SPATIOTEMPORAL AND HABITAT-MEDIATED FOOD WEB DYNAMICS IN LAVACA BAY, TEXAS

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ABSTRACT

Examining food web dynamics is important for understanding ecosystem-wide interactions in marine systems. The purpose of this study was to examine spatial and temporal trophic structure in subtidal oyster reefs as compared to other estuarine habitat types (i.e., intertidal marsh and non-vegetated bottom) in Lavaca Bay, Texas. This study also integrated spatiotemporal food web analysis by combining stomach content analysis and stable isotope techniques. Sampling occurred seasonally from July 2006 to April 2007. Samples of macroinvertebrates and fishes were collected using epi-benthic sleds, modified epi-benthic sleds, and gill nets for both stomach content and stable isotope analyses. In addition, samples of vegetation, particulate organic matter, and benthic organic matter were collected for stable isotope analysis. The Lavaca Bay food web is dynamic supporting a variety of organisms representing trophic levels from primary producers to tertiary consumers. Stomach content analysis showed that economically important species, such as *Brevoortia patronus* and penaeid shrimp, were not only exceptionally abundant within the estuary, but also have a high index of relative importance as prey items. The distribution of trophic levels among habitat types varied, with the subtidal oyster reef habitat supporting a higher mean trophic level as compared to the marsh and non-vegetated habitats. Subtidal oyster reef was the only habitat that supported both large numbers of low trophic level consumers and apex predators. Spatially, the lower region of the bay supports a more robust food web with comparably more links. This could be due to many factors such as variation in fresh water inflow (i.e. salinity), available habitat types, and proximity to a tidal inlet. Temporally, the summer and fall food webs of Lavaca Bay support a higher trophic level food web with more secondary and tertiary consumers and available links. Combining both stomach content

and stable isotope methods provides detailed assessments of food web dynamics in these systems, especially for lower trophic level species. This information is particularly timely because oyster reef coverage in the Lavaca Bay system, and many others, have been diminishing in recent years, and alterations to this habitat type may have wide-ranging impacts. Thus, this study provides information on the ecological roles of subtidal oyster reefs and aids in planning for improved management ensuring the persistence of these reefs.

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INTRODUCTION

Determining the ecological role of estuarine habitats is critical for effective management and protection of Essential Fish Habitat (EFH) as mandated by the 1996 Magnuson-Stevens Fisheries Conservation and Management Act (and its recent reauthorization). This act directs fishery management councils and the National Marine Fisheries Service to identify EFH for all managed fishery species and to identify adverse impacts, actions to ensure conservation and enhancement, and approaches to the restorations of EFH (Minello 1999). The ability of fisheries managers to identify EFH depends on the availability of information on various habitats, particularly in estuaries.

It is well understood that estuaries are one of the most productive natural ecosystems in the world (Schelske and Odum 1962). Along the Texas coast, estuaries contain productive habitats such as intertidal marshes, seagrass beds, mangrove forests, and oyster reefs that serve as nursery grounds for the majority of estuarine-dependent sport and commercial fishes (Skud and Wilson 1960, Carr and Adams1973). Habitat selection is critical to estuarine organisms because it determines their relative fitness, food selection, and ultimate survival (Werner et al. 1983). Several studies have documented the importance of vegetated habitats to the survival of fishes and invertebrates by reporting higher growth rates in vegetated habitats relative to non-vegetated bottom (Minello et al. 1989, Stunz and Minello 2001).

In the past, much work has been done on these vegetated habitats and intertidal oyster reefs along the east coast of the U.S. within estuarine systems (Coen et al. 1995, Wenner et al. 1996, Boudreaux et al. 2006), while little research has focused on subtidal oyster reefs, especially along the Gulf coast (Boesch and Turner 1984, Bell and Westoby 1986, Minello et al 1989). There is a growing appreciation of the need to quantify the value of subtidal oyster reef as habitat for estuarine fishes (Zimmerman et al. 1989, Harding and Mann 1999, Lenihan et al. 2001). Oyster reefs qualify as EFH because of the importance of reefs to individual oysters themselves (Coen et al. 1999); however, scientists are beginning to understand what precise characteristics of oyster reefs enhance oyster recruitment, growth, and their importance as a habitat for fishes and other macroinvertebrates (Coen et al 1999, Peterson et al. 2003, Heck et al. 2005).

Understanding importance of habitat requires the ability to predict food web behavior under external (e.g., climate, anthropogenic exploitation and nutrient input) and internal (e.g., population dynamics and feedback) influences in order to manage for a sustainable ecosystem (de Ruiter et al. 2005). By defining the food web structure of subtidal oyster reefs, we can provide an ecosystem based management plan for these biogenic reefs (Crowder et al. 1996). A food web is defined as a summary of resource-consumer interactions in a community that enhance the understanding of ecosystem structure and population dynamics (Pimm et al. 1991, Winemiller and Polis 1996, de Ruiter et al. 2005, Winemiller and Layman 2005).

Defining food webs is a tool used to assess the trophic structure and species interactions of ecosystems and can be used to better manage and preserve essential habitats. Understanding community structure through food webs provides basic information on the abundance and dynamics of organisms belonging to different trophic levels in an estuarine system (Anderson and Cabana 2007). Oyster reef food web models can provide important data on the role that oysters have in estuaries, particularly in terms of habitat use by fish and crustaceans. With this information scientist will be able to compare subtidal oyster reefs to more extensively studied vegetated, non-vegetated, and intertidal oyster reef habitats.

Reefs of the Eastern Oyster (*Crassostrea virginica*) are both a fishery resource and an estuarine habitat acting as "ecosystem engineers" composing a potentially complex dynamic food web supporting a large variety of fish and macroinvertebrates (Peterson et al. 2003). However, the extent of their role in the food web of the ecosystem as a whole is poorly understood. Oyster reefs can be found in both the intertidal and subtidal regions of the bay. The majority of the existing studies on community structure and food webs have focused on intertidal oyster reefs and suggest that these reefs provide habitat for many invertebrates and fish species. However, much of the Gulf coast oyster reefs are subtidal due to the narrow tidal range (Kilgen and Dugas 1989). Subtidal oyster reefs have been difficult to sample due to structural complexity and depth parameters, thus few studies have attempted to quantitatively assess the value of subtidal oyster reefs to estuarine communities and food web structure.

Recently, oyster reef habitat has been shown to substantially benefit the entire estuarine ecosystem complex. The importance of oysters to water filtration and nutrient cycling is well established (Newell 1988). Feeding oysters remove inorganics, phytoplankton, and detrital particles from the water column, thereby reducing turbidity and improving water quality (Newell 1988). Oyster reefs serve as important biogenic habitat for benthic invertebrates (Zimmerman et al. 1989) as well as fishes and mobile crustaceans (Coen et al. 1999, Lenihan et al 2001, Peterson 2003). Furthermore, the physical structure of an oyster reef can serve to protect seagrass and marsh habitats by dissipating erosive water energy.

Oyster reefs are created by years of successive settlement of larvae on adult shells (Boudreaux et al. 2006). These large, three-dimensional reef structures are unique and provide very complex habitat in an estuarine system typically dominated by non-vegetated bottom habitats. Subtidal oyster reefs are used by many organisms in a variety of ways: (1) feeding directly on live oysters, (2) using shell surfaces for spawning, (3) seeking refuge from predation, and (4) using the abundant available prey field as a food source (Boudreaux et al. 2006). Oyster reefs provide a significant amount of total available habitat in many bays along the United States, Gulf of Mexico coast. With this major contribution, it is still unclear to what quantifiable degree of service or value they may provide for diverse assemblages of estuarine fish and invertebrates. Bucci et al. (2007) showed a decline in blue crab (*Callinectes sapidus*) stock with the reduction in oyster reef coverage. Therefore, loss of oyster reefs could potentially impact other estuarine organisms that depend of the blue crab for food or that use these reefs as a habitat in a similar manner.

Oyster reefs were once a prominent feature along the Gulf and Atlantic coasts. Over-harvesting, other anthropogenic impacts, and disease have reduced many oyster reefs to a fraction of their historic coverage inducing major changes in marine food webs (Carpenter and Kitchell 1993, Botsford et al. 1997, Micheli and Peterson 1999, Lenihan et al. 2001). Between 1880 and 1910, the U.S. oyster fishery peaked at more than 72.7 million kg of meat per year (Coen et al. 1999), but by 1995, landings had declined by more than 18.4 million kg (MacKenzie 1996). The over-harvesting of oyster reefs exemplifies the unsustainable use of a natural resource (Kirby 2004). It is important to determine the role of subtidal oyster reef as a habitat because many reefs are declining.

For example, the percent coverage of oyster reefs has decreased by 60% in upper Lavaca Bay, Texas since 1913 (Wrast unpublished data, Simons et al. 2003). The decline may be due to channel dredging, and commercial harvesting of reefs which increases boat traffic and suspension of sediments into the water column. Decreasing water quality due to these reasons has been shown to decrease the settlement of oyster spat (Boudreaux et al. 2006), reducing the ability of the reefs in this system to rebound after disturbances. The continued loss of this estuarine habitat could affect numerous ecologically and commercially important species and ultimately alter the flow of nutrients and energy through the bay system.

Food web interactions are the basis of ecosystem processes and influence important pathways in the global cycling of matter, energy, and nutrients (de Ruiter et al. 2005). Stomach content and stable isotope analyses are commonly used to determine food web structure. Coupling both techniques is beneficial because stomach content analysis helps determine specific temporal or spatial feeding patterns and specific species interactions that may not be apparent using stable isotope ratios alone (de Ruiter et al. 2005). Estimates by stomach content analysis of food sources consumed by fish are influenced by many factors: ontogeny of fish, amount of food eaten in a meal, number of meals eaten in a day, rate of gastric clearing, water temperature, activity of fish, type of food eaten, and prior feeding history (Rudershausen and Locascio 2001). Stomach content analysis provides snapshots of the organism's diet; however, it can not be used to determine the rate of ingestion and assimilation of food; thus simultaneous stable isotope analysis is necessary for defining the multidimensionality and complexity of a comprehensive food web.

Isotopes are atoms having the same number of protons, but different number of neutrons, thus differing in mass but not in chemical properties. Nitrogen (N) and carbon (C) stable isotope data are widely used to describe the trophic levels of individuals, populations, and communities; as well as identifying the source materials that support them (Barnes et al. 2007). Each of these elements has a number of stable isotopes, of which the lightest is present in far greater abundance. The carbon isotope composition ($\delta^{13}C$) varies widely among different producers, but isotopic composition of a consumer resembles that of its prey (Deniro and Epstein 1978). The carbon isotope composition of a top predator can, under appropriate circumstances, be used to infer basal carbon sources that support its growth (Havens et al. 2003) as different energy sources can have distinct $\delta^{13}C$ values (Hecky and Hesslein 1995). Once the basal carbon sources have been defined, stable nitrogen isotopes can be used to investigate trophic structure and specific predator-prey relationships in the food web.

Isotopic fractionation in biochemical reactions occurs when similar molecules of slightly different mass react at different rates (Peterson and Fry 1987). Fractionation occurring in predator-prey relationships is termed trophic fractionation. In marine systems, organisms are grouped into trophic levels based on how many links they are removed from the primary producers of that ecosystem. Nitrogen isotope values ($\delta^{15}N$) can be used to estimate the trophic fractionation and thus vertical position of consumers in a food web (Havens et al. 2003). Stable isotope analysis provides information on the food that is assimilated, and not food that is merely ingested, giving it an advantage over stomach content methods in elucidating trophic dynamics. Stomach contents in conjunction with stable isotope data can provide an estimate of the mean level of organic matter actually assimilated by a given species (Creach et al. 1997) creating checks and balances in formulating the most precise and accurate account of the food web present in a system. Recently, food web scientists have seen greater efforts in obtaining superior food web descriptions based on higher resolution data that encompasses multiple techniques allowing further investigation into temporal and spatial variations (Akin and Winemiller 2006).

Few studies have formulated food webs incorporating both temporal and spatial differences (de Ruiter et al. 2005), which are necessary to properly illustrate the highly dynamic nature of food webs. Ecologists are beginning to understand and recognize food webs are open systems influenced by processes in adjacent systems and are spatially heterogeneous (Polis and Winemiller 1996). Each food web can be defined according to habitat units nested within larger ecosystems. Consequently, an observed food web is a module (de Ruiter et al. 2005), in an essentially much larger scheme. Small scale food webs are spatially linked by transient predators that connect sub-webs of varying habitats into a single complex system encompassing the entire ecosystem. Spatial factors such as habitats types and distance from a coastal inlet are also important factors that can influence the distribution of nekton within an estuarine food web. Estuaries are dynamic systems in which organisms change their diets in association with life stage and seasonal and spatial dynamics of prey availability (Werner and Gilliam 1984). Temporal differences in food web structure through stomach fullness have shown greater energy demands of fishes during warm summer months (Baird et al. 2004), supporting the need for seasonal food web analysis. The warmer temperatures during summer should increase metabolism and rates of feeding by ectotherms. Seasonal influxes of estuarine dependent marine fishes and shrimp have been shown (Akin and Winemiller 2006) to alter community structure and the potential number of feeding interactions.

The purpose of this study is to determine the spatiotemporal food web dynamics of subtidal oyster reefs and compare this to other estuarine habitats (marsh edge, and non-vegetated bottom) in Lavaca Bay, Texas. Defining community structure, trophic structure, and carbon sources of oyster reef habitats will provide a better understanding of whether these are essential fish habitats. There is growing appreciation of the need to quantify the value of oyster reefs for estuarine fishes (Zimmerman et al. 1989, Harding and Mann 1999, Lenihan et al. 2001). Investigation of subtidal oyster reef food webs will provide information on their role in terms of habitat use by fish and crustaceans, and compare this use to other available habitats providing critical information for fisheries managers. Ultimately, this information will be important for resource managers to make informed decisions, as oyster reefs have historically been degraded and lost due to anthropogenic impacts (Rothschild et al. 1994, Lenihan and Peterson 1998). This study is particularly unique in that it simultaneously examines and compares spatial and temporal food web dynamics among several estuarine habitats and integrates food web analysis by combining gut content analysis and stable isotope techniques.

MATERIALS AND METHODS

Study Site

Lavaca Bay is a shallow embayment (190 km^2) located in the northwest corner of the Matagorda Bay system on the central Texas coastline (Bloom et al. 1999) (Fig. 1). It is approximately 20.6 km in length and varies in width from of 3.6 to 10.3 km (Byrne 1975). The average depth of the bay varies from 1.2 m in the northern bay to 2.8 m in the south, with a depth of 10.5 m in the ship channel. Lavaca Bay has a subhumid climate with average annual precipitation range from 91.4 to 101.6 cm (Carr 1967, Byrne 1975), with rainfall increasing during June through September coinciding with hurricanes (Hayes 1965, Byrne 1975). Two major rivers, the Lavaca and Navidad, combine and discharge the majority of freshwater and sediment into the northeast corner of the bay. Minor freshwater contributions also come from Keller Bay, Cox Bay, Garcitas delta and small intermittent streams and creeks (Bronikowski 2005). Shallow temperate estuaries, such as Lavaca Bay, are highly dynamic ecosystems with hydrologic changes influenced by precipitation, winds, and tides (Akin and Winemiller 2006). This understanding makes it imperative to sample these shallow temperate estuary systems over spatial and temporal scales.

Estuarine habitat types in the Lavaca Bay system include: intertidal and subtidal oyster reefs (*Crassostrea virginica*), non-vegetated bottom, submerged aquatic vegetation (SAV) (*Halodule wrightii*), and intertidal salt marshes (*Spartina alterniflora*). Upper Lavaca Bay contains all habitat types with the exception of SAV, and lower Lavaca Bay (Keller Bay) contains all four habitat types.

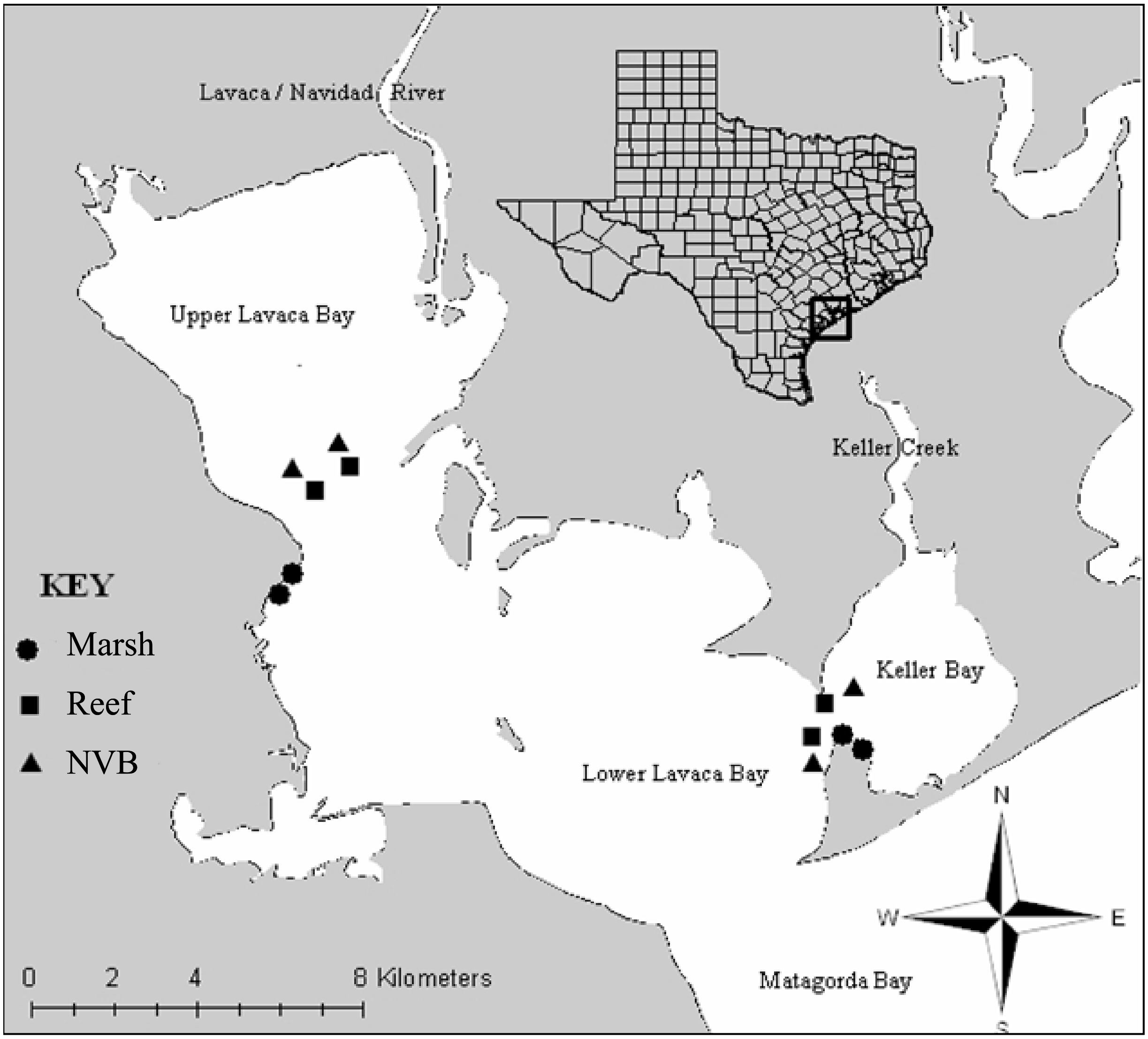

Fig 1. Lavaca Bay, Texas study site locations in both the upper and lower regions of the bay. Habitat types sampled are indicated by black shapes; marsh edge = ●, subtidal oyster reef = ■, and non-vegetated bottom (NVB) = ▲.

Sampling Design

This study focused on assessing the food web structure in two separate regions (upper and lower) and three different habitat types (subtidal oyster reef, marsh edge, and non-vegetated bottom) within Lavaca Bay, Texas. Upper Lavaca Bay sites were located in the northern portion of the bay, just north of the Lavaca Bay causeway. The lower Lavaca Bay sites were both inside and outside the mouth of Keller Bay (a tertiary bay in the Matagorda Bay system) (Fig. 1). In each region two replicates for each habitat were selected. In Upper Lavaca Bay, samples were collected on subtidal oyster reef (Reef), non-vegetated bottom (NVB), and marsh edge (Marsh) habitats adjacent to non-vegetated bottom. In the lower Lavaca Bay, samples were collected on subtidal oyster reef, non-vegetated bottom, and marsh edge adjacent to submerged aquatic vegetation (Marsh/SAV). (Table 1). Each site was sampled four times on a seasonal basis with sampling dates separated by approximately 3 months. Sampling was conducted in summer (July) and fall (October) of 2006, and winter (February) and spring (April) of 2007.

Sampling gear included an epibenthic sled and a modified epibenthic sled for small nekton. The epibenthic sled is described in detail in Stunz et al. 2002. Briefly, it is a fixed frame sampling device with a mesh size of 1mm and has been used to collect nekton in a variety of studies. The epibenthic sleds were employed by hand and covered approximately 10 m^2 of substrate. The modified epibenthic sled was used to sample nekton on both subtidal oyster reef habitat as well a non-vegetated bottom and was trawled behind the boat to cover approximately 10 m^2. This is also a fixed frame sampling device but unlike the epibenthic sled, is equipped with steel teeth that are designed to agitate the oyster reef surface and an oyster exclusion net keeping oyster shells from entering the net while continuing to collect the nekton. Gear efficiency analysis has been completed by Stunz (unpublished data) and both the epibenthic sled and the modified epibenthic sled were determined to sample effectively and similarly with no significant differences in densities of nekton caught. Gill nets (29 m by 1 m: half consisting of 5 cm and the other half 2.5 cm mesh) were used to capture larger transient fish at each site with a soak time of 2 h (except for summer = 4 h). An oyster dredge was used to collect live oysters from all reef sites. A Van Veen grab was deployed for sediment collection, and a Niskin bottle was used to collect water for particulate organic matter (POM) filtration. Hydrological parameters were measured using a Hydrolab Quanta at each site including: depth (m), dissolved oxygen (DO) (mg l^{-1}), salinity (psu), and temperature (ºC). At NVB and reef sites with a depth greater than 1m, a surface and bottom measurements were taken. A Secchi disk was used to determine turbidity.

Table 1. Habitats sampled in Lavaca Bay, Texas in 2006-2007 and the sample size (n) by season. NVB = non-vegetated bottom; SAV = submerged aquatic vegetation, EBS = epibenthic sled; MEBS = modified epibenthic sled, U = upper Lavaca Bay, L = lower Lavaca Bay.

Habitat	Region	Gear	Sample Size (n)				
			Summer	Fall	Winter	Spring	Total
Reef	U	MEBS	6	6	6	6	24
		Gill Net	2	2	2	2	8
	L	MEBS	6	6	6	6	24
		Gill Net	2	2	2	2	8
NVB	U	MEBS	6	6	6	6	24
		Gill Net	2	2	2	2	8
	L	MEBS	6	6	6	6	24
		Gill Net	2	2	2	2	8
Marsh	U	EBS	6	6	6	6	24
		Gill Net	2	2	2	2	8
Marsh/SAV	L	EBS	6	6	6	6	24
		Gill Net	2	2	2	2	8

* The marsh habitat sampled in the upper was adjacent to NVB, while the marsh sampled in the lower was adjacent to SAV.

Stomach content analysis

Stomach content analysis was performed on fishes captured with gill nets. All fish captured were identified to species and measured to the nearest 1mm total length. The species kept for food habits and stable isotope analysis characterized the range and occurrence of representative species from different trophic levels captured throughout the study. Approximately 10 specimens of each species of interest (to include all trophic levels) were retained for analysis. Either the whole fish or the dissected stomach were preserved in 10% formalin (for 48 hours to 7 days) and then later stored in 70% ethanol solution. If not excised in the field, the entire GI tract was dissected in the laboratory and all food items in the anterior half of the gut were removed and examined under a dissecting or compound microscope. Stomachs were categorized by fullness and stomach contents by condition (digestion levels) (see Fisheries Ecology Laboratory Standard Operating Procedures Manual). The fullness index is a scale of six categories indicating the fullness of the stomach. The condition index is a scale of four categories ranging from intact to unidentifiable prey items.

Contents were then identified to lowest possible taxon, enumerated, and measured volumetrically based on the methods by Akin and Winemiller (2006). Prey items were placed into one of 65 categories with variable levels of taxonomic aggregation, ranging from species to orders and functional groups. Volume was measured for large prey items (>0.1 ml) by blotting the item dry and using water displacement method in a graduated cylinder. For volumes of prey items <0.1 ml, items were placed on a glass slide and visually estimated by comparing its size with a water droplet of known volume extracted from a graduated pipette.

Stable isotope analysis

Samples of vegetation (*Halodule wrightii* and *Spartina alterniflora*), particulate organic matter (POM, mostly phytoplankton), benthic algae, benthic organic matter (BOM), macroinvertebrates, and fish tissue were collected for C and N stable isotope analysis. Fish and invertebrate species collected by epibenthic and modified epibenthic sleds were rough sorted in the field and selected individuals were placed on dry-ice for stable isotope analysis. To ensure isotope sample purity, fish collected by gill net were processed in the field to remove approximately 10 g of dorsal epaxial white muscle tissue, then immediately frozen with dry ice.

Submerged vegetation and marsh plants were collected during each sampling event and placed on dry ice while in the field. Water samples for particulate organic matter (POM) were collected at each sampling site using a Niskin bottle as well as at both freshwater sections of the Lavaca/Navidad River and Keller Creek. Water column POM samples (with phytoplankton assumed as a main component) were collected by passing water samples through a pre-combusted glass microfibre filters (Whatman GF/F). Particulate organic matter samples were collected in the winter and spring sampling events only and stored in pre-combusted aluminum foil packets on dry ice for stable isotope analysis. Finally, benthic organic matter (BOM) samples were taken with a Van Veen grab from each site. The top ~0.5 cm was removed from the grab and placed into nalgene sample bottles and stored on dry ice. All samples (both whole organisms and tissue samples) for stable isotope analysis were thoroughly rinsed with DI water and immediately frozen for transport to the lab where they were stored in a -80^{o} freezer.

Fish tissue, macroinvertebrate tissue, benthic organic matter (BOM), and vegetation samples were freeze-dried for approximately 48 hours until all moisture was removed. Dried samples were ground to a fine powder with a pre-combusted mortar and pestle and then stored in pre-combusted glass vials. Particulate Organic Matter (POM) filters were freeze-dried for approximately 48 hours and stored in pre-combusted glass vials.

Organic samples were analyzed for stable isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) at the Analytical Chemistry Laboratory, Institute of Ecology, University of Georgia, Athens. Samples were weighed to 10^{-6} g and pressed into Ultra-Pure tin capsules (Costech). Benthic organic matter (BOM) samples and macroinvertebrate samples with suspected inorganic carbon present were weighed in Ultra-Pure silver capsules (Costech), acidified with 20% HCl, and re-dried. Samples were then dry-combusted (micro Dumas technique) with a Carlo Erba CHN elemental analyzer. Purified gases (CO_2 and N_2) were introduced into a Finnigan Delta C mass spectrometer, and the isotopic composition was quantified relative to a standard reference material; carbon in the PeeDee Belemnide and molecular nitrogen gas in the air. Results were reported as parts per mille (‰) differences from the corresponding standard:

$$\delta X = [(R_{sample}/R_{standard}) - 1] \times 10^3$$

where R = $^{13}C/^{12}C$ or $^{15}N/^{14}N$.

Data Analysis

Stomach Content Analysis

Trophic Levels (TL) of fishes were calculated using the formula presented in Adams et al. (1983):

$$TL_i = 1.0 + \sum_{j=1}^{n} TL_j\,(P_{ij})$$

where TL_i is the trophic level of consumer species i, TL_j is the trophic level of prey item j, and p_{ij} is the fraction of the consumed food (volume) of species i consisting of prey species j. Prey item trophic level was calculated as the mean TL values of values from researched sources (Appendix 1).

The index of relative importance (IRI) was also calculated and can be defined as:

$$IRI = (N + V)\ FO$$

Where N is the percent number of a certain prey item, V is the percent volume and FO is the frequency of occurrence. IRI values were calculated for each prey item in the stomach content of each individual. Then the mean values for the food items were determined by each parameter investigated (habitat type, spatial and temporal scales).

Stable Isotope Analysis

The trophic levels (TL) of consumers were calculated following the method described in Jepsen and Winemiller 2002. The formula used for the calculation of the TL for a species was:

$$TL = [(\delta^{15}N_{consumer} - \delta^{15}N_{reference})/3.3] + 1$$

Where $\delta^{15}N_{reference} = 5.97$ which was the mean of all vegetation, sediment/BOM, phytoplankton/POM samples, and the denominator value (3.3) was the estimated mean trophic enrichment (fractionation) of $\delta^{15}N$ between consumers and their food sources as defined in Winemiller et al. (2007).

Statistical Analysis

Differences in average isotopic signatures, calculated trophic levels, percent index of relative importance, and environmental parameters were tested among seasons, regions, sites and habitat using analysis of variance (ANOVA). Significant differences among treatments were evaluated post hoc using Tukey's HSD. I used random-effects ANOVA's, Tukey's multiple range test, and where appropriate, the Student's t-test to compare differences in mean isotopic signatures, percent index of relative importance (%IRI), trophic levels (TL), environmental parameters. For all statistical analyses a significance level of $\alpha = 0.05$ was used. Data were log transformed as necessary to most closely approximate the assumptions required for the use of parametric procedures. In some cases there was a positive relationship between the variance and the mean and transformation eliminated this problem. The replicate sites were found to exhibit no significant differences, and were pooled for all analyses in this study.

RESULTS

Environmental

Environmental parameters measured throughout the study showed significant differences between habitat and region (Table 2). Salinity was significantly higher in the lower region compared to the upper region of Lavaca Bay, Texas in the summer (ANOVA, $F_{1,11} = 12.7$, $p = 0.006$,), fall (ANOVA, $F_{1,11} = 432.6$, $p < 0.001$), winter (ANOVA, $F_{1,11} = 98.5$, $p < 0.001$), and spring (ANOVA, $F_{1,11} = 195.5$, $p < 0.001$). Temperature was significantly higher in the upper region of the bay in the summer (ANOVA, $F_{1,10} = 11.5$, $p = 0.008$), and lower in the fall (ANOVA, $F_{1,11} = 11.2$, $p = 0.007$) and winter (ANOVA, $F_{1,11} = 24.1$, $p < 0.001$). Dissolved oxygen (DO) was significantly lower in the lower region of the bay but only in the summer sampling season (ANOVA, $F_{1,10} = 24.2$, $p < 0.001$).

Community assemblage

Over 20,000 macroinvertebrates and fishes were collected throughout this study with all sampling gears and nearly 500 stomachs and 455 stable isotope samples were analyzed. Six species comprised 98.7 % of the invertebrates collected in both the epibenthic and modified epibenthic sleds (Table 3). *Palaemonetes* spp. was the dominant invertebrate captured by epibenthic sled comprising 66.3% of the catch. Eleven fish species comprised 92.4 % of the fishes collected in both epibenthic sleds, and 10 species of fish comprised 94.9 % of all fishes collected by gillnet throughout this study. *Anchoa mitchilli* was the most abundant species collected with an epibenthic sled comprising 30.7% of the total catch of fishes. *Brevoortia patronus* was the most abundant species caught in Lavaca Bay comprising nearly 50% of the fishes captured by gill net.

Food web overall

Twenty four species of fishes from 15 families were examined for stomach content analysis (Table 4). A total of 483 stomachs were analyzed throughout all habitat types, regions, and seasons combined. Only 13.5% of stomachs investigated were empty. *Brevoortia patronus* (25.5%) represented the largest percentage of stomachs examined while *Ariopsis felis* (15.5%) and *Bagre marinus* (16.9%) also comprised a high percentage of the stomachs examined (Table 5). Shark species, *Sphyrna tiburo* and *Carcharhinus limbatus* were captured only in the lower region of the bay, in the summer, over oyster and non-vegetated bottom habitats. Eight of the 24 species collected for stomach content analysis did not occur on subtidal oyster reef habitat. Ten of the 24 species of fishes kept for stomach content analysis were captured during only one of the four seasons.

Table 2. Comparison of environmental characteristics among habitat types and between regions seasonally in Lavaca Bay, Texas. Mean and standard error (SE) are given for variables measured in each habitat type and region sampled seasonally from July 2006 through April 2007. Each mean was estimated from 2 samples, except stations with a depth >1.0 m, then the surface and bottom were measured and averaged making n = 4. In summer upper reef, only one sample was collected. Results (p-values) are given for ANOVA analysis used to compare all habitat types (HABITAT EFFECT) and regions of the bay (REGION EFFECT). An * indicates a significant effect.

	Reef				Marsh		Marsh/SAV		NVB				HABITAT		REGION	
	Upper		Lower		Upper		Lower		Upper		Lower		EFFECT		EFFECT	
Environmental Variable	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	p-value		p-value	
Summer																
Water Temperature (^{o}C)	31.3	(0.00)	30.6	(0.02)	32.7	(0.34)	29.1	(1.17)	31.4	(0.04)	30.4	(0.09)	0.996		0.008	*
Salinity (psu)	21.6	(0.00)	23.3	(0.33)	19.8	(0.15)	21.9	(0.55)	21.2	(0.49)	23.1	(0.78)	0.172		0.006	*
Water Depth (m)	2.20	(0.00)	2.00	(0.10)	0.50	(0.10)	0.40	(0.10)	2.05	(0.05)	1.85	(0.15)	<0.001	*	0.934	
Dissolved Oxygen (mg l^{-1})	6.2	(0.00)	4.9	(0.04)	6.9	(0.26)	5.6	(0.06)	6.0	(0.18)	4.9	(0.21)	0.273		<0.001	*
Fall																
Water Temperature (^{o}C)	21.2	(0.15)	23.2	(0.41)	23.0	(0.23)	25.7	(0.14)	21.2	(0.03)	23.2	(0.41)	0.074		0.007	*
Salinity (psu)	11.3	(0.11)	21.5	(0.05)	13.0	(0.16)	21.4	(0.10)	10.6	(0.43)	21.4	(0.01)	0.924		<0.001	*
Water Depth (cm)	2.15	(0.25)	1.85	(0.15)	1.15	(0.05)	0.60	(0.20)	2.05	(0.05)	1.55	(0.35)	0.004	*	0.212	
Dissolved Oxygen (mg l^{-1})	7.9	(0.47)	8.0	(0.42)	8.6	(0.52)	8.3	(0.06)	8.2	(0.09)	8.4	(0.86)	0.483		0.992	
Winter																
Water Temperature (^{o}C)	8.6	(0.00)	10.3	(0.21)	8.5	(0.74)	12.5	(0.29)	8.1	(0.42)	10.3	(0.03)	0.515		<0.001	*
Salinity (psu)	10.7	(0.14)	16.4	(0.85)	9.9	(0.46)	15.3	(0.13)	11.4	(0.95)	15.5	(0.48)	0.882		<0.001	*
Water Depth (cm)	1.35	(0.05)	1.55	(0.15)	0.38	(0.03)	0.37	(0.07)	1.45	(0.05)	1.15	(0.15)	<0.001	*	0.910	
Dissolved Oxygen (mg l^{-1})	12.8	(0.44)	11.4	(0.14)	12.0	(0.36)	9.7	(1.80)	11.7	(0.58)	11.7	(0.06)	0.405		0.114	
Spring																
Water Temperature (^{o}C)	23.5	(0.30)	23.6	(0.18)	24.2	(0.29)	23.1	(0.07)	23.5	(0.15)	23.8	(0.03)	0.927		0.927	
Salinity (psu)	8.3	(0.31)	14.8	(0.20)	9.3	(0.06)	13.4	(0.13)	8.1	(0.09)	14.9	(0.25)	0.997		<0.001	*
Water Depth (cm)	2.45	(0.25)	1.80	(0.20)	0.70	(0.00)	0.55	(0.05)	2.40	(0.00)	1.90	(0.10)	<0.001	*	0.373	
Dissolved Oxygen (mg l^{-1})	6.6	(0.29)	7.1	(0.14)	7.5	(0.01)	5.6	(0.37)	6.8	(0.11)	6.8	(0.06)	0.734		0.229	

Table 3. Abundances (density per unit effort) and percent relative abundance of macrofauna collected by three survey methods (EBS, MEBS, and Gillnet) at Lavaca Bay, Texas for all habitat types, regions, and seasons sampled.

Species	Common Name	Abundance	%
Sled Samples			
Invertebrates		**no. m^{-2}**	
Palaemonetes spp.	Grass shrimp	5.71	66.3
Penaeidae	Penaeid shrimp	2.11	24.5
Tozeuma carolinense	Arrow shrimp	0.20	2.3
Callinectes sapidus	Blue crab	0.18	2.1
Xanthoidea	Xanthid crab	0.17	1.9
Sergestidae	Sergestid shrimp	0.13	1.5
Additional 6 Taxa		0.12	1.3
Fishes			
Anchoa mitchilli	Bay anchovy	0.53	30.7
Micropogonias undulatus	Atlantic croaker	0.30	17.1
Syngnathus spp.	Pipefish	0.17	10.1
Gobiosoma bosc	Naked goby	0.16	9.0
Brevoortia patronus	Gulf menhaden	0.14	8.3
Lagodon rhomboides	Pinfish	0.11	6.2
Microgobius thalassinus	Green goby	0.10	5.6
Gobionellus boleosoma	Darter goby	0.03	2.0
Stellifer lanceolatus	Star drum	0.03	1.5
Citharichthys spilopterus	Bay whiff	0.02	1.0
Gobiosoma robustum	Code goby	0.02	1.0
Eucinostomus argenteus	Spotfin mojarra	0.01	0.8
Sciaenops ocellatus	Red drum	0.01	0.7
Additional 34 Taxa		0.11	6.1
Gill net Samples		**no. h^{-1}**	
Brevoortia patronus	Gulf menhaden	4.80	47.1
Bagre marinus	Gafftopsail catfish	1.19	12.6
Ariopsis felis	Hardhead catfish	1.28	12.2
Leiostomus xanthurus	Spot	0.66	6.0
Polydactylus octonemus	Atlantic threadfin	0.63	5.9
Menticirrhus littoralis	Gulf kingfish	0.55	5.3
Cynoscion arenarius	Sand seatrout	0.19	2.2
Micropogonias undulatus	Atlantic croaker	0.11	1.4
Cynoscion nebulosus	Spotted seatrout	0.10	1.2
Archosargus probatocephalus	Sheepshead	0.10	0.9
Additional 14 Taxa		0.48	5.1

Table 4. List of all families and species examined in stomach content analysis, size range (in mm total length), season(s), region of the bay, habitat types at which they were collected, number of stomachs examined and the number of those which were empty for the fishes collected from Lavaca Bay, Texas from July 2006-April 2007. SU = summer, FA = fall, WI = winter, SP = spring, U = upper, L = lower, R = oyster reef, NVB = non-vegetated bottom, M = marsh, M/SAV = marsh/submerged aquatic vegetation.

Family	Species	Common Name	Size Range	Season	Region	Habitat	Number Examined	Number Empty
Sphyrnidae	*Sphyrna tiburo*	Bonnethead Shark	600 – 652	SU	L	R, NVB	4	0
Carcharhinidae	*Carcharhinus limbatus*	Blacktip Shark	407 – 606	SU	L	R, NVB	4	1
Dasyatidae	*Dasyatis sabina*	Atlantic Stingray	137 – 137	SP	U	M	1	0
Elopidae	*Elops saurus*	Ladyfish	348 – 348	SU	U	NVB	1	0
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	136 – 355	SU, WI, FA, SP	U,L	R, NVB, M	123	6
Polynemidae	*Polydactylus octonemus*	Atlantic Threadfin	155 – 203	SU, WI, FA, SP	U,L	R, NVB, M	34	18
Ariidae	*Ariopsis felis*	Hardhead Catfish	152 – 402	SU, FA, SP	U, L	R, NVB, M, M/SAV	75	3
	Bagre marinus	Gafftopsail Catfish	207 – 625	SU, FA, SP	U, L	R, NVB	82	3
Mugilidae	*Mugil cephalus*	Striped Mullet	213 – 430	SU, FA, SP	U,L	M, M/SAV	5	1
Sparidae	*Archosargus probatocephalus*	Sheepshead	235 – 502	FA	U,L	M, M/SAV	8	1
	Lagodon rhomboides	Pinfish	126 – 126	FA	L	NVB	1	0
Haemulidae	*Orthopristis chrysoptera*	Pigfish	163 – 163	FA	L	R	1	0
Stromateidae	*Peprilus paru*	Harvestfish	76 – 213	SU, FA	U,L	R, NVB	3	0
Sciaenidae	*Bairdiella chrysoura*	Silver Perch	170 – 196	FA, WI, SP	U,L	R, NVB, M/SAV	8	0
	Cynoscion arenarius	Sand Seatrout	216 – 371	SU, FA, SP	U,L	R, NVB	17	6
	Cynoscion nebulosus	Spotted Seatrout	221 – 465	SU, FA, SP	U,L	R, NVB, M, M/SAV	13	2
	Leiostomus xanthurus	Spot	140 – 197	FA, WI, SP	U,L	R, NVB, M/SAV	39	16
	Menticirrhus littoralis	Gulf Kingfish	197 – 273	SU, FA, SP	U,L	R, NVB, M, M/SAV	37	4
	Micropogonias undulatus	Atlantic Croaker	174 – 176	SU	L	R	3	0
	Pogonias cromis	Black Drum	296 – 370	FA, SP	U,L	M, M/SAV	6	0
	Sciaenops ocellatus	Red Drum	355 – 568	FA, SP	U,L	M, M/SAV	6	2
Pomatomidae	*Pomatomus saltatrix*	Bluefish	183 – 183	SP	U	M	1	1
Carangidae	*Caranx hippos*	Crevalle Jack	141 – 175	SU	U, L	R, NVB, M/SAV	7	0
Scombridae	*Scomberomorus maculatus*	Spanish Mackerel	534 – 560	SU, SP	U,L	R, NVB	4	1
Total							483	65

The trophic levels (TL) calculated for fish species from stomach content analysis ranged from 1.91 (*Pogonias cromis*) to 4.03 (*Carcharhinus limbatus*) (Table 5). The value for *P. cromis* is below the lowest possible consumer TL of 2 because of the low number of that species sampled, and the lack of identifiable food items in the guts of those fish. Some of the other high TL fishes in the system include: *Sciaenops ocellatus* (3.7), *Cynoscion nebulosus* (3.5), *Cynoscion arenarius* (3.5), and *Sphyrna tiburo* (3.4).

In the entire Lavaca Bay food web, the six prey items that contribute the most to the consumers in the system according to percent index of relative importance (%IRI) are: *Farfantepenaeus aztecus* (100%), Ampharetidae spp. (100%), Glyceridae spp. (84.27%), Actinopterygii spp. (71.77%), Rhodophyceae spp. (66.04%), Penaeidae spp. (64.12%), and *Brevoortia patronus* (64.12%) (Table 6). These prey items represent six different families and four classes from a wide range of taxonomic origin. Digestate was the largest by volume (259.9 ml) category of prey item recovered from stomachs in this study with the total volume of all prey items recovered at 957.3mL. Digestate is a broad term which encompasses many point sources, which are nearly impossible to distinguish through raw examination alone. *Callinectes sapidus* was the next largest prey item by volume, with 205.3 ml recovered from stomach content analysis.

Table 5. Total number (n) and percent abundance (%) of species used for stomach content analysis for all habitat types, regions, and seasons in Lavaca Bay, Texas, June 2006-April 2007. Trophic level (TL) was calculated from stomach content analysis.

Family	Species	Common Name	n	(%)	TL
Sphyrnidae	*Sphyrna tiburo*	Bonnethead shark	4	0.83	3.38
Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	4	0.83	4.03
Clupeidae	*Brevoortia patronus*	Gulf menhaden	123	25.47	2.00
Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	34	7.04	3.59
Ariidae	*Ariopsis felis*	Hardhead catfish	75	15.53	2.43
	Bagre marinus	Gafftopsail catfish	82	16.98	2.54
Mugilidae	*Mugil cephalus*	Striped mullet	5	1.04	2.00
Sparidae	*Archosargus probatocephalus*	Sheepshead	8	1.66	2.00
Sciaenidae	*Bairdiella chrysoura*	Silver perch	8	1.66	3.24
	Cynoscion arenarius	Sand seatrout	17	3.52	3.47
	Cynoscion nebulosus	Spotted seatrout	13	2.69	3.53
	Leiostomus xanthurus	Spot	39	8.07	2.15
	Menticirrhus littoralis	Gulf kingfish	37	7.66	2.49
	Micropogonias undulatus	Atlantic croaker	3	0.62	2.34
	Pogonias cromis	Black drum	6	1.24	1.91
	Sciaenops ocellatus	Red drum	6	1.24	3.70
Carangidae	*Caranx hippos*	Crevalle jack	7	1.45	2.64
Scombridae	*Scomberomorus maculatus*	Spanish mackerel	4	0.83	2.67

Table 6. Prey items identified from stomach contents from all seasons, regions, and habitat types at Lavaca Bay, Texas sampled from July 2006-April 2007. Percent number (%N), percent volume (%V), percent frequency of occurrence (%FO), index of relative importance (IRI), and percent index of relative importance (%IRI) were calculated for each stomach sample, and values illustrated in this table are averages of these calculated values.

Phylum (Division)	Class	Order	Family	Species	%N	% V	%FO	IRI	%IRI
Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	18.70	24.67	9.95	184.18	6.24
		Najadales	Cymodoceaceae	*Halodule beaudettei*	46.90	38.55	43.50	4529.80	46.41
Rhodophyta	Rhodophyceae			Rhodophyceae spp.	66.67	82.81	50.00	7473.75	66.04
Arthropoda	Insecta			Insecta spp.	32.32	9.93	4.10	135.14	11.27
		Diptera		Diptera spp.	25.00	0.55	1.67	42.67	0.97
		Hymenoptera		Hymenoptera spp.	28.36	34.07	12.79	818.07	25.30
	Arachnida	Araneae		Araneae spp.	7.14	8.33	1.67	25.85	0.95
	Malacostraca	Amphipoda		Amphipoda spp.	55.48	7.97	8.33	528.53	35.93
			Ampeliscidae	*Ampelisca spp.*	61.90	27.79	19.00	1700.29	42.11
			Ischyroceridae	*Erichtonius brasiliensis*	45.92	14.74	9.34	668.87	22.60
		Decapoda		Anomura spp.	7.14	2.77	20.00	198.26	4.78
				Brachyura spp.	7.48	3.01	5.63	59.08	2.76
				Decapoda spp.	41.42	48.12	9.22	814.11	43.60
				Pleocyemata spp.	32.87	43.14	18.20	1403.12	45.26
			Alpheidae	*Alpheus heterochaelis*	46.27	44.81	10.34	805.13	38.70
			Callianassidae	Callianassidae spp.	46.16	68.65	16.09	2052.47	59.61
			Dendrobranchiata	Dendrobranchiata spp.	68.97	57.93	13.88	1859.02	60.69
			Hippolytidae	*Tozeuma carolinense*	14.29	16.67	10.00	309.52	2.55
			Menippidae	*Menippe adina*	47.84	66.08	16.44	1817.64	54.85
			Ocypodidae	*Uca spp.*	33.33	66.61	1.67	166.91	9.11
			Palaemonidae	*Palaemonetes vulgaris*	39.72	36.60	13.96	1264.36	32.88
			Panopeidae	*Neopanope texana*	39.54	40.76	9.62	845.47	33.97
			Peneaidae	*Farfantepenaeus aztecus*	100.00	100.00	9.09	1818.00	100.00
				Farfantepenaeus spp.	12.70	28.80	2.82	117.03	2.27
				Peneaidae spp.	61.83	69.77	30.51	4027.95	64.12
			Porcellanidae	Porcellanidae spp.	20.00	13.04	1.67	55.18	1.73
			Portunidae	*Callinectes sapidus*	40.69	59.48	30.38	3782.56	48.87
			Sergestidae	Sergestidae spp.	50.00	47.62	3.45	336.79	18.19
			Xanthidae	Xanthidae spp.	26.50	35.49	17.38	1102.91	27.70
		Isopoda		Isopoda spp.	14.33	5.76	6.67	133.95	5.74
			Cymothoidae	*Aegathoa oculata*	38.89	19.74	14.71	897.40	10.08
			Idoteidae	*Erichsonella spp.*	50.04	50.39	7.85	1429.61	50.02
		Mysida		Mysida spp.	46.77	4.40	20.34	1536.79	13.43
		Stomatopoda	Squillidae	*Squilla empusa*	41.67	69.48	5.84	665.22	22.06
	Maxilliopoda	Poecilostomatoida	Ergasilidae	*Ergasilus sp.*	9.09	3.68	1.67	21.32	0.38
Mollusca	Bivalvia			Bivalave spp.	40.83	34.14	29.64	1819.18	36.98
		Mytiloida	Mytilidae	*Ischadium recurvum*	56.25	51.14	1.54	153.34	50.34
		Ostreoida	Ostreidae	*Crassostrea virginica*	33.34	22.70	23.56	1025.54	24.17
		Veneroidea	Pharidae	*Ensis minor*	37.50	97.21	10.84	1556.07	48.67
	Cephalopoda			Cephalopoda spp.	13.89	0.88	2.82	41.65	0.99
	Gastropoda			Gastropoda spp.	39.33	16.23	11.98	570.31	22.92
Nemertea				Nemertea spp.	39.55	52.87	10.23	906.37	45.17
Annelida	Polychaeta			Polycheate spp.	51.41	52.47	19.57	2187.89	53.50
		Aciculata	Eunicidae	Eunicidae spp.	50.00	93.75	3.45	495.94	33.84
			Glyceridae	Glyceridae spp.	75.00	88.91	16.09	2844.36	84.27
		Canalipalpata	Ampharetidae	Ampharetidae spp.	100.00	100.00	33.33	6666.00	100.00
			Pectinariidae	Pectinariidae spp.	40.67	32.43	6.03	358.75	38.01
			Terebellidae	Terebellidae spp.	25.00	7.69	1.67	54.59	2.11
Chrodata	Appendicularia			*Appendicularia spp.*	50.00	50.00	3.45	345.00	33.33
Vertebrata	Actinopterygii			Actinopterygii spp.	61.74	48.79	50.91	6066.15	71.77
		Anguilliformes		Anguilliformes spp.	41.67	75.98	8.52	900.21	32.20
		Aulopiformes	Synodontidae	*Synodus foetens*	50.00	50.00	33.33	3333.00	50.00
		Clupeiformes	Clupeidae	*Brevoortia patronus*	59.81	88.70	15.65	2374.89	64.12
		Gasterosteiformes	Sygnathidae	*Sygnathus spp.*	35.97	23.15	8.15	434.32	19.00
		Perciformes	Gobiidae	Gobiidae spp.	66.67	60.61	16.67	2121.64	50.31
			Gobisocidae	*Gobiesox spp.*	20.00	2.52	1.41	31.75	0.66
		Siluriformes	Ictaluridae	Ictaluridae spp.	62.50	88.59	5.63	850.61	59.04

The overall diet preferences of fishes in Lavaca Bay as illustrated by percent index of relative importance (IRI) over all seasons, regions, and habitat types sampled ranged from *Gobiesox* spp. with a percent IRI = 0.66 (randomly consumed) to Actinopterygii spp. with a percent IRI = 71.8 (primarily consumed) (Fig 2). Prey items with larger percent IRI constitute the more primarily consumed, thus higher impact prey items within Lavaca Bay. The prey items within the primary and secondary categories represent the most utilized food sources for consumers in this estuarine system. Prey items in the randomly consumed category are rarely consumed, and most likely not relied on as a major nutritional source by the consumers of this system. *Halodule wrightii* and *Spartina alterniflora* are most likely a derivative of a more primarily consumed prey item.

A total of 60 species of plants, invertebrates, and fishes from 41 different families were sampled for carbon and nitrogen stable isotopic signatures. Species codes for all stable isotope sample organisms (Table 7) will be used for all species labeling on figures. Prominent vegetation sampled in this study was *Halodule wrighitii* with an average $\delta^{13}C$ value of -11.74, *Spartina alterniflora* -13.25, benthic organic matter (BOM) -17.61, *Ulva lactuca* -18.54, and particulate organic matter (POM) with an average $\delta^{13}C$ value of -20.34 (Table 7).

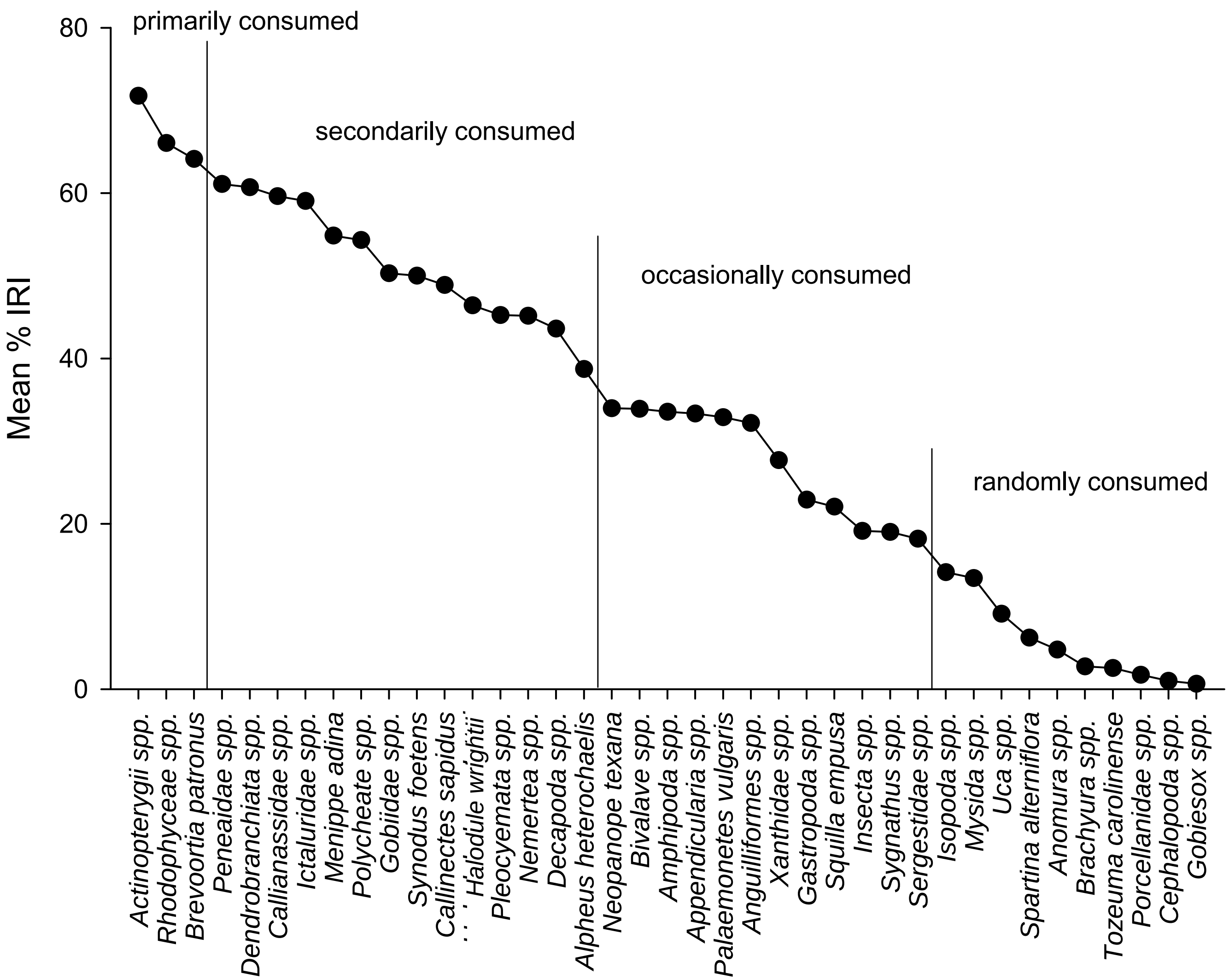

Fig 2. Diet preference of fishes from all sampling seasons, region, and habitats in the Lavaca Bay system from stomach content analysis presented as mean percent index of relative importance (%IRI).

Table 7. $\delta^{13}C$ and $\delta^{15}N$ values of fauna collected in Lavaca Bay, Texas among all seasons, habitat types, and regions. The species code in this table is used in subsequent figures. Values are mean ± standard error (SE) with sample size (n).

Sample Type	Family	Species	Code	$\delta^{13}C$	$\delta^{15}N$	n
Veg	BOM	Benthic Organic Matter	BOM	-17.61 ± 0.60	5.57 ± 0.18	(36)
	Cymodoceaceae	*Halodule wrightii*	HAWR	-11.74 ± 0.20	3.50 ± 0.62	(4)
	Poaceae	*Spartina alterniflora*	SPAL	-13.25 ± 0.17	6.01 ± 0.66	(12)
	POM	Particulate Organic Matter	POM	-20.34 ± 0.99	6.47 ± 0.34	(24)
	Ulvaceae	*Ulva lactuca*	ULLA	-18.54 ± 0.00	5.96 ± 0.00	(1)
Invert	Alpheidae	*Alpheus heterochaelis*	APHE	-18.26 ± 3.75	11.36 ± 0.24	(2)
	Diogenidae	*Clibanarius vittatus*	CLVI	-13.93 ± 0.00	7.33 ± 0.00	(1)
	Hippolytidae	*Tozeuma carolinense*	TOCA	-13.11 ± 0.00	7.47 ± 0.00	(1)
	Menippidae	*Menippe adina*	MEAD	-17.55 ± 1.13	9.18 ± 0.81	(9)
	Ostreidae	*Crassostrea virginica*	CRVI	-22.79 ± 0.38	9.29 ± 0.24	(10)
	Palaemonidae	*Palaemonetes vulgaris*	PAVU	-16.54 ± 0.56	9.35 ± 0.42	(21)
	Porcellanidae	Porcellanidae spp.	POSP	-18.47 ± 2.38	9.40 ± 2.90	(2)
	Portunidae	*Callinectes sapidus*	CASA	-17.32 ± 0.65	9.58 ± 0.52	(15)
	Xanthidae	Xanthidae spp.	XASP	-22.00 ± 0.29	11.99 ± 0.66	(2)
	Peneaidae	Peneaidae spp.	PESP	-17.10 ± 0.48	9.84 ± 0.90	(3)
		Farfantepenaeus aztecus	FAAZ	-16.56 ± 0.60	8.65 ± 0.37	(16)
		Farfantepenaeus spp.	FASP	-17.39 ± 0.59	9.99 ± 0.51	(10)
		Litopenaeus setiferus	LISE	-17.45 ± 0.81	9.93 ± 0.50	(10)
Fish	Ariidae	*Ariopsis felis*	ARFE	-19.23 ± 0.37	14.05 ± 0.22	(24)
		Bagre marinus	BAMA	-18.62 ± 0.20	15.53 ± 0.23	(21)
	Atherinopdisae	*Menidia menidia*	MEME	-17.70 ± 0.00	10.13 ± 0.00	(1)
	Carangidae	*Chasmodes bosquianus*	CHBO	-22.00 ± 0.00	14.59 ± 0.00	(1)
	Carcharhinidae	*Caranx hippos*	CAHI	-18.65 ± 0.78	14.47 ± 0.51	(4)
	Clupeidae	*Carcharhinus limbatus*	CALI	-17.01 ± 0.50	16.16 ± 0.30	(2)
	Cynoglossidae	*Brevoortia patronus*	BRPA	-19.96 ± 0.20	13.47 ± 0.21	(36)
	Cyprinodontidae	*Symphurus plagiusa*	SYPL	-19.14 ± 0.28	11.79 ± 0.47	(3)
	Dasyatidae	*Cyprinodon variegatus*	CYVA	-14.47 ± 1.36	7.06 ± 0.27	(3)
	Elopidae	*Dasyatis sabina*	DASA	-17.88 ± 0.00	14.09 ± 0.00	(1)
	Engraulidae	*Elops saurus*	ELSA	-18.54 ± 0.05	13.94 ± 1.50	(2)
	Gerreidae	*Anchoa mitchilli*	ANMI	-21.00 ± 0.59	13.43 ± 0.36	(10)
	Gobiesocidae	*Eucinostomus argenteus*	EUAR	-17.47 ± 0.00	10.55 ± 0.00	(1)
	Gobiidae	*Gobiesox* spp.	GOS1	-21.01 ± 0.14	13.98 ± 0.35	(2)
		Gobiosoma bosc	GOBO	-18.32 ± 0.85	11.92 ± 0.54	(16)
		Gobius spp.	GOS2	-21.00 ± 0.07	14.49 ± 0.13	(2)
		Microgobius gulosus	MIGU	-17.84 ± 3.68	11.98 ± 1.89	(2)
		Microgobius thalassinus	MITH	-18.65 ± 0.00	13.29 ± 0.00	(1)
	Haemulidae	*Orthopristis chrysoptera*	ORCH	-18.49 ± 0.22	13.70 ± 0.04	(2)
	Lutjanidae	*Lutjanus argentimaculatus*	LUAR	-15.15 ± 0.00	11.51 ± 0.00	(1)
	Mugilidae	*Mugil cephalus*	MUCE	-16.14 ± 0.94	9.36 ± 1.32	(4)
	Paralichtyidae	*Citharichthys spilopterus*	CISP	-18.50 ± 0.58	12.28 ± 0.30	(7)
		Paralichthys lethostigma	PALE	-16.54 ± 0.00	10.36 ± 0.00	(1)
	Polynemidae	*Polydactylus octonemus*	POOC	-17.50 ± 0.00	15.12 ± 0.00	(1)
	Pomatomidae	*Pomatomus saltatrix*	POSA	-17.23 ± 0.00	15.27 ± 0.00	(1)
	Sciaenidae	*Bairdiella chrysoura*	BACH	-18.79 ± 0.79	16.16 ± 1.11	(5)
		Cynoscion arenarius	CYAR	-18.12 ± 0.28	15.20 ± 0.15	(7)
		Cynoscion nebulosus	CYNE	-17.45 ± 0.69	13.71 ± 0.71	(12)
		Leiostomus xanthurus	LEXA	-19.36 ± 0.53	13.78 ± 0.42	(16)
		Menticirrhus littoralis	MELI	-17.08 ± 0.35	13.94 ± 0.24	(13)
		Micropogonias undulatus	MIUN	-17.37 ± 0.47	12.82 ± 0.37	(13)
		Pogonias cromis	POCR	-17.06 ± 1.35	12.03 ± 1.14	(4)
		Sciaenops occelatus	SCOC	-15.78 ± 1.08	12.38 ± 1.01	(4)
	Scombridae	*Scomberomorus maculatus*	SCMA	-19.17 ± 0.29	15.93 ± 0.52	(3)
	Sparidae	*Archosargus probatocephalus*	ARPR	-18.57 ± 0.74	13.09 ± 0.76	(6)
		Lagodon rhomboides	LARH	-16.59 ± 0.56	11.03 ± 0.50	(10)
	Sphyrnidae	*Sphyrna tiburo*	SPTI	-16.74 ± 0.01	13.94 ± 0.20	(2)
	Stromateidae	*Peprilus paru*	PEPA	-20.66 ± 0.71	14.35 ± 1.07	(2)
	Syngnathidae	*Syngnathus* spp.	SYSP	-19.29 ± 1.40	9.41 ± 1.03	(5)
Grand Total						(430)

The distribution of mean $\delta^{13}C$ values of various fauna ranged from -16.54 for shrimp to -22.78 for the eastern oyster, *Crassostrea virginica* (Fig 3). The x-axis displays the $\delta^{13}C$ values and these values closely approximate the isotopic composition of their respective diets. The larger SE range indicates isotopic dissimilarity between diets, meaning those organisms such as epibenthic fish, crabs, and shrimp have a diet consisting of a greater diversity of prey items that use different carbon sources.

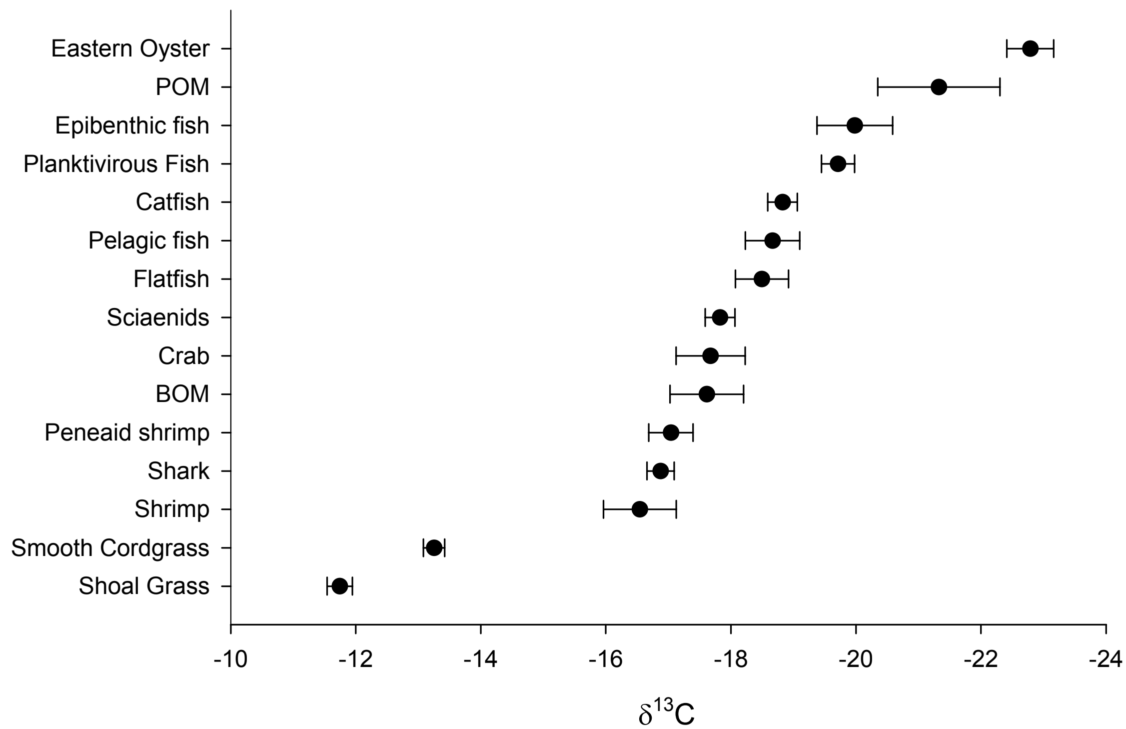

Fig 3. Mean $\delta^{13}C$ values of the fauna and flora (± SE) for common groups of organisms collected in the Lavaca Bay system. POM = particulate organic matter, BOM = benthic organic matter

Nitrogen isotopic distributions have been shown to be robust indicators of trophic position in marine ecosystems, where ^{15}N enrichment increases predictably with trophic level of consumers (Peterson and Fry 1987, Kwak and Zelder 1997). Thus the univariate plot of $\delta^{15}N$ values of consumers from Lavaca Bay provided a progressive ranking of trophic position that corresponded with the calculated TL using isotopic analysis (Fig 4). Fishes occurring in TL 2-3 or between $\delta^{15}N$ values of 9-12‰ include mostly planktivorous and herbivorous feeding guilds, while progressive delineations in TLs represent omnivorous and finally piscivorous feeding guilds. Fishes such as *Bairdiella chrysoura, Microgobius gulosus, Mugil cephalus,* and *Peprilus paru*, show a wide range of $\delta^{15}N$ values, evidence for a non-static position in the food web, caused by alterations of TL of that fish based on region of the bay, or time of the year.

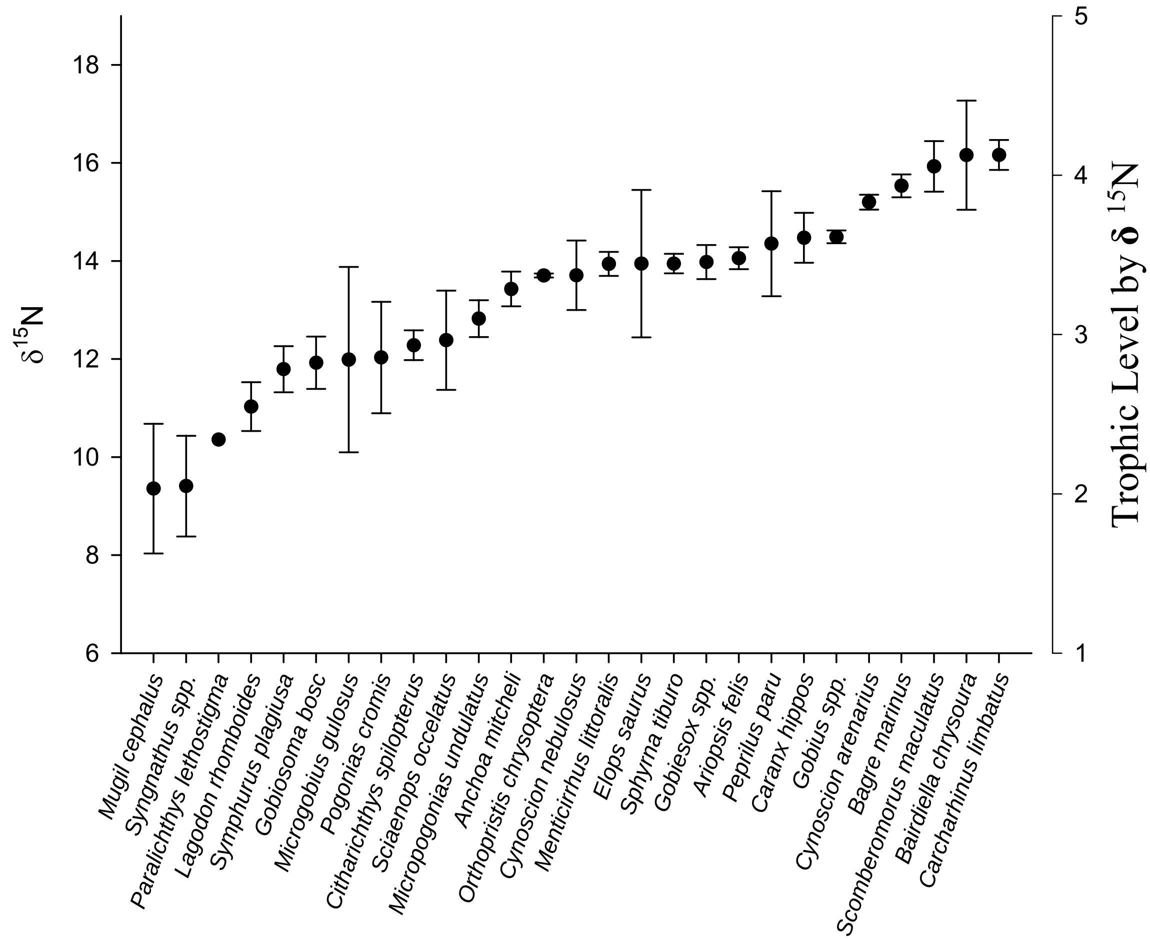

Fig 4. Trophic level estimation for fishes of the Lavaca Bay system based on mean (± SE) ranked $\delta^{15}N$ isotopic distributions.

By graphing the generalized taxonomic groups (primary producers, invertebrates, and fish), the food web of the Lavaca Bay system displays some distinct patterns (Fig 5). Fish are enriched in terms of $\delta^{15}N$ relative to invertebrates. Invertebrates are also enriched in $\delta^{15}N$ relative to producers indicating a higher trophic position. There does not appear to be any differences in $\delta^{13}C$ by taxonomic groups, showing the possibility of multiple primary carbon sources being used simultaneously within a single system. However, inferences can be made about the carbon sources of many of the fauna by placement along the x axis relative to the flora represented.

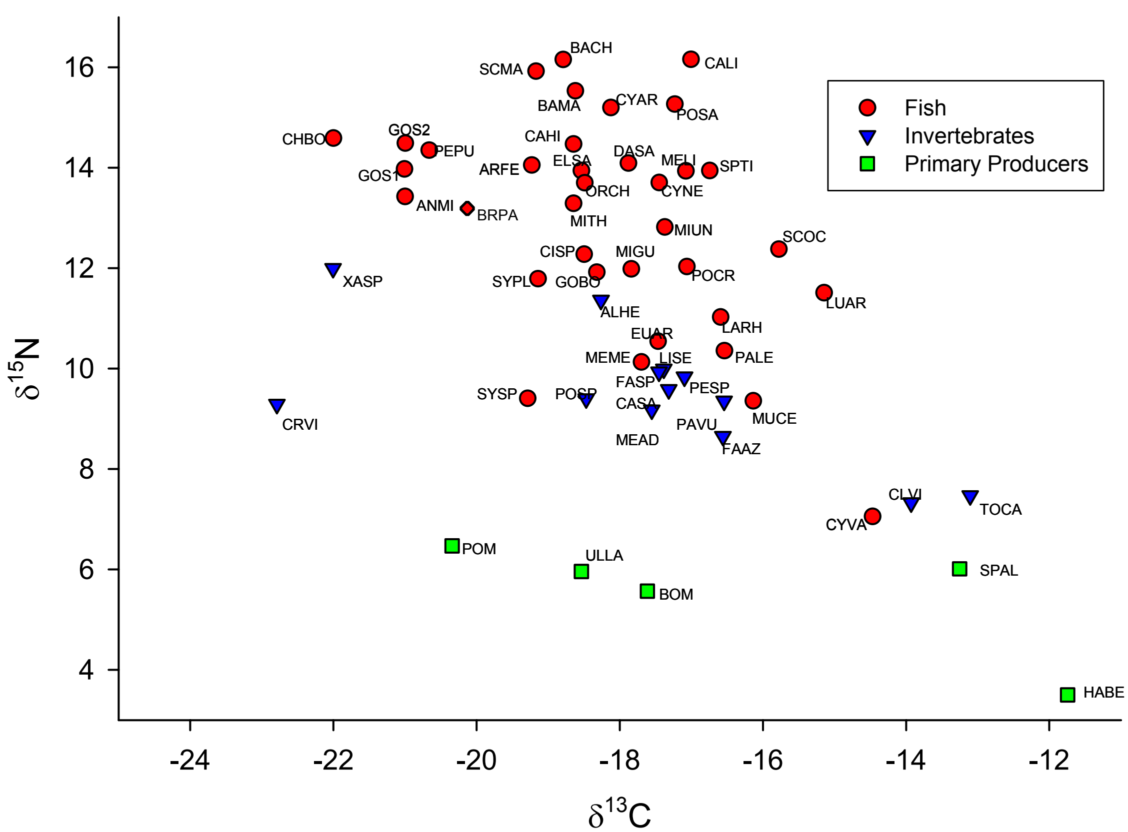

Fig 5. $\delta^{15}N$ and $\delta^{13}C$ values for major food web elements in the Lavaca Bay system. Square = primary production sources, triangle = invertebrates, and circle = fishes. Species codes in Table 7. Potential assimilation of carbon sources by consumers is indicated by degree of alignment among taxa relative to the x-axis, trophic level by relative position on the y-axis.

Habitat mediated food web dynamics

Stomach content analysis compares aspects of the food web as determined through dietary analysis among different habitat types in Lavaca Bay, Texas. The top predator according to calculated trophic levels (TL) using stomach contents in both NVB and reef habitats is *Carcharhinus limbatus*, while the top predator in marsh habitat is *Cynoscion nebulosus* (Table 8). Mean trophic levels by fish species by habitat type were compared and NVB exhibited the lowest mean TL value (3.75) with reef (3.95) and marsh exhibited the highest (4.21). Non-vegetated bottom (NVB) was found to be significantly lower than marsh (ANOVA, $F_{2,409} = 3.955$, $p = 0.018$), and reef mean TL was not significantly different than the NVB (ANOVA, $F_{2,409} = 3.955$, $p = 0.216$, $\beta = 0.05$), or marsh values (ANOVA, $F_{2,409} = 3.955$, $p = 0.277$, $\beta = 0.05$). *Arius felis*, a common species captured across all habitat types, is a good example of the general trend in the difference in TL by habitat type with the mean TL over reef habitats 2.69, NVB 2.5, and Marsh 2.98.

The percent index of relative importance (%IRI) calculated for each prey item by habitat type (Appendix 2) showed that %IRI values found in the prey items at the marsh sites were significantly different than the higher %IRI values at the NVB sites (ANOVA, $F_{2,111} = 3.42$, $p = 0.040$). However, reef habitat %IRI was not significantly different compared to NVB (ANOVA, $F_{2,111} = 3.42$, $p = 0.143$, $\beta = 0.05$), or marsh habitats (ANOVA, $F_{2,111} = 3.42$, $p = 0.788$, $\beta = 0.05$). The top 5 prey items by %IRI for each habitat are: Reef, *Brevoortia patronus* 78.9%, Decapoda spp. 73.2%, Polycheata spp. 72.0%, Actinopterygii spp.70.0%, and *Menippe adina* 67.4%; NVB, *Palaemonetes vulgaris* 100%, Actinopterygii spp. 82.0%, *Alpheus heterochaelis* 79.2%, Penaeidae spp.

71.1%, and Dendrobranchiata spp. 70.4%; and marsh, Callianassidae spp. 74.0%, Penaeidae spp. 73.0%, Rhodophyceae spp. 66.9%, *Halodule beaudettei* 53.4%, and Isopoda spp. 52.0% (Fig 6). The most important prey items are quite variable by habitat type with large differences in the %IRI.

Table 8. Total number (n) and percent abundance (%) of species used for stomach content analysis throughout four seasons of sampling in Lavaca Bay, Texas. Trophic level (TL) calculated from stomach content analysis. NVB = non-vegetated bottom.

Habitat	Family	Species	Common Name	n	%	TL
Reef	Sphyrnidae	*Sphyrna tiburo*	Bonnethead shark	2	1.12	3.46
	Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	2	1.12	3.65
	Clupeidae	*Brevoortia patronus*	Gulf menhaden	54	30.34	1.98
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	5	2.81	2.00
	Ariidae	*Ariopsis felis*	Hardhead catfish	26	14.61	2.69
		Bagre marinus	Gafftopsail catfish	43	24.16	2.91
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	2	1.12	2.81
		Cynoscion arenarius	Sand seatrout	8	4.49	3.37
		Cynoscion nebulosus	Spotted seatrout	4	2.25	3.64
		Leiostomus xanthurus	Spot	11	6.18	2.00
		Menticirrhus littoralis	Gulf kingfish	12	6.74	2.84
		Micropogonias undulatus	Atlantic croaker	3	1.69	2.76
	Carangidae	*Caranx hippos*	Crevalle jack	3	1.69	3.59
	Scombridae	*Scomberomorus maculatus*	Spanish mackerel	3	1.69	3.15
NVB	Sphyrnidae	*Sphyrna tiburo*	Bonnethead shark	2	1.16	3.58
	Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	1	0.58	4.84
	Clupeidae	*Brevoortia patronus*	Gulf menhaden	55	31.98	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	10	5.81	2.00
	Ariidae	*Ariopsis felis*	Hardhead catfish	30	17.44	2.50
		Bagre marinus	Gafftopsail catfish	36	20.93	2.88
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	3	1.74	3.65
		Cynoscion arenarius	Sand seatrout	3	1.74	3.78
		Cynoscion nebulosus	Spotted seatrout	2	1.16	3.57
		Leiostomus xanthurus	Spot	11	6.40	2.16
		Menticirrhus littoralis	Gulf kingfish	17	9.88	2.61
	Carangidae	*Caranx hippos*	Crevalle jack	2	1.16	2.11
Marsh	Clupeidae	*Brevoortia patronus*	Gulf menhaden	8	13.33	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	1	1.67	3.59
	Ariidae	*Ariopsis felis*	Hardhead catfish	16	26.67	2.98
	Mugilidae	*Mugil cephalus*	Striped mullet	4	6.67	2.00
	Sparidae	*Archosargus probatocephalus*	Sheepshead	7	11.67	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	3	5.00	3.12
		Cynoscion nebulosus	Spotted seatrout	5	8.33	3.60
		Leiostomus xanthurus	Spot	1	1.67	2.00
		Menticirrhus littoralis	Gulf kingfish	4	6.67	3.15
		Pogonias cromis	Black drum	6	10.00	2.32
		Sciaenops ocellatus	Red drum	4	6.67	3.73
	Carangidae	*Caranx hippos*	Crevalle jack	1	1.67	3.48

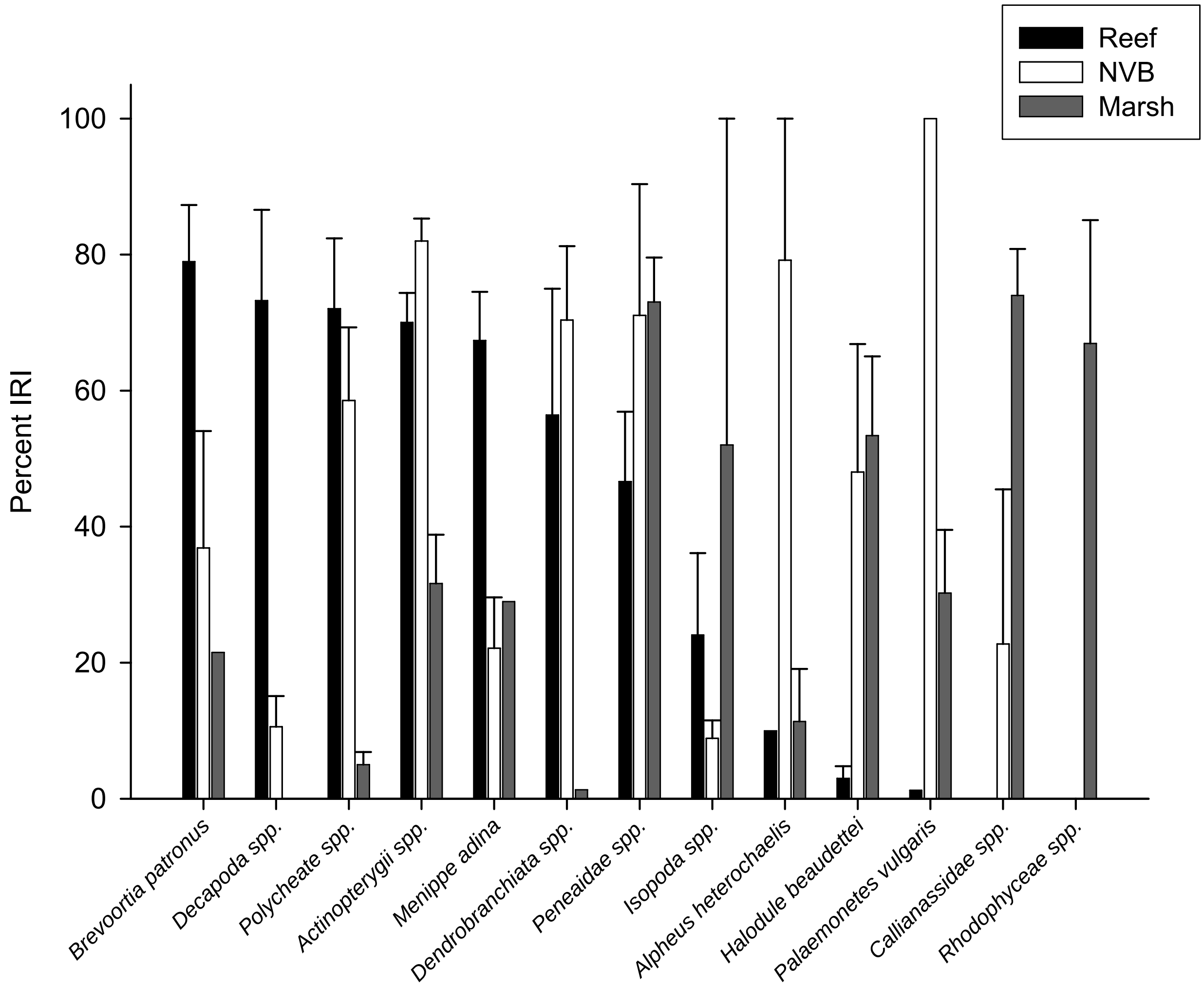

Fig 6. Percent index of relative importance (%IRI) for the top 5 prey items by each habitat type in the Lavaca Bay system. Reef habitat is represented by the black bars, non-vegetated bottom (NVB) by the hollow bars, and marsh habitat by the grey.

Mean $\delta^{13}C$ values of fishes and macroinvertebrates captured on marsh habitat (-16.6) were more enriched than NVB (-18.7) and reef (-19.4). In fact, marsh values were significantly different that of NVB (ANOVA, $F_{2,110} = 23.47$, $p < 0.001$) and reef (ANOVA, $F_{2,110} = 23.47$, $p < 0.001$) habitats. However, NVB and reef were not significantly different (ANOVA, $F_{2,110} = 23.47$, $p = 0.352$, $\beta = 0.05$).

Combining all field observations, stomach content and stable isotope analysis I was able to construct a diagram illustrating the food webs among habitat types in Lavaca Bay, Texas (Fig 7). The general trend seen in this illustration is that both the species and interactions by habitat vary greatly. This shows that the NVB and the reef habitats support more high level predators compared to the marsh habitats. The NVB food web has many high level transient predators but a less abundant prey base, while the reef food web supports the most robust food web with high level predators as well as a strong prey base. This diagram shows only a fraction of the species and interactions that actually occur in Lavaca Bay at any one time; however, simplification was necessary to show only the most abundant species and most prevalent links.

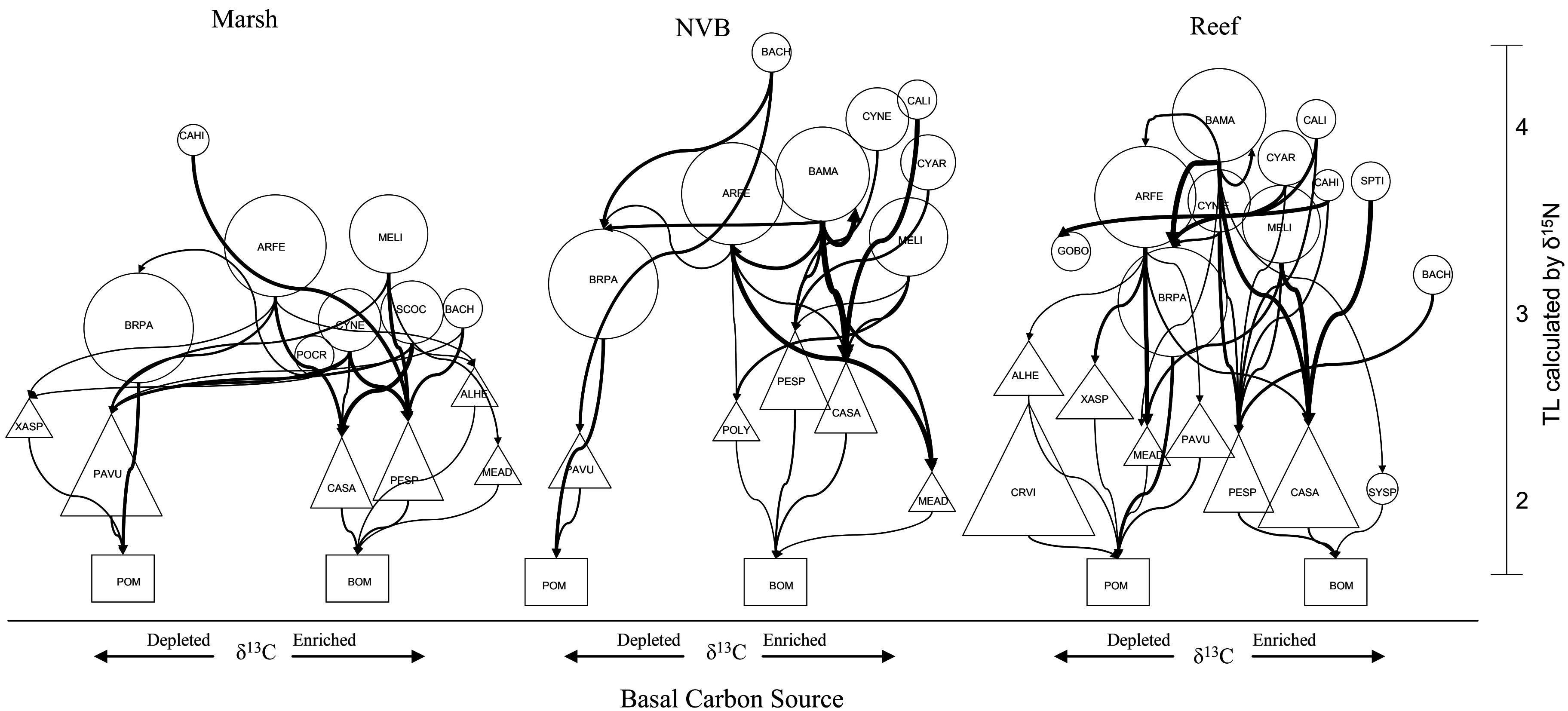

Figure 7. Food web diagram by habitat type for Lavaca Bay, Texas constructed from field observations, stomach content, and stable isotope analysis. Position on the x-axis is based on the $\delta^{13}C$ value, and region of the bay; y-axis is based on the trophic position ($\delta^{15}N$). Relative sizes of nodes (Circle = fishes, triangle = invertebrates, and square = basal carbon source) depict total abundance. Relative thickness of links is an interpretation of numerical and volumetric contribution of prey in the diet of each consumer. Species Codes as in Table 5.

Spatially mediated food web dynamics

The spatial variation in food web structure was determined by both stomach content and stable isotope analysis in the upper and lower regions of Lavaca Bay, Texas. The top predator based on calculated trophic levels (TL) using stomach contents in the upper region of Lavaca Bay is *Cynoscion nebulosus*, while the top predator in lower region of the bay is *Carcharhinus limbatus* (Table 9). Certain economically important species such as *Menticirrhus littoralis*, *Cynoscion arenarius*, and *Scomberomorus maculatus* either occurred only in the lower region or occurred much more frequently in the lower region of the bay.

The mean percent IRI (%IRI) calculated for each prey item by region (Appendix 3) showed that the upper region had significantly lower %IRI (ANOVA, $F_{1,86} = 7.44$, $p = 0.008$) than the lower region of Lavaca Bay. The top 5 prey items according to the percent IRI values for the upper region of Lavaca Bay were Callianassidae spp. 67.3%, Actinopterygii spp. 67.3%, Penaeidae spp. 63.6%, *Brevoortia patronus* 56.0%, and *Alpheus heterochaelis* 55.2%. While the top prey items for the lower were: Ictaluridae spp. 100%, Actinopterygii spp. 71.7%, Dendrobranchiata spp. 70.8, *Brevoortia patronus* 70.5%, and Rhodophyceae spp. 66.9% (Fig 8). While many of the top prey items for each region have comparable % IRI, prey items such as Rhodophyceae spp. and Callianassidae spp. were only recovered in one region of the bay.

Table 9. Total number (n) and percent abundance (%) of species used for stomach content analysis for both regions sampled in Lavaca Bay, Texas. Trophic level (TL) was calculated from stomach content analysis.

Region	Family	Species	Common Name	n	%	TL
Upper	Clupeidae	*Brevoortia patronus*	Gulf menhaden	65	33.85	1.99
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	8	4.17	2.20
	Ariidae	*Ariopsis felis*	Hardhead catfish	50	26.04	2.70
		Bagre marinus	Gafftopsail catfish	37	19.27	2.96
	Mugilidae	*Mugil cephalus*	Striped mullet	3	1.56	2.00
	Sparidae	*Archosargus probatocephalus*	Sheepshead	1	0.52	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	5	2.60	3.31
		Cynoscion arenarius	Sand seatrout	1	0.52	3.93
		Cynoscion nebulosus	Spotted seatrout	4	2.08	3.58
		Leiostomus xanthurus	Spot	9	4.69	2.00
		Menticirrhus littoralis	Gulf kingfish	4	2.08	3.20
		Pogonias cromis	Black drum	2	1.04	2.27
		Sciaenops ocellatus	Red drum	2	1.04	3.85
	Carangidae	*Caranx hippos*	Crevalle jack	1	0.52	3.86
Lower	Sphyrnidae	*Sphyrna tiburo*	Bonnethead shark	4	1.83	3.52
	Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	3	1.38	4.05
	Clupeidae	*Brevoortia patronus*	Gulf menhaden	52	23.85	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	8	3.67	2.00
	Ariidae	*Ariopsis felis*	Hardhead catfish	22	10.09	2.62
		Bagre marinus	Gafftopsail catfish	42	19.27	2.84
	Mugilidae	*Mugil cephalus*	Striped mullet	1	0.46	2.00
	Sparidae	*Archosargus probatocephalus*	Sheepshead	6	2.75	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	3	1.38	3.12
		Cynoscion arenarius	Sand seatrout	10	4.59	3.44
		Cynoscion nebulosus	Spotted seatrout	7	3.21	3.62
		Leiostomus xanthurus	Spot	14	6.42	2.13
		Menticirrhus littoralis	Gulf kingfish	29	13.30	2.70
		Micropogonias undulatus	Atlantic croaker	3	1.38	2.76
		Pogonias cromis	Black drum	4	1.83	2.35
		Sciaenops ocellatus	Red drum	2	0.92	3.61
	Carangidae	*Caranx hippos*	Crevalle jack	5	2.29	2.92
	Scombridae	*Scomberomorus maculatus*	Spanish mackerel	3	1.38	3.15

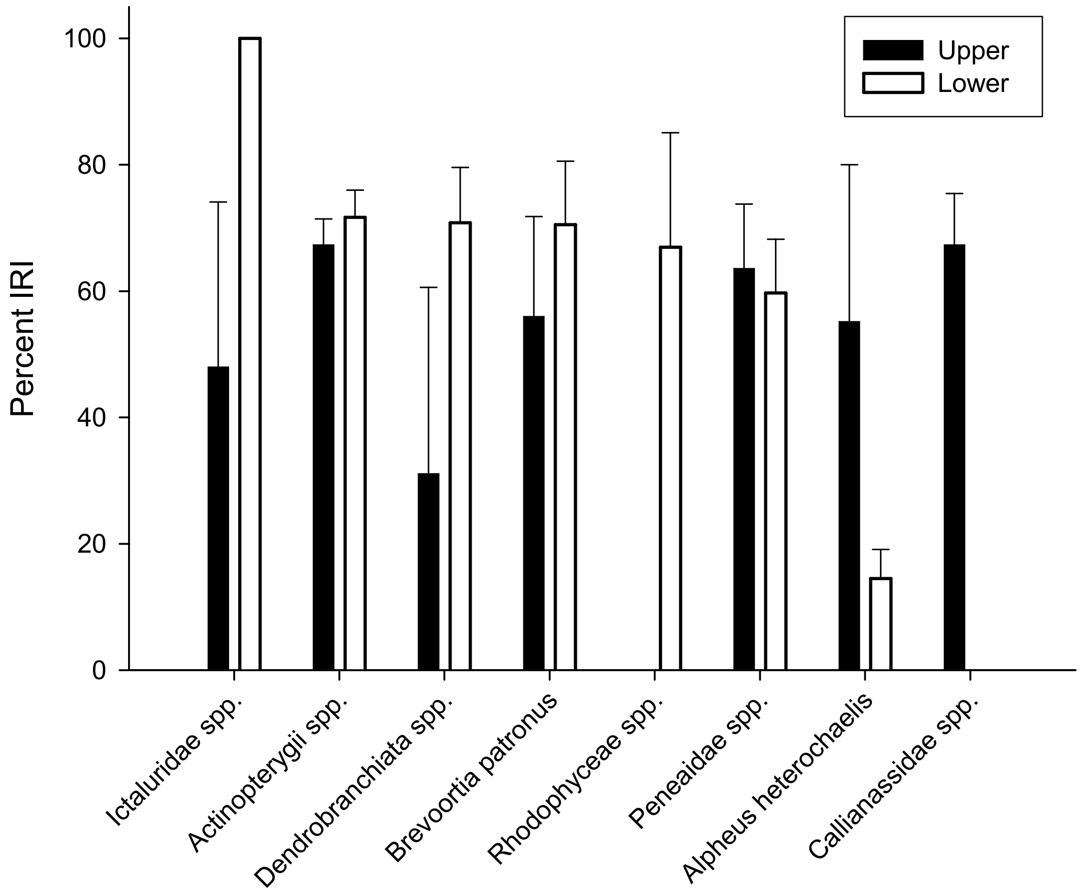

Fig 8. Percent index of relative importance (%IRI) for the top 5 prey items by region of the bay in the Lavaca Bay system. Upper region indicated by filled bars and lower region by open bars.

The mean $\delta^{13}C$ signatures of the fishes and macroinvertebrates captured in the lower region were significantly more enriched (-16.90) than the upper (-19.08) region of Lavaca Bay (ANOVA, $F_{1,92} = 25.35$, $p < 0.001$) (Appendix 6). The frequency distribution of the $\delta^{13}C$ values by region appears to be disjointed, suggesting a difference in the major contributing carbon source of each region (Fig 9).

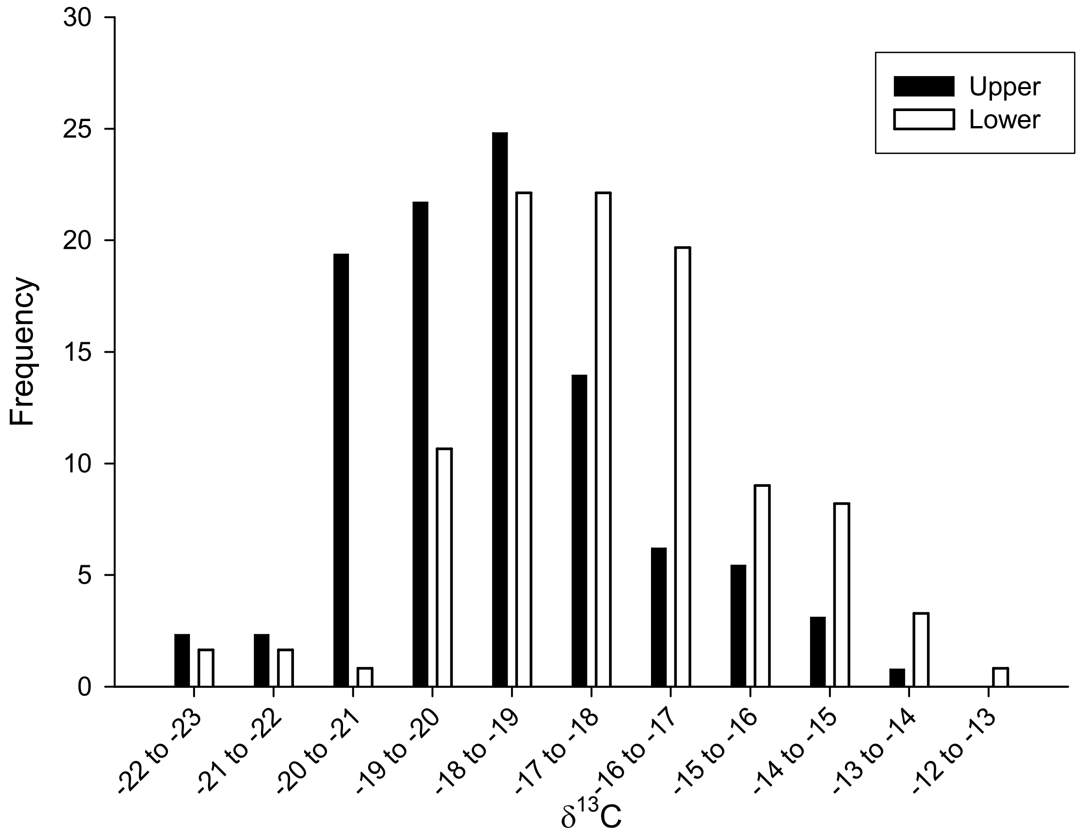

Fig 9. Frequency distributions of δ^{13}C values for organisms from the upper region (filled bars) and the lower region (open bars) of the Lavaca Bay system.

Combining all field observations, stomach content and stable isotope analysis I was able to construct a diagram illustrating the food web in both the upper and lower regions of Lavaca Bay (Fig 10). The general trend seen in this illustration is that species found in both regions of the bay have a higher trophic level, based on N^{15}, in the upper region than the lower region of the bay. The figure also shows that the lower region of the bay supports a larger more complex food web. This diagram shows only a fraction of the species and interactions that actually occur in Lavaca Bay at any one time; however, simplification was necessary to show only the most abundant species and most prevalent links.

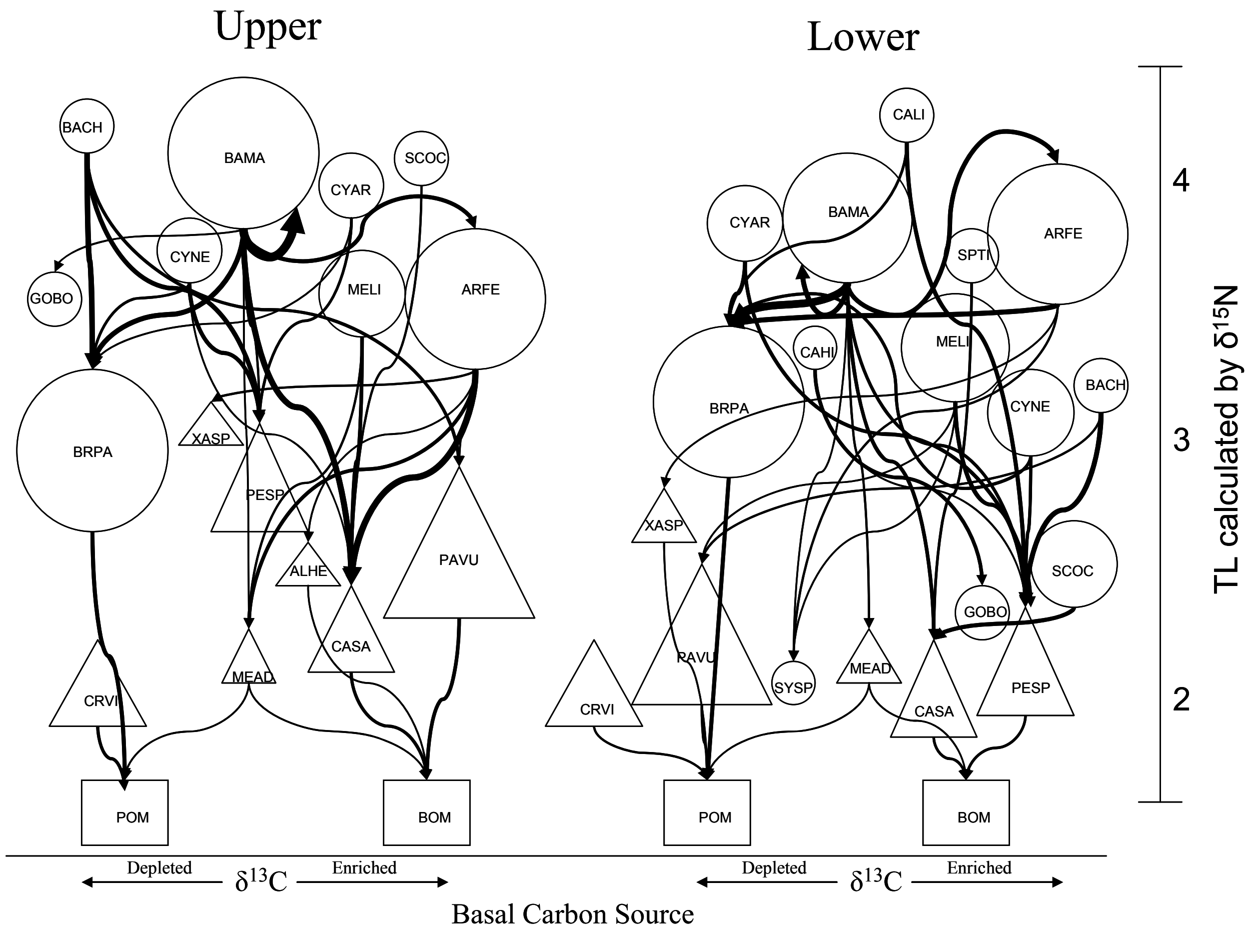

Figure 10. Spatial food web diagram for Lavaca Bay, Texas constructed from field observations, stomach content, and stable isotope analysis. Position on the x-axis is based on the δ^{13}C value, and region of the bay; y-axis is based on the trophic position (δ^{15}N). Relative sizes of nodes (Circle = fishes, triangle = invertebrates, and square = basal carbon source) depict abundance. Relative thickness of links is an interpretation of numerical and volumetric contribution of prey in the diet of each consumer. Species codes as in Table 5.

Temporally mediated food web dynamics

There were several dissimilarities in the seasonal food web structure of Lavaca Bay, Texas as determined by dietary analysis. However, due to the extremely low numbers of fishes captured in the winter season, the most commonly observed prey items were not included in some calculations. The average volume of food recovered from a consumer's stomach during summer was 1.17 ml compared to 0.90 ml for fall and 0.84

ml for spring. The top predator according to calculated trophic levels (TL) using stomach contents in both spring and winter sampling events was *Bairdiella chrysoura* (Table 10). The top predator for the fall sampling event was *Cynoscion nebulosus* and for summer it was *Carcharhinus limbatus*. *Scomberomorus maculatus* in the summer and *Leiostomus xanthurus* in the spring only presented empty stomachs for analysis, thus there is no TL information and this and is illustrated as an X in Table 10.

The top prey items determined by percent IRI values for each season represent a wide range of organisms (Appendix 4). The top prey items in the summer generally consisted of fishes while the top prey items in the fall were dominated by benthos, and finally the spring food web is dependant on macroinvertebrates as an important food source (Fig 11). Certain prey items occurred in high numbers regardless of the season such as Actinopterygii spp., Peneaidae spp., and *Brevoortia patronus* (Fig 11). There was no significant difference in the basal carbon source for the Lavaca Bay system ($\delta^{13}C$) by season (ANOVA, $F_{3,122} = 1.67$, $p = 0.176$, $\beta = 0.05$) (Appendix 7).

Table 10. Total number (n) and percent abundance (%) of species used for stomach content analysis throughout four sampling seasons in Lavaca Bay, Texas. Trophic level (TL) as calculated from stomach content analysis.

Season	Family	Species	Common Name	n	%	TL
Summer	Sphyrnidae	*Sphyrna tiburo*	Bonnethead shark	4	2.82	3.52
	Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	4	2.82	4.05
	Clupeidae	*Brevoortia patronus*	Gulf menhaden	38	26.76	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	1	0.70	3.59
	Ariidae	*Ariopsis felis*	Hardhead catfish	27	19.01	2.79
		Bagre marinus	Gafftopsail catfish	38	26.76	2.69
	Mugilidae	*Mugil cephalus*	Striped mullet	1	0.70	2.00
	Sciaenidae	*Cynoscion arenarius*	Sand seatrout	6	4.23	2.94
		Cynoscion nebulosus	Spotted seatrout	9	6.34	3.52
		Menticirrhus littoralis	Gulf kingfish	3	2.11	3.42
		Micropogonias undulatus	Atlantic croaker	3	2.11	2.76
	Carangidae	*Caranx hippos*	Crevalle jack	7	4.93	3.08
	Scombridae	*Scomberomorus maculatus*	Spanish mackerel	1	0.70	X
Fall	Clupeidae	*Brevoortia patronus*	Gulf menhaden	30	16.85	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	29	16.29	2.00
	Ariidae	*Ariopsis felis*	Hardhead catfish	12	6.74	2.91
		Bagre marinus	Gafftopsail catfish	10	5.62	3.49
	Mugilidae	*Mugil cephalus*	Striped mullet	1	0.56	2.00
	Sparidae	*Archosargus probatocephalus*	Sheepshead	8	4.49	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	4	2.25	2.84
		Cynoscion arenarius	Sand seatrout	9	5.06	3.77
		Cynoscion nebulosus	Spotted seatrout	2	1.12	3.92
		Leiostomus xanthurus	Spot	37	20.79	2.08
		Menticirrhus littoralis	Gulf kingfish	26	14.61	2.65
		Pogonias cromis	Black drum	5	2.81	2.28
		Sciaenops ocellatus	Red drum	5	2.81	3.82
Winter	Clupeidae	*Brevoortia patronus*	Gulf menhaden	12	70.59	2.00
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	2	11.76	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	2	11.76	3.60
		Leiostomus xanthurus	Spot	1	5.88	2.00
Spring	Clupeidae	*Brevoortia patronus*	Gulf menhaden	43	31.16	1.98
	Polynemidae	*Polydactylus octonemus*	Atlantic threadfin	2	1.45	2.00
	Ariidae	*Ariopsis felis*	Hardhead catfish	36	26.09	2.51
		Bagre marinus	Gafftopsail catfish	34	24.64	2.97
	Mugilidae	*Mugil cephalus*	Striped mullet	3	2.17	2.00
	Sciaenidae	*Bairdiella chrysoura*	Silver perch	2	1.45	3.68
		Cynoscion arenarius	Sand seatrout	2	1.45	3.43
		Cynoscion nebulosus	Spotted seatrout	2	1.45	3.64
		Leiostomus xanthurus	Spot	1	0.72	X
		Menticirrhus littoralis	Gulf kingfish	8	5.80	3.00
		Pogonias cromis	Black drum	1	0.72	2.54
		Sciaenops ocellatus	Red drum	1	0.72	3.45
	Scombridae	*Scomberomorus maculatus*	Spanish mackerel	3	2.17	3.15

X = No trophic level data available due to empty stomachs.

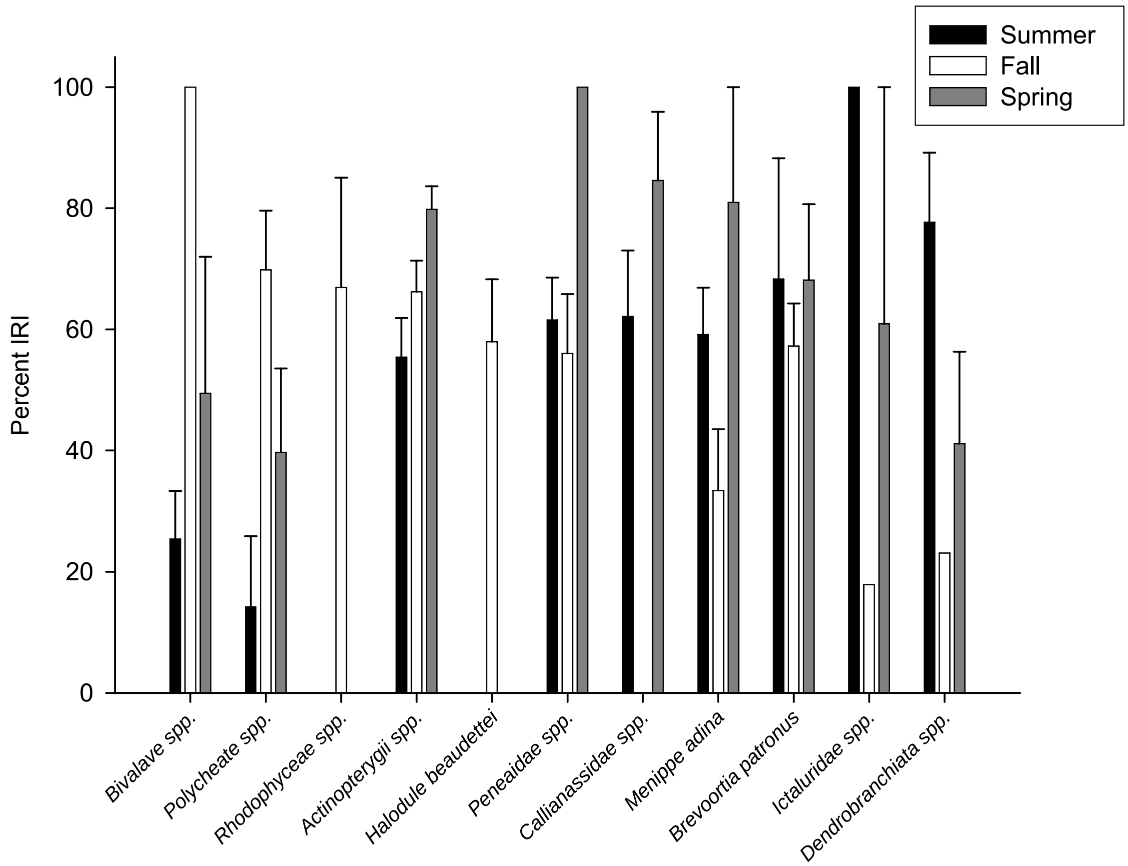

Fig 11. Percent index of relative importance (IRI) for the top 5 prey items by season sampled in the Lavaca Bay system. Summer data is indicated by the black bars, fall by the empty bars, and spring by the grey bars. Winter data was excluded due to the extremely low catch available for stomach content analysis.

Stomach content vs stable isotope analysis

Trophic levels calculated using stable isotopes and stomach content analysis are relatively similar (Fig 12). In Figure 12 the stomach content trophic level bars contains only fish species, while the stable isotope also includes invertebrate samples. The peak in TL for isotopic data occurred in the 3-3.5 range while the peak with stomach content data encompassed 2-2.5. However the overall pattern in distribution is quite similar.

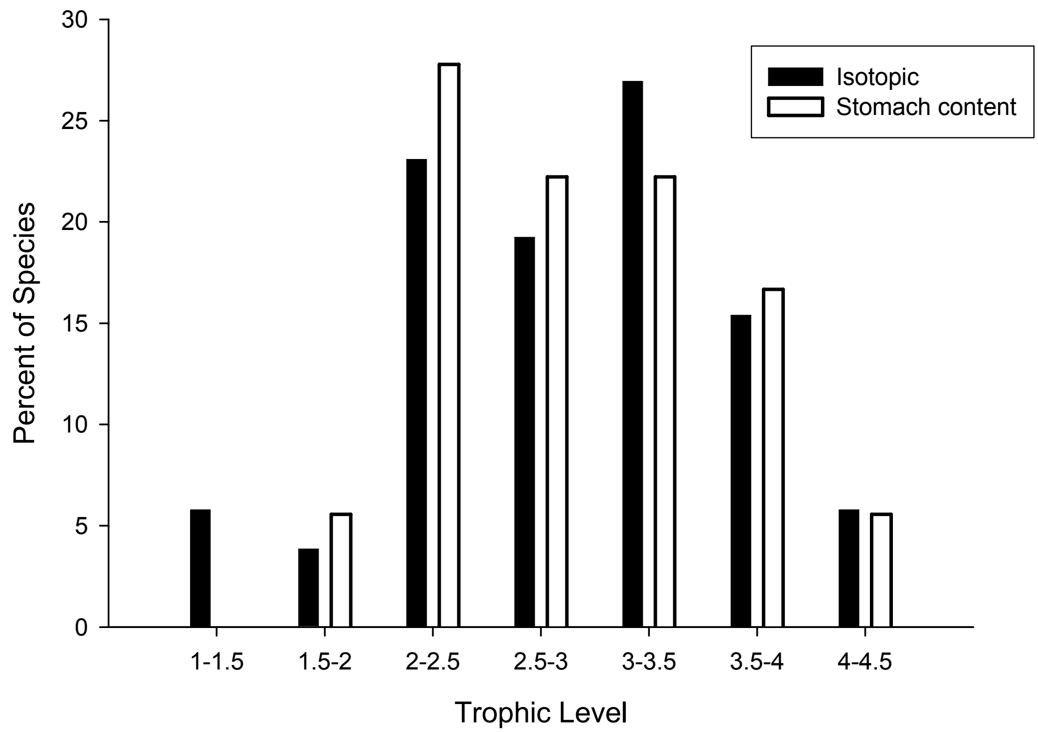

Fig 12. Frequency distributions of trophic levels of Lavaca Bay system taxa based on $\delta^{15}N$ data (filled bars) and stomach content data (open bars).

The distribution of trophic levels varied among habitat types (Fig 13). The isotopic data shows a trend in the mean TL, while the stomach content data shows a more scattered spread in TL by habitat types. Oyster reef habitat supported a greater percent of species with high TL placement (3-4), while the NVB habitat and marsh habitat support a consecutively lower TL species placement (Fig 13). This trend is also illustrated in the diagrammatic food web model for the habitat types (Fig 7).

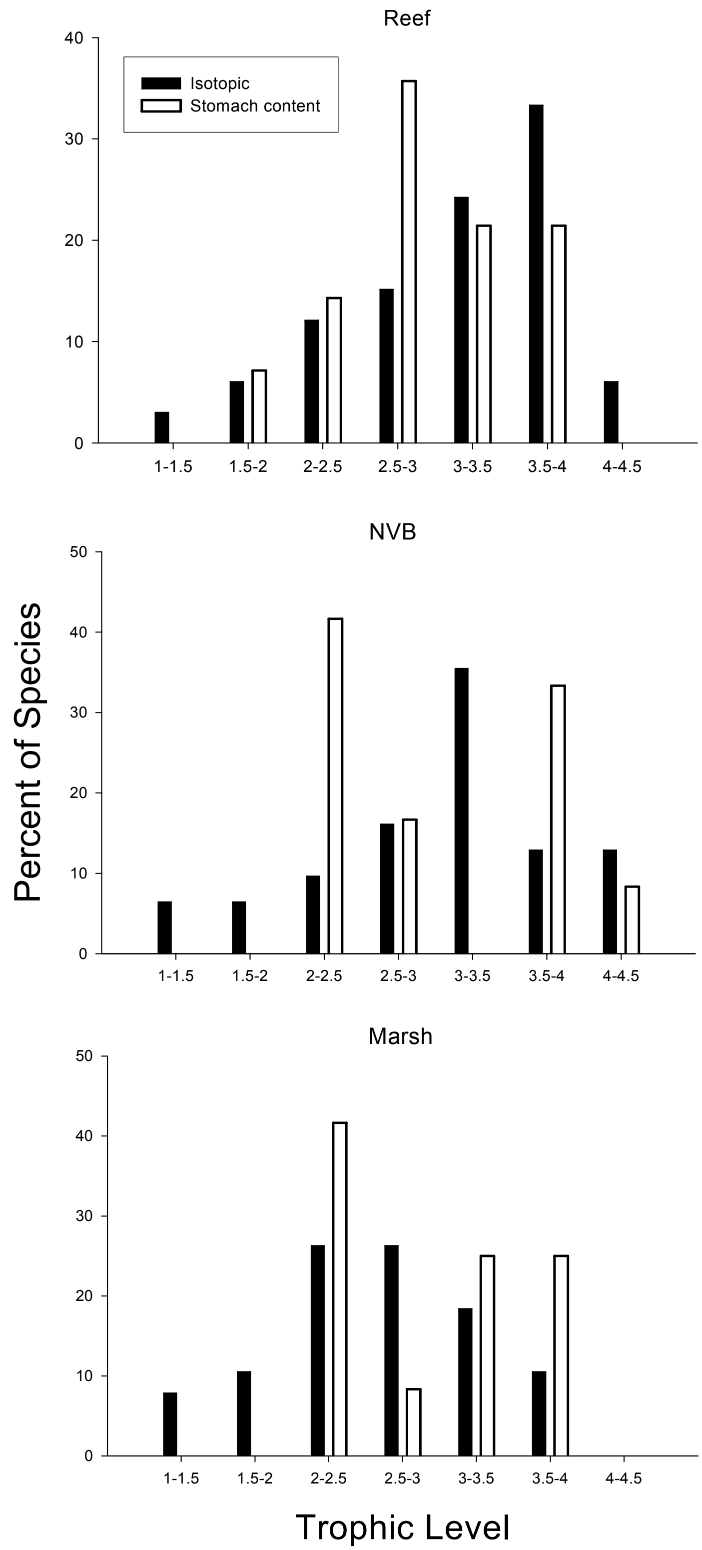

Fig 13. Frequency distributions of trophic levels of Lavaca Bay system taxa by habitat type based on $\delta^{15}N$ data (filled bars) and stomach content data (open bars).

The isotopic and stomach content analysis gave similar frequency distributions in both the upper and lower regions of Lavaca Bay (Fig 14). However, the upper region supports a greater frequency of higher TL according to the isotopic analysis than the lower region of the bay.

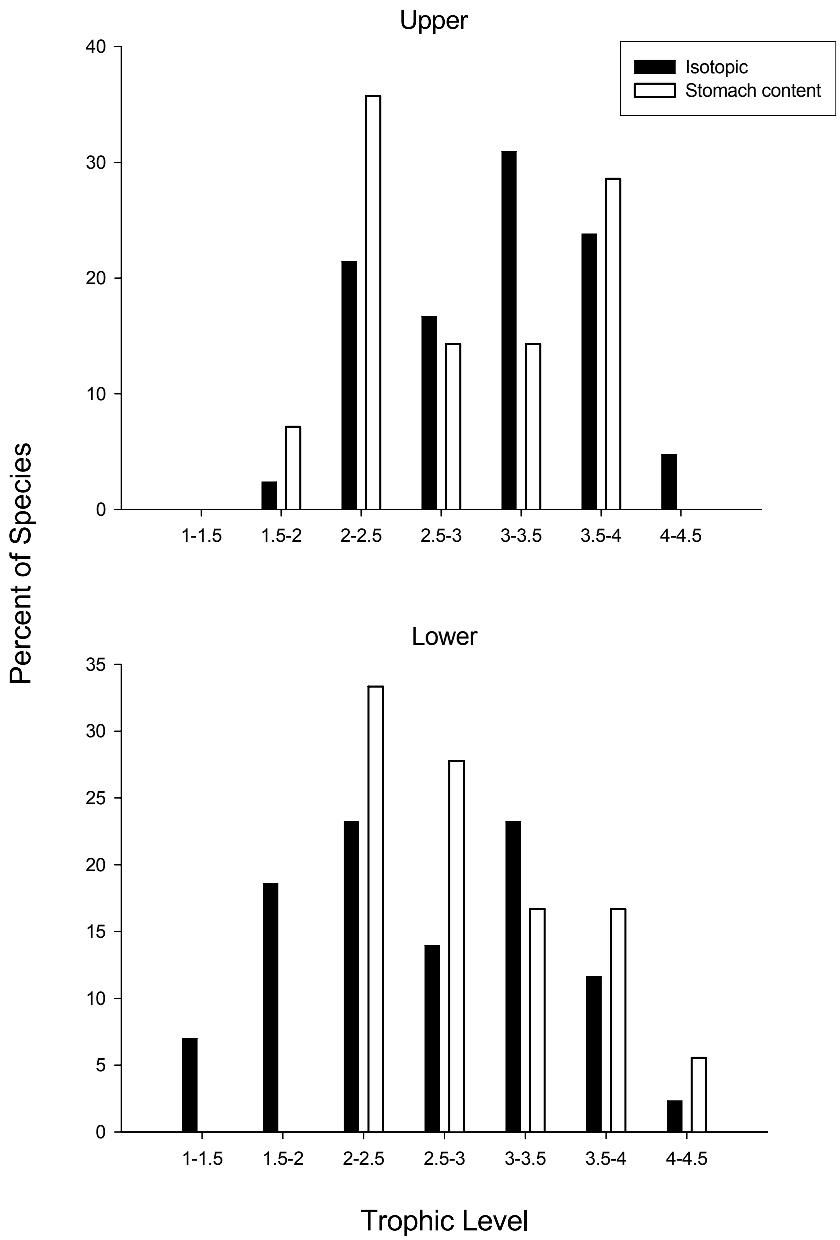

Fig 14. Frequency distributions of trophic levels of Lavaca Bay system taxa by region based on $\delta^{15}N$ data (filled bars) and stomach content data (open bars).

Temporally, the distribution of trophic levels vary by season with the summer and spring (warmer months) exhibiting a food web dominated by the higher TL while the winter and fall seasons have a more moderate spread of species frequencies (Fig 15). Based on the same set of abundant consumer taxa, I compared trophic level estimates calculated using dietary data with estimates calculated from stable isotope data. With four exceptions, the two methods yielded fairly similar results (Fig 16). Three of the taxa with dissimilar trophic levels based on the two methods were *Brevoortia patronus, Archosargus probatocephalus*, and *Polydactylus octonemus*. All three of these species had much higher trophic levels calculated from the stable isotope analysis compared to estimates based on stomach contents analysis. *Leiostomus xanthurus*, the fourth species removed as an outlier had a much lower trophic level as calculated from dietary analysis compared to isotopic analysis. This was due to the high number of *L. xanthurus* used for dietary analysis having empty or nearly empty stomachs. When these species were removed from the statistical analysis, the correlation between the isotopic and dietary methods was significant ($p = 0.02$ and $r = 0.60$). Similar species have been excluded from this type of analysis with similar justification (For example, see Winemiller et al. 2007).

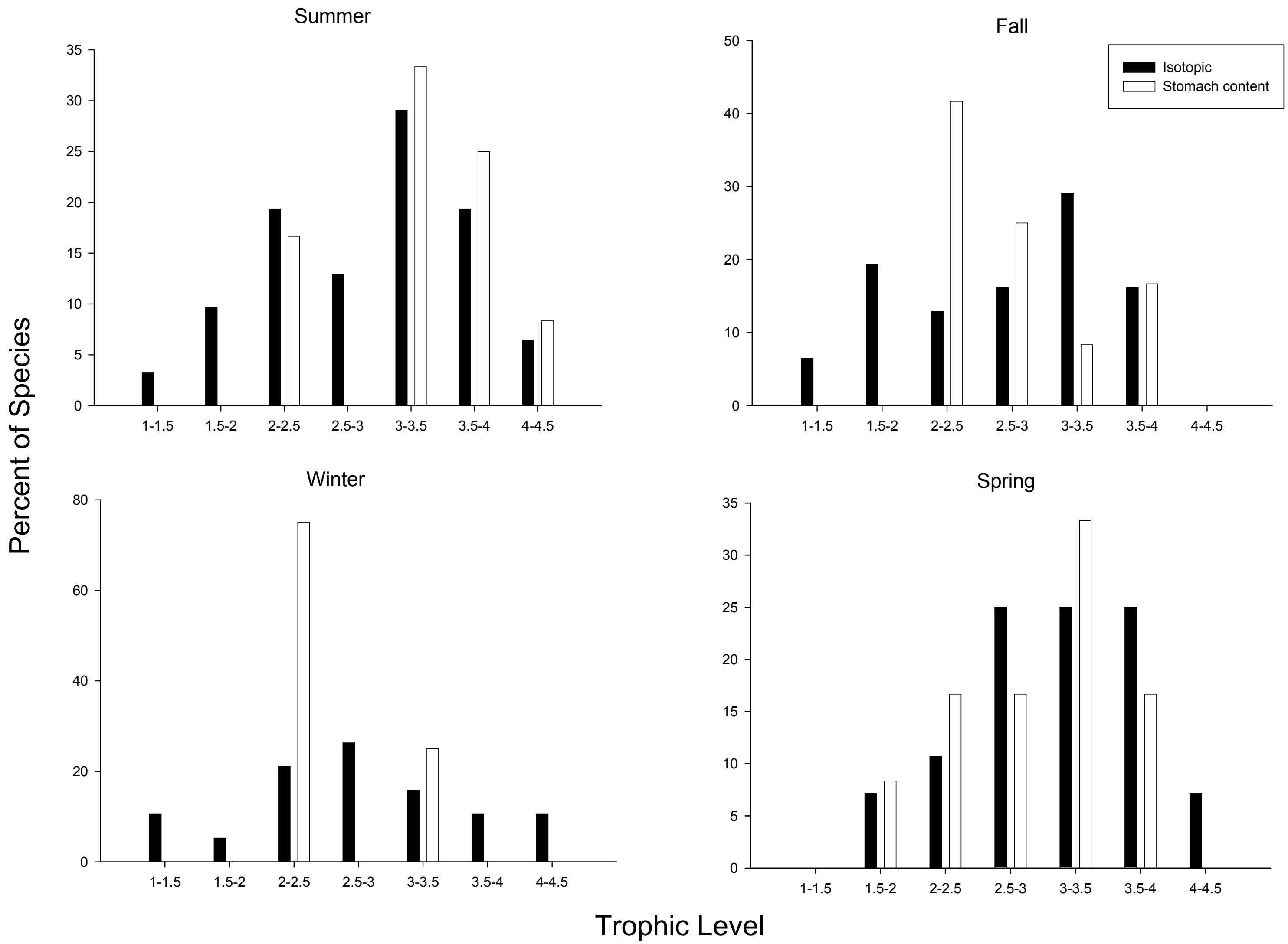

Fig 15. Frequency distributions of trophic levels of Lavaca Bay system taxa by season based on $\delta^{15}N$ data (filled bars) and stomach content data (open bars).

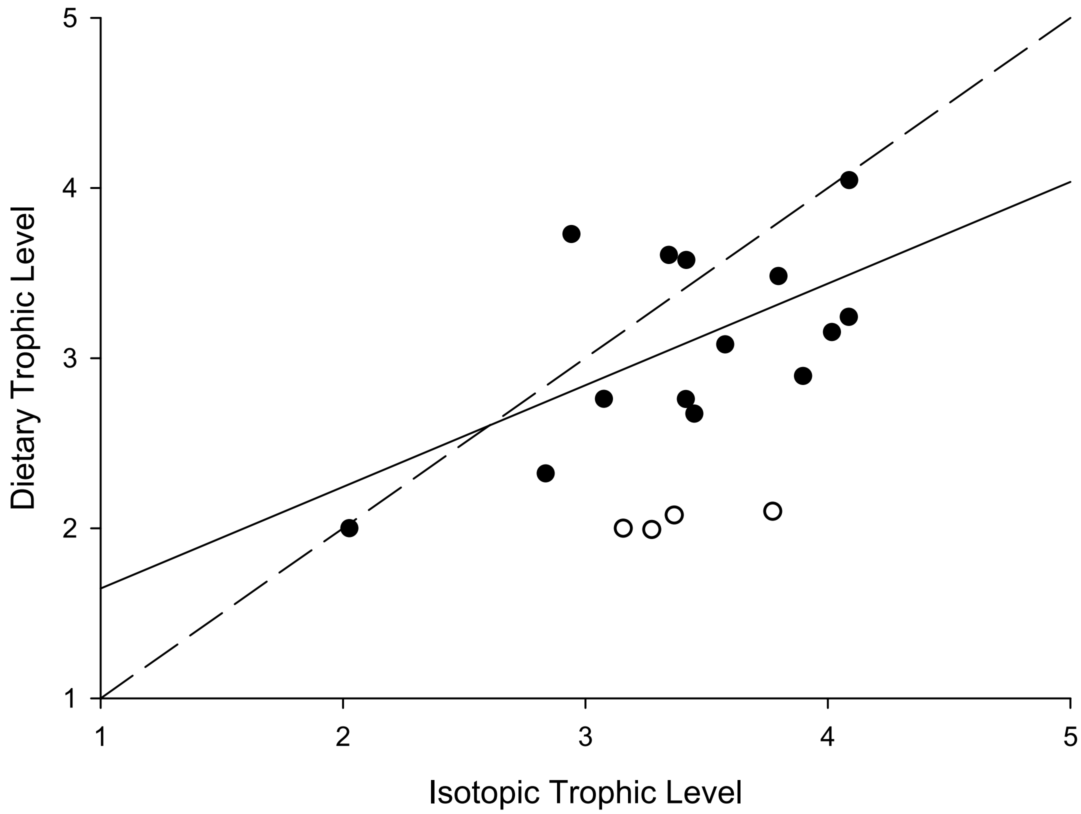

Fig 16. Comparison of trophic level values for Lavaca Bay, Texas consumer species derived from $\delta^{15}N$ vs. stomach content data. Four outlying species (hollow points) were *Brevoortia patronus*, *Archosargus probatocephalus*, *Polydactylus octonemus*, and *Leiostomus xanthurus* (r for full data set = 0.46, p = 0.05). In the data set without the 4 outliers r = 0.60, p = 0.02. The dashed diagonal line represents the 1:1 line.

DISCUSSION

Ecosystems are complex systems, and food webs are currently the most suitable tool we have to analyze the impact of perturbations on trophic systems and their potential consequences in a fisheries context. Clearly, more research is needed to improve our understanding of the current fisheries management practices and their effects on marine ecosystems. One way is to develop ecosystem-wide food webs and species interaction models for incorporation into management decisions. Modeling programs such as Ecopath with EcoSim and EcoNetwrk are recently developed programs being used by fisheries ecologists (Pauly et al. 2000, Ulanowicz 2005); however they have not yet been effectively incorporated into scientific advice for fishery management. This is due to the lack of significant base knowledge in trophic interactions and food webs of ecosystems. Providing a better understanding of species interactions, trophic structure, and the construction of entire food webs needs to be accomplished so that these models can be completed, and their true value in fisheries management can be known. The apparent variability of trophic structure on spatiotemporal scales and between habitat types found in this study provides new information on the dynamic nature of food webs and the need for more thorough sampling. This study provides an integral link necessary to gain knowledge on food web structure of subtidal oyster reefs and how they relate to other known EFHs. Research from this study will provide managers with much needed information on the food web dynamics of Lavaca Bay, Texas.

Overall food web analysis

A primary concern in assessing any healthy ecosystem is food availability. By examining stomach content of fishes I was able to determine the levels of food acquisition by noting fullness of stomachs. Only 13.5% of stomachs investigated were empty, which is lower than 16.2% reported by Arrington and Winemiller (2002). Acquisition of energy is a realized difficulty common to nearly all organisms, and this energy acquisition directly affects fitness, thus affecting the health of a community's food web functioning. The low number of empty stomachs gives strong evidence that food availability and therefore energy acquisition in the Lavaca Bay system are at healthy levels.

After examining all of the stomach contents I found there was a wide range in food preference of fishes as illustrated by the percent IRI in the Lavaca Bay system. Some of the most preferred and utilized food sources for higher level consumers were *Brevoortia patronus* and peneaid shrimp. Both *B. patronus* and peneaid shrimp were found to be abundant, and not only do these species make up a large possible biomass within the estuary, they are being utilized as a major source of energy and are supporting the food web in Lavaca Bay.

Palaemonetes spp. and penaeid shrimp were the most dominant invertebrate catch (90.8%) with the epibenthic sled, providing a solid prey source for omnivorous fishes. Penaeid shrimp are not only an economically important species, but they have high nutritional values providing nutritional support for large food webs. Over 40ml of Peneaidae spp. were consumed by the fishes examined throughout this study. Penaeid shrimp comprised 63.2 % by volume of all shrimp consumed by fishes in the Lavaca Bay system.

Brevoortia patronus was the most abundant fish species sampled in Lavaca Bay comprising nearly 50% of the fishes captured by gill net. *B. patronus* is a planktivorous fish that provides the Lavaca Bay system with a large amount of available biomass for secondary consumers. They provide an important link to the food web by converting planktivorous matter into useable energy for larger piscivorous predators (Winemiller 2007). *B. patronus* is not only an economically important species, but they also provide nutritional support to many other economically and ecologically important species such as: *Cynoscion arenarius, Cynoscion nebulosus, Bairdiella chrysoura*, and *Carcharhinus limbatus.*

Cannibalism exists in many food webs, generally on juvenile piscivores that occur in high densities (Winemiller 1990). In this study, *Bagre marinus* was found to be opportunistically cannibalistic, with juveniles of the same species found intact in the guts of multiple adult *B. marinus*. This cannibalistic behavior was observed across all temporal and spatial scales. These types of feeding loops are common in food webs and can sometimes cause confusion in creating a schematic flow encompassing all feeding interactions.

The $\delta^{13}C$ values of the consumer closely approximate the isotopic composition of their respective diets. A large variety of organisms were sampled for stable isotope analysis in this study to encompass the community using the Lavaca Bay system. Oysters and planktivirous fishes exhibited $\delta^{13}C$ values very similar to the particulate organic matter (POM) collected, which is their major dietary source. Other benthic organisms such as crabs exhibited $\delta^{13}C$ values very similar to the benthic organic matter (BOM) collected. However, I found that many demersal fishes and crustaceans had a large variance in their $\delta^{13}C$ values, indicating they have a diverse diet and a single carbon source could not be identified.

Dietary analyses revealed that many planktivirous species consumed large amounts of particulate organic matter. In general, the $\delta^{13}C$ value for planktivirous species were most reflective of POM $\delta^{13}C$ signature showing they in fact were assimilating organic carbon in the form of particulate organic matter (mainly phytoplankton). Emergent *Spartina alterniflora* dominate shallow marginal areas of the bay throughout the year and SAV (*Halodule wrightii*) dominate shallow portions in the lower region of the bay. The submerged grasses are abundant in broader areas during summer and fall and die back during winter (Winemiller et al. 2007). Detritus from both *S. alterniflora* and *H. wrightii* is probably present in sediments throughout the year. Despite the fact that both of these species of vegetation dominate the standing plant biomass of the system very few organisms directly consume the plant itself. More likely, the major food source contribution to the system is through detrital matter produced by these plants. Previous studies indicate that the $\delta^{13}C$ ratios of plant carbon are conserved during decay exhibiting generally similar isotopic values (Haines and Montague 1979).

Crassostrea virginica's $\delta^{13}C$ signature was very similar to the particulate organic matter (POM) $\delta^{13}C$ signature. Other studies have also shown that *C. virginica* rely on phytoplankton as a major food source (Haines and Montague 1979). However, a more precise comparison of carbon signature of the POM could be attained with better sample purification removing more suspended solids and larger zooplankton from the filtered POM samples. These results indicate probable direct assimilation of POM by the standing *C. virginica* population in Lavaca Bay.

These isotopic results confirm this pattern with little direct assimilation from the vegetation themselves with most carbon signatures presenting a detrital, epifaunal, and particulate organic matter foundation. Previous studies of estuarine and marsh food webs using stable isotopes suggest that macrofauna are supported mostly by a combination of detrital and non-detrital C_4 marsh grasses, algae, and to a lesser extent terrestrial C_3 plants (Haines and Montague 1979, Peterson and Howarth 1987, Deegan and Garritt 1997, Winemiller et al. 2007). Most fishes assimilate a combination of these sources, thereby obscuring a direct trophic connection to one basal carbon source for individual fishes. Moncreiff and Sullivan (2001) showed that epiphytic growth on seagrasses provides the majority (75%) of assimilated nutrition for consumers. However, in this study, epiphytic isotopic values were not examined, although the isotopic ratios of the seagrass blades and epiphytes generally are known to demonstrate similar values (Moncreiff and Sullivan 2001).

Habitat mediated food web dynamics

This is the first study to combine NVB, subtidal oyster reef, and marsh edge habitats both on a spatial and temporal scale while investigating the entire food web. There have been several studies comparing community assembly and even food web structure between different estuarine habitat types (Minello et al. 1989, Minello 1999, Akin 2001), however only a few included oyster reefs (Shervette 2006). Plunket and Peyre (2005) studied differences in nekton community structure of subtidal oyster reef habitat to that of NVB and found that the abundance of organisms on the oyster reef were approximately twice that of NVB; however they did not include any vegetated habitats. Shervette (2006) found intertidal oyster reef habitat of a Mississippi estuary compared with adjacent vegetated and non-vegetated habitats was occupied by a distinct community of fishes and invertebrates with high densities of these residents.

Subtidal oyster reefs were found to support a more robust food web with the greatest number of links and higher level predators as compared to the other available habitat types in Lavaca Bay, Texas. Each habitat type exhibited a specifically structured food web with some species occurring only in certain habitats. The top predator of both NVB and subtidal oyster reef habitats was *Carcharhinus limbatus*, while the top predator in marsh habitat was *Cynoscion nebulosus*. *Carcharhinus limbatus* (blacktip shark), is a tertiary consumer and is important to NVB and reef food web systems by providing top down control. The average TL (N^{15}) of organisms found on subtidal oyster reefs was greater than the average TL found on both marsh edge and NVB. To assess what is supporting these large food webs, the useable prey base needs to be examined.

The prey bases found on the different habitat types studied are very diverse. Food webs are structured based on the prey base available to the system. Using stomach content analysis we determined what species were the most important prey items. Certain prey items were found in all habitat types and have relatively similar IRIs (Penaeidae spp, Actinopterygii spp, and *Menippe adina*), while other prey items with high IRIs could be found in only certain habitats such as Rhodophyceae in the marsh. Diverse prey bases attract a diversity of predators to that habitat type creating very differently structured communities.

Greater differences are seen in food web structures by habitat types when looking at the $\delta^{13}C$ signatures. The fish assemblage from both NVB and reef habitats were more depleted in $\delta^{13}C$ as compared to individuals from marsh habitats. This reflects the greater input of both C3 and C4 detrital matter that would occur in the marsh habitats relative to the "open water" NVB and reef habitats, providing additional support to the core differences in community structures by habitat type.

Spatially mediated food web dynamics

This study assessed spatially mediated food web dynamics by comparing two regions of Lavaca Bay. I found that the food web in Lavaca Bay varied greatly spatially with the lower region comprising a more robust food web with higher trophic levels and more links. Understanding spatial dynamics and creating spatial boundaries for marine food webs is an important topic that marine ecologists are just beginning to explore (Sogard et al. 1989, Winemiller 1990, Holt 2002, Melville and Connolly 2003, Heck et al. 2005, Winemiller et al. 2007). It is difficult to spatially compartmentalize systems that have no apparent physical barriers, and place boundaries on systems that in reality have no borders. Communities are mixes of species with radically different spatial strategies experiencing the world at different spatial scales (Holt 1996, 2002). Thus it is a daunting task to describe a large system, such as an estuarine food web, in terms of spatial boundaries.

This is the first study to include both stable isotope and stomach content analysis to determine both spatial and temporal differences in estuarine food web structure. The overall species composition between the upper and lower regions of Lavaca Bay is very similar, however, a few more rarely occurring species were found in the lower region of the bay, closer to the tidal inlet. A previous analysis of food web structure in the Matagorda Bay system (Mad Island Marsh) (Winemiller et al. 2007) noted that a potential source of bias for their study was a lack of spatial variation. Shark species, *Sphyrna tiburo* and *Carcharhinus limbatus* were captured only in the lower region of the bay. While only occurring in very specific locations of the bay the presence of these apex predatory sharks adds another layer to the food web of this system and provides a very important top down control for this system. Adult *Lagodon rhomboides*, *Orthopristis chrysoptera*, and *Micropogonias undulatus* were also captured only in the Lower region of the bay. Certain economically important species such as *Menticirrhus littoralis*, *Cynoscion arenarius*, and *Scomberomorus maculatus* either occurred only in the lower region or occurred much more frequently in the lower region of the bay. These data show that the lower region of the bay supports a more robust food web with comparably more links. The more robust a food web is (or the more species occupying the same link in the food web) the more elastic the community is in changing circumstances (de Ruiter et al. 2005). This evidence suggests that lower Lavaca Bay is providing an environment more conducive to a robust food web. The top five prey items according to percent IRI were present in both regions of the bay except for Rhodophyceae spp. in the lower region and Callianassidae spp. in the upper. Thus the prey fields the fish are utilizing appear to be similar regionally. Further studies are necessary to describe what features allow the lower region to support a larger, healthier food web.

The occurrence of submerged aquatic vegetation and the proximity to the tidal inlet and Matagorda Bay in the lower region of the bay, but not the upper, may be a contributing factor to the larger more stable food web found in the lower region of Lavaca Bay. The volume of food eaten by individual fish species was highly variable, however when the data for all the fish species examined were combined and the volume was calculated and corrected for the number of fish sampled, the lower bay showed a greater mean volume in food consumed. Previous studies show a similar result, Minello et al. (1989) tested habitat related diet patterns by comparing coastal to delta habitats in Lavaca Bay, Texas. They found that the overall, mean weight of fish consumed at the coastal sites was consistently larger than the values from the delta. These differences could indicate difference in the availability of food and the relative quality of these areas for foraging.

The frequency distribution of $\delta^{13}C$ values by region appears to be disjointed, suggesting a difference in the major contributing carbon source in each region. The lower region of the bay appears to have a greater C_4 plant influence than the upper region of the bay. This is attributed to the extensive cover of seagrass and marsh edge habitat observed in the lower bay, compared to a more riverine particulate organic matter influence seen in the upper region of Lavaca Bay. Further sampling is necessary to pinpoint the $\delta^{13}C$ signatures of all possible contributions to both systems.

Fish movement can increase variation in isotopic data (Herzka 2005). New immigrants may reflect a history of feeding in the habitat from which they emigrated rather than the receiving habitat. Thus more transient fish may exhibit skewed isotopic signatures relative to their capture location. Spatial factors can increase or decrease the likelihood of fish movement such as distance from a pass. If this is the case, the lower region of the bay in which most of the largest transitory fishes were captured may exhibit isotopic signatures covering a larger spatial scale. However, it is notable that both the stomach content and stable isotope methods yielded similar TL for most of the species examined in this study. For this reason, isotopic data was approached with caution when inferring spatial conclusions. All isotopic data was closely compared to stomach content data, and no extreme outliers were found to misrepresent spatial data in this study.

Physical parameters are thought to be a major influence on the food web structure of the upper and lower regions of Lavaca Bay. There were significant differences in salinity between regions of the bay which is primarily caused by the location of each region to major freshwater inflow and proximity to a coastal pass introducing water exchange with the Gulf of Mexico. The upper region of the bay is highly influenced by the Lavaca River, which deposits an average of 382.2 cubic feet per second of fresh water into the Lavaca/Matagorda Bay system (USGS, NWISWeb). This freshwater influence creates a reduced salinity environment in the upper region of the bay. The lower region of the bay is influenced by the Keller Creek freshwater inflow, but more so by the exchange of water with Matagorda Bay which is highly influenced by the elevated salinity through water exchange with the Gulf of Mexico. Water temperature between regions of the bay over all seasons (except for spring) was found to be significantly different. The upper bay exhibits more extreme fluctuation in temperatures. This could be due to the influence of this region of the bay to more influence by land based temperatures, while the lower region of the bay is more influenced by water based temperatures which tend to stay more moderate across seasons.

There are many differences in the physical and biological makeup of these two regions of the Lavaca Bay system. It is beyond the scope of this study to determine if one is functioning at a higher level than the other. However, our data suggests that there are significant differences in food web structure in the spatial scales examined in Lavaca Bay which supports the idea that ecosystems based management needs to employ careful consideration of "boundaries" and spatial margins in developing management practices of systems.

Temporally mediated food web dynamics

This study is the first to combine stomach contents and stable isotope analysis to construct an estuarine food web including a temporal parameter. Many studies are now documenting temporal variation in marine communities, however, only a few studies have attempted to explore effects of temporal variation on food web structure (Paterson and Whitfield 1997, Akin 2001). Many of the early studies creating food webs illustrated them as static models without incorporation of a temporal scale, thus only providing a snap shot of the food web at a particular moment in space and time. Also, many food webs combine much spatial and temporal data, thus making them appear more robust than they really are. These snapshots were key pieces of science that has lead to the greater understanding of food web structure, however they are not useful tools for making management decisions for marine systems due to their highly dynamic nature. A previous study on the seasonal variation in food web structure within the Matagorda Bay system (Akin and Winemiller 2006) revealed low temporal variation in most general food web properties. A more recent study (Winemiller et al. 2007) combined this data with stable isotope values for that system, but was unable to compare their data temporally because they collected isotopic data only once. In order to provide managers with more scientific data there has been a recent push for ecologists to study these systems over temporal scales to understand how the trophic structure naturally fluctuates.

The summer and fall food webs of Lavaca Bay support a greater numbers of high level predators and more available links. The top predator according to calculated trophic levels (TL) using stomach contents in both spring and winter sampling events was *Bairdiella chrysoura*. The top predator for the fall sampling event was *Cynoscion nebulosus* and for summer was *Carcharhinus limbatus*. This can be attributed to the larger prey field available in the summer and fall, in this bay system, as well as known migration patterns leading larger transient fishes into estuaries. Major causes for seasonally driven or temporal variation in food webs are changing availabilities and qualities of aquatic habitat and food resources. Akin and Winemiller (2006) reported that a suite of environmental variables (salinity, temperature, vegetation cover, dissolved oxygen, and water depth) were associated with distinct seasonal assemblage structures at Mad Island Marsh in the Matagorda Bay system. In connection with the temporal variation in physical parameters, food web size varied dramatically by season (Akin and Winemiller 2006). I determined the temporal variation in the food web structure of the Lavaca Bay system via dietary and stable isotope analysis and demonstrated some significant dissimilarity.

The top prey items determined by percent IRI values for each season represent a wide range of organisms. The top prey items in the summer generally consisted of fishes while the top prey items in the fall were dominated by benthos. The spring food web is dependant on shrimp as a major food source of importance. Certain prey items occurred in high numbers regardless of the season such as Actinopterygii spp., Peneaidae spp., and *Brevoortia patronus*. Just as consumers move in and out of a system seasonally, the prey base also changes dramatically temporally, as shown with the shifts in the most important prey items seasonally. Fish migration patterns are very dynamic and they tend to enter and leave bay systems outlined by seasonal migrations. Hardegree (1997) conducted a study comparing community structure on serpulid reefs to that of NVB in Baffin Bay, Texas. He found a significant seasonal effect in the catch rate, which he attributed to the recruitment of those fishes into the bay. Estuarine systems are considered “nursery grounds” for many species and seasonal recruitment into the estuary can cause major, but predictable, changes in the community structure. Understanding when these changes occur and how they affect trophic level processes is the next step to properly being able to manage these systems.

Species with short life cycles can show large temporal variation in isotopic signatures, whereas longer-lived species will reflect a time-integrated record of material assimilation. Thus, isotopic data may reflect various amounts of time integration that depend on species, life history strategy, and ontogeny. These factors may have affected and possibly masked temporal differences in diet and therefore food web structure through isotopic analysis. Due to these reasons, it is important to use stomach content analysis data as a check and balance system which provides a more definitive method for viewing the temporal food web structure of the Lavaca Bay system.

Stomach content vs stable isotope analysis

Evaluating the pathways which nutritionally link a consumer to its food base and the succeeding links to the diets of higher consumers are understandably complex (Creach et al. 1997). The feeding behavior of organisms within marine communities is usually demonstrated to be more diverse and complex than a simple trophic level would suggest (Pimm et al. 1990). Sometimes isotopic data can provide an indistinct estimate of consumer-resource interactions; however the ordination of species according to stable isotope signatures can be used to precisely and accurately distinguish patterns of trophic differentiation. An advantage of the stable isotope approach is that large amounts of data can be collected and analyzed with minimal time and effort compared to dietary analysis. A limitation of this method is that it depends on isotopically distinct carbon sources which are not available in all systems. The use of multiple elements in analysis can sometimes increase the resolution in these cases (Phillips 2001).

Diet estimates based on stomach content analysis require large sample sizes, particularly for species with broad diets and high intraspecific, ontogenetic, and seasonal variation. Thus dietary analysis is time and labor intensive, and also requires considerable taxonomic expertise to identify and quantify food items that are often fragmented or partially digested. Also, just because a food item is recovered from the stomach of an individual that does not mean that that individual assimilated that food source and used it for energy or nutrition. Much of the coarse vegetative detritus consumed by fishes and crustaceans was probably refractory and not assimilated. Conversely, large samples that include individuals of different size classes collected over time from different locations permit examination of ecological performance in relation to ontogenetic and environmental factors.

Estimates of trophic structure by both stable isotope and stomach content analysis methods in this study were found to be similar. Exceptions included zooplanktivorous and detritivorous fishes, which showed higher trophic levels according to stable isotope analysis compared with estimates from stomach content analysis. Winemiller et al. (2007) also demonstrated this dissimilarity with related species. An explanation for this variation is that the dietary analysis of these species showed major contribution of detrital matter to the diet, with nominal contribution attributed to higher trophic level prey items.

The stable isotope signatures infer that the less commonly observed invertebrate contribution to the diet is in fact one of the possible primary nutritional resources for those species. It is likely that the isotope method more accurately illustrated the trophic levels of these species when compared to the stomach content analysis which depends on accurate dietary estimation and assumes equal assimilation efficiencies for elements found in stomach contents. A specific example is *Brevoortia patronus* where their stomachs consisted mostly of detrital organic matter; however isotopic analysis inferred that invertebrates and other microorganisms were the primary nutritional source for the *B. patronus*. This assumption is similar to the conclusion obtained from stable isotope studies of menhaden (Peterson and Howarth 1987).

Few studies have used both stable isotope and stomach content analysis methods (see Winemiller et al 2007) to study an entire food web, and no other study has done so using habitat differences, and spatial or temporal scales. Both methods have limitations that reduce precision and accuracy of inferred web structure. Yet, when applied together, stable isotope and stomach content analyses provide a more detailed and accurate model of trophic structure and dynamics, including greater taxonomic, temporal, and spatial resolution. Thus, it is important to use the two methods, in tandem, especially for lower TL species. Additionally, stable isotopes are assimilated over time, and the rate of assimilation depends on the life history strategy of the organism and many times isotope data can not be used to illustrate temporal trends. Previous studies have documented the positive attributes of using both methods (Harrigan et al. 1989, Hentschel 1998, Creach et al. 1997, Beaudoin et al. 1999, Mantel et al. 2004). Stomach content data needs to be used to set more realistic boundaries for isotope data through time and space.

Conclusions and future directions

The overall food web in Lavaca Bay, Texas can be described as a dynamic system supporting a variety of trophic levels from primary producers to secondary and tertiary consumers. Certain species such as *Brevoortia patronus* and penaeid shrimp were shown to be major contributors to not only the biomass of this system but also as major food sources supporting the robust food web. Assessing the food web as a whole is important in understanding major predator-prey relationships but is also important to gain a complete understanding of the dynamics of this system. However, differences in the food web structure by habitat types, spatial scales, and temporal changes must be investigated.

The distribution of trophic levels among habitat types varied, with the subtidal oyster reef habitat supporting a generally higher TL (3-4) food web while the marsh edge habitat supports only a 2-3 TL dominated food web. The elevated levels in the food web observed over the oyster reef habitat provide strong evidence that this is an important habitat for many fishes and invertebrates but also gives cause for concern due to the diminishing coverage of oyster reefs in the Lavaca Bay system. Oyster reefs support many ecosystem services and are important biogenic system components. The continued loss of oyster reefs in Lavaca Bay could permanently alter system-wide community structure and existing food web. Proper management of oyster removal from the bay, restoration projects, and the establishment of reef sanctuaries to increase the oyster coverage to historic levels are all recommended management actions for Lavaca Bay, Texas. Moreover, providing areas with concentrated abundant food sources for game fish, subtidal oyster reefs may enhance the value of recreational fisheries.

This study and others like it are important links in the quest to understanding food web dynamics of estuarine systems spatially and temporally for the purpose of more sound fisheries management practices. Gaining a better understanding of ecosystem wide interactions through trophic structure, community dynamics, and inter-species interactions allows scientists to increase their understanding of these non static systems. Spatiotemporal analyses may be one of the greatest challenges faced by fishery managers. The ability to tie landing and fisheries-independent data to finer spatial scales, such as habitat type, through food web analysis will allow researchers to examine local population trends and localized depletions. Understanding the spatial scales associated with habitat types is necessary for scientists to define essential fish habitats, and make decisions on habitat mitigation, restoration, and even reconstruction.

Commercially important and protected fish species are believed to directly use submerged oyster reef habitat as foraging grounds, as well as potential nursery grounds. A greater number of *Cynoscion arenarius*, *Leiostomus xanthurus*, *Scomberomorus maculatus*, and *Sphyrna tiburo* were captured over subtidal reef habitats than NVB or marsh in this study. Observations from stomach content analysis suggest that these fishes feed directly on the prey base that resides on the subtidal oyster reefs in Lavaca Bay. Under the Magnuson-Stevens Act, defining EFH for managed fishery species is a priority for fisheries managers. Essential fish habitat can be defined as any waters or substrate necessary for fish to carry out any part of their life cycle such as; habitats necessary for breeding, feeding, and growing to maturity (Minello 1999, Levin and Stunz 2005). The direct use of subtidal oyster reefs as feeding grounds suggest that these habitats function as EFH for numerous economically important fishes in Lavaca Bay, Texas. Thus, proper management for ensuring the persistence of these reefs needs to be a goal of fisheries managers.

Trophic level calculations using stomach contents as a proxy require the knowledge of the trophic level of each prey item found in the stomach of each fish. This information is neither readily available, nor do most sources yield the same values. I compiled a table of known prey item TL values and averaged the values calculated for each of the prey items identified in my study. This lack of information is a huge stepping stone that is missing in the path to fully understanding ecosystems as a whole through food web studies. The benefits of developing a database of all known trophic levels calculated through all studies by species could provide a wealth of knowledge for future studies, especially in the Gulf of Mexico.

In this study, the NVB studied was parallel with the reef habitats sampled, however future studies are encouraged to also investigate the NVB habitats occurring in shallower waters parallel to marsh and SAV habitats to determine if community and trophic structure differences are a function of depth or other parameters. Future studies need to monitor the food web structure of Lavaca Bay over time to adaptively manage this and other estuarine systems that are so vital to the health of our marine resources.

Over time, food webs change in species composition, structure, abundance, and richness of individual organisms (de Ruiter et al. 2007). Food webs are dynamic systems with fishes migrating into and out of a system based on seasonal changes and recruitment patterns. The more links a food web has, the more resilient it is to change. Healthy, robust systems with numerous links can withstand perturbations and tolerate the dynamic nature of estuarine systems. It is particularly critical for ecologists to understand the spatial, temporal, and habitat mediated differences in food web structures due to their dynamic nature.

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APPENDIX

Appendix 1. Prey item trophic levels from researched sources, and the determined trophic level designations for the prey items in the food web of Lavaca Bay, Texas.

		Source							
		Christian 1999	Milessi 2005	Cortez 1999	Hobson 1992	www.fishbase.org	Arregiun-Sanchez 2004	www.seaaroundus.org	Determined TL for Lavaca Bay
Prey Category	Prey Item	TL	TL	TL	TL	TL	TL	TL	**TL**
Amphipod	*Ampelisca* spp.	2.15		2.20	2.60		2.10		2.26
	Amphipoda spp.	1.00		2.20	2.60		2.10		2.23
	Erichtonius brasiliensis	1.00		2.20	2.60		2.10		2.23
Bivalve	Bivalave spp.	2.23	2.00	2.10	2.00		2.00	2.00	2.06
	Ensis minor	2.23	2.00	2.10	2.00		2.00	2.00	2.06
	Ischadium recurvum	2.23	2.00	2.10	2.00		2.00	2.00	2.06
Crab	*Anomura* spp.	2.12		2.52					2.32
	Brachyura spp.			2.50				2.60	2.53
	Callianassidae spp.	2.23		2.52				2.60	2.45
	Callinectes sapidus	3.22		2.52				2.60	2.78
	Menippe adina	2.23		2.52				2.60	2.45
	Neopanope texana	2.23		2.52					2.38
	Pleocyemata spp.	2.23		2.52					2.53
	Porcellanidae spp.	2.23		2.52					2.38
	Uca spp.	2.23		2.52					2.38
	Xanthidae spp.			2.52					2.38
Decapod	Decapoda spp.			2.52	3.40			2.60	2.84
Detritus	Detritus	1.00		1.00					1.00
Fish	Actinopterygii spp.			3.24					3.24
	Anguilliformes spp.		4.34	3.24		3.70			3.76
	Brevoortia patronus	3.37	2.75	3.24		2.20		2.19	2.75
	Gobiesox spp.	3.10		3.24		3.00			3.11
	Gobiidae spp.	3.10		3.24		3.00			3.11
	Ictaluridae spp.	3.20		3.24		3.20	3.10		3.19
	Sygnathus spp.	3.10		3.24		3.30			3.21
	Synodus foetens	3.91		3.24		4.50	4.00		3.91
Gastropod	Gastropoda spp.	2.04		2.10				2.00	2.05
Insect	Araneae spp.			2.10					2.50
	Diptera spp.			2.50					2.50
	Hymenoptera spp.			2.50					2.50
	Insecta spp.			2.50					2.50

Appendix 1 cont.

		Source							
Prey Category	Prey Item	Christian 1999 TL	Milessi 2005 TL	Cortez 1999 TL	Hobson 1992 TL	www.fishbase.org TL	Arregiun-Sanchez 2004 TL	www.seaaroundus.org TL	Determined TL for Lavaca Bay **TL**
Isopod	*Aegathoa oculata*	2.00		2.20			2.10		2.10
	Ergasilus sp.	2.00		2.20			2.10		2.10
	Erichsonella spp.	2.00		2.20			2.10		2.10
	Isopoda spp.	2.00		2.20			2.10		2.10
Mysid	Mysida spp.			2.20	2.30				2.25
Nemertean	Nemertea spp.	3.03		2.50					2.77
Polycheate	Ampharetidae spp.	2.30		2.50			2.00		2.27
	Eunicidae spp.	3.03		2.50			2.00		2.51
	Glyceridae spp.	3.03		2.50			2.00		2.51
	Pectinariidae spp.	2.30		2.50			2.00		2.27
	Polycheate spp.			2.50			2.00		2.25
	Terebellidae spp.	2.30		2.50			2.00		2.27
Shell Hash	*Crassostrea virginica*							2.00	2.00
Shrimp	*Alpheus heterochaelis*	2.00		2.52			2.30	2.20	2.26
	Dendrobranchiata spp.			2.52			2.30		2.45
	Farfantepenaeus aztecus	2.95		2.52			2.30	2.80	2.64
	Farfantepenaeus spp.	2.95		2.52			2.30	2.70	2.62
	Palaemonetes vulgaris	2.95		2.52			2.30		2.59
	Peneaidae spp.	2.95	2.52	2.52			2.30	2.70	2.62
	Sergestidae spp.			2.52			2.30		2.41
	Squilla empusa	2.95		2.52			2.30		2.59
	Tozeuma carolinense			2.52			2.30		2.41
Squid	Cephalopoda spp.		3.80	3.20			3.80	3.25	3.51
Tunicate	Appendicularia spp.			2.50					2.50
Vegetation	*Halodule beaudettei*	1.00		1.00	1.00		1.00		1.00
	Rhodophyceae spp.	1.00		1.00	1.00		1.00		1.00
	Sargassum natans	1.00		1.00	1.00		1.00		1.00
	Spartina alterniflora	1.00		1.00	1.00		1.00		1.00

Appendix 2. Prey items identified from stomach contents of habitats in Lavaca Bay, Texas sampled from July 2006-April 2007. Percent volume (%V), percent number (%N), percent frequency of occurrence (%FO), index of relative importance (IRI), and percent index of relative importance (%IRI) were calculated for each stomach sampled, and values illustrated in this table are averages of these calculated values.

Habitat	Phylum (Division)	Class	Order	Family	Species	%N	% V	%FO	IRI	%IRI
Reef	Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	3.06	12.00	26.25	203.83	2.46
			Najadales	Cymodoceaceae	*Halodule beaudettei*	15.85	1.21	20.28	192.72	2.99
	Arthropoda	Insecta			Insecta spp.	60.00	0.50	4.76	287.97	30.25
			Diptera		Diptera spp.	25.00	0.55	4.76	121.63	2.37
			Hymenoptera		Hymenoptera spp.	27.32	16.38	19.05	832.53	27.54
		Malacostraca	Amphipoda		Amphipoda spp.	75.00	0.83	4.76	360.93	37.91
				Ischyroceridae	*Erichtonius brasiliensis*	85.71	44.44	4.76	619.56	31.77
			Decapoda		Brachyura spp.	1.37	0.08	2.50	3.62	0.19
					Decapoda spp.	68.89	69.77	10.90	1461.89	73.24
					Pleocyemata spp.	37.14	44.17	19.29	1482.30	42.85
				Alpheidae	*Alpheus heterochaelis*	25.00	40.00	4.76	309.40	10.00
				Dendrobranchiata	Dendrobranchiata spp.	60.92	67.47	8.95	1137.70	56.41
				Menippidae	*Menippe adina*	53.19	63.47	33.31	3499.85	67.39
				Palaemonidae	*Palaemonetes vulgaris*	7.14	4.65	4.76	56.14	1.25
				Panopeidae	*Neopanope texana*	41.19	36.80	14.51	1291.05	28.57
				Peneaidae	*Farfantepenaeus* spp.	14.29	0.72	2.50	37.52	0.87
					Peneaidae spp.	58.55	58.61	33.05	4710.30	50.14
				Porcellanidae	Porcellanidae spp.	20.00	13.04	4.76	157.29	3.30
				Portunidae	*Callinectes sapidus*	41.59	56.63	33.93	4149.08	48.45
				Xanthidae	Xanthidae spp.	51.19	34.22	4.76	406.56	8.60
			Isopoda	Cymothoidae	*Aegathoa oculata*	50.00	21.21	66.67	4747.71	35.61
			Mysida		Mysida spp.	50.00	13.79	2.50	159.48	7.24
			Stomatopoda	Squillidae	*Squilla empusa*	41.67	69.48	9.53	1077.76	29.46
		Maxilliopoda	Poecilostomatoida	Ergasilidae	*Ergasilus* sp.	9.09	3.68	4.76	60.77	0.99
	Mollusca	Bivalvia			Bivalave spp.	26.04	17.67	37.53	2150.52	21.82
			Ostreoida	Ostreidae	*Crassostrea virginica*	21.34	12.89	35.24	1478.62	18.10
			Veneroidea	Pharidae	*Ensis minor*	25.00	99.17	4.76	591.07	62.09
		Cephalopoda			Cephalopoda spp.	16.67	1.73	2.50	46.00	1.14
		Gastropoda			Gastropoda spp.	55.56	36.07	5.20	647.55	34.61
	Nemertea				Nemertea spp.	58.33	51.92	16.67	1837.97	55.03
	Annelida	Polychaeta			Polycheate spp.	70.83	68.85	28.57	3703.29	73.17
			Aciculata	Glyceridae	Glyceridae spp.	50.00	77.83	16.67	2130.85	68.63
	Vertebrata	Actinopterygii			Actinopterygii spp.	64.41	54.21	51.86	6596.78	70.03
			Anguilliformes		Anguilliformes spp.	40.00	76.26	6.11	735.46	40.70
			Clupeiformes	Clupeidae	*Brevoortia patronus*	66.52	96.37	22.66	3790.34	78.96
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	35.83	9.52	15.91	634.47	14.76
			Perciformes	Gobiidae	Gobiidae spp.	66.67	60.61	33.33	4242.00	63.64
				Gobisocidae	*Gobiesox* spp.	20.00	2.52	2.50	56.30	1.10
			Siluriformes	Ictaluridae	Ictaluridae spp.	62.50	92.86	5.00	776.79	60.44

Appendix 2 cont.

Habitat	Phylum (Division)	Class	Order	Family	Species	%N	% V	%FO	IRI	%IRI
Non-Veg	Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	50.00	50.00	7.14	714.00	24.99
			Najadales	Cymodoceaceae	*Halodule beaudettei*	44.22	31.38	52.86	1962.24	48.04
	Arthropoda	Insecta			Insecta spp.	50.00	34.78	3.23	273.85	3.55
			Hymenoptera		Hymenoptera spp.	36.50	60.53	10.08	1083.47	34.34
		Malacostraca	Amphipoda		Amphipoda spp.	50.60	9.76	16.67	1006.12	31.63
				Ampeliscidae	Ampelisca spp.	54.29	35.60	12.50	1123.55	43.10
			Decapoda		Brachyura spp.	9.52	3.99	9.68	130.76	3.86
					Decapoda spp.	13.94	26.47	11.38	394.92	10.57
					Pleocyemata spp.	31.50	33.66	16.72	1275.44	40.23
				Alpheidae	*Alpheus heterochaelis*	83.33	75.00	8.33	1318.92	79.17
				Callianassidae	Callianassidae spp.	25.02	37.55	3.70	260.84	22.75
				Dendrobranchiata	Dendrobranchiata spp.	79.13	58.94	26.36	3907.27	70.38
				Hippolytidae	*Tozeuma carolinense*	14.29	16.67	33.33	1031.64	8.39
				Menippidae	*Menippe adina*	28.13	83.22	7.39	831.87	22.14
				Palaemonidae	*Palaemonetes vulgaris*	100.00	100.00	33.33	6666.00	100.00
				Peneaidae	*Farfantepenaeus aztecus*	100.00	100.00	50.00	10000.00	100.00
					Farfantepenaeus spp.	11.11	56.88	3.23	219.62	3.47
					Peneaidae spp.	83.33	95.56	14.57	2762.60	83.96
				Portunidae	*Callinectes sapidus*	49.38	75.68	31.82	4625.97	56.19
				Sergestidae	Sergestidae spp.	50.00	47.62	7.14	697.00	32.27
				Xanthidae	Xanthidae spp.	17.46	42.86	8.33	502.44	26.20
			Isopoda		Isopoda spp.	14.33	5.76	16.67	334.77	9.20
				Cymothoidae	*Aegathoa oculata*	40.28	25.08	5.69	351.91	11.38
				Idoteidae	*Erichsonella* spp.	0.09	0.77	3.23	2.78	0.05
	Mollusca	Bivalvia			Bivalave spp.	100.00	100.00	7.14	1428.00	100.00
			Mytiloida	Mytilidae	*Ischadium recurvum*	100.00	100.00	3.23	646.00	100.00
			Ostreoida	Ostreidae	*Crassostrea virginica*	53.33	39.04	20.44	742.81	37.28
		Cephalopoda			Cephalopoda spp.	11.11	0.03	3.23	35.98	0.57
		Gastropoda			Gastropoda spp.	42.78	25.64	16.77	441.04	27.86
	Nemertea				Nemertea spp.	36.19	61.84	13.22	1263.03	47.75
	Annelida	Polychaeta			Polycheate spp.	45.56	51.11	16.97	1935.39	47.41
			Aciculata	Eunicidae	Eunicidae spp.	50.00	93.75	7.14	1026.38	45.99
				Glyceridae	Glyceridae spp.	100.00	100.00	28.57	5714.00	100.00
			Canalipalpata	Ampharetidae	Ampharetidae spp.	100.00	100.00	50.00	10000.00	100.00
				Pectinariidae	Pectinariidae spp.	42.50	40.53	11.16	769.88	47.32
	Vertebrata	Actinopterygii			Actinopterygii spp.	70.24	50.52	56.20	7265.46	82.00
			Anguilliformes		Anguilliformes spp.	43.33	75.71	35.80	3657.45	36.95
			Aulopiformes	Synodontidae	*Synodus foetens*	50.00	50.00	100.00	10000.00	50.00
			Clupeiformes	Clupeidae	*Brevoortia patronus*	50.36	79.57	13.31	2065.94	36.88
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	36.25	50.39	11.31	1025.47	41.06
			Siluriformes	Ictaluridae	Ictaluridae spp.	62.50	84.31	6.45	946.95	56.79

Appentix 2 cont.

Habitat	Phylum (Division)	Class	Order	Family	Species	%N	% V	%FO	IRI	%IRI
Marsh	Magnoliophyta	Liliopsida	Najadales	Cymodoceaceae	*Halodule beaudettei*	55.09	49.93	55.00	7484.81	53.40
	Rhodophyta	Rhodophyceae			Rhodophyceae spp.	66.67	82.81	50.00	7473.75	66.94
	Arthropoda	Insecta			Insecta spp.	9.64	2.21	13.33	158.00	2.50
			Hymenoptera		Hymenoptera spp.	10.10	3.30	13.33	178.55	3.07
		Arachnida	Araneae		Araneae spp.	7.14	8.33	6.67	103.23	1.80
		Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca* spp.	73.33	16.08	40.00	3576.61	44.71
				Ischyroceridae	*Erichtonius brasiliensis*	35.97	7.32	20.00	865.66	18.88
			Decapoda		*Anomura* spp.	7.14	2.77	20.00	198.26	4.78
					Pleocyemata spp.	21.35	56.37	26.67	2072.91	39.14
				Alpheidae	*Alpheus heterochaelis*	19.84	17.02	15.84	739.96	11.36
				Callianassidae	Callianassidae spp.	50.38	74.87	56.50	6815.18	73.99
				Dendrobranchiata	Dendrobranchiata spp.	7.69	0.10	6.67	51.99	1.30
				Menippidae	*Menippe adina*	25.00	47.06	33.33	2401.72	28.99
				Ocypodidae	*Uca* spp.	33.33	66.61	6.67	666.63	23.07
				Palaemonidae	*Palaemonetes vulgaris*	35.10	31.36	36.39	2485.52	30.23
				Panopeidae	*Neopanope texana*	36.24	48.67	20.00	1698.30	40.03
				Peneaidae	Peneaidae spp.	59.64	76.55	62.67	8167.45	73.02
				Portunidae	*Callinectes sapidus*	27.39	43.24	38.52	2855.05	40.25
				Xanthidae	Xanthidae spp.	16.06	31.43	28.89	1757.07	23.47
			Isopoda	Cymothoidae	*Aegathoa oculata*	12.50	0.79	33.33	442.87	4.04
				Idoteidae	*Erichsonella* spp.	100.00	100.00	33.33	6666.00	100.00
			Mysida		Mysida spp.	46.23	2.83	40.00	2458.25	17.83
	Mollusca	Bivalvia	Mytiloida	Mytilidae	*Ischadium recurvum*	12.50	2.27	6.67	98.53	1.25
			Veneroidea	Pharidae	*Ensis minor*	50.00	95.24	20.00	2904.76	72.62
		Gastropoda			Gastropoda spp.	30.41	2.36	37.14	1154.26	15.89
	Nemertea				Nemertea spp.	18.75	9.90	6.67	191.10	3.28
	Annelida	Polychaeta			Polycheate spp.	10.71	7.41	22.50	400.69	7.76
			Canalipalpata	Pectinariidae	Pectinariidae spp.	33.33	0.02	6.67	222.48	2.18
				Terebellidae	Terebellidae spp.	25.00	7.69	6.67	218.02	2.31
	Chrodata	Appendicularia			Appendicularia spp.	50.00	50.00	33.33	3333.00	33.33
	Vertebrata	Actinopterygii			Actinopterygii spp.	29.77	26.90	52.31	2952.77	31.64
			Clupeiformes	Clupeidae	*Brevoortia patronus*	33.33	50.00	20.00	1666.67	21.51

Appendix 3. Prey items identified from stomach contents by regions of the bay in Lavaca Bay, Texas sampled from July 2006-April 2007. Percent volume (%V), percent number (%N), percent frequency of occurrence (%FO), index of relative importance (IRI), and percent index of relative importance (%IRI) were calculated for each stomach sampled, and values illustrated in this table are averages of these calculated values.

Region	Phylum (Division)	Class	Order	Family	Species	%N	%V	%FO	IRI	%IRI
Upper	Magnoliophyta	Liliopsida	Najadales	Cymodoceaceae	*Halodule beaudettei*	33.33	0.08	2.44	81.54	3.86
	Arthropoda	Insecta			Insecta spp.	32.32	9.93	6.21	214.71	11.69
			Diptera		Diptera spp.	25.00	0.55	2.44	62.35	1.20
			Hymenoptera		Hymenoptera spp.	30.90	32.64	12.20	775.09	30.77
		Arachnida	Araneae		Araneae spp.	7.14	8.33	2.44	37.76	1.07
		Malacostraca	Amphipoda	Ischyroceridae	*Erichtonius brasiliensis*	39.54	11.50	9.76	498.15	20.38
			Decapoda		Decapoda spp.	46.83	60.74	9.67	1054.99	44.37
					Pleocyemata spp.	33.25	48.30	23.39	1815.36	45.78
				Alpheidae	*Alpheus heterochaelis*	63.89	63.33	7.32	931.27	55.17
				Callianassidae	Callianassidae spp.	50.35	74.88	26.72	3520.00	67.30
				Dendrobranchiata	Dendrobranchiata spp.	23.85	49.80	4.88	359.41	31.07
				Menippidae	*Menippe adina*	38.13	62.50	23.52	2222.57	50.29
				Ocypodidae	*Uca* spp.	33.33	66.61	2.44	243.86	11.54
				Palaemonidae	*Palaemonetes vulgaris*	43.13	48.92	17.02	2166.46	40.76
				Panopeidae	*Neopanope texana*	32.59	38.01	12.95	983.61	28.22
				Peneaidae	Peneaidae spp.	60.28	62.94	69.98	8742.14	63.56
				Porcellanidae	Porcellanidae spp.	20.00	13.04	2.44	80.63	2.07
				Portunidae	*Callinectes sapidus*	28.78	55.70	27.29	2428.68	36.29
				Xanthidae	Xanthidae spp.	35.85	30.89	9.76	651.43	25.58
			Isopoda	Cymothoidae	*Aegathoa oculata*	50.00	41.67	51.43	4309.67	22.84
			Mysida		Mysida spp.	40.67	4.15	23.65	1657.23	12.98
			Stomatopoda	Squillidae	*Squilla empusa*	50.00	57.14	2.44	261.43	27.78
		Maxilliopoda	Poecilostomatoida	Ergasilidae	*Ergasilus* sp.	9.09	3.68	2.44	31.15	0.47
	Mollusca	Bivalvia			Bivalave spp.	12.50	0.49	2.86	37.16	0.49
			Mytiloida	Mytilidae	*Ischadium recurvum*	56.25	51.14	2.65	304.02	50.39
			Ostreoida	Ostreidae	*Crassostrea virginica*	24.59	11.26	9.76	349.89	9.44
			Veneroidea	Pharidae	*Ensis minor*	50.00	95.24	100.00	14523.81	72.62
		Cephalopoda			Cephalopoda spp.	16.67	1.73	2.86	52.63	1.16
		Gastropoda			Gastropoda spp.	39.62	12.47	25.89	1370.58	22.15
	Nemertea				Nemertea spp.	17.71	6.87	17.89	376.80	4.78
	Annelida	Polychaeta			Polycheate spp.	18.38	10.71	17.89	714.54	6.11
			Canalipalpata	Pectinariidae	Pectinariidae spp.	33.33	0.02	2.44	81.39	1.96
				Terebellidae	Terebellidae spp.	25.00	7.69	2.44	79.75	2.10
	Chrodata	Appendicularia			Appendicularia spp.	50.00	50.00	33.33	3333.00	50.00
	Vertebrata	Actinopterygii			Actinopterygii spp.	59.62	38.22	58.34	5846.86	67.29
			Anguilliformes		Anguilliformes spp.	20.00	86.21	2.86	303.75	4.51
			Clupeiformes	Clupeidae	*Brevoortia patronus*	57.64	78.81	15.95	2200.39	55.96
			Gasterosteiformes	Sygnathidae	Sygnathus spp.	33.33	5.98	14.29	561.83	13.78
			Perciformes	Gobisocidae	*Gobiesox* spp.	20.00	2.52	2.86	64.41	1.19
			Siluriformes	Ictaluridae	Ictaluridae spp.	50.00	84.78	8.57	1155.07	47.94

Appednix 3 cont.

Region	Phylum (Division)	Class	Order	Family	Species	%N	%V	%FO	IRI	%IRI
Lower	Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	18.70	24.67	10.54	208.06	6.25
			Najadales	Cymodoceaceae	*Halodule beaudettei*	47.58	40.48	48.13	4789.31	49.09
	Rhodophyta	Rhodophyceae			Rhodophyceae spp.	66.67	82.81	50.00	7473.75	66.94
	Arthropoda	Insecta	Hymenoptera		Hymenoptera spp.	26.25	35.26	15.89	1018.81	27.28
		Malacostraca	Amphipoda		Amphipoda spp.	55.48	7.97	26.32	1669.99	46.84
				Ampeliscidae	Ampelisca spp.	61.90	27.79	29.47	2639.86	44.12
				Ischyroceridae	*Erichtonius brasiliensis*	71.43	27.70	25.00	2478.24	47.79
			Decapoda		*Anomura* spp.	7.14	2.77	25.00	247.82	4.78
					Brachyura spp.	7.48	3.01	11.11	116.58	2.88
					Decapoda spp.	33.84	30.45	9.21	641.91	33.05
					Pleocyemata spp.	32.09	32.82	13.98	894.78	30.03
				Alpheidae	*Alpheus heterochaelis*	19.84	17.02	27.63	1399.91	14.49
				Callianassidae	Callianassidae spp.	0.04	0.09	2.78	0.37	0.01
				Dendrobranchiata	Dendrobranchiata spp.	75.42	59.09	29.86	4053.22	70.82
				Hippolytidae	*Tozeuma carolinense*	14.29	16.67	11.11	343.88	2.96
				Menippidae	*Menippe adina*	71.43	74.79	11.28	1575.77	62.79
				Palaemonidae	*Palaemonetes vulgaris*	36.31	24.28	25.37	1241.72	22.91
				Panopeidae	*Neopanope texana*	63.89	50.37	4.56	556.05	47.94
				Peneaidae	*Farfantepenaeus aztecus*	100.00	100.00	14.29	2858.00	100.00
					Farfantepenaeus spp.	12.70	28.80	5.56	230.74	4.91
					Peneaidae spp.	62.96	74.78	28.49	3780.26	64.33
				Portunidae	*Callinectes sapidus*	53.92	63.67	47.48	6634.35	60.98
				Sergestidae	Sergestidae spp.	50.00	47.62	3.85	375.83	21.04
				Xanthidae	Xanthidae spp.	14.02	41.63	35.09	2226.10	24.35
			Isopoda		Isopoda spp.	14.33	5.76	21.05	422.74	10.39
				Cymothoidae	*Aegathoa oculata*	33.33	8.78	15.34	529.78	9.54
				Idoteidae	*Erichsonella* spp.	50.04	50.39	18.06	3334.19	50.02
			Mysida		Mysida spp.	83.33	5.88	33.33	2973.56	28.70
			Stomatopoda	Squillidae	*Squilla empusa*	33.33	81.82	11.11	1279.33	27.94
	Mollusca	Bivalvia			Bivalave spp.	47.92	42.55	37.08	2301.17	46.40
			Ostreoida	Ostreidae	*Crassostrea virginica*	42.08	34.14	40.55	1831.96	40.53
			Veneroidea	Pharidae	*Ensis minor*	25.00	99.17	5.26	653.15	24.66
		Cephalopoda			Cephalopoda spp.	11.11	0.03	2.78	30.97	0.64
		Gastropoda			Gastropoda spp.	38.61	25.64	9.99	322.50	26.39
	Nemertea				Nemertea spp.	46.83	68.20	13.67	1599.93	56.18
	Annelida	Polychaeta			Polycheate spp.	56.92	59.43	24.52	2619.90	60.40
			Aciculata	Eunicidae	Eunicidae spp.	50.00	93.75	3.85	553.44	33.85
				Glyceridae	Glyceridae spp.	75.00	88.91	16.99	2981.05	86.49
			Canalipalpata	Ampharetidae	Ampharetidae spp.	100.00	100.00	33.33	6666.00	100.00
				Pectinariidae	Pectinariidae spp.	42.50	40.53	12.81	714.05	47.71
	Vertebrata	Actinopterygii			Actinopterygii spp.	63.86	59.35	47.76	6635.95	71.67
			Anguilliformes		Anguilliformes spp.	46.00	73.94	10.71	1165.70	40.61
			Aulopiformes	Synodontidae	*Synodus foetens*	50.00	50.00	33.33	3333.00	50.00
			Clupeiformes	Clupeidae	*Brevoortia patronus*	61.00	94.10	18.19	2861.42	70.52
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	37.86	35.40	10.55	824.09	34.54
			Perciformes	Gobiidae	Gobiidae spp.	66.67	60.61	20.00	2545.45	50.30
			Siluriformes	Ictaluridae	Ictaluridae spp.	100.00	100.00	2.78	556.00	100.00

Appendix 4. Prey items identified from stomach contents by seasons in Lavaca Bay, Texas sampled from July 2006-April 2007. Percent volume (%V), percent number (%N), percent frequency of occurrence (%FO), index of relative importance (IRI), and percent index of relative importance (%IRI) were calculated for each stomach sampled, and values illustrated in this table are averages of these calculated values. Winter season sampling data was excluded due to the extremely low catch of fishes for stomach content analysis.

Season	Phylum (Division)	Class	Order	Family	Species	%N	%V	%FO	IRI	%IRI
Summer	Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	3.06	12.00	14.17	125.95	1.40
			Najadales	Cymodoceaceae	*Halodule beaudettei*	14.29	1.05	48.33	498.96	4.87
	Arthropoda	Insecta			Insecta spp.	50.00	34.78	3.33	282.33	5.77
			Hymenoptera		Hymenoptera spp.	10.67	22.75	7.50	234.08	6.91
		Malacostraca	Amphipoda	Ischyroceridae	*Erichtonius brasiliensis*	23.72	0.29	8.33	199.97	8.93
			Decapoda		Brachyura spp.	7.48	3.01	13.33	139.88	4.25
					Decapoda spp.	34.51	36.18	11.50	772.10	32.54
					Pleocyemata spp.	43.18	49.85	23.40	2126.28	51.03
				Alpheidae	*Alpheus heterochaelis*	50.69	49.67	20.83	2090.67	51.87
				Callianassidae	Callianassidae spp.	36.54	61.77	30.00	3276.29	62.19
				Dendrobranchiata	Dendrobranchiata spp.	84.84	62.47	20.00	3179.47	77.71
				Menippidae	*Menippe adina*	48.72	67.06	26.72	3054.16	59.15
				Ocypodidae	*Uca* spp.	33.33	66.61	4.17	416.77	15.79
				Palaemonidae	*Palaemonetes vulgaris*	29.73	31.89	9.72	675.49	23.69
				Panopeidae	*Neopanope texana*	44.43	49.79	25.00	2355.63	49.31
				Peneaidae	Peneaidae spp.	58.04	70.05	41.32	5133.13	61.55
				Porcellanidae	Porcellanidae spp.	20.00	13.04	4.17	137.79	2.88
				Portunidae	*Callinectes sapidus*	44.64	68.13	42.00	6243.80	55.63
				Sergestidae	Sergestidae spp.	50.00	47.62	50.00	4880.95	42.49
				Xanthidae	Xanthidae spp.	31.14	26.38	12.50	718.89	20.68
			Isopoda	Cymothoidae	*Aegathoa oculata*	34.72	14.22	23.33	1587.23	12.30
				Idoteidae	*Erichsonella* spp.	0.09	0.77	3.33	2.86	0.06
			Mysida		Mysida spp.	47.38	4.31	28.17	2033.78	15.50
			Stomatopoda	Squillidae	*Squilla empusa*	41.67	69.48	27.09	3102.18	50.54
	Mollusca	Bivalvia			Bivalave spp.	30.56	23.40	61.11	3361.52	30.94
			Mytiloida	Mytilidae	*Ischadium recurvum*	56.25	51.14	3.75	363.80	50.61
			Ostreoida	Ostreidae	*Crassostrea virginica*	23.82	11.65	32.15	1278.32	15.84
		Cephalopoda			Cephalopoda spp.	16.67	1.73	3.33	61.27	1.33
		Gastropoda			Gastropoda spp.	36.39	18.09	21.53	1142.12	24.24
	Nemertea				Nemertea spp.	25.00	47.62	50.00	3630.95	31.61
	Annelida	Polychaeta			Polycheate spp.	50.00	25.00	33.33	2499.75	37.50
			Canalipalpata	Pectinariidae	Pectinariidae spp.	33.33	0.02	4.17	139.09	2.44
				Terebellidae	Terebellidae spp.	25.00	7.69	4.17	136.30	2.63
	Vertebrata	Actinopterygii			Actinopterygii spp.	52.80	39.95	50.75	4978.88	55.44
			Anguilliformes		Anguilliformes spp.	35.00	49.49	18.33	1781.35	28.18
			Aulopiformes	Synodontidae	*Synodus foetens*	50.00	50.00	33.33	3333.00	50.00
			Clupeiformes	Clupeidae	*Brevoortia patronus*	69.17	77.21	19.33	3081.43	68.32
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	15.56	4.79	10.00	203.50	4.70
			Perciformes	Gobiidae	Gobiidae spp.	66.67	60.61	16.67	2121.64	50.31
			Siluriformes	Ictaluridae	Ictaluridae spp.	100.00	100.00	3.33	666.00	100.00

Appendix 4 cont.

Season	Phylum (Division)	Class	Order	Family	Species	%N	%V	%FO	IRI	%IRI
Fall	Magnoliophyta	Liliopsida	Najadales	Cymodoceaceae	*Halodule beaudettei*	57.56	50.29	46.93	6101.12	57.98
	Rhodophyta	Rhodophyceae			Rhodophyceae spp.	66.67	82.81	50.00	7473.75	66.94
	Arthropoda	Insecta			Insecta spp.	9.64	2.21	20.00	237.06	3.83
			Diptera		Diptera spp.	25.00	0.55	10.00	255.52	2.92
		Arachnida	Araneae		Araneae spp.	7.14	8.33	10.00	154.76	2.95
		Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca* spp.	73.33	16.08	50.00	4470.76	44.71
				Ischyroceridae	*Erichtonius brasiliensis*	48.21	14.35	17.50	1369.07	25.45
			Decapoda		Anomura spp.	7.14	2.77	25.00	247.82	4.78
					Decapoda spp.	31.67	37.88	10.56	728.25	18.22
					Pleocyemata spp.	13.26	40.08	29.31	1754.38	20.10
				Alpheidae	*Alpheus heterochaelis*	28.57	25.34	33.33	1796.91	19.08
				Dendrobranchiata	Dendrobranchiata spp.	50.00	25.00	4.76	357.00	23.08
				Hippolytidae	*Tozeuma carolinense*	14.29	16.67	16.67	515.98	4.38
				Menippidae	*Menippe adina*	23.74	47.83	29.84	2314.12	33.38
				Palaemonidae	*Palaemonetes vulgaris*	32.14	24.28	21.43	996.39	27.64
				Panopeidae	*Neopanope texana*	32.14	31.90	7.38	473.26	12.88
				Peneaidae	*Farfantepenaeus* spp.	12.70	28.80	22.22	922.15	11.61
					Peneaidae spp.	59.26	64.45	45.24	5692.79	63.45
				Portunidae	*Callinectes sapidus*	28.92	37.57	37.49	2794.25	30.44
				Xanthidae	Xanthidae spp.	30.16	44.54	36.67	2475.52	28.85
			Isopoda	Cymothoidae	*Aegathoa oculata*	12.50	0.79	33.33	442.87	4.04
				Idoteidae	*Erichsonella* spp.	100.00	100.00	33.33	6666.00	100.00
			Mysida		Mysida spp.	45.24	4.61	21.67	1539.16	15.35
		Maxilliopoda	Poecilostomatoida	Ergasilidae	*Ergasilus* sp.	9.09	3.68	10.00	127.67	0.98
	Mollusca	Bivalvia	Ostreoida	Ostreidae	*Crassostrea virginica*	100.00	100.00	4.76	952.00	100.00
		Cephalopoda			Cephalopoda spp.	11.11	0.03	11.11	123.76	1.48
		Gastropoda			Gastropoda spp.	44.79	20.97	17.84	733.77	28.62
	Nemertea				Nemertea spp.	40.10	30.36	13.22	976.20	32.69
	Annelida	Polychaeta			Polycheate spp.	59.24	58.83	26.64	3339.03	62.19
			Aciculata	Eunicidae	Eunicidae spp.	50.00	93.75	4.76	684.25	38.97
				Glyceridae	Glyceridae spp.	75.00	88.91	19.05	3294.31	87.21
			Canalipalpata	Ampharetidae	Ampharetidae spp.	100.00	100.00	33.33	6666.00	100.00
	Chrodata	Appendicularia			Appendicularia spp.	50.00	50.00	4.76	476.00	33.33
	Vertebrata	Actinopterygii			Actinopterygii spp.	60.46	45.69	66.46	6916.20	66.21
			Anguilliformes		Anguilliformes spp.	50.00	89.90	7.94	1113.31	56.77
			Clupeiformes	Clupeidae	*Brevoortia patronus*	18.65	90.84	33.33	3649.47	57.26
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	41.67	44.46	10.05	848.87	36.03
			Siluriformes	Ictaluridae	Ictaluridae spp.	25.00	68.63	11.11	1040.20	17.87

Appendix 4 cont.

Season	Phylum (Division)	Class	Order	Family	Species	%N	%V	%FO	IRI	%IRI
Spring	Magnoliophyta	Liliopsida	Cyperales	Poaceae	*Spartina alterniflora*	50.00	50.00	16.67	1667.00	50.00
			Najadales	Cymodoceaceae	*Halodule beaudettei*	50.00	50.00	16.67	1667.00	50.00
	Arthropoda	Insecta			Insecta spp.	60.00	0.50	3.85	232.92	30.25
			Hymenoptera		Hymenoptera spp.	38.47	40.53	26.92	2126.78	52.19
		Malacostraca	Amphipoda		Amphipoda spp.	55.48	7.97	19.23	1220.13	45.73
				Ampeliscidae	*Ampelisca* spp.	54.29	35.60	11.54	1037.26	42.81
				Ischyroceridae	*Erichtonius brasiliensis*	85.71	44.44	3.85	501.11	21.04
			Decapoda		Decapoda spp.	52.22	64.16	9.42	1114.50	53.77
					Pleocyemata spp.	29.58	29.34	9.42	642.78	26.02
				Callianassidae	Callianassidae spp.	75.00	89.29	38.46	7417.36	84.58
				Dendrobranchiata	Dendrobranchiata spp.	48.33	56.60	13.67	1366.27	41.15
				Menippidae	*Menippe adina*	91.67	97.67	7.88	1535.63	80.97
				Panopeidae	*Neopanope texana*	25.00	4.29	3.13	91.66	2.89
				Peneaidae	*Farfantepenaeus aztecus*	100.00	100.00	100.00	20000.00	100.00
					Peneaidae spp.	100.00	100.00	26.57	5313.00	100.00
				Portunidae	*Callinectes sapidus*	46.53	68.74	23.50	2904.10	51.22
				Xanthidae	Xanthidae spp.	1.59	35.71	3.85	143.61	4.81
			Isopoda		Isopoda spp.	14.33	5.76	15.38	308.87	8.79
				Cymothoidae	*Aegathoa oculata*	58.33	37.50	3.49	332.96	13.18
	Mollusca	Bivalvia			Bivalave spp.	56.25	50.25	9.90	1687.33	50.27
			Veneroidea	Pharidae	*Ensis minor*	37.50	97.21	51.93	7500.94	48.65
		Gastropoda			Gastropoda spp.	36.11	4.62	35.66	1903.47	12.47
	Nemertea				Nemertea spp.	43.65	84.62	11.54	1480.27	59.23
	Annelida	Polychaeta			Polycheate spp.	34.15	45.03	12.82	967.14	33.88
			Canalipalpata	Pectinariidae	Pectinariidae spp.	42.50	40.53	12.82	1214.67	45.54
	Vertebrata	Actinopterygii			Actinopterygii spp.	69.22	57.18	62.02	8225.88	79.81
			Anguilliformes		Anguilliformes spp.	40.00	88.56	3.49	456.71	27.77
			Clupeiformes	Clupeidae	*Brevoortia patronus*	68.34	94.37	24.04	4232.75	68.16
			Gasterosteiformes	Sygnathidae	*Sygnathus* spp.	43.33	21.66	10.46	697.04	27.25
			Perciformes	Gobisocidae	*Gobiesox* spp.	20.00	2.52	3.13	70.49	1.37
			Siluriformes	Ictaluridae	Ictaluridae spp.	62.50	92.86	6.25	970.98	60.92

Appendix 5. $\delta^{13}C$ and $\delta^{15}N$ values of fauna collected in Lavaca Bay, Texas by habitat. Values are mean ± standard error (SE) and the number of samples is indicated in parenthesis.

Habitat	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Reef	Veg	BOM	Benthic Organic Matter	-16.53 ± 1.55	6.14 ± 0.29	(13)
		POM	Particulate Organic Matter	-20.65 ± 1.96	7.27 ± 0.51	(8)
	Invert	Alpheidae	*Alpheus heterochaelis*	-22.01 ± 0.00	11.60 ± 0.00	(1)
		Menippidae	*Menippe adina*	-19.07 ± 1.16	10.01 ± 1.02	(6)
		Ostreidae	*Crassostrea virginica*	-22.77 ± 0.42	9.19 ± 0.25	(9)
		Palaemonidae	*Palaemonetes vulgaris*	-18.67 ± 1.49	10.45 ± 0.90	(4)
		Porcellanidae	Porcellanidae spp.	-20.85 ± 0.00	12.30 ± 0.00	(1)
		Portunidae	*Callinectes sapidus*	-17.47 ± 1.27	9.76 ± 1.03	(5)
		Xanthidae	Xanthidae spp.	-22.29 ± 0.00	11.34 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus aztecus*	-18.09 ± 0.94	8.85 ± 0.69	(5)
			Farfantepenaeus spp.	-18.22 ± 0.66	10.27 ± 0.63	(4)
			Litopenaeus setiferus	-17.61 ± 0.37	11.00 ± 0.41	(2)
	Fish	Ariidae	*Ariopsis felis*	-19.74 ± 0.47	14.30 ± 0.22	(9)
			Bagre marinus	-18.22 ± 0.28	15.90 ± 0.41	(11)
		Carangidae	*Caranx hippos*	-19.27 ± 1.69	14.30 ± 0.02	(2)
		Carcharhinidae	*Carcharhinus limbatus*	-17.51 ± 0.00	15.86 ± 0.00	(1)
		Clupeidae	*Brevoortia patronus*	-19.94 ± 0.24	13.77 ± 0.31	(18)
		Cynoglossidae	*Symphurus plagiusa*	-18.82 ± 0.00	12.42 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-21.61 ± 1.56	13.51 ± 0.89	(3)
		Gobiesocidae	*Gobiesox* spp.	-20.87 ± 0.00	14.33 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-20.99 ± 0.35	13.83 ± 0.23	(7)
			Microgobius gulosus	-21.52 ± 0.00	13.88 ± 0.00	(1)
		Haemulidae	*Orthopristis chrysoptera*	-18.49 ± 0.22	13.70 ± 0.04	(2)
		Paralichtyidae	*Citharichthys spilopterus*	-19.17 ± 0.72	12.91 ± 0.10	(3)
		Sciaenidae	*Bairdiella chrysoura*	-19.35 ± 0.04	15.89 ± 0.09	(2)
			Cynoscion arenarius	-18.32 ± 0.35	15.26 ± 0.20	(5)
			Cynoscion nebulosus	-19.13 ± 1.30	14.51 ± 0.56	(4)
			Leiostomus xanthurus	-19.50 ± 0.63	14.53 ± 0.70	(8)
			Menticirrhus littoralis	-18.01 ± 0.61	14.28 ± 0.32	(5)
			Micropogonias undulatus	-18.02 ± 0.76	13.18 ± 0.66	(5)
		Scombridae	*Scomberomorus maculatus*	-19.38 ± 0.36	15.46 ± 0.38	(2)
		Sphyrnidae	*Sphyrna tiburo*	-16.74 ± 0.01	13.94 ± 0.20	(2)
		Stromateidae	*Peprilus paru*	-21.37 ± 0.00	15.42 ± 0.00	(1)
		Syngnathidae	*Syngnathus* spp.	-16.44 ± 0.00	6.36 ± 0.00	(1)
		Blennidae	*Chasmodes bosquianus*	-22.00 ± 0.00	14.59 ± 0.00	(1)

Appednix 5 cont.

Habitat	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Non-Veg	Veg	BOM	Benthic Organic Matter	-19.02 ± 0.48	5.74 ± 0.20	(15)
		POM	Particulate Organic Matter	-20.68 ± 1.90	6.23 ± 0.59	(8)
	Invert	Menippidae	*Menippe adina*	-14.90 ± 0.00	7.12 ± 0.00	(1)
		Ostreidae	*Crassostrea virginica*	-22.96 ± 0.00	10.16 ± 0.00	(1)
		Palaemonidae	*Palaemonetes vulgaris*	-20.47 ± 0.00	13.91 ± 0.00	(1)
		Porcellanidae	Porcellanidae spp.	-16.08 ± 0.00	6.50 ± 0.00	(1)
		Portunidae	*Callinectes sapidus*	-17.50 ± 0.00	11.15 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus aztecus*	-17.01 ± 0.80	8.83 ± 0.57	(5)
			Farfantepenaeus spp.	-18.13 ± 1.10	9.77 ± 1.18	(3)
			Litopenaeus setiferus	-17.81 ± 0.00	10.26 ± 0.00	(1)
			Peneaidae spp.	-18.04 ± 0.00	11.58 ± 0.00	(1)
	Fish	Ariidae	*Ariopsis felis*	-19.58 ± 0.64	14.59 ± 0.30	(8)
			Bagre marinus	-19.06 ± 0.24	15.13 ± 0.11	(10)
		Carangidae	*Caranx hippos*	-17.92 ± 0.00	13.43 ± 0.00	(1)
		Carcharhinidae	*Carcharhinus limbatus*	-16.51 ± 0.00	16.46 ± 0.00	(1)
		Clupeidae	*Brevoortia patronus*	-20.15 ± 0.34	13.31 ± 0.31	(15)
		Cynoglossidae	*Symphurus plagiusa*	-19.30 ± 0.39	11.48 ± 0.61	(2)
		Elopidae	*Elops saurus*	-18.49 ± 0.00	12.44 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-20.92 ± 1.09	13.07 ± 0.58	(4)
		Gobiesocidae	*Gobiesox* spp.	-21.14 ± 0.00	13.63 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-21.73 ± 0.06	13.21 ± 0.14	(2)
			Gobius spp.	-21.00 ± 0.07	14.49 ± 0.13	(2)
			Microgobius thalassinus	-18.65 ± 0.00	13.29 ± 0.00	(1)
		Paralichtyidae	*Citharichthys spilopterus*	-18.74 ± 0.62	11.79 ± 0.54	(3)
		Sciaenidae	*Bairdiella chrysoura*	-19.80 ± 0.05	18.06 ± 1.83	(2)
			Cynoscion arenarius	-17.63 ± 0.13	15.05 ± 0.18	(2)
			Cynoscion nebulosus	-17.57 ± 1.02	15.94 ± 2.37	(2)
			Leiostomus xanthurus	-19.68 ± 0.88	13.23 ± 0.30	(7)
			Menticirrhus littoralis	-16.61 ± 0.23	13.64 ± 0.21	(5)
			Micropogonias undulatus	-18.17 ± 1.27	12.67 ± 0.59	(3)
		Scombridae	*Scomberomorus maculatus*	-18.76 ± 0.00	16.86 ± 0.00	(1)
		Sparidae	*Lagodon rhomboides*	-14.70 ± 0.00	8.73 ± 0.00	(1)
		Stromateidae	*Peprilus paru*	-19.95 ± 0.00	13.28 ± 0.00	(1)

Appendix 5 cont.

Habitat	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Marsh	Veg	BOM	Benthic Organic Matter	-16.92 ± 0.48	4.31 ± 0.28	(8)
		Cymodoceaceae	*Halodule wrighitii*	-11.74 ± 0.20	3.50 ± 0.62	(4)
		Poaceae	*Spartina alterniflora*	-13.25 ± 0.17	6.01 ± 0.66	(12)
		POM	Particulate Organic Matter	-19.69 ± 1.47	5.90 ± 0.64	(8)
		Ulvaceae	*Ulva lactuca*	-18.54 ± 0.00	5.96 ± 0.00	(1)
	Invert	Alpheidae	*Alpheus heterochaelis*	-14.51 ± 0.00	11.12 ± 0.00	(1)
		Diogenidae	*Clibanarius vittatus*	-13.93 ± 0.00	7.33 ± 0.00	(1)
		Hippolytidae	*Tozeuma carolinense*	-13.11 ± 0.00	7.47 ± 0.00	(1)
		Menippidae	*Menippe adina*	-14.33 ± 2.22	7.69 ± 1.27	(2)
		Palaemonidae	*Palaemonetes vulgaris*	-15.72 ± 0.49	8.79 ± 0.37	(16)
		Portunidae	*Callinectes sapidus*	-17.21 ± 0.89	9.31 ± 0.68	(9)
		Xanthidae	Xanthidae spp.	-21.72 ± 0.00	12.65 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus aztecus*	-14.91 ± 0.97	8.34 ± 0.75	(6)
			Farfantepenaeus spp.	-15.52 ± 0.80	9.83 ± 1.29	(3)
			Litopenaeus setiferus	-17.35 ± 1.19	9.58 ± 0.67	(7)
			Peneaidae spp.	-16.62 ± 0.15	8.96 ± 0.40	(2)
	Fish	Ariidae	*Ariopsis felis*	-18.18 ± 0.77	13.13 ± 0.49	(7)
		Atherinopdisae	*Menidia menidia*	-17.70 ± 0.00	10.13 ± 0.00	(1)
		Carangidae	*Caranx hippos*	-18.13 ± 0.00	15.87 ± 0.00	(1)
		Clupeidae	*Brevoortia patronus*	-19.13 ± 0.88	12.54 ± 0.50	(3)
		Cyprinodontidae	*Cyprinodon variegatus*	-14.47 ± 1.36	7.06 ± 0.27	(3)
		Dasyatidae	*Dasyatis sabina*	-17.88 ± 0.00	14.09 ± 0.00	(1)
		Elopidae	*Elops saurus*	-18.58 ± 0.00	15.45 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-20.49 ± 0.35	13.82 ± 0.50	(3)
		Gerreidae	*Eucinostomus argenteus*	-17.47 ± 0.00	10.55 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-14.68 ± 0.27	9.65 ± 0.19	(7)
			Microgobius gulosus	-14.16 ± 0.00	10.09 ± 0.00	(1)
		Lutjanidae	*Lutjanus argentimaculatus*	-15.15 ± 0.00	11.51 ± 0.00	(1)
		Mugilidae	*Mugil cephalus*	-16.14 ± 0.94	9.36 ± 1.32	(4)
		Paralichtyidae	*Citharichthys spilopterus*	-15.77 ± 0.00	11.87 ± 0.00	(1)
			Paralichthys lethostigma	-16.54 ± 0.00	10.36 ± 0.00	(1)
		Polynemidae	*Polydactylus octonemus*	-17.50 ± 0.00	15.12 ± 0.00	(1)
		Pomatomidae	*Pomatomus saltatrix*	-17.23 ± 0.00	15.27 ± 0.00	(1)
		Sciaenidae	*Bairdiella chrysoura*	-15.64 ± 0.00	12.88 ± 0.00	(1)
			Cynoscion nebulosus	-16.28 ± 0.84	12.43 ± 0.98	(6)
			Leiostomus xanthurus	-16.04 ± 0.00	11.59 ± 0.00	(1)
			Menticirrhus littoralis	-16.29 ± 0.73	13.86 ± 0.95	(3)
			Micropogonias undulatus	-16.25 ± 0.41	12.56 ± 0.71	(5)
			Pogonias cromis	-17.06 ± 1.35	12.03 ± 1.14	(4)
			Sciaenops occelatus	-15.78 ± 1.08	12.38 ± 1.01	(4)
		Sparidae	*Archosargus probatocephalus*	-18.57 ± 0.74	13.09 ± 0.76	(6)
			Lagodon rhomboides	-16.80 ± 0.58	11.28 ± 0.48	(9)
		Syngnathidae	*Syngnathus* spp.	-20.00 ± 1.56	10.17 ± 0.89	(4)
Grand Total						(430)

Appendix 6. $\delta^{13}C$ and $\delta^{15}N$ values of fauna collected in Lavaca Bay, Texas by region. Values are mean ± standard error (SE) and the number of samples is indicated in parenthesis.

Region	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Upper	Veg	BOM	Benthic Organic Matter	-18.01 ± 1.19	5.97 ± 0.20	(16)
		Poaceae	*Spartina alterniflora*	-12.97 ± 0.20	7.77 ± 0.65	(6)
		POM	Particulate Organic Matter	-22.05 ± 1.11	7.02 ± 0.33	(12)
	Invert	Alpheidae	*Alpheus heterochaelis*	-18.26 ± 3.75	11.36 ± 0.24	(2)
		Menippidae	*Menippe adina*	-18.47 ± 1.14	9.60 ± 0.95	(7)
		Ostreidae	*Crassostrea virginica*	-23.51 ± 0.42	9.74 ± 0.39	(5)
		Palaemonidae	*Palaemonetes vulgaris*	-18.54 ± 0.71	10.67 ± 0.60	(10)
		Porcellanidae	Porcellanidae spp.	-18.47 ± 2.38	9.40 ± 2.90	(2)
		Portunidae	*Callinectes sapidus*	-18.46 ± 0.96	10.23 ± 1.17	(4)
		Xanthidae	Xanthidae spp.	-21.72 ± 0.00	12.65 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus aztecus*	-19.63 ± 0.67	9.48 ± 1.18	(3)
			Farfantepenaeus spp.	-18.83 ± 0.45	11.23 ± 0.51	(5)
			Litopenaeus setiferus	-19.21 ± 0.92	11.00 ± 0.33	(5)
			Peneaidae spp.	-17.41 ± 0.63	10.47 ± 1.11	(2)
	Fish	Ariidae	*Ariopsis felis*	-19.97 ± 0.32	14.10 ± 0.17	(18)
			Bagre marinus	-19.36 ± 0.13	15.81 ± 0.39	(11)
		Carangidae	*Caranx hippos*	-20.95 ± 0.00	14.32 ± 0.00	(1)
		Clupeidae	*Brevoortia patronus*	-20.57 ± 0.19	13.49 ± 0.31	(23)
		Cynoglossidae	*Symphurus plagiusa*	-19.26 ± 0.44	12.25 ± 0.17	(2)
		Cyprinodontidae	*Cyprinodon variegatus*	-14.08 ± 0.00	7.59 ± 0.00	(1)
		Dasyatidae	*Dasyatis sabina*	-17.88 ± 0.00	14.09 ± 0.00	(1)
		Elopidae	*Elops saurus*	-18.49 ± 0.00	12.44 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-21.55 ± 0.58	13.87 ± 0.25	(8)
		Gobiesocidae	*Gobiesox* spp.	-21.01 ± 0.14	13.98 ± 0.35	(2)
		Gobiidae	*Gobiosoma bosc*	-21.42 ± 0.13	13.81 ± 0.18	(8)
			Gobius spp.	-21.00 ± 0.07	14.49 ± 0.13	(2)
			Microgobius gulosus	-21.52 ± 0.00	13.88 ± 0.00	(1)
		Mugilidae	*Mugil cephalus*	-16.60 ± 0.80	10.39 ± 2.05	(2)
		Paralichtyidae	*Citharichthys spilopterus*	-18.78 ± 1.52	12.48 ± 0.31	(3)
			Paralichthys lethostigma	-16.54 ± 0.00	10.36 ± 0.00	(1)
		Polynemidae	*Polydactylus octonemus*	-17.50 ± 0.00	15.12 ± 0.00	(1)
		Pomatomidae	*Pomatomus saltatrix*	-17.23 ± 0.00	15.27 ± 0.00	(1)
		Sciaenidae	*Bairdiella chrysoura*	-19.58 ± 0.13	16.97 ± 0.98	(4)
			Cynoscion arenarius	-18.60 ± 0.00	15.47 ± 0.00	(1)
			Cynoscion nebulosus	-19.34 ± 1.39	15.14 ± 0.30	(3)
			Leiostomus xanthurus	-20.05 ± 0.63	13.72 ± 0.30	(9)
			Menticirrhus littoralis	-18.25 ± 0.74	14.73 ± 0.10	(4)
			Micropogonias undulatus	-18.22 ± 0.66	13.80 ± 0.23	(6)
			Pogonias cromis	-19.23 ± 1.16	13.97 ± 0.46	(2)
			Sciaenops occelatus	-17.58 ± 0.73	14.06 ± 0.70	(2)
		Scombridae	*Scomberomorus maculatus*	-18.76 ± 0.00	16.86 ± 0.00	(1)
		Sparidae	*Archosargus probatocephalus*	-19.46 ± 0.74	13.89 ± 0.83	(4)
			Lagodon rhomboides	-17.17 ± 1.03	12.34 ± 0.62	(4)
		Stromateidae	*Peprilus paru*	-21.37 ± 0.00	15.42 ± 0.00	(1)
		Blennidae	*Chasmodes bosquianus*	-22.00 ± 0.00	14.59 ± 0.00	(1)

Apendix 6 cont.

Region	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Lower	Veg	BOM	Benthic Organic Matter	-17.29 ± 0.55	5.24 ± 0.28	(20)
		Cymodoceaceae	*Halodule wrighitii*	-11.74 ± 0.20	3.50 ± 0.62	(4)
		Poaceae	*Spartina alterniflora*	-13.53 ± 0.24	4.25 ± 0.52	(6)
		POM	Particulate Organic Matter	-18.63 ± 1.54	5.91 ± 0.57	(12)
		Ulvaceae	*Ulva lactuca*	-18.54 ± 0.00	5.96 ± 0.00	(1)
	Invert	Diogenidae	*Clibanarius vittatus*	-13.93 ± 0.00	7.33 ± 0.00	(1)
		Hippolytidae	*Tozeuma carolinense*	-13.11 ± 0.00	7.47 ± 0.00	(1)
		Menippidae	*Menippe adina*	-14.33 ± 2.22	7.69 ± 1.27	(2)
		Ostreidae	*Crassostrea virginica*	-22.07 ± 0.44	8.84 ± 0.09	(5)
		Palaemonidae	*Palaemonetes vulgaris*	-14.91 ± 0.42	8.15 ± 0.27	(11)
		Portunidae	*Callinectes sapidus*	-16.90 ± 0.81	9.35 ± 0.60	(11)
		Xanthidae	Xanthidae spp.	-22.29 ± 0.00	11.34 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus aztecus*	-15.85 ± 0.57	8.46 ± 0.38	(13)
			Farfantepenaeus spp.	-15.94 ± 0.56	8.75 ± 0.38	(5)
			Litopenaeus setiferus	-15.69 ± 0.77	8.87 ± 0.66	(5)
			Peneaidae spp.	-16.48 ± 0.00	8.56 ± 0.00	(1)
	Fish	Ariidae	*Ariopsis felis*	-17.00 ± 0.35	13.91 ± 0.78	(6)
			Bagre marinus	-17.81 ± 0.18	15.23 ± 0.22	(10)
		Atherinopdisae	*Menidia menidia*	-17.70 ± 0.00	10.13 ± 0.00	(1)
		Carangidae	*Caranx hippos*	-17.88 ± 0.16	14.52 ± 0.72	(3)
		Carcharhinidae	*Carcharhinus limbatus*	-17.01 ± 0.50	16.16 ± 0.30	(2)
		Clupeidae	*Brevoortia patronus*	-18.88 ± 0.21	13.44 ± 0.21	(13)
		Cynoglossidae	*Symphurus plagiusa*	-18.91 ± 0.00	10.87 ± 0.00	(1)
		Cyprinodontidae	*Cyprinodon variegatus*	-14.67 ± 2.33	6.79 ± 0.07	(2)
		Elopidae	*Elops saurus*	-18.58 ± 0.00	15.45 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-18.78 ± 0.26	11.65 ± 0.13	(2)
		Gerreidae	*Eucinostomus argenteus*	-17.47 ± 0.00	10.55 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-15.23 ± 0.59	10.03 ± 0.42	(8)
			Microgobius gulosus	-14.16 ± 0.00	10.09 ± 0.00	(1)
			Microgobius thalassinus	-18.65 ± 0.00	13.29 ± 0.00	(1)
		Haemulidae	*Orthopristis chrysoptera*	-18.49 ± 0.22	13.70 ± 0.04	(2)
		Lutjanidae	*Lutjanus argentimaculatus*	-15.15 ± 0.00	11.51 ± 0.00	(1)
		Mugilidae	*Mugil cephalus*	-15.67 ± 2.06	8.33 ± 2.05	(2)
		Paralichtyidae	*Citharichthys spilopterus*	-18.29 ± 0.12	12.13 ± 0.51	(4)
		Sciaenidae	*Bairdiella chrysoura*	-15.64 ± 0.00	12.88 ± 0.00	(1)
			Cynoscion arenarius	-18.04 ± 0.31	15.15 ± 0.17	(6)
			Cynoscion nebulosus	-16.82 ± 0.72	13.23 ± 0.89	(9)
			Leiostomus xanthurus	-18.48 ± 0.83	13.86 ± 0.93	(7)
			Menticirrhus littoralis	-16.56 ± 0.25	13.59 ± 0.28	(9)
			Micropogonias undulatus	-16.64 ± 0.57	11.98 ± 0.48	(7)
			Pogonias cromis	-14.89 ± 0.30	10.09 ± 0.20	(2)
			Sciaenops occelatus	-13.98 ± 0.14	10.70 ± 0.13	(2)
		Scombridae	*Scomberomorus maculatus*	-19.38 ± 0.36	15.46 ± 0.38	(2)
		Sparidae	*Archosargus probatocephalus*	-16.78 ± 0.25	11.47 ± 0.75	(2)
			Lagodon rhomboides	-16.20 ± 0.67	10.15 ± 0.46	(6)
		Sphyrnidae	*Sphyrna tiburo*	-16.74 ± 0.01	13.94 ± 0.20	(2)
		Stromateidae	*Peprilus paru*	-19.95 ± 0.00	13.28 ± 0.00	(1)
		Syngnathidae	*Syngnathus* spp.	-19.29 ± 1.40	9.41 ± 1.03	(5)
Grand Total						(430)

Appendix 7. $\delta^{13}C$ and $\delta^{15}N$ values of fauna collected in Lavaca Bay, Texas by season. Values are mean ± standard error (SE) and the number of samples is indicated in parenthesis.

Season	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Summer	Veg	BOM	Benthic Organic Matter	-18.65 ± 0.62	5.28 ± 0.32	(8)
		Cymodoceaceae	*Halodule wrighitii*	-11.78 ± 0.21	3.68 ± 1.19	(2)
		Poaceae	*Spartina alterniflora*	-12.73 ± 0.14	6.22 ± 0.97	(4)
	Invert	Alpheidae	*Alpheus heterochaelis*	-18.26 ± 3.75	11.36 ± 0.24	(2)
		Menippidae	*Menippe adina*	-16.19 ± 1.48	8.31 ± 0.98	(5)
		Ostreidae	*Crassostrea virginica*	-22.23 ± 0.73	9.58 ± 0.58	(2)
		Palaemonidae	*Palaemonetes vulgaris*	-14.20 ± 1.29	9.23 ± 1.86	(3)
		Porcellanidae	Porcellanidae spp.	-16.08 ± 0.00	6.50 ± 0.00	(1)
		Portunidae	*Callinectes sapidus*	-18.25 ± 0.74	10.68 ± 0.75	(4)
		Peneaidae	*Farfantepenaeus aztecus*	-16.45 ± 1.00	8.86 ± 0.69	(7)
			Litopenaeus setiferus	-17.20 ± 1.63	10.23 ± 0.98	(3)
			Peneaidae spp.	-18.04 ± 0.00	11.58 ± 0.00	(1)
	Fish	Ariidae	*Ariopsis felis*	-18.54 ± 0.72	13.59 ± 0.55	(7)
			Bagre marinus	-18.63 ± 0.19	15.22 ± 0.13	(8)
		Carangidae	*Caranx hippos*	-18.65 ± 0.78	14.47 ± 0.51	(4)
		Carcharhinidae	*Carcharhinus limbatus*	-17.01 ± 0.50	16.16 ± 0.30	(2)
		Clupeidae	*Brevoortia patronus*	-19.77 ± 0.48	13.58 ± 0.31	(9)
		Cynoglossidae	*Symphurus plagiusa*	-18.91 ± 0.00	10.87 ± 0.00	(1)
		Elopidae	*Elops saurus*	-18.54 ± 0.05	13.94 ± 1.50	(2)
		Gobiesocidae	*Gobiesox* spp.	-21.14 ± 0.00	13.63 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-18.50 ± 1.25	11.79 ± 0.76	(8)
			Gobius spp.	-21.00 ± 0.07	14.49 ± 0.13	(2)
		Mugilidae	*Mugil cephalus*	-13.61 ± 0.00	10.37 ± 0.00	(1)
		Paralichtyidae	*Citharichthys spilopterus*	-18.54 ± 0.00	12.98 ± 0.00	(1)
		Polynemidae	*Polydactylus octonemus*	-17.50 ± 0.00	15.12 ± 0.00	(1)
		Sciaenidae	*Cynoscion arenarius*	-18.51 ± 0.09	15.30 ± 0.17	(2)
			Cynoscion nebulosus	-17.47 ± 0.97	13.96 ± 1.08	(7)
			Menticirrhus littoralis	-17.44 ± 0.00	13.91 ± 0.00	(1)
			Micropogonias undulatus	-18.76 ± 0.00	13.61 ± 0.00	(1)
		Scombridae	*Scomberomorus maculatus*	-18.76 ± 0.00	16.86 ± 0.00	(1)
		Sparidae	*Lagodon rhomboides*	-15.16 ± 1.39	9.58 ± 0.79	(2)
		Sphyrnidae	*Sphyrna tiburo*	-16.74 ± 0.01	13.94 ± 0.20	(2)
		Stromateidae	*Peprilus paru*	-20.66 ± 0.71	14.35 ± 1.07	(2)
		Syngnathidae	*Syngnathus* spp.	-21.57 ± 0.00	11.03 ± 0.00	(1)
Fall	Veg	BOM	Benthic Organic Matter	-16.79 ± 1.74	6.06 ± 0.32	(8)
		Cymodoceaceae	*Halodule wrighitii*	-11.27 ± 0.00	2.40 ± 0.00	(1)
		Poaceae	*Spartina alterniflora*	-13.03 ± 0.27	4.10 ± 0.65	(2)
	Invert	Diogenidae	*Clibanarius vittatus*	-13.93 ± 0.00	7.33 ± 0.00	(1)
		Hippolytidae	*Tozeuma carolinense*	-13.11 ± 0.00	7.47 ± 0.00	(1)
		Menippidae	*Menippe adina*	-22.43 ± 0.00	10.80 ± 0.00	(1)
		Ostreidae	*Crassostrea virginica*	-22.66 ± 0.77	9.62 ± 0.47	(4)
		Palaemonidae	*Palaemonetes vulgaris*	-17.65 ± 2.49	7.73 ± 0.76	(3)
		Portunidae	*Callinectes sapidus*	-16.28 ± 1.88	8.73 ± 1.39	(4)
		Peneaidae	*Farfantepenaeus aztecus*	-16.65 ± 0.79	8.49 ± 0.43	(9)
			Litopenaeus setiferus	-17.49 ± 1.20	9.54 ± 0.66	(6)
	Fish	Ariidae	*Ariopsis felis*	-20.10 ± 0.52	13.94 ± 0.29	(9)
			Bagre marinus	-18.64 ± 0.45	14.98 ± 0.09	(6)
		Clupeidae	*Brevoortia patronus*	-19.98 ± 0.44	14.14 ± 0.37	(9)
		Engraulidae	*Anchoa mitchilli*	-20.83 ± 0.17	14.25 ± 0.43	(2)
		Gerreidae	*Eucinostomus argenteus*	-17.47 ± 0.00	10.55 ± 0.00	(1)
		Gobiesocidae	*Gobiesox* spp.	-20.87 ± 0.00	14.33 ± 0.00	(1)
		Gobiidae	*Gobiosoma bosc*	-17.12 ± 1.42	11.26 ± 0.84	(6)
			Microgobius gulosus	-17.84 ± 3.68	11.98 ± 1.89	(2)
			Microgobius thalassinus	-18.65 ± 0.00	13.29 ± 0.00	(1)
		Haemulidae	*Orthopristis chrysoptera*	-18.49 ± 0.22	13.70 ± 0.04	(2)
		Lutjanidae	*Lutjanus argentimaculatus*	-15.15 ± 0.00	11.51 ± 0.00	(1)
		Mugilidae	*Mugil cephalus*	-17.40 ± 0.00	8.34 ± 0.00	(1)
		Paralichtyidae	*Citharichthys spilopterus*	-18.36 ± 0.00	13.04 ± 0.00	(1)
		Sciaenidae	*Bairdiella chrysoura*	-17.51 ± 1.87	14.34 ± 1.46	(2)
			Cynoscion arenarius	-17.64 ± 0.22	15.28 ± 0.21	(4)
			Cynoscion nebulosus	-16.30 ± 0.46	12.60 ± 1.31	(3)
			Leiostomus xanthurus	-20.00 ± 0.67	13.57 ± 0.42	(11)
			Menticirrhus littoralis	-16.94 ± 0.51	13.94 ± 0.43	(7)
			Pogonias cromis	-16.73 ± 1.84	11.23 ± 1.14	(3)
			Sciaenops occelatus	-14.94 ± 0.96	11.59 ± 0.89	(3)
		Sparidae	*Archosargus probatocephalus*	-18.03 ± 0.62	13.19 ± 0.92	(5)
			Lagodon rhomboides	-14.70 ± 0.00	8.73 ± 0.00	(1)
		Syngnathidae	*Syngnathus* spp.	-18.08 ± 2.15	8.04 ± 1.06	(3)

Appendix 7 cont.

Season	Sample Type	Family	Species	$\delta^{13}C$	$\delta^{15}N$	n
Winter	Veg	BOM	Benthic Organic Matter	-16.62 ± 1.31	5.35 ± 0.46	(11)
		Cymodoceaceae	*Halodule wrighitii*	-12.15 ± 0.00	4.25 ± 0.00	(1)
		Poaceae	*Spartina alterniflora*	-13.73 ± 0.14	7.10 ± 1.04	(4)
		POM	Particulate Organic Matter	-16.39 ± 0.97	5.90 ± 0.57	(12)
	Invert	Menippidae	*Menippe adina*	-16.70 ± 0.14	8.34 ± 0.61	(2)
		Palaemonidae	*Palaemonetes vulgaris*	-16.46 ± 0.71	9.81 ± 0.62	(9)
		Porcellanidae	Porcellanidae spp.	-20.85 ± 0.00	12.30 ± 0.00	(1)
		Portunidae	*Callinectes sapidus*	-17.87 ± 0.66	9.51 ± 0.82	(5)
		Xanthidae	Xanthidae spp.	-21.72 ± 0.00	12.65 ± 0.00	(1)
	Fish	Atherinopdisae	*Menidia menidia*	-17.70 ± 0.00	10.13 ± 0.00	(1)
		Clupeidae	*Brevoortia patronus*	-20.40 ± 0.38	12.40 ± 0.42	(9)
		Cyprinodontidae	*Cyprinodon variegatus*	-14.47 ± 1.36	7.06 ± 0.27	(3)
		Engraulidae	*Anchoa mitchilli*	-21.50 ± 0.94	13.32 ± 0.55	(6)
		Gobiidae	*Gobiosoma bosc*	-21.20 ± 0.46	14.45 ± 0.23	(2)
		Mugilidae	*Mugil cephalus*	-17.73 ± 0.00	6.28 ± 0.00	(1)
		Paralichtyidae	*Citharichthys spilopterus*	-17.34 ± 0.79	11.46 ± 0.22	(3)
			Paralichthys lethostigma	-16.54 ± 0.00	10.36 ± 0.00	(1)
		Sciaenidae	*Bairdiella chrysoura*	-19.80 ± 0.05	18.06 ± 1.83	(2)
			Leiostomus xanthurus	-19.04 ± 0.00	18.14 ± 0.00	(1)
			Micropogonias undulatus	-17.23 ± 0.50	12.91 ± 0.45	(10)
		Sparidae	*Lagodon rhomboides*	-16.70 ± 0.63	11.56 ± 0.32	(4)
		Syngnathidae	*Syngnathus* spp.	-20.64 ± 0.00	11.89 ± 0.00	(1)
		Blennidae	*Chasmodes bosquianus*	-22.00 ± 0.00	14.59 ± 0.00	(1)
Spring	Veg	BOM	Benthic Organic Matter	-18.82 ± 0.52	5.65 ± 0.26	(9)
		Poaceae	*Spartina alterniflora*	-13.56 ± 0.68	5.34 ± 3.12	(2)
		POM	Particulate Organic Matter	-24.30 ± 0.59	7.03 ± 0.34	(12)
		Ulvaceae	*Ulva lactuca*	-18.54 ± 0.00	5.96 ± 0.00	(1)
	Invert	Menippidae	*Menippe adina*	-21.18 ± 0.00	13.54 ± 0.00	(1)
		Ostreidae	*Crassostrea virginica*	-23.20 ± 0.51	8.81 ± 0.18	(4)
		Palaemonidae	*Palaemonetes vulgaris*	-17.43 ± 0.86	9.53 ± 0.62	(6)
		Portunidae	*Callinectes sapidus*	-16.13 ± 3.17	9.28 ± 1.77	(2)
		Xanthidae	Xanthidae spp.	-22.29 ± 0.00	11.34 ± 0.00	(1)
		Peneaidae	*Farfantepenaeus* spp.	-17.39 ± 0.59	9.99 ± 0.51	(10)
			Litopenaeus setiferus	-17.98 ± 0.00	11.42 ± 0.00	(1)
			Peneaidae spp.	-16.62 ± 0.15	8.96 ± 0.40	(2)
	Fish	Ariidae	*Ariopsis felis*	-18.86 ± 0.64	14.59 ± 0.30	(8)
			Bagre marinus	-18.59 ± 0.47	16.36 ± 0.58	(7)
		Clupeidae	*Brevoortia patronus*	-19.69 ± 0.29	13.78 ± 0.40	(9)
		Cynoglossidae	*Symphurus plagiusa*	-19.26 ± 0.44	12.25 ± 0.17	(2)
		Dasyatidae	*Dasyatis sabina*	-17.88 ± 0.00	14.09 ± 0.00	(1)
		Engraulidae	*Anchoa mitchilli*	-19.67 ± 0.14	12.94 ± 0.00	(2)
		Mugilidae	*Mugil cephalus*	-15.80 ± 0.00	12.43 ± 0.00	(1)
		Paralichtyidae	*Citharichthys spilopterus*	-20.28 ± 0.32	12.78 ± 0.07	(2)
		Pomatomidae	*Pomatomus saltatrix*	-17.23 ± 0.00	15.27 ± 0.00	(1)
		Sciaenidae	*Bairdiella chrysoura*	-19.32 ± 0.00	15.98 ± 0.00	(1)
			Cynoscion arenarius	-19.30 ± 0.00	14.64 ± 0.00	(1)
			Cynoscion nebulosus	-19.08 ± 2.53	14.48 ± 0.92	(2)
			Leiostomus xanthurus	-17.68 ± 0.40	13.28 ± 0.51	(4)
			Menticirrhus littoralis	-17.19 ± 0.62	13.94 ± 0.27	(5)
			Micropogonias undulatus	-17.37 ± 2.29	12.01 ± 0.84	(2)
			Pogonias cromis	-18.08 ± 0.00	14.43 ± 0.00	(1)
			Sciaenops occelatus	-18.30 ± 0.00	14.76 ± 0.00	(1)
		Scombridae	*Scomberomorus maculatus*	-19.38 ± 0.36	15.46 ± 0.38	(2)
		Sparidae	*Archosargus probatocephalus*	-21.27 ± 0.00	12.57 ± 0.00	(1)
			Lagodon rhomboides	-18.03 ± 0.98	12.05 ± 1.01	(3)
Grand Total						(430)