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EDITED BY
Adrian C. Gleiss,
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REVIEWED BY
Eric Reyier,
Herndon Solutions Group, LLC,
United States
Jorge Manuel Morales-Saldaña,
McGill University, Canada

*CORRESPONDENCE
Kesley Gibson-Banks
✉ Kesley.Banks@tamucc.edu

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Evidence of a potential sandbar shark (*Carcharhinus plumbeus*) nursery in the Western Gulf of Mexico

Kesley Gibson-Banks[1]*, P. Dominguez Rein-Loring[2], Jensen M. Smith[1], J. Marcus Drymon[3], R. J. David Wells[2], Fernando Martinez-Andrade[4], William T. Driggers[5] and Matthew K. Streich[1]

[1]Harte Research Institute, Texas A&M University-Corpus Christi, Corpus Christi, TX, United States, [2]Department of Marine Biology, Texas A&M University at Galveston, Galveston, TX, United States, [3]Mississippi State University, Coastal Research and Extension Center, Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS, United States, [4]Coastal Fisheries Division, Texas Parks and Wildlife Department, Corpus Christi, TX, United States, [5]Mississippi Laboratories, Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA), Pascagoula, MS, United States

Introduction: Nursery areas for sandbar sharks (*Carcharhinus plumbeus*) are well-delineated along the Atlantic coast of the United States, with only a single nursery area identified in the Gulf of Mexico on the west coast of Florida.
Methods: Fishery-independent surveys and fishery-dependent data were used to explore the frequency and seasonality of young-of-the-year (YOY) sandbar sharks off the coast of Texas.
Results: Data presented in this study demonstrate YOY are caught off the Texas coast, suggesting a potential nursery in the region. Data collected by the Texas Parks and Wildlife Department estuarine gillnet surveys and recreational shore-based shark anglers documented the presence of YOY sandbar sharks in nearshore and estuarine waters of Texas.
Discussion: While the increase in YOY individuals were detected in the decades long fishery-independent surveys (i.e., estuarine gillnet, SEAMAP coastal and NMFS offshore longlines), fishery-dependent data collected via a shore-based recreational shark tournament documented a substantial rise in YOY sandbar sharks over a much shorter time period (10 years), supporting the usefulness of data collected by citizen scientists. For shark species, especially those with rebuilding plans, such as sandbar sharks, identifying and conserving nursery areas is important, as the decreasing amount of suitable habitat could be a limiting factor for population recovery.

KEYWORDS
citizen scientist, nursery, pups, sandbar sharks, Texas, young of the year

1 Introduction

Sandbar sharks (*Carcharhinus plumbeus*) are a large, highly migratory, coastal species that inhabits temperate, subtropical and tropical waters of the western North Atlantic Ocean, including the Gulf of Mexico (also known as the 'Gulf of America' in U.S. federal documents, hereafter Gulf; Casey and Kohler, 1990, Heist et al., 1995; Heist and Gold, 1999) and have been classified as globally endangered on the IUCN Red List of Threatened Species (Rigby et al., 2021). Sharks like sandbar sharks are highly susceptible to overexploitation due to their life history characteristics (e.g., slow growth and low reproductive output; Musick et al., 2000). Sandbar sharks were historically the primary targeted species of the U.S. commercial shark fishery, leading to overfishing as identified by the 2006 stock assessment (SEDAR, 2006). As a result, directed fisheries were closed in 2008 and remained closed today, except for a limited entry research fishery (NMFS, 2008; Baremore and Hale, 2012). This closure significantly limited the availability of new and updated biological data (e.g., reproductive variables, litter size, and parturition) for the species. However, effective management strategies rely on updated and accurate data, especially for those species that are in rebuilding fishery management plans.

Periodic reassessment of reproduction, continued monitoring of the age structure, and habitat use of sandbar sharks will ensure that assessment scientists and managers have the best data possible. Size and age at 50% maturity were 151.6 cm FL and 12.1 years for males while females were 154.9 cm or 13.1 years (Baremore and Hale, 2012). Peak mating and parturition occur from April through July, with an average of 8 pups per litter (Medved and Marshall, 1981, Musick and Colvocoresses, 1988, Castro, 1993; Baremore and Hale, 2012). The reproductive cycle is at least biennial, although there is evidence that some females have triennial cycles (Springer, 1960, Clark and von Schmidt, 1965, Cliff et al., 1988; McAuley et al., 2007; Baremore and Hale, 2012).

Adult sandbar sharks are known to aggregate offshore and make large north–south migrations off the east coast of the United States, including the Gulf (Casey and Natanson, 1992; Kohler et al., 1998; Altobelli and Szedlmayer, 2020, Stunz, *unpublished data*). Neonate and juvenile sandbar sharks frequent coastal nursery areas (Medved et al., 1985), with the largest and most well-known nursery area in the western North Atlantic Ocean for this species in Chesapeake Bay (Springer, 1960, Musick and Colvocoresses, 1988), with smaller nurseries reported in New York, Delaware, Virginia, South Carolina, and Florida (Springer, 1960; Castro, 1993; Merson, 1998; Carlson, 1999; Merson and Pratt, 2001; Grubbs et al., 2007). Juvenile sandbar sharks have been reported in Chesapeake Bay and eastern shore of Virginia in depths less than 10 m (Medved and Marshall, 1981; Musick et al., 1993), and in Bulls Bay, South Carolina (Castro, 1993). Pratt and Merson (1996) have also reported Delaware Bay, New Jersey, as a major nursery area for neonate and juvenile sharks.

Although the nursery areas for this species in U.S. waters are largely considered to be off the east coast, a nursery area has been suggested in the western Gulf, based on a few females collected with full-term pups near the mouth of the Mississippi River and few juveniles captured off Texas and Louisiana (Bigelow and Schroeder, 1948; Springer, 1960; Branstetter, 1987, Hueter and Tyminski, 2007). This nursery area was hypothesized to result from gravid females occasionally making their way into the Gulf but not be self-sustaining (Springer, 1960). Carlson (1999) documented the capture of neonates and juvenile sandbar sharks (n = 105) in Indian Pass and St. Andrew Sound, and because neonates (age <1) reside through their first summer in the parturition areas (Pratt and Merson, 1996), he reported these individuals were unlikely to have migrated from other areas. This description of a nursery area in the eastern Gulf suggests that nursery areas in the Gulf might be more extensive than previously reported (Carlson, 1999; Baremore and Hale, 2012). Texas bays have previously been described as nursery habitat for several other shark species, including blacktip sharks (*Carcharhinus limbatus*) and bull sharks (*Carcharhinus leucas*), with the highest catches historically in Matagorda and San Antonio Bay (Jones and Grace, 2002, Froeschke et al., 2010; Matich et al., 2017b, 2022).

The abundance estimates and diversity of shark populations have traditionally been described using fishery independent sampling (Xu et al., 2015; Hendon et al., 2025). These standardized survey methods allow for more statistically robust assessments because their continuity and random stratified designs allow for more accurate assessments of population dynamics, climate change, management actions, and migratory dynamics (Miller et al., 2007; Bonar et al., 2009). One such fishery independent survey is the National Marine Fisheries Service bottom longline (NMFS BLL) survey, which samples shark species in offshore waters (>9 nautical miles (nm) or 16.67 km). A complementary survey is the Southeast Area Monitoring and Assessment Program (SEAMAP), which is a collaboration between federal/state/universities that focus on collecting bottom longline data in coastal waters (<9 nm; Hendon et al., 2025). State sampling programs (e.g., Texas Parks and Wildlife Department [TPWD] gillnet and BLL) are used to monitor state waters and bays and estuaries (hereafter, estuaries). Despite their value to the assessment process, fishery-independent surveys are relatively expensive and may be restricted both temporally and geographically by funding (Dennis and Plagaányi, 2015, Howard et al., 2023).

An increasing trend in fisheries science is the incorporation of recreational anglers to provide data that otherwise would not have been logistically and financially feasible (Williams et al., 2015; Gibson et al., 2019). The Texas Shark Rodeo (TSR, texassharkrodeo.com) is an annual 10-month tournament, where anglers target sharks from the shore (<500 m from shore and <5 m depth) following best practices for catch-photo-release. Anglers participating in the TSR tag and submit a photograph of their catch along with biological measurements. Beginning in 2014, this tournament has recorded over 13,000 shark submissions, with anglers correctly identifying shark species 97.2% of the time, providing a unique long-term dataset for the Texas coast (Gibson et al., 2019). Gibson et al. (2019) reported that sandbar sharks were the third most commonly caught species in the TSR. The purpose of this study was to compare fishery-independent (e.g., BLL and gillnet surveys) and dependent (e.g., TSR) datasets for sandbar shark seasonality and size composition, particularly for YOY individuals associated with the Texas coast.

2 Methods

This research was approved by the Texas A&M University-Corpus Christi Institutional Animal Care and Use Committee under protocols #08–15, #08–18, and #2023-007, and also by National Park Service permits PAIS-2010-SCI-0009, PAIS-2015-SCI-0001, and PAIS-2016-SCI-0018. Tournament participants captured and tagged sharks following the rules and regulations of the TPWD and the TSR.

2.1 NMFS Offshore BLL

Since 1995, the NOAA National Marine Fisheries Service (NMFS, Grace and Henwood, 1997; Driggers et al., 2008, https://www.fisheries.noaa.gov/inport/item/28636) conducts fisheries-independent BLL surveys along the US continental shelf waters from Cape Hatteras, NC to Brownsville, TX, from late July to the beginning of October. The longline, which is 1,852 meters long, is deployed at depths ranging from 9 to 366 m. It consists of a 536 kg test monofilament mainline and 100 gangions, each with a 3.7 m, 3.0 mm diameter monofilament leader and a hook. Bait used was Atlantic Mackerel (*Scomber scombrus*). Weights are placed at the beginning, middle, and end of the line. Hook types varied over time, with J-hooks used from 1995 to 1998 and 15/0 circle hooks from 2001 to the present. In 1999 and 2000, both hook types were used. Given changes in hook type prior to 2001 and the subsequent standardization of longline gear and sampling procedures, this study includes only data collected from 2001 onward. Soak times are generally limited to one hour to minimize mortality rates of all captured organisms. Survey locations are randomly selected by stratified-random sampling with proportional allocation based on depth and continental shelf area. Catch data, including species identification, length, weight, and sex, as well as environmental data, such as temperature, salinity, and dissolved oxygen, are collected at each site (Driggers et al., 2008).

2.2 SEAMAP Coastal BLL

In 2008, recognizing the gap in the NMFS offshore BLL survey, which only samples at depths greater than 9 m, SEAMAP launched a complementary fishery-independent BLL survey in the coastal waters of the U.S. Gulf. SEAMAP is a collaborative program between federal, state, and university partners that focuses on collecting and sharing fisheries-independent, gear-standardized data. The sampling methodology used by SEAMAP mirrors that of the NMFS BLL survey (Hendon et al., 2025).

From 2008 to 2014, SEAMAP survey design and effort allocation parameters varied between states. In 2015, several changes were implemented: the depth range was modified to 3–10 m to include previously unsampled waters while minimizing overlap with the NMFS BLL survey's range of 9–366 m, and sampling efforts were redistributed to create a more spatially balanced survey. Additionally, prior to 2015, SEAMAP surveys were conducted from March to October, but in 2015, sampling was reorganized into three seasonal periods: Spring (April–May), Summer (June–July), and Fall (August–September; Hendon et al., 2025). For this study, all months were analyzed separately to avoid differences between seasonal sampling and allow comparable results between datasets.

2.3 TPWD Estuarine Gillnet

Gillnet data were obtained from the TPWD fishery-independent gillnet monitoring program. Since 1982, 45 gillnets were deployed in each major estuarine system during the spring (April–June) and fall (September–November) seasons. During each 10-week sampling period, a minimum of three gillnet deployments were conducted per week, to ensure sampling was distributed throughout the full sampling period (Zapp Sluis et al., 2025). Gill nets (182.9 m × 1.2 m) were comprised of four sections with varying mesh sizes: 76 mm, 102 mm, 127 mm, and 152 mm. These nets were deployed overnight, beginning approximately one hour before sunset and retrieved three to four hours after sunrise (average soak time ± SD = 13.7 ± 1.4 hours). Gillnets were set perpendicular to the shoreline, with the 76 mm mesh closest to the shore, at randomly selected locations (Fontaine et al., 2024; Martinez-Andrade, 2018; Matich et al., 2017a; Plumlee et al., 2018).

All organisms larger than 5 mm caught in gillnets were identified to the lowest taxonomic level (typically species), counted, and measured to the nearest millimeter for stretched total length (TL). 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 parameters such as temperature, salinity, and dissolved oxygen were measured approximately 0.15 m below the water surface (Fontaine et al., 2024; Plumlee et al., 2018). Environmental conditions were only measured at deployment and retrieval of the gillnets, limiting the ability to assess how overnight variations during sampling influenced shark captures (Matich et al., 2017a). Thus, the average environmental conditions of each sampling event at deployment and retrieval were used for analyses.

All major estuaries in the TPWD dataset were included in analyses, with the exception of Cedar Lakes and East Matagorda Bay, which were excluded due to irregular sampling and low sample sizes over the sampling period (Plumlee et al., 2018). Moreover, data prior to 1983 have also been excluded, due to variation in sample sizes (Matich et al., 2017a). Data from 2024 was excluded due to sampling inconsistency in the fall. Thus, the temporal scope covered by this dataset is from 1983 to 2023, except for Sabine Lake where sampling began in 1986 (Zapp Sluis et al., 2025).

2.4 Shore-based TSR

Texas Shark Rodeo has been on-going since 2014, providing a long-term, fishery-dependent dataset. Each year, a mean of 325 teams (range: 180–560 teams/year) participate with teams consisting of up to 6 anglers. Although variations exist, the general strategy for shore-based shark fishing involves the use of large reels spooled with 800-1,000 m of 50-lb to 100-lb test of either monofilament or braided line with a top shot of approximately 100 m of monofilament of increased strength. A leader made of either wire or monofilament, a weight, and a hook (13/0 to 24/0) is attached to the top shot line and baited with typically sections of stingray

(*Rhinoptera* spp. or *Dasyatis* spp.), crevalle jack (*Caranx hippos*), or striped mullet (*Mugil cephalus*), which is either surf casted or kayaked out 100–400 m offshore (Ajemian et al., 2016).

Captured sharks were identified to species, measured, photographed with a tournament issued ruler, and then released. Date of capture, location, stretched total length (STL; measured from the tip of the snout to the tip of the stretched upper caudal lobe), fork length (FL), sex, species, and tag number if applicable, were recorded. Photos submitted to TSR were viewed for species confirmation (Gibson et al., 2019, Gibson-Banks et al., 2025). Environmental data were not submitted as part of the tournament.

2.5 Data analyses

Statistical analyses were completed in *R*. Pups, a.k.a. young-of-the-year (YOY) were defined as less than 71 cm FL (age-1 length as used in SEDAR 54 [2017]). For NMFS offshore BLL surveys where FL was not measured but natural total length (TL) data were recorded, FL was estimated using the equation from Kohler et al. (1996):

$$\mathrm{FL(cm)} = 0.8175 \times \mathrm{TL(cm)} + 2.5675$$

For the SEAMAP coastal BLL and estuarine gillnet surveys, where only stretched total length was recorded, the NOAA calculator was used to determine the relationship between stretched total length and FL (Natanson et al., 2022).

For all fishery-independent datasets (i.e., offshore BLL, coastal BLL and estuarine gillnet), total length to fork length conversions were calculated to ensure consistency across all datasets. When FL was already measured, the recorded value was retained. Fork length was reported for all sharks in TSR, so no conversion was necessary.

Sandbar shark catch data were then standardized as catch-per-unit-effort (CPUE). For the shore-based TSR dataset, CPUE was calculated as:

$$CPUE = \frac{catch}{A}$$

Where catch is the number of sandbar sharks captured, and A is the total number of angler-days. An angler-day was defined as each unique combination of angler and date in which any shark was reported. In the case of estuarine gillnet data, CPUE was calculated as catch per net-hour (soak time):

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

Estuarine gillnet and shore-based TSR CPUE calculations were visualized along the Texas coast using *ggplot2*, *ggspatial*, and *sf* packages in R.

For the coastal and offshore BLL datasets, CPUE was calculated as:

$$CPUE = \left(\frac{c}{h * t}\right) * 60 * 100$$

Where c is the number of sharks captured, 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 number of sharks caught per 100 hook hours (Driggers et al., 2008; Pickens et al., 2022). The fishery-independent datasets (i.e., offshore BLL, coastal BLL, and estuarine gillnet) included environmental data, therefore, generalized additive models (GAMs) with CPUE as response variable and environmental, spatial, and temporal predictors with a Tweedie distribution were applied. The Tweedie distribution was selected for the GAMs due to its flexibility in handling both zero-inflated data and overdispersion (Gilchrist and Drinkwater, 2000), which are common features of ecological datasets. Model parametrization ranged from simpler to more complex GAMs incorporating smooth cubic regression spline functions of continuous predictors (year, depth and environmental variables), cyclic cubic splines for month predictors and thin-plate regression splines of spatial coordinates. In the case of NMFS BLL dataset, as sampling only occurred during the summer months, month was not included in the models. To account for potential effects associated with the sampling station, survey was included as a random effect in the BLL models and bay was included as a random effect in the gillnet models. Random effects were retained only when they improved model performance. Models included a gamma value of 1.4 to penalize overfitting and k was left as default to allow for model flexibility.

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., 2025; Peterson et al., 2017), except for the depth variable in the case of the offshore NMFS BLL dataset, which was removed due to high correlation (0.83) with other environmental variables.

Model selection was based on Akaike's Information Criterion (AIC; Akaike, 1973; Burnham and Anderson, 2002). Manual backwards stepwise model fitting was performed to select explanatory variables influencing CPUE, based on minimizing the AIC. At each step of the backward selection process, the variable with the highest p-value ($p > 0.05$) was removed from the model. This process was repeated until further removal of variables led to an increase in AIC of >1%, at which point the variable was retained and the selection process was finished (Akaike, 1973; Cornic and Rooker, 2018; Dance and Rooker, 2019; Sluis et al., 2021).

Model performance was evaluated using 5-fold cross-validation, assessing root mean square error (RMSE), mean absolute error (MAE), and the Pearson correlation between predicted and observed values (O'Brien et al., 2025). Temporal autocorrelation in model residuals was initially assessed through visual inspection of autocorrelation function (ACF) plots (Araujo et al., 2020; Carvalho et al., 2020; Makwinja et al., 2021). Formal testing of temporal autocorrelation was conducted using the testTemporalAutocorrelation() function from the *DHARMa* package in R (Hartig et al., 2024). In addition to temporal checks, DHARMa diagnostics were also used for broader model validation, with diagnostic plots evaluated to detect any systematic trends or overdispersion (Flowers et al., 2022; King et al., 2024; O'Brien et al., 2025). 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., 2025; Potts and Rose, 2018; Rooker et al., 2012).

Test results were considered acceptable when no significant autocorrelation was detected (p-value > 0.05). Finally, partial effects of individual covariates on CPUE were visualized using the *ggplot2* package in R.

3 Results

The total number of sandbar sharks and the number of YOY individuals were recorded for each of the four datasets used in this study. A total of 1,333 individuals were sampled across the four datasets (offshore BLL, coastal BLL, estuarine gillnet, and shore-based TSR; Table 1) spanning the Texas coast. Based on length, 267 individuals were classified as YOY, with YOY catches concentrated between Corpus Christi Bay to north of Galveston Bay (Figure 1).

3.1 Offshore BLL

The offshore BLL surveys (since 2001) reported 184 sandbar sharks and suggested an increase in individuals overtime (Figure 2). To formally evaluate temporal patterns in CPUE, two candidate models were developed and compared based on statistical performance and residual diagnostics. Model Offshore A_1 (AIC = 484.23, deviance explained = 46.6%; Supplementary Material Table 1) showed no signs of overfitting, with training and cross-validation metrics remaining consistent (CV RMSE = 0.82, CV MAE = 0.37, CV R = 0.365; Supplementary Material Table 2), indicating reliable out-of-sample predictive performance. DHARMa residual diagnostics revealed no significant violations of model assumptions, although the outlier and dispersion tests returned significant results (Supplementary Material Figure 1). The dispersion test indicated mild under dispersion ($\varphi = 0.96$), meaning the observed variance in the response variable was slightly lower than expected under the model. This pattern can increase sensitivity to a small number of extreme observations (Zuur et al., 2009), consistent with the significant outlier test result. Given the characteristically right-skewed and zero-inflated nature of CPUE data for relatively rare size classes such as neonates, these deviations are not unexpected and are unlikely to meaningfully bias the directional trends inferred from the model. A Durbin-Watson test indicated the presence of temporal autocorrelation ($p < 0.002$), this was acknowledged as a limitation affecting the precision of standard errors rather than the validity of the model structure itself.

Model B_1, despite achieving a lower AIC (466.42) and higher deviance explained (67.6%), exhibited clear signs of overfitting, with a substantial divergence between training and cross-validation R values (0.868 vs. 0.375) (Supplementary Material Table 2). Additionally, DHARMa diagnostics for Model Offshore B_1 revealed a significant combined adjusted quantile test (Supplementary Material Figure 2), indicating misspecification of the residual distribution. Given that a lower AIC value is insufficient justification for model selection when accompanied by overfitting and residual misspecification, Model A_1 was retained as the preferred model for inference. The temporal autocorrelation identified in Model A_1 was accounted for in the interpretation of results, and temporal trends are discussed descriptively with appropriate caution regarding the precision of significance tests.

```
Model_Offshore_A_1 <- gam(CPUE ~.
s(YEAR, bs="cr") +.
s(TEMP, bs="cr") + s(SALINITY, bs="cr") +.
s(FLYLAST_OUTLON, FLYLAST_OUTLAT, bs="tp"),
family = tw(link = "log"), gamma=1.4,
data = offshore_data_C_plumbeus, method = "REML").
```

Adult sandbar shark CPUE increased from 2000 to 2015 and then gradually declined thereafter, supported by the GAM analysis, in which *Year* was a significant predictor of CPUE ($p = 8.18 \times 10^{-7}$; Figure 2B), though this result should be interpreted cautiously given temporal autocorrelation in the model residuals. Size-composition patterns indicate that YOY sandbar sharks were rare offshore (Figure 3D), with only four YOY individuals recorded (mean: 56.85 cm FL; range: 54.5 - 59.6 cm FL), three females and one male. These occurred almost exclusively in September, coinciding with sampling times for Texas (Figure 4D). Larger juveniles and adults size structure was relatively consistent across months. The significant smooth term for location in the GAM model of the BLL data (s(Lat,Lon), p < 2e-16) confirmed that CPUE varied geographically offshore.

3.2 Coastal BLL

The coastal BLL (since 2008) recorded 30 sandbar sharks, of which two were YOY individuals (mean: 70.45 cm FL; range: 70.4 - 70.5 cm FL), one female and one male (Figure 3C). The YOY individuals were caught in May and July (Figure 4C). The GAM model for BLL coastal data did not converge due to low sample size and outliers, and therefore, it was not presented here.

3.3 Estuarine gillnet

The estuarine gillnet survey recorded a much higher proportion of YOY sandbar sharks, with 40 out of 43 (93%) individuals measuring <71 cm FL (mean: 57.66 cm FL; range: 40.1 - 68.0 cm FL; Figure 3B). Of these 40 individuals, 12 were females, 13 were males and no sex was recorded for 15 individuals. These catches first appeared in the 2000s and showed an increase after 2015 (Figure 4B). The observed increase in sandbar and YOY individuals was supported by the GAM analysis, in which *Year* was a significant predictor of CPUE ($p = 0.0033$; Figure 2A). The estuarine gillnet model selected through backward stepwise selection included smooth terms for year, month (cyclic cubic spline, k = 5), salinity, and depth, a thin-plate regression spline of spatial coordinates (longitude and latitude), and bay as a random effect (Model Gillnet C_1 in Supplementary Material Table 3). QQ plot and DHARMa residual diagnostics indicated no significant deviations from expected distributional assumptions, and the model was therefore retained (Supplementary Material Figure 3).

```
Model_Gillnet_C_1<- gam (CPUE ~.
s(YEAR, bs="cr") + s(MONTH, bs="cc", k=5) +.
```

TABLE 1 Individual sandbar shark catches for fishery independent surveys (i.e., offshore BLL, coastal BLL, estuarine gillnet survey) and fishery dependent surveys (i.e., TSR) in and off Texas.

Year	All				<71 cm FL			
	Offshore BLL	Coastal BLL	Gillnet	Shore-based TSR	Offshore BLL	Coastal BLL	Gillnet	Shore-based TSR
1983	NA	NA	0	NA	NA	NA	0	NA
1984	NA	NA	0	NA	NA	NA	0	NA
1985	NA	NA	0	NA	NA	NA	0	NA
1986	NA	NA	1	NA	NA	NA	1	NA
1987	NA	NA	0	NA	NA	NA	0	NA
1988	NA	NA	1	NA	NA	NA	0	NA
1989	NA	NA	0	NA	NA	NA	0	NA
1990	NA	NA	0	NA	NA	NA	0	NA
1991	NA	NA	0	NA	NA	NA	0	NA
1992	NA	NA	0	NA	NA	NA	0	NA
1993	NA	NA	0	NA	NA	NA	0	NA
1994	NA	NA	1	NA	NA	NA	0	NA
1995	NA	NA	0	NA	NA	NA	0	NA
1996	NA	NA	0	NA	NA	NA	0	NA
1997	NA	NA	0	NA	NA	NA	0	NA
1998	NA	NA	0	NA	NA	NA	0	NA
1999	NA	NA	1	NA	NA	NA	1	NA
2000	NA	NA	3	NA	NA	NA	3	NA
2001	5	NA	0	NA	0	NA	0	NA
2002	11	NA	0	NA	0	NA	0	NA
2003	8	NA	1	NA	1	NA	1	NA
2004	10	NA	0	NA	0	NA	0	NA
2005	0	NA	0	NA	0	NA	0	NA
2006	5	NA	0	NA	0	NA	0	NA
2007	7	NA	2	NA	0	NA	2	NA
2008	1	0	0	NA	0	NA	0	NA
2009	13	0	4	NA	1	0	4	NA
2010	10	22	1	NA	0	0	1	NA
2011	0	0	0	NA	0	0	0	NA
2012	15	0	0	NA	0	0	0	NA
2013	18	1	0	NA	0	0	0	NA
2014	5	0	1	54	0	0	1	2
2015	8	0	0	102	0	0	0	74
2016	11	0	4	93	0	0	4	53
2017	18	0	4	45	2	0	4	30
2018	5	0	2	98	0	0	2	13
2019	12	0	1	88	0	0	1	16
2020	0	0	4	48	0	0	3	6
2021	4	5	12	105	0	0	12	9
2022	4	2	0	201	0	2	0	8
2023	9	0	0	130	0	0	0	9
2024	5	0	0	92	0	0	0	2
TOTAL	**184**	**30**	**43**	**1056**	**4**	**2**	**40**	**222**

NA means the survey had not been implemented yet or were excluded from these analyses (see methods for details). Bold numbers are totals.

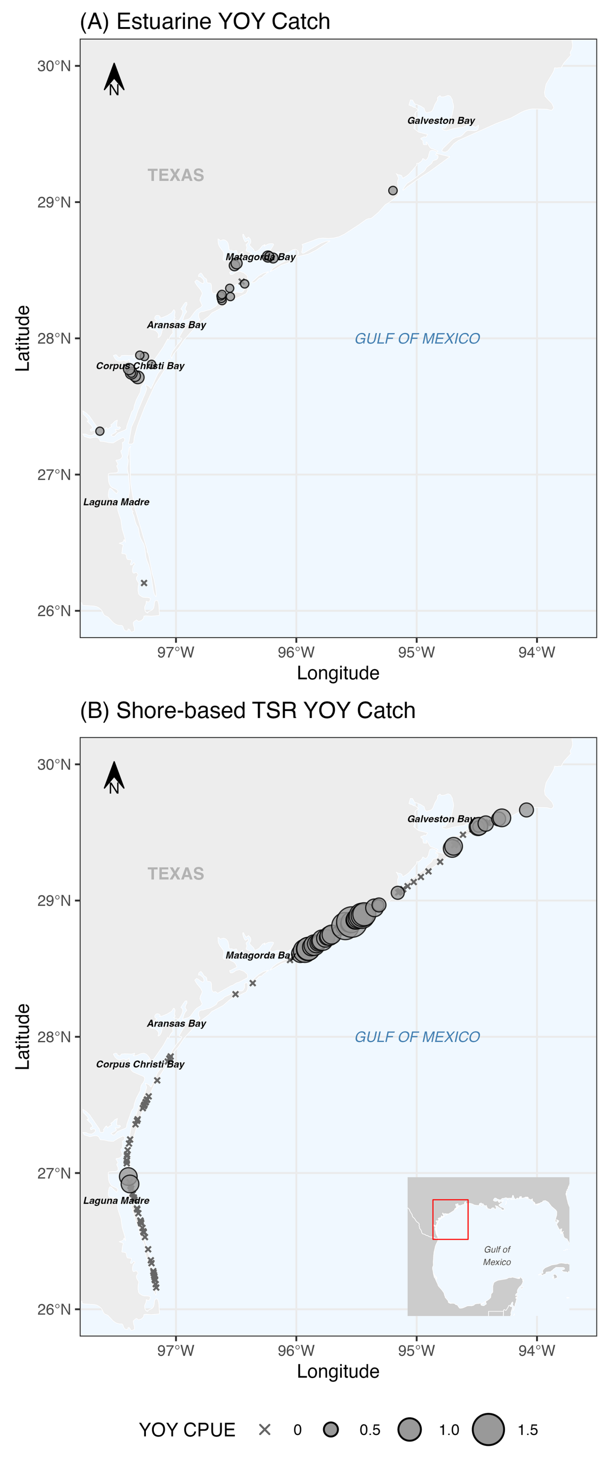

FIGURE 1
Maps showing catch per unit effort (CPUE) for YOY sandbar shark along the Texas coast by gear type. Estuarine gillnet CPUE **(A)** is calculated as YOY catch per net-hour (soak time) and shore-based TSR CPUE **(B)** is calculated as YOY catch per angler-day. The symbol × indicates effort with no YOY catch.

```
s(SALINITY, bs="cr") +.
s(START_DEEP_DEPTH, bs="cr") +.
s(START_LONGITUDE, START_LATITUDE, bs="tp") +.
s(MAJOR_AREA_CODE, bs="re"),
family = tw(link = "log"), gamma=1.4,
data = gillnet_data_C_plumbeus, method = "REML").
```

Size-composition patterns indicate that YOY sandbar sharks were more common in estuaries than adults, with a more distinct temporal pattern in size composition, with the largest number of sandbar sharks captured in September, indicating a strong seasonal peak late in the summer (Figure 4B). However, the smallest individuals observed in the gillnet data were captured earlier in the year, specifically in June, suggesting an early-summer presence of younger juveniles in estuaries. Relative abundance of YOY has been generally increasing annually (Figure 5). Spatially, YOY sandbar shark captures were concentrated along the central Texas coast, particularly in Matagorda Bay and Corpus Christi Bay, with only a single catch recorded near south Galveston Bay and another in Baffin Bay (Figure 1A). The significant smooth term for location in the GAM model of the estuaries (s(Lat, Lon), $p = 0.011637$) confirmed that YOY CPUE varied geographically along the coast.

3.4 Shore-based TSR

From 2014 to 2024, 1,056 sandbar sharks were caught and reported through the shore-based TSR tournament. Of those, 849 were female and 207 were male. Of the total, 222 individuals classified as YOY (<71 cm FL; mean: 57.37 cm FL; range: 43.18 - 69.85 cm FL; Figure 3A) based on reported FL, with 131 of those females and 91 males (Table 1). An increased proportion of YOY was observed in summer months (June to September), coinciding with a decrease in the number of larger individuals starting in May (Figure 4A). Years 2015 to 2017 had the highest number of YOY sandbar sharks reported in the shore-based fishery despite the highest total number of all sandbar sharks reported in later years (2022-2023; Figure 6). Relative abundance (CPUE) peaked for YOY in 2016, declined until 2020, and has since been steady (Figure 6). Overall, CPUE of sandbar sharks has been increasing since the inception of TSR in 2014 (Figure 6). Highest CPUE was observed between Matagorda Bay and Galveston Bay systems with higher abundance also observed near Corpus Christi Bay. Lower CPUE was observed along the rest of the coast. For YOY, CPUE was also highest between Matagorda Bay and Galveston Bay systems; however, YOY CPUE was lower along the remaining coastline, especially south of Matagorda Bay despite significant fishing effort in that region (Figure 1B).

4 Discussion

While most sandbar shark nurseries have been documented along the Atlantic coast (Grubbs et al., 2007; Baremore and Hale, 2012), currently, the only nursery described for the Gulf is in the Florida panhandle (Carlson, 1999). However, the prevalence of YOY individuals across Texas suggests an undescribed sandbar shark nursery exists in the western Gulf. Sandbar sharks are currently in a rebuilding plan and have been since 2005 (Curtis et al., 2025); thus, documenting all areas where parturition takes place is important for designating important nursery habitat. Future efforts to formally identify areas along the Texas coast should follow

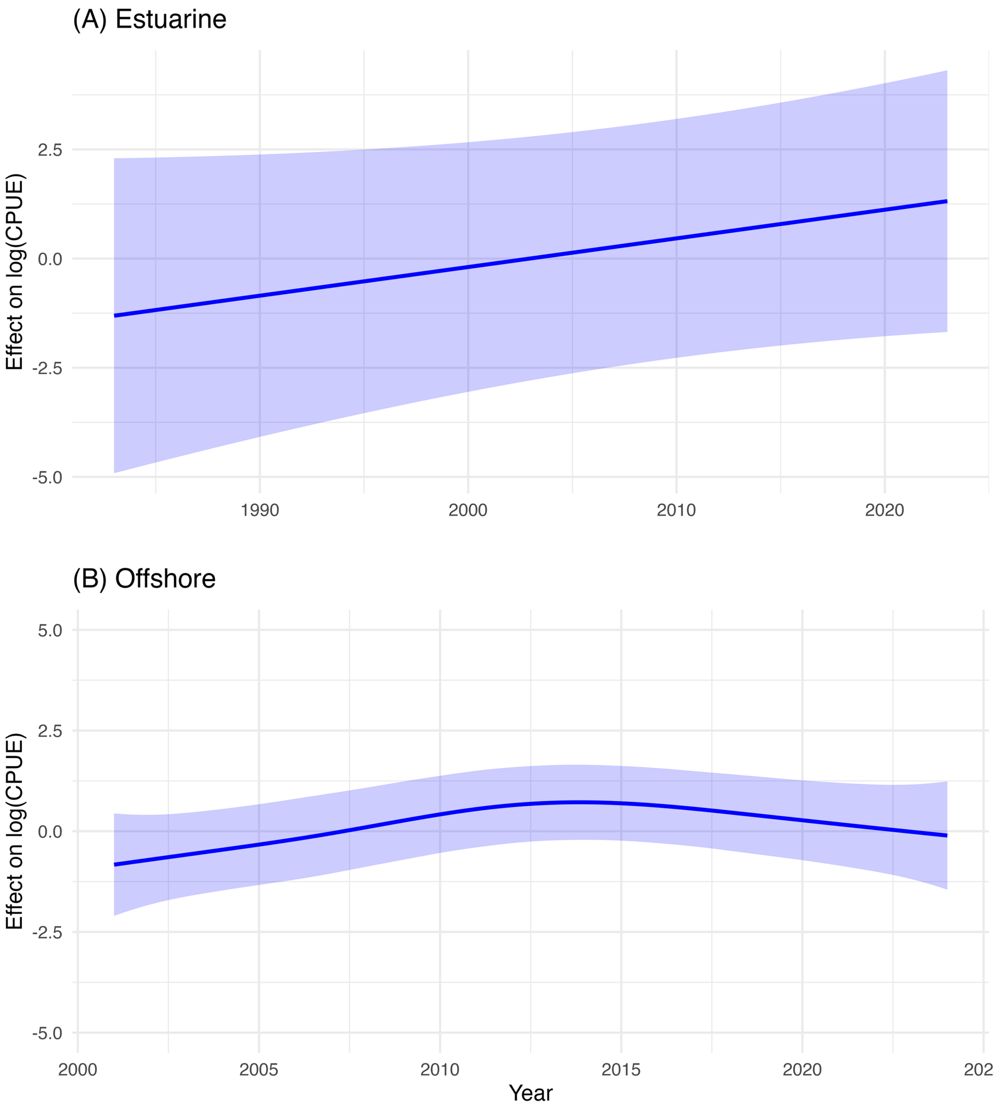

FIGURE 2
Temporal trends in predicted GAM effects on log(CPUE) for **(A)** the estuarine gillnet data (1983–present) and **(B)** the offshore NOAA bottom longline survey data (2001–present). Solid lines represent the estimated year effect, and shaded ribbons indicate 95% confidence intervals. Note the different time scales between the two panels, with the estuarine dataset providing a longer-term perspective beginning two decades earlier than the offshore survey.

established criteria for nursery habitat designation (e.g., Heupel et al., 2007; Froeschke et al., 2010; Matich et al., 2022).

In this study, sandbar shark CPUE has increased over time across three datasets (coastal, estuarine, and shore-based), suggesting an increasing trend in abundance in the western Gulf and supporting the effectiveness of the rebuilding plan. The offshore BLL predominantly captured adult sandbar sharks, reporting 184 sandbar sharks encountered in the 22-year survey period. The coastal BLL survey had even less encounters with a total of 30 individuals reported in the 16-year survey period. The estuarine gillnet survey had the longest time period of 41 years and reported 43 sandbar shark encounters, most of which were YOY. The catch has continued to increase in this survey starting in 2016. Data collected through the shore-based TSR, which has the shortest survey period of 10 years, sampled 1,056 sandbar sharks of all age classes, with about 21% being YOY. This sample size was ~5x more than the offshore BLL, ~35x more than the coastal BLL, and ~25x more than the estuarine gillnet data. These results may be interpreted in a few ways. Directly, as the sandbar shark population rebuilds, more individuals will be observed. However, the significant difference in catch numbers between the surveys may be explained spatially. The inshore surveys (i.e., estuarine gillnet and shore-based TSR) may be better suited to monitoring potential nursery habitat than the coastal and offshore BLL surveys (Jones and Grace, 2002, Drymon et al., 2010). However, the standardized methods of the fishery-independent gillnet survey may provide a more direct indicator of recruitment in nursery habitats than the non-standardized fishery-dependent shore-based TSR data. Lastly, because the method to calculate CPUE in the shore-based TSR is influenced by the total abundance of all sharks, if overall shark catches decline, anglers may experience more zero-catch days, which are not accounted for due to zero-catch days not being reported. As a result, this may artificially inflate the shore-based TSR CPUE.

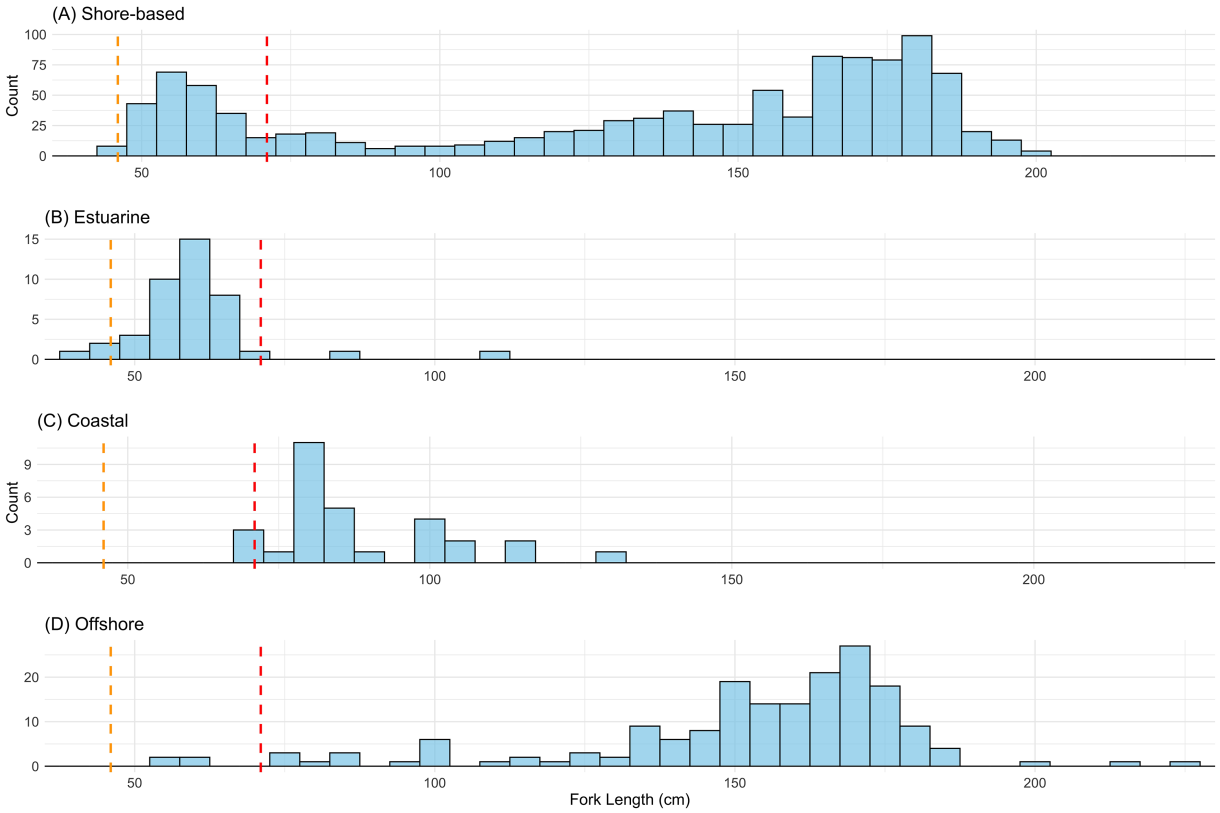

FIGURE 3
Lengths of sandbar sharks caught in shore-based **(A)**, estuarine **(B)**, coastal **(C)** and offshore **(D)**. Red line indicates 71 cm FL (age-1 length as used in SEDAR 54 [2017]). Orange line indicates 56 cm FL (average length at birth as reported by Baremore and Hale, 2012).

Although not standardized, the intensive sampling conducted by citizen scientists during events like the shore-based TSR demonstrates that these programs can help monitor stocks of species that are routinely encountered (e.g., Ajemian et al., 2016; Gibson et al., 2019; Gibson Banks et al., 2023). Unfortunately, this dataset does not provide reproductive status or detailed habitat information for individual catches, other than general location. Ideally, tournaments would collect these data along with effort data so that catch data could be standardized in the future, especially if the intent is for the data to inform management decisions. The nearshore nature of the shore-based recreational shark fishery in Texas allowed for anglers to catch YOY sandbar sharks and submit through a tournament portal for monitoring. While fishing methods were different between the surveys, anglers in TSR fish with hook and line with larger sized hooks that are typically more selective for larger sharks. Despite this, a large portion of the catch was YOY individuals (21%). Gillnet surveys likely target smaller individuals (<2 m long) known to frequent estuaries than BLL gear, which is typically set further offshore where adults are known to frequent (Musick et al., 2000, Jones and Grace, 2002). While this study generally focuses on YOY (<71 cm FL or <1 year old), the range of lengths reported in both the shore-based TSR and estuarine gillnet datasets span from neonates (average 46 cm FL at birth as defined by Baremore and Hale, 2012) to 1 year olds. This is important as neonates may use nursery habitat differently compared to young juveniles and both are present in these locations. Neither the coastal nor offshore BLL datasets report neonates. Sandbar sharks demonstrate an ontogenetic shift from nursery grounds to offshore feeding habitat (Ellis and Musick, 2007), which was observed in these datasets, further supporting that an undescribed nursery ground may be present in Texas.

Seasonal trends were also evident in this study. Catches of YOY sandbar sharks were highest during the summer months, from June to September, which overlaps with the known pupping time for sandbar sharks in the northwestern Atlantic (Baremore and Hale, 2012). In contrast, the offshore BLL offshore data shows that most individuals caught offshore were larger than 130 cm FL, but notably, only four neonate sandbar sharks were captured in this survey. A noticeable decrease in adult sandbars was observed in the shore-based TSR catches during the summer months as YOY individuals increased. Likely, the adults moved back offshore as the YOY and juveniles utilized the nursery area. Additionally, the sex ratio for the shore-based TSR catches skewed largely female (~4:1 F:M), which may suggest increased use of nearshore habitat by mature females. Many shark species, including sandbar sharks, are known to segregate by sex for much of the year (Drymon et al., 2020).

Relative abundance of sandbar sharks in both the shore-based TSR and TPWD estuarine gillnet surveys, despite their statewide coverage, were concentrated near the Matagorda Bay and Galveston Bay systems, suggesting that this might be the location of a potential nursery in Texas. For this area to be a nursery, three proposed criteria must be met as described by Heupel et al. (2007). They are: (1) sharks are more commonly encountered in the area than other areas; (2) sharks have a tendency to remain or return for extended periods; and (3) the area or habitat is repeatedly used across years.

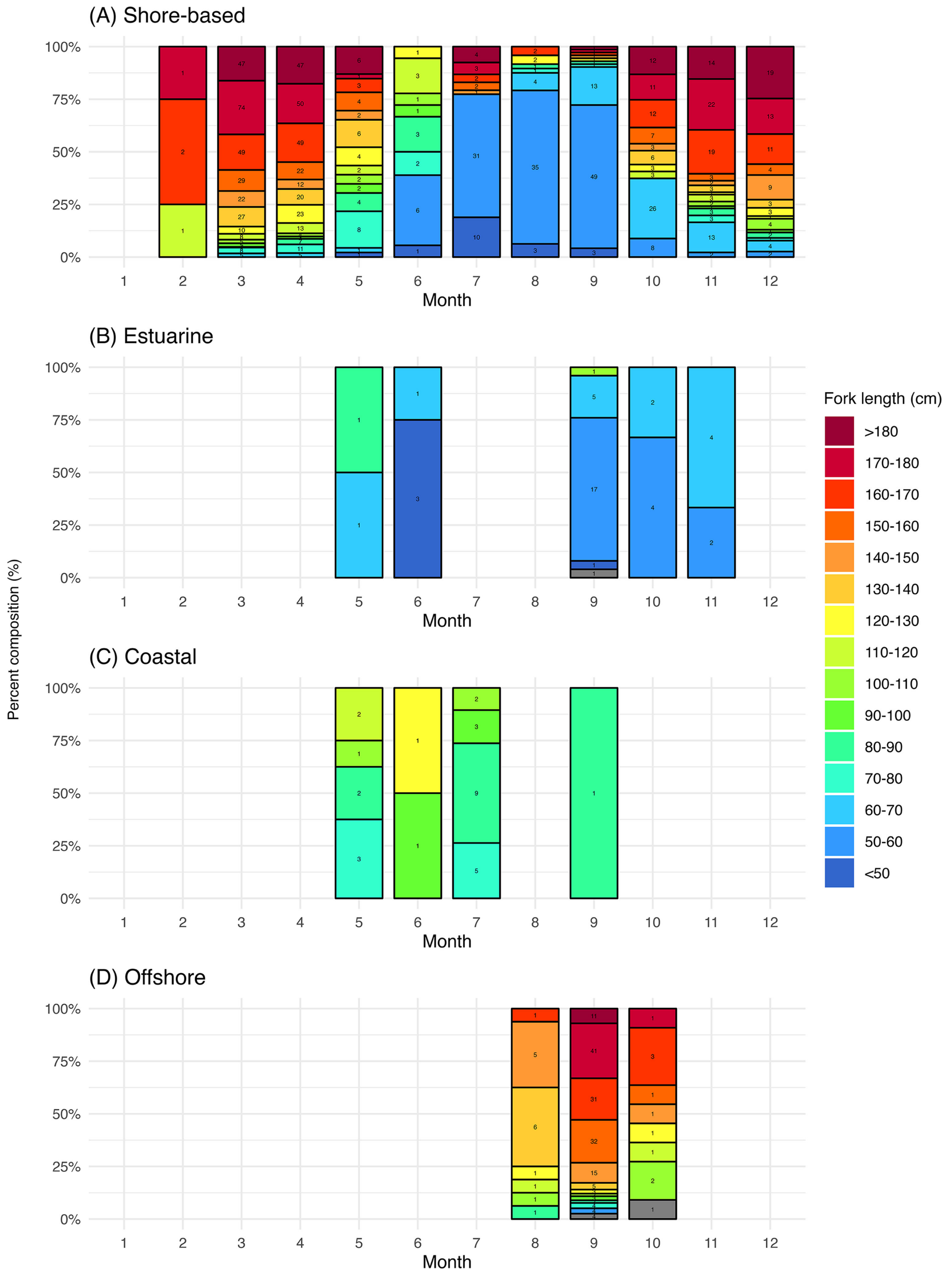

FIGURE 4
Fork length size composition of sandbar sharks for each data series: shore-based **(A)**, estuaries **(B)**, coastal **(C)** and offshore **(D)**.

For sandbar sharks, we might expect that new nursery areas will be established as the population continues to recover. Accordingly, defining nursery habitat using these criteria is a process that should be done periodically (Matich et al. 2026). The data in this study demonstrate that YOY sandbar sharks are more prevalent seasonally along the Texas coast than other areas. In fact, beginning in 2014, the Louisiana Department of Wildlife and Fisheries (LDWF) also began conducting coastal BLL surveys following standard

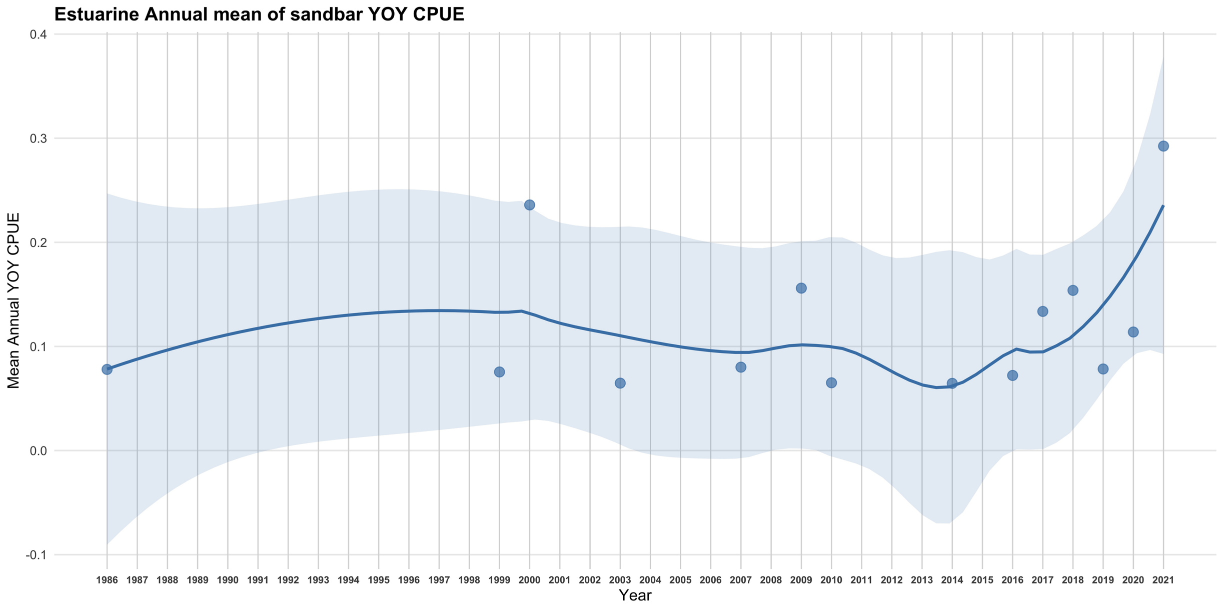

FIGURE 5
Annual mean CPUE of young-of-the-year (YOY) sandbar sharks (<71 cm FL) from the TPWD gillnet survey conducted in Texas estuaries.

SEAMAP protocols. In those 11 years, 26 sandbar sharks have been encountered, of which four were classified as YOY. Since 1985, no sandbar sharks, YOY or otherwise, have been captured by gillnet surveys in Louisiana estuarine waters (Chris Schieble, LDWF, *personal communication*). The SEAMAP surveys conducted in Mississippi and Alabama report very few YOY sandbar sharks (https://seamapdata.gsmfc.org/). The lack of encounters in these surveys, as well as the offshore BLL survey, suggest that the potential nursery ground may be limited to Texas. However, while there is a possibility that the nursery extends southward into northeastern Mexico, no surveys are known to the authors showing that YOY sandbar sharks are caught in northeastern Mexico. A BLL survey conducted over the entire Gulf also reported the lowest abundance of sandbar sharks off Mexico (Murawski et al., 2018). This along

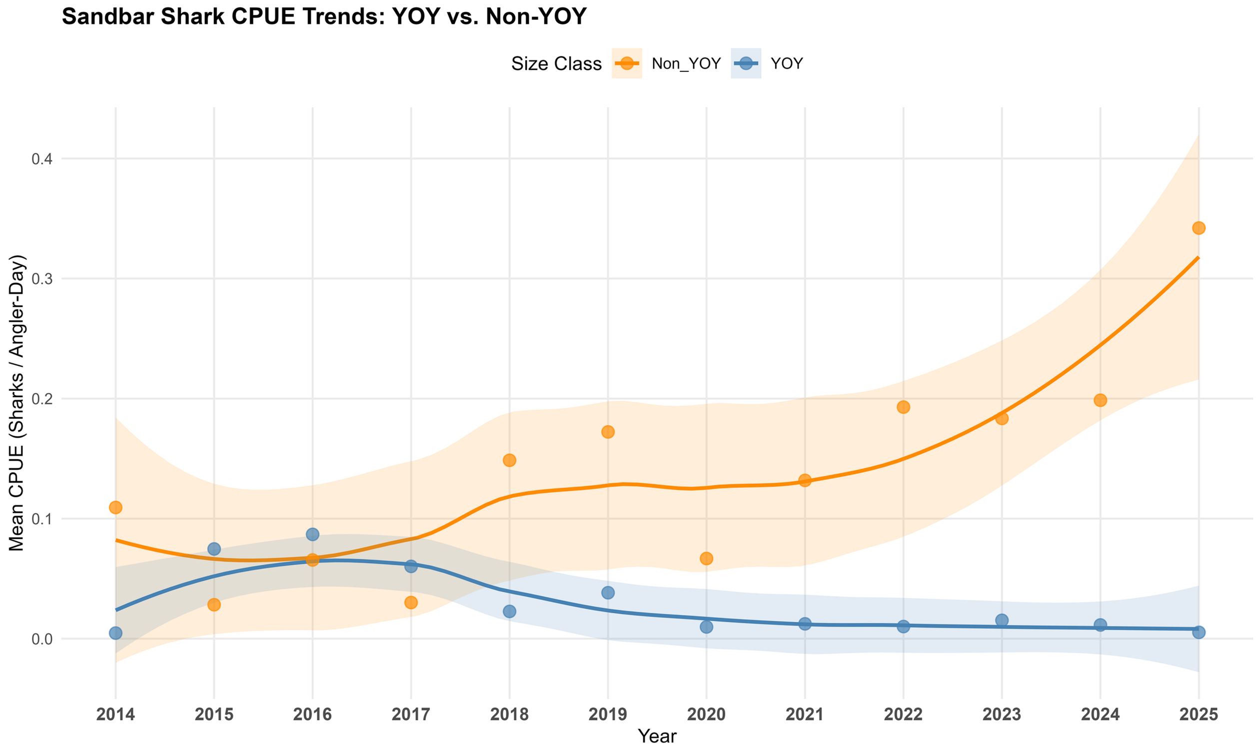

FIGURE 6
Mean CPUE trends for sandbar sharks caught in the shore-based TSR. Young-of-the-year (YOY) are individuals <71 cm FL.

with the few reported catches south of Corpus Christi Bay suggest that this nursery may be limited to the central coast of Texas. The repeated catch of YOY individuals for years (10+ years) suggests that this habitat is repeatedly used across multiple years. Unfortunately, these datasets are limited in their ability to show residency or movement patterns of individual sharks (criterion 2). While sandbar sharks have been recaptured in the shore-based fishery, tournament rules state that only sharks >32 in (>81 cm) can be tagged, meaning individual YOY were not able to be identified if previously caught (Gibson et al., 2019; Gibson-Banks et al., 2025, Banks, *unpublished data*). However, further research is needed to understand exactly how the YOY sandbar sharks are using this area.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by Texas A&M University-Corpus Christi Institutional Animal Care and Use Committee for the studies involving animals because data was collected under state and federal permits or through citizen submitted data. No protocol was deemed to be needed. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

KG-B: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. PDR-L: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. JS: Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. JD: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. RW: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. FM-A: Data curation, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing. WD: Data curation, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing. MS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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