Development of estuarine environmental indices for SEDAR 87 Gulf of Mexico White, Pink, and brown shrimp stock assessment

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Development of estuarine environmental indices for SEDAR 87 Gulf of Mexico White, Pink, and brown shrimp stock assessment

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BACKGROUND

There are three commercially important shrimp species, brown (*Farfantepenaeus aztecus*), pink (*Farfantepenaeus duorarum*), and white (*Litopenaeus setiferus*), in the US Gulf of Mexico that are the focus of a SEDAR stock assessment (SEDAR 87). Our objective for this working paper was to develop species-specific environmental indices of estuarine conditions as potential drivers of abundance. These indices will serve as inputs into alternative population models designed to hindcast past abundances and provide future abundance projections for management advice by the Gulf of Mexico Fishery Management Council.

The literature search carried out by the Environment and Industry Working Group during the SEDAR 87 Data Workshop indicates that the environmental window over which to summarize estuarine conditions differs by species based on where and when the bulk of the stocks are thought to spend most of their time as juveniles in estuarine nursery areas. We used these species-specific spatiotemporal windows to create environmental indices for new environmentally linked models. Temperature and salinity were the variables the Environment and Industry Working Group at the Data Workshop recommended to include in the assessment process as they capture most of the environmental variability experienced by juvenile shrimps.

METHODS

Long-term monitoring data collected by the Louisiana Department of Wildlife and Fisheries (LDWF; 16 ft trawl survey conducted monthly) and the Texas Parks and Wildlife Department (TPWD; Bay Trawl Survey conducted monthly) were used for brown and white shrimp environmental indices. The Florida Fish and Wildlife Commission does not have a monitoring program that samples Florida Bay, the primary nursery area for pink shrimp that supplies the bulk of commercial catches north-northwest of the Dry Tortugas (Costello and Allen 1966). As a result, we used Everglades National Park buoy data to create indices for pinks. References for

the life history traits and environmental preferences described below can be found in the SEDAR 87 Data Workshop Report.

Pink shrimp tend to spend September through October in the estuaries in South Florida. Brown shrimp tend to spend February through mid-May in the estuaries with most of the nursery areas found in Louisiana and Texas north of Laguna Madre. White shrimp tend to spend August through October in the estuaries with a similar distribution as browns. We understand that these species have wider spatio-temporal distributions than our scope; however, we focused on timing and regions that are thought to supply the bulk of the commercial catches for the respective stocks. Thus our methods were designed to accurately capture the variability and trends of the environmental drivers (salinity and temperature) that are most likely to influence recruitment success and, as a result, exploitable biomass.

We developed environmental indices for pink shrimp using continuous buoy data maintained by Everglades National Park in Florida Bay (Table 1; Figure 1). The buoys record instantaneous data every 15 minutes. The data were downloaded via an Environmental Research Division's Data Access Program (ERDDAP) data server maintained by the Southeast Coastal Ocean Observing Association (SECOORA) along with automated quality assurance and quality control flags. Data that did not pass QA/QC (flag code equal to one passed) were converted to NAs for downstream analyses. Automated QA/QC processing by SECOORA follows the Quality Assurance and Quality Control of Oceanographic Data (QARTOD) (https://ioos.noaa.gov/project/qartod/) recommended methods and QA/QC code definitions are in the original metadata found on SECOORA's ERDDAP server. After download and initial QA/QC screening, the original 15-minute buoy data were aggregated daily and then monthly per buoy to get aggregate mean values. Next, the data were aggregated per year (restricted to the core months of September and October) per buoy. Finally, a simple average across buoys was calculated to get yearly mean estimates.

We developed area-weighted indices for brown and white shrimp using the state monitoring data supplied by Louisiana and Texas. Data from Louisiana and Texas were combined to produce singular salinity and temperature indices for brown shrimp. We developed alternative white shrimp indices. One version follows a similar method as the brown shrimp indices that combine data from Louisiana and Texas. The second version only uses data from Louisiana that allows a longer time series to be produced (1980-2022 for LA-only versus 1987-2022 for LA-TX combined). This is because the Texas monitoring data starts in 1987 and Louisiana data starts in the 1960s. Data back to 1980 for white shrimp is desired because the Indices Working Group recommended the LDWF 16' trawl survey for its abundance index development beginning in 1980.

The data from TPWD was collected in 6 large estuaries (Figure 2; Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aranas Bay, and Corpus Christi Bay) and were aggregated to produce a yearly index (restricted to the core months specified above for brown and white shrimps). The TPWD surveys are conducted monthly using a stratified random sampling design per estuary. Each month 20 stations are sampled per estuary except for Sabine Lake where only 10 stations are sampled. Half the samples are collected in the first half of the month (days 1-15) and the other half are collected in the second half (days 16-31) to ensure sufficient temporal coverage (TPWD, 2023). The survey data were first aggregated per month per estuary, then the monthly estimates were aggregated per estuary to produce estuary-specific median values per year. Next, the estuary estimates were combined by estimating a weighted mean in which the weights were equal to the area in kilometers squared of the estuary to produce yearly estimates for salinity and temperature. We determined the area of the estuaries using a shapefile called “Major Bays” available from TPWD (https://tpwd.texas.gov/gis/).

A different approach was used for Louisiana because marsh habitats are extensive existing on a spectrum from freshwater to full seawater. We used estimates of different marsh types produced by the United States Geological Survey (USGS) (Figure 3; Nyman et al. 2022) and the LDWF survey locations to estimate the potential juvenile shrimp habitat. The areas of the suitable habitats were used as the areal weights for the Louisiana weighted mean. To do this, we used the 6-foot trawl survey sampling locations used by the LDWF as a reference to identify the USGS habitat categories that would qualify as nursery habitats. The 6-foot survey is designed to sample the habitats of interest for juvenile shrimps and thus was deemed to be a good representation of potential juvenile shrimp habitat. The 6-foot trawl survey is sampled from April to July at fixed stations (LDWF, 2023). We then summed all the areas in kilometers squared for those habitats to get the total area for the weights. In addition, we removed open water that was classified as fully saline and Lake Pontchartrain because neither was deemed representative of the juvenile shrimp habitat. While the 6-foot survey stations were used to characterize juvenile shrimp habitat, we used the 16-foot trawl environmental data to develop the environmental indices as the sites are more consistently surveyed.

The 16-foot survey is sampled monthly at fixed stations within each Coastal Study Area (CSA) (LDWF, 2023). The 16-foot survey data include surface and bottom values for salinity and temperature. The indices were developed using the bottom data when available; however, there were ~14% missing bottom values in the data set. We substituted surface data for missing bottom data decreasing the missing data to ~3%. This assumes that shallow estuaries are well-mixed and differences are minimal. The surface and bottom values were correlated (temperature $r = 0.99$, p-value $< 2.2e\text{-}16$; salinity $r = 0.95$, p-value $< 2.2e\text{-}16$). The bottom values present in the survey data were similar in distribution to the surface values used to replace the missing bottom values in each month. Taken together, we interpreted that there was no systematic bias in the data potentially affecting index construction once the missing

bottom values were substituted with surface values. Once the juvenile habitat was identified from the USGS data and the 6-foot trawl stations, only 16-foot trawl data collected within the identified habitat were aggregated for the indices. The survey data were first aggregated per month per CSA, then the monthly estimates were aggregated per CSA to produce median values per estuary per year. Next, the CSA estimates were combined by estimating a weighted mean in which the weights were equal to the area in kilometers squared of the juvenile nursery habitat to produce yearly estimates for salinity and temperature.

All data were processed and manipulated using the R Statistical Computing Language, ver. 4.3.2 (R Core Team, 2023) using the RStudio integrated development environment, ver. 2023.9.1.494 (Posit Team, 2023). Florida Bay buoy data were downloaded using the rerddap package, ver. 1.0.4 (Chambers, 2023) using the SECOORA ERDDAP data server (https://erddap.secoora.org/erddap/). The R packages data.table, ver. 1.14.10 (Barrett and Srinivasan, 2023), lubridate, ver. 1.9.3 (Grolemund and Wickham, 2011), terra, ver. 1.7-55 (Hijmans, 2023), and sf, ver. 1.0-14 (Pebesma, 2018; Pebesma and Bivand, 2023) were used to perform data manipulation, analysis, and assist plotting.

RESULTS

The area per sampling location was used to calculate the weights (Figure 4). The weights were divided up ~73% and ~27% for Louisiana and Texas (Table 2) respectively.

The pink shrimp indices spanned from 2000 to 2023 (Table 3). For salinity, the indices ranged from 22.19 to 37.92 and a median of 31.12 PSU (Figure 5 top). The temperature indices ranged from 27.83 to 30.23 with a median of 29.1 °C (Figure 5 bottom).

The brown shrimp indices spanned from 1987 to 2022 (Table 3). For salinity, the indices ranged from 4.17 to 14.30 and a median of 8.87 practical salinity units (PSU) (Figure 6 top). The temperature indices ranged from 18.72 to 22.72 with a median of 20.46 °C (Figure 6 bottom).

The LA-TX combined white shrimp indices spanned from 1987 to 2022 (Table 3). For salinity, the indices ranged from 7.79 to 18.01 and a median of 12.69 PSU (Figure 7 top). The temperature indices ranged from 26.42 to 29.35 with a median of 28.26 °C (Figure 7 bottom).

The LA-only white shrimp indices spanned from 1980 to 2022 (Table 3). For salinity, the indices ranged from 4.66 to 16.80 and a median of 9.60 PSU (Figure 7 top). The temperature indices ranged from 25.67 to 29.65 and had a median of 28.13 °C (Figure 7 bottom).

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TABLES

Table 1. Florida Bay Buoy locations

Buoy ID	Longitude (°W)	Latitude (°N)
gov-nps-ever-mukf1	-80.9423	25.10613
gov-nps-ever-jkyf1	-80.9045	25.05254
gov-nps-ever-lrkf1	-80.8257	24.98158
gov-nps-ever-pkyf1	-80.7468	24.91806
gov-nps-ever-bobf1	-80.6814	25.02663
gov-nps-ever-wrbf1	-80.7351	25.07209
gov-nps-ever-bkyf1	-80.8336	25.12111
gov-nps-ever-gbtf1	-80.8013	25.16723
gov-nps-ever-tbyf1	-80.7248	25.15734
gov-nps-ever-lmdf1	-80.6327	25.1758
gov-nps-ever-bnkf1	-80.519	25.08668
gov-nps-ever-dkkf1	-80.49	25.18009
gov-nps-ever-tcvf1	-80.5334	25.21275
gov-nps-ever-bwsf1	-80.4384	25.17834
gov-nps-ever-lbsf1	-80.4322	25.21434
gov-nps-ever-lsnf1	-80.4568	25.23516
gov-nps-ever-mnbf1	-80.4218	25.23945
gov-nps-ever-thrf1	-80.3723	25.20338

Table 2. Areal weights for Louisiana and Texas

Name	Area (km^2)	Total (km^2)	Proportion	Total proportion
CSA 1	995.43		0.06	
CSA 2	1,432.75		0.08	
CSA 3	2,152.79		0.12	
CSA 4	1,064.95		0.06	
CSA 5	1,406.70		0.08	
CSA 6	2,232.32		0.13	
CSA 7	3,440.09		0.20	
Louisiana		12,725.04		0.73
Sabine	291.26		0.02	
Galveston	1,565.85		0.09	
Matagorda	1,154.44		0.07	
San Antonio	521.13		0.03	
Corpus Christi	617.67		0.04	
Aransas	493.94		0.03	
Texas		4,644.28		0.27

Table 3. Environmental Indices for brown, pink, and white shrimp

	Brown Shrimp		Pink Shrimp		White Shrimp (LA-TX combined)		White Shrimp (LA-only)	
Year	Temperature (C)	Salinity (PSU)	Temperature (C)	Salinity (PSU)	Temperature (C)	Salinity (PSU)	Temperature (C)	Salinity (PSU)
1980							29.65	15.63
1981							28.74	13.39
1982							27.71	10.24
1983							28.02	8.60
1984							28.36	12.04
1985							27.82	13.39
1986							29.01	16.80
1987	18.74	10.43			28.68	15.65	29.01	14.43
1988	19.73	11.43			27.99	16.55	28.11	12.81
1989	19.86	12.62			27.36	12.13	27.56	7.78
1990	19.89	6.69			29.17	11.23	29.48	6.99
1991	20.64	5.02			27.74	11.86	27.57	8.52
1992	20.18	3.99			28.05	10.54	28.37	7.01
1993	20.42	4.68			28.56	9.06	28.68	4.76
1994	21.42	9.48			27.46	13.05	27.46	10.20
1995	20.87	6.29			29.14	12.96	28.97	9.90
1996	19.07	12.12			29.35	11.50	29.43	6.56
1997	19.74	4.15			29.20	11.49	29.36	8.92
1998	19.22	8.31			28.52	11.17	28.12	8.14
1999	21.51	7.57			28.18	16.15	28.00	13.07
2000	20.66	14.90	27.83	32.89	27.36	18.01	27.02	13.19
2001	19.59	7.53	28.02	30.75	27.37	8.96	27.22	6.70
2002	21.83	8.14	29.30	26.10	27.72	9.19	27.83	6.76
2003	20.39	6.88	29.08	27.08	27.90	10.77	28.03	7.81
2004	20.88	6.01	28.17	35.34	28.52	10.32	28.57	7.55
2005	19.81	6.91	29.26	26.09	29.16	12.73	29.12	9.49
2006	22.33	13.12	29.07	29.40	28.34	13.17	28.54	10.72
2007	20.96	6.63	29.04	27.69	28.92	8.82	28.77	8.25
2008	20.29	6.61	28.34	32.75	26.94	13.62	26.45	9.60
2009	20.07	10.26	30.23	31.52	28.70	12.65	28.78	6.26
2010	18.90	5.80	28.10	28.35	26.42	12.17	25.67	9.49
2011	21.83	13.91	28.43	34.35	26.57	17.59	25.99	11.53
2012	22.85	9.69	29.05	22.19	27.99	15.91	27.86	11.74
2013	18.82	11.17	29.19	28.52	28.76	17.93	28.59	13.66
2014	18.72	12.33	28.74	37.23	27.71	13.31	27.25	7.99
2015	20.54	8.65	29.43	37.92	26.79	13.87	25.89	11.80
2016	21.04	7.60	28.86	31.04	29.17	7.79	28.92	4.66
2017	22.72	10.96	29.32	27.75	29.00	9.27	29.19	7.26
2018	20.93	9.03	29.39	30.92	29.20	12.86	29.46	9.99
2019	19.66	6.92	29.11	35.87	28.59	13.57	28.24	11.20
2020	20.97	8.98	29.65	32.47	27.63	14.00	27.47	10.45
2021	20.07	11.06	29.84	33.43	27.59	8.52	26.74	5.17
2022	20.85	14.30	29.33	35.08	28.60	17.25	28.39	13.43
2023			29.34	31.20				

FIGURES

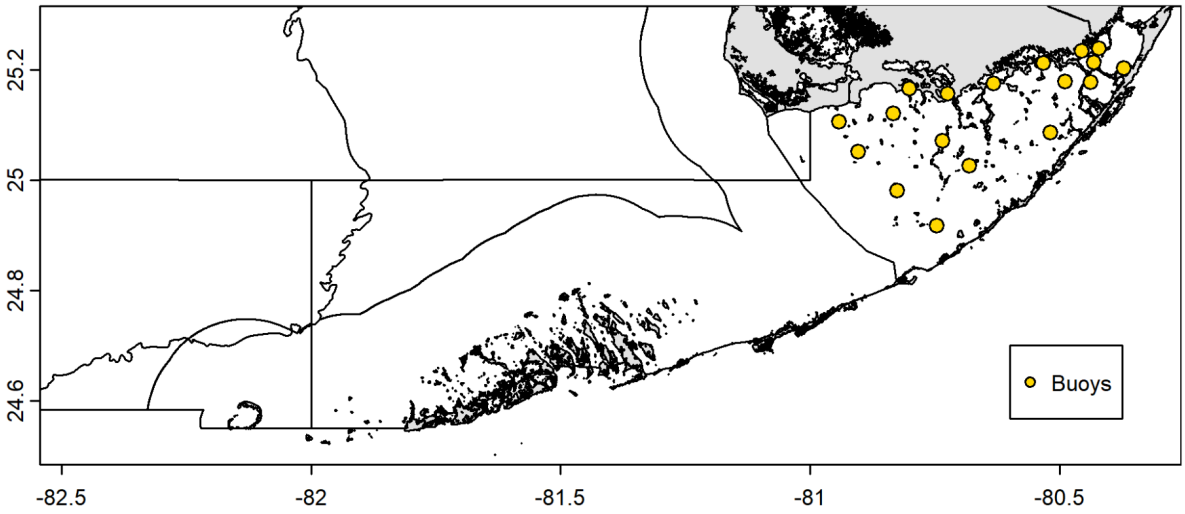

Figure 1. Location of buoys maintained by Everglades National Park, Florida, USA (Table 1). Temperature and salinity data were used in the Pink shrimp environmental indices. Data was downloaded via the ERDDAP server (https://erddap.secoora.org/erddap/) maintained by the Southeast Coastal Ocean Observing Association (https://www.secoora.org).

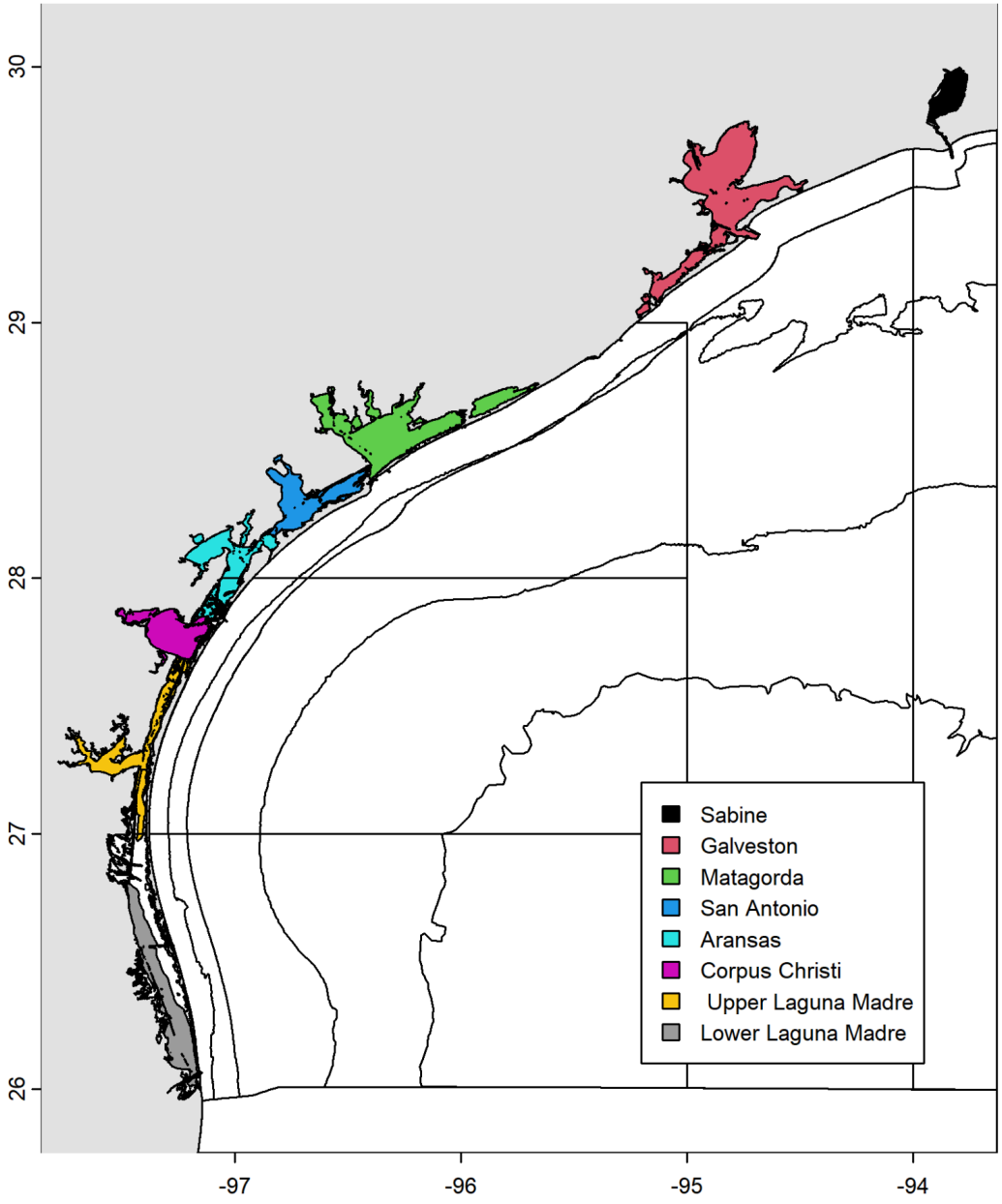

Figure 2. Map of Texas estuaries used to develop Brown and White Shrimp environmental indices. Upper and Lower Laguna Madre basins were excluded from indices based on input from the SEDAR Assessment Development Team. The areas of the estuaries, excluding Upper and Lower Laguna Madre, were calculated to define the spatial weights for environmental indices. The area of estuaries was estimated using the shapefile “Major Bays” available from TPWD (https://tpwd.texas.gov/gis/). Sampling locations were excluded for clarity.

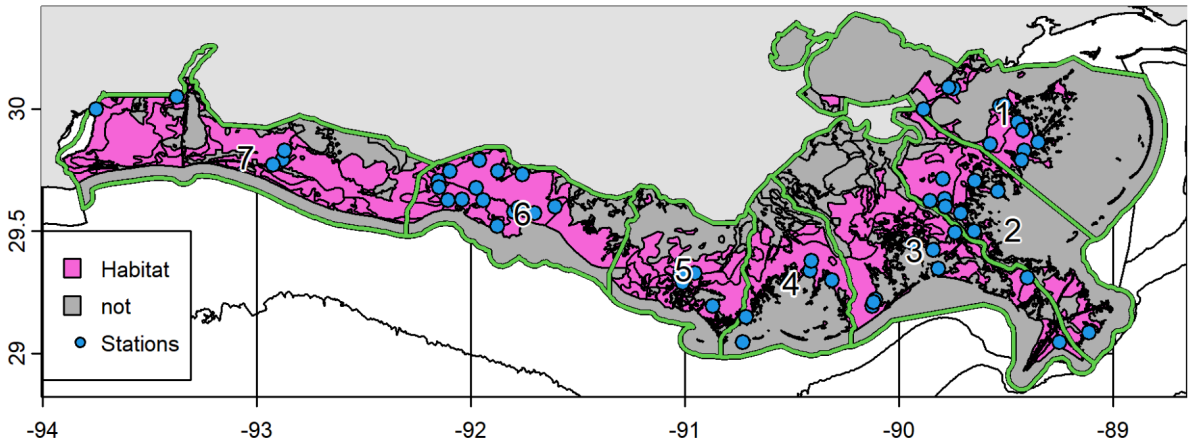

Figure 3. Map of Coastal Louisiana displaying habitat defined as shrimp nursery habitat for both Brown and White Shrimps. Habitat was defined using USGS survey data (Nyman et al. 2022) spatially joined to the LDWF 6-foot-trawl survey data. Habitat extent within each CSA (1 - 7; outlined in green) was used to calculate area and develop spatial weights for environmental indices. Blue dots are the stations of the LDWF survey (16-foot trawl) used to calculate the environmental indices.

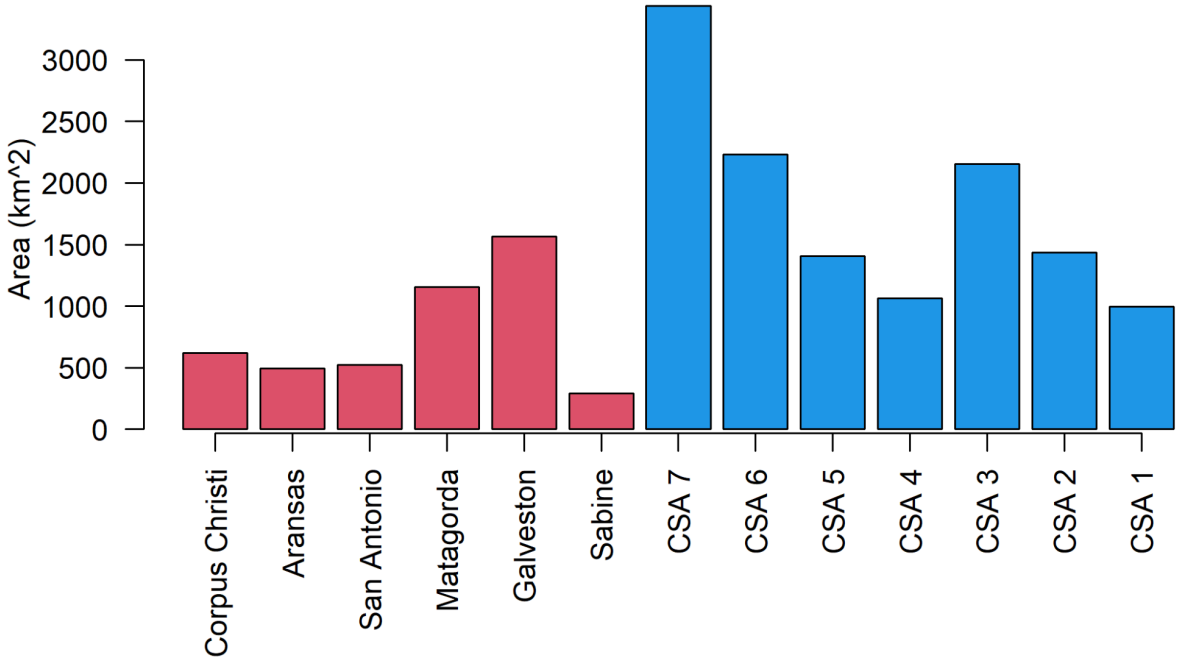

Figure 4. Area of estuaries (km^2) used to develop spatial weights for Brown and White shrimp environmental indices (Table 2). Red bars represent Texas estuaries, and blue bars represent Louisiana.

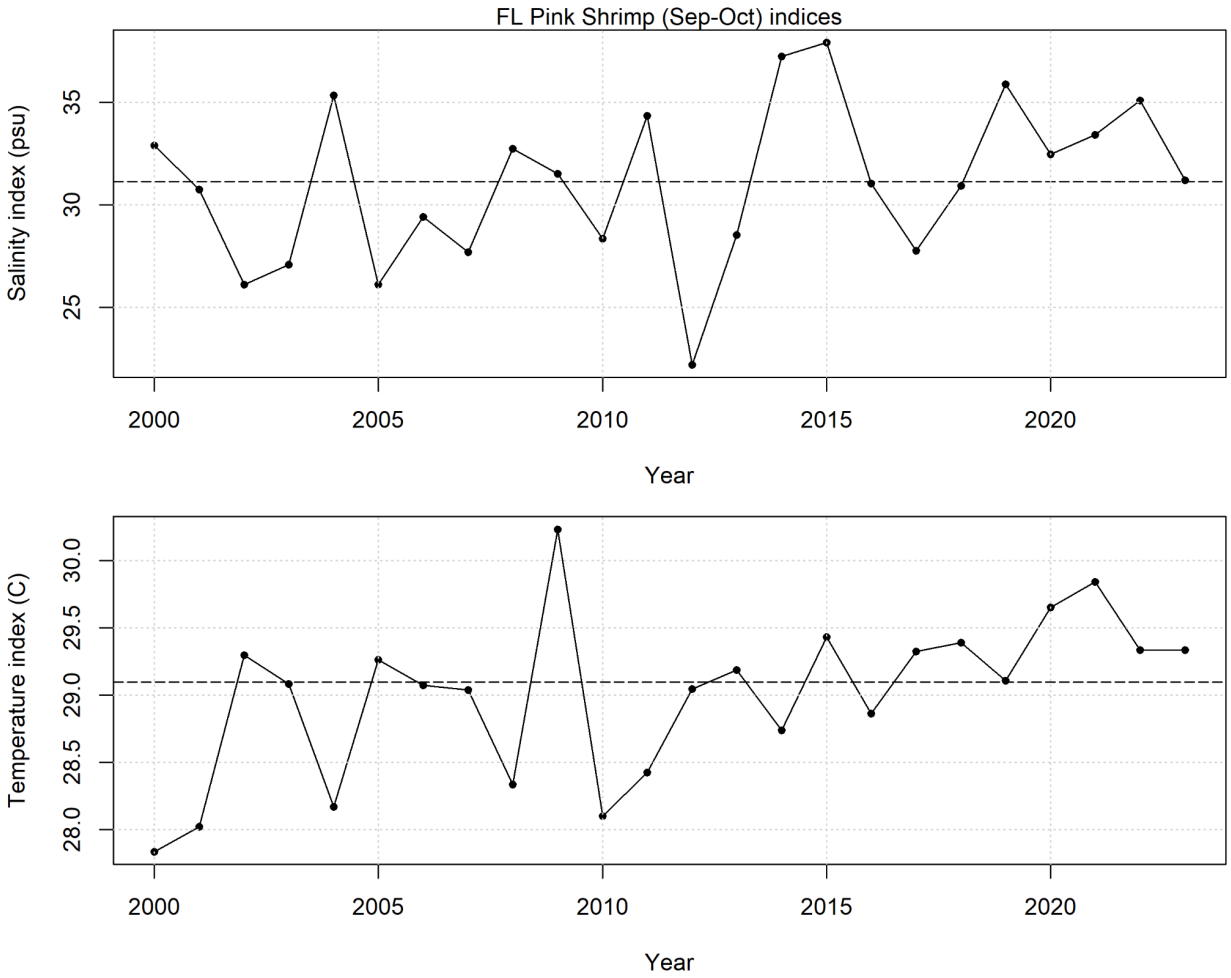

Figure 5. Time series of the environmental indices (salinity top row and temperature bottom row) developed for Pink shrimp using Everglades buoy data (Fig. 1, Table 1) from September to October. The dashed line is the overall median value for the time series.

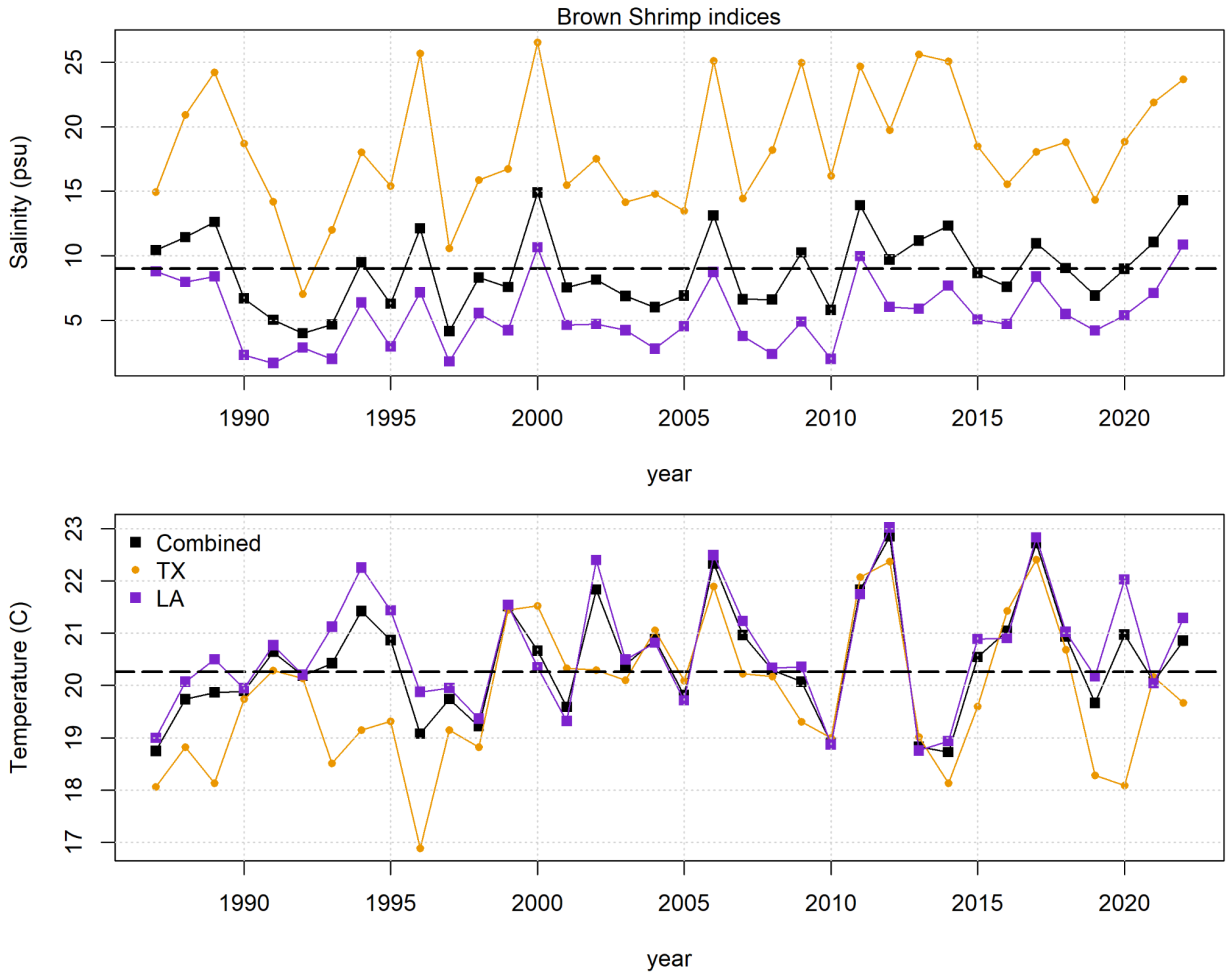

Figure 6. Time series of the environmental indices (salinity top row and temperature bottom row) developed for Brown shrimp using Texas and Louisiana state monitoring data (Figs. 2 and 3) from February to May. The dashed lines are the overall median values of the combined indices. The combined indices (black) are weighted using the calculated areas (Figs. 2, 3, and 4)

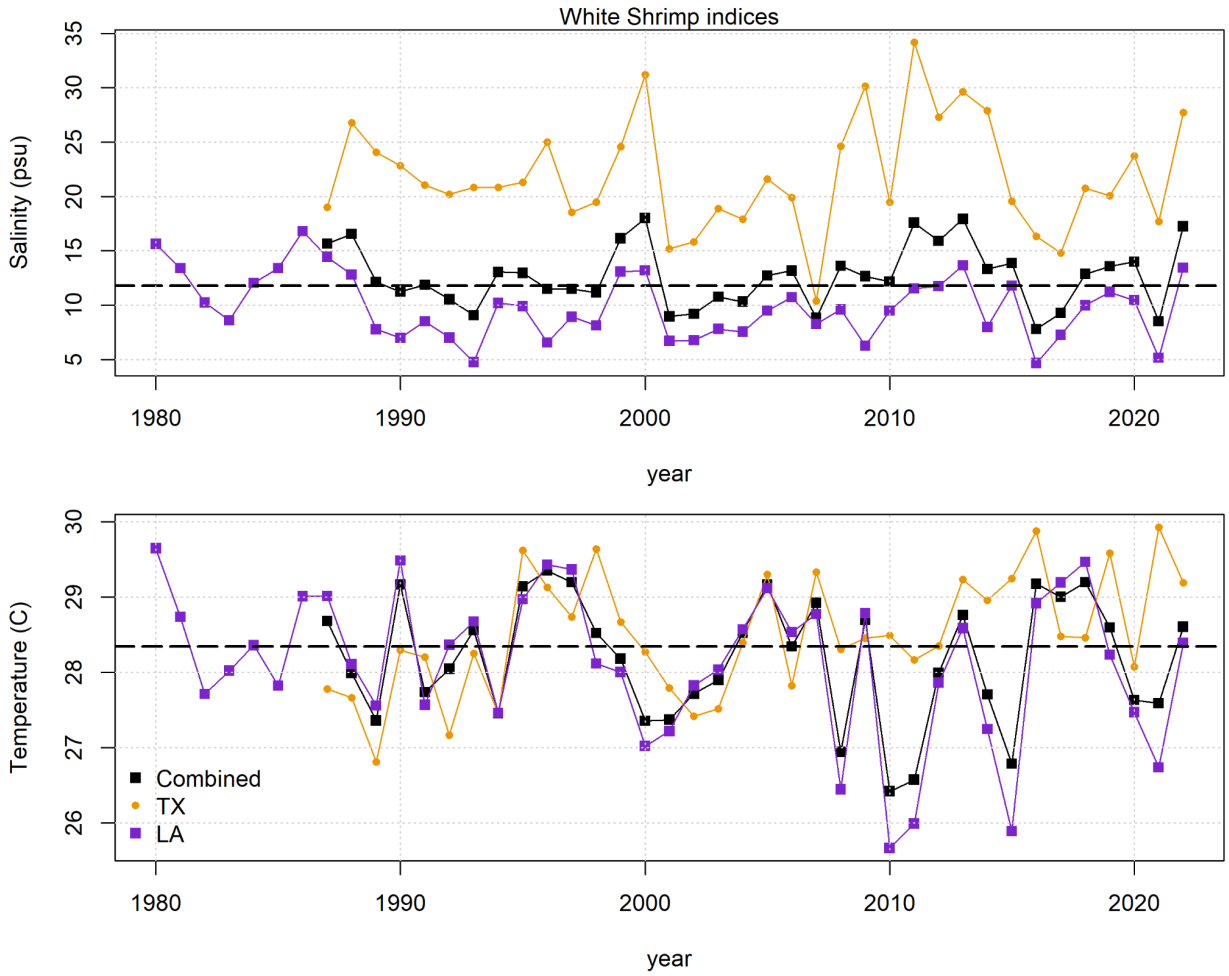

Figure 7. Time series of the environmental indices (salinity top row and temperature bottom row) developed for White shrimp using Texas and Louisiana state monitoring data (Figs. 2 and 3) from August to October. The dashed lines are the overall median values for the combined indices. The combined indices (black) are weighted using the calculated areas (Figs. 2, 3, and 4). The Louisiana-only indices (purple) were estimated using the calculated areas for Louisiana only (Figs. 3 and 4 blue bars only) as the weights.