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Tracking sharks through time: Long-term trends along the Texas coast

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ABSTRACT

Sharks play a critical role in maintaining marine ecosystem resilience, yet many populations have declined due to overfishing and environmental change. In Texas, shark relative abundance trends across estuarine, nearshore, and offshore environments remain poorly understood. This study integrated three complementary fishery-independent surveys spanning ~40 years (1983–2024), to improve understanding of cross-shelf shark assemblage structure and evaluate temporal and environmental drivers of relative abundance for 12 shark species, using Generalized Additive Mixed Models (GAMMs). This multi-dataset approach captured a broad range of environments and life stages, reducing bias associated with single-survey analyses. Of the 12 species examined, relative abundance of seven increased in at least one environment, three showed no directional change, and two declined consistently across environments. Blacktip Sharks (+149% [95% CI:101, 208] estuarine; +60% [95% CI:13, 125] offshore) and Bonnetheads (+481% [95% CI:366, 624] estuarine; +398% [95% CI:27, 1855] offshore) exhibited the most consistent multi-environment increases. Bull Sharks (+128% [95% CI:106, 154]) and Scalloped Hammerheads (+373% [95% CI:224, 591]) increased significantly in estuaries, while Great Hammerheads increased in nearshore waters. In contrast, Lemon Sharks showed the most severe decline (−99% [95% CI:−100, −98]) in estuaries, and Atlantic Sharpnose Sharks declined consistently across environments (estuarine: −65% [95% CI:−79, −41]; nearshore: −79% [95% CI:−88, −65]). Overall, these findings support reported increases in shark encounters by fishers, while also identifying species-specific declines that warrant concern. By establishing a unified baseline across environments, this study provides critical context for bycatch assessment and stock monitoring, and supports the development of adaptive, evidence-based shark management strategies in Texas waters.

1. Introduction

Sharks play a key role in maintaining marine ecosystem structure, function and resilience, by influencing predator-prey dynamics and supporting species diversity (Dedman et al., 2024). Given their important role in marine food webs (Heithaus et al., 2008), a decline in shark populations or shifts in their distribution can disrupt ecosystem health and negatively impact key fisheries at lower trophic levels (Britten et al., 2014; O'Brien et al., 2024). Despite their ecological importance, global shark populations have declined by 71.1% since 1970 (Pacoureau et al., 2021) due to overfishing and other human-driven threats like habitat loss and climate change (Dulvy et al., 2021; Osgood et al., 2021). Beyond direct exploitation, environmental fluctuations - including rising ocean temperatures - and habitat degradation in marine ecosystems can alter shark distribution and abundance (Drymon et al., 2010; Plumlee et al., 2018). Together, these pressures may alter shark distribution in ways that disrupt current interaction with management boundaries, as species shift into or out of managed areas (Hammerschlag et al., 2022; Niella et al., 2022; Osgood et al., 2021).

In the Gulf of Mexico (also known as the 'Gulf of America' in U.S.

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federal documents, hereafter, Gulf) populations have declined since commercial exploitation began in the 1970s (Peterson et al., 2017). For example, declines of over 80% were seen in Scalloped Hammerheads (*Sphyrna lewini*) (Hayes et al., 2009), while Blacktip shark (*Carcharhinus limbatus*) catch rates fell by 50% (SEDAR, 2012). In response to these declines, the National Oceanic and Atmospheric Administration (NOAA) implemented the first Fishery Management Plan for sharks in 1993 (NOAA National Marine Fisheries Service, 1993), establishing a management framework that grouped sharks into complexes, such as Large Coastal Sharks (LCS) and Small Coastal Sharks (SCS) based on life-history characteristics and body size. Overall, LCS have experienced greater declines and slower recovery than smaller coastal species (O'Brien et al., 2024; Peterson et al., 2022). Environmental factors such as salinity, temperature and depth, also play a critical role in shaping shark populations in the Gulf (Drymon et al., 2010; Froeschke et al., 2010), and these may interact with ongoing anthropogenic pressures to further complicate population recovery.

Within Texas waters specifically, early foundational work by Baughman and Springer (1950) documented shark occurrence and identification in the Gulf coast. More recent studies have advanced this understanding by describing habitat associations and environmental drivers (Froeschke et al., 2010) and examining shark assemblages and species-specific patterns in habitat use (Plumlee et al., 2018) of coastal sharks in estuarine environments. Together, these studies establish that Texas waters support a diverse coastal shark community (Plumlee et al., 2018), with species composition and relative abundance varying across estuarine, nearshore, and offshore environments. However, these efforts have been spatially or temporally limited, and long-term trends in species relative abundance across multiple environments within Texas waters remain poorly understood. Without a clear understanding of how changing conditions are altering species relative abundance and distributions, management strategies and conservation efforts may fail to address shifting habitat use and potential range expansions.

Fishers have reported an increase in shark interactions, which they often attribute to the success of conservation and management efforts implemented across the United States (Drymon and Scyphers, 2017; Gallagher et al., 2016; Prasky et al., 2023). This perceived recovery has coincided with changes in fishing activity and interactions with sharks,

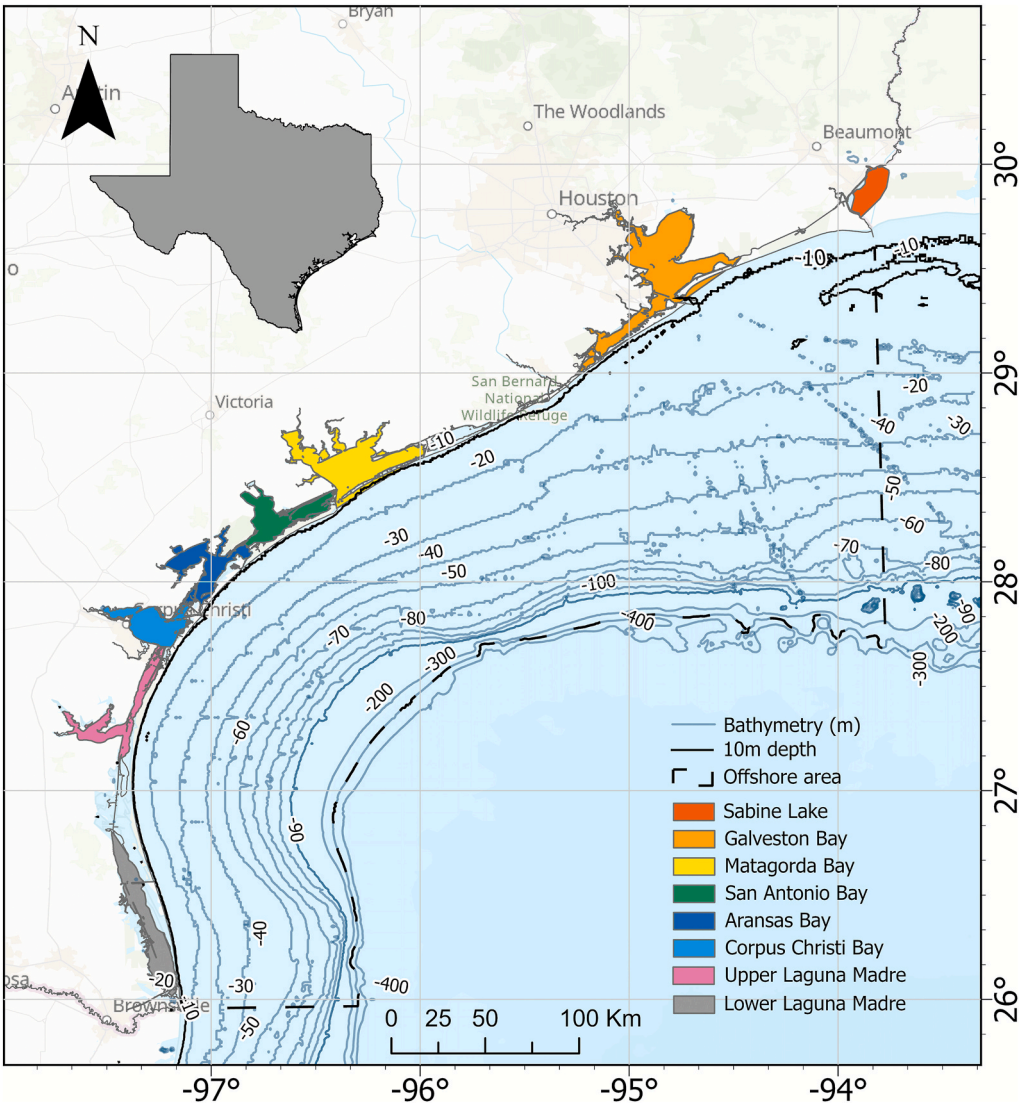

Fig. 1. Map of the study area in Texas showing the three survey environments included in this analysis. Estuarine sampling locations correspond to the major bay systems monitored by the Texas Parks and Wildlife Department (TPWD) Estuarine Gill Net survey: Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, Upper Laguna Madre, and Lower Laguna Madre. The nearshore environment encompasses coastal waters inshore of the 10 m depth contour (solid black line), and the offshore environment corresponds to the area surveyed by the NOAA NMFS Offshore Bottom Longline survey (dashed boundary). Bathymetric contours (m) are shown in blue. Inset shows the location of the study area within the state of Texas. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

leading to more frequent human–shark encounters (Drymon et al., 2026). In particular, shark depredation has increasingly been reported (Drymon et al., 2024, 2026; Klizentyte et al., 2023; Prasky et al., 2023). While conservation efforts aim to restore shark populations, they must also account for the socio-economic realities of coastal communities that depend on fisheries. Providing a robust empirical baseline on shark population status is a necessary first step toward navigating these trade-offs — one that must precede any meaningful evaluation of socio-economic consequences and the design of management strategies that are both ecologically sound and socially feasible.

This study aimed to analyze long-term trends in relative abundance for several shark species across Texas bays and estuaries (hereafter estuaries), nearshore and offshore areas. While previous studies have examined these regions or datasets individually (Froeschke et al., 2010; Plumlee et al., 2018), this study integrates information from three distinct fishery-independent surveys to provide a more comprehensive view. The specific objectives are to: 1) Examine temporal trends of common shark species over ~40-year period across estuaries, nearshore, and offshore areas of Texas; and 2) Evaluate the influence of environmental variables on common shark species relative abundance trends.

2. Methods

2.1. Study site

Texas is composed of a mosaic of habitats ranging from estuaries, to coastal shelves, to offshore environments (Fig. 1). The Texas coastline consists of a semi-enclosed estuarine system separated from the Gulf by barrier islands, limiting physical and biological connectivity (Montagna et al., 2025). These estuaries are dynamic ecosystems that support diverse ecological communities and valuable fisheries (Froeschke et al., 2010; Plumlee et al., 2018; Reese et al., 2008).

Texas estuaries exhibit significant environmental variation in salinity and precipitation, with a latitudinal salinity gradient ranging from near zero in the predominantly freshwater Sabine Lake in the north to over 40 psu in the hypersaline Laguna Madre in the south (Kim et al., 2014; Tolan, 2007). Latitudinal variability is also observed in water temperature and dissolved oxygen levels, with temperature being typically colder as latitude increases and higher dissolved oxygen concentrations in mid-latitude bay systems such as San Antonio Bay and Aransas Bay (Froeschke et al., 2010; Matich et al., 2017). These climatic and physical gradients play a key role in shaping the distribution and abundance of various elasmobranch species along the Texas coast (Froeschke et al., 2010; Plumlee et al., 2018).

The nearshore sampling area along the Texas coast is characterized by a broad, shallow continental shelf that extends an average of 100 km offshore before slowly descending into deeper waters (Hill et al., 1982). In the shallow nearshore environment, bottom substrates are dominated by a mix of mud, clay, silt and sandy areas (U.S. Department of the Interior, 1976). Due to the shallow character of these habitats, the region is influenced by high temperatures, especially during the summer, with values nearing 30°C (Turner et al., 2017).

Offshore, the survey area extends onto the deeper continental shelf and to the continental slope, reaching depths of approximately 366 m (Driggers et al., 2008). Around 180 m, the slope begins, where soft-mud sediments dominate the seafloor and the bathymetry steepens (Byrnes et al., 2017). Within this zone, scattered natural and artificial hard structures, such as reef patches and oil-platform bases, contribute to increased habitat heterogeneity (Bollinger et al., 2022; Schulze et al., 2020). Here, temperature patterns follow typical seasonal variations with surface temperatures in the summer reaching 30°C, decreasing to 20°C during the winter (Smith, 1980). Closer to the coast, on the innershelf, salinity gradients are more prevalent due to freshwater discharge from the rivers and disappear once moving out offshore (Smith, 1980). This broad depth and environment coverage—ranging from estuarine, to nearshore (<10 m), and into deeper offshore waters (up to ~366 m)—allows the multi-dataset approach to capture the full range of habitat types and environmental regimes inhabited by sharks.

2.2. Field sampling and data sources

A comparison of the temporal, spatial, and methodological characteristics of all three surveys is provided in Supplementary Materials (SM) Table 1. These surveys employ two different gear types and target distinct environments, capturing complementary portions of shark habitat use and life stages, from estuarine juveniles to nearshore and offshore adults. Using multiple datasets reduces potential spatial bias associated with individual surveys and provides a broader assessment of shark relative abundance and population trends across Texas waters.

2.2.1. Estuarine data

Estuarine data were obtained from the Texas Parks and Wildlife Division (TPWD) fishery-independent gill net monitoring program. Since 1983, 45 gill nets have been deployed in each major bay system during spring (April–June) and fall (September–November) seasons, with at least three deployments per week over 10-week periods (Martinez-Andrade, 2018). Gill nets measure 182.9 m × 1.2 m, consist of four mesh sizes (76, 102, 127, 152 mm), and are deployed perpendicular to shore for overnight soaks averaging 13.7 ± 1.4 h (mean ± SD, Martinez-Andrade, 2018). Due to size selectivity, sharks exceeding 2 m total length are typically not captured (Plumlee et al., 2018). At each sampling location, environmental data were recorded while nets soaked, including date, location, water temperature (°C), salinity (psu), dissolved oxygen (mg L^{-1}), and water depth (m). Environmental conditions were only measured at deployment and retrieval of the gill nets, limiting the ability to assess how overnight variations during sampling influenced shark captures (Matich et al., 2017). As such, the average environmental conditions during deployment and retrieval were used for analyses. More details on sampling procedures can be found in Martinez-Andrade (2018).

All major Texas estuaries sampled by TPWD were included in analyses, with the exception of Cedar Lakes and East Matagorda Bay, which were excluded due to irregular effort and low sample sizes during the sampling period (Plumlee et al., 2018). Data from 2024 were excluded due to sampling being discontinued that year. Thus, the temporal scope covered by this dataset is from 1983 to 2023, except for Sabine Lake where sampling began in 1986 (Sluis et al., 2025).

2.2.2. Offshore and nearshore data

Fishery-independent bottom longline (BLL) surveys have been conducted across the western Gulf by NOAA National Marine Fisheries Service (NMFS) since 1995, typically between July and October. Only data from 2001 onward were included in this study, following standardization of gear and sampling procedures. Sampling stations were selected using a stratified-random design with proportional allocation, and each deployment used 1852 m longline equipped with 100 gangions, 3.7 m leaders, and 15/0 circle hooks, with a soak time of 1 h. Surveys covered offshore waters from 9 to 366 m depth, divided into three depth strata: 9–55 m, 55–183 m, and 183–366 m. At each station, catch composition—including species identification, total length, weight, and sex—and environmental variables including temperature, salinity, and dissolved oxygen—were recorded (Driggers et al., 2008).

In 2008, the Southeast Area Monitoring and Assessment Program (SEAMAP) initiated a complementary bottom longline survey in nearshore waters of the western Gulf, to address spatial gaps in NOAA NMFS offshore bottom longline coverage (9–366 m). In this study, the nearshore environment is defined according to the sampling framework of the SEAMAP bottom longline survey, and includes waters extending to the 10 m isobath. The nearshore survey followed similar gear and sampling protocols as the NMFS offshore survey (Hendon et al., 2025; SEAMAP, 2025). Between 2008 and 2014, survey design and effort allocation varied among states. In 2015, the survey was standardized by

adjusting the depth range to 3–10 m, redistributing effort to improve spatial balance, and establishing three defined seasonal sampling periods: spring (April–May), summer (June–July), and fall (August–September) (Hendon et al., 2025). For this study, all months were analyzed separately to account for seasonal sampling and maintain comparability among datasets. More details on survey protocols can be found in the SEAMAP Bottom Longline Operations Manual (2025).

2.3. Data analysis

All catch data were standardized as catch-per-unit-effort (CPUE), a commonly used metric for estimating relative abundance (Maunder and Punt, 2004; Hoyle et al., 2024), and included in the models as the response variable. For the nearshore and offshore longline datasets, CPUE was calculated as:

$$CPUE = \left(\frac{c}{h\,x\,t} \right) x\,60\,x100$$

where c is the number of sharks captured per species, h is the number of hooks deployed and t is the soak time in minutes. The multipliers 60 min and 100 hooks were used to standardize CPUE data as the number of sharks caught per 100 hook hours (Driggers et al., 2008; Pickens et al., 2022). For estuarine gill net data, CPUE was calculated as catch per net-hour:

$$CPUE = \frac{catch}{Soak\ time\ (h)}$$

Multicollinearity and pairwise correlations among predictor variables were assessed prior to model fitting using scatter plot matrices and variance inflation factors (VIFs). All correlations were below 0.7 and VIFs were below 5, allowing retention of all variables in the models (O'Brien et al., 2024; Peterson et al., 2017), except for depth in the offshore NOAA NMFS bottom longline dataset, which was removed due to high correlation (0.83) with other environmental variables.

For each species and dataset, GAMMs were fit with CPUE as response variable and environmental (temperature, salinity, dissolved oxygen and depth), spatial (latitude and longitude), and temporal (year) predictors with a Tweedie distribution using the `mgcv` package (Wood, 2017). The Tweedie distribution was selected for the GAMMs due to its flexibility in handling both zero-inflated data and overdispersion (Gilchrist and Drinkwater, 2000), which are common features of CPUE ecological and fishery-independent datasets. All models were fitted using restricted maximum likelihood (REML) method (Carvalho et al., 2020).

Model parametrization ranged from simple to more complex GAMMs, incorporating smooth cubic regression splines of continuous predictors, smooth cubic cyclic splines for monthly variations and thin-plate regression splines of spatial coordinates. To account for unmeasured spatial or sampling effects, GAMMs included random effect terms. For nearshore and offshore longline data, survey was modeled as a random effect, while estuarine gill net models included a nested random structure of area, minor bay, and station. Random effects were retained only when they improved model performance. All GAMMs were fitted with a gamma value of 1.4 to penalize overfitting (Carvalho et al., 2020; Kim and Gu, 2004) and k was left as default to allow for model flexibility.

Model selection was guided by a combination of Akaike's Information Criterion (AIC; Akaike, 1973; Burnham and Anderson, 2002) and cross-validation performance metrics. Alternative model parametrizations with varying covariate combinations were evaluated, and explanatory variables influencing shark CPUE were selected through manual backward stepwise selection. Backward selection proceeded by removing the variable with the highest p-value ($p > 0.05$) at each step. Selection terminated when removing any remaining variable increased the AIC by more than 1%, at which point that variable was retained in the final model (Akaike, 1973; Sluis et al., 2021). When models showed comparable AIC values and cross-validation performance, the simpler model was retained.

Model performance was further evaluated through 3- and 5-fold cross-validation, using root mean square error (RMSE), mean absolute error (MAE), and the Pearson correlation between predicted and observed values (O'Brien et al., 2024). Temporal autocorrelation in model residuals was assessed visually inspecting autocorrelation function (ACF) plots (Araujo et al., 2020; Carvalho et al., 2020; Makwinja et al., 2021), and formally tested using the `testTemporalAutocorrelation(.)` function from the DHARMa package in R (Hartig et al., 2024). Broader model DHARMa diagnostics, including QQ plots and residual distributions, were used to detect overdispersion and confirm appropriate handling of zero-inflation (Flowers et al., 2022; King et al., 2024; O'Brien et al., 2024). Spatial autocorrelation in residuals was assessed separately using a variogram of the residuals (Zuur et al., 2009) and Monte Carlo simulation of Moran's I (Jackson et al., 2010; O'Brien et al., 2024; Potts and Rose, 2018; Rooker et al., 2012). Models were considered acceptable when no significant autocorrelation was detected (p-value >0.05). Final models with the corresponding AIC and cross-validation metrics can be found in SM Table 2.

Where temporal autocorrelation was detected in model residuals, a tensor product of year, latitude, and longitude `(te(year, lat, lon))` was evaluated as an alternative model structure. Although this reduced residual autocorrelation, it obscured the independent effect of year and complicated interpretation of temporal trends. Consequently, the simpler models without the tensor product were retained, with general temporal patterns remaining consistent (O'Brien et al., 2024). Supplementary analyses including the tensor models indicate that spatial heterogeneity in trends exists, but the overall temporal patterns are unchanged, demonstrating that the simpler models capture the key biological signal while maintaining interpretability and ensuring consistency across species.

Partial effects of GAMM individual covariates on CPUE were visualized using the `ggplot2` package in R. The magnitude of temporal change in relative abundance was quantified by extracting the linear predictor matrix from each fitted GAMM using the `predict(.)` function with `type` = "`lpmatrix`" in *mgcv* package in R (Wood, 2017). A contrast vector was then computed as the difference between the mean predictor rows corresponding to the first and last five years of the time series, capturing the net change in the year smooth on the log scale while holding all other covariates constant. The variance of this contrast was propagated analytically from the model's variance-covariance matrix, and a 95% confidence interval was derived from the resulting standard error. The contrast was back-transformed via exponentiation and expressed as a percent change in relative abundance. Sensitivity to window size was assessed by repeating the analysis using windows of 3, 5, and 7 years. Results were considered robust when the direction and significance of change were consistent across all three windows. Additionally, linear regressions were applied to examine long-term trends in environmental variables (temperature, salinity and dissolved oxygen) over the study period. These regressions complemented the GAMMs by providing an independent assessment of temporal patterns in abiotic conditions.

Shark species were excluded from the analysis primarily due to limited data availability and statistical modeling constraints. Species with very low or inconsistent occurrences were removed because sparse data can produce unreliable estimates, and others were excluded when generalized additive mixed models (GAMMs) showed poor convergence, uninformative smoothers, or clear signs of overfitting (e.g., unrealistically high deviance explained). Species were retained if they appeared in multiple datasets or were regionally important and frequently reported (e.g., Lemon (*Negaprion brevirostris*), Silky (*Carcharhinus falciformis*), and Tiger sharks (*Galeocerdo cuvier*)), resulting in a final set of 12 species included in the analysis (Table 1).

Residuals from the GAMMs showed some temporal autocorrelation

Table 1
Shark species examined in this study, organized by NOAA National Marine Fisheries Service management complex (Large Coastal Sharks, LCS; Small Coastal Sharks, SCS), with the fishery-independent survey environments in which each species was captured along the Texas coast.

Species	Environments
Large Coastal Shark Complex	
Bull Sharks (*Carcharhinus leucas)*	Estuarine, Nearshore, Offshore
Blacktip Sharks (*Carcharhinus limbatus)*	Estuarine, Nearshore, Offshore
Spinner Sharks (*Carcharhinus brevipinna)*	Estuarine, Nearshore, Offshore
Scalloped Hammerhead (*Sphyrna lewini)*	Estuarine, Nearshore, Offshore
Great Hammerhead (*Sphyrna mokarran)*	Estuarine, Nearshore, Offshore
Lemon Sharks (*Negaprion brevirostris)*	Estuarine
Tiger Sharks (*Galeocerdo cuvier)*	Offshore
Silky Sharks (*Carcharhinus falciformis)*	Offshore
Small Coastal Shark Complex	
Atlantic Sharpnose Sharks (*Rhizoprionodon terraenovae)*	Estuarine, Nearshore, Offshore
Bonnethead (*Sphyrna tiburo)*	Estuarine, Nearshore, Offshore
Finetooth Sharks (*Carcharhinus isodon)*	Estuarine, Nearshore
Blacknose Sharks (*Carcharhinus acronotus)*	Nearshore, Offshore

for Spinner Sharks (estuarine) and Atlantic Sharpnose Sharks (offshore), with Durbin-Watson statistics of 1.97 ($p < 0.006$) and 1.68 ($p < 0.0002$), respectively. However, the degree of autocorrelation was low enough that the overall temporal patterns and model interpretations remained consistent. Magnitude estimates of temporal change were not calculated for these species–environment combinations, as autocorrelation would reduce the precision and reliability of the estimated percent change. Additionally, several species–environment combinations yielded magnitude estimates that could not be reliably interpreted quantitatively. The nearshore and offshore datasets span a considerably shorter time period than the estuarine gill net survey, limiting the ability to detect a robust early-to-late contrast for species with lower catch rates or non-significant year smooth terms in the model. For species–environment combinations where the year smooth was not significant — indicating that year did not explain meaningful variation in CPUE —, or confidence intervals were too wide to support directional interpretation, trends are discussed in qualitative terms only. Finally, sensitivity analysis of Bull Sharks in offshore environments yielded inconsistent significance across window sizes (3, 5, and 7 years), and the magnitude estimate for this combination is therefore not reported.

3. Results

Total catches and mean CPUE varied among species and environments (Table 2). In estuarine environments, Bull Sharks exhibited the highest abundance among LCS species (11,624 individuals; mean CPUE = 0.03 sharks per net-hour), followed by Blacktip (4372; 0.011) and Spinner Sharks (1053; 0.003). Lemon Sharks had moderate total catches relative to other LCS species (187 individuals) and the second-lowest mean CPUE (0.0005 per net-hour). Among SCS, Bonnetheads had the highest total catch (n = 6512; 0.017), while Atlantic Sharpnose and Finetooth Sharks occurred at lower mean CPUE (0.002 and 0.002). In nearshore areas, Blacktip Sharks exhibited the highest relative abundance among LCS species (792 individuals; 2.77 sharks per 100 hook-hours), followed by Spinner (160; 0.556) and Bull Sharks (144; 0.508). Atlantic Sharpnose Sharks were the most abundant SCS (910 individuals; 3.22), whereas Bonnetheads were comparatively scarce. Offshore, Atlantic Sharpnose Sharks exhibited the highest relative abundance across all species and environments (4747 individuals; 7.47 per 100 hook-hours), while Blacktip Sharks showed highest relative abundance among LCS species (784; 1.23). Tiger and Silky Sharks occurred exclusively offshore and occurred at relatively low abundance compared to other species (Table 2).

Table 2
Summary of total abundance, mean catch-per-unit-effort (CPUE), and CPUE range for large coastal shark (LCS) and small coastal shark (SCS) species captured across estuarine, nearshore, and offshore environments in Texas. CPUE is expressed as sharks per net-hour for the estuarine gill net survey and sharks per 100 hook-hours for the nearshore and offshore bottom longline surveys. CPUE range represents the maximum CPUE recorded across all sampling events for a given species–environment combination. A dash (–) indicates that the species was captured in that environment but the model failed to converge due to insufficient sample size.

		Estuarine	Nearshore	Offshore
Large Coastal Shark Complex				
Bull Shark	Total abundance	11,624	144	166
	Mean CPUE	0.03	0.508	0.26
	CPUE Range	2.61	7.12	16.7
Blacktip Shark	Total abundance	4372	792	784
	Mean CPUE	0.011	2.77	1.226
	CPUE Range	3.98	31.5	27.5
Spinner Shark	Total abundance	1053	160	149
	Mean CPUE	0.003	0.556	0.234
	CPUE Range	4.99	21.6	10.5
Scalloped Hammerhead	Total abundance	648	24	89
	Mean CPUE	0.002	0.088	0.136
	CPUE Range	0.921	2	3
Great Hammerhead	Total abundance	12	28	26
	Mean CPUE	0.00003	0.095	0.041
	CPUE Range	0.193	2.07	2.07
Lemon Shark	Total abundance	187	-	0
	Mean CPUE	0.0005	-	0
	CPUE Range	1.62	-	0
Tiger Shark	Total abundance	0	-	75
	Mean CPUE	0	-	0.118
	CPUE Range	0	-	3.05
Silky Shark	Total abundance	-	0	42
	Mean CPUE	-	0	0.067
	CPUE Range	-	0	4.14
Small Coastal Shark Complex				
Atlantic Sharpnose Shark	Total abundance	733	910	4747
	Mean CPUE	0.002	3.22	7.469
	CPUE Range	1.48	44.9	60
Bonnethead	Total abundance	6512	16	17
	Mean CPUE	0.017	0.056	0.026
	CPUE Range	4.11	3	2
Finetooth Shark	Total abundance	660	45	0
	Mean CPUE	0.002	0.156	0
	CPUE Range	1.23	4	0
Blacknose Shark	Total abundance	0	31	842
	Mean CPUE	0	0.107	1.32
	CPUE Range	0	5	39.3

3.1. Spatiotemporal trends of LCS

Large coastal shark relative abundance trends varied by species and environment over the study period (Fig. 2). In estuarine environments, four species showed significant increases: Bull Sharks (+128% [95% Confidence Interval (CI): 106, 154]), Scalloped Hammerheads (+373% [95% CI: 224, 591]), and Spinner Sharks (no magnitude calculated) increased significantly since the 1980s, while Blacktip Sharks increased (+149% [95% CI: 101, 208]) from 2012 onwards. In contrast, Lemon Sharks declined continuously (−99% [95% CI: −100, −98]) in estuaries since 1983, with the GAMM estimating the most negative temporal effect (i.e., largest decline in the smooth term) among all species modeled. The failure of the nearshore model to converge further underscores the very low abundance of Lemon Sharks in that environment (n = 5 over the sampling period). The selectivity of the gill nets effectively excludes all sharks over 2 m total length; consequently, increases among larger coastal sharks may be underestimated, and any rising abundances of adults could remain undetected in these estuarine surveys.

In nearshore waters, Blacktip and Spinner Sharks showed significant declines beginning around 2017. Conversely, Great Hammerheads increased significantly in nearshore environments, while their relative abundance remained constant in estuaries. Offshore, Bull Sharks decreased significantly starting in 2015, whereas Blacktips increased significantly (+60% [95% CI: 13, 125]), suggesting a potential offshore expansion. Overall, LCS populations in Texas appear stable or increasing across environments, with notable exceptions including the ongoing decline of Lemon Sharks and recent declines in nearshore populations of Blacktip and Spinner Sharks relative abundance. Similar patterns were evident in the biennial mean CPUE histograms (SM Fig. 1), where observed catch rates broadly reflected the temporal trends estimated by the GAMM models.

Spatially, smooth terms for latitude and longitude were significant for seven LCS species (SM Table 3), with the exception of Scalloped Hammerhead and Silky Sharks offshore and Great Hammerheads in estuarine and offshore environments. In estuaries, Bull, Blacktip and Spinner Sharks exhibited lower relative abundance in southern regions and higher relative abundance in northern areas, particularly from southern Galveston Bay to Corpus Christi (SM Fig. 2). For these three species, nearshore data indicate a decline in relative abundance toward southern Texas. Great Hammerheads showed significant spatial variation in nearshore waters, with higher relative abundance near central Texas, especially from Matagorda Bay to Corpus Christi, whereas Scalloped Hammerheads were more abundant in southern nearshore areas. Tiger Sharks showed increased relative abundance further offshore rather than closer to nearshore environments. Lastly, Lemon Sharks displayed a distinct hotspot near Matagorda Bay, with relative abundance decreasing toward both the north and south (SM Fig. 2).

3.2. Spatiotemporal trends of SCS

Small coastal sharks exhibited variable trends across environments (Fig. 3). Finetooth Shark relative abundance increased significantly in estuaries (+127% [95% CI: 46, 254]) since 2005. Bonnetheads exhibited significant increases across all environments — 481% [95% CI: 366, 624] estuarine, and 398% [95% CI: 27, 1855] offshore —indicating a broad population expansion in Texas. Nearshore trends were also significantly positive, although magnitude was not calculated; however, this increase was moderated, with a slight decline evident after 2017. In contrast, Atlantic Sharpnose Sharks showed significant declines consistently across all environments (−65% [95% CI: −79, −41] in estuarine and −79% [95% CI: −88, −65]) in nearshore habitats—while offshore trends were also significantly negative, reflecting widespread reductions in abundance. Blacknose Shark relative abundance remained generally stable over time, with only minor significant temporal fluctuations offshore: an increase until 2009, followed by a decline through 2015, and stabilization thereafter.

The spatial smooth terms were significant for all SCS species, except for nearshore Blacknose Sharks, indicating distinct latitudinal and longitudinal gradients in relative abundance across the Texas coast (SM Table 4). Finetooth Sharks, Bonnethead and Atlantic Sharpnose Sharks exhibited peak relative abundances in estuaries of central Texas, particularly around Matagorda Bay (SM Fig. 3). This pattern was especially pronounced for Bonnetheads, which showed increasing relative abundance in multiple bay systems, from Galveston Bay southward.

3.3. Environmental drivers of LCS and SCS

Environmental drivers of shark relative abundance and species-specific statistical values are summarized in SM Table 3 and 4. Salinity was a significant predictor for most species except Blacknose Sharks, Great Hammerheads, Silky Sharks, and Tiger Sharks (SM Fig. 4). In estuarine and nearshore environments, most species were captured between 20 and 38 psu, with catch rates declining above 40 psu. Bull Sharks were frequently caught at salinities below 10 psu and freshwater environments and Blacktip Sharks were common at 13–18 psu in estuaries. Blacknose Sharks were consistently associated with higher nearshore salinities (33–37 psu). Offshore, all species occurred within salinities of 28–36 psu (SM Table 5). Captures at very high salinities were rare, with one Atlantic Sharpnose Shark recorded at 43 psu and five Bonnetheads at 41–43 psu. Long-term salinity increased significantly in estuaries (slope = 0.011 psu yr^{-1}, $p < 0.001$) and decreased offshore (slope = −0.051 psu yr^{-1}, $p < 0.001$).

Temperature was positively associated with CPUE for most species where significant effects were detected (SM Fig. 5), with CPUE increasing at higher temperatures. In estuarine environments, temperature effects were significant for Bull Sharks, Scalloped Hammerheads, Bonnetheads, and Finetooth Sharks. Offshore, significant effects were detected for Great Hammerheads, Silky Sharks, Tiger Sharks, Atlantic Sharpnose Sharks, and Blacknose Sharks, while Blacktip Sharks showed significant temperature effects in both estuarine and offshore environments. The only exception to the positive trend was Silky Sharks, which exhibited peak CPUE near 20°C followed by a decline at higher temperatures. No significant temperature effects were detected for Lemon or Spinner Sharks, nor in nearshore environments. Long-term water temperatures increased significantly in estuaries (slope = 0.028°C yr^{-1}, $p < 0.001$) and offshore (slope = 0.051°C yr^{-1}, $p < 0.001$), supporting the observed positive relationships between CPUE and temperature warming in these environments.

Depth was positively associated with CPUE and significant for all species in estuarine environments (SM Fig. 6), with the exception of Lemon Sharks, which showed an inverse relationship with higher CPUE in shallower water. In nearshore waters, depth was significant only for SCS (Atlantic Sharpnose, Finetooth, and Blacknose Sharks; SM Tables 3 and 4). Dissolved oxygen was the least consistent predictor, with significant effects limited to Blacktip Sharks across all environments, Bull Sharks and Bonnetheads in estuaries, and Spinner Sharks nearshore. Where significant, CPUE peaked at 6–8 mg/L (SM Fig. 7). Multiple species were recorded at low oxygen concentrations below 3 mg/L across all environments, including: Scalloped Hammerheads and Bonnetheads and Bull, Blacktip, Spinner, Tiger, Atlantic Sharpnose, Finetooth and Blacknose Sharks (SM Table 5). Long-term dissolved oxygen decreased significantly in estuaries (slope = −0.016 mg/L yr^{-1}, $p < 0.001$) and increased nearshore (slope = 0.172 mg/L yr^{-1}, $p < 0.001$) and offshore (slope = 0.005 mg/L yr^{-1}, $p < 0.001$).

4. Discussion

This study provides a comprehensive, multi-environment assessment of long-term shark relative abundance across Texas estuarine, nearshore, and offshore ecosystems by integrating three complementary fishery-independent datasets. Overall, results reveal predominantly stable or increasing shark relative abundance for most species across

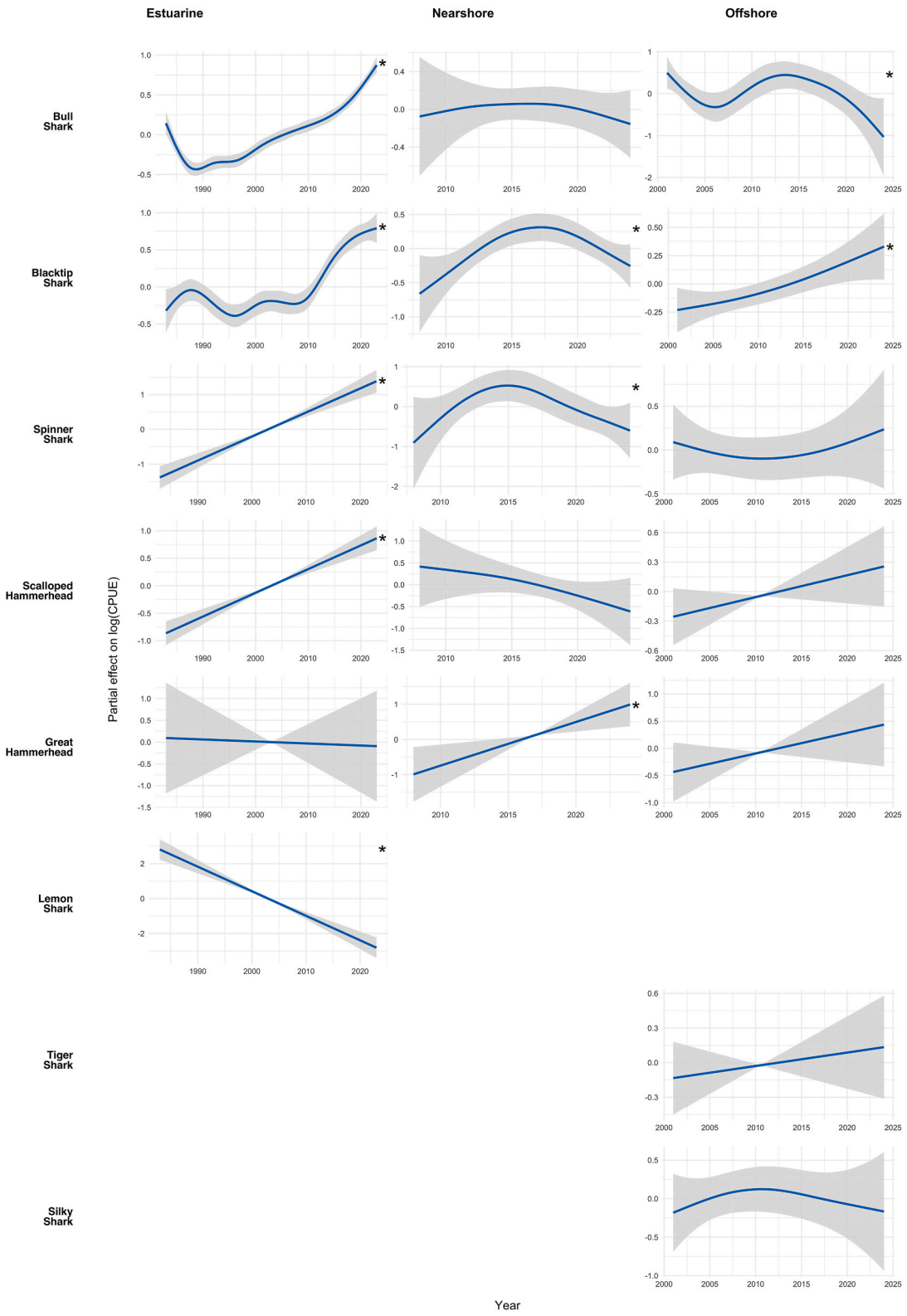

Fig. 2. Partial effects of year on the relative abundance (CPUE) of Large Coastal Shark species, estimated from Generalized Additive Mixed Models (GAMMs). Rows correspond to species: Bull Shark, Blacktip Shark, Spinner Shark, Scalloped Hammerhead, Great Hammerhead, Lemon Shark, Tiger Shark, and Silky Shark; and columns correspond to survey environment: Estuarine, Nearshore, and Offshore. The solid blue line represents the estimated smooth effect of year on log (CPUE), centered at zero; values above zero indicate higher-than-average relative abundance and values below zero indicate lower-than-average relative abundance over the time series. Shaded bands denote 95% confidence intervals. Asterisks (*) indicate a statistically significant effect of year ($p < 0.05$). Blank panels indicate species–environment combinations not included in the analysis due to absence or insufficient sample size. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

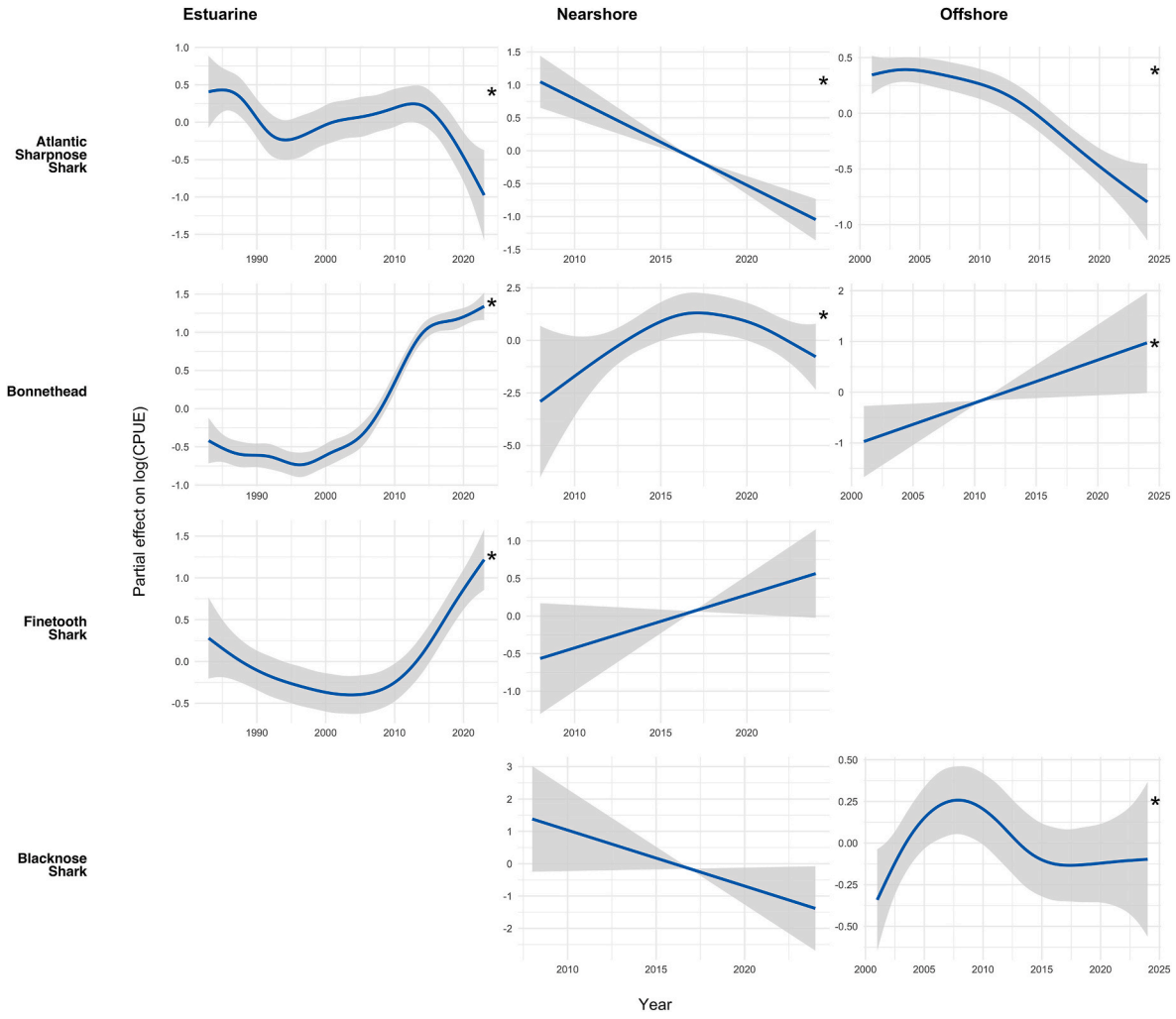

Fig. 3. Partial effects of year on the relative abundance (CPUE) of Small Coastal Shark species, estimated from Generalized Additive Mixed Models (GAMMs). Rows correspond to species: Atlantic Sharpnose Shark, Bonnethead, Finetooth Shark, and Blacknose Shark; and columns correspond to survey environment: Estuarine, Nearshore, and Offshore. The solid blue line represents the estimated smooth effect of year on log (CPUE), centered at zero; values above zero indicate higher-than-average relative abundance and values below zero indicate lower-than-average relative abundance over the time series. Shaded bands denote 95% confidence intervals. Asterisks (*) indicate a statistically significant effect of year ($p < 0.05$). Blank panels indicate species–environment combinations not included in the analysis due to absence or insufficient sample size. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Texas waters, consistent with other recovery narratives reported in the Gulf and east coast of the U.S. (Peterson et al., 2017; Pacoureau et al., 2023), while also identifying important species-specific exceptions, particularly for Lemon Sharks and Atlantic Sharpnose Sharks. These results demonstrate that reliance on a single survey can fail to elucidate cross-shelf dynamics and assemblage-level shifts (Drymon et al., 2010; Froeschke et al., 2010; Plumlee et al., 2018) and could overlook trends occurring outside the spatial scope of an individual dataset.

Lemon Sharks emerged as a species of particular concern in this study, as they were the only LCS species showing sustained decreases in abundance in estuarine environments (~99% over the study period) and low relative abundance in nearshore Texas. These declines are consistent with Plumlee et al. (2018) and Ajemian et al. (2016), who reported reductions in both relative abundance and body size among Lemon Sharks in the region. Because estuarine gill nets primarily capture juveniles and neonates, excluding sharks over 2 m total length (Plumlee et al., 2018), these declines are especially concerning. Lemon Sharks are highly vulnerable to overexploitation (Cortes, 1998), likely due to their slow population growth, late maturity (Brown and Gruber, 1988), and biennial reproductive cycle (Feldheim et al., 2002). Although globally listed as Vulnerable by the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, with a decreasing population trend (Carlson et al., 2021), Lemon Sharks have historically been documented throughout Texas bays (McCandless et al., 2002; Ajemian et al., 2016). Many of these bays may serve as important nursery habitats during the summer (McCandless et al., 2002), further increasing their vulnerability to fisheries and habitat disturbance (Murchie et al., 2010). Taken together, these findings highlight a need for strengthened conservation and management in Texas, particularly given that current recreational regulations still permit harvest of individuals >163 cm (64 inches TL; TPWD, 2025). Potential management actions could include reducing or eliminating recreational harvest, implementing mandatory catch-and-release regulations, establishing species-specific handling guidelines to minimize post-release mortality, and increasing angler education and outreach regarding the conservation status and vulnerability of Lemon Sharks.

Atlantic Sharpnose Sharks represented the second major exception identified in this study, showing declines across all environments. This species is typically considered one of the most abundant across Gulf ecosystems (Bethea et al., 2015; Drymon et al., 2010, 2020) and was among the most abundant in the present study. However, despite their dominance in nearshore and offshore assemblages (Table 2), it showed consistent declines, demonstrating that even abundant species can experience population declines. In estuarine environments, Atlantic

Sharpnose Shark relative abundance showed interannual variability, with declines from 1983 to 1998, increases from 1998 to 2012, and subsequent declines after 2012. Similar high year-to-year variability in CPUE was reported by Parsons and Hoffmayer (2005), who documented major fluctuation in catch rates, including a doubling in CPUE in 2000. The causes of these recent decreases remain unknown, but may reflect broader distributional shifts. Previous studies documented higher Atlantic Sharpnose Shark densities in the northeastern compared to the northwestern Gulf (Plumlee et al., 2018), as well as size-specific spatial shifts, with smaller individuals moving northward and larger individuals shifting southward (O'Brien et al., 2024). Another possible explanation is increased top-down pressure associated with the recovery of larger shark species documented in this study. As mesopredators within Gulf ecosystems (Drymon et al., 2010; Harrington et al., 2016), Atlantic Sharpnose Sharks may experience greater predation or competition as larger shark populations increase following reductions in fishing effort (Baum and Worm, 2009), potentially reversing previously hypothesized mesopredator release dynamics (Heupel et al., 2014; Ritchie and Johnson, 2009). In Texas, Atlantic Sharpnose Sharks are currently legal to harvest if larger than 61 cm (24 inches TL; TPWD, 2025. Continued harvest pressure, combined with potential ecological shifts, may therefore contribute to the declining regional trends observed in this study.

Estuaries in Texas have previously been identified as areas where many shark species co-occur (Matich et al., 2017; Plumlee et al., 2018). Consistent with this, the present study documented increasing trends for several estuarine-associated species, including Blacktip Sharks, Bull Sharks, Bonnetheads, Finetooth Sharks, Spinner Sharks, and Scalloped Hammerheads. Blacktip Sharks and Bonnetheads showed steady increases across estuarine, nearshore, and offshore environments, corroborating previously documented high catch rates for these species in the Gulf (Bethea et al., 2015) and along the Texas coast (Froeschke et al., 2010). For Blacktip Sharks, rising estuarine and nearshore abundances coincided with long-term warming trends and positive relationships between CPUE and temperature in the models, suggesting that warming conditions may be contributing to increased habitat suitability. These patterns are consistent with O'Brien et al. (2024), who reported strong associations between Blacktip Shark occurrence and warmer temperatures.

In nearshore environments, however, Blacktip Sharks, Spinner Sharks and Bonnetheads showed a slight decline in relative abundance after 2017, which should be interpreted cautiously. In 2015, SEAMAP standardized nearshore longline survey design by reducing the depth range to 3–10 m, expanding coastwide coverage in Texas, and implementing defined seasonal sampling periods. Therefore, these changes might have contributed to observed post-2015 patterns, reflecting both real population dynamics and effects of the modified sampling effort. Additionally, Blacktip and Spinner Sharks are the most common species in nearshore environments both in terms of total catches and relative abundance, which further supports the idea that the observed declines could be influenced by changes in sampling procedures rather than solely representing actual decreases in abundance.

The increase in relative abundance for Bonnetheads is particularly noteworthy, given documented declines in their primary adult prey, blue crabs *Callinectes sapidus* (Bethea et al., 2007; Harrington et al., 2016; Plumlee and Wells, 2016) across the Gulf (Perry et al., 2022). In estuarine environments, Bonnethead relative abundance has increased since the early 2000s, with CPUE rising ~481% over the study period. Although Bonnetheads can incorporate other prey sources into their diet (Bethea et al., 2015), the slight decline in nearshore abundance observed after 2017 may reflect both the post-2015 survey standardization and potential early ecological effects associated with reduced blue crab availability. Additionally, Bonnethead relative abundance in nearshore and offshore bottom longline surveys remained low, as expected for a species primarily associated with estuarine environments (Froeschke et al., 2010). Despite these environment preferences, Bonnetheads exhibited increasing trends across all sampled environments in this study. Notably, this regional increase contrasts with the species' Endangered status and decreasing trend on the IUCN Red List of Threatened Species (Pollom et al., 2021), suggesting a potential disconnect between regional population trajectories under U.S. fisheries management and broader global conservation assessments. Future research should evaluate whether the observed regional increases reflect localized management success, spatial redistribution, or demographic processes not captured in global assessments, while also assessing whether continued declines in blue crab populations could ultimately constrain Bonnethead abundance or alter their broader foraging dynamics.

Bull and Finetooth Shark relative abundance exhibited increasing trends in estuarine environments, likely responding to warming waters and expanded habitat use documented in recent studies (Matich et al., 2024; O'Brien et al., 2025). The observed offshore decline and northward distribution of Bull Sharks may reflect warming-driven expansions of suitable juvenile habitat (Mullins et al., 2024) and aligns with observed long-term increases in water temperature in estuarine and offshore environments. For Finetooth Sharks, a clear hotspot was observed around Matagorda Bay, likely reflecting constraints associated with estuarine salinity. Although Finetooth Shark are currently managed in Texas under regulations allowing retention of individuals >163 cm (64 inches) TL (TPWD, 2025), only eight individuals exceeding this size were recorded across all datasets. The low occurrence of legally retainable individuals may indicate that the current management regime remains precautionary and could be contributing to population stability or increases, although additional demographic and fishery-dependent data would be needed to directly evaluate management effectiveness.

Spinner Sharks showed increases in both estuarine and nearshore environments, consistent with O'Brien et al. (2024) who reported a shift of the species into inshore waters. Scalloped Hammerheads also exhibited increased relative abundance in estuaries, a pattern that is best interpreted in the context of ontogenetic habitat use, as juveniles are known to use shallow coastal and estuarine nursery areas. These observations are consistent with previous work in Corpus Christi Bay, south Texas, that reported repeated captures of Scalloped Hammerheads and Spinner Sharks, across seasons and years, suggesting these systems may function as important nursery or juvenile habitats under suitable environmental conditions (Heupel et al., 2007; Swift and Portnoy, 2021). Accordingly, increased estuarine occurrence likely reflects enhanced juvenile presence and potentially improved recruitment. The higher catches observed in this study and in Swift and Portnoy (2021) relative to earlier studies, further support increased estuarine abundance by these species and contrasts with historic declines reported in the Gulf (Hayes et al., 2009). Pawluk et al. (2022) similarly reported increasing catches of Scalloped Hammerheads in Texas estuarine systems, consistent with broader climate-driven tropicalization of these habitats. While tropical species expansions into subtropical habitats may increase local species richness, functional analyses indicate they can also promote functional homogeneity by increasing the relative abundance of species with similar life-history traits (Pawluk et al., 2022).

Blacknose Sharks showed increasing relative abundance offshore, suggesting habitat use of deeper environments. Historically, this species has been associated with nearshore waters and mid-depth strata (10–30 m; Drymon et al., 2010; NMFS, 2009), and nearshore data have been considered essential for detecting population patterns (Drymon et al., 2010). Results from this study extend this understanding by revealing high offshore relative abundance, underscoring the need to integrate both nearshore and offshore data when assessing relative abundance patterns across environments. One possible explanation to the mechanisms underlying this pattern is that increased species interactions in nearshore and estuarine environments — where several shark species have shown increasing relative abundance — may reduce habitat suitability for Blacknose Sharks. For example, Great Hammerheads have increased in nearshore environments, which, together with other results

from this study, signals a continued recovery of hammerhead species from historical overfishing in the Gulf (Hayes et al., 2009). Additionally, recent assessments such as SEDAR 77 indicate that both Scalloped and Great Hammerheads are exhibiting stable patterns in Gulf waters (SEDAR, 2024).

More broadly, niche differentiation may also contribute to the relative abundance increase in offshore environments (O'Brien et al., 2024). As multiple species, particularly LCS, expand or recover within nearshore and estuarine nursery systems, increased competition and predation risk may alter habitat suitability for smaller sharks — a process that, if occurring, would be consistent with space partitioning across size classes documented in other shark assemblages (O'Brien et al., 2024). The tendency of Blacknose Sharks to occupy higher-salinity environments (33–37 psu in nearshore areas and 30–36 psu offshore in this study) is consistent with previous observations of the species in high-salinity waters (31–35 psu; Ulrich et al., 2007) and further supports their use of offshore environments relative to other species that are more common at lower salinities. Similarly, Silky Sharks were captured mainly offshore in this study and were never recorded in nearshore environments. This offshore occurrence is consistent with their classification as a largely epipelagic species and contrasts with several other LCS that have expanded into estuarine and nearshore habitats. Because environmental data for offshore surveys were derived from bottom measurements, environmental associations for Silky Sharks should be interpreted cautiously, as individuals may have been captured during gear retrieval rather than occupying bottom habitat. Consequently, bottom temperature and salinity values may not fully represent the environmental conditions experienced by this species.

Across species, environmental gradients—particularly temperature, salinity and depth—played a central role in shaping shark relative abundance (Drymon et al., 2010; Matich et al., 2017; Plumlee et al., 2018). Consistently lower CPUE in southern Texas across several species suggests a broad-scale spatial gradient that may be linked to warmer temperatures and hypersaline conditions characteristic of southern estuaries such as the Laguna Madre (Tolan, 2007). Across species, relative abundance was strongly driven by depth and salinity, with highest abundances generally occurring at depths of ~6 m in estuarine and >20 m in nearshore environments and salinities between 20 and 38 psu, whereas dissolved oxygen was a less consistent predictor.

Many of the species with increasing relative abundance reached their highest CPUE at salinities between 22 and 38 psu, consistent with well-established habitat preferences for Gulf shark species (Froeschke et al., 2010). These consistent relationships suggest that ongoing changes in coastal hydrography, including long-term increases in estuarine salinity linked to reduced freshwater inflow and altered circulation (Bugica et al., 2020), may be enhancing habitat suitability for some taxa (Scalloped Hammerheads) while constraining others (Finetooth or Blacktip Sharks) (O'Brien et al., 2024; Ward-Paige et al., 2015). In this study, most cases where temperature was significant, relative abundance increased as waters warmed, indicating a positive association between relative abundance and temperature. Thus, long-term increasing temperatures may be favoring shark species that prefer warmer waters, including Blacktip Sharks, Bonnetheads, Scalloped Hammerheads, Spinner Sharks (Ward-Paige et al., 2015) and Bull Sharks (Mullins et al., 2024), which are becoming more abundant in estuarine and nearshore environments. Notably, juvenile Atlantic Sharpnose Shark have also been reported to prefer warmer temperatures (Ward-Paige et al., 2015), yet this species showed declining relative abundance across all environments despite long-term warming. This pattern is inconsistent with temperature-driven habitat suitability alone and suggests that other factors, such as increased predation pressure from recovering larger shark species or broader distributional shifts, may be driving these declines.

Dissolved oxygen had comparatively weak effects in statistical models. Expanding low-oxygen zones in the Gulf, particularly the seasonal hypoxic shelf region (Matli and Obenour, 2024), can compress available habitat and alter shark movement patterns (O'Brien et al., 2025). Interestingly, O'Brien et al. (2025) found that Bull Shark densities were higher within the Northern Gulf of Mexico Hypoxic Zone, and in the present study, dissolved oxygen was a significant predictor of Bull Shark relative abundance in estuarine environments, with individuals captured in very low oxygen conditions (~2 mg/L). The low apparent significance of dissolved oxygen in relative abundance for other shark species in Texas could reflect behavioral avoidance of hypoxic areas (Fulford et al., 2024) or aspects of the sampling design, which may limit detection of these effects. While such influences were not strongly reflected in the models used here, they warrant continued monitoring as deoxygenation intensifies globally.

Taken together, increases in relative abundance of several shark species may reflect reduced fishing mortality following regulatory changes, including federal shark management measures (Pacoureau et al., 2023) and bycatch reduction initiatives such as Turtle Excluder Devices (Raborn et al., 2012). However, it is important to consider that the datasets used in this study do not pre-date commercial exploitation rates (pre-1970), and therefore, increases in relative abundance cannot be used as a pre-disturbance baseline. Alongside these trends, increases in relative abundance appear linked to warming temperatures, increasing salinities in estuaries, and expanding suitable habitat in estuarine and nearshore environments. However, species-specific exceptions—including the sustained declines of Lemon Sharks and the multi-environment decreases of Atlantic Sharpnose Sharks—highlight the importance of revisiting management strategies. Existing regulations, such as size-based harvest rules, may need to be reevaluated to ensure that management priorities align with current population trajectories, while disentangling the effects of environmental drivers from fisheries management influences is also essential.

Management strategies would also benefit from expanding participatory monitoring programs that integrate fishers' ecological knowledge with fishery-independent survey data to improve spatial and temporal coverage, particularly in estuarine and nearshore environments where recreational fishers are often the first to detect changes in shark presence and behavior. Previous research has shown that conservation outcomes improve when fishers participate in decision-making processes, contribute to monitoring efforts, and help design region-specific strategies (Cooke et al., 2021; Granek et al., 2008). Incorporating fishers directly into management planning is therefore essential for developing measures that are both ecologically effective and socially feasible. Moreover, this study provides scientific support for the shark interaction increases widely reported by fishers (Drymon et al., 2024; Prasky et al., 2023) and stock assessments. Expanding fisher-based reporting networks, particularly within recreational fisheries, would enhance monitoring of estuarine and nearshore population changes (Mitchell et al., 2024) that recreational anglers are often the first to observe.

Drawing on the longest unified time series available for the region, this study provides a combined estuary–nearshore–offshore assessment of shark abundance in Texas. The results reveal a mix of recovering populations and species-specific declines, helping quantify whether population increases reported by fishermen reflect true recoveries. These findings address key knowledge gaps regarding shark population trends, contribute to an evidence base for management decisions, and inform efforts to address concerns within the fishing community, including rising tensions over human–shark interactions.

The results of this study suggest several patterns — including northward shifts in relative abundance, cross-shelf variation, multi-environment increases and species-specific decreases — but the mechanisms underlying these trends remain to be confirmed. Future research should prioritize acoustic telemetry and tagging studies to determine whether cross-shelf patterns reflect true ontogenetic shifts in habitat use, seasonal connectivity between environments, or the recolonization of historically depleted areas as population recover. Partitioning studies examining how LCS and SCS spatially co-occur across size classes and

seasons would further clarify whether niche differentiation is structuring assemblage composition. Climate-adaptive management frameworks should incorporate salinity and temperature projections into habitat models. The documented sensitivity of species to temperature and salinity variations suggests that estuarine nursery habitats may already be experiencing conditions that alter their suitability, warranting targeted monitoring under future climate scenarios. Finally, specific management priorities should include reassessing size-based harvest rules for Lemon Sharks and Atlantic Sharpnose Sharks in light of the sustained declines documented here, and evaluating whether current minimum size limits remain appropriate given observed population trajectories.

Data statement

The estuarine gill net data and SEAMAP coastal bottom longline data used in this study are owned by and publicly available from Texas Parks and Wildlife Department, Coastal Fisheries Division, upon request: mark.fisher@tpwd.texas.gov and/or Fernando.Martinez-Andrade@tpwd.texas.gov. Offshore bottom longline data used in this study are owned by and publicly available from NOAA NMFS upon request: william.driggers@noaa.gov.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used Claude in order to perform grammar checks, improve coherence, and refine phrasing. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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CRediT authorship contribution statement

Paula Dominguez Rein-Loring: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **J. Marcus Drymon:** Conceptualization, Methodology, Writing – review & editing. **Mark Fisher:** Conceptualization, Methodology, Writing – review & editing. **Fernando Martinez-Andrade:** Conceptualization, Methodology, Writing – review & editing. **William B. Driggers:** Conceptualization, Methodology, Writing – review & editing. **Jay R. Rooker:** Conceptualization, Methodology, Writing – review & editing. **Masami Fujiwara:** Conceptualization, Methodology, Writing – review & editing. **R.J. David Wells:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2026.110088.

Data availability

Data will be made available on request.

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