Macrofaunal food web structure associated with subtidal and intertidal oyster reefs and non-vegetated bottom in the Mission-Aransas estuary

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ABSTRACT

Examining food web dynamics is important for identifying species interactions. Tracking energy flow between organisms within habitats clarifies the ecological functions between predators and their prey. Understanding the interactions between organisms and the energy flows within habitats is critical in explaining estuarine ecosystem productivity and structure. The purpose of this study was to examine macrofaunal food web structure associated with subtidal and intertidal oyster reefs and non-vegetated bottom in the Mission-Aransas estuarine system. Food webs were analyzed by combining stomach content analysis and stable isotope techniques. Sampling occurred seasonally from November 2008 to September 2009. A total of 5226 macroinvertebrates and fishes were collected using a modified epi-benthic sled and multi-sized mesh gill nets for both stomach content and stable isotope analyses. Vegetation, particulate organic matter, and benthic organic matter were also collected for stable isotope analysis. Diet preference was reflected as the Percent Index of Relative Importance (%IRI) and showed that decapod crabs, and *Crassostrea virginica* were the top prey items for predators within the system. Gut content analysis showed a high number (35%) of empty stomachs which could indicate that food availability and resource acquisition may be deficient in the system. The system was going through a historic drought, and experienced high salinities (40+ ppt) and reduced freshwater inflows, and these extreme abiotic conditions may have altered food webs during the course of study. Nonetheless, this study provides food web information that are useful in planning fisheries population management when droughts are expected, and for comparative purposes during "normal" environmental conditions.

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INTRODUCTION

Estuarine habitats, such as seagrass beds, mangroves, salt marsh, and oyster reefs are critical to maintaining highly productive coastal environments (Hemminga & Duarte 2000). These estuarine habitats support the high productivity and abundance of marine life in seagrass, mangroves, and oyster reefs (Coen et al. 1999; Stunz 2010). High densities of nekton are the result of the elevated productivity from the estuarine habitats (Minello and Zimmerman 1991; Corona 2000; Stunz et al. 2002). Estuaries offer a variety of habitat types to the organisms found within them, particularly oyster reef. These biogenic habitats have been the subject of much study; however, further research leading towards a complete understanding of oyster reefs and their ecosystem benefits is needed (Coen et al. 2007). Unfortunately removal and loss of oyster reefs within coastal habitats is at an all-time high (Jackson et al. 2001) making understanding their ecology even more pressing. Thus, the ecological function of these areas must be understood in order to evaluate the roles of these essential habitats, their preservation and ensure ecosystem productivity.

One preferred method of monitoring ecosystem productivity is through food web studies. Food web studies give ecologists insight into predator-prey interactions in ecosystems, trace energy flow, and help identify ecosystem structure within coastal ecosystems. Food web data is commonly collected through gut content analysis and stable isotope analysis (Winemiller et al. 2007). Understanding the interactions between organisms and the energy flows within habitats is critical in explaining ecosystem productivity and structure.

To increase our understanding of ecosystems, it is necessary to study the flow of energy/matter between the various components (biota) of the system and between the system and the environment (Dame and Patton 1981). Predator/prey interactions, energy flow patterns, and the food web structure on oyster reefs defines the energy sources/sinks for oyster reefs, aiding in proper management of oyster reef ecosystems (Crowder et al. 1996). Understanding food web structure and behavior will assist in managing oyster reef ecosystems toward sustainability. Estimation of the direction and magnitude of predator/prey interactions is of key importance in maintaining sustainable fisheries (Ulrich et al. 2001).

Food webs summarize resource-consumer interactions within communities and help ecosystem managers understand ecosystem structure and population dynamics (Pimm et al. 1990; Winemiller and Polis 1996; De Ruiter et al. 2005; Winemiller and Layman 2005). Food web data has been successfully collected by using gut content analysis, and stable isotope analysis (Peterson et al. 1985; Vander Zanden and Rasmussen 1999; Wrast 2008). Examination of stomach contents provides a direct link to an organism's range of prey, and preferred food habits. Once gut contents are assimilated the stable isotope analysis can show food habits of an individual after prey items have been digested. When combined with gut content analysis, stable isotopes may be used to assess the potential role of unidentifiable, undetectable, or unquantifiable prey in an organism's diet (Johannsson et al. 2001). Coupling both techniques allows more detailed and accurate understanding of an organism's particular food habits over short and long time periods.

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 is 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). The carbon isotope composition ($\delta^{13}C$) varies between different producers however; isotopic composition of a consumer reflects that of its prey (Deniro and Epstein 1978). Once basal carbon sources have been identified, stable nitrogen isotopes ($\delta^{15}N$) can be used to examine trophic structure and calculate trophic levels of predator-prey relationships within the food web. Stable isotope analysis provides information on the food items that are assimilated, and not food that is merely ingested. Long term food habits give overall diet preferences versus opportunistic feeding occurrences.

The eastern oyster *Crassostrea virginica*, is found from the Gulf of St. Lawrence to the Gulf of Mexico in dense aggregations, and over time create oyster reefs and form complex habitats. Oyster reefs sustain high nekton density, biomass and richness compared to other habitat types (Stunz et al. 2010). Oyster reefs benefit the surrounding habitats by simply feeding and processing waste. Biodeposits from feces and pseudofeces of oysters accumulate around reefs and induce denitrification (Newell et al. 2002). Filter feeding oysters also help counteract impacts of estuarine eutrophication (Jackson et al. 2001) by removing suspended inorganics, phytoplankton, and detrital particles, thereby reducing turbidity and improving water quality (Dame 1996). Through their removal of organic particles in the water column, oysters redirect energy to benthic food chains that would otherwise be unusable (Newell 1988). Furthermore, the physical structure of a fringing oyster reef can serve to protect salt marsh habitat by dissipating wave energy (Meyer et al. 1996). Intertidal reefs along marsh edges and can stabilize and control erosion by trapping sediments and dispersing wave energy.

Overfishing is the single greatest disturbance to coastal ecosystems (Jackson et al. 2001). Oyster reefs have been overfished in many estuaries of the southeast USA and the world (Rothschild et al. 1994; Lenihan and Peterson 1998). Since the 1980’s oyster reefs in Texas have been declining primarily due to commercial harvest, and other anthropogenic uses: road bed material, concrete mix, and railroad beds (The Nature Conservancy 2008). Commercial harvest combined with varying environmental conditions has reduced oyster reefs in coastal ecosystems. Oyster populations vary naturally over time depending on: salinity, runoff, food availability, recruitment, and a host of other factors (Powell et al. 1995); however, coupled with overfishing oyster populations cannot sustain themselves. Removal of reefs has a direct negative effect on the surrounding ecosystems including: loss of essential fish habitat, increased erosion, and decreased energy flow (Bahr and Lanier 1981; Dame et al. 1984; Newell 1988; Luckenbach et al. 1997; and Peterson et al. 2003). Success of oyster reefs depends on recruitment of spat for continued reef building (Smith et al. 2002). By removing the existing reef new incoming spat loses a prime location for recruitment, and the reef cannot maintain its biomass eventually subsiding into the sediment.

Preventing loss of oyster reef communities is critical to maintaining ecosystem productivity of coastal fisheries. Knowledge of the benefits that oyster reefs provide to the surrounding water quality is well known (Coen et al. 2007). However, the food web structure that oyster reefs provide is poorly known. The importance of oyster reefs in coastal ecosystem food webs needs to be better understood. Food webs of intertidal and subtidal oyster reefs have not been completely explored. Knowledge of the energy sources and sinks of organisms that use oyster reefs would help explain and quantify the value of oyster reefs to coastal ecosystems. Thus, the goal of this study is to determine differences in macrofaunal food web structure associated with estuarine subtidal and intertidal oyster reefs in reference to non-vegetated bottom habitat. The combination of using gut content and stable isotope analysis will provide significant food web data for the oyster reefs in the Mission-Aransas estuarine system.

Materials and Methods

Study Site

The Mission-Aransas estuarine complex is located along the central Texas coast; included within this complex are the Aransas and Copano Bays (Figure 1). Aransas Bay is shallow (3.0 m average depth) primary bay, covering ~320 km². Copano Bay is a shallow (3.0 m), secondary bay covering ~167 km². Freshwater inflow is provided via the Mission and Aransas Rivers as well as Copano Creek. Combined discharge from the three rivers averaged 7 $m^3 s^{-1}$ from 1981-2005 (United States Geological Survey 2005).

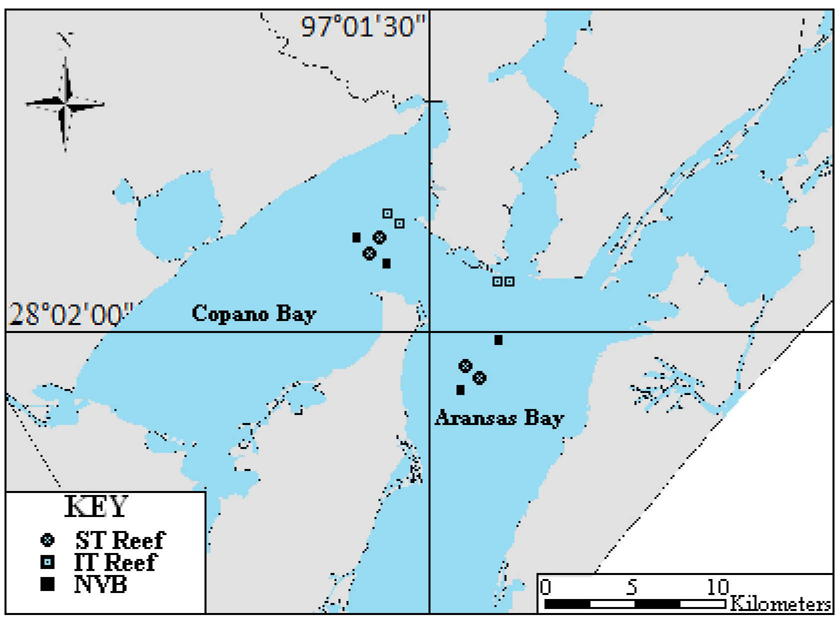

Figure 1. Map showing sampling locations in Copano and Aransas Bays, Texas. Habitat types samples are indicated by black shapes; subtidal reefs (ST) = ⊗, intertidal reef (IT) = ▣, non-vegetated bottom (NVB) = ■

Salinities within the system range from 5 ppt-40 ppt depending on annual rainfall (Parker 1960), and average ~15 ppt (TPWD unpublished data). Habitats found within Aransas and Copano Bays include: non-vegetated bottom ~7,500 ha, seagrass beds ~5,000 ha, marsh ~3,500 ha, oyster reef ~2,000 ha, and mangrove ~800 ha (TPWD unpublished data).

Sampling Design

This study focused on determining the food web structure of three different habitat types (intertidal oyster reefs, subtidal oyster reefs and non-vegetated bottoms) within Aransas and Copano Bays, Texas. In each bay system two replicates for each habitat were selected (Table 1). In Aransas and Copano Bays samples were collected on subtidal reef, intertidal reef, and non-vegetated bottom. Each site was sampled on a seasonal basis (approximately every 3 months) in fall (November 2008), winter (March 2009), spring (June 2009), and summer (September 2009).

Table1. Habitats sampled in Aransas and Copano Bays, Texas in 2008-2009 and the sample size (n) by season. NVB = non-vegetated bottom; MEBS = modified epibenthic sled.

			Sample Size (n)				
Habitat	Bay System	Gear	Summer	Fall	Winter	Spring	Total
Intertidal Reef	Aransas	MEBS	12	12	12	12	48
		Gill Net	4	4	4	4	12
	Copano	MEBS	12	12	12	12	48
		Gill Net	4	4	4	4	12
Subtidal Reef	Aransas	MEBS	6	6	6	6	24
		Gill Net	4	4	4	4	12
	Copano	MEBS	6	6	6	6	24
		Gill Net	4	4	4	4	12
NVB	Aransas	MEBS	6	6	6	6	24
		Gill Net	4	4	4	4	12
	Copano	MEBS	6	6	6	6	24
		Gill Net	4	4	4	4	12

A modified epibenthic sled (MEBS) was used to sample nekton on both oyster reef habitats as well as on non-vegetated bottom; the sled was trawled by boat for subtidal reefs and non-vegetated bottom and pulled by hand on intertidal reefs (the hand pulled sled cover ~10 m^2, and boat pulled trawls covered ~100 m^2. The modified epibenthic sled is equipped with steel teeth that are designed to agitate and re-suspend the oyster reef surface; the oyster exclusion net prevents the oyster shells from entering the cod end of the net (1-mm mesh plankton net) where the nekton collects. The MEBS has been successfully used, and calibrated in Robillard et al. 2010.

Gill nets (30.46 m long by 1.22 m wide) were deployed at each sampling site. Each net had 6 panels (each 5.07 m long) of increasing size (1.27 cm, 2.54 cm, 3.81 cm, 5.08 cm, 6.35 cm, and 7.62 cm of stretched mesh). One net was set parallel and the other was placed perpendicular to the sampling site. The nets fished for ~3 h and all fish captured were identified to species and measured to the nearest 1mm total length (TL). The species kept for food habits characterized the range and occurrence of representative species from different trophic levels.

Hydrological parameters

Hydrological parameters including: depth, DO (mg/L), salinity (ppt), and water temperature (ºC) were measured using a Quanta Hydrolab or YSI multiparameter probe at each site. A Kestrel 3600 weather meter was used to measure current weather conditions including wind speed, barometric pressure, humidity, and air temperature. Water depth was also measured at all sites through the course of this study.

Gut content sample collection

Gut content analysis was performed on organisms captured via the methods described above. Species were selected for gut content analysis (GCA) based upon size, trophic level, and representation within the bay system. Fish were removed from gillnets and stored on ice and frozen upon returning to the lab. If selected for GCA the entire GI tract was dissected out. Once removed the stomachs were categorized by fullness index and gut contents by a condition index. The fullness index is a scale of six categories indicating the anecdotal fullness of the gut. The categories are loosely defined as follows: Category 0: (Empty) gut contains no trace of any prey item Category 1: (Almost empty) gut contains only traces of a prey item or prey items; prey items not obviously stretching the gut Category 2: (Not very full) gut contains loosely packed prey item(s) along less than half the entire length; prey items generally not stretching the gut Category 3: (Moderately full) gut contains loosely packed prey item(s) along entire length; prey items may slightly stretch the gut but not generally along the entire length Category 4: (Full) gut contains moderately packed prey item(s) along entire length; prey items moderately stretching the gut along much or all of its length or distinctly stretching the gut along less than half of its Length Category 5: (Very Full) gut contains densely packed prey item(s) along the entire length; stomach distinctly stretched along entire length or maximally stretched along any portion of its length.

The fullness index was a scale of four categories indicating the fullness of the stomach. The GI tract and all contents in the anterior half of the gut was removed and placed on a sorting tray. The condition index of the prey items is a scale of four categories ranging from: (1) Intact: the prey item is basically intact, and the vast majority of the bulk is still present. (2) Significant Loss: much bulk, typically soft tissue, has been lost through maceration, other physical damage, or by digestion. (3) Hard Parts: essentially only bones, teeth, scales, exoskeleton or other, digestion-resistant fragments remain. (4) Undetermined: used for items such as indigestible sand, plants, or detritus or for indeterminate items such as digestate and unidentified objects. Individual prey items were identified to the lowest possible taxon, enumerated and volumetrically measured based on the methods by Winemiller (1990). Prey items were placed into 35 categories with variable levels of taxonomic aggregation ranging from species to orders and functional groups. Large prey items (>0.1 ml) were blotted dry and placed in a graduated cylinder with a known volume of DI water and the displacement was recorded. Prey items <0.1 ml were placed on a glass slide and visually estimated by comparison to a known volume of DI water extracted from a graduated pipette.

Stable Isotope Analysis

Samples of vegetation, 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 in coolers for stable isotope analysis.

Submerged vegetation and algae were collected during each sampling event and placed in coolers while in the field, and processed back at the lab. Water samples for particulate organic matter (POM) were collected at each sampling site using a Niskin bottle. Freshwater samples were collected at sections of the Aransas and Mission Rivers, as well as a tidal creek North of St. Charles Bay. Water column POM samples (with phytoplankton assumed as a main component) were collected by passing water samples through a pre-combusted glass microfiber filters (Whatman GF/F). Particulate organic matter samples were collected during all four seasons, and stored in pre-combusted aluminum foil packets on 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 ice. All samples (both whole organisms and tissue samples) for stable isotope analysis were stored in a -80 ºC freezer.

Fish tissue, macro-invertebrate tissue, benthic organic matter (BOM), and vegetation samples were freeze-dried 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 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.

Data analysis

Stomach Content Analysis

Trophic levels (TL) of predators using stomach content analysis (TL_{gc}) were calculated using the formula presented in Adams et al. (1983):

$$TL_{gc_i} = 1.0 + \Sigma\, TL_j\, (P_{ij})^{\,j=1}$$

Where TL_{gc_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 (Wrast 2008 and Froese and Pauly 2009).

The stable isotope of nitrogen was used to calculate trophic levels (TL_{si}) of consumers following the method described in Jepsen and Winemiller 2002. The formula used for the calculation of the TL for a species was:

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

Where $\delta^{15}N_{reference} = 6.76$ 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).

The index of relative importance (IRI) was calculated following the method described in Pinkas et al. (1971) 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 percent frequency of occurrence. IRI values were calculated for each prey item in the stomach content of each individual. Percent index of relative importance (%IRI) was calculated for prey items based upon bay system (Aransas or Copano), and habitat (NVB, intertidal reef and subtidal reef). The mean values for the food items were determined by each parameter investigated (habitat type, spatial and temporal scales)

RESLUTS

Environmental

There was not a significant difference in water depth for each season (ANOVA, $F_{3,60}$ = 0.054, p=0.98) for both bay systems. A significant difference was found between seasons for water temperature (ANOVA, $F_{3,60}$ =677.09, p<.0001), dissolved oxygen (ANOVA, $F_{2,45*}$ =65.57, p<.0001), and salinity (ANOVA, $F_{3,60}$ =80.97,p<.0001) (*dissolved oxygen levels were not collected for summer 2009 for Copano Bay due to a faulty DO sensor). Water temperatures ranged from 14.8-28.5°C, and salinities ranged from 32-44 ppt for Aransas Bay. In Copano Bay temperatures ranged from 13.6-29.4°C, and salinities ranged from 31-43 ppt (Table 2 and 3).

Table 2. Environmental characteristics among habitat types in Aransas Bay, Texas. Mean and standard error (SE) are given for variables measured in each habitat type and region sampled seasonally from fall 2008 through summer 2009. 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.

Aransas Bay				
Environmental Variable	Subtidal Reef MEAN	Intertidal Reef WW MEAN	Intertidal Reef LW MEAN	NVB MEAN
Fall (2008)				
Water temperature (°C)	18.1 (0.40)	16.65 (0.75)	16.95 (1.15)	18.2 (0.80)
Salinity (ppt)	33.5 (1.50)	32.5 (1.50)	34.5 (0.50)	34.5 (0.50)
Water depth (m)	1.25 (0.05)	0.5 (0.0)	0.5 (0.0)	2.35 (0.04)
Dissolved oxygen (mg 1^{-1})	8.28 (0.0)	8.28 (0.20)	8.63 (0.24)	8.48 (0.14)
Winter (2009)				
Water temperature (°C)	15.85 (0.05)	14.8 (0.30)	14.75 (0.35)	15.9 (0.40)
Salinity (ppt)	37.5 (2.50)	36 (1.0)	35.5 (0.50)	35 (1.0)
Water depth (m)	1.5 (0.03)	0.5 (0.0)	0.5 (0.0)	2.35 (0.25)
Dissolved oxygen (mg 1^{-1})	9.29 (0.11)	6.525 (0.03)	8.05 (0.28)	8.28 (0.98)
Spring (2009)				
Water temperature (°C)	30.15 (0.15)	28.65 (0.05)	29.45 (0.05)	30.15 (0.05)
Salinity (ppt)	35 (0.0)	32 (0.0)	32 (0.0)	35.5 (0.50)
Water depth (m)	0.95 (0.05)	0.35 (0.15)	0.35 (0.15)	2.45 (0.25)
Dissolved oxygen (mg 1^{-1})	5.12 (0.27)	5.18 (0.86)	5.49 (0.69)	5.3 (0.09)
Summer (2009)				
Water temperature (°C)	28.4 (0.15)	27.4 (0.0)	27.6 (0.10)	28.5 (0.20)
Salinity (ppt)	40.53 (0.04)	44 (1.0)	44 (1.0)	40.68 (0.28)
Water depth (m)	1.5 (0.73)	0.35 (0.05)	0.4 (0.10)	2.55 (0.25)
Dissolved oxygen (mg 1^{-1})	5.49 (0.10)	5.33 (0.54)	4.55 (0.10)	5.66 (0.05)

Table 3. Environmental characteristics among habitat types in Copano Bay, Texas. Mean and standard error (SE) are given for variables measured in each habitat type and region sampled seasonally from fall 2008 through summer 2009. 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.

	Copano Bay			
	Subtidal Reef	Intertidal Reef WW	Intertidal Reef LW	NVB
Environmental Variable	MEAN	MEAN	MEAN	MEAN
Fall (2008)				
Water temperature (°C)	14.7 (0.0)	13.6 (0.0)	13.6 (0.0)	18.2 (0.80)
Salinity (ppt)	31.25 (0.25)	33.5 (0.0)	31.5 (0.0)	34.5 (0.50)
Water depth (m)	2.15 (0.05)	0.5 (0.0)	0.5 (0.0)	2.35 (0.04)
Dissolved oxygen (mg 1^{-1})	9.35 (0.0)	9.3 (0.14)	9.3 (0.14)	8.48 (0.14)
Winter (2009)				
Water temperature (°C)	14.45 (0.15)	13.6 (0.0)	15.75 (0.05)	14.5 (0.15)
Salinity (ppt)	36 (1.0)	38 (3.0)	38 (3.0)	36 (1.0)
Water depth (m)	2.15 (0.05)	0.5 (0.0)	0.5 (0.0)	2.4 (0.3)
Dissolved oxygen (mg 1^{-1})	6.2 (0.30)	9.3 (0.14)	6.88 (0.13)	6.65 (0.05)
Spring (2009)				
Water temperature (°C)	28.85 (0.05)	29 (0.0)	29 (0.0)	29.4 (0.7)
Salinity (ppt)	37 (2.0)	34 (2.0)	32.75 (0.75)	35 (0.0)
Water depth (m)	1.6 (0.50)	0.5 (0.0)	0.55 (0.05)	2.5 (0.2)
Dissolved oxygen (mg 1^{-1})	5.6 (0.49)	5.52 (0.27)	5.49 (0.19)	6.44 (1.29)
Summer (2009)				
Water temperature (°C)	29 (0.25)	29.3 (0.55)	29.3 (0.55)	27.5 (0.75)
Salinity (ppt)	43 (0.0)	42 (0.0)	42 (0.0)	42 (1.0)
Water depth (m)	1.45 (0.65)	0.5 (0.0)	0.5 (0.0)	2.5 (0.2)
Dissolved oxygen (mg 1^{-1})	NA	NA	NA	NA

Community assemblage

Over 5000 macroinvertebrates and fishes were collected throughout this study with all sampling gears. Ten species comprised 96% of the invertebrates collected in modified epibenthic sleds (Table 4). Xanthidae sp. was the dominant invertebrate captured by epibenthic sled

Table 4. Number and percent abundance of macrofauna collected by modified epibenthic sled (MEBS) for Aransas and Copano Bays, Texas for all habitat types and seasons.

Species	Number (n)	Percent (%)
Xanthidae sp.	1302	29.81
Palaemonetes sp.	1154	26.43
Porcellanidae sp.	482	11.04
Tozeuma carolinense	360	8.24
Gobiidae sp.	261	5.98
Callinectes sapidus	257	5.89
Clupeidae sp.	98	2.24
Peneaidae sp.	98	2.24
Ogyrides sp.	97	2.22
Sygnathus sp.	82	1.88
Alpheus heterochaelis	63	1.44
Farfantepenaeus sp.	32	0.73
Menidia sp.	16	0.37
Micropogonias undulatus	13	0.30
Mysidae sp.	12	0.27
Menippe adina	11	0.25
Opsanus beta	7	0.16
Heterocrypta granulata	4	0.09
Palaemonetes vulgaris	3	0.07
Ophichthus gomesii	3	0.07
Anchoa mitichii	2	0.05
Citharichthys spilopterus	2	0.05
Lagodon rhomboides	2	0.05
Squilla eumpusa	2	0.05
Paguridae sp.	1	0.02
Litopenaeus setiferus	1	0.02
Pogonias cromis	1	0.02
Symphurus plaguisa	1	0.02
TOTAL	**4367**	**100**

comprising 29.81% of the catch. Eleven fish species comprised 10.81 % of the organisms collected in epibenthic sleds. *Ariopsis felis* was the most abundant species (271 individuals) caught in gillnets in both bay systems: 26% Aransas, 42% Copano Bays (31.55% of total catch). *Brevoortia patronus* was the second most abundant species with 11.41% of the total catch with 98 individuals. *Bagre marinus* was the third most abundant species with 10.01% of the total catch with 86 individuals. Popular sport fish: *Sciaenops ocellatus* (3.61%), *Pogonias cromis*

(2.21), *Paralichthys lethostigma* (1.28) represented only 61 individuals.

Food web overall

Thirty-four species of fishes from 22 families were examined for stomach content analysis (Table 5). A total of 859 stomachs were analyzed throughout all habitat types, and seasons combined. Large percentage (35.49%) of stomachs investigated was empty. *Brevoortia patronus* (20.76%) represented the largest percentage of stomachs examined. While *Bagre marinus* (17.99%) and *Ariopsis felis* (16.96%) also comprised a high percentage of the stomachs examined (Table 5). Shark species, *Sphyrna tiburo, Sphyrna lewini*, *Carcharhinus limbatus*, and *Carcharhinus leucas* were captured in both bays, in all seasons except fall and winter, over subtidal oyster and non-vegetated bottom habitats. Fourteen species were only found in one season, and 12 species were only examined from one bay system.

Species were selected for stable isotope analysis based upon habitat, abundance, size class, and season. Some selected fish specimens were used in both gut content analysis as well as, stable isotope analysis.

Table 5. List of all families and species examined in stomach content analysis, size range (in mm total length), season(s), bay system, habitat types at which they were collected, number of stomachs examined and the number of those which were empty for the fishes collected from Aransas and Copano Bays, Texas from 2008-2009. SU = summer, FA = fall, WI = winter, SP = spring, A = Aransas, C = Copano, R = oyster reef, NVB = non-vegetated bottom.

Family	Species	Common name	Size Range	Season	Bay	Number	Empty
Ariidae	*Ariopsis felis*	Hardhead catfish	123 - 408	SU FA WI SP	A C	176	95
	Bagre marinus	Gafftop sailfish	197 - 604	SU WI SP	AC	72	14
Batrachoididae	*Opsanus beta*	Gulf toadfish	24 - 104	SU WI SP	A C	9	1
Belonidae	*Strongylura marina*	Atlantic needlefish	361 - 405	SU FA WI	A C	7	3
Blenniidae	*Chasmodes bosquianus*	Striped blenny	32 - 58	WI	A	7	1
Carcharhinidae	*Carcharhinus leucas*	Bull shark	732 - 1060	SP	A C	5	2
	Carcharhinus limbatus	Blacktip shark	598 - 644	SP	A	2	0
Clupeidae	*Brevoortia patronus*	Gulf menhaden	27 - 362	SU FA WI SP	A C	79	19
	Dorosoma cepedianum	Gizzard shad	250 - 274	SU WI SP	A C	5	1
	Harengula jaguana	Scaled sardine	97 - 101	SU	C	2	0
Cynoglossidae	*Symphurus plagiusa*	Blackcheek tonguefish	78	WI	C	2	0
Elopidae	*Elops saurus*	Ladyfish	315 - 480	SU SP	A C	4	1
Exocoetidae	*Hemiramphus brasiliensis*	Ballyhoo	227 - 237	SU SP	A	2	1
Fundulidae	*Fundulus grandis*	Gulf killifish	90	WI	A	1	1
Gerreidae	*Eucinostomus argenteus*	Spotfin mojarra	93	SU	C	1	0
Gobiesocidae	*Gobiesox strumosus*	Skilletfish	62	WI	C	1	0
Gobiidae	*Gobiosoma bosc*	Naked goby	22 - 51	WI	A C	58	17
Mugilidae	*Mugil cephalus*	Striped mullet	186 - 377	SU FA WI SP	A C	10	2
Myliobatidae	*Rhinoptera bonasus*	Cownose ray	485 - 490	SP	C	2	1
Ophichthidae	*Ophichthus gomesii*	Shrimp eel	52 - 101	WI SU	C	2	2
Paralichthyidae	*Paralichthys lethostigma*	Southern flounder	24 - 440	SU FA WI SP	A C	8	3
Sciaenidae	*Bairdiella chrysoura*	Silver perch	86 - 103	FA WI	A C	11	4
	Cynoscion arenarius	Sand trout	106 - 276	SU FA SP	A C	8	3
	Cynoscion nebulosus	Spotted sea trout	255 - 450	SP FA WI	A C	12	11
	Menticirrhus americanus	Southern kingfish	114 - 247	SU WI SP	A C	4	2
	Micropogonias undulatus	Atlantic croaker	144 - 250	SP	C	17	4
	Pogonias cromis	Black drum	184 - 1065	SU FA WI SP	A C	17	2
	Sciaenops ocellatus	Red drum	13 - 479	SU FA WI SP	A C	25	6
Sparidae	*Archosargus probatocephalus*	Sheepshead	209	SP	C	1	0
	Lagodon rhomboides	Pinfish	15 - 164	SU WI SP	A C	30	5
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead	511 - 605	SP	A C	3	0
	Sphyrna tiburo	Bonnethead shark	622 - 885	SU SP	A C	8	0
Syngnathidae	*Syngnathus scovelli*	Gulf pipefish	22 - 188	SU WI SP	A C	40	22
Synodontidae	*Synodus foetens*	Inshore lizardfish	38 - 233	SP	A C	2	1
					TOTAL	**634**	**225**

The trophic levels (TL_{gc}) calculated for fish species from stomach content analysis ranged from 2.00 (*Chasmodes bosquianus*, *Brevoortia patronus*, *Dorosoma cepedianum*, *Harengula jaguana*, *Mugil cephalus*, *Archosargus probatocephalus*) to 4.21 (*Elops saurus*) (Table 6). The value for *C. bosquianus* is low because of the low number of that species sampled, and the only identifiable food item in the gut was unidentifiable algae. Some of the other high TL_{gc} fishes in the system include: *Sphyrna lewini* (4.01), *Carcharhinus limbatus* (3.99), *B. marinus* (3.77) *Carcharhinus leucas* (3.71), *Ariopsis felis* (3.65) *Sphyrna tiburo* (3.62), and *Sciaenops ocellatus* (3.60). *E. saurus* showed to consume 75% unidentifiable fish, and 25% *Mulinia lateralis*. *S. lewini* consumed 50% unknown fish, 25% *B. patronus*, and 25% Peneaidae spp. *C. limbatus* consumed 50%unknown fish and 50% *B. patronus*. *B. marinus* had the most diverse feeding habits consuming 12 different prey items seeming to prefer: *Callinectes sapidus* (25 occurrences) *Menippe adina* (12 occurrences), unknown fish (6 occurrences), unknown crab (3 occurrences), as well as *B. patronus*, Ariidae larvae, *Farfantepenaeus aztecus*, unknown penaeid shrimp, *Lolliguncula brevis, Squilla eumpusa*, *Alpheus heterochaelis,* and *Persephona mediterranea*.

Table 6. Total number (N) and percent abundance (%) mean trophic level (TL_{gc}), and standard deviation for species used for stomach content analysis for all habitat types, regions, and seasons in Aransas and Copano Bays, Texas, in 2008-2009.

Family	Species	Common name	N	%	TL ± SD
Ariidae	*Ariopsis felis*	Hardhead Catfish	49	16.96	3.65 ± 0.32
	Bagre marinus	Gafftop Sailfish	52	17.99	3.77 ± 0.19
Batrachoididae	*Opsanus beta*	Gulf toadfish	4	1.38	3.42 ± 0.11
Blenniidae	*Chasmodes bosquianus*	Striped Blenny	1	0.35	2.00 ± 0.00
Carcharhinidae	*Carcharhinus leucas*	Bull Shark	3	1.04	3.71 ± 0.56
	Carcharhinus limbatus	Blacktip shark	2	0.69	3.99 ± 0.35
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	60	20.76	2.00 ± 0.00
	Dorosoma cepedianum	Gizzard shad	4	1.38	2.00 ± 0.00
	Harengula jaguana	Scaled sardine	2	0.69	2.00 ± 0.00
Elopidae	*Elops saurus*	Ladyfish	3	1.04	4.21 ± 0.04
Gobiesocidae	*Gobiesox strumosus*	Skilletfish	1	0.35	3.45 ± 0.00
Gobiidae	*Gobiosoma bosc*	Naked Goby	20	6.92	3.09 ± 0.50
Mugilidae	*Mugil cephalus*	Striped Mullet	9	3.11	2.00 ± 0.00
Paralichthyidae	*Paralichthys lethostigma*	Southern Flounder	4	1.38	3.36 ± 0.11
Portunidae	*Callinectes sapidus*	Blue Crab	1	0.35	3.00 ± 0.00
Sciaenidae	*Bairdiella chrysoura*	Silver Perch	2	0.69	3.23 ± 0.00
	Cynoscion arenarius	Sand trout	1	0.35	3.75 ± 0.00
	Menticirrhus americanus	Southern kingfish	1	0.35	3.5 ± 0.00
	Micropogonias undulatus	Atlantic Croaker	9	3.11	3.12 ± 0.49
	Pogonias cromis	Black Drum	14	4.84	3.12 ± 0.23
	Sciaenops ocellatus	Red Drum	15	5.19	3.60 ± 0.54
Sparidae	*Archosargus probatocephalus*	Sheepshead	1	0.35	2.00 ± 0.00
	Lagodon rhomboides	Pinfish	15	5.19	3.23 ± 0.32
Sphyrnidae	*Sphyrna lewini*	Scalloped Hammerhead	2	0.69	4.01 ± 0.32
	Sphyrna tiburo	Bonnethead	8	2.77	3.62 ± 0.32
Syngnathidae	*Syngnathus scovelli*	Gulf pipefish	5	1.73	3.26 ± 0.09
Synodontidae	*Synodus foetens*	Inshore lizardfish	1	0.35	3.64 ± 0.00
		TOTAL	**289**	**100**	

In the entire Aransas/Copano 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: *Callinectes sapidus* (54.75%), *Menippe adina* (15.45%), *Crassostrea virginica* (14.99%), Actinopterygii (5.16%), Cyclopidea sp. (2.88%), and *B. patronus* (2.28%) (Table 7). A total of 1972.09 mL of prey was recovered. *C. sapidus* was the largest prey item by volume (456.20 mL). Digestate was found in the most (220) stomachs, and was the second largest prey item by volume (340.70 mL). *M. adina* (255.25 mL) and *C. virginica* (246.93 mL) were also major prey items. Prey items were combined into broad categories of similar taxon (crabs, fish, shrimp, etc.), and insignificant prey items were omitted for simplification of Table 7. A full list of prey items can be found in appendix 1 (Copano Bay), and appendix 2 (Aransas Bay). Diet preference of predatory fishes bases upon mean percent IRI showed that in the entire Aransas/Copano Bay food web. The prey items that contribute the most to the consumers in the system according to percent index of relative importance (%IRI) are: *C. sapidus* (54.75%), *M. adina* (15.45%), *C. virginica* (14.99%), and Actinopterygii (5.16%) (Fig. 2). Overall 35.5% of the stomachs examined were empty. Empty guts by season were as follows for both bays: fall 65.0%, winter 27.0%, spring 41.2%, and summer 29.8%

Table 7. Prey items identified from stomach contents from all seasons, regions, and habitat types at Aransas and Copano Bays, Texas sampled from Fall 2008-Summer 2009. 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 from all stomach samples

Prey Item Phylum (Division)	Prey Item Class	Prey Item Order	Prey Item Family	Prey Item Species	%N	%V	%FO	IRI	%IRI
Arthropoda	Malacostraca	Decapoda	Alpheidae	Alpheus heterochaelis	0.34	0.05	1.54	2.31	0.01
			Menippidae	Menippe adina	19.66	18.80	9.23	2436.92	15.45
			Peneaidae	Farfantepenaeus aztecus	0.69	0.53	3.08	24.00	0.15
				Peneaidae spp.	0.69	0.02	3.08	6.69	0.04
			Porcellanidae	Porcellanidae sp.	7.93	1.16	6.15	220.31	1.40
			Portunidae	Callinectes sapidus	16.90	38.02	18.46	8634.46	54.75
			Xanthidae	Xanthidae spp.	2.76	1.33	4.62	104.31	0.66
				Pleocyemata sp.	7.24	0.61	4.62	127.85	0.81
		Mysida		Mysida sp.	3.10	0.01	4.62	41.91	0.27
	Maxillopoda	Copepoda	Cyclopidae	Cyclopidae sp.	16.90	0.02	9.23	454.30	2.88
Mollusca	Bivalvia	Veneroida	Mactridae	Mulinia lateralis	0.34	0.00	1.54	1.55	0.01
		Ostreoida	Ostreidae	Crassostrea virginica	4.48	22.08	9.23	2364.00	14.99
Rhodophyta	Rhodophyceae			Rhodophyceae spp.	1.03	0.00	1.54	4.68	0.03
Vertebrata	Actinopterygii	Atheriniformes	Atherinopsidae	Atherinopsidae sp.	0.69	0.05	3.08	7.69	0.05
		Clupeiformes	Clupeidae	Brevoortia patronus	1.38	4.95	6.15	360.00	2.28
		Gasterosteiformes	Syngnathidae	Syngnathus scovelli	2.76	0.41	1.54	19.23	0.12
		Mugiliformes	Mugilidae	Mugil cephalus	0.34	2.91	1.54	50.77	0.32
		Siluriformes	Ariidae	Ariidae sp. eggs	5.17	1.48	3.08	96.31	0.61
				Actinopterygii sp.	7.59	7.60	7.69	813.08	5.16

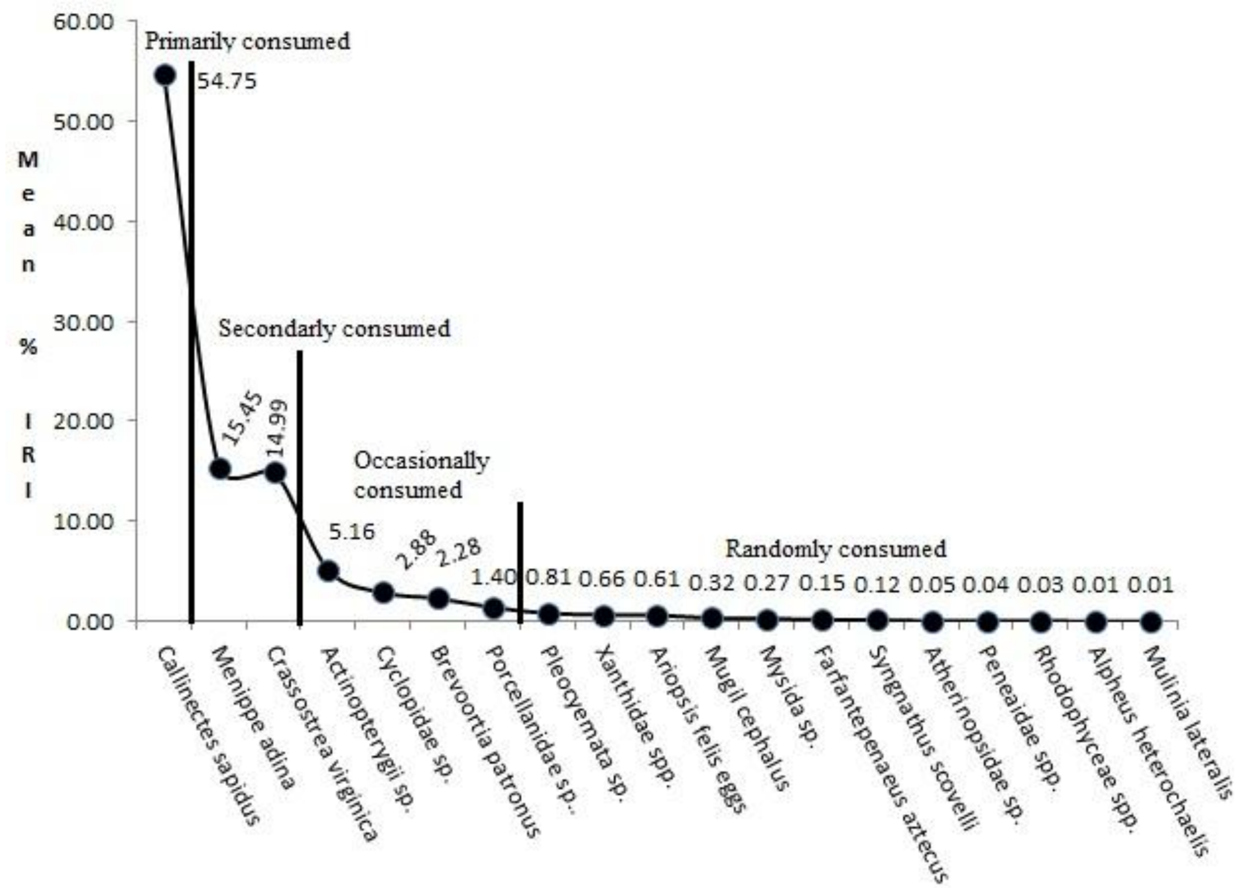

Fig 2. Diet preference of fishes from all sampling seasons, and habitats in the Aransas and Copano Bays from stomach content analysis presented as mean percent index of relative importance (%IRI).

Food habits by bay system and habitat (species specific)

For Copano Bay Subtidal reef (STR) the top five %IRI were as follows: *C. sapidus* (29.40%), *M. adina* (27.03%), *C. virginica* (12.12%), Actinopterygii (7.91%), and *Brevoortia patronus* (7.59). For Copano Bay Intertidal reef (ITR) the top five %IRI were as follows: Copepod (28.53%), *Syngnathus scovii* (22.18%), Actinopterygii (9.85%), *C. virginica* (8.49%), Pleocemata sp. (5.54%). For Copano Bay Nov-vegetated bottom (NVB) the top five %IRI were as follows: *C. sapidus* (70.30%), *B. patronus* (16.61%), Unknown fish (5.85%), Ariidae sp. eggs (4.88%), and *M. adina* (1.26%) (Fig. 3).

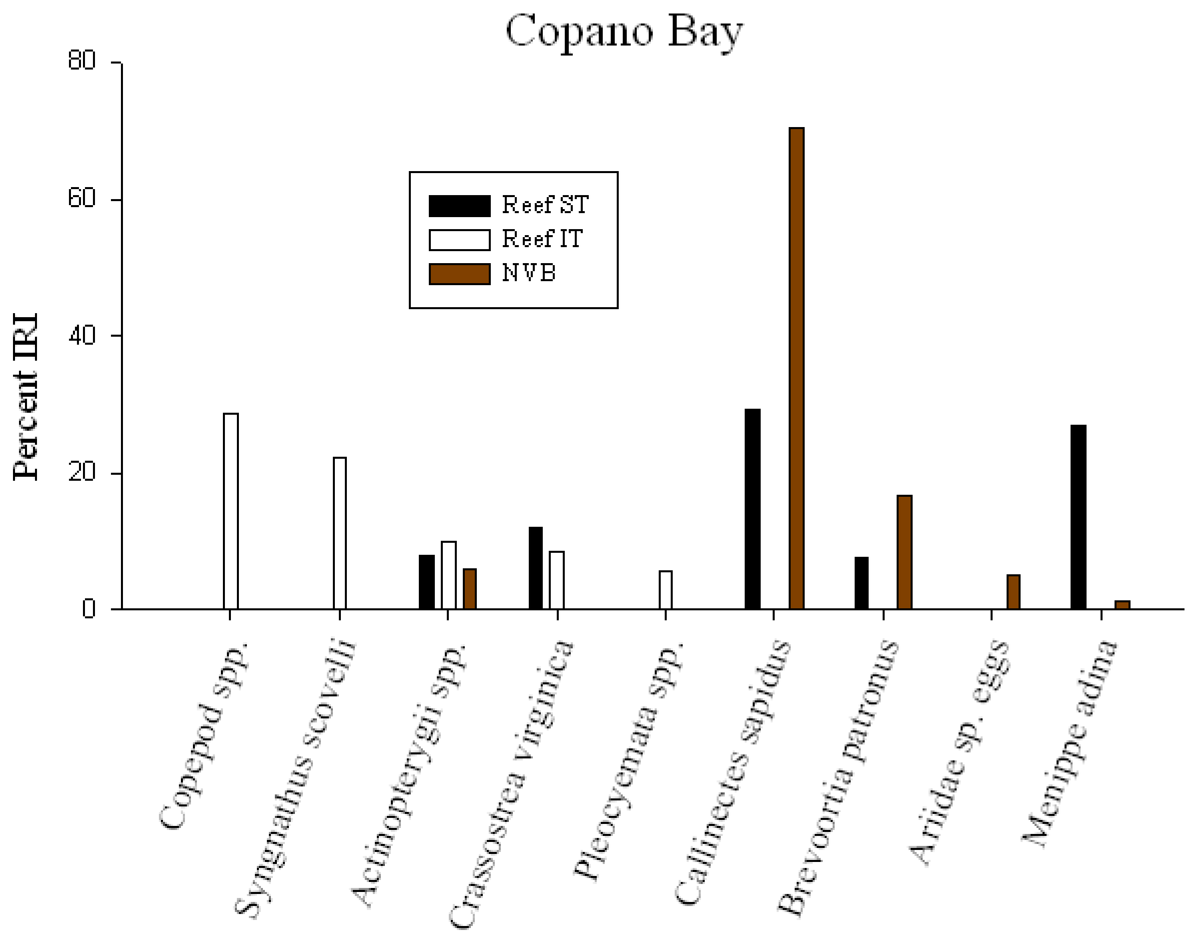

Figure 3. Percent of relative importance (%IRI) for the top five prey items by each habitat type in Copano Bay. Subtidal oyster reef habitat is represented by black bars, intertidal oyster reef habitat is represented by white bars, and non-vegetated bottom is represented by brown bars.

For Aransas Bay Subtidal reef (STR) the top five %IRI were as follows: Actinopterygii (42.44%), *Callinectes sapidus* (27.84%), *M. adina* (15.28%), *Mugil cephalus* (5.55%), and *B. patronus* (3.87%). For Aransas Bay Intertidal reef (ITR) the top five %IRI were as follows: *M. adina* (32.91%), *Crassostrea virginica* (23.43%), Pleocemata sp. (13.86%), Porcellanidae spp.(7.95) and *Ischadium recurvum* (5.59%). For Aransas Bay Nov-vegetated bottom (NVB) the top five %IRI were as follows: *C. virginica* (38.85%), *C. sapidus* (25.61%), *B. patronus* (9.36%), Actinopterygii (7.54%) and *M. adina* (6.01%). (Fig. 4).

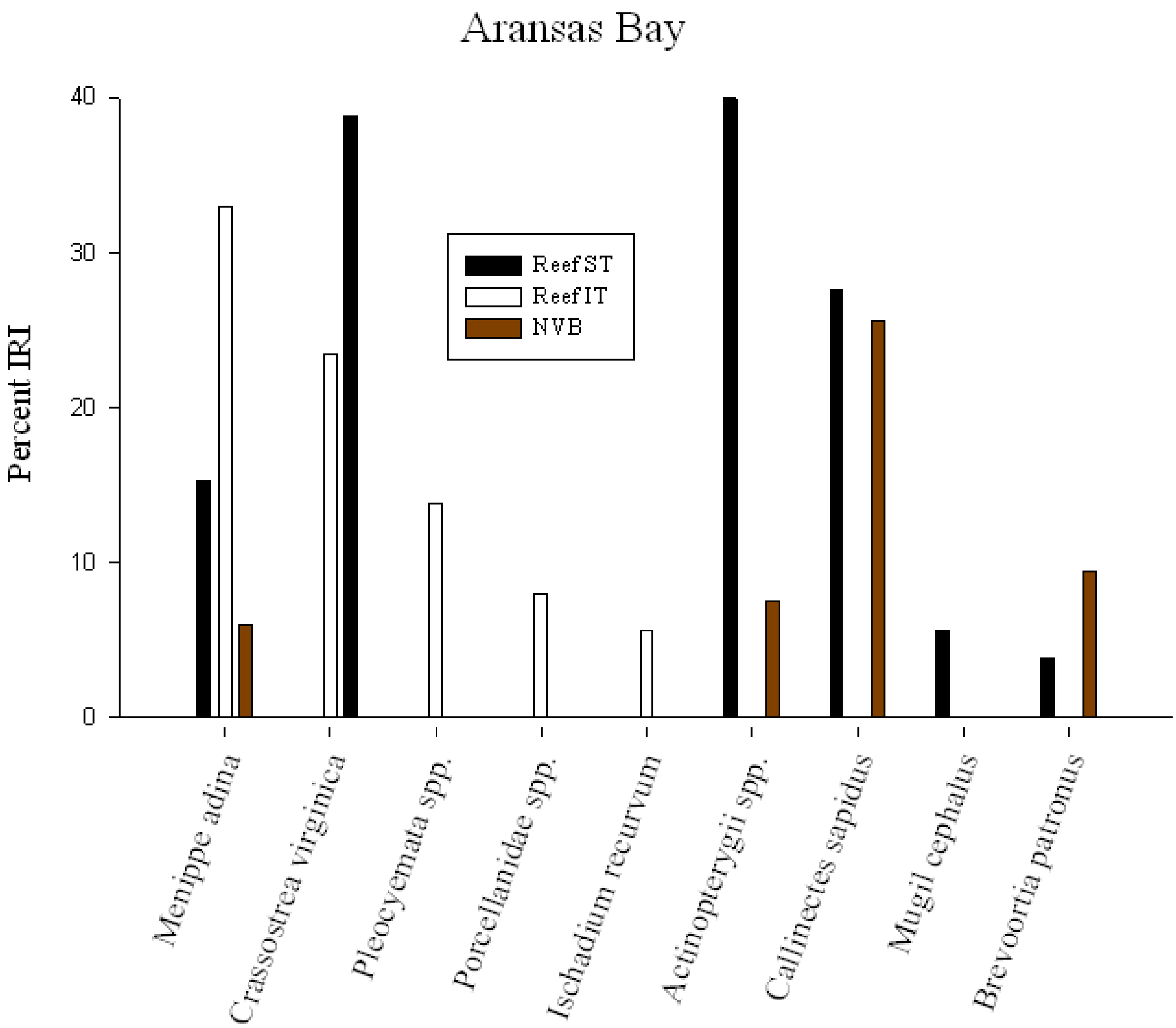

Figure 4. Percent of relative importance (%IRI) for the top five prey items by each habitat type in Aransas Bay. Subtidal oyster reef habitat is represented by black bars, intertidal oyster reef habitat is represented by white bars, and non-vegetated bottom is represented by brown bars.

Food habits by bay system and habitat (general categories)

For simplification prey items were also grouped into broad categories (by combining groups of similar taxon) and their %IRI is displayed by Bay system, and by habitat (Fig. 5 Copano Bay and Fig. 6 Aransas Bay).

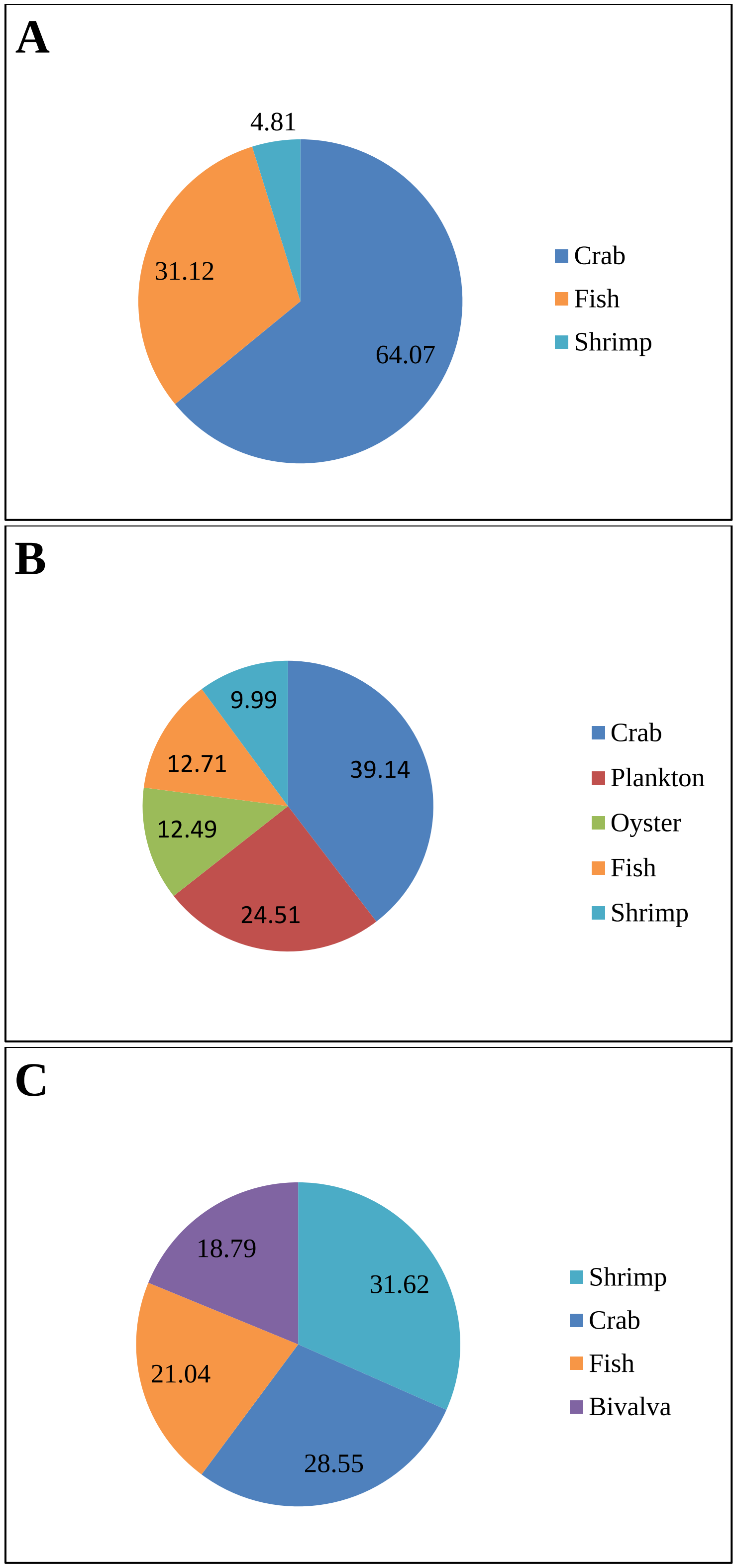

Figure 5. Percent IRI for Copano Bay by habitat: A –Non-vegetated bottom, B –Subtidal reef, C –Intertidal reef.

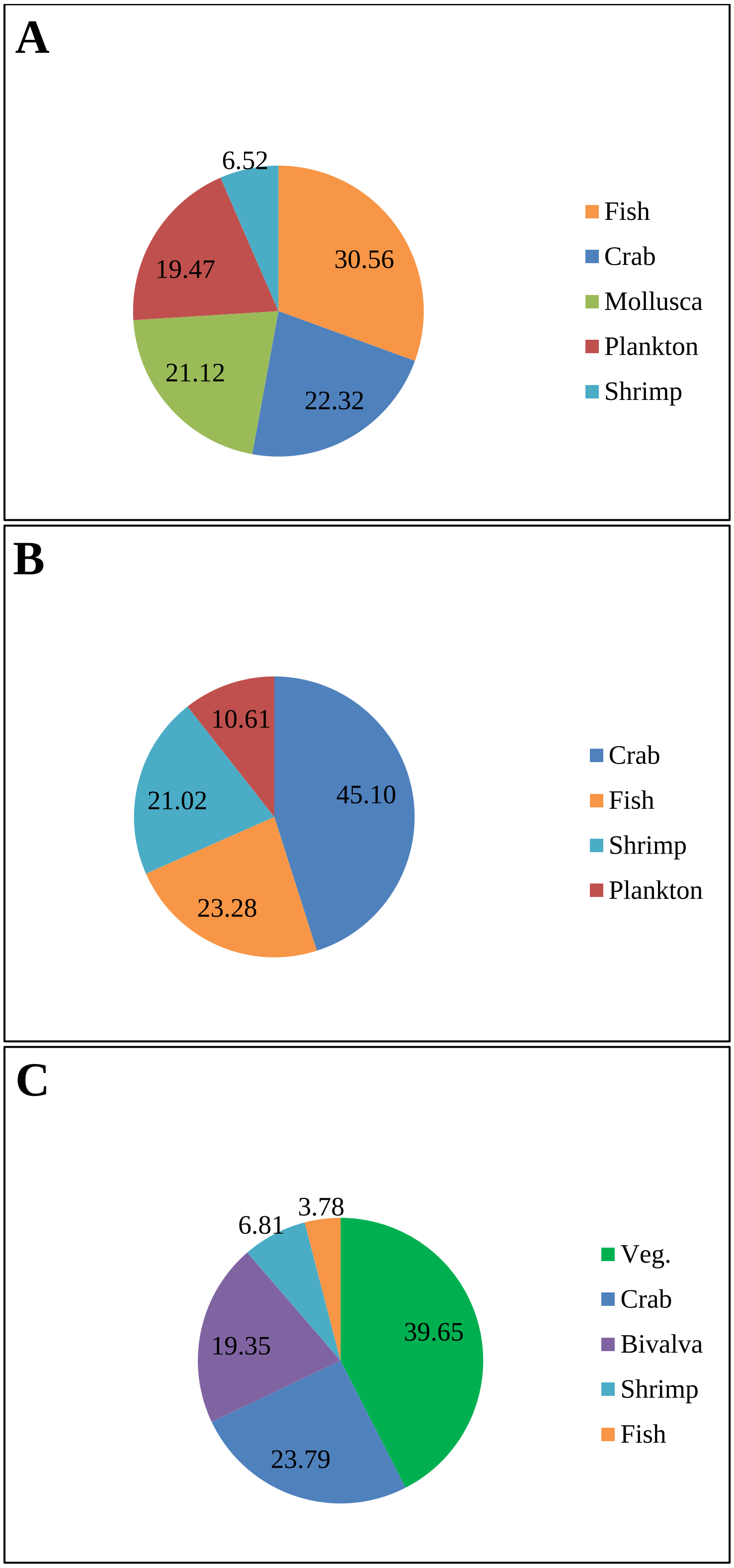

Figure 6. Percent IRI for Aransas Bay by habitat: A –Non-vegetated bottom, B –Subtidal reef, C –Intertidal reef.

Crab is a combination of: *C. sapidus*, *M. adina*, Porcellanidae spp., and Pleocemata. Fish is a combination of *B. patronus*, and Actinopterygii; while shrimp is a combination of *F. aztecus*, *L. setiferus,* Palaemonetes spp., unknown Penaeid shrimp and *A. heterochaelis*. Bivalva is a combination of *C. virginica*, *Mulina lateralis*, and *Ischadium recurvum*. Vegetation (Veg.) is a combination of algae, Rhodophyceae and Cymodoceaceae.

The mean %IRI of prey items was calculated by predator for both bays combined (Figure 7): *A. felis* fed upon fish, and invertebrates, *B. marinus* fed upon invertebrates, *P. cromis* fed upon *C. virginica*, and multiple crab species, *S. ocellatus* fed upon fish, shrimp and crabs, and *S. tiburo* fed primarily on *B. patronus*, as well as crabs, and *C. virginica.*

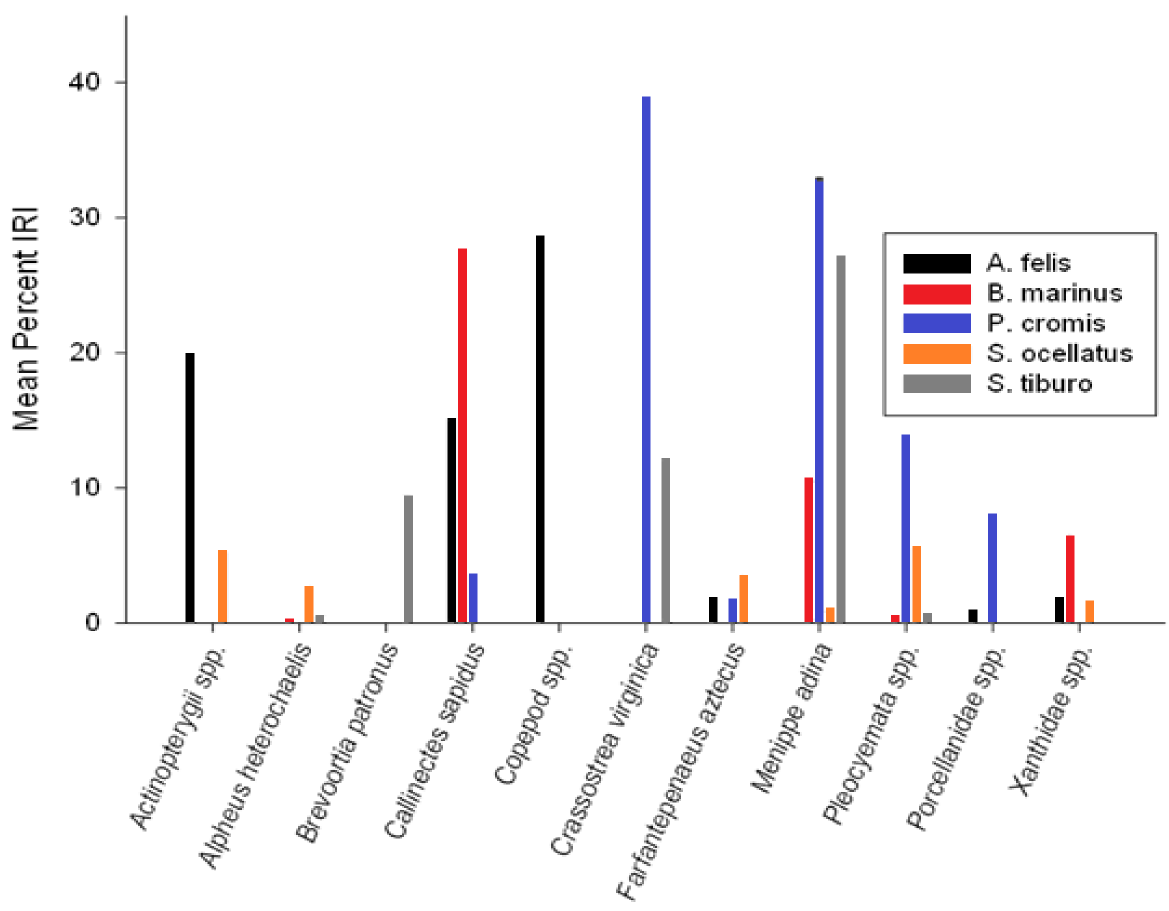

Figure 7. Mean percent index of relative importance (%IRI) by predator for Aransas and Copano Bays, Texas.

Winter food webs for Aransas and Copano Bays and using stable isotopes and gut content analysis

Food web diagrams were created from gut content analysis and calculated trophic levels using stable isotope values from δN^{15} for Aransas and Copano Bays. Food web diagrams show only the observed species and interactions that actually occur in both bays at any one time during this study; however oversimplification was necessary to show only the most abundant species and most established links.

For the Aransas Bay food webs (Fig. 8) the top predators according to calculated trophic levels (TL_{si}) using stomach contents were: *Pogonias cromis* 3.67 (ITR), *Bagre marinus* 3.64 (NVB), and *Ariopsis felis* 3.61 (STR). *P. cromis* fed upon *C. virginica*, which is consistent within the literature (Sutter et al. 1986). While *B. marinus* fed on invertebrates: *F. aztecus*, and *C. sapidus*, and *A. felis* preyed heavily upon *L.rhomboides, and C. sapidus*. Aransas Bay NVB was the least complex food web of all three Aransas Bay habitats, while the intertidal reef habitat showed to be the most complex food web for Aransas Bay (based upon the number of observed interactions). For the Aransas Bay subtidal reef food web showed two species of sharks (*S. tiburo*, and *S. lewini*) but neither were top predators for the particular habitat.

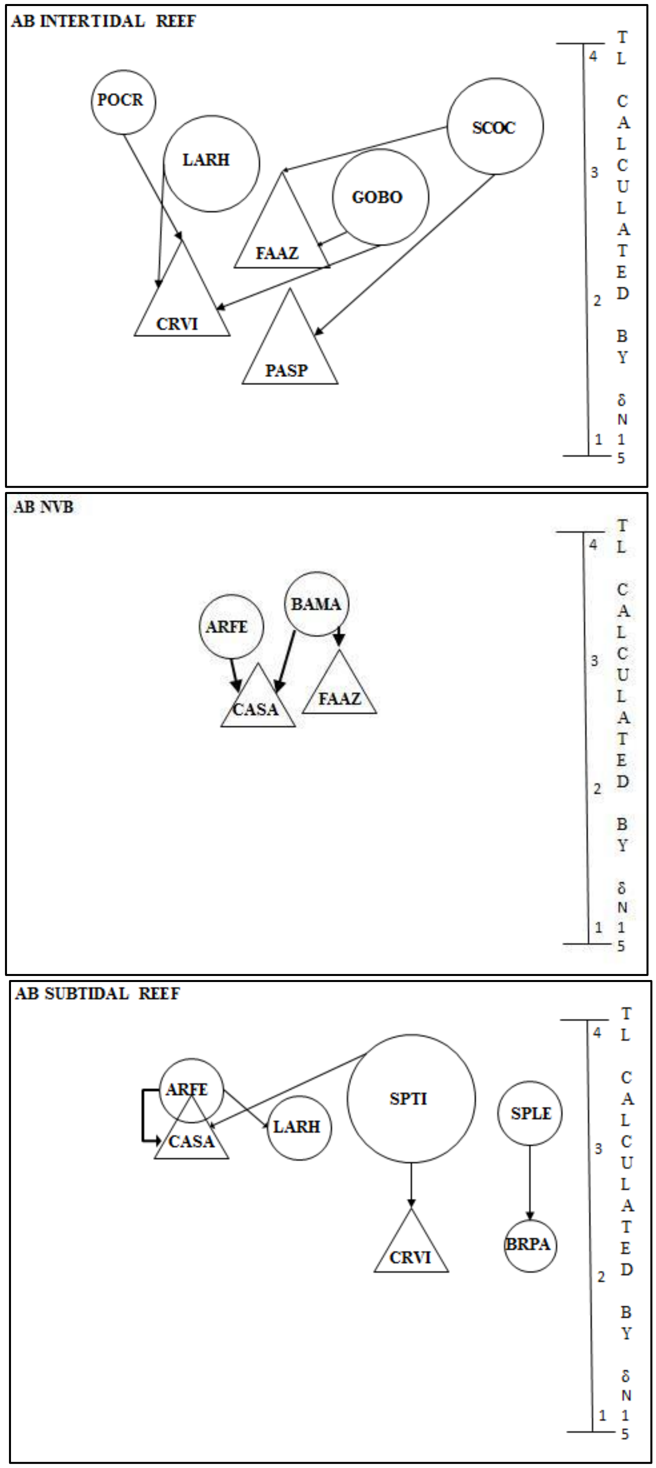

Figure 8. Food web diagram by habitat type for all seasons for Aransas Bay Texas, constructed from stomach content analysis. Position on the y-axis is based on the trophic position ($\delta^{15}N$). The relative size of nodes (circle = fishes, triangle = invertebrates, and square = basal carbon source) is based upon numbers of individuals. Thickness of link is based upon number of times the prey occurred in the predator's diet for each habitat, and arrow size is based upon volume of prey. Species codes are defined in Appendix 3

For the Copano Bay food webs (Fig. 9) the top predators according to calculated trophic levels (TL_{si}) using stomach contents were: *Pogonias cromis* 3.93 (intertidal reef), *Bagre marinus* 3.89 (NVB), and *Carcharhinus limbatus* 3.59 (subtidal reef). Similar results of the Aransas Bay system; *P. cromis* consumed *C. virginica*, and *B. marinus* fed on invertebrates: *F. aztecus*, and *C. sapidus*. In the subtidal reef habit *C. limbatus* fed on *B. patronus* which were found in abundance in Copano Bay. The Copano Bay subtidal reef had the least complex food webs among the Copano Bay habitats (based upon the number of observed interactions). Copano Bay intertidal reef had the most complex food web among habitats as well as bay systems.

DISCUSSION

Estuarine habitats are complex ecosystems and they support high productivity and abundance of marine life; food web studies are used to analyze biotic and abiotic potential impacts in estuarine habitats. More information is needed to improve our understanding of how fisheries management practices effect estuarine habitats and the organisms within them. This study provides an integral link needed to gain information on the food web structure of subtidal and intertidal oyster reefs, as well as non-vegetated bottom habitat of Aransas and Copano Bays, Texas.

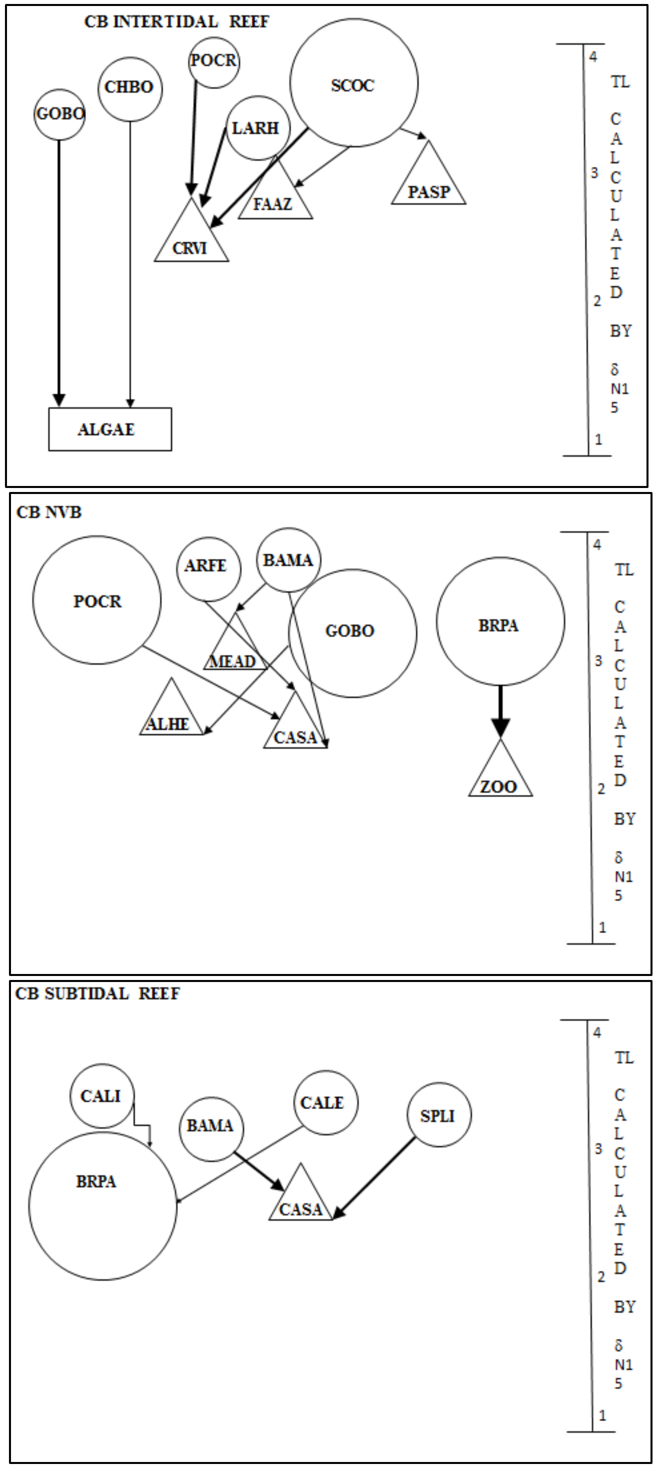

Figure 9. Food web diagram by habitat type for Copano Bay Texas, constructed from stomach content analysis. Position on the y-axis is based on the trophic position ($\delta^{15}N$). The relative size of nodes (circle = fishes, triangle = invertebrates, and square = basal carbon source) is based upon numbers of individuals. Thickness of link is based upon number of times the prey occurred in the predator's diet for each habitat, and arrow size is based upon volume of prey. Species codes are defined in Appendix 3

Overall food web analysis

Food availability can show how healthy estuarine habitats are. By examining gut content of fishes I was able to determine the levels of food acquisition by observing the fullness of stomachs. Unfortunately 35.5% of the examined fish's gut contents were empty which is significantly higher than other reported similar studies (16.2% Arrington and Winemiller 2002; 13.5% Wrast 2008). Accumulation of food resources is necessary and at times difficult for all organisms. Resource and energy acquisition has a direct effect on and organism's fitness, thus affecting the health of the members within a communities' food web. A high number of empty stomachs give solid evidence that food availability and resource acquisition in the Aransas/Copano bay system were deficient.

I found a wide range in food preference of fishes as illustrated by the %IRI in both Aransas and Copano Bays. Higher trophic level consumers preyed upon were *B. patronus, C. virginica, C. sapidus, M. adina, F. aztecus,* and *L. rhomboides.* Except for *C. sapidus* (5.89% of total catch), none of these prey items were caught in abundance in the modified epibenthic sled (MEBS). Xanthidae and *Palaemonetes* spp. were the most dominant invertebrate catch (56.24%) with the MEBS, but only *Palaemonetes* spp. was found in the intertidal food webs of both bays. The variability of prey items for consumers could indicate unstable feeding habits and high occurrences of opportunistic feeding incidences. Food webs were different between habitats (subtidal oyster reefs, intertidal oyster reefs, and non-vegetated bottom), as well as bays (Aransas and Copano Bays). The food webs for Copano Bay in general were more complex than similar habitats in Aransas Bay. This could be a result of Copano Bay being a secondary bay with more estuarine habitat versus Aransas Bay (which is a primary bay). Food webs could have also been affected by environmental parameters.

During the duration of this study (Fall 2008-Summer 2009), Texas was under a historical drought: "the 24 month period is among the driest 24 month non-overlapping periods on record, the intensity of the 2008-2009 drought has been greater than most... of the big historical droughts of the past 110 years" (Rose 2009). The decline in freshwater inflow has a direct effect on salinities for the Aransas Bay complex. Salinities were on average 2-3 higher (average 15 ppt, salinities recorded were as high as 45 ppt) than normal during the study. Extremely high salinities, which results from low input of fresh water, can cause far-reaching changes in the ecology and productivity of an estuary. High salinities can cause of multitude of problems including: increased parasitism/disease, change in nutritional requirements of local biota, decrease in reproductive ability, decreases in primary productivity, and effect the life cycles of fish (Copeland 1966). Parasitism and disease of *Crassostrea virginica* increase significantly as salinities increase above 20 ppt. Also with increased salinity, the dietary and metabolic needs of biota changes: osmoregulation increases requiring higher nutrient intakes to cope with the increased demand. Increased salinity can change spawning locations, reduce overall productivity and fecundity. With higher salinities ideal estuarine nursery habitats may become unavailable, uninhabitable, and unviable. Increased osmoregulation can deplete nutrients reserved for spawning reducing fecundity and overall spawning success.

With less freshwater coming into the bays: estuarine habitats reduce in area as the saltwater barrier penetrates farther into freshwater habitats. Migration patterns of penaeid shrimp are disrupted, and their predators must adapt to the changing conditions. Important nutrient inflows decrease further stressing estuarine species and alter micro food webs. Sessile organisms must adapt to unfavorable conditions, hibernate or perish. Motile organisms can try and migrate to more favorable environments; however there can be consequences from migration. Nonfavorable habitats may expose organisms to: higher predation, inadequate food sources, and higher competition with other migrating species further stressing themselves. Fish for example are morphologically adapted to feed on certain prey items, and if their primary food sources have migrated to different areas, perished, or been depleted, it must migrate or alter its feeding habits.

Sciaenid fishes (*S. ocellatus* and *P. cromis*) have adapted over time to feed on benthic crustaceans, mollusca, and fishes, while Ariidae fish (*A. felis* and *B. marinus*) are morphologically adapted to feed on benthic crustaceans, and but primarily consume unidentified organic material (Yaiiez-Arancibia et al. 1988) as opportunistic scavengers. In this study the important prey species were those commonly found in the surrounding habitats. On oyster reef habitats both subtidal and intertidal the prey items that were of higher relative importance to both the Sciaenid's, and Ariidae were: *Callinectes sapidus*, *Menippe adina*, *Crassostrea virginica*, and Actinopterygii. These results are consistent within the literature and compliment similar studies (Yaiiez-Arancibia et al; 1988 Wrast 2008,). This shows that the sciaenid and Ariidae species diets didn't really vary by habitat (oyster reefs subtidal or intertidal, and non-vegetated bottom) or season. Unfortunately the most common prey item and second largest prey item by volume was digestate. This unidentifiable matter was at one point a prey item, and could possibly help identify, and construct more accurate food webs for the system. By not knowing what the prey items were a key component for this system is missing.

Conclusions and future directions

The overall food web for the Aransas/Copano Bay complex can be described as a dynamic system supporting a variety of organisms from different trophic levels. Evaluating the food web is important in understanding predator-prey relationships, and their interactions.

This study is important in understanding food web of estuarine habitats for better ecosystem based fisheries management. Acquiring knowledge of the ecosystem interactions through food web studies and species interaction allows managers to fully understand the sources and sinks of resources for the ecosystem. Gut content analysis showed that predators feed directly on the prey base that occupies the surrounding habitats (subtidal and intertidal oyster reef, and non-vegetated bottom) in Aransas and Copano Bays. Sustainable management of oyster reef habitats must be a priority for fisheries managers to ensure the survival of the numerous associated species.

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APPENDIX

Appendix 1. Percent IRI by habitat in Copano Bay.

Copano NVB	
Callinectes sapidus	42.77
Actinopterygii sp.	20.85
Porcellanidae sp.	18.90
Ariopsis felis eggs	5.42
Brevoortia patronus	4.85
Peneaidae sp.	3.29
Menippe adina	1.81
Farfantepenaeus aztecus	1.52
Pleocyemata sp.	0.59

Copano IT Reef	
Mysida sp.	18.79
Syngnathus scovelli	17.63
Crassostrea virginica	11.80
Pleocyemata sp.	11.78
Xanthidae sp.	7.89
Peneaidae sp.	7.09
Mulinia lateralis	6.26
Callinectes sapidus	5.39
Polycheate sp.	3.89
Alpheus heterochaelis	3.11
Actinopterygii sp.	2.59
Farfantepenaeus aztecus	1.41
Porcellanidae sp.	1.24
Menippe adina	1.14

Copano ST Reef	
Copepod sp.	24.51
Callinectes sapidus	14.74
Porcellanidae sp.	14.29
Crassostrea virginica	12.49
Peneaidae spp.	7.92
Actinopterygii sp.	5.82
Xanthidae spp.	5.03
Brevoortia patronus	4.72
Pleocyemata sp.	2.63
Menippe adina	2.45
Alpheus heterochaelis	1.61
Bairdiella chrysoura	1.60
Gracilaria spp.	1.16
Dendrobranchiata sp.	0.47
Syngnathus scovelli	0.39
Ophichthus gomesii	0.18

Appendix 2. Percent IRI by habitat in Aransas Bay.

Aransas Bay NVB	
Atherinopsidae sp.	24.24
Crassostrea virginica	20.95
Copepod sp.	19.47
Callinectes sapidus	13.03
Mysida spp.	4.77
Xanthidae sp.	4.44
Actinopterygii sp.	4.15
Porcellanidae sp.	3.00
Brevoortia patronus	1.71
Menippe adina	1.28
Farfantepenaeus aztecus	0.92
Peneaidae sp.	0.62
Pleocyemata sp.	0.58
Ophichthus gomesii	0.47
Alpheus heterochaelis	0.22
Squilla eumpusa	0.17

Aransas IT Reef	
Rhodophyceae sp.	36.14
Crassostrea virginica	17.93
Menippe adina	14.76
Pleocyemata sp.	5.30
Copepod sp.	4.01
Alpheus heterochaelis	3.56
Halodule beaudettei	3.44
Farfantepenaeus aztecus	3.24
Polycheate sp.	2.61
Porcellanidae sp.	2.57
Actinopterygii sp.	2.44
Ischadium recurvum	1.39
Ophichthus gomesii	1.33
Callinectes sapidus	0.71
Xanthidae spp.	0.43
Detritus	0.13

Aransas ST Reef	
Menippe adina	26.63
Mysida sp.	21.02
Callinectes sapidus	17.90
Mugil cephalus	14.70
Copepod sp.	10.61
Actinopterygii sp.	8.58
Persephona mediterranea	0.45
Pleocyemata sp.	0.12

Appendix 3 δ^{13}C and δ^{15}N values of fauna collected in Aransas and Copano Bays, Texas among all seasons, and habitat types. The species code in this table is used in figures 7 and 8. Values are mean ± standard error (SE) with sample size (n).

Sample type	**Family**	**Species**	**Code**	**δC13**	**δN15**	**N**
Veg	POM	ALGAE	ALGAE	-10.47 ± 1.38	6.60 ± 0.76	(12)
	BOM	Benthic organic material	BOM	-9.81 ± 0.43	7.54 ± 0.10	(4)
	Cymodoceaceae	*Halodule beaudettei*	HABE	*-12.31 ± 0.51*	6.46 ± 0.56	(3)
Invert	Alpheidae	*Alpheus heterochaelis*	ALHE	*-17.44 ± 0.68*	12.08 ± 0.86	(5)
	Portunidae	*Callinectes sapidus*	CASA	*-18.61 ± 0.73*	12.38 ± 1.32	(9)
	Ostreidae	*Crassostrea virginica*	CRVI	*-23.15 ± 0.39*	10.47 ± 0.24	(15)
	Sciaenidae	*Micropogonias undulatus*	MIUN	*-19.38 ± 0.38*	10.57 ± 0.20	(3)
	Palaemonidae	*Palaemonetes sp.*	PASP	*-16.82 ± 0.43*	12.06 ± 0.32	(14)
	POM	Phytoplankton	POM	-16.73 ± 0.69	6.56 ± 0.75	(3)
	BOM	Zooplankton	ZOO	-24.02 ± 0.46	9.46 ± 0.55	(9)
Fish	Ariidae	*Ariopsis felis*	ARFE	*-19.34 ± 1.21*	15.10 ± 0.32	(4)
		Bagre marinus	BAMA	*-18.82 ± 0.75*	15.40 ± 0.60	(5)
	Belonidae	*Strongylura marina*	STMA	*-18.58 ± 0.41*	14.80 ± 0.54	(4)
	Blenniidae	*Chasmodes bosquianus*	CHBO	*-20.67 ± 0.31*	14.88 ± 0.30	(6)
	Carcharhinidae	*Carcharhinus leucas*	CALE	*-12.65 ± 0.11*	14.28 ± 0.24	(5)
		Carcharhinus limbatus	CALI	*-15.50 ± 0.73*	15.31 ± 0.15	(2)
	Clupeidae	*Brevoortia patronus*	BRPA	*-20.69 ± 0.54*	14.08 ± 0.43	(18)
	Gobiidae	*Gobiosoma bosc*	GOBO	*-17.80 ± 0.18*	14.36 ± 0.12	(39)
	Hippolytidae	*Tozeuma carolinense*	TOCA	*-17.62 ± 0.58*	10.19 ± 0.78	(11)
	Menippidae	*Menippe adina*	MEAD	*-20.04 ± 0.00*	13.14 ± 0.00	(1)
	Mugilidae	*Mugil cephalus*	MUCE	*-21.33 ± 0.93*	15.37 ± 0.50	(2)
	Myliobatidae	*Rhinoptera bonasus*	RHBO	*-17.04 ± 0.00*	12.65 ± 0.00	(1)
	Paralichthyidae	*Paralichthys lethostigma*	PALE	*-18.86 ± 0.22*	13.92 ± 0.34	(7)
	Peneaidae	*Farfantepenaeus aztecus*	FAAZ	*-16.51 ± 0.32*	11.55 ± 0.40	(14)
	Sciaenidae	*Bairdiella chrysoura*	BACH	*-17.43 ± 0.67*	13.78 ± 0.38	(9)
		Cynoscion arenarius	CYAR	*-21.59 ± 0.00*	14.67 ± 0.00	(10)
		Cynoscion nebulosus	CYNE	*-17.74 ± 0.48*	15.71 ± 0.28	(2)
		Pogonias cromis	POCR	*-19.89 ± 0.39*	15.49 ± 0.29	(8)
		Sciaenops ocellatus	SCOC	*-18.05 ± 0.29*	14.66 ± 0.47	(16)
	Sparidae	*Lagodon rhomboides*	LARH	*-18.63 ± 0.26*	12.91 ± 0.26	(10)
	Sphyrnidae	*Sphyrna lewini*	SPLE	*-16.08 ± 0.34*	14.70 ± 0.31	(3)
		Sphyrna tiburo	SPTI	*-16.80 ± 0.16*	14.95 ± 0.06	(5)
	Syngnathidae	*Syngnathus scovelli*	SYSC	*-17.34 ± 0.19*	12.84 ± 0.27	(16)
Grand total						(275)