3.2 Coastal Fisheries

3.2.1 Length of Commercial and Recreational Species

The Texas Parks and Wildlife (TPWD) Coastal Fisheries Division regularly monitors finfish populations in Galveston Bay using three gear types (bag seine, shrimp trawl, and gill net). TPWD sampling procedures require that every organism captured in a sample be recorded in the Coastal Fisheries Independent Monitoring database. Collected data include spatial and temporal information describing the sample location and time, gear information, hydrological data and weather conditions, species caught, number of each species captured, and total length (length of fish from snout to tip of caudal fin) of the first 19 individuals of a captured species. The next two sections of the Status and Trends Report analyze length data for commercially and recreationally important species of finfish and shellfish captured in Galveston Bay. The analyses look at relationships between length and water quality parameters as well length trends over time.

Correlation of Length with Environmental Variables

The TPWD Coastal Fisheries Independent Monitoring database contains variables describing the length of individuals of measurable species and environmental conditions that occurred when the sample was collected. The data on length and the environmental variables temperature, dissolved oxygen, salinity and turbidity were extracted from the TPWD databases. Six species were selected from the data on collections by bag seine and shrimp trawl. Species selected from bag seine data were Atlantic croaker, blue crab, brown shrimp, Gulf menhaden, striped mullet and white shrimp. For shrimp trawl analysis, the same set of species was used with the substitution of spot for striped mullet. These analyses were performed by Ying Zhao as a project for the M.S. program in statistics at University of Houston-Clear Lake under the supervision of Status and Trends subcontractor, Dr. Raj Chhikara. The data provided to Ms. Zhao (sample years: 1983-2002) had been quality controlled by the HARC staff before delivery and Dr. Chhikara provided quality assurance under the QAPP for this project.

The selection of variables and gear types was based on the following logic. Temperature, dissolved oxygen, salinity and turbidity are fundamental estuarine descriptors that influence growth or habitat selection of mobile species. The species and life history stages sampled by bag seine and shrimp trawl are more likely to be actively growing than those sampled by gill net. This would bias the analysis toward an investigation of effect on growth more than habitat selection, although there is no control over the causation of the effects noted. The species selected are all common in bag seine and shrimp trawl collections and spend their early life history stages, and in some cases most of their lives, in the estuary.

Bag Seine Results

The collections used for the bag seine analysis occurred at different times and places than the shrimp trawl collections. Thus the environmental variables (temperature, dissolved oxygen, salinity and turbidity) comprise a distinct data set. For the purposes of detecting strong relationships between the growth or size of species and the environmental variable, it is preferable that the environmental variables be uncorrelated. If the variables are correlated, then it is difficult to separate the relationships of two correlated environmental variables with growth or size. In the case of the variables used in this study, there are two cases of correlation between environmental variables. Increasing temperature reduces the solubility of oxygen in water; therefore temperature and dissolved oxygen are negatively correlated. Also, low salinity conditions in Galveston Bay tend to be associated with precipitation, which carries sediment into the water and increases turbidity. As seen in Table 3.2.1, this results in a small negative correlation between turbidity and salinity.

Table 3.2.1. Correlations between environmental variables associated with bag seine collections.

	Temperature	Dissolved Oxygen	Salinity
Dissolved oxygen	-0.537***		
Salinity	0	0	
Turbidity	0	0	-0.173***

*** p<0.001

Bag seine sampling usually collects the young of the year. These organisms are in general rapidly growing and pre reproductive. The following table (Table 3.2.2) shows the number of individuals from each species included in the analyses and their average length.

Table 3.2.2. List of species selected for analysis from bag seine data, the number included in the sample and the average length in mm of the sampled individuals.

Species	Sample Number	Average Length (mm)
Atlantic croaker	7,107	60
Blue crab	4,838	42
Brown shrimp	6,496	58
Gulf menhaden	5,215	45
Striped mullet	3,089	114
White shrimp	7,480	58

Length of all of the species, except white shrimp, shows a moderate, but significant (p<0.001), positive correlation with temperature. Length of all of the species, except blue crab, shows a moderate negative correlation with dissolved oxygen. Those species with significant relationships should demonstrate an association between larger size and higher temperature, lower oxygen environments. Atlantic croaker and Gulf menhaden in bag seine samples tend to be larger in higher salinity environments, but blue crabs show a slight tendency for larger individuals to occur in lower salinity environments. Atlantic croaker and gulf menhaden exhibit the pattern predicted for salinity and turbidity based on the negative correlation of the parameters. Brown shrimp show a relationship with turbidity that appears independent of salinity. Larger brown shrimp tend to occur in more turbid waters.

Table 3.2.3. Correlation between lengths of selected species collected in bag seine and water quality variables.

Length of Species	Temperature (p value)	Dissolved Oxygen (p value)	Salinity (p value)	Turbidity (p value)
Atlantic croaker	0.565 <0.001	-0.251 <0.001	0.235 <0.001	-0.243 <0.001
Blue crab	0.387 <0.001	-0.120 0.012	-0.125 <0.001	0.075 0.129
Brown shrimp	0.611 <0.001	-0.149 0.004	0.127 0.015	0.254 <0.001
Gulf menhaden	0.471 <0.001	-0.297 <0.001	0.448 <0.001	-0.321 <0.001
Striped mullet	0.262 <0.001	-0.147 0.002	0.094 0.051	0.003 0.954
White shrimp	0.146 0.025	-0.226 <0.001	-0.070 0.173	0.089 0.096

The length data were also analyzed for temporal patterns using year and season. The seasonal arrangement was based on month of sampling. Winter (season 1) consists of December, January and February; spring was comprised of March, April and May; summer was June, July and August; and fall was September, October and November. An ANOVA using the model of years and seasons as independent factors predicting length was performed for the bag seine data. The length data was log transformed because it deviated from normality. The results of the ANOVA are shown below for the six species. None of the species exhibited a significant effect of year on length. This suggests that these species tend not to have years that are much better for growth than other years. Five of six species showed highly significant effects of season on size. Blue crab was the only exception.

Table 3.2.4. Results of ANOVA analysis of temporal variation in log transformed length data of six selected species from bag seine collections.

	Species					
Factor	Atlantic croaker	Blue Crab	Brown Shrimp	Gulf Menhaden	Striped Mullet	White Shrimp
Year	ns	ns	ns	ns	ns	ns
Season	P<0.001	ns	P<0.001	P<0.001	P<0.001	P<0.001

The significant effect of seasons was examined with multiple comparison tests. The explanation differs by species. White shrimp collected in the spring are larger than those collected in other seasons. Atlantic croaker in spring and summer bag seine samples are larger than those from fall and winter samples. Brown shrimp are larger in summer samples. Gulf menhaden and striped mullet are larger in summer and fall samples.

Shrimp Trawl

Although the shrimp trawl samples were collected at times and places that are different from the bag seine samples, the environmental variables associated with them show the same correlations as seen in Table 3.2.1, however, the negative correlations between temperature and dissolved oxygen plus salinity and turbidity are slightly stronger (Table 3.2.5).

Table 3.2.5. Correlations between environmental variables associated with shrimp trawl collections.

	Temperature	Dissolved Oxygen	Salinity
Dissolved Oxygen	-0.683***		
Salinity	0.013	-0.097	
Turbidity	-0.009	0.005	-0.221***

*** $p<0.001$

Shrimp trawl sampling occurs in deeper waters than do bag seine samples and usually collects larger organisms found in the open bay. The species selected from shrimp trawl are the same as those chosen from bag seine samples with the exception of a change from striped mullet to spot. The following table (Table 3.2.6) shows the number of individuals from each species included in the analyses along with average length.

Table 3.2.6. List of species selected for analysis from shrimp trawl data, the number included in the sample and the average length in mm of the sampled individuals.

Species	Sample Number	Average Length (mm)
Atlantic croaker	12,618	106
Blue crab	4,612	68
Brown shrimp	6,448	89
Gulf menhaden	5,578	87
Spot	2,920	120
White shrimp	9,046	91

As seen in Table 3.2.7, five of the six species selected for analysis from shrimp trawl collection data show a significant correlation between length and temperature; only Gulf menhaden does not. However, spot shows a negative correlation between length and temperature. Four of six species have significant correlations ($p<0.01$) between length and salinity. Blue crab and white shrimp are the exceptions. The other species have a modest tendency for larger individuals to be collected from higher salinity waters. Brown shrimp and spot captured by shrimp trawl show a significant tendency for larger individuals to be captured in lower turbidity water.

Table 3.2.7. Correlation between length of selected species collected in shrimp trawls and water quality variables

Length of Species	Temperature (p value)	Dissolved Oxygen (p value)	Salinity (p value)	Turbidity (p value)
Atlantic croaker	0.248 <0.001	-0.217 <0.001	0.147 -0.006	-0.014 -0.795
Blue crab	0.248 <0.001	-0.213 <0.001	0.138 -0.011	0.131 -0.016
Brown shrimp	0.458 <0.001	-0.363 <0.001	0.244 <0.001	-0.182 -0.002
Gulf menhaden	-0.026 -0.626	0.130 -0.015	0.392 <0.001	0.072 -0.179
Spot	-0.498 <0.001	0.299 <0.001	0.141 -0.008	-0.336 <0.001
White shrimp	0.533 <0.001	-0.393 <0.001	0.014 -0.796	0.011 -0.845

The length data from shrimp trawl collections of the selected species was log transformed to improve the normality of the data for ANOVA. The model used for the ANOVA compared sample year and sample season as independent effects. The significance of these effects on the variation of length of the six species is shown in Table 3.2.8. Atlantic croaker and Gulf menhaden yielded a significant effect of year on length. In some years shrimp trawl samples contain samples that have lengths larger on average than samples in other years. There is no way of determining the environmental conditions that cause those length differences.

Four of six species (Atlantic croaker, blue crab, brown shrimp, and white shrimp) show significant variation in length over seasons in Table 3.2.8. Blue crab, which showed no seasonality in length for bag seine data (Table 3.2.4), shows a significant effect for shrimp trawl data. In contrast, Gulf menhaden, which had a significant effect of season on length for bag seine data, exhibits no significant effect for shrimp trawl data. The explanation for these seasonal effects as illuminated by multiple comparison tests is as follows. Length of Atlantic croaker increases during the year with fall samples containing the largest individuals, although winter samples are highly variable in size. Shrimp trawl samples of blue crab contain larger individuals in summer and winter, and spring samples are smaller. Brown shrimp are larger in summer samples than in other seasons. Gulf menhaden collected by shrimp trawl are smaller in fall samples than in other seasons. White shrimp collected in spring and summer are larger than fall and winter samples.

Table 3.2.8. Results of ANOVA analysis of temporal variation in log transformed length data of six selected species from shrimp trawl collections.

	Species					
Factor	Atlantic croaker	Blue Crab	Brown Shrimp	Gulf Menhaden	Spot	White Shrimp
Year	p<0.01	ns	ns	p<0.001	ns	ns
Season	p<0.001	p<0.01	p<0.001	ns	ns	p<0.001

Conclusion

In general the results from this statistical examination of data on length of species sampled by bag seine and shrimp trawl quantify relationships that are known to biologists. The seasonality of life history stages in the estuary is well known and the relationship between the life (growth) cycle and size of collected animals is obvious. Most of the species begin their life cycle with spawning in winter or spring, but white shrimp tend to spawn in late summer, so their growth process is seasonally offset. Some species migrate out of the estuary after a period of growth and can no longer be captured.

Perhaps the most interesting relationships described by this analysis are the correlations of length to salinity and length to turbidity. Atlantic croaker, brown shrimp, Gulf menhaden, and spot all show relationships between size and salinity and turbidity. All sizes of Atlantic croaker and Gulf menhaden show a positive effect of salinity on size in the samples. Smaller individuals captured in bag seines also showed a negative correlation with turbidity. Brown shrimp exhibit a positive correlation between size and turbidity at smaller sizes and a negative correlation at larger sizes. Spot captured by shrimp trawl tended to be larger in high salinity conditions and smaller in high turbidity conditions. None of these patterns are counterintuitive because they are consistent with variation in water quality that would be encountered as the animals move around and out of the estuary according to their life cycle. The developmental stages encounter different water quality conditions, according to the type of bay habitat or the time of year, as they mature or migrate and are sampled under those conditions.

Trends in Length of Selected Fisheries Species

Total length data from the TPWD Coastal Fisheries Independent Monitoring database were analyzed for trends in lengths of selected recreational and commercially important fish species over time. Samples collected using two sample gears were analyzed: gill net (Years = 1976-2004) and shrimp trawl (Years = 1982-2004). Gill net data typically describe larger fish captured as they move parallel to shore while shrimp trawl samples typically include species of fish found in open water. Bag seine data were not analyzed as this gear type typically captures juveniles or very small individuals.

Table 3.2.9 provides the list of ten species analyzed for trends in length. Gear types, sample years, the number of samples analyzed in the linear regression analysis, average length, and length range (minimum and maximum lengths) are shown. Data collected for brown shrimp and white shrimp captured in gill net were not included in the analysis as gill net is not an appropriate method of capture for these species and any capture would be purely incidental.

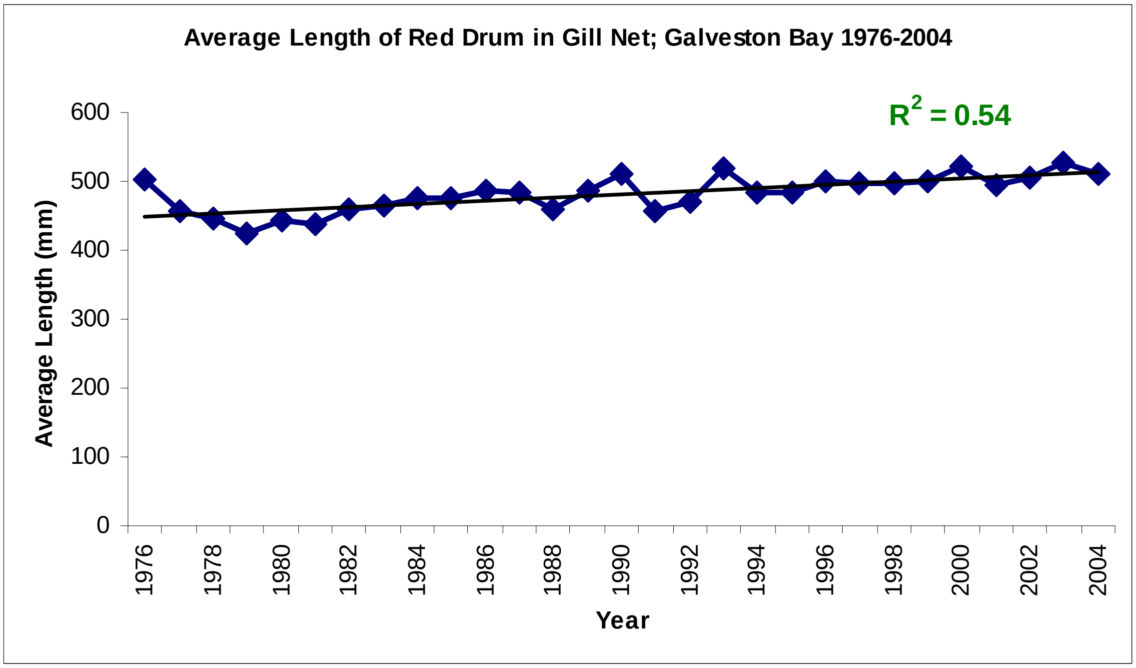
Table 3.2.9. Species of commercially and recreationally imported fish analyzed for two gear types as well as the number of samples analyzed in the linear regression analysis, average length in millimeters (mm), minimum and maximum length in mm.

Gear	Species	Sample Size	Average Length (mm)	Minimum Length (mm)	Maximum Length (mm)
Gill Net (1976-2004)	Atlantic croaker	6,420	276	120	681
	Black drum	13,317	375	114	1100
	Brown shrimp	na	na	na	na
	Red drum	18,119	488	141	1080
	Sand seatrout	895	289	140	476
	Sheepshead	1,132	368	127	710
	Southern flounder	1,658	355	150	603
	Spotted seatrout	12,848	461	229	783
	Striped mullet	5,381	362	136	664
	White shrimp	na	na	na	na
Shrimp Trawl (1982-2004)	Atlantic croaker	28,752	112	12	304
	Black drum	277	275	47	915
	Brown shrimp	18,346	89	15	169
	Red drum	49	149	21	760
	Sand seatrout	4,990	117	12	409
	Sheepshead	250	352	92	556
	Southern flounder	328	183	30	455
	Spotted seatrout	167	175	23	690
	Striped mullet	1,789	248	13	465
	White shrimp	34,615	93	10	198

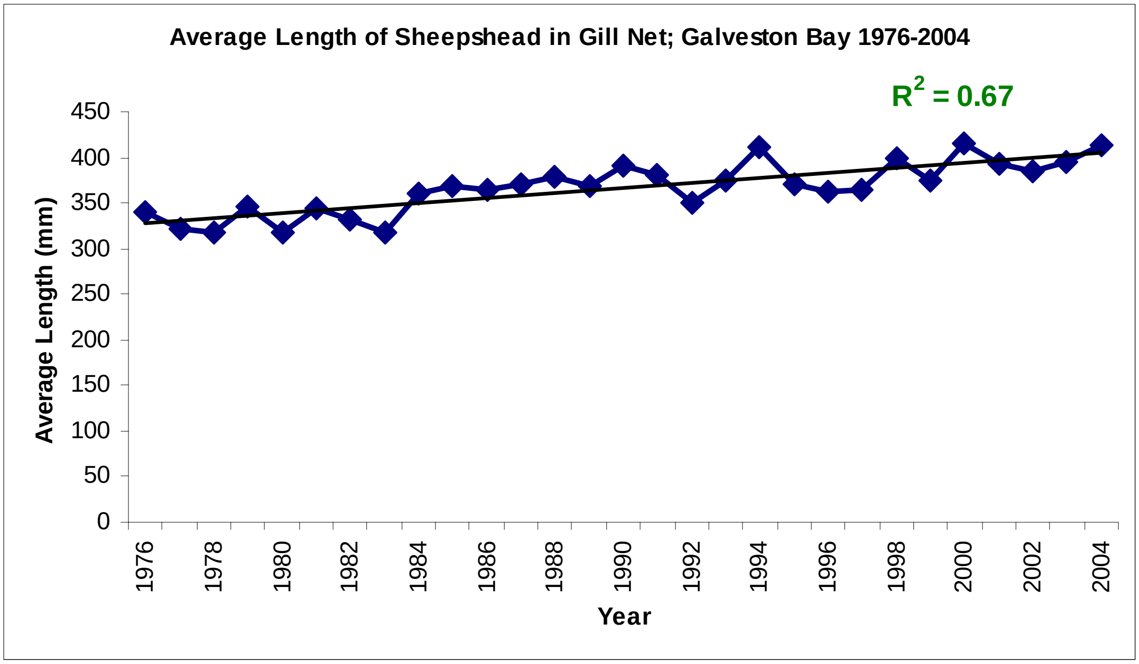
Of the eight species analyzed from gill net samples, three exhibited increasing trends ($R^2 \geq 0.25$) in length of fish captured during the 1976-2004 time period: red drum ($R^2 = 0.54$), sheepshead ($R^2 = 0.67$), and southern flounder ($R^2 = 0.40$). Only spotted seatrout had a declining trend ($R^2 = 0.36$).

Figure 3.2.1. Trends in annual average length of (a) Red drum in gill net, (b) sheepshead in gill net, (c) Southern flounder in gill net, and (d) spotted seatrout in gill net.

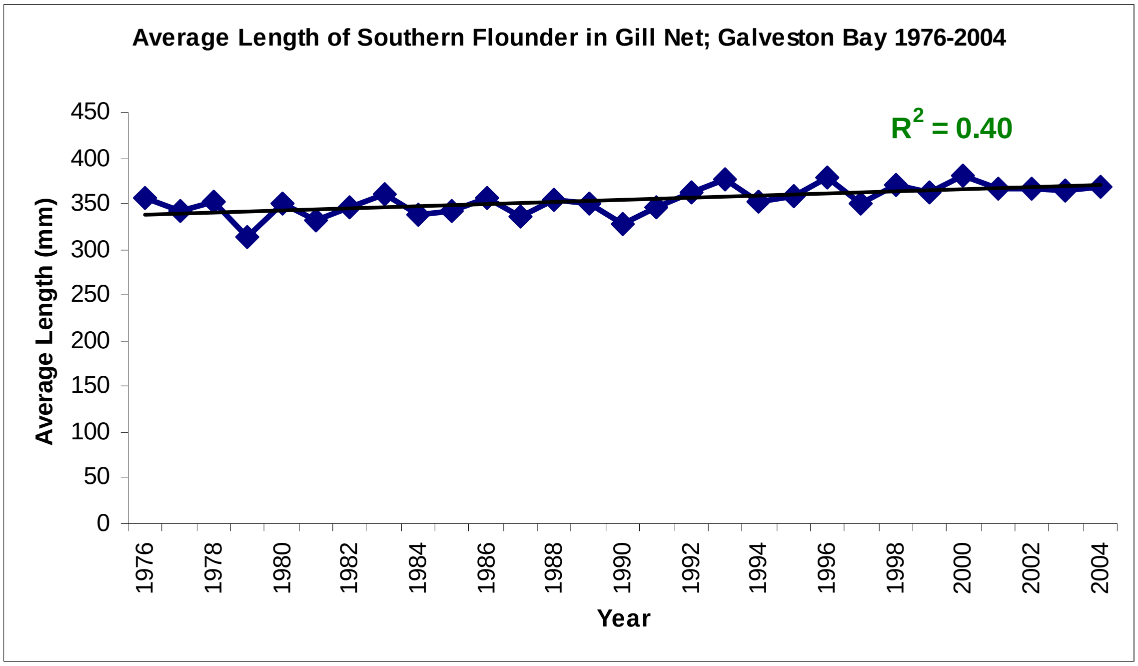
(a)



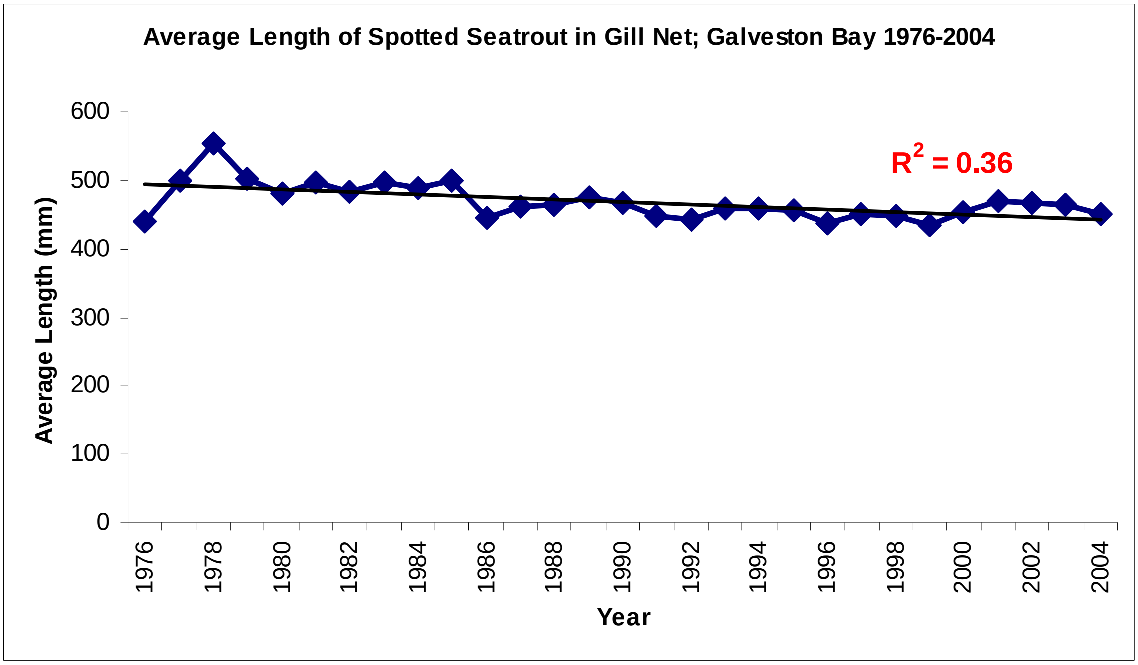
(b)



(c)


Average Length of Southern Flounder in Gill Net; Galveston Bay 1976-2004
$R^2 = 0.40$
Average Length (mm)
450
400
350
300
250
200
150
100
50
0
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year

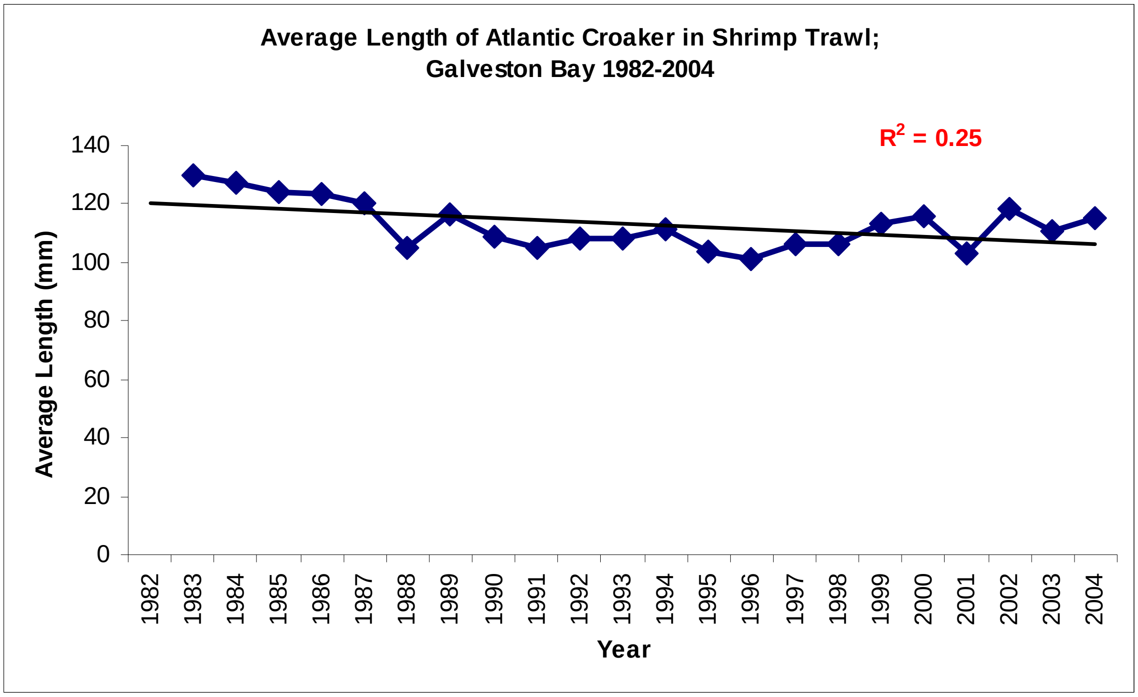
(d)


Average Length of Spotted Seatrout in Gill Net; Galveston Bay 1976-2004
$R^2 = 0.36$
Average Length (mm)
600
500
400
300
200
100
0
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year

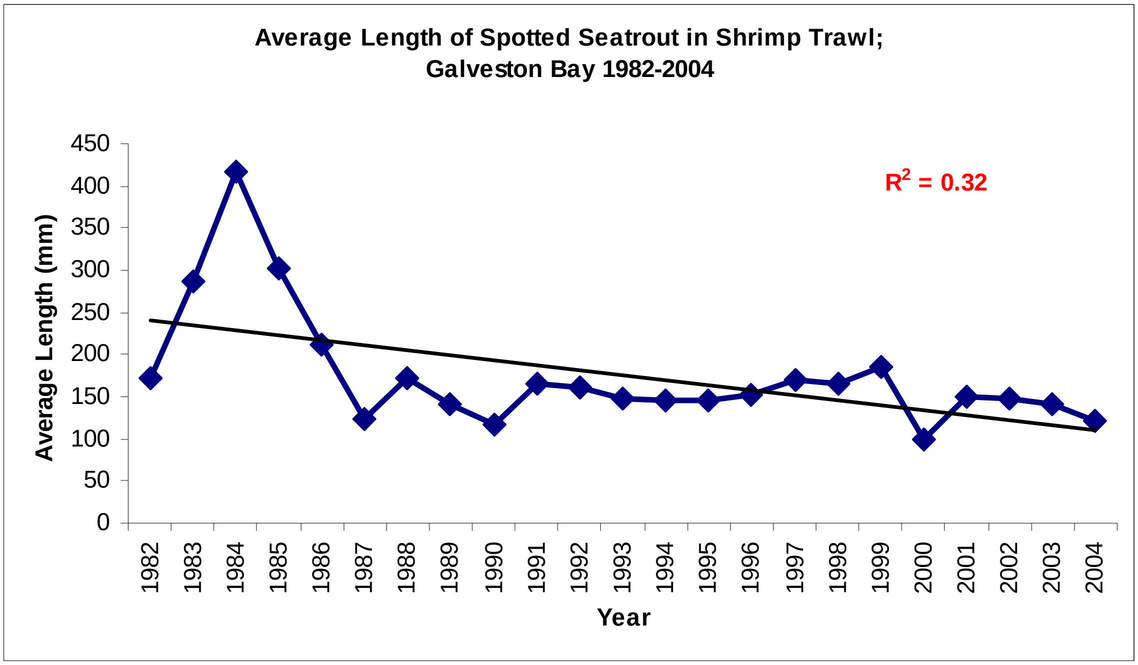
Of the nine species analyzed from shrimp trawl samples (Table 3.2.9), three exhibited decreasing trends ($R^2 \geq 0.25$) in length of fish captured during the 1982-2004 time period: Atlantic croaker ($R^2 = 0.25$), spotted seatrout ($R^2 = 0.32$), and white shrimp ($R^2 = 0.28$).

Figure 3.2.2. Trends in annual average length of (a) Atlantic croaker in shrimp trawl, (b) spotted seatrout in shrimp trawl, and (c) white shrimp in shrimp trawl.

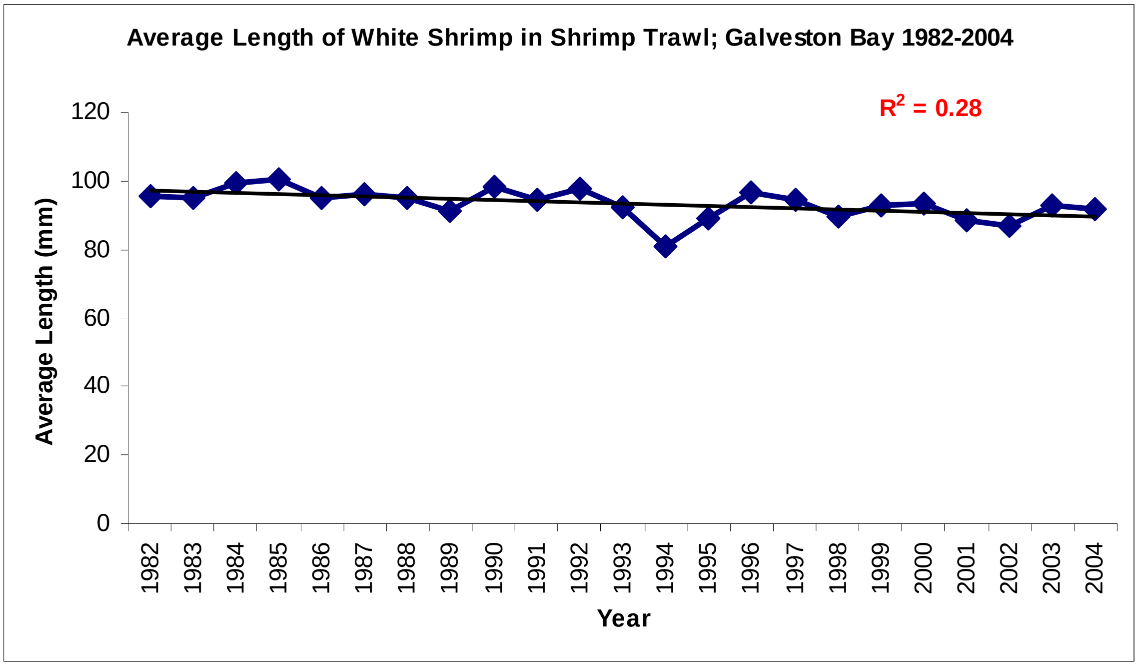
(a)



(b)



(c)



The trends shown above were used to update the indicator (Table 3.2.10) describing commercially and recreationally important fish species originally developed by the Galveston Bay Indicators Project in 2005.

Table 3.2.10. Indicator describing trends in length of commercially and recreationally import species of fish captured in gill net and shrimp trawl.

Common Name	Gill Net	Shrimp Trawl
Atlantic croaker		🟥
Black drum		
Brown shrimp	*	
Red drum	🟩	**
Sand seatrout		
Sheepshead	🟩	
Southern flounder	🟩	
Spotted seatrout	🟥	🟥
Striped mullet		
White shrimp	*	🟥

* Gear not appropriate for this species
** Sample size too small for trend analysis

Conclusion

An analysis of fisheries length data provides insight into the health of fisheries populations over time; describing the ability of populations to overcome 1) stresses placed on them by human uses, i.e. fishing pressure and bycatch and 2) the effects of unfavorable environmental conditions on growth and mortality. Declining trends in length over a period of years can indicate that mortality or harvest is higher than that which can be sustained by the population. Increasing trends in length indicate that conditions are favorable for the success of the population and age-specific rates of mortality and harvest are such that recruits have the ability to grow to a larger size. Stocking programs also impact overall length of fish and may be instituted when it is believed that fishing pressure and other mortalities may have adverse effects on a population.

Three species of finfish captured in TPWD Coastal Fisheries gill net samples exhibited increasing trends in length over the period of record: red drum, sheepshead, and Southern flounder (Figure 3.2.1a-c). The gill net samples represent large predatory fish at or near the top of the Galveston Bay food web. Of the three gill net species with increasing trends, one (red drum) is the subject of a TPWD annual stocking program. Red drum is a popular recreational species caught throughout the year in Galveston Bay. As such, red drum fry and fingerlings have been stocked in Galveston Bay in large numbers.

Two species in shrimp trawl samples also exhibited declines in length of fish: Atlantic croaker and white shrimp (Figure 3.2.2 a and c). Atlantic croaker is an important benthic predator in Gulf of Mexico estuaries. It is not as popular as red drum, spotted seatrout, or Southern flounder in terms of recreational catch, but is landed by anglers. Croaker is also an important commercial species harvested in the Eastern Gulf of Mexico. White shrimp also exhibited declining trends in length.

3.2.2 Biodiversity Analysis of Coastal Fisheries Resources

One important property of ecosystems is the diversity of species linked together by the food web and by adaptations to similar environments. Some environments have a high number of abundant species and others are depauperate in species. In some environments, certain taxa are abundant, e.g. corals in coral reefs, and in others the diversity is spread across many groups. Studies of taxonomic diversity (i.e. biodiversity) can be performed in a variety of ways. Some limit the taxa they will investigate, e.g. diversity of phytoplankton, and others limit their scope according to the methods used to collect samples of organisms, e.g. trawling.

Ecosystems with high biodiversity are generally viewed as stable, i.e. not highly disturbed. High biodiversity is viewed as a beneficial property in that some yet unstudied organisms may represent valuable resources or knowledge for human uses. Obviously human land use has resulted in loss of habitat for many species. In some cases human activity has caused the extinction of species and a concomitant loss of biodiversity.

Estuaries are not noted as ecosystems of high biodiversity when compared to coral reefs or tropical rain forests. However, tropical and subtropical estuaries, such as Galveston Bay, do provide habitat for a wide variety of organisms and serve as nurseries for many marine organisms.

Data Collection and Data Selection Criteria

In this study, we employed fisheries independent monitoring data collected by Texas Parks and Wildlife Department (TPWD) to analyze the community composition of the various ecosystems in the Galveston Bay system and their variation. Community composition can be examined using the relative abundances of the many species captured by the TPWD monitoring collections. From the relative abundances biodiversity can be estimated and used to look for spatial or temporal trends in the index. Several questions posed in the analysis are whether any of the subbays in the Galveston Bay system have exhibited a decline in biodiversity over the period of record and whether any subbay exhibits a distinctly lower or higher measure of biodiversity when compared to the other subbays. The data were also used to look at the seasonal change in biodiversity which results from species entering and leaving the ecosystem being sampled over periods of less than one year.

The data provided by TPWD were collected with standard gear types that limit the variety of organisms captured. None of the gear types are effective in collecting microfauna or flora, meiofauna or benthic infauna. Bag seine is deployed near shore in shallow water and does a very poor job of capturing large, highly mobile organisms. The majority of the catch consists of small fish and crustaceans, many in juvenile stages. Shrimp trawls can only be deployed in water depths that permit navigation of a large boat. Trawl data also is unrepresentative of large, highly mobile species, but the catch contains larger and more mobile organisms than bag seine data. Gillnets are deployed overnight in locations away from navigation channels and in water depths suitable for vertical extension of the net. Gill net data consists primarily of records of adult fish by design. Each collection gear captures a different assortment of species and sizes of organisms and provides a distinct view of the species diversity in the Galveston Bay system.

The calculation of biodiversity statistics starts with recording the number of individuals of identifiable species or species types (e.g. grass shrimp) captured in a sampling event, e.g. a 10 minute deployment of a shrimp trawl. Some species captured in the gear cannot be identified or counted and must be omitted. For example, soft bodied jellyfish or comb jellies, are usually damaged and can not be reliably counted as individuals. Some individuals cannot be identified to species and are recorded as members of a family. These we have deleted, with the exception of grass shrimp, which are an important component of the near shore estuarine community. After elimination of samples that are not precisely counted or classified, there are 101 species in the TPWD data set that could be used for estimation of biodiversity patterns. The list of these species is provided in Appendix B.

There are sometimes methodological problems with sampling events. It is our contention that there is a relationship between methodological sampling problems and poor sampling results. This is the basis for exclusion of collections with fewer than five individuals of all species. After deletion of all small sampling events, there were 9,938 sampling events that met the criterion for this analysis. Table 3.2.11 shows the large number of sampling events from which this analysis is derived. Christmas Bay is too shallow across most of its area for sampling by shrimp trawl; therefore, that subbay was omitted from the analysis of shrimp trawl data.

Table 3.2.11. Number of sampling events for each gear type in each subbay of the Galveston Bay System used in calculating biodiversity.

	Bag Seine	Shrimp Trawl	Gill Net
Trinity Bay	482	1,303	291
Upper & Lower Galveston Bay	653	2,318	404
East Bay	536	528	338
West Bay	1,091	630	674
Christmas Bay	438	27 (omitted)	225

The sampling events are identified with subbays as defined by the Galveston Bay Estuary Program (GBEP) segmentation regime (see Figure 3.1.1). Using this segmentation system allows us to distinguish among areas of the Galveston Bay system that differ in proximity to the Gulf of Mexico or the mouth of the Trinity River. Despite historical separation of Upper and Lower Galveston Bay by Redfish Reef, the two bodies of water have been continuous for many years and are combined for the purposes of this study. Performing analyses at the subbay level permits comparisons between subbays that are surrounded by different land uses or separated from the water circulation of the main bay system, such as West Bay and Christmas Bay. All of the subbays have been sampled sufficiently for diversity analyses based on all three sampling gear types with the exception of shrimp trawl samples in the Christmas Bay Complex. Diversity based on shrimp trawl samples is only analyzed for Trinity, Upper and Lower Galveston, East and West Bays.

Calculating Biodiversity from Relative Abundance

We used the Shannon-Weiner measure of biodiversity, which we will label the S-W Index. It is derived from information theory and reflects the increase in biological information represented in an ecosystem as the number of species increases and the evenness of their abundances increases. Maximum values of the Shannon-Weiner index are obtained when a large number of species are collected and every species in the data set has the same relative abundance.

Relative abundance is calculated by dividing the number of individuals of a given species in the collection by the total number of individuals of all species in the collection. These relative abundances (p_i) are combined in the following equation to yield the index value: $H = - \sum p_i (\ln p_i)$. In the following discussion of biodiversity, we focus on temporal and spatial changes.

The S-W Index values were calculated in two ways. First, an S-W Index was calculated for every collection event of the three gear types in each subbay. These were used for describing the annual and monthly patterns among subbays over the period of record. Second, we employed annual average relative abundances obtained by averaging relative abundances for a given gear type over the collections made in a particular year in a particular subbay. This approach minimizes the variation attributable to individual sampling events affected by special circumstances of a site, time or collectors. The S-W Index calculated in this way represents a maximal biodiversity for the subbays.

Characterization of Subbay Communities Using Relative Abundance

Before compressing the relative abundances into a single index of biodiversity it is useful to employ them in comparisons of the communities sampled by the three gear types in the five subbays. Every collection is a sample from the community of species living in that location. Over the period of record for these data, there has been considerable variation in the environments of the subbays. These are certainly reflected in the abundance of particular species and community composition. However, by considering the relative abundance of a large set of species captured by a gear type over many years, we can obtain information on fundamental differences among the biological communities residing in the several parts of the Galveston Bay system.

Bag Seine Collections

Upon examination of the lists of species in Table 3.2.12, it is apparent that the bag seine collections from the five subbays are revealing ecological differences. The relative abundance of small white shrimp in Upper and Lower Galveston Bay is less than that in collections from the other subbays. This is likely to be due to the difference in preferred habitat for juvenile shrimp. The higher relative abundance (RA) of brown shrimp for West Bay and Christmas Bay is likely attributable to the sandier substrates in those locations. However, the species composition and their relative abundances are quite similar.

If the relative abundances of all species captured by bag seine in each of the subbays is ranked, a Spearman rank order correlation can be calculated. The results are shown in Table 3.2.13. The species ranks of all of the subbays are significantly correlated, but the highest correlation is between West Bay and Christmas Bay (r=0.92), which shared 61 species in their bag seine data. This suggests that the ecological communities sampled by bag seine are more similar in these two subbays. The lowest correlation was between Christmas Bay and Trinity Bay (r=0.77), which shared 46 species in their bag seine data.

Table 3.2.12. Lists of the common names of the 25 species captured by bag seine in the five subbays that have the highest ranks in relative abundance over the period of record from 1977 to 2004. The total number of species in the record for each subbay out of the entire number examined is shown in parentheses after the subbay.

	East Bay Species (n=67)	**RA**	**Trinity Bay Species (n=52)**	**RA**	**Upper & Lower Galveston Bay Species (n=69)**	**RA**	**West Bay Species (n=73)**	**RA**	**Christmas Bay Species (n=64)**	**RA**
1	White Shrimp	0.1943	White Shrimp	0.1778	Atlantic croaker	0.1085	White Shrimp	0.154	White Shrimp	0.1439
2	Grass shrimp	0.1516	Grass shrimp	0.1549	Bay Anchovy	0.1029	Brown Shrimp	0.1121	Brown Shrimp	0.1133
3	Brown Shrimp	0.1154	Atlantic croaker	0.099	White Shrimp	0.0943	Inland Silverside	0.0826	Inland Silverside	0.1055
4	Atlantic croaker	0.1079	Gulf menhaden	0.0903	Gulf menhaden	0.0916	Spot	0.0755	Pinfish	0.0903
5	Gulf menhaden	0.0911	Brown Shrimp	0.0771	Blue Crab	0.0744	Grass shrimp	0.0696	Grass shrimp	0.063
6	Bay Anchovy	0.052	Striped Mullet	0.0715	Brown Shrimp	0.0695	Atlantic croaker	0.0589	Sheepshead minnow	0.0607
7	Blue Crab	0.0489	Blue Crab	0.0711	Grass shrimp	0.0649	Pinfish	0.0564	Spot	0.0605
8	Striped Mullet	0.0352	Sheepshead minnow	0.0383	Striped Mullet	0.0504	Gulf menhaden	0.0543	Atlantic croaker	0.0548
9	Inland Silverside	0.0351	Spot	0.0339	White Mullet	0.0385	Sheepshead minnow	0.0431	Gulf menhaden	0.0434
10	Spot	0.0212	White Mullet	0.0334	Spot	0.037	Bay Anchovy	0.0401	Blue Crab	0.0331
11	White Mullet	0.0211	Bay Anchovy	0.0307	Longnose killifish	0.0313	Blue Crab	0.0388	Striped Mullet	0.0305
12	Sand Seatrout	0.0186	Inland Silverside	0.0275	Thinstripe hermit	0.0262	Longnose killifish	0.0384	Longnose killifish	0.0283
13	Hard Head Catfish	0.015	Gulf Killfish	0.0162	Inland Silverside	0.0257	Striped Mullet	0.0372	White Mullet	0.0281
14	Red Drum	0.013	Sand Seatrout	0.0115	Lesser blue crab	0.0231	White Mullet	0.0328	Gulf Killfish	0.0256
15	Sheepshead minnow	0.0108	Red Drum	0.0084	Southern Kingfish	0.0215	Gulf Killfish	0.0175	Bay Anchovy	0.0224
16	Gulf Killfish	0.0101	Hard Head Catfish	0.0079	Sheepshead minnow	0.02	Thinstripe hermit	0.0131	Thinstripe hermit	0.0147
17	Pinfish	0.0075	Longnose killifish	0.0074	Hard Head Catfish	0.0198	Red Drum	0.0097	Red Drum	0.0107
18	Southern Flounder	0.0059	Pinfish	0.006	Sand Seatrout	0.0179	Spotted Seatrout	0.0062	Lesser blue crab	0.0085
19	Longnose killifish	0.0054	Threadfin Shad	0.0055	Pinfish	0.0133	Lesser blue crab	0.0054	Spotfin Mojarra	0.0067
20	Black Drum	0.0041	Spotfin Mojarra	0.0034	Gulf Killfish	0.0077	Scaled sardine	0.0051	Black Drum	0.0063
21	Least Puffer	0.0038	Spotted Seatrout	0.0033	Least Puffer	0.007	Spotfin Mojarra	0.0051	Rough Silverside	0.0055
22	Thinstripe hermit	0.0034	Southern Flounder	0.0029	Rough Silverside	0.0068	Southern Kingfish	0.0048	Hard Head Catfish	0.0051
23	Silver Perch	0.0031	Rough Silverside	0.0027	Scaled sardine	0.0065	Sand Seatrout	0.0048	Bay Whiff	0.0049
24	Rough Silverside	0.0026	Bay Whiff	0.0025	Seabob	0.0065	Hard Head Catfish	0.0042	Spotted Seatrout	0.0041
25	Lesser blue crab	0.0025	Southern Kingfish	0.0025	Red Drum	0.0049	Rough Silverside	0.004	Sand Seatrout	0.0034

Table 3.2.13. Spearman rank order correlations of the ranked relative abundances of species captured by bag seine in the five subbays of Galveston Bay. Number of shared species is shown in parenthesis. All values are significant at p<0.001.

	Upper & Lower Galveston Bay	East Bay	West Bay	Christmas Bay
Trinity	0.78 (50)***	0.88 (49)***	0.80 (49)***	0.77 (46)***
Upper & Lower Galveston Bay		0.89 (62)***	0.87 (62)***	0.80 (58)***
East			0.84 (63)***	0.81 (58)***
West				0.92 (61)***

Shrimp Trawl Collections

Of Galveston Bay's five subbays, four subbays are evaluated here using shrimp trawl data. Christmas Bay had too few trawl samples in the record. The similarity of the communities sampled by shrimp trawls is evident in Table 3.2.14, which shows the top 25 species ranked by average relative abundance in the shrimp trawl samples from the four subbays. The top three species are identical for Trinity and Upper and Lower Galveston Bays. Atlantic croaker is ranked one or two in all subbays. There are differences, of course. Trinity and Upper and Lower Galveston Bay have three freshwater species, blue catfish, common carp and smallmouth buffalo, among those ranked. West Bay has none of these species in the shrimp trawl record, and East Bay has only blue catfish.

The similarity in the community composition of the subbays that is sampled by shrimp trawl is quite apparent when Spearman rank order correlations are calculated. The highest similarity between areas is shown by Upper and Lower Galveston Bay and East Bay (r =0.90), which share 51 species in the data set. Trinity and West Bays have the lowest similarity, r =0.61 with 47 shared species. Despite differences in level of correlation, all of the Spearman correlations are highly significant. The shrimp trawl samples represent similar species communities, as would be expected in a single estuary.

Table 3.2.14. Lists of the common names of the 25 species captured by shrimp trawl in four subbays that have the highest ranks in relative abundance over the period of record from 1982 to 2004. The total number of species in the record for each subbay out of the entire number examined is shown in parentheses after the subbay.

East Bay Species (n=52)*	RA**	Trinity Bay Species (n=58)	RA	Upper & Lower Galveston Bay Species (n=75)	RA	West Bay Species (n=61)	RA
White Shrimp	0.2381	Atlantic croaker	0.2176	Atlantic croaker	0.2176	Atlantic croaker	0.2196
Atlantic croaker	0.18	White Shrimp	0.1527	White Shrimp	0.1527	Spot	0.1294
Brown Shrimp	0.0987	Gulf menhaden	0.0909	Gulf menhaden	0.0909	Atlantic brief squid	0.12
Gulf menhaden	0.0901	Blue Crab	0.0798	Blue Crab	0.0798	Pinfish	0.1049
Spot	0.0705	Atlantic Rangia	0.077	Atlantic Rangia	0.077	White Shrimp	0.061
Blue Crab	0.0573	Bay Anchovy	0.0645	Bay Anchovy	0.0645	Brown Shrimp	0.0539
Bay Anchovy	0.047	Spot	0.0541	Spot	0.0541	Blue Crab	0.0445
Striped Mullet	0.0468	Brown Shrimp	0.0537	Brown Shrimp	0.0537	Bay Anchovy	0.0392
Atlantic brief squid	0.0235	Blue Catfish	0.0421	Blue Catfish	0.0421	Sand Seatrout	0.035
Hard Head Catfish	0.0176	Brown Rangia	0.0244	Brown Rangia	0.0244	Silver Perch	0.0345
Threadfin Shad	0.0165	Striped Mullet	0.0222	Striped Mullet	0.0222	Gulf menhaden	0.0198
Sand Seatrout	0.0153	Hard Head Catfish	0.0217	Hard Head Catfish	0.0217	Hard Head Catfish	0.0152
Least Puffer	0.0096	Threadfin Shad	0.0208	Threadfin Shad	0.0208	Fringed Flounder	0.0129
Gulf butterfish	0.0084	Sand Seatrout	0.018	Sand Seatrout	0.018	Altantic Sting Ray	0.0114
Gafftopsail Catfish	0.0079	Atlantic brief squid	0.0116	Atlantic brief squid	0.0116	Thinstripe hermit	0.0114
Fringed Flounder	0.0079	Gizzard shad	0.0053	Gizzard shad	0.0053	Bay Whiff	0.0081
Bay Whiff	0.0074	Bay Whiff	0.0053	Bay Whiff	0.0053	Gulf butterfish	0.007
Black Drum	0.0069	Altantic Bumper	0.0043	Altantic Bumper	0.0043	Least Puffer	0.0063
Lesser blue crab	0.0065	Black Drum	0.0036	Black Drum	0.0036	Threadfin Shad	0.0063
Gizzard shad	0.0056	Gafftopsail Catfish	0.0034	Gafftopsail Catfish	0.0034	Mantis Shrimp	0.0061
Silver Perch	0.0056	Pinfish	0.003	Pinfish	0.003	Striped Mullet	0.0053
Cabbagehead	0.0049	Least Puffer	0.0028	Least Puffer	0.0028	Cabbagehead	0.0048
Altantic Bumper	0.0039	Sheepshead	0.0026	Sheepshead	0.0026	Altantic Cutlass Fish	0.0047
Pinfish	0.0028	Southern Flounder	0.0023	Southern Flounder	0.0023	Altantic Bumper	0.004
Thinstripe hermit	0.0028	Silver Perch	0.0021	Silver Perch	0.0021	Lesser blue crab	0.0038

* n = total number of species in the record for this bay and gear type out of 101 selected species

** RA = relative abundance calculated as average of all relative abundances for each selected sample of this gear type in this bay

Table 3.2.15. Spearman Rank Order Correlations of the Ranked Relative Abundances of Species Captured by Shrimp Trawl in the Four Subbays. Number of shared species is shown in parenthesis. All values are significant at p<0.001.

	Upper & Lower Galveston Bay	East Bay	West Bay
Trinity	0.81 (55)***	0.79 (48)***	0.61 (47)***
Upper & Lower Galveston Bay		0.90 (51)***	0.81 (56)***
East			0.76 (46)***

Gill Net Collections

The gill net collection record contains fewer species than the data from the other two gear types. The number of species for which we calculated relative abundances ranged from 30 in Trinity Bay to 41 in Upper and Lower Galveston Bay. Once again the similarity of the communities sampled is evident from the listing of ranked relative abundances in Table 3.2.16. Hard head catfish is the first or second most abundant species in all subbays. Red drum is among the top four in all subbays. The most obvious differences appear to be related to the salinity regimes of the subbays. Freshwater fish species, blue catfish, common carp and smallmouth buffalo, are ranked among the top 25 species in Trinity Bay, Upper and Lower Galveston Bay and East Bay. These species do not occur in the gill net data for West Bay or Christmas Bay.

Gill nets tend to sample adult, highly mobile organisms, quite capable of habitat choice. The correlation analysis using Spearman rank order correlation shows less similarity among the subbays for gill net collections than other gear types. This implies that the organisms sampled by gear net are distinguishing between the habitats in the subbays. Despite the lower values, all correlations are significant. The correlations of gill net data from Trinity Bay with the data from East Bay (r =0.62), West Bay (r =0.59) and Christmas bay (r =0.69) are the lowest in Table 3.2.17. The highest correlation in Table 3.2.17 is between the gill net relative abundances from West Bay and Christmas Bay. These results are consistent with expectations based on the importance of salinity and substrate in determining the species composition of estuarine areas. East Bay, West Bay and Christmas Bay are higher in salinity and have sandier substrates than Trinity Bay because they are closer to the Gulf.

Table 3.2.16. Lists of the common names of the 25 species captured by gill net in five subbays that have the highest ranks in relative abundance over the period of record from 1977 to 2004. The total number of species in the record for each subbay out of the entire number examined is shown in parentheses after the subbay.

Trinity Bay Species (n=30)	RA	Upper & Lower Galveston Bay Species (n=41)	RA	East Bay Species (n=34)	RA	West Bay Species (n=39)	RA	Christmas Bay Species (n=32)	RA
Hard Head Catfish	0.2656	Hard Head Catfish	0.3304	Hard Head Catfish	0.3003	Hard Head Catfish	0.1895	Red Drum	0.2142
Red Drum	0.1807	Gizzard shad	0.1247	Red Drum	0.1348	Gulf menhaden	0.1659	Hard Head Catfish	0.1784
Gizzard shad	0.1499	Gulf menhaden	0.1234	Gizzard shad	0.1331	Red Drum	0.1327	Gizzard shad	0.0923
Striped Mullet	0.0888	Red Drum	0.0896	Black Drum	0.1148	Spotted Seatrout	0.1018	Spotted Seatrout	0.0921
Black Drum	0.0683	Spotted Seatrout	0.0865	Spotted Seatrout	0.0781	Black Drum	0.0984	Gulf menhaden	0.0837
Blue Catfish	0.0403	Black Drum	0.0698	Gulf menhaden	0.0478	Atlantic croaker	0.0731	Black Drum	0.0777
Spotted Seatrout	0.0389	Striped Mullet	0.047	Striped Mullet	0.0476	Gizzard shad	0.0561	Gafftopsail Catfish	0.0537
Atlantic croaker	0.0325	Atlantic croaker	0.0466	Atlantic croaker	0.0469	Spot	0.0376	Atlantic croaker	0.0522
Smallmouth Buffalo	0.0258	Spot	0.016	Gafftopsail Catfish	0.0427	Striped Mullet	0.0373	Striped Mullet	0.035
Spotted Gar	0.0214	Gafftopsail Catfish	0.0136	Spot	0.0089	Gafftopsail Catfish	0.0363	Blue Crab	0.0271
Gulf menhaden	0.0204	Blue Crab	0.0127	Blue Crab	0.0086	Southern Flounder	0.0193	Spot	0.0228
Southern Flounder	0.0163	Southern Flounder	0.0085	Southern Flounder	0.0081	Blue Crab	0.014	Southern Flounder	0.0209
Blue Crab	0.0129	Sand Seatrout	0.0085	Spotted Gar	0.0071	Sheepshead	0.0096	Sheepshead	0.0165
Sheepshead	0.0091	Sheepshead	0.008	Blue Catfish	0.0061	Sand Seatrout	0.0058	Gulf Stone Crab	0.0055
Common Carp	0.0088	Spanish Mackerel	0.0031	Sand Seatrout	0.0057	Spanish Mackerel	0.0055	Sand Seatrout	0.005
Sand Seatrout	0.0056	Blue Catfish	0.0022	Sheepshead	0.0042	Gulf Stone Crab	0.0043	Thinstripe hermit	0.0048
Spot	0.0052	Cabbagehead	0.0014	Spanish Mackerel	0.0017	Thinstripe hermit	0.002	Pinfish	0.0043
Gafftopsail Catfish	0.0049	Smallmouth Buffalo	0.001	Triple tail	0.0008	Pinfish	0.0019	Cabbagehead	0.0033
Spanish Mackerel	0.0022	Spotted Gar	0.001	Smallmouth Buffalo	0.0006	Altantic Sting Ray	0.0011	Spanish Mackerel	0.0021
Atlantic Rangia	0.0011	Common Carp	0.0007	Southern Kingfish	0.0004	Southern Kingfish	0.001	Pigfish	0.002
Altantic Sting Ray	0.0003	Gulf Stone Crab	0.0007	Silver Perch	0.0004	Triple tail	0.001	Silver Perch	0.0012
Threadfin Shad	0.0002	Thinstripe hermit	0.0007	White Mullet	0.0003	Pigfish	0.001	Altantic Sting Ray	0.0012
Tarpon	0.0002	Southern Kingfish	0.0007	Gulf Stone Crab	0.0002	Silver Perch	0.0006	White Mullet	0.0011
White Mullet	0.0001	Pigfish	0.0005	Altantic Sting Ray	0.0002	Gray Snapper	0.0003	Southern Kingfish	0.0011
Brown Rangia	0.0001	Triple tail	0.0004	Pigfish	0.0002	Spotted Gar	0.0002	Triple tail	0.0007

Table 3.2.17. Spearman rank order correlations between the species captured in gill net samples from the five subbays ranked by average relative abundance over the period of record.

	Upper and Lower Galveston Bay	East Bay	West Bay	Christmas Bay
Trinity Bay	0.75 (29)***	0.62 (28)***	0.59 (24)**	0.69 (23)***
Upper and Lower Galveston Bay		0.91 (31)***	0.91 (32)***	0.92 (29)***
East Bay			0.91 (28)***	0.84 (28)***
West Bay				0.94 (28)***

Monthly Patterns of Biodiversity Based on Analysis of S-W Index

Bag Seine

When the S-W Indexes calculated for all collections meeting the criterion were averaged by month, they produced the values shown in Table 3.2.18. One way ANOVA of the monthly values for each subbay showed significant variation in all five tests. The explanation for significant variation is clear from an examination of the change in S-W Index over the annual cycle. Biodiversity in bag seine samples is low in winter, i.e. values for December, January and February, and highest in summer, i.e. S-W values for June, July and August. When the monthly bag seine biodiversity indices were analyzed by ANOVA across subbays, there is no significant difference among the subbays.

Table 3.2.18. Monthly mean S-W Index values over the period of record from 1977 to 2004 based on bag seine collections from five subbays. Variation among months in all subbays is significant (p<0.001). Number of months in which samples were collected is shown as n.

	Trinity Bay		Upper & Lower Galveston Bay		East Bay		West Bay		Christmas Bay	
Month	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
January	34	0.923	35	0.914	41	0.839	62	0.994	41	1.056
February	42	0.987	33	0.783	38	1.143	82	1.074	25	1.051
March	40	1.027	45	1.062	52	1.002	90	1.103	43	1.145
April	28	1.09	68	1.082	52	1.16	96	1.201	37	1.245
May	46	1.061	66	1.169	49	1.24	105	1.143	36	1.195
June	32	1.421	57	1.284	44	1.329	106	1.339	41	1.36
July	53	1.302	69	1.400	41	1.371	90	1.466	48	1.399
August	50	1.308	56	1.363	51	1.373	93	1.381	37	1.327
September	45	0.872	64	1.233	53	1.101	93	1.301	36	1.216
October	36	0.861	67	1.19	42	0.922	94	1.036	32	0.933
November	40	1.215	58	1.046	37	1.001	93	0.978	38	1.043
December	36	0.877	35	0.886	36	0.998	87	1.009	24	1.164

Shrimp Trawl

Christmas Bay is too shallow to be sampled consistently with this gear and is omitted. Applying ANOVA to the monthly biodiversity indices obtained from shrimp trawl collections shows some interesting differences. There are significant differences among subbays. Upper and Lower Galveston Bay, the largest sampling area, tends to exhibit higher biodiversity as does West Bay. Monthly estimates of biodiversity also have significant differences ($p < 0.001$) within subbay. Collections in the period from July to October have higher biodiversity than those from other months in general. However, shrimp trawl collections in West Bay show high S-W Index values from April to October. In Trinity and East Bay the biodiversity values fall after September. The winter season from December to February shows the same pattern of lower biodiversity seen in bag seine samples.

Table 3.2.19. Monthly mean S-W Index values based on shrimp trawl samples collected in four subbays over the period of record from 1982 to 2004. Variation among months in all subbays is significant ($p<0.001$). Number of months in which samples were collected is shown as n.

	Trinity Bay		Upper & Lower Galveston Bay		East Bay		West Bay	
Month	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
January	87	1.051	36	1.078	166	1.145	25	0.857
February	93	1.028	52	1.134	158	1.21	32	0.909
March	105	1.116	47	1.135	212	1.254	43	1.121
April	126	1.07	49	1.278	197	1.266	63	1.492
May	117	1.226	49	1.25	210	1.288	55	1.441
June	116	1.201	47	1.288	198	1.311	62	1.381
July	122	1.384	36	1.480	203	1.355	63	1.4
August	116	1.325	44	1.373	189	1.405	65	1.348
September	105	1.257	51	1.433	202	1.442	57	1.473
October	113	1.105	43	1.18	184	1.456	70	1.423
November	103	1.161	41	1.111	209	1.268	61	1.25
December	100	1.134	33	0.972	190	1.155	34	1.122

Gill Net

The record of gill net collections shows temporal gaps when analyzed by month. Months with fewer than two collections in the record were omitted from the table. It appears that summer and winter are under-sampled with gill nets. The focus is on spring and fall. July and August are not represented in Trinity Bay, August and December in East Bay, July in Upper and Lower Galveston Bay, and February, March and August in Christmas Bay. Despite the gaps, there appear to be patterns similar to those shown in monthly biodiversity values for other gear types. January and February exhibit lower S-W Index values than other months. High biodiversity values can occur as early as March and as late in the year as November. This suggests that the use of bay habitat by adult fish is less episodic than the use of bay habitat by the life history stages and species captured by shrimp trawl and bag seine.

Table 3.2.20. Monthly mean S-W Index values based on gill net samples collected in five subbays over the period of record from 1977 to 2004. Variation among months in all subbays is significant ($p<0.01$). Number of months in which samples were collected is shown as n.

	Trinity Bay		East Bay		Upper & Lower Galveston Bay		West Bay		Christmas Bay	
Month	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
January	3	1.171	3	1.07	5	0.79	5	0.892	4	1.202
February	4	0.229	2	0.348	10	0.959	3	1.024	1	-
March	3	1.514	4	1.219	6	1.497	5	1.782	0	-
April	34	1.487	66	1.341	53	1.277	96	1.516	34	1.717
May	62	1.331	71	1.354	80	1.206	147	1.535	37	1.736
June	39	1.396	26	1.447	44	1.242	63	1.646	32	1.764
July	1	-	2	1.511	1	-	3	1.303	3	1.65
August	0	-	1	-	3	1.421	5	1.291	0	-
September	28	1.633	60	1.582	51	1.429	129	1.698	34	1.845
October	57	1.485	55	1.656	95	1.523	150	1.721	53	1.843
November	57	1.406	45	1.527	50	1.437	58	1.506	23	1.766
December	2	1.374	1	-	6	1.209	10	1.283	3	1.472

Annual Patterns of Biodiversity Based on Analysis of S-W Index

Shannon-Weiner biodiversity indices can be estimated from whatever sampling of species abundances one considers to comprise a collection. All of the prior S-W Index values were calculated for individual collection events. We also performed calculations of the S-W Index using relative abundances that were annualized. In order to annualize the biodiversity data for the three gear types, we averaged the relative abundance values for each of the target species over all of the sampling events during the particular year.

Some sampling events capture very large numbers of species that are patchily distributed or occur in very high abundances for a short temporal period. The method adopted here reduces the effect of such sampling events and increases the effect of rare species captured in samples of few individuals. It is our intention to reduce the effect of samples with large numbers of white shrimp, brown shrimp, Gulf menhaden, and similar highly abundant species with patchy distributions. This method has the effect of increasing evenness among species and increasing the apparent number of species in a collection. The S-W indices resulting from this approach can be considered to be maximal annual biodiversity values.

Bag Seine

The difference resulting from the method of calculating annual S-W Index values from S-W indices for individual sampling events and annualized S-W indices can be seen by comparing Tables 3.2.21 and 3.2.22. In Trinity Bay, the range of annual S-W values calculated from individual sampling events ranges from 0.873 in 1999 to 1.381 in 1982. Those same years have S-W indices calculated from annualized relative abundances that are both 2.35.

The variation among subbays in biodiversity calculated from S-W indices for each sample is not significant. Individual samples tend to have small numbers of species and large variation in sample numbers resulting in low estimates of biodiversity.

Table 3.2.21. Annual average S-W Index values for bag seine samples from five subbays over the period of 1978 to 2004. Number of samples in a year is shown as n. One way ANOVA results are only significant for Upper and Lower Galveston Bay (p<0.01).

	Trinity Bay		Upper & Lower Galveston Bay		East Bay		West Bay		Christmas Bay	
YEAR	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
1978	4	1.147	14	1.356	5	1.238	15	1.234	10	1.526
1979	3	1.133	12	0.668	5	1.148	27	1.231	9	1.515
1980	6	1.198	8	1.087	2	1.064	25	1.135	15	1.339
1981	9	1.074	13	1.095	10	0.784	33	1.202	7	1.027
1982	10	1.381	19	1.170	12	1.086	42	1.229	15	1.399
1983	7	1.286	16	1.252	12	1.417	43	1.320	14	1.239
1984	8	1.122	18	1.324	17	1.308	28	1.117	8	1.103
1985	14	1.195	15	1.116	18	1.158	12	1.198	12	1.128
1986	19	1.016	10	1.198	17	1.119	25	1.222	9	1.041
1987	10	1.215	19	1.056	11	1.269	24	1.446	11	1.001
1988	13	0.948	28	1.096	14	1.083	28	1.256	13	0.974
1989	6	1.004	32	1.264	20	1.381	26	0.833	13	1.251
1990	18	0.920	30	1.262	23	1.153	41	1.095	13	1.261
1991	11	1.319	29	1.043	20	1.027	46	1.210	14	1.375
1992	29	1.101	24	1.030	22	1.013	72	1.197	16	1.192
1993	32	1.185	26	1.233	24	1.188	53	1.146	17	1.338
1994	34	1.079	27	0.961	28	1.162	51	1.023	17	1.292
1995	20	0.991	35	1.169	27	1.297	44	1.071	27	1.208
1996	27	1.098	32	1.159	32	0.977	50	1.121	17	1.003
1997	24	1.049	29	1.306	31	1.253	54	1.216	16	1.012
1998	33	1.056	33	1.093	32	1.107	54	1.120	15	1.135
1999	18	0.873	30	1.321	27	1.115	52	1.202	31	1.148
2000	26	1.162	27	1.075	24	0.996	47	1.178	27	1.223
2001	28	1.182	23	1.146	20	1.245	53	1.298	22	1.195
2002	29	1.103	37	1.219	28	1.055	45	1.209	19	0.966
2003	21	0.947	34	0.940	28	0.989	47	1.135	21	1.058
2004	20	0.961	30	1.333	27	1.033	51	1.211	24	1.285
Mean		**1.102**		**1.147**		**1.136**		**1.180**		**1.194**

The values in Table 3.2.22 represent the number of species and the distribution of relative abundances observed over an annual sampling period. The number of species increases and generates higher S-W values if the sampling time is extended as in this method. This approach may facilitate a comparison between subbays, but obscures any variation associated with seasonality. There is considerable year-to-year variation within a subbay and sampling gear with the annualized, maximal S-W values, but the variance is generally less than observed within a year in a subbay among individual samples.

Table 3.2.22. Bag Seine Biodiversity by Subbay based on annualized samples.

YEAR	Trinity Bay	Upper & Lower Galveston Bay	East Bay	West Bay	Christmas Bay
1978	2.02	2.58	2.06	2.53	2.52
1979	1.87	2.46	2.13	2.79	2.77
1980	2.04	2.23	1.46	2.59	2.75
1981	2.10	2.60	2.04	2.43	2.22
1982	2.35	2.66	2.13	2.58	2.80
1983	2.26	2.51	2.51	2.70	2.59
1984	2.28	2.49	2.45	2.69	2.45
1985	2.43	2.69	2.52	2.54	2.51
1986	2.33	2.57	2.53	2.74	2.23
1987	2.38	2.80	2.28	2.68	2.48
1988	1.98	2.62	2.38	2.57	2.44
1989	2.18	2.88	2.65	2.44	2.66
1990	2.37	2.86	2.40	2.68	2.65
1991	2.48	2.60	2.40	2.78	2.76
1992	2.44	2.81	2.36	2.86	2.74
1993	2.53	2.73	2.50	2.73	2.58
1994	2.34	2.60	2.19	2.70	2.87
1995	2.40	2.99	2.40	2.80	2.62
1996	2.25	2.90	2.35	2.71	2.43
1997	2.39	2.75	2.58	2.82	2.60
1998	2.53	2.75	2.42	2.81	2.66
1999	2.35	2.70	2.38	2.78	2.69
2000	2.69	2.90	2.34	2.91	2.78
2001	2.51	2.73	2.53	2.73	2.68
2002	2.39	2.93	2.61	2.75	2.57
2003	2.45	2.87	2.45	2.63	2.48
2004	2.31	2.92	2.38	2.80	2.66
Mean	**2.32**	**2.71**	**2.35**	**2.70**	**2.60**

The S-W Index for bag seine samples from Trinity Bay range from 1.87 to 2.69 with the annualized method. East Bay shows a relatively extreme year in 1980 with a reported biodiversity of 1.46 compared to 2.65 in 1989. We have no explanation for this anomalous year in East Bay, but it suggests caution in basing conclusions about ecosystem changes on limited data sets. Overall the diversity levels in Upper and Lower Galveston, West and Christmas Bays are higher than those in Trinity and East Bays. Upper and Lower Galveston Bays have an advantage over the other subbays in that the area is larger. Number of species sampled tends to increase with sampling area. However, West and Christmas Bays are smaller than Trinity Bay, but have higher diversity values. This higher diversity may result from closer proximity to the Gulf of Mexico, which is a pool of many more species than typically reside in the estuary.

Shrimp Trawl

As seen in Table 3.2.23, West Bay has the highest mean S-W values with a range of annual S-W values calculated from individual sampling events from 1.127 in 2000 to 1.537 in 1983. The lowest mean S-W values over the period of record occur in Trinity Bay with a mean value of 1.177. The variation among subbays in biodiversity calculated from S-W indices for each sample is significant in Trinity (p>0.001), Upper and Lower (p>0.01), and East Bays (p>0.001).

Table 3.2.23. Annual Shannon-Wiener Index for Shrimp Trawl Samples from Four Subbays for the Period of Record; 1982-2004.

	Trinity Bay		**Upper & Lower Galveston Bay**		**East Bay**		**West Bay**	
Year	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
2000	56	1.370	95	1.347	26	1.618	27	1.127
1995	60	1.230	111	1.329	24	1.373	19	1.149
1998	57	1.205	122	1.256	18	1.317	25	1.174
1996	54	1.152	99	1.297	15	1.247	29	1.177
1987	51	1.156	101	1.329	18	1.151	30	1.214
1988	56	1.191	108	1.323	19	1.018	24	1.237
1994	49	1.123	92	1.284	23	1.345	36	1.260
1997	55	1.028	107	1.196	28	1.328	23	1.266
2003	66	1.159	94	1.289	26	1.115	23	1.286
1999	59	1.319	96	1.400	28	1.434	26	1.287
2004	61	1.093	106	1.378	27	1.368	23	1.287
1992	48	1.169	106	1.354	29	1.227	27	1.309
2002	63	1.363	97	1.298	19	1.179	36	1.322
2001	64	1.205	103	1.276	29	1.021	23	1.330
1991	57	1.249	96	1.235	15	1.065	30	1.343
1993	59	1.169	97	1.273	16	1.274	30	1.351
1982	56	1.129	105	1.223	18	1.018	32	1.378
1986	55	1.174	97	1.249	26	1.236	30	1.388
1989	57	1.064	111	1.281	26	1.234	22	1.416
1984	54	1.068	90	1.327	21	1.014	30	1.436
1990	54	1.132	81	1.234	21	1.297	34	1.460
1985	53	1.275	113	1.421	26	1.197	26	1.534
1983	59	1.027	91	1.263	30	1.096	25	1.537
Mean		**1.177**		**1.299**		**1.232**		**1.319**
		p<0.001		**p<0.01**		**p<0.001**		**ns**

Gill Net

Comparing Tables 3.2.24 and 3.2.25 shows a dramatic difference between the annualized values in Table 3.2.25 and the individual sample values in Table 3.2.24. Only one value in Table 3.2.24 exceeds 2.0 and few in Table 3.2.25 fall below that value. However, the results of comparing across subbays are the same. West Bay and Christmas Bay have higher biodiversities as measured by samples from gill net collections than Trinity, Upper and Lower Galveston and East Bays. There are fewer gill net samples per year than bag seine and shrimp trawl, but this result is consistent with generally accepted opinions about the subbays. Christmas Bay is designated as a coastal preserve and considered to be closer to pristine than the other bays. Departure from pristine conditions is normally associated with loss of biodiversity.

Table 3.2.24. Gill net biodiversity by year in all subbays of Galveston Bay based on average S-W values from individual collections.

	Trinity Bay		Upper & Lower Galveston Bay		East Bay		West Bay		Christmas Bay	
Year	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**
1977	4	0.808	12	1.067	3	0.762	13	1.284	4	1.879
1978	5	1.345	11	1.063	1	-	5	1.471	3	1.748
1979	7	1.063	14	1.146	8	1.181	13	1.356	4	1.541
1980	5	1.406	12	1.202	3	1.538	13	1.573	5	1.674
1981	8	1.145	10	1.256	7	1.379	25	1.546	7	1.526
1982	7	1.474	9	1.379	12	1.562	39	1.587	15	1.757
1983	13	1.200	11	1.283	9	1.455	32	1.702	14	1.761
1984	8	1.313	10	1.454	13	1.726	27	1.779	11	1.645
1985	9	1.481	16	1.394	17	1.477	23	1.595	9	1.866
1986	13	1.337	12	1.464	15	1.521	27	1.673	8	1.834
1987	9	1.617	15	1.197	14	1.193	23	1.555	11	1.832
1988	15	1.375	12	1.391	14	1.428	24	1.626	6	1.943
1989	15	1.437	13	1.216	17	1.399	23	1.499	10	1.728
1990	6	1.591	11	1.333	14	1.217	33	1.515	9	1.978
1991	5	1.218	12	1.288	12	1.551	34	1.596	9	1.816
1992	16	1.438	18	1.402	13	1.551	24	1.602	6	1.534
1993	12	1.370	11	1.206	14	1.234	28	1.402	9	1.575
1994	15	1.371	14	1.400	12	1.502	28	1.665	8	1.515
1995	10	1.401	23	1.261	11	1.423	24	1.631	7	1.829
1996	9	1.465	18	1.303	12	1.395	28	1.659	9	1.789
1997	8	1.585	15	1.380	16	1.677	28	1.569	7	1.583
1998	18	1.573	14	1.700	9	1.519	26	1.645	6	1.759
1999	12	1.569	11	1.627	16	1.696	25	1.741	6	1.912
2000	13	1.408	17	1.383	14	1.534	24	1.525	9	1.714
2001	12	1.592	19	1.416	14	1.454	25	1.582	5	1.815
2002	11	1.669	18	1.411	16	1.479	23	1.703	6	2.017
2003	13	1.467	19	1.571	16	1.386	18	1.680	10	1.842
2004	12	1.377	20	1.385	15	1.571	16	1.832	11	1.958
Mean		**1.396**		**1.342**		**1.437**		**1.593**		**1.763**
		ns		**ns**		**p<0.001**		**p<0.01**		**ns**

Table 3.2.25. S-W Biodiversity values calculated using annualized relative abundances for gill net collections.

Year	Trinity Bay	Upper and Lower Galveston Bay	East Bay	West Bay	Christmas Bay
1977	1.808	1.957	1.264	2.161	2.201
1978	1.710	1.897	-	2.103	2.186
1979	1.745	1.880	1.970	2.109	2.052
1980	1.996	2.007	1.750	2.276	2.216
1981	2.162	1.961	2.130	2.290	2.079
1982	1.991	2.076	2.255	2.222	2.313
1983	1.948	1.897	2.059	2.275	2.341
1984	1.775	1.959	2.054	2.340	2.001
1985	2.084	2.034	1.909	2.290	2.298
1986	1.765	2.091	2.106	2.330	2.155
1987	2.153	2.082	1.695	2.356	2.348
1988	2.002	1.866	1.838	2.306	2.306
1989	2.148	1.836	1.978	2.307	2.088
1990	1.891	2.217	1.752	2.155	2.415
1991	1.480	2.001	2.092	2.335	2.436
1992	2.194	1.990	2.000	2.272	1.915
1993	2.129	1.991	1.969	2.343	2.225
1994	2.010	1.843	1.994	2.326	1.912
1995	1.980	2.179	2.039	2.419	2.423
1996	2.064	2.005	1.934	2.443	2.267
1997	2.184	2.091	2.343	2.272	2.123
1998	2.254	2.269	2.004	2.349	2.119
1999	2.309	2.145	2.211	2.418	2.308
2000	2.126	2.126	2.128	2.444	2.230
2001	2.137	2.162	2.085	2.212	2.226
2002	2.184	2.223	2.053	2.410	2.320
2003	2.210	2.125	2.146	2.180	2.264
2004	2.224	2.096	2.363	2.404	2.438
Mean	**2.024**	**2.036**	**1.982**	**2.298**	**2.222**

Spatial and Temporal Change in Annualized Biodiversity Indices

Samples were located according to the latitude and longitude of the starting point of the sampling event. These points were located in a segment of the GBEP segmentation scheme (Figure 3.1.1). Based on the segment in which the sampling began, the sample was assigned to a particular subbay within the system. All of the subbays were sampled by all gear types at an appropriate frequency with the exception of Christmas Bay, which has a depth profile that is not appropriate for trawl samples.

In Table 3.2.26, the average S-W Index value over all of the years of record is displayed for all subbays for which it can be calculated. It is clear that there is very little variation among the subbays in diversity estimates obtained by a particular sampling gear. All of the bag seine values range from 2.32 to 2.71. Gill net values range from 1.98 to 2.30 and shrimp trawl from 2.28 to 2.57. This result is expected for samples from areas in such close proximity and sharing so many ecological characteristics. The variation within these statistics was shown in the listing of common species in the samples.

Table 3.2.26. Average over all years for all subbays based on the annualized S-W Index for all gear types.

Subbay	Bag Seine	Shrimp Trawl	Gill Net
Trinity Bay	2.32	2.38	2.02
Upper & Lower Galveston Bay	2.71	2.57	2.04
East Bay	2.35	2.28	1.98
West Bay	2.7	2.47	2.3
Christmas Bay	2.6	NA	2.22

Annualized S-W indices for samples collected in Upper and Lower Galveston Bay over the period of record are graphed in Figure 3.2.3 for each of the three gear types: bag seine, shrimp trawl, and gill net. Both bag seine and gill net biodiversity values appear to be showing significant increasing trends over time with $R^2 = 0.52$ and $R^2 = 0.35$, respectively. Shrimp trawl exhibited no trend ($R^2 = 0.02$). Of the three gear types, the highest annualized Shannon-Wiener Index values occur for samples collected in bag seine and gill net samples.

This finding is difficult to explain. It appears that, when using annualize relative abundance values, the biodiversity of small near shore animals and large mobile organisms captured by these two gear types has increased in a linear fashion. The increases are small, but the trend is clear. This might be interpreted as an indication that better ecological conditions obtain now than in the early 1980's. Additional trend analyses for the remaining subbays are planned for the future.

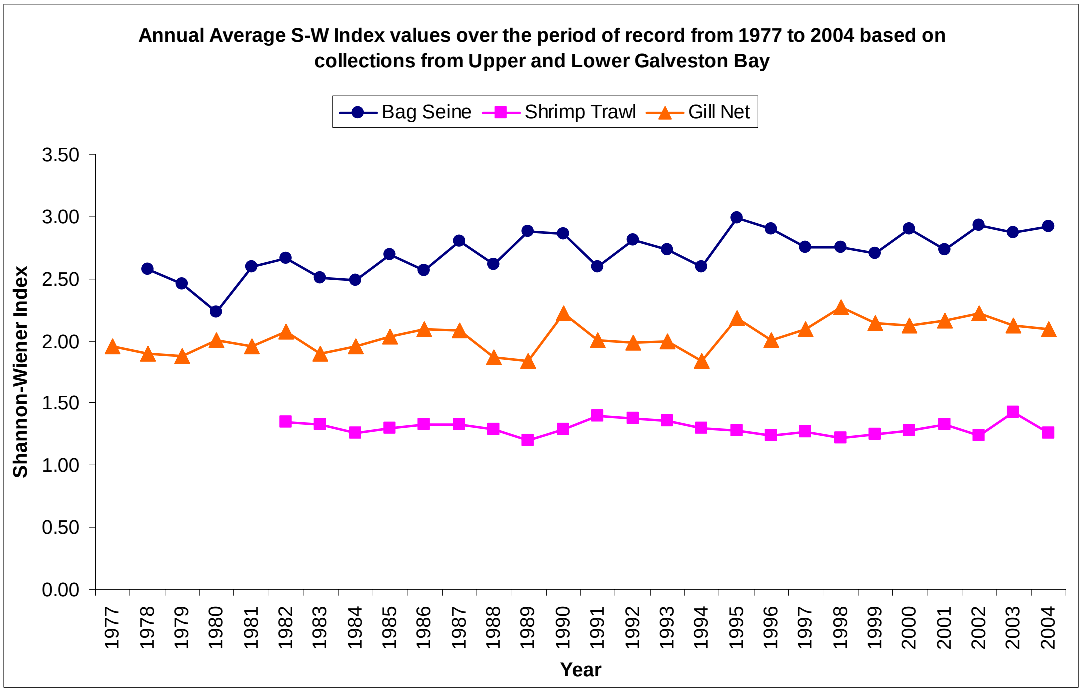


Figure 3.2.3. Trends in Annual Average S-W Index values over the period of record from 1977 to 2004 based on collections from Upper and Lower Galveston Bay. Both bag seine and gill net biodiversity values appear to be showing significant increasing trends over time with $R^2 = 0.52$ and $R^2 = 0.35$, respectively.