4.3.5. Analysis of Variance of Individual Fisheries Species

TPWD has long archived records of fisheries independent monitoring data collected with bag seine, shrimp trawl, gill net, and oyster. The data set records the number of animals of each taxon collected in each deployment of the collecting devices. The records were combined into CPUE (catch per unit effort) for a set of indicator species by counting the number of each species captured in each sample and dividing by the area covered by the bag seine or the time of the trawl or gill net to yield a catch per hectare or per hour. The CPUE's for this analysis are calculated by summing the count of the target species over a year in the selected segment and summing the collection effort in area or time before dividing to calculate the CPUE. Annual values were calculated to examine long term trends. These values were used in the following analyses to determine whether there are large scale spatial and temporal patterns identifiable by ANOVA. This approach ignores the variance in CPUE that exists within segments and within years. It gives equal weighting to each segment and each year, thus avoiding the impact of heterogeneous sample sizes on the analysis.

Analysis of variance partitions the variation in a measurement among one or more factors that might affect the measured variable. The proportion of variation assigned to an explanatory factor determines the significance of the relationship. For example, the major sub-bays making up the Galveston Bay system could differ enough in the amount of habitat suitable for juvenile Atlantic croaker that the ANOVA would show a significant effect associated with location/sub-bay. Similarly, development in the watershed over time might have gradually degraded the water quality or habitat sufficiently that the CPUE of spot would exhibit significant differences among time periods of decades.

Analysis of Annual CPUE from Bag Seine Collections of Various Species

Bag seine samples capture small organisms and young of year of larger species in shallow water. The capture rates are highly variable because the juvenile stage of short-lived animals is seasonal and weather conditions can reduce the suitability of shallow water habitats. Seven commonly captured species were selected for analysis of variance tests to determine the significance of location and time period on abundance in bag seine samples. The species selected were Atlantic croaker, bay anchovy, brown shrimp, Gulf menhaden, spot, striped mullet and white shrimp.

Analysis of annual bag seine CPUE for bay anchovy, striped mullet and white shrimp in major bays of the Galveston Bay system showed no significant effects of location and decade. Those species that did exhibit a significant effect due to location (GBEP segment) or time period (decade) are listed in Table 4.3.5.1. Although the relationship between bag seine annual CPUE and time period is significant for Atlantic croaker, brown shrimp, and Gulf menhaden, the amount of variation in CPUE explained by the ANOVA model is less than 20%. The same is true for the amount of variation in CPUE explained by the sub-bay in which spot were collected by bag seine. Only 15% of the variation in annual CPUE is explained.

Table 4.3.5.1. Summary table of results of ANOVAs on the effect of location represented by major bay and time period represented by decade on the average annual CPUE of bag seine collections of selected species. The major bays are Christmas, East, Galveston, Trinity and West. The decades are 1976-1979, 1980-1989, 1990-1999 and 2000-2001. The adjusted R^2 is a conservative measure of the goodness of fit between the ANOVA model and the annual CPUE data. Bay anchovy, striped mullet and white shrimp were also analyzed, but are not listed because they showed no significant effect from area or time period.

Species	Adjusted R^2	Segment	Decade
Atlantic Croaker	0.093	ns	*
Brown Shrimp	0.183	ns	*
Gulf Menhaden	0.058	ns	*
Spot	0.157	*	ns

* = p<0.01
ns = not significant

Table 4.3.5.2. The sample sizes for all of the analyses of bag seine CPUE that follow are shown in this table. There are five sub-bays included in the data set, but one of the sub-bays was not sampled in the first two years of the data set. The decade of the 1970s includes four years, but only 18 samples.

		N
Decade	2000s	10
	1990s	50
	1980s	50
	1970s	18
Segment	Christmas	26
	East	24
	Galveston	26
	Trinity	26
	West	26

Atlantic Croaker Bag Seine CPUE Analysis of Variance
Atlantic croaker is an abundant bottom-feeding finfish species that ingests both living invertebrates and detritus as part of its diet. They are very abundant in the recreational catch and as bycatch in the shrimp trawl fishery. Primarily young of the year are captured in bag seines. Table 4.3.5.3 shows that the annual CPUE for Atlantic croaker does not differ significantly across sub-bays, but has shown significant fluctuation over decadal time periods.

Table 4.3.5.3. The results of an ANOVA performed on annual CPUE of Atlantic Croaker collected by Bag Seine from the Galveston Bay system. Main effects are segment, which represents five major bays in the system, and decade, which assigns a value to a time period of 1976-1979, 1980-1989, 1990-1999 and 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	14,724,822.983	19	774,990.683	1.685	0.050
Intercept	10,323,590.537	1	10,323,590.537	--	0.000
Segment	1,358,177.392	4	339,544.348	0.738	0.568
Decade	5,564,520.358	3	1,854,840.119	4.034	0.009
Segment*Decade	4,837,202.093	12	403,100.174	0.877	0.573
Error	49,660,813.420	108	459,822.346	--	--
Total	89,448,677.104	128	--	--	--
Corrected Total	64,385,636.404	127	--	--	--

R^2= .229 (Adjusted R^2 = .093)

According to Table 4.3.5.4, the CPUE of Atlantic croaker in bag seine collections has fluctuated from 262 fish per hectare in the 1970s to 701 fish per hectare in the 1980s followed by a further decline to 148 fish per hectare in the early 2000s. Despite this large variation in CPUE, none of the average values for the decades are statistically different from each other.

Table 4.3.5.4. Mean annual CPUE of Atlantic croaker for decadal time periods are shown. Pairwise comparison of means of annual CPUE among time periods for Atlantic croaker by Tukey tests yielded a single grouping. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 459,822.346. The test uses the harmonic mean sample size = 20.455. Alpha = .01

Decade	N	Mean CPUE (number of fish captured/hectare) Subset 1
2000s	10	147.6[a]
1990s	50	307.5 [a]
1980s	50	701.3 [a]
1970s	18	262.4 [a]

Brown Shrimp Bag Seine Annual CPUE Analysis of Variance

Brown shrimp are seasonally abundant invertebrates that feed on benthic invertebrates and detritus. They are important prey items for a wide variety of predatory fish. Their peak of abundance occurs in late spring, but they can be found in bag seine collections in any month of the year. Brown shrimp are important to the local economy and to the ecology of the bay.

Table 4.3.5.5 shows the results of an analysis of variance using annual CPUE by bag seine of brown shrimp. The analysis examines the effect of sub-bay location and time period on variation in CPUE. The time periods are arbitrarily divided at the beginning of new decades. This species meets the criterion for significance, $p < 0.01$, for the effect of time period, but also shows an effect due to sub-bay location that would be significant at $p < 0.05$. The comparison among means of different sub-bays is provided because there is a likelihood that this expression of habitat preference is real.

Table 4.3.5.5. The results of an ANOVA performed on annual CPUE of Brown Shrimp collected by Bag Seine from the Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns the value to a time period of 1976-1979, 1980-1989, 1990-1999 and 2000-2001.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Corrected Model	10,139,044.446	19	533,633.918	2.496	0.002
Intercept	17,791,889.089	1	17,791,889.089	83.231	<0.001
Decade	2,630,348.959	3	876,782.986	4.102	0.008
Segment	2,643,509.655	4	660,877.414	3.092	0.019
Segment*Decade	1,482,098.149	12	123,508.179	0.578	0.856
Error	23,086,630.067	108	213,765.093	--	--
Total	70,346,558.190	128	--	--	--
Corrected Total	33,225,674.513	127	--	--	--

R Squared = 0.305 (Adjusted R Squared = 0.183)

Brown shrimp abundance varies over time periods, i.e. monthly, yearly, etc., such that significant differences are expressed when decades are compared. The effect of decade is not an expression of a linear trend, but of fluctuations in conditions. The highest bag seine CPUE for brown shrimp was in the 1980s, 682 shrimp/hectare. Annual CPUEs in the 1970s averaged about 30% of the 1980s values, 219 shrimp/hectare, and the 1990s and 2000s were intermediate. This species shows large natural fluctuations in juvenile abundance.

Table 4.3.5.6. Mean annual CPUE of brown shrimp for four decadal time periods. A comparison of means of annual CPUE among time periods for Brown Shrimp using the Tukey test yielded the homogenous groupings of decadal averages shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 213765.093. The test uses the harmonic mean sample size = 20.455. Alpha = .05

Decade	N	Mean CPUE (number of fish captured/hectare)	
		Subset 1	Subset 2
2000s	10	434.1	434.1
1990s	50	530.8	530.8
1980s	50	--	682.1
1970s	18	219.1	--

Brown shrimp show a habitat preference for larger grain size in the sediment than white shrimp. The rivers tend to deliver small size sediments to the Bay suspended in their water. Tides and storms bring larger sediments into the Bay through the Gulf passes. So brown shrimp have a preference for habitats nearer the Gulf. The Tukey test comparing mean annual CPUEs shows that East, West and Christmas Bays, which are close to the Gulf, form a homogeneous grouping and Galveston and Trinity Bays, which receive the greatest freshwater input, form another. The mean annual CPUEs range from 208.9 shrimp per hectare in Galveston Bay to 783.9 shrimp per hectare in Christmas Bay.

Table 4.3.5.7. Mean annual CPUE of brown shrimp for five major sub-bays are shown. A comparison of means of annual CPUE among sub-bays for brown shrimp using the Tukey test yielded the homogenous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 213765.093. The test uses the harmonic mean sample size = 25.574. Alpha = .05

Segment	N	Annual CPUE (shrimp/hour)		
		Subset 1	Subset 2	Subset 3
Galveston	26	208.9	--	--
Trinity	26	387.9	387.9	--
East	24	--	628.3	628.3
West	26	--	690.6	690.6
Christmas	26	--	--	783.9

Gulf Menhaden Bag Seine Annual CPUE Analysis of Variance

Gulf menhaden are plankton feeders that spend much of their first year in the estuary growing to 4 to 5 inches in length. They are common prey items for predatory fish in the bay. They return to the Gulf for reproduction and occur in large schools. This fish supports a large fishery in the Gulf of Mexico, which processes them for fish meal.

Table 4.3.5.8 shows the results of an analysis of variance to determine the effects of time period and sub-bay location on annual CPUE. Decade of sampling had a significant effect on the annual CPUE, but sub-bay was not significant. Bag seines sample primarily young of the year menhaden. The time period effect could be related to changing conditions in the Gulf where reproduction occurs or in the Bay where juveniles must survive.

Table 4.3.5.8. The results of an ANOVA performed on annual CPUE of Gulf Menhaden collected by Bag Seine from the Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns the value to a time period of 1976-1979, 1980-1989, 1990-1999 and 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	144,0372,656.548	19	75,809,087.187	1.375	0.155
Intercept	396,934,298.664	1	396,934,298.664	7.201	0.008
Decade	828,614,056.445	3	276,204,685.482	5.011	0.003
Segment	34,597,958.543	4	8,649,489.636	0.157	0.959
Segment*Decade	426,826,153.850	12	35,568,846.154	0.645	0.799
Error	5,953,147,554.958	108	55,121,736.620	--	--
Total	8,662,720,379.932	128	--	--	--
Corrected Total	7,393,520,211.506	127	--	--	--

R^2= 0.195 (Adjusted R^2 = 0.053)

The variation across decades is not a linear trend in menhaden abundance. The mean CPUE value for the 1990s is much higher than that of other time periods, but it is not significantly different from the lower CPUEs of the 1980s and 2000s. The CPUE for bag seine collections of menhaden in the 1970s is 128.7 and is significantly different from that observed in the 1990s, 6,307.2. The abundance of this fish in nursery habitats is clearly subject to large natural fluctuations.

Table 4.3.5.9. Mean annual CPUE of Gulf menhaden collected by bag seine in four decadal time periods. A comparison of means of annual CPUE among time periods for Gulf Menhaden using the Tukey test yielded the homogenous grouping shown. The significance test is based on Type III Sum of Squares the error term is Mean Squares (Error) = 55121736.620. The test uses harmonic mean sample size = 20.455. Alpha = 0.05.

Decade	N	Mean CPUE (number of fish captured / hectare)	
		Subset 1	Subset 2
2000s	10	909.5	909.5
1990s	50	--	6307.2
1980s	50	1525.7	1525.7
1970s	18	128.7	--

Spot Bag Seine Annual CPUE Analysis of Variance

Spot have feeding habits similar to Atlantic croaker. Their diet is composed of primarily benthic invertebrates, especially polychaetes, but they also ingest detritus. Adult spot do not reside in the estuary year-round, but migrate to and from the Gulf. This species is common in the bycatch of the trawl fishery and is a common prey item for predatory fish in the bay. Table 4.3.5.10 shows the results of analysis of variance on the CPUE of spot captured in bag seines. The model using effect of sub-bay and decade on CPUE is significant ($p<0.001$). The primary factor affecting the variation of bag seine CPUE for this species is location.

Table 4.3.5.11. The results of an ANOVA performed on annual CPUE of Spot collected by bag seine from the Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns a value to a time period of 1976-1979, 1980-1989, 1990-1999 and 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	3,565,020.058	19	187,632.635	2.246	0.005
Intercept	4,295,061.830	1	4,295,061.830	51.406	<0.001
Decade	80,226.861	3	26,742.287	.320	0.811
Segment	1,379,907.847	4	344,976.962	4.129	0.004
Segment*Decade	1,733,061.241	12	144,421.770	1.729	0.070
Error	9,023,577.531	108	83,551.644	--	--
Total	19,798,075.425	128	--	--	--
Corrected Total	12,588,597.589	127	--	--	--

$R^2 = 0.283$ (Adjusted $R^2 = 0.157$)

The five major bays analyzed in this test show quite different average annual CPUEs as listed in Table 4.3.5.12. Young spot appear to favor Christmas and West Bays over East and Galveston Bays. The CPUE for Trinity Bay is intermediate.

Table 4.3.5.12. Mean annual CPUE of spot in bag seine collections for five sub-bays in the Galveston Bay system. A comparison of means of annual CPUE among bays for Spot using the Tukey test yielded the homogenous grouping shown. The significance test is based on Type III Sum of Squares the error term is Mean Squares (Error) = 83551.644. The test uses harmonic mean sample size = 25.574. Alpha = 0.05.

Segment	N	Subset 1	Subset 2
East	24	108.9333	--
Galveston	26	113.2119	--
Trinity	26	220.4292	220.4292
West	26	331.3146	331.3146
Christmas	26	--	402.8688

Analysis of Annual CPUE from Shrimp Trawl Collections of Various Species

The collections made by TPWD using shrimp trawls for fisheries independent monitoring have been compiled since 1982 into a data set for analysis of abundance and distribution of estuarine species. Seven species were chosen to serve as indicators of potential large scale patterns in this type of data from this gear type: Atlantic croaker, blue crab, brown shrimp, Gulf menhaden, sand seatrout, threadfin shad and white shrimp. All of these are common components of the catch in shrimp trawls during at least part of the year. They represent different habitats, from benthic mud to upper water column, and feeding strategies, from planktivore to predator.

The annual CPUE data for each species was analyzed in a two-way ANOVA using segment (major bay) and decade (1982-1989, 1990-1999, 2000-2001) as factors. Three species showed significant effects due to collection area and three species exhibited a significant effect due to decade. Only blue crab CPUE was significantly affected by both factors. A summary table of the ANOVA results is presented below.

Table 4.3.5.13. Summary table of results of ANOVAs on the effect of location represented by major bay and time represented by decade on the average annual CPUE of shrimp trawl collections of selected species. The major bays are East, Galveston, Trinity and West. The decades are the 1982-1989, 1990s and 2000-2001.

Species	Adjusted R^2	Segment	Decade
Atlantic croaker	0.203	ns	*
Blue crab	0.371	*	*
Brown shrimp	0.104	ns	ns
Gulf menhaden	0.229	*	ns
Sand seatrout	0.074	ns	ns
Threadfin shad	0.313	ns	*
White shrimp	0.261	*	ns

* = $p < 0.01$

Atlantic Croaker Shrimp Trawl Annual CPUE Analysis of Variance

The number of Atlantic croaker captured per hour by shrimp trawl over a year does not differ significantly across the major bays. The annual CPUE for Atlantic croaker has been significantly higher in the 1990s and 2000 - 2001 than in the period of 1982 to 1989. Sample sizes for the ANOVA and the table of ANOVA results are shown below in Tables 4.3.5.14 and 4.3.5.15.

Table 4.3.5.14. Sample sizes for the categories of the major effects, segment and decade, tested in this ANOVA. All of the subsequent ANOVAs are based on the same numbers of samples in each category.

		N
Segment	East	20
	Galveston	20
	Trinity	20
	West	20
Decade	1980s	32
	1990s	40
	2000s	8

Table 4.3.5.15. The results of an ANOVA performed on annual CPUE of Atlantic croaker collected by shrimp trawl from the Galveston Bay system. Main effects are segment, which represents four major bays in the system, Galveston, East, West and Trinity, and decade, which assigns a value to a time period of 1982-1989, 1990-1999 and 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	37,336.630	11	3,394.239	2.825	0.004
Intercept	194,615.587	1	194,615.587	161.992	0.000
Decade	5,369.329	3	1,789.776	1.490	0.225
Segment	30,006.503	2	15,003.251	12.488	0.000
Segment*Decade	3,462.719	6	577.120	.480	0.821
Error	81,694.668	68	1,201.392	--	--
Total	381,671.579	80	--	--	--
Corrected Total	119,031.298	79	--	--	--

$R^2 = 0.314$ (Adjusted $R^2 = 0.203$)

Table 4.3.5.16. Mean annual CPUE of Atlantic croaker in shrimp trawl for three decadal time periods. Comparison of means of annual CPUE by Tukey tests yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 1201.392. The test uses the harmonic mean sample size = 16.552. Alpha = 0.01

Decade	N	Subset 1	Subset 2
1980s	32	33.9747	--
1990s	40	--	70.8092
2000s	8	--	83.0300

Blue Crab Shrimp Trawl Annual CPUE Analysis of Variance

Blue crab is an important commercial species supporting a large trapping fishery. The species is nearly omnivorous and acts as both a predator and scavenger. It is ubiquitous in the estuary.

Blue crab is the only species that shows significant effects on annual CPUE due to location, i.e. major bay, and decade. Sample sizes for segment and decade are the same as those found in the table for Atlantic croaker. Table 4.3.5.17 shows the results of an ANOVA examining the effects of location and decade on annual blue crab CPUE.

Table 4.3.5.17. The results of an ANOVA performed on annual CPUE of blue crab collected by shrimp trawl from the Galveston Bay system. Main effects are segment, which represents the four major bays in the system, and decade, which assigns the value to a time period of 1982 to 1989, 1990 to 1999 or 2000-2001.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Corrected Model	4,632.560	11	421.142	5.228	0.000
Intercept	9,703.933	1	9,703.933	120.474	0.000
Decade	1,297.209	3	432.403	5.368	0.002
Segment	1,146.552	2	573.276	7.117	0.002
Segment*Decade	1,198.407	6	199.735	2.480	0.031
Error	5,477.241	68	80.548	--	--
Total	29,458.667	80	--	--	--
Corrected Total	10,109.801	79	--	--	--

$R^2 = 0.458$ (Adjusted $R^2 = 0.371$)

The significant difference detected among bays in the system was further analyzed using a test for comparison of means. The mean annual CPUE for blue crab captured in shrimp trawls is lowest in West Bay and highest in Trinity and Galveston Bays. The mean values and their relationships are shown in Table 4.3.5.18.

Table 4.3.5.18. Mean annual CPUE of blue crab in shrimp trawl for four major sub-bays of the Galveston Bay system. A comparison of means of annual CPUE using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 80.548. The test uses the harmonic mean sample size = 20.000. Alpha = 0.01.

Segment	**N**	**Subset 1**	**Subset 2**
West	20	7.940	--
East	20	13.119	13.119
Trinity	20	--	20.385
Galveston	20	--	20.764

Blue crab CPUE in shrimp trawl collections also differed significantly across time periods. The annual CPUE decreases in each subsequent time period as shown in Table 4.3.5.19. The CPUE was more than ten crabs per hour higher in the 1980s compared to 2000 – 2001.

Table 4.3.5.19. Mean annual CPUE of blue crab in shrimp trawl for decadal time periods. A comparison of means of annual CPUE among time periods using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square(Error) = 80.548. The group sizes are unequal. The test uses the harmonic mean sample size = 16.55. Alpha = 0.01.

Decade	N	Subset 1	Subset 2
2000s	8	8.581	--
1990s	40	13.508	13.508
1980s	32	--	19.849

Gulf Menhaden Shrimp Trawl Annual CPUE Analysis of Variance

Gulf Menhaden is a common planktivorous fish captured in shrimp trawls. The annual CPUE in shrimp trawl samples is significantly impacted by the segment of the Galveston Bay system being sampled. Table 4.3.5.20 shows the results of an ANOVA examining the effects of Bay segment and time period.

Table 4.4.20. The results of an ANOVA performed on annual CPUE of Gulf Menhaden collected by shrimp trawl from the Galveston Bay system. Main effects are segment, which represents the four major bays in the system, and decade, which assigns the value to a time period of 1982 to 1989, 1990 to 1999 or 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	9,956.230	11	905.112	3.133	0.002
Intercept	20,414.926	1	20,414.926	70.671	<0.001
Decade	5,398.485	3	1,799.495	6.229	0.001
Segment	1,794.391	2	897.196	3.106	0.051
Segment*Decade	613.374	6	102.229	.354	0.905
Error	19,643.474	68	288.875	--	--
Total	57,929.450	80	--	--	--
Corrected Total	29,599.703	79	--	--	--

$R^2 = 0.336$ (Adjusted $R^2 = 0.229$)

A comparison of means using a Tukey test was performed to determine the source of the significant effect from location of sample on Gulf menhaden CPUE. As shown in Table 4.3.5.21 below, the principal variation is between West Bay and all other segments of the Bay system. The annual CPUE for Gulf menhaden in shrimp trawl collections is only 3.36 in West Bay compared to 30.19 in East Bay.

Table 4.3.5.21. Mean annual CPUE of Gulf menhaden in shrimp trawl for four sub-bays in the Galveston Bay system. A comparison of means of annual CPUE among major bays using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square(Error) = 288.875. Alpha = 0.01.

Segment	N	Subset 1	Subset 2
West	20	3.360	--
Trinity	20	20.215	20.215
Galveston	20	--	21.511
East	20	--	30.187

Threadfin Shad Shrimp Trawl Annual CPUE Analysis of Variance

Threadfin shad is a common lower trophic level fish collected by shrimp trawls. Annual values of catch per hour by shrimp trawl range from less than 1 to more than 4. The ANOVA results shown in Table 4.3.5.22 show that annual CPUE across bays is not significantly different, but there is a significant effect from time period. The annual CPUE in the decade of the 1990s is significantly higher than the annual CPUE calculated for the 1982 to 1989 period. The model of variance components based on time period, location and interaction explains 31% of the variance among annual CPUE values.

Table 4.3.5.22. The results of an ANOVA performed on annual CPUE of threadfin shad collected by shrimp trawl from the Galveston Bay system. Main effects are segment, which represents the four major bays in the system, and decade, which assigns the value to a time period of 1982 to 1989, 1990 to 1999 or 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	436.456	11	39.678	4.275	<0.001
Intercept	293.506	1	293.506	31.620	<0.001
Decade	72.336	3	24.112	2.598	0.059
Segment	199.549	2	99.775	10.749	<0.001
Segment*Decade	79.823	6	13.304	1.433	0.215
Error	631.187	68	9.282	--	--
Total	1620.416	80	--	--	--
Corrected Total	1067.642	79	--	--	--

$R^2 = 0.409$ (Adjusted $R^2 = 0.313$)

The significant effect for decade results from the change shown in 4.34.23 below. Annual CPUE of threadfin shad increased dramatically from 0.8 per hour in the period of 1982 to 1989 to 4.1 per hour in the period 1990-1999.

Table 4.3.5.23. Mean annual CPUE of threadfin shad in shrimp trawls for three time periods. A comparison of means of annual CPUE among time periods using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square(Error) = 9.282. The group sizes are unequal. The test uses the harmonic mean sample size = 16.552. Alpha = 0.01.

Decade	N	Subset 1	Subset 2
2000s	8	2.345	2.345
1990s	40	--	4.147
1980s	32	0.802	---

White Shrimp Trawl Annual CPUE Analysis of Variance
White shrimp are an important commercial species that use the Galveston Bay system on a seasonal basis. The annual CPUE varies considerably according to the area trawled, from low values of less than ten per hour in West Bay to more than 150 per hour in East Bay. Summary Table 4.3.5.24 shows that the ANOVA to determine the significance of effects from location and effects from time periods is significant only for segment or major bay. The results of that ANOVA are shown in Table 4.3.5.24 below. The model used for this table explains 26% of the variance in the annual CPUE data.

Table 4.3.5.24 The results of an ANOVA performed on annual CPUE of white shrimp collected by shrimp trawl from the Galveston Bay system. Main effects are segment, which represents the four major bays in the system, and decade, which assigns the value to a time period of 1982 to 1989, 1990 to 1999 or 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	37,081.480	11	3,371.044	3.543	0.001
Intercept	93,486.837	1	93,486.837	98.255	<0.001
Decade	25,650.930	3	8,550.310	8.986	<0.001
Segment	1,181.613	2	590.807	0.621	0.540
Segment*Decade	2,499.813	6	416.635	0.438	0.851
Error	64,700.209	68	951.474	--	--
Total	260,121.599	80	--	--	--
Corrected Total	101,781.689	79	--	--	--

$R^2 = 0.364$ (Adjusted $R^2 = 0.261$)

The explanation for the significant effect of segment is shown in Table 4.3.5.25 below. The annual mean CPUE of white shrimp collected by shrimp trawl in each major sub-bay of the Galveston Bay system was compared by a pairwise means test (Tukey). The results show that West Bay has a significantly lower white shrimp CPUE in shrimp trawl collections than Galveston and East Bays. The difference between West and East Bays is large, 13.45 white shrimp per hour of trawling in West Bay versus 70.68 white shrimp per hour of trawling in East Bay.

Table 4.3.5.25. Mean annual CPUE of white shrimp in shrimp trawl for major sub-bays. A comparison of means of annual CPUE among major bays using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square(Error) = 951.474. Alpha = 0.01.

Segment	**N**	**Subset 1**	**Subset 2**
West	20	13.4540	--
Trinity	20	44.7885	44.7885
Galveston	20	--	49.0295
East	20	--	70.6830

The trends of abundance measured by CPUE for all of these species can be seen in graphs in section 4.3.2. The intent of these analyses is to summarize patterns found in some common species on a large scale. The striking difference between East and West Bays is clearly seen in the analyses of Gulf menhaden and white shrimp. The temporal patterns shown in Atlantic croaker, which are increasing in abundance, appear to involve the entire Galveston Bay system. Conversely, the changes in blue crab CPUE are different across the major bays as shown by a significant interaction between segment and decade.

Analysis of Annual CPUE from Gill Net Collections of Various Species

Five common species taken in gill net samples were chosen for analysis of the effects of time and spatial variation on their abundance as adults in the Galveston Bay system. The species are black drum, red drum, southern flounder, spotted seatrout and striped mullet. All of the higher trophic level species, i.e. both drum, flounder and seatrout, show significant effects when the samples are divided into the major bays of the system, Christmas, Trinity, Galveston, East and West. Only flounder and seatrout show significant effects due to decade. Striped mullet is omitted from further discussion because it showed no significant effects. Results for each species with significant effects are explained in more detail below.

Table 4.3.5.26. Summary table of results of ANOVAs on the effect of location, represented by major bay, and time, represented by decade, on the annual average CPUE of Gill Net collections of selected species. The major bays are Christmas, East, Galveston, Trinity and West. Decades are 1975-1979, 1980s, 1990s and 2000-2001. The adjusted r^2 is the amount of variation explained by the model incorporating the effects and interaction of bays and decades with the autocorrelation removed.

Species	Adjusted R^2	Segment	Decade
Black Drum	0.301	*	ns
Red Drum	0.205	*	ns
Southern Flounder	0.285	*	*
Spotted Seatrout	0.471	*	*

* = p<0.01
ns = not significant

Black Drum Gill Net Annual CPUE Analysis of Variance
Black drum are common predators of shellfish in the Bay and are caught at rates from 0.35 to more than 1 fish per hour with gill nets. These catch rates differ significantly among major bays in the Galveston Bay system, as shown in Table 4.3.5.27, but variation over time has not resulted in significant differences among decades.

Table 4.3.5.27. The results of an ANOVA performed on annual CPUE of Black Drum collected by gill net from the Galveston Bay system. Main effects are segment, which represents the five major bays in the system (Christmas, East, Galveston, Trinity and West), and decade, which distinguishes among time periods of 1975 to 1979, 1980 to 1989, 1990 to 1999 and 2000 to 2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	11.659	19	0.614	4.040	<0.001
Intercept	30.269	1	30.269	199.298	<0.001
Decade	0.794	3	0.265	1.742	0.162
Segment	5.042	4	1.261	8.300	<0.001
Segment*Decade	1.831	12	0.153	1.005	0.449
Error	17.466	115	0.152	--	--
Total	70.470	135	--	--	--
Corrected Total	29.125	134	--	--	--

R^2= 0.400 (Adjusted R^2 = 0.301)

The significant difference among areas in the Bay system results from a CPUE in East Bay that is more than double the CPUE in all other major bays of the system. Black drum CPUE with gill net in East Bay exceeds 1 fish per hour, but is less than ½ fish per hour in all other components of the Bay system. The table below shows how East Bay has exhibited a significantly higher CPUE for black drum in gill net over the 27 year time period. This is a striking example of habitat preference. It may be related to the combination of large areas of oyster reef and salinity regimes found in East Bay.

Table 4.3.5.28. Mean annual CPUE of black drum in gill net for five major bays of the Galveston Bay system. Comparison of means of annual CPUE among major bays by Tukey tests yielded the homogeneous groupings shown. Based on Type III Sum of Squares. The error term is Mean Square (Error) = .152. The test uses a Harmonic Mean Sample Size = 27.00. Alpha = 0.05

Segment	**N**	**CPUE Values (number fish captured/hour)**	
		Subset 1	**Subset 2**
Trinity	27	0.3548	--
Galveston	27	0.4063	--
Christmas	27	0.4681	--
West	27	0.4744	--
East	27	--	1.0633

Red Drum Gill Net Annual CPUE Analysis of Variance

Red drum are important sportfish that spend their subadult life in the estuary. In Galveston Bay, they are significant predators of shrimp, crabs and lower trophic level demersal fishes. Table 4.3.5.29 shows the results of an analysis of variance on the annual CPUE values looking at the effects of sample area, i.e. major bay, and time period, i.e. samples from the decades. There is a significant spatial effect on CPUE, but no significant effect due to variation among decades.

Table 4.3.5.29. The results of an ANOVA performed on annual CPUE of Red Drum collected by Gill Net from Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns the value to a time period of 1975 to 1979, 1980 to 1989, 1990 to 1999 and 2000 to 2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	14.980	19	0.788	2.813	<0.001
Intercept	63.424	1	63.424	226.317	<0.001
Decade	0.433	3	0.144	0.515	0.673
Segment	8.739	4	2.185	7.796	<0.001
Segment*Decade	2.809	12	0.234	0.835	0.614
Error	32.228	115	0.280		
Total	136.463	135			
Corrected Total	47.208	134			

$R^2 = 0.317$ (Adjusted $R^2 = 0.205$)

Table 4.3.5.30 shows that the spatial effect on CPUE of red drum is due primarily to the difference between the low CPUEs of Galveston and West Bays and the high CPUEs of East and Christmas Bays. Trinity Bay is intermediate in CPUE or abundance of red drum. East Bay and Christmas Bays are both higher in salinity and lower in human impacts than the other bays.

Table 4.3.5.30. Mean annual CPUE of red drum in gill net for five major bays in the Galveston Bay system. A comparison of means of annual CPUE among major bays using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = .280. The test uses the harmonic mean sample 27.000. Alpha = 0.05.

Segment	N	CPUE Values (number fish captured/hour)		
		Subset 1	Subset 2	Subset 3
Galveston	27	.4374	--	--
West	27	.6048	--	--
Trinity	27	.7393	.7393	--
East	27	--	1.0230	1.0230
Christmas	27	--	--	1.2611

Southern Flounder Gill Net Annual CPUE Analysis of Variance

Southern flounder are the largest flatfish in the southern estuaries. They spend the warm months of the year in the estuary. During their residence they feed on epibenthic crustaceans, like shrimp and crabs, and small demersal fish, like Atlantic croaker and Gulf menhaden. An analysis of variance examining the effects of area or major bay and decade was performed and the results are shown below in Table 4.3.5.31. The CPUE of southern flounder with gill net is significantly affected both by location and decade. Yields of gill net sampling vary across the major bays of the system, Christmas, East, Galveston, Trinity, and West Bays.

Table 4.3.5.31. The results of an ANOVA performed on annual CPUE of Southern Flounder collected by Gill Net from Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns the value to a time period of 1975 to 1979, 1980 to 1989, 1990 to 1999 and 2000 to 2001.

Source	Type III Sum of Squares	Df	Mean Square	F	Significance
Corrected Model	0.108	19	0.006	3.808	<0.001
Intercept	0.329	1	0.329	220.853	<0.001
Decade	0.021	3	0.007	4.772	0.004
Segment	0.029	4	0.007	4.873	0.001
Segment*Decade	0.028	12	0.002	1.570	0.110
Error	0.171	115	0.001	--	--
Total	0.841	135	--	--	--
Corrected Total	0.279	134	--	--	--

$R^2 = 0.386$ (Adjusted $R^2 = 0.285$)

The significant effect of decade on southern flounder CPUE is not due to a linear trend in abundance. Table 4.3.5.32 below shows that the most significant change in CPUE occurred from a low in the 1970s to a high in the 1980s. In the 1970s, gill net capture of flounders occurred at a rate of approximately 1 fish in 20 hours. The CPUE rose in the 1980s to a catch rate of 1 fish in 12 hours. Annual CPUEs have been lower in subsequent decades.

Table 4.3.5.32. Mean annual CPUE of Southern flounder in gill net for four decades. A comparison of means of annual CPUE among time periods using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 1.488E-03. The test uses the harmonic mean sample 22.222. Alpha = 0.05.

Decade	N	CPUE Values (number fish captured/hour)	
		Subset 1	Subset 2
2000s	10	0.057	0.057
1990s	50	0.060	0.060
1980s	50	--	0.080
1970s	25	0.047	--

Southern flounder appear to have a preference for West and Christmas Bays as shown in Table 4.3.5.33 below. Galveston, East and Trinity Bays have mean annual CPUE values that are not significantly different and are lower than those obtained for gill net samples in West and Christmas Bays.

Table 4.3.5.33. Mean annual CPUE of Southern flounder in gill net for five major bays in the Galveston Bay system. A comparison of means of annual CPUE among major bays using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 1.488E-03. The test uses the harmonic mean sample 27.000. Alpha = 0.05.

Segment	N	CPUE Values (number fish captured/hour)		
		Subset 1	Subset 2	Subset 3
Galveston	27	0.041	--	--
East	27	0.052	0.052	--
Trinity	27	0.054	0.054	--
West	27	--	0.074	0.074
Christmas	27	--	--	0.100

Spotted Seatrout Gill Net Annual CPUE Analysis of Variance

The spotted seatrout is one of the top predators in the Galveston Bay system and a highly prized sportfish. As an adult of the size to be captured by gill net, it feeds mainly on lower trophic level, pelagic fishes, e.g. mullet and menhaden. An analysis of variance examining the effect of spatial and temporal variation on the mean annual CPUE of spotted seatrout by gill net shows a significant impact of both main effects. Segment refers to different major bays within the Galveston Bay system and decade refers to time periods explained in the table legend. Spotted seatrout has been shown to have an increasing linear trend in abundance across the entire Bay system over the last 27 years.

Table 4.3.5.34. The results of an ANOVA performed on annual CPUE of Spotted Seatrout collected by Gill Net from Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns the value to a time period of 1975 to 1979, 1980 to 1989, 1990 to 1999 and 2000 to 2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	6.689	19	0.352	7.277	<0.001
Intercept	19.270	1	19.270	398.286	<0.001
Decade	2.403	3	0.801	16.559	<0.001
Segment	2.167	4	0.542	11.198	<0.001
Segment*Decade	0.843	12	0.070	1.452	0.153
Error	5.564	115	0.048	--	--
Total	39.699	135	--	--	--
Corrected Total	12.253	134	--	--	--

$R^2 = 0.546$ (Adjusted $R^2 = 0.471$)

Annual CPUE of spotted seatrout with gill net has been increasing since the 1970s. Table 4.3.5.35 shows that CPUEs in the 1970s were significantly lower than those observed in the 1990s and early years of the 2000s. The CPUE across the Bay has risen from one fish in about 4 hours to one fish in about 1.5 hours.

Table 4.3.35. Mean annual CPUE of Spotted seatrout in gill net for decadal time periods. A comparison of means of annual CPUE with gill net among time periods using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 4.838E-02. The test uses the harmonic mean sample 22.222. Alpha = 0.05.

Decade	N	CPUE Values (number fish captured/hour)		
		Subset 1	Subset 2	Subset 3
1970s	25	0.2372	--	--
1980s	50	0.3984	0.3984	--
1990s	50	--	0.5688	0.5688
2000s	10	--	--	0.6580

The spatial difference in seatrout CPUE with gill net is attributable to a much lower yield from gill net samples collected in Trinity Bay. While Trinity Bay gill net samples average one fish every 6.6 hours, a gill net set in East Bay yields a spotted seatrout in an average of 1.6 hours. East Bay's average annual CPUE is not significantly different from that in Galveston, Christmas and West Bays. Some characteristic of Trinity Bay, perhaps related to salinity, results in a lower abundance of this species.

Table 4.3.5.36. Mean annual CPUE of spotted seatrout with gill net for major bays in the Galveston Bay system. A comparison of means of annual CPUE among major bays using the Tukey test yielded the homogeneous groupings shown. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 0.048. The test uses the harmonic mean sample 27.000. Alpha = 0.05.

Segment	**N**	**CPUE Values (fish/hr)**	
		Subset 1	**Subset 2**
Trinity	27	0.1511	--
Galveston	27	--	0.4474
Christmas	27	--	0.4926
West	27	--	0.5526
East	27	--	0.6107

Analysis of Annual CPUE from Oyster Dredge Collections of Eastern Oyster

Eastern oyster is a very significant species in the Galveston Bay system. These bivalves form dense aggregations, oyster reefs that change the physical nature of the Bay by altering substrate and circulation patterns. Oyster reefs also support a food web that is distinct from other parts of the bay bottom where oysters do not occur (McFarlane 1993). They form an important component of the diet of several sport fish and support a commercial fishery.

Analysis of the annual CPUE for oysters collected by TPWD using a dredge in major sub-bays of the Galveston Bay system shows significant variation over location and time period. Table 4.3.5.37 shows the distribution of samples of annual CPUE values for five major sub-bays and three time periods. Time periods are labeled decades because the periods divide between 1989 and 1990, and 1999 and 2000. Table 4.3.5.38 describes the results of the ANOVA. The adjusted R^2 is 0.41, which indicates that a considerable portion of the variation in oyster abundance in Galveston Bay is related to long time period fluctuations in conditions and variation in habitat suitability of different sub-bays. This is consistent with previous findings on the spatial and temporal factors affecting oyster distribution.

Table 4.3.5.37. The number of annual CPUE samples for each sub-bay and each decade.

		N
Segment	Christmas	17
	East	18
	Galveston	18
	Trinity	18
	West	17
Decade	1980s	28
	1990s	50
	2000s	10

Table 4.3.5.38. The results of an ANOVA performed on annual CPUE of Eastern oyster collected by oyster dredge from the Galveston Bay system. Main effects are segment, which represents the five major bays in the system, and decade, which assigns a value to time periods from 1984-1989, 1990-1999 or 2000-2001.

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	122191409.288	14	8727957.806	5.275	<0.001
Intercept	720811830.455	1	720811830.455	435.607	<0.001
Decade	50125090.775	4	12531272.694	7.573	<0.001
Segment	31279267.498	2	15639633.749	9.451	<0.001
Segment*Decade	8280114.070	8	1035014.259	0.625	0.754
Error	120795151.960	73	1654728.109	--	--
Total	1347257850.534	88	--	--	--
Corrected Total	242986561.248	87	--	--	--

R^2 = 0.503 (Adjusted R^2 = . 408)

Development of oyster reefs is related to the salinity regime and circulation patterns at a site. The high salinities of Christmas and West Bays are not as suitable for oyster settlement and survival as the regimes in Galveston, East and Trinity Bays, as shown in Table 4.3.5.39. CPUEs of oysters from Christmas and West Bays are less than 2500 oysters per hour while the CPUEs for Galveston, East and Trinity Bays all exceed 4100 oyster per hour.

Table 4.3.5.39. Mean annual CPUE of Eastern oyster for major bays in the Galveston Bay system. A comparison of means of annual CPUE among major bays using the Tukey test yielded these homogenous subsets of major bays. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 1654728.109. The test uses the harmonic mean sample size = 17.586. Alpha = .05

Segment	**N**	**Annual CPUE (number of oysters captured/hour)**	
		Subset 1	**Subset 2**
Christmas	17	2,234.76	--
West	17	2,450.65	--
Galveston	18	--	4,101.61
East	18	--	4,350.38
Trinity	18	--	4,441.27

The Tukey test of CPUEs from different decades showed that the annual CPUEs in the 1980s were significantly lower than those observed in the 1990s and 2000s. The CPUEs jump from 2,710 oysters per hour in the 1980s to 3,907 oysters per hour in the 1990s and 4,046 oysters per hour in 2000-2001.

Table 4.3.5.40. Mean annual CPUE of Eastern oyster for decadal time periods. A comparison of mean annual CPUE among time periods using the Tukey test yielded these subsets of time periods. Samples were divided into decadal time periods consisting of 1984-1989, 1990-1999, and 2000-2001. The significance test is based on Type III Sum of Squares. The error term is Mean Square (Error) = 1654728.11. The test uses the harmonic mean sample size = 19.27. Alpha = .05

Decade	**N**	**Mean CPUE (number of oysters captured / hour)**	
		Subset 1	**Subset 2**
2000s	10	--	4,046.46
1990s	50	--	3,907.31
1980s	28	2,710.73	--

Abundance of live oysters is clearly responsive to environmental changes over time and space. While the species is ubiquitous in the Galveston Bay system, when viewed at a large spatial scale, the level of variation observed in this analysis suggests that the species is a good indicator of the impact of some changes in the properties of the Bay system.

4.3.6. Biodiversity Trends of Aquatic Living Resources in Galveston Bay

Analysis of Species Richness from Fisheries Independent Data Collected by TPWD

The TPWD Coastal Fisheries database obtained for the Status and Trends study contains records of all of the individual animals and plants collected by a variety of gear types from the marine and estuarine waters of Texas. The data set was filtered to eliminate all of the collection points outside the GBEP segments representing the Galveston Bay watershed. The segments were coalesced into major and minor bays of the Galveston Bay system for most analyses.

For the analysis of species richness, the data were summarized by counting the number of species codes per sample. Before summarizing the data, all species codes representing plants, non-living material and animal taxa above the level of family were eliminated. Counting the number of "species" per sample rather than summarizing the number of species collected in an area over a period of time avoids the complication of species-area or species-effort effects. These effects manifest themselves in an increase in number of species observed as the area sampled or the sampling effort increase.

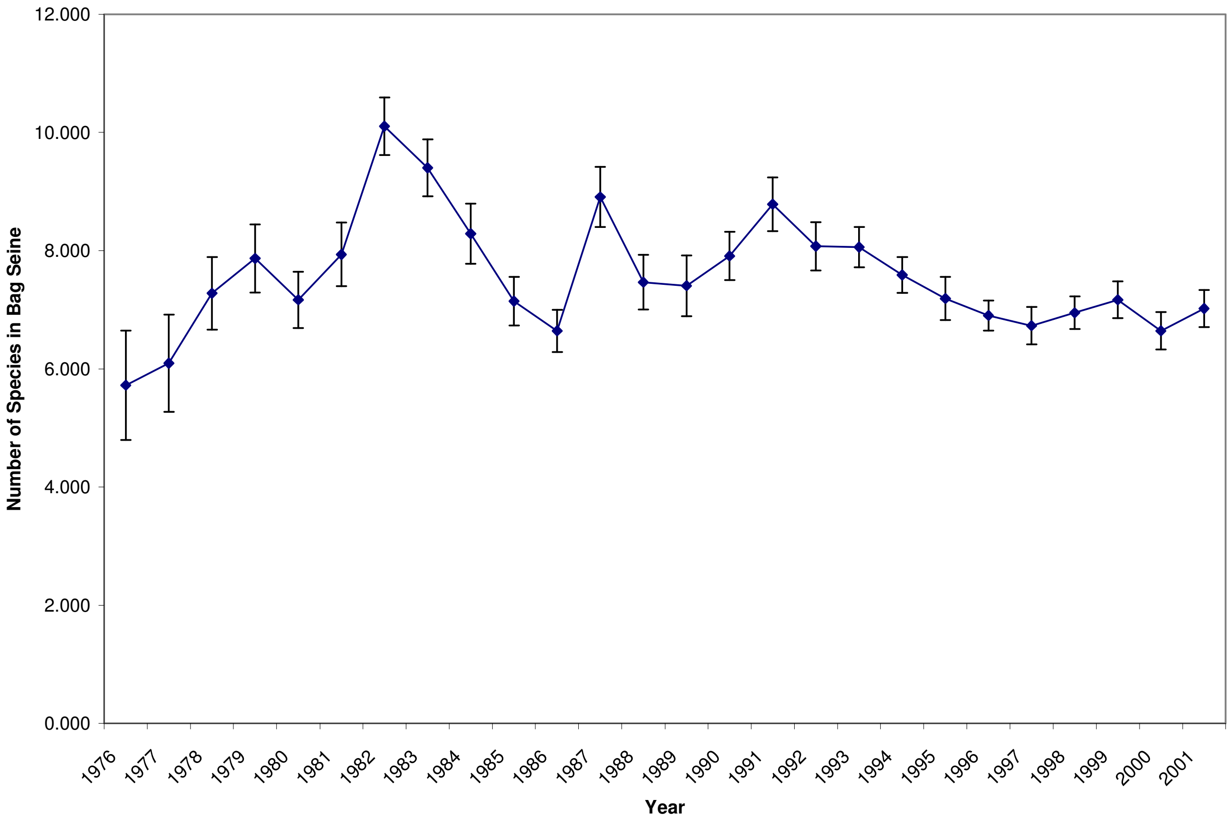
The areas analyzed are different for the different gear types. Bag seine and gill net data are analyzed from the following major and minor bays: East, Galveston, Trinity, West, Chocolate, Christmas and Dickinson. Areas suitable for shrimp trawl samples are restricted in Christmas and Dickinson Bays so those areas are left out of the analyses for that gear type.

Species Richness in Bag Seine Samples

Annual Species Richness Trend

The graph shown in Figure 4.3.6.1 plots the annual average of number of species per bag seine collected from the entire Galveston Bay system. The averages have standard error bars that permit an estimation of statistical significance of the differences between averages. The peak value in 1982 is significantly higher than years from 1995 to present. The number of species sampled per bag seine appears to rise from 1976 to 1982, then decline from 1982 to 1986, and remain relatively steady around 6.5 species per bag seine from 1996 to 2001.

Figure 4.3.6.1. The annual average of number of species per bag seine collected from the entire Galveston Bay system. Standard error bars are shown for the annual averages.



Effect of Location and Time of Year on Species Richness

The species richness values were analyzed by ANOVA to determine the effect of collection area and time of year on the number of species captured. Both factors have significant effects on species richness, but there is no interaction. The model of variance due to segment plus variance due to month plus interaction and error variances explains 37% of the variation in number of species per bag seine.

Table 4.3.6.1 Sample sizes used in the analysis of number of species in bag seine collections. Number of bag seine collections in the data set obtained in different months and different sub-bays are shown.

FACTOR		**N**
MONTH	January	119
	February	121
	March	125
	April	125
	May	127
	June	117
	July	126
	August	121
	September	120
	October	132
	November	130
	December	111
SEGMENT	Christmas	230
	Chocolate	145
	Dickinson	127
	East	216
	Galveston	264
	Trinity	215
	West	277

Table 4.3.6.2 Results of analysis of variance examining the effect of month and segment on the species richness of bag seine samples in the TPWD data set. Both factors have significant effects on the dependent variable, bag seine species richness.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Corrected Model	7,625.094	83	91.869	11.255	<0.001
Intercept	80,693.130	1	80,693.130	9,885.546	<0.001
Month	5,573.326	11	506.666	62.071	<0.001
Segment	852.607	6	142.101	17.409	<0.001
Segment*Decade	446.041	66	6.758	.828	0.835
Error	11,346.207	1390	8.163	--	--
Total	106,457.870	1474	--	--	--
Corrected Total	18,971.301	1473	--	--	--

$R^2 = 0.402$ (Adjusted $R^2 = 0.366$)

When the values of different bays are compared in a Tukey test of means, the homogeneous sets of sub-bays separate Galveston and East Bays as lower in richness than the other bays. The highest mean number of species per bag seine is found in the small nursery bays: Chocolate, Christmas and Dickinson Bays. The results of the comparison of means are shown in Table 4.3.6.3. Bag seines in Chocolate Bay collect an average of two more species than bag seines in Galveston Bay.

Table 4.3.6.3. Mean number of species collected by bag seine from different bays. Mean values are grouped into homogeneous subsets based on a Tukey comparison of means. Type III Sum of Squares is used and the error term is Mean Square (Error) = 8.163. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

Segment	N	Subset 1	Subset 2	Subset 3	Subset 4
Galveston	264	6.69	--	--	--
Trinity	215	6.70	--	--	--
West	277	--	7.76	--	--
East	216	--	7.93	7.93	--
Dickinson	127	--	8.05	8.05	8.05
Christmas	230	--	--	8.64	8.64
Chocolate	145	--	--	--	8.81

The same type of test was performed to determine the pairwise differences among months. The months with the lowest values for species richness are the winter months: December to February. The highest species richness for bag seine collections are the months of May to September. These results are shown in Table 4.3.6.4. Bag seine collections from January have on average six fewer species than collections with the same gear type in August.

Table 4.3.6.4. Mean number of species collected by bag seine in different months. Mean values are grouped into homogeneous subsets after a Tukey comparison of means. Type III Sum of Squares is used and the error term is Mean Square(Error) = 8.163. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

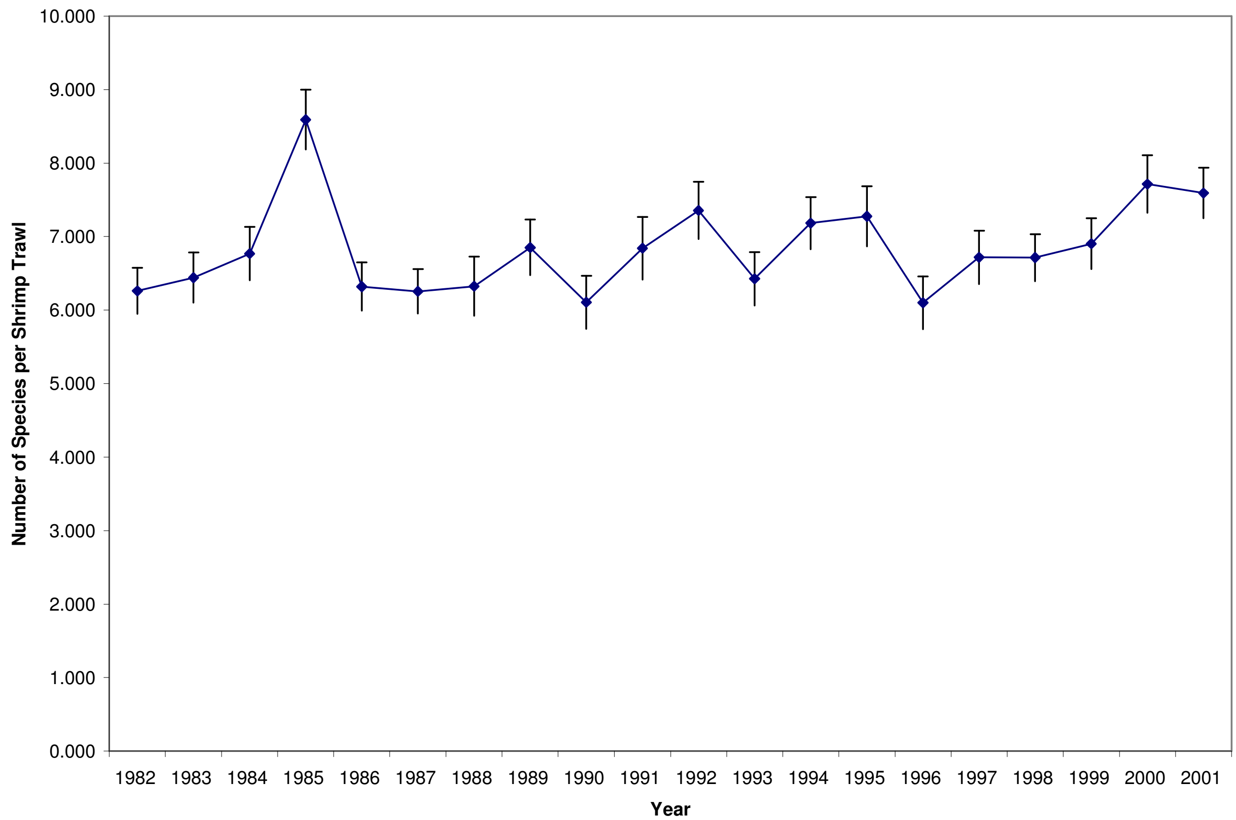
Month	N	Subset 1	Subset 2	Subset 3	Subset 4	Subset 5	Subset 6
January	119	4.23	--	--	--	--	-
December	111	5.07	5.07	--	--	--	--
February	121	5.36	5.36	5.36	--	--	--
November	130	--	6.19	6.19	--	--	--
March	125	--	--	6.38	6.38	--	--
October	132	--	--	--	7.49	7.49	--
April	125	--	--	--	--	8.07	--
September	120	--	--	--	--	--	9.44
May	127	--	--	--	--	--	9.86
July	126	--	--	--	--	--	9.90
June	117	--	--	--	--	--	9.96
August	121	--	--	--	--	--	10.27

Species Richness in Shrimp Trawl Samples by Year, Segment and Month

Annual Species Richness Trend

The record for shrimp trawls is sporadic before 1982, so the data set was truncated to begin in that year for analysis. Figure 4.3.6.2 shows the annual average and standard error bars for the number of species collected per shrimp trawl from 1982 to 2001. Most of the annual means fall between 6 and 7.5 species, but 1985 is unusually high. In recent years, more than 7 species are typically collected in TPWD monitoring trawls. Bag seine collections in West Bay taken in the period from May to September 1985 contained an average of 13.4 species.

Figure 4.3.6.2. The annual average and standard error for the number of species collected per shrimp trawl from 1982 to 2001.



Effect of Location and Time of Year on Species Richness in Shrimp Trawls

An ANOVA was performed to test the effects of collection area and seasonality. The number of collections in each month and bay segment are shown below.

The ANOVA model with month and segment as main effects and an interaction explains 35% of the variation in species richness in shrimp trawl collections. Both main effects are significant: month and segment/bay. With this gear type there is a significant area-month interaction. This interaction implies that different bays have different seasonality patterns. The results of the ANOVA analysis are shown in Table 4.3.6.5.

Table 4.3.6.5. Sample sizes used in the analysis of number of species in shrimp trawl collections. Number of shrimp trawl collections in the data set obtained in different months and different sub-bays are shown.

FACTORS		N
MONTH	January	82
	February	84
	March	81
	April	84
	May	83
	June	82
	July	83
	August	82
	September	79
	October	81
	November	82
	December	79
SEGMENT	Chocolate	58
	East	212
	Galveston	240
	Trinity	240
	West	232

Table 4.3.6.6. Results of a two-way ANOVA to determine the effect of segment/bay and month of collection on the number of species captured per shrimp trawl.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Corrected Model	2,737.219	59	46.394	10.131	<0.001
Intercept	31,032.222	1	31,032.222	6,776.489	<0.001
Month	1,857.665	11	168.879	36.878	<0.001
Segment	184.721	4	46.180	10.084	<0.001
Segment*Decade	346.619	44	7.878	1.720	<0.003
Error	4222.203	922	4.579	--	--
Total	52,555.761	982	--	--	--
Corrected Total	6,959.422	981	--	--	--

R^2 = .393 (Adjusted R^2 = .354)

In order to understand the sources of the significant differences related to the main effects in the ANOVA, Tukey pairwise comparison of means was performed and homogeneous subsets of the bays were determined. Although Trinity and Galveston Bays are broadly conjoined, they exhibit significantly different mean number of species per shrimp trawl. The typical shrimp trawl in Galveston Bay yields approximately one more species than a trawl collection in Trinity Bay. The grouped means are shown in Table 4.3.6.7.

Table 4.3.6.7. Mean number of species collected by shrimp trawl in different bays shown as homogeneous subsets after Tukey comparison of means. Type III Sum of Squares is used and the error term is Mean Square(Error) = 4.579. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

SEGMENT	N	Subset 1	Subset 2	Subset 3
Trinity	240	6.139	--	--
Chocolate	58	6.586	6.586	--
East	212	--	6.892	6.892
West	232	--	6.966	6.966
Galveston	240	--	--	7.328

The effect of month on species richness in the sample is clearly demarcated between the winter and early spring, December to March is lower than all other months. The results are shown in Table 4.3.6.8. Species richness declines by more than 4 species between August and January.

Table 4.3.6.8. Mean number of species collected by shrimp trawl in different months shown as homogeneous subsets after Tukey comparison of means. Type III Sum of Squares issued and the error term is Mean Square (Error) = 4.862. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

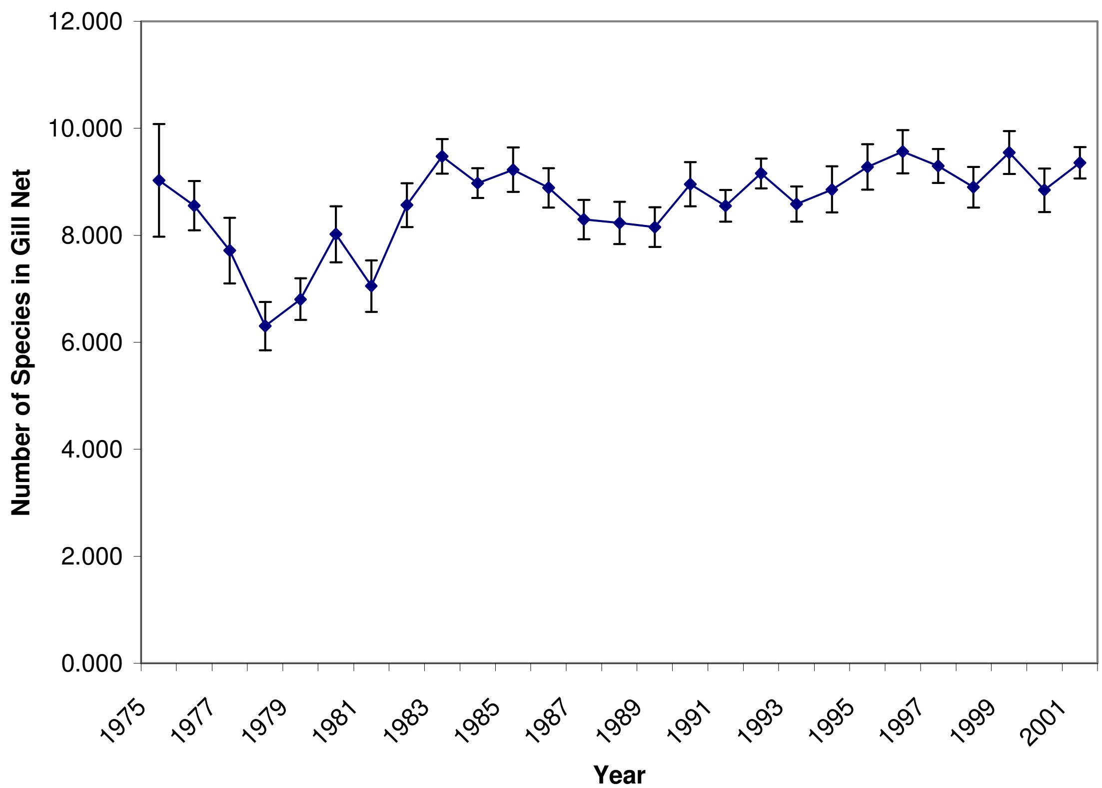
Month	N	Subset 1	Subset 2	Subset 3	Subset 4	Subset 5
January	91	4.076	--	--	--	--
February	91	4.323	--	--	--	--
December	89	4.957	4.957	--	--	--
March	88	--	5.633	--	--	--
April	97	--	--	7.164	--	--
June	94	--	--	7.318	7.318	--
November	94	--	--	7.582	7.582	7.582
October	92	--	--	7.795	7.795	7.795
May	98	--	--	7.956	7.956	7.956
September	94	--	--	8.023	8.023	8.023
July	94	--	--	--	8.369	8.369
August	97	--	--	--	--	8.476

Species Richness in Gill Net Samples from Selected Bays

Annual Species Richness Trend

Figure 4.3.6.3 shows the annual values and standard error bars for the average number of species captured per gill net sample from all regions of the Galveston Bay system. The years dip in the early portion of the record in the years 1978 and 1979. Values are higher and much more stable over the years from 1984 to 2001. The pattern of annual species richness suggests that something changed in the early 1980s. This was the period when commercial gill netting was banned along the Texas coast. Following this period, annual gill net species richness appears relatively stable between 8.5 and 9.5 species captured per gill net sample.

Figure 4.3.6.3. The annual values and standard error bars for the average number of species captured per gill net sample from all regions of the Galveston Bay system.



Effect of Location and Time of Year on Species Richness

The data on gill net species richness was analyzed by ANOVA to determine the significance of seasonality and location on values. The distribution of samples over months and over segments of the Bay are shown in Table 4.3.6.9 For this gear type, there is an uneven distribution of samples over time. July and August have low sample sizes and the period from December to March has fewer samples than spring and fall months. Sample sizes over different bays are much more robust. The effect of segment and month are significant. The analysis shows that a variance model using variance due to month, segment, and the interaction explains over 39% of the variation in the data. There is a significant interaction between location and month of collection, which suggests that seasonality of species richness varies by sub-bay within the Galveston Bay system.

Table 4.3.6.9. Sample sizes used in the analysis of number of species in gill net collections. Number of gill net collections in the data set obtained in different months and different sub-bays are shown.

Factor		**N**
MONTH	January	24
	February	24
	March	22
	April	104
	May	115
	June	94
	July	12
	August	11
	September	103
	October	136
	November	102
	December	26
SEGMENT	Christmas	99
	Chocolate	55
	Dickinson	84
	East	117
	Galveston	144
	Trinity	111
	West	163

Table 4.3.6.10. Results of a two-way ANOVA to determine the effect of segment region and month of collection on the number of species captured per gill net.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Corrected Model	1,973.001	78	25.295	7.315	<0.001
Intercept	18,809.853	1	18,809.853	5,439.380	<0.001
Month	1,093.449	11	99.404	28.745	<0.001
Segment	118.312	6	19.719	5.702	<0.001
Segment*Decade	281.641	61	4.617	1.335	0.050
Error	2,399.913	694	3.458	--	--
Total	61,616.709	773	--	--	--
Corrected Total	4,372.914	772	--	--	--

$R^2 = .451$ (Adjusted $R^2 = .390$)

The pattern that appears in Table 4.3.6.10 may be related to the relationship between the Galveston Bay system and the Gulf of Mexico. Mean species richness values for gill net samples are smallest in Trinity, Galveston and Dickinson Bays. Trinity Bay is the most distant from the Gulf and has the lowest salinity. Galveston Bay connects to a pass to the Gulf, but extends as far north as Trinity Bay. Dickinson Bay is less than halfway along the western shore of Galveston Bay, but farther from a pass than Chocolate and Christmas Bays. The Gulf of Mexico is the ultimate reservoir of marine species that move into and out of the Galveston Bay system. It appears that contiguity may increase the number of species observed. Christmas Bay shows the highest value for number of species captured per gill net. This bay is designated as a coastal reserve and receives less anthropogenic stress than West Bay, which adjoins it. Differences in anthropogenic stress may also help to explain some of the variation in species richness in gill net samples.

Table 4.3.6.11. Mean number of species collected by gill net in different bays shown as homogeneous subsets after Tukey comparison of means. Type III Sum of Squares is used and the error term is Mean Square(Error) = 3.458. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

Segment	N	Subset 1	Subset 2	Subset 3
Trinity	111	7.57	--	--
Galveston	144	7.94	--	--
Dickinson	84	8.04	--	--
West	163	--	8.90	--
East	117	--	9.00	--
Chocolate	55	--	9.44	9.44
Christmas	99	--	--	9.79

The effect of time of year on the richness of species in gill net samples is clearly shown in Table 4.3.6.12. The winter months of January and February are significantly lower in richness than all other months. Despite the small number of gill net samples taken in July and August, there is a pattern of high number of species taken by this gear type throughout the summer and early fall, from June to October. The difference between warm and cold weather samples is more than 4 species per sample. This suggests that a significant fraction of species are transient in this system.

Table 4.3.6.12. Mean number of species collected by gill net in different months shown as homogeneous subsets after Tukey comparison of means. Type III Sum of Squares is used and the error term is Mean Square(Error) = 3.458. The group sizes are unequal. The harmonic mean of the group sizes is used. Alpha = .05.

MONTH	N	Subset 1	Subset 2	Subset 3	Subset 4	Subset 5
January	24	4.64	--	--	--	--
February	24	5.02	--	--	--	--
December	26	--	6.75	--	--	--
March	22	--	7.11	7.11	--	--
November	102	--	8.04	8.04	8.04	--
April	104	--	8.18	8.18	8.18	
May	115	--	--	8.60	8.60	
June	94	--	--	--	9.07	9.07
August	11	--	--	--	9.36	9.36
July	12	--	--	--	9.54	9.54
October	136	--	--	--	9.57	9.57
September	103	--	--	--		10.26

Discussion

Annual values for species richness in collections by bag seine and gill net appear to have increased following the 1970s. Data for species richness in shrimp trawl show one anomalously high year and no trend pattern. The increase in number of species captured per gill net may be associated with changes in fishing regulations.

Differences in species richness by bay also differ by gear type. Bag seine and gill net samples show similar patterns. Galveston and Trinity Bays yield lower number of species per collection and Chocolate and Christmas Bays yield more species per collection. Shrimp trawl collections result in a very different pattern that may be related to size of the segment sampled. Christmas Bay is omitted because there are fewer collections. Trinity and Chocolate Bays have the fewest number of species per shrimp trawl. Galveston Bay has the highest value.

All three gear types produce the same pattern of seasonality in the values for species richness. There is a winter period of two to three months with species richness values lower by 3 to 4 species than the values for summer collections. There is a five to six month period covering summer plus late spring and early fall during which species richness stays high. The difference between winter and summer collections is least for shrimp trawl collections.