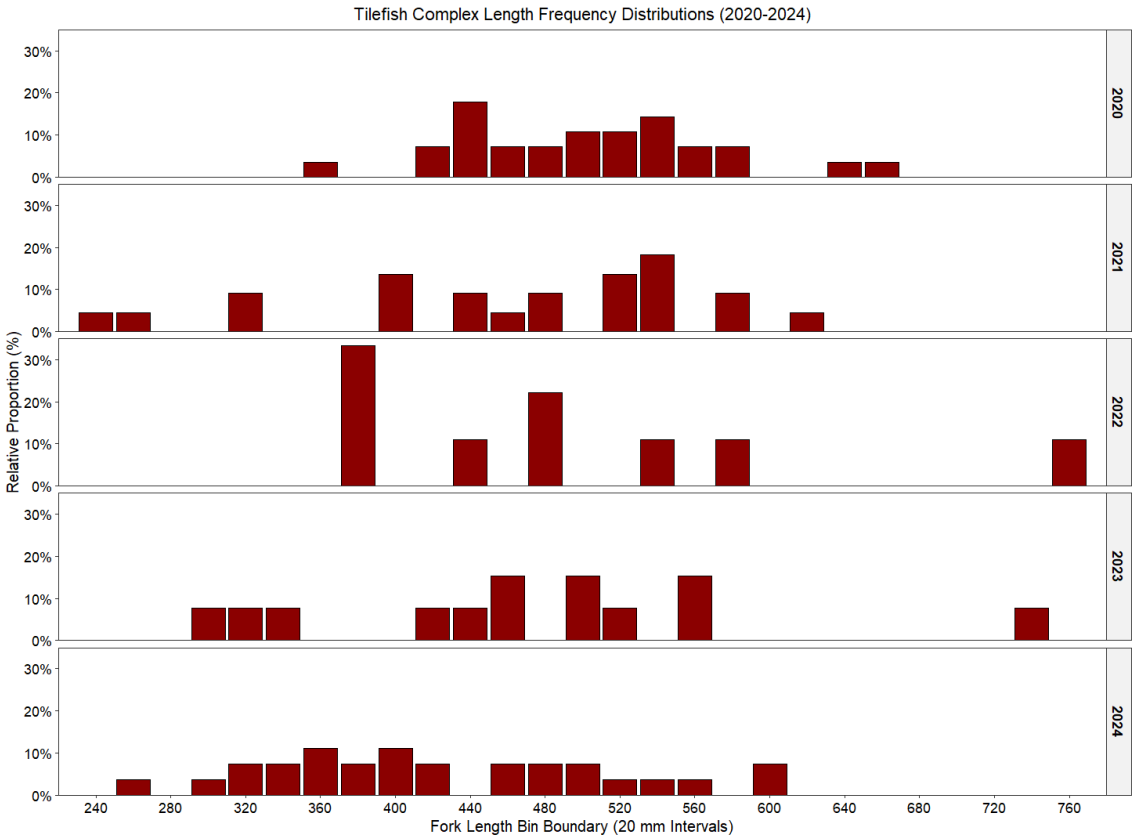

Figure 5. Annual relative length frequency composition distributions (proportions) for the Tilefish Complex across 20 mm fork length (FL) bins.

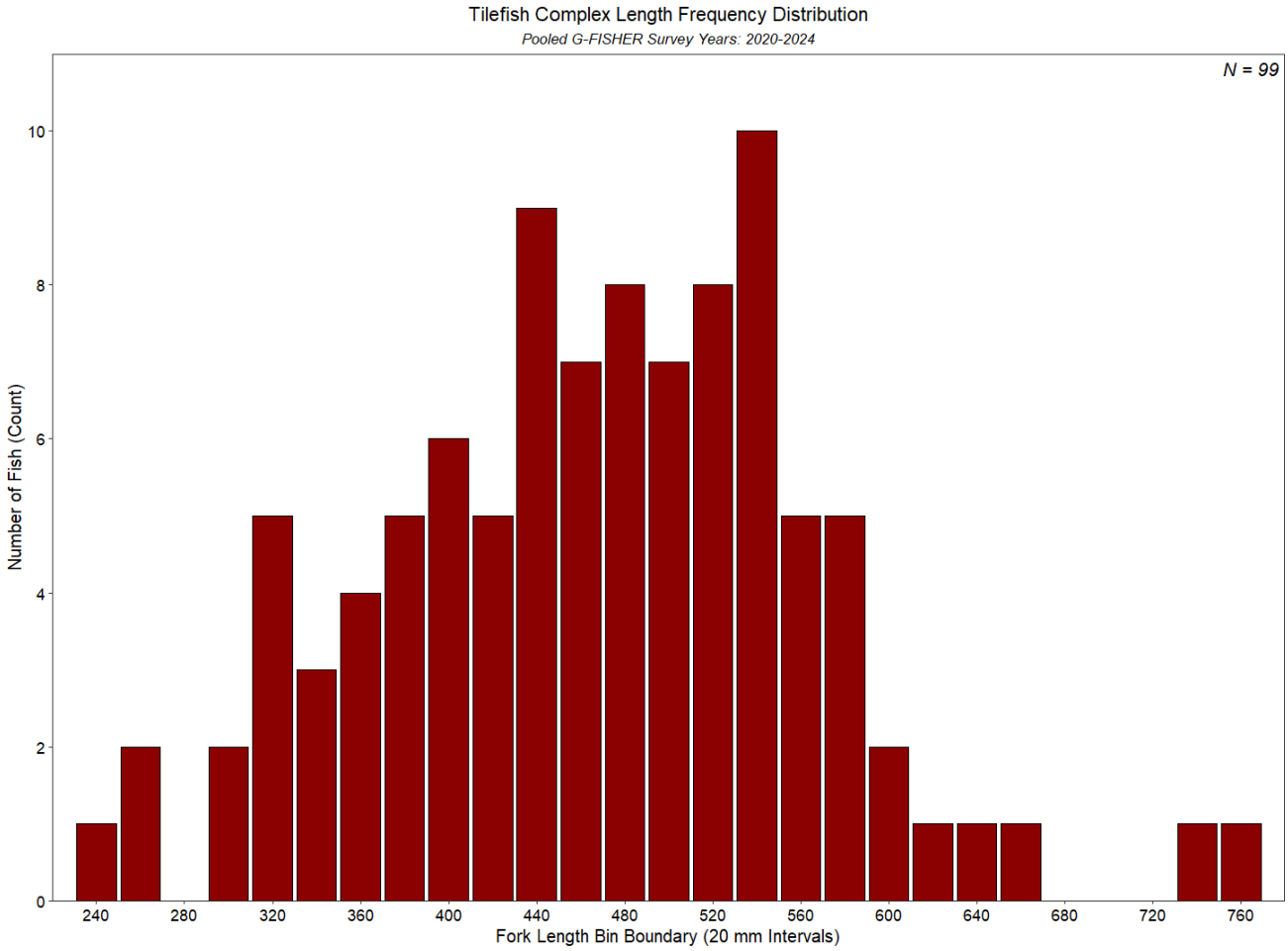

Figure 6. Pooled length-frequency distribution by raw count (n = 99).