THE IMPACT OF A NEW TIDAL INLET ON ESTUARINE NEKTON RECRUITMENT: THE OPENING OF PACKERY CHANNEL IN CORPUS CHRISTI, TEXAS

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Abstract

In the Gulf of Mexico the vast majority of commercially important species are estuarine-dependent with larvae migrating through tidal inlets to reach their “nursery” grounds. Access to high quality habitats in estuarine areas via tidal inlets is critical for reproduction, growth, survival, and sustainability of these populations. Packery Channel, a natural tidal inlet, has been closed since the 1930’s due to sedimentation. The US Army Corps of Engineers recently dredged and reopened this inlet to allow water exchange from the Gulf of Mexico into the Laguna Madre near Corpus Christi Bay, Texas. To assess the impact of this new inlet on estuarine nekton, I established seven sampling locations at varying distances from Packery Channel. Within each location I selected two sites in seagrass meadows dominated by *Halodule wrightii* and collected triplicate nekton samples (10 m^2) twice per season using an epibenthic sled. Sampling took place seasonally prior to the opening of Packery Channel (October 2004 – May 2005) and one year after (July 2005 – April 2006). I found distinct differences in nekton mean densities post-channel opening. My results show that estuarine-dependent nekton are using Packery Channel as a means of ingress into the estuary. Economically important species such as red drum *Sciaenops ocellatus* and penaeid shrimp (brown shrimp *Farfantepenaeus aztecus*, pink shrimp *Farfantepenaeus duorarum*, and white shrimp *Litopenaeus setiferus*) were more abundant post-opening and their mean sizes were significantly smaller. These results suggest that the Packery Channel may have important implications to fisheries and other recruiting nekton along the Texas coast by allowing increased access to the extensive seagrass meadows of the upper Laguna Madre. Otolith microstructure analysis of newly settled red drum from Aransas Bay, Corpus Christi Bay, and the upper Laguna Madre indicate there are similar growth rates among all three bays, and that habitats adjacent to Packery Channel function as nursery habitats for red drum in terms of growth. Differences in community assemblages were also found after Packery Channel was open. Diversity was significantly higher post-opening; although, it is not clear if this was due to the inlet or other environmental variables. Bray-Curtis multivariate analysis showed that community assemblages changed the most for locations closest to Packery Channel. Loss of seagrass and high current in areas closest to the channel possibly resulted in fewer grass shrimp and other estuarine resident species post-opening. The change observed at these locations may be attributed to a shift from a low-energy backwater lagoon pre-opening to a high-energy habitat adjacent to an inlet post-opening. At the conclusion of this study, Packery Channel showed substantial flow, but was still under construction. Once the channel is fully dredged flow may increase which could potentially impact recruitment potential for nekton that rely on these tidal inlets for access to estuarine nursery habitats.

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Introduction

In the Gulf of Mexico 75% of commercially important species are estuarine-dependent (Chambers 1991). Many economically and ecologically important nekton live and spawn in coastal waters where their larvae migrate through tidal inlets into estuaries and use these shallow areas as "nursery" grounds (Weinstein 1979, Baltz et al. 1993, Kneib 1993, Minello 1999). Access to high quality habitat in estuarine areas via tidal inlets is critical for reproduction, growth, survival, and sustainability of these populations.

Many areas along the Gulf coast are characterized by long chains of barrier islands bisected by tidal inlets allowing water exchange between the Gulf of Mexico and bay systems. Most tidal inlets along this chain of islands exist permanently because of construction of jetty breakwaters and dredging (Britton and Morton 1989). Packery Channel, a natural tidal inlet, was periodically open until the 1930s but has since been closed due to sedimentation. It is located in the southeast corner of Corpus Christi Bay at the Mustang/Padre Island boundary.

A project by the US Army Corps of Engineers, North Padre Island Storm Damage Reduction and Environmental Restoration Project, began in 2003 to dredge and permanently reopen this inlet to allow water exchange from the Gulf of Mexico into Corpus Christi Bay and the upper Laguna Madre. The new channel across North Padre Island will connect the Gulf of Mexico with the upper Laguna Madre and be approximately 4 m deep and 37 m wide. The existing channel will connect the new inlet with the Gulf Intracoastal Waterway (GIWW) and once complete will be dredged to approximately 2 m deep and 24 m wide. The total length of Packery Channel from the

GIWW to the seaward end of the jetties is approximately 5.6 km (US Army Corps of Engineers 2003). Impacts to the upper Laguna Madre are expected to extend north into Corpus Christi Bay and south to Baffin Bay (US Army Corps of Engineers 2003). Given that the Laguna Madre is one of five negative estuaries in the world (Javor 1989), the new inlet may affect the dynamics of the hypersaline lagoon. The opening of Packery Channel will result in water exchange between the Gulf of Mexico and the upper Laguna Madre that is expected to alter salinity levels of the system and result in an insignificant decrease of tidal range in the Laguna Madre (~3 cm) (US Army Corps of Engineers 2003). According to the Final Environmental Impact Statement (FEIS) by the US Army Corps of Engineers (2003), this project will periodically reduce hypersaline conditions in the upper Laguna Madre, however overall changes are expected to be minimal to the system.

From a fisheries perspective this channel will create a direct link between the Gulf of Mexico and nearby habitats (e.g., seagrass meadows) in the upper Laguna Madre for estuarine-dependent juvenile fishes and crustaceans. A new inlet into the estuarine system should result in higher fisheries productivity since these adjacent nursery habitats were previously inaccessible to nekton recruiting from other inlets. In general, extensive seagrass meadows in the upper Laguna Madre could potentially sustain high densities of newly recruiting fisheries species, support rapid growth rates, and ultimately increase survival of juveniles contributing to adult populations because of the high primary productivity of estuarine ecosystems (Rozas and Minello 1997, Minello 1999, Beck et al. 2001). However, this may be difficult to predict because few studies have assessed the role of a new tidal inlet on fisheries productivity.

Few studies have assessed the impact of reopening a tidal inlet to estuarine organisms. Reid (1957) examined the impacts of opening Rollover Pass in Galveston Bay, Texas from 1954-1956. He found that fish populations were not significantly altered, although there was a fluctuation in shrimp species with an increase in white shrimp *Litopenaeus setiferus* after the opening. Reid also suggested that stenohaline marine forms were immigrating into the bay system after the opening of the inlet due to higher salinity levels. Once the inlet was partially blocked (due to erosion) the bay seemed to revert back to its natural condition. This study is significant because it contains some of the only published data that examines the effects of opening an inlet on fish and crustacean abundance (Simmons and Hoese 1959).

Estuaries are one of the most productive systems in the world despite the high environmental stress of these areas. Packery Channel may have a direct impact on the upper Laguna Madre, which is a highly productive hypersaline estuary. It contributes more than one-half of the state's inshore finfish catch (Hedgpeth 1967) and is a prime wintering location for redhead ducks (Quammen and Onuf 1993). The reason for its high productivity is because it is shallow (average depth 75 cm) and the bottom is covered by seagrasses (Quammen and Onuf 1993). Submerged aquatic vegetation (SAV) such as seagrass supports high nekton abundance and richness because it has high food availability, provides sediment stability, refuge from predation, and habitat complexity (Orth et al. 1984, Quammen and Onuf 1993, Kneib and Wagner 1994).

The opening of Packery Channel may have important ecological impacts on estuarine species living in the upper Laguna Madre. Many of these species are estuarine-dependent meaning they use estuaries to complete some phase of their life cycle (Day and

Quinn 1989). Adults spawn offshore in the Gulf of Mexico, typically near inlets where their eggs, larvae, and juveniles recruit into estuarine habitats through tidal inlets. These habitats are often termed "nursery" habitats due to high productivity, survival, and growth rates of juveniles to adults (Minello 1999, Beck et al. 2001). As a result, the new inlet will provide an opportunity for newly recruiting nekton to use the extensive seagrass meadows of the upper Laguna Madre. The influx of new recruits into habitats of the upper Laguna Madre that were historically inaccessible could potentially influence nekton community dynamics (Kneib 1997).

It is important to examine nekton differences from a multi-species perspective (Greenstreet and Hall 1996) and determine these differences by community assemblages. Biotic factors as well as physical factors help determine community assemblages. Estuarine systems are dynamic and undergo physical changes seasonally and annually (Livingston 1976, Akin et al. 2003). Salinity, water depth, dissolved oxygen, temperature, distance from tidal inlets, and current velocities are some of the physical processes that drive estuarine systems (Akin et al. 2003). Many estuarine species such as grass shrimp (*Palaemonetes* spp.), bay anchovy (*Anchoa mitchilli)* and Atlantic croaker (*Micropogonias undulatus*) select habitats because of biotic factors such as abundant food and few predators (Kneib 1997, Akin et al. 2003). Communities may be influenced by seasonal variations in physical parameters and migrations of estuarine-dependent species (Akin et al. 2003). Variation in seasonal migrations of estuarine-dependent species may play a vital role in determining community structure.

Diversity is an important concept in ecological theory and plays a central role in ecology and conservation biology (Patil and Taillie 1982, Lande 1996) and is a comprehensive index of community structure (Castillo-Rivera et al. 2002). Species diversity can be used to determine major changes in species richness and evenness before and after an event has occurred (Fisher and Frank 2002). The Simpson (1/D) and Shannon-Wiener (H') indices are some of most common measures of species diversity used (Lande 1996). These indices along with other multivariate indices can provide important ecological information about community structure and how it has changed due to a disturbance, such as Packery Channel. Not only is community structure important when determining nekton differences but also in understanding the functionality of the habitat the nekton use.

Juvenile fishes and crustaceans use shallow estuarine areas as nursery habitat, where they have refuge from predation and access to abundant food sources to support rapid growth (Heck and Thoman 1981, Levin et al. 1997, Minello 1999, Stunz et al. 2002*b*). Rapid growth rates reduce the time juvenile fish and invertebrates spend at sizes most vulnerable to predation. Growth rates are determined by a variety of mechanisms within habitats such as abundance of prey, foraging ability, behavioral responses to stimuli, and genetic variability. Habitat quality is spatially variable, and this can have an affect on recruitment of estuarine-dependent fishes. Sub-optimal habitats may lower growth rates as much as 82% due to lack of food, increased predation, and/or competition (Sogard 1994). Often newly settled nekton do not have a choice in the habitat they occupy due to physical and biological factors. Increases in nekton recruitment may occur in the habitats of the upper Laguna Madre that were previously inaccessible. It is important to document nekton growth rates in these habitats near Packery Channel to determine habitat quality and how it may affect productivity of certain fishery species.

Changes in the physical and biological dynamics of the upper Laguna Madre from the opening of Packery Channel could influence growth rates of estuarine-dependent species. Water exchange between the upper Laguna Madre and the Gulf of Mexico via Packery Channel could potentially increase food availability and dissolved oxygen levels and decrease salinity. These parameters could potentially change the quality of the habitats adjacent to Packery Channel. Modest changes in daily growth rates can cause major changes in recruitment levels of fish. Small daily differences in growth rates in the first year of life can result in large differences (1-2 orders of magnitude) in the number of individuals attaining sexual maturity (Houde 1987). Understanding the effects of the environment on growth rates of fishes during the first year of life is essential to understanding the role of the environment in regulating the abundance of marine fishes (Buckley et al. 1999).

The value of nursery habitat can be characterized by examining growth rates of estuarine-dependent organisms using a variety of techniques. Otolith microstructure analysis is a useful tool for determining growth rates of fish at various life history stages (Stunz et al. 2002*b*). There is a strong correlation between otolith growth and somatic growth (Panella 1971). Daily growth patterns that are recorded in otoliths can be used as a proxy for fish growth by measuring the width of daily otolith depositions (Levin et al. 1997, Stunz et al. 2002*b*).

Red drum are an economically and ecologically important species along the Atlantic and Gulf coasts and has been used as a model species in determining habitat value for estuarine-dependent species (Rooker et al. 1999, Stunz et al. 2002*b*). Rooker et al. (1999) found that once red drum settled in seagrass meadows they demonstrated exponential growth rates, providing additional evidence to the high value of SAV to the recruitment dynamics of estuarine-dependent fish. Determining growth rates of newly settled nekton after Packery Channel is open can provide valuable information on the overall impacts that the inlet may have on the nekton communities of the upper Laguna Madre.

The opening of Packery Channel provides a unique opportunity to examine the impacts of a new tidal inlet on juvenile fish and crustacean density and community structure in the adjacent estuarine seagrass habitats. The purpose of this project is to: (1) characterize nekton use of habitats adjacent to Packery Channel prior to opening of the new inlet, (2) monitor seasonal changes post-opening, and (3) examine potential impacts to the functionality of estuarine systems by assessing growth rates of selected estuarine species.

Objectives

1) Establish baseline data on fish and crustacean assemblages and abundance in adjacent habitats near Packery Channel seasonally one year prior to the opening of the inlet.
2) Monitor seasonal changes to fish and crustacean abundance and recruitment for one year after Packery Channel has been opened.

   H_{01}: Abundances of fishes and crustaceans are not different seasonally after the opening of Packery Channel.

   H_{A1}: Seasonal changes in abundance will be observed after the opening of Packery Channel.

3) Assess the impact of Packery Channel opening on the functionality of an estuarine system by measuring growth rates of an estuarine-dependent species.

H_{02}: Growth rates will be similar regardless of proximity to Packery Channel.

H_{A2}: Growth rates may vary among bay systems due to functionality constraints.

Methods

Nekton Density and Abundance

Study Location

The Laguna Madre is a bar-built coastal lagoon that is bordered by barrier islands to the east and the mainland to the west. The Rio Grande Delta divides it into two separate lagoons: the Laguna Madre of Texas, USA, to the north, and the Laguna Madre de Tamaulipas, Mexico, to the south. Together these two lagoons form the largest of five hypersaline systems in the world (Javor 1989). It is termed a negative estuary as a result of the following: limited freshwater input, evaporation exceeds precipitation, shallow bathymetry, microtidal tide regime, limited circulation, and limited connection with the Gulf of Mexico (Britton and Morton 1989, Tunnell 2002). The Texas Laguna Madre historically has contributed more than one-half of the state's inshore finfish catch (Hedgpeth 1967). It is a coastal embayment that extends 445 km from Corpus Christi Bay, Texas, to Rio Soto la Marina, Mexico, with a mean width of approximately seven km (Tunnell 2002). The mean depth is slightly less than one m (Britton and Morton 1989). In Texas it extends 200 km south from Corpus Christi Bay to the Mexico border (Quammen and Onuf 1993), and is separated into two sub-units (the upper Laguna Madre and lower Laguna Madre) by the Land Cut south of Baffin Bay (Tunnell 2002). The upper Laguna Madre and lower Laguna Madre are connected by the Gulf Intracoastal

Waterway (GIWW) via the 26 mile long Land Cut. The Laguna Madre is protected by Padre Island from the high-energy Gulf of Mexico. Padre Island extends the entire length of the Laguna Madre, interrupted only by Port Mansfield Pass, a man-made inlet into the lower Laguna Madre (Tunnell 2002). Salinities in the upper Laguna Madre are typically 40 ppt, but historically salinities have reached >100 ppt (Quammen and Onuf 1993).

This lagoon-system may be directly affected by the opening of Packery Channel due to water exchange with the Gulf of Mexico. Sites were selected in seagrass meadows predominated by shoal grass *Halodule wrightii* at varying distances from the mouth of Packery Channel. Seagrass meadows are the primary habitat in this area, and *H. wrightii* is the dominant seagrass in the upper Laguna Madre due to its ability to tolerate high salinities (Britton and Morton 1989).

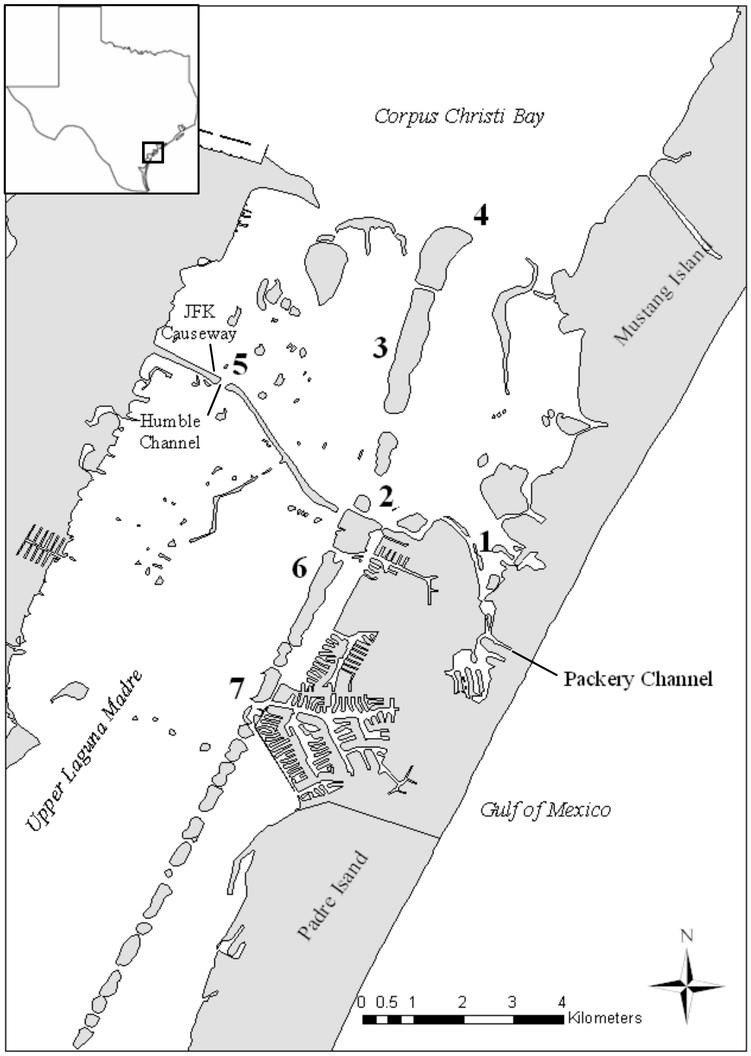


Figure 1. Map representing the nekton sampling locations (1-7) in the upper Laguna Madre, Texas.

<u>Delineation of sites and sampling</u>

Seven sampling locations were established at varying distances, but not further than 10 km from the mouth of Packery Channel (Fig. 1). It was hypothesized that areas within 10 km of Packery Channel would be the most influenced. Within each location there were two sampling sites (14 total sites). I selected locations starting from the first seagrass meadows nearest the opening of the Packery Channel and approximately 1 km thereafter extending north in the upper Laguna Madre along the GIWW into Corpus Christi Bay, south into the Laguna Madre, and northwest near the Humble Channel on the JFK Causeway. Each sampling occurred in *H. wrightii* meadows, the dominant habitat type in the area (Quammen and Onuf 1993).

Nekton abundance was sampled seasonally for two years, one-year prior to the opening of Packery Channel and one-year after. I took six replicate samples at each location (three per site), twice seasonally, for a total of 84 samples each season. The only exception was during summer when I collected 42 samples both pre- and post-opening when Packery Channel was opened midway into the summer season. The epibenthic sled used consists of a metal frame with an opening of 0.6 m (length) by 0.75 m (height) with a 1-mm mesh conical plankton net. The sled was pulled ~17 m, which covers 10 m^2 of bottom. This has been shown as effective gear for sampling nekton in seagrass meadows (Stunz et al. 2002*a*). The sampling dates for both pre- and post-opening follow respectively: fall (October 2004-November 2004; October 2005-November 2005), winter (February 2005; February 2006), spring (March 2005-April 2005; March 2006-April 2006), and summer (May 2005; July 2005). The samples were rough-sorted in the field and preserved in 10% formalin. In the lab, nekton were sorted, identified to lowest possible taxon, measured, and preserved in 70% ethanol. Fish were measured to the nearest 0.1 mm (SL) and crustaceans were measured to the nearest 0.1 mm total carapace width (CW) for crabs and total length (TL) for shrimp. If more than 20 individuals were collected for each species, the largest and smallest and 20 other random individuals were measured. Brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus* *duorarum*), and white shrimp (*Litopenaeus setiferus*) were all were grouped into "penaeid shrimp" because many of them were at an unidentifiable length range (10 – 18 mm TL) (Rozas and Minello 1998). Of the identifiable penaeid shrimp, brown shrimp were the predominant species. Juvenile red drum settle between six to eight mm SL, so individuals collected smaller than six mm SL were not counted or measured (Rooker et al. 1998). Also, blue crabs are considered juvenile when they are two mm CW, therefore individuals collected smaller than two mm CW were not counted or measured (Etherington and Eggleston 2000).

At each of the sites (14 total) water temperature (°C) and dissolved oxygen (ppm) were measured using a YSI DO 200 meter. Salinity (ppt) was measured using a refractometer and water depth (cm) was also recorded using a meter stick during each sampling period.

Statistical Analysis

Physical parameters

Physical parameters (dissolved oxygen (mg/L), salinity (‰), temperature (ºC), and depth (cm) were analyzed by season pre- and post-opening. Student's *t*-test ($\alpha = 0.05$) was used to determine significant differences in the parameters pre-and post-opening each season. Dissolved oxygen, salinity, and temperature were not measured summer pre-opening; therefore differences in pre- verses post-opening were not analyzed.

Nekton analysis

To assess the overall impact of Packery Channel on the adjacent habitats, I grouped all locations and seasons each year (pre- and post-opening) and used a Student's *t*-test ($\alpha = 0.05$) to determine differences in mean densities of nekton before and after the opening of Packery Channel. Differences among sites and locations were assessed using a two-way Analysis of Variance (ANOVA). Significant ANOVA results were further analyzed using Tukey's post-hoc multiple comparison procedure to determine specific differences among locations (Day and Quinn 1989, Raposa et al. 2003). I tested differences in nekton density seasonally (pre- verses post-opening) by choosing several commercially important species that have different seasonal recruitment patterns and may not have been dominant in all seasons. Student's *t*-tests ($\alpha = 0.05$) were used to compare species densities pre- verses post-opening. Total catch was converted to density (organisms/m^2) and then log transformed (log (x+1)) to minimize heteroscedasticity. Size differences pre- and post-opening were also tested using the above species of fish. Mean lengths for each species were computed and pre- and post-opening were compared using a Student's *t*-test ($\alpha = 0.05$).

To determine if Packery Channel was functioning as a natural inlet (Aransas Pass) I used red drum as a model species and compared their densities in the upper Laguna Madre (habitats near Packery Channel) pre- and post-opening to densities measured in Corpus Christi Bay and Aransas Bay (habitats near Aransas Pass). Differences were tested using one-way ANOVA. Significant ANOVA results were further analyzed using Tukey's post-hoc multiple comparison procedure to determine specific differences among locations (Day and Quinn 1989, Raposa et al. 2003)

Community analysis

Relative abundance (RA %) was calculated seasonally for all fishes and crustaceans caught. An overall RA (%) was also calculated for each species of fish and crustacean by combining both pre-opening and post-opening seasonally. The change in relative abundance (RA % Change) was then calculated for each species and group of nekton seasonally. The post-opening RA (%) was subtracted from the pre-opening RA (%) to calculate the change. A negative value shows a decline in relative abundance and a positive value indicates an increase in relative abundance.

Both the Simpson index and the Shannon-Wiener index were used to determine diversity within all locations pre- and post-opening. All locations were combined for analysis to eliminate minor variations in diversity (Livingston 1976). The Simpson index is sensitive to changes in abundant species and the Shannon-Weiner index is more sensitive to changes in rare species (Greenstreet and Hall 1996, Fisher and Frank 2002). Diversity was calculated using each index for each sampling date with all locations and sites combined. Overall diversity was also compared pre- verses post-opening for each index using a Student's *t*-test ($\alpha = 0.05$).

Often univariate diversity indices mask differences in community structure, therefore a multivariate similarity matrix was also used to assess differences in community assemblages (Dawson Shepherd et al. 1992, Hall and Greenstreet 1998, Fisher and Frank 2002). I assessed similarities among the densities of nekton in locations (combined seasonally) pre- and post-opening using the Bray-Curtis similarity matrix using Biodiversity Pro software. It has been used in many marine studies and has been shown to be the only similarity index that accurately reflects similarity between groups of species or resources (Bloom 1981). The goal of this type of analysis is to elucidate underlying biological and environmental factors that may determine community structure, as well as to simplify large data sets to determine ecological relationships (Ludwig and Reynolds 1988).

Nekton Growth

Study location

Aransas Bay is a primary coastal embayment estuary with freshwater inflows from the Mission and Aransas Rivers (Britton and Morton 1989). Aransas Bay is connected to the Gulf of Mexico via the Lydia Ann Channel and Aransas Pass, situated between Mustang and San Jose Islands. Aransas Bay has an average depth of approximately three m with a mean salinity of 13 ppt (Britton and Morton 1989). It contains approximately 85 km^2 of submerged aquatic vegetation (mostly *H. wrightii*) (USEPA 1999). Corpus Christi Bay is south of Aransas Bay and has limited freshwater inflow from the Nueces River and Oso Creek, and has a mean salinity of 22 ppt. The average depth of Corpus Christi Bay is three m (Nipper et al. 2006). Water exchange with the Gulf of Mexico is primarily through Aransas Pass, however with the opening of Packery Channel there will be additional water exchange with the Gulf of Mexico. Corpus Christi Bay has slightly less submerged aquatic vegetation (mostly *H. wrightii*) with 53 km^2 (USEPA 1999).

Red drum were collected from the upper Laguna Madre (areas adjacent to Packery Channel), Corpus Christi Bay, and Aransas Bay for otolith growth analysis and for density comparisons among bays. Red drum were collected near location 6 (Fig. 1) from the upper Laguna Madre. They were collected in Corpus Christi Bay in the seagrass meadows in the northeast part of Corpus Christi Bay near the Corpus Christi Ship Channel. Fish from Aransas Bay were collected in the extensive seagrass meadows at the end of Lydia Ann Channel (Fig. 2).

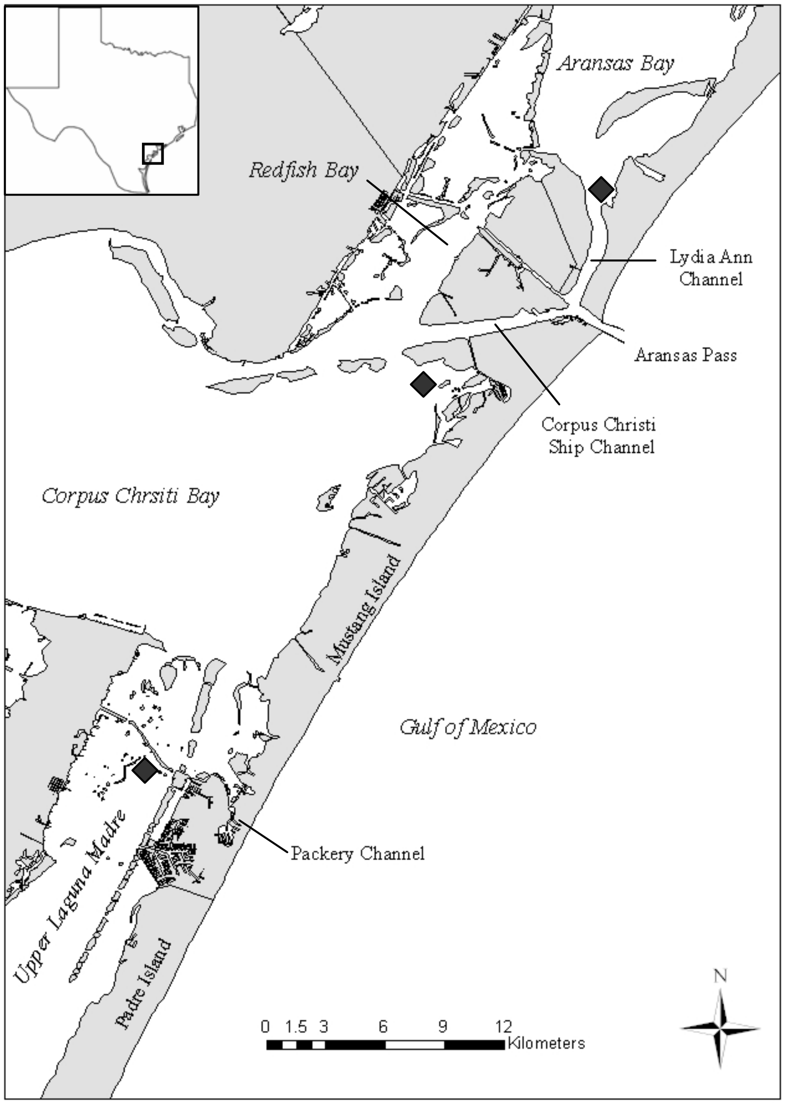


Figure 2. Map showing the different Texas bay systems (Laguna Madre, Corpus Christi Bay, and Aransas Bay) where red drum were collected for the growth analysis. The diamond symbol in each bay system indicates the location where red drum were collected.

Otolith microstructure procedure

Because growth of individual organisms is an important indicator of estuarine health, I used growth as a proxy to examine the effects of the opening of Packery Channel on the functionality of a nursery ground on a commercially important species.

Sciaenops ocellatus (red drum) was used as a "model" species and growth rates were determined from the upper Laguna Madre, Corpus Christi Bay, and Aransas Bay during the fall 2005 peak recruitment season. Red drum are an important recreational fishery that historically was subject to an intense commercial fishery throughout the Gulf of Mexico (Patillo et al. 1997). Red drum are estuarine-dependent and spawn during late summer and early fall in offshore waters near inlets. The pelagic eggs and larvae are carried by tides and currents into shallow bays and estuaries (Holt et al. 1989, Stunz et al. 2002*b*). Postlarval red drum (6-8 mm SL) settle into shallow seagrass meadows and remain there during their early juvenile stages (Reagan 1985, Stunz et al. 2002*b*).

I collected approximately 20 red drum from each bay system (the upper Laguna Madre, Corpus Christi Bay, and Aransas Bay) using a bag seine (6 m long with 5-mm mesh wings and a 3-mm mesh bag) during peak red drum recruitment in November 2005. All red drum were collected in *H. wrightii* seagrass meadows, the dominant SAV. They were immediately placed in 70% ethanol and later measured to the nearest 0.1 mm SL.

The right asteriscus otolith was dissected for growth analysis because it provides the most accurate estimate of age for juvenile red drum (David et al. 1994). Asterisci (N = 17, N = 20, N = 16 for Aransas Bay, Corpus Christi Bay, and the upper Laguna Madre respectively) were extracted and all tissue removed following the procedures by Secor et al. (1991). They were placed in immersion oil for at least one week, and the entire otolith was then mounted on petrographic slides and allowed to harden for 24 h. Otoliths did not require further processing because daily rings were visible for the entire otolith. The age of the fish was determined using light microscopy and counting daily rings and adding six d because asterisci are not present at hatching, but on average form six d post-hatch

(David et al. 1994). I used an image analysis system, Motic Images 2000 1.3, to determine growth rates of fish by measuring the last seven d of growth nearest the periphery of the otolith (Rooker and Holt 1997). Because some of the red drum collected were very small, (approximately nine mm) only the last seven d of growth was measured.

Statistical analysis

I used analysis of covariance (ANCOVA) to compare red drum growth rates among the different bay systems integrated over the life of the fish. I first used the interaction regression model to test for an interaction between the treatment (bay) on the dependent variable (fish length). I then used ANCOVA to test for differences in y-intercepts.

I also analyzed the recent growth (last seven d) of red drum among the bay systems. I used regression analysis for recent seven d growth on age, which indicated growth rates were not significantly related to age ($R^2 = 0.07$, $N = 53$, $P = 0.054$, $1\text{-}\beta = 0.512$). I then analyzed red drum growth among bay systems using mean otolith increment width of the last seven d of growth using a one-way ANOVA ($\alpha = 0.05$). Significant ANOVA results were further analyzed using Tukey's post-hoc multiple comparison procedure to determine specific differences among locations (Day and Quinn 1989).

Results

Physical Parameters

There were significant differences in water depth (cm), temperature (ºC), and salinity (‰) seasonally pre- verses post-opening (Table 1). Dissolved oxygen (mg/L) was not different during fall (P = 0.893; t = 0.135; *df* = 40; 1- β = 0.050), winter (P = 0.294; t = 1.061; *df* = 54; 1- β = 0.060), or spring (P = 1.000; t = 0.000; *df* = 13; 1- β = 0.050) pre- verses post-opening. Dissolved oxygen, water temperature, and salinity were not measured pre-opening in summer 2005. Water depth (P = 0.005; t = -2.951; *df* = 40), temperature (P = 0.003; t = -3.122; *df* = 48), and salinity (P < 0.001; t = -5.513; *df* = 48) were all significantly higher during fall post-opening. In the winter water depth was significantly lower post-opening (P < 0.001; t = 5.361; *df* = 54) and both water temperature (P < 0.038; t = -2.125; *df* = 54) and salinity (P < 0.001; t = -12.814; *df* = 54) were significantly higher post-opening. Similar to fall, water depth (P < 0.001; t = -5.213; *df* = 54), temperature (P < 0.001; t = -5.196; *df* = 54), and salinity (P < 0.001; t = -12.060; *df* = 54) were all significantly higher in the spring post-opening. Water depth was not different pre- verses post-opening during the summer (P = 0.136; t = 1.537; *df* = 26; 1- β = 0.190).

Monthly precipitation (cm) was compared to salinity (ppt) over the sampling period of the project (October 2004 – April 2006). Precipitation records were obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) online database (http://www.ncdc.noaa.gov/oa/ncdc.html). Generally, precipitation decreased and salinity increased over the two years of sampling in habitats near Packery Channel (Fig. 3).

Table 1. Physical parameters (with standard errors, S.E.) for both pre-opening, October 2004-July 2005, and post-opening, July 2005-April 2006 are listed below. Measurements were taken at each sampling site twice each season (28 total) for fall, winter, and spring. There are a few missing parameters due to instrument malfunction and only depth was measured in the summer pre-opening (May 2005). Measurements for summer post-opening were only taken once. Results of the comparison between pre- and post-opening using a Student's *t*-test (P-value) for each parameter are also listed. An * listed indicates the value was significant.

	Pre-			Post			
Parameter	Mean	S.E.	n	Mean	S.E.	n	P
Fall							
Water depth (cm)	30	(2.6)	14	38	(1.7)	28	0.005*
Dissolved oxygen (mg/L)	7.76	(0.2)	14	7.53	(0.3)	28	0.893
Water temperature (°C)	22.9	(1.3)	22	26.8	(0.2)	28	0.003*
Salinity (‰)	33	(0.4)	22	40	(0.7)	28	0.001*
Winter							
Water depth (cm)	37	(1.6)	28	22	(1.6)	28	0.001*
Dissolved oxygen (mg/L)	8.18	(0.2)	28	7.90	(0.1)	28	0.294
Water temperature (°C)	14.0	(0.6)	28	15.8	(0.2)	28	0.038*
Salinity (‰)	29	(0.2)	28	37	(0.3)	28	0.001*
Spring							
Water depth (cm)	21	(1.3)	28	35	(2.0)	28	0.001*
Dissolved oxygen (mg/L)	7.07	(0.3)	28	7.33	(0.2)	28	1.000
Water temperature (°C)	21.6	(0.5)	28	24.1	(0.2)	28	0.001*
Salinity (‰)	27	(0.2)	28	39	(1.1)	28	0.001*
Summer							
Water depth (cm)	35	(1.1)	14	30	(1.6)	14	0.136
Dissolved oxygen (mg/L)	NA	(NA)	0	6.75	(0.5)	14	NA
Water temperature (°C)	NA	(NA)	0	33.3	(0.4)	14	NA
Salinity (‰)	NA	(NA)	0	40	(0.8)	14	NA

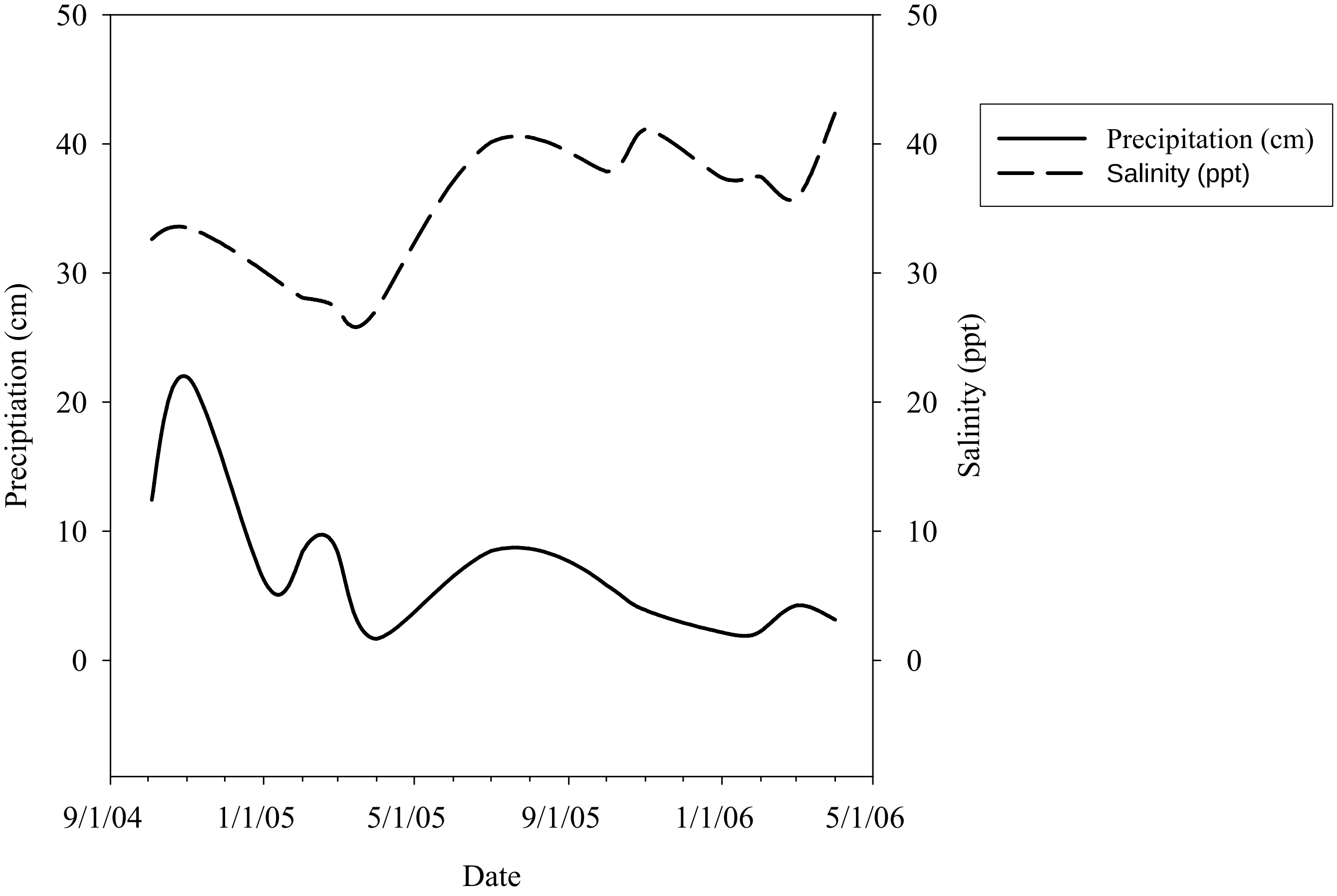


Figure 3. Precipitation (cm) and salinity over the two sampling years (October 2004 – April 2006) in areas near Packery Channel. Salinities reported were measured twice seasonally in all sampling locations and mean values were graphed. Precipitation values were obtained from NOAA's NCDC online climate database. (http://www.ncdc.noaa.gov/oa/ncdc.html). The data points are not necessarily continuous; however a line was used for illustrative purposes.

Nekton Density

Locations and sites were analyzed to assess differences between sites within each location and differences among all locations. There was no statistically significant interaction between site and location therefore sites were combined within each location ($P = 0.848$; $F = 0.446$; *df* = 6; $1\text{-}\beta = 0.050$). Differences of overall nekton densities within each location pre- and post-opening are illustrated in Fig. 4. All seasons were combined for each location to provide an overall view of how each of the locations changed pre- verses post-opening. Locations 1, 2, and 6 showed distinct declines in nekton density post-opening. Although there were differences in these locations, nekton densities for all locations were combined for further analysis.

Overall, there were significantly higher densities of nekton pre-opening ($P<0.001$; $t = 10.791$; *df* = 586) than post-opening (Fig. 5). Crustaceans dominated nekton total catch pre- and post-opening, 96% and 89% respectively. Grass shrimp (*Palaemonetes* spp.) dominated the crustacean abundance both pre- and post-opening, 83% and 52% respectively. I separated densities into fish, crustaceans (excluding grass shrimp), and grass shrimp to determine which group was driving the difference in overall nekton density. There were no significant differences in mean densities of fish or crustaceans (excluding grass shrimp) pre- verses post-opening ($P = 0.092$; $t = 1.687$; *df* = 586; $1\text{-}\beta = 0.257$; $P = 0.368$; $t = -0.901$; *df* = 586; $1\text{-}\beta = 0.050$ respectively) (Fig. 6). There were significantly fewer grass shrimp post-opening ($P < 0.001$; $t = 13.740$; *df* = 586). Grass shrimp densities were then analyzed by location. Post-opening densities decreased at locations 1, 2, and 6, which is the same density pattern per location as seen with the overall nekton densities pre- and post-opening (Fig. 7).

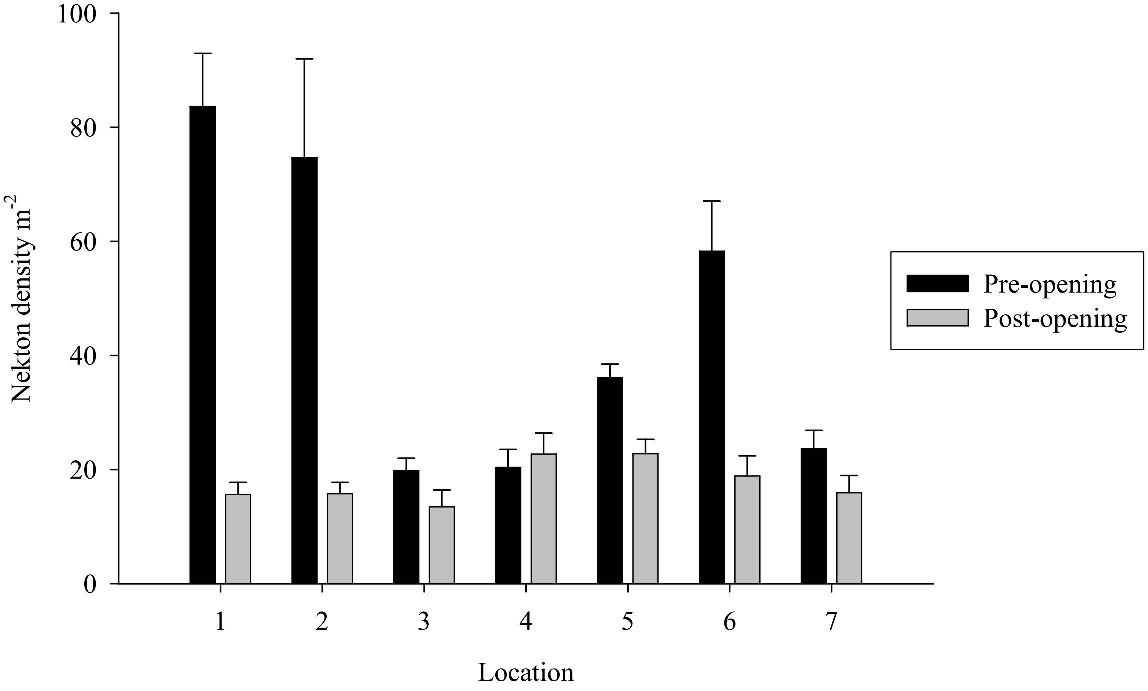


Figure 4. Overall mean densities of all nekton collected at each location over all seasons both pre-opening (October 2004 – May 2005) and post opening (July 2005 – April 2006). The two sites per location were combined since there was no significant interaction between location and site ($P = 0.848$; $F = 0.446$; $df = 6$; $1\text{-}\beta = 0.050$). Location 1 and 2 are along Packery Channel. Location 3 is north of Packery Channel on the GIWW near Corpus Christi Bay. Location 4 is in Corpus Christi Bay. Location 5 is near the Humble Channel by the JFK Causeway. Sites 6 and 7 are south of Packery Channel along the GIWW.

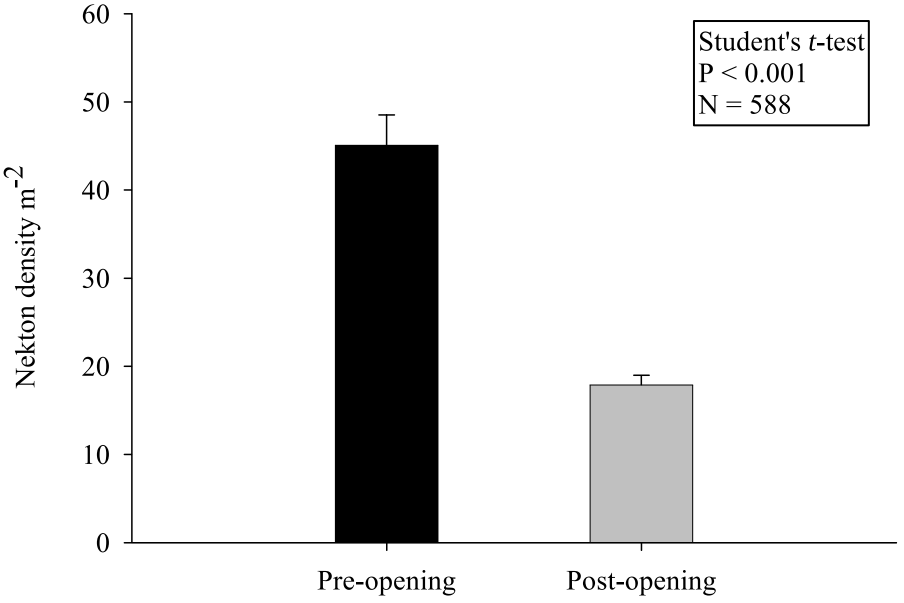


Figure 5. Mean nekton densities pre- and post-opening for all seasons, locations, and sites combined.

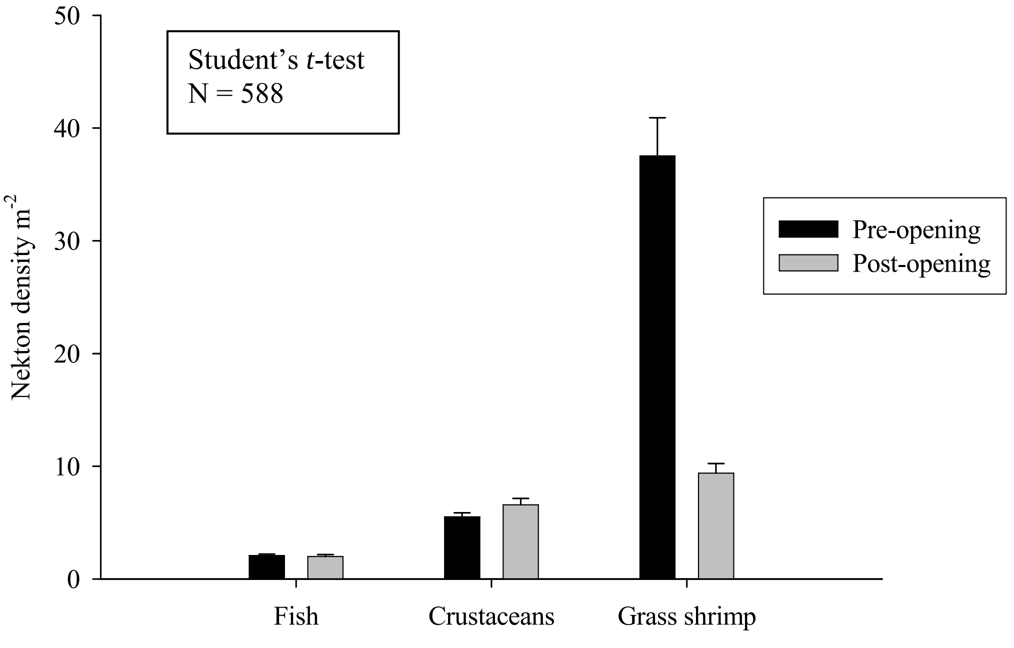


Figure 6. Mean densities of fish, crustaceans (excluding grass shrimp), and grass shrimp pre- and post-opening for all seasons and locations. Means and standard error bars were calculated from 588 samples for all three groups.

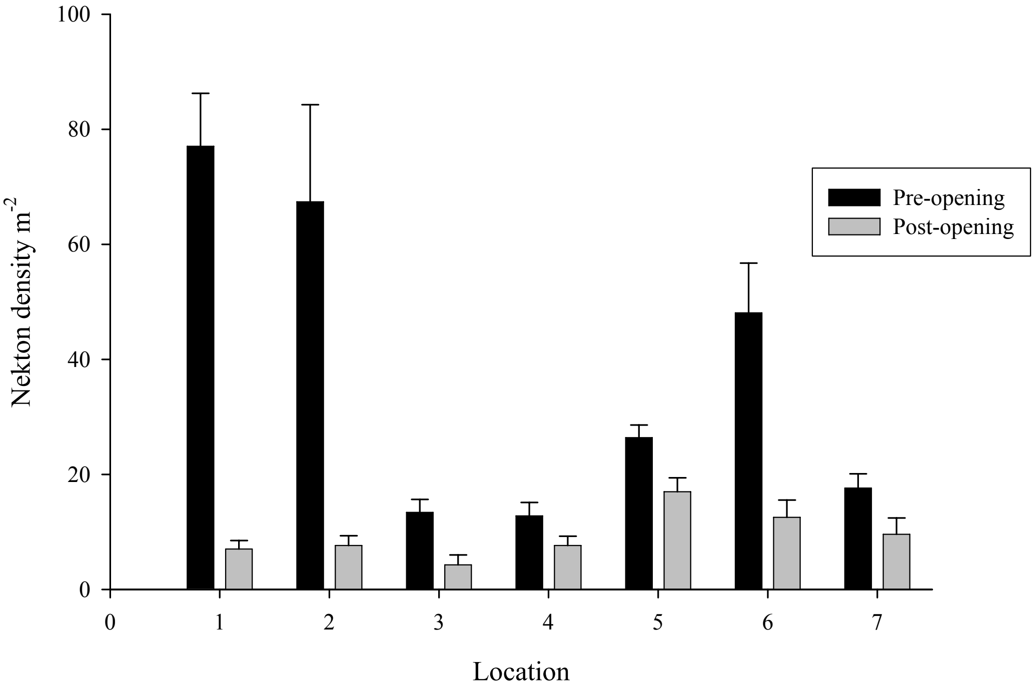


Figure 7. Overall mean densities of grass shrimp *Palaemonetes* spp. collected at each location over all seasons both pre-opening (October 2004 – May 2005) and post opening (July 2005 – April 2006). Location 1 and 2 are along Packery Channel. Location 3 is north of Packery Channel on the GIWW near Corpus Christi Bay. Location 4 is in Corpus Christi Bay. Location 5 is near the Humble Channel by the JFK Causeway. Sites 6 and 7 are south of Packery Channel in the GIWW.

Table 2 summarizes mean densities seasonally for all species and groups of nekton that were collected pre- and post-opening. Fishes and crustaceans are separated in the table and calculations were performed for each group. The total number of organisms collected (total catch) for each group is listed seasonally pre-opening, post-opening, and overall (combined pre- and post-opening). The relative abundance (RA), overall RA, and RA % change are listed for each species and group of nekton seasonally and only includes species that have an RA of at least 0.1%.

Killifish (Fundulidae) and pipefish (*Syngnathus* spp.) were the most abundant fishes (53.7% and 24.1%) in the fall pre-opening. For the purpose of analysis, all killifish collected (*Cyprinodon variegatus*, *Adinia xenica*, *Fundulus grandis*, *F. similis*, and *Lucania parva*) were grouped into the family Fundulidae. *Cyprinodon variegatus*, which is in the Cyprinodontidae family, was also included in the Fundulidae grouping because until recently all the killifish were in the Cyprinodontidae family. Killifish, pipefish, and darter gobies (*Gobiosoma boleosoma*) were the most abundant fishes (36.0%, 25.3%, and 20.8%) in the fall post-opening. In the winter, killifish and pinfish (*Lagodon rhomboides*) were the most abundant fishes (39.0% and 30.9%) pre-opening; post-opening pinfish, killifish, and Atlantic croaker (*Micropogonias undulatus*) were the most abundant fishes (37.3%, 18.6%, and 16.0%). In the spring pinfish, killifish, and code gobies (*Gobiosoma robustum*) were the most abundant fishes (47.6%, 21.2%, and 15.5%) pre-opening; post-opening pinfish and darter gobies were the most abundant (45.2% and 21.8%). Pinfish and code gobies were the most abundant fishes in the summer both pre-opening (54.6% and 20.4%) and post-opening (35.2% and 18.6%). Grass shrimp (*Palaemonetes* spp.) were the most abundant crustaceans over all seasons both pre- and post-opening (refer to Table 2). The mean sizes for all fish and crustaceans collected were also recorded and have been summarized in Table 3.

Table 2. Mean densities, number per m^2 (with standard errors, S.E.) of all nekton collected are shown seasonally for both pre-opening, October 2004-July 2005, and post-opening, July 2005-April 2006. All locations and sites were combined for overall mean densities by season. Each mean density is calculated from a total of 84 samples taken each season, with the exception of summer when only 42 samples were collected each pre- and post-opening sampling. The mean number of total fish and crustaceans are also listed by season. The total number of organisms caught (total catch) is given seasonally for pre-opening, post-opening, and overall (pre- and post-opening combined) for all groups and species. The relative abundance (RA) is listed seasonally for fishes and crustaceans, and only includes species or groups that have a relative abundance of at least 0.1% for pre-opening, post-opening, and overall (pre- and post-opening combined). The change in relative abundance (RA % Change) was also calculated for each species and group of nekton seasonally. The post-opening RA (%) was subtracted from the pre-opening RA (%) to calculate the change. A negative value shows a decline in relative abundance, and a positive number indicated an increase in relative abundance.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Fall											
FISHES											
Total Fishes	2.217	(0.142)	1862		1.519	(0.080)	1279		3141		
Anchoa mitchilli					0.005	(0.000)	4	0.3	4	0.1	0.3
Citharichthys spilopterus	0.001	(0.000)	1	0.1					1		-0.1
Cynoscion nebulosus	0.001	(0.000)	1	0.1	0.001	(0.000)	1	0.1	2	0.1	0.0
Eucinostomus argenteus					0.012	(0.004)	10	0.8	10	0.3	0.8
Fundulidae	0.256	(0.082)	1000	53.7	0.020	(0.011)	130	10.2	1130	36.0	-43.5
Gobionellus boleosoma	0.035	(0.016)	29	1.6	0.744	(0.136)	624	48.8	654	20.8	47.2
Gobiosoma bosc					0.001	(0.000)	1	0.1	1		0.1
Gobiosoma robustum	0.333	(0.054)	280	15.0	0.099	(0.031)	83	6.5	363	11.6	-8.5
Unidentified Gobiidae					0.002	(0.000)	2	0.2	2	0.1	0.2
Hippocampus zosterae	0.015	(0.005)	13	0.7	0.002	(0.000)	2	0.2	15	0.5	-0.5

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Hypsoblennius hentz	0.005	(0.006)	4	0.2	0.001	(0.000)	1	0.1	5	0.2	-0.1
Lagodon rhomboides	0.010	(0.000)	8	0.4	0.018	(0.004)	15	1.2	23	0.7	0.7
Lobotes surinamensis					0.001	(0.000)	1	0.1	1		0.1
Lutjanus griseus					0.002	(0.000)	2	0.2	2	0.1	0.2
Menidia beryllina	0.054	(0.070)	45	2.4	0.014	(0.037)	12	0.9	57	1.8	-1.5
Microgobius gulosus	0.015	(0.024)	13	0.7	0.002	(0.000)	2	0.2	15	0.5	-0.5
Opsanus beta	0.007	(0.005)	6	0.3	0.001	(0.000)	1	0.1	7	0.2	-0.2
Scartella cristata	0.001	(0.000)	1	0.1					1		-0.1
Sciaenops ocellatus	0.012	(0.004)	10	0.5	0.032	(0.006)	27	2.1	37	1.2	1.6
Symphurus plagiusa	0.004	(0.008)	3	0.2	0.013	(0.009)	11	0.9	14	0.4	0.7
Syngnathus spp.	0.533	(0.051)	448	24.1	0.414	(0.043)	348	27.2	796	25.3	3.1
Synodus foetens					0.001	(0.000)	1	0.1	1		0.1
Unidentified fish					0.001	(0.000)	1	0.1	1		0.1
CRUSTACEANS											
Total Crustaceans	36.798	(2.016)	30910		22.882	(1.436)	19221		50131		
Alpheus heterochaelis	0.017	(0.003)	14		0.002	(0.000)	2		16		0.0
Callinectes sapidus	0.277	(0.085)	233	0.8	0.114	(0.036)	96	0.5	329	0.7	-0.3
Libinia spp.	0.001	(0.000)	1						1		0.0
Palaemonetes spp.	32.962	(2.536)	27688	89.6	15.656	(1.857)	13151	68.4	40839	81.5	-21.2
Penaeid Shrimp	1.180	(0.139)	991	3.2	1.958	(0.172)	1645	8.6	2636	5.3	5.4
Tozeuma carolinense	2.204	(0.578)	1851	6.0	5.062	(1.733)	4252	22.1	6103	12.2	16.1
Xanthidae	0.157	(0.050)	132	0.4	0.089	(0.021)	75	0.4	207	0.4	0.0

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Winter											
FISHES											
Total Fishes	2.752	(0.075)	1361		3.833	(0.157)	2385		3746		
Anchoa mitchilli	0.002	(0.000)	2	0.1					2	0.1	-0.1
Chasmodes bosquianus	0.001	(0.000)	1	0.1					1		-0.1
Citharichthys spilopterus	0.008	(0.000)	7	0.5	0.049	(0.016)	41	1.7	48	1.3	1.2
Fundulidae	0.632	(0.113)	531	39.0	0.196	(0.073)	165	6.9	696	18.6	-32.1
Gobionellus boleosoma	0.051	(0.011)	43	3.2	0.451	(0.066)	379	15.9	422	11.3	12.7
Gobiosoma robustum	0.244	(0.048)	205	15.1	0.014	(0.007)	12	0.5	217	5.8	-14.6
Unidentified Gobiidae	0.005	(0.000)	4	0.3	0.064	(0.055)	54	2.3	58	1.5	2.0
Hippocampus zosterae	0.013	(0.012)	11	0.8					11	0.3	-0.8
Lagodon rhomboides	0.500	(0.079)	420	30.9	1.162	(0.228)	976	40.9	1396	37.3	10.1
Menidia beryllina	0.007	(0.031)	6	0.4	0.001	(0.000)	1	0.0	7	0.2	-0.4
Micropogonias undulatus	0.020	(0.009)	17	1.2	0.693	(0.249)	582	24.4	599	16.0	23.2
Mugil cephalus	0.004	(0.008)	3	0.2	0.067	(0.114)	56	2.3	59	1.6	2.1
Opsanus beta					0.001	(0.000)	1		1		0.0
Paralichthys lethostigma	0.007	(0.005)	6	0.4	0.008	(0.006)	7	0.3	13	0.3	-0.1
Sciaenops ocellatus	0.001	(0.000)	1	0.1	0.004	(0.008)	3	0.1	4	0.1	0.1
Symphurus plagiusa					0.005	(0.000)	4	0.2	4	0.1	0.2
Syngnathus spp.	0.123	(0.023)	103	7.6	0.123	(0.035)	103	4.3	206	5.5	-3.2
Synodus foetens					0.001	(0.000)	1		1		0.0
Unidentified fish	0.001	(0.000)	1	0.1					1		-0.1

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
CRUSTACEANS											
Total Crustaceans	50.154	(3.780)	42129		13.850	(1.110)	11634		53763		
Alpheus heterochaelis	0.004	(0.000)	3						3		0.0
Callinectes sapidus	0.243	(0.038)	204	0.5	0.450	(0.060)	378	3.2	582	1.1	2.8
Palaemonetes spp.	47.965	(6.109)	40291	95.6	8.715	(1.889)	7321	62.9	47612	88.6	-32.7
Penaeid Shrimp	0.605	(0.086)	508	1.2	3.564	(0.556)	2994	25.7	3502	6.5	24.5
Tozeuma carolinense	1.132	(0.238)	951	2.3	0.994	(0.540)	835	7.2	1786	3.3	4.9
Unidentified crab	0.001	(0.000)	1						1		0.0
Xanthidae	0.204	(0.031)	171	0.4	0.126	(0.035)	106	0.9	277	0.5	0.5

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Spring											
FISHES											
Total Fishes	2.317	(0.120)	1946		1.933	(0.120)	1624		3570		
Anchoa mitchilli					0.005	(0.006)	4	0.2	4	0.1	0.2
Citharichthys spilopterus	0.011	(0.004)	9	0.5	0.021	(0.007)	18	1.1	27	0.8	0.6
Fundulidae	0.492	(0.156)	413	21.2	0.029	(0.029)	24	1.5	437	12.2	-19.7
Gobionellus boleosoma	0.163	(0.054)	137	7.0	0.762	(0.169)	640	39.4	777	21.8	32.4
Gobiosoma robustum	0.358	(0.045)	301	15.5	0.026	(0.016)	22	1.4	323	9.0	-14.1
Unidentified Gobiidae	0.005	(0.000)	4	0.2	0.099	(0.088)	83	5.1	87	2.4	4.9

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Hippocampus zosterae	0.015	(0.005)	13	0.7					13	0.4	-0.7
Hyporhamphus unifasciatus	0.001	(0.000)	1	0.1	0.001	(0.000)	1	0.1	2	0.1	0.0
Lagodon rhomboides	1.102	(0.181)	926	47.6	0.819	(0.150)	688	42.4	1614	45.2	-5.2
Leiostomus xanthurus	0.035	(0.044)	29	1.5	0.049	(0.024)	41	2.5	70	2.0	1.0
Menidia beryllina	0.017	(0.023)	14	0.7	0.024	(0.098)	20	1.2	34	1.0	0.5
Microgobius gulosus	0.005	(0.000)	4	0.2					4	0.1	-0.2
Micropogonias undulatus	0.006	(0.000)	5	0.3	0.027	(0.008)	23	1.4	28	0.8	1.2
Mugil cephalus					0.001	(0.000)	1	0.1	1		0.1
Ophichthus gomesii					0.002	(0.000)	2	0.1	2	0.1	0.1
Opsanus beta	0.004	(0.000)	3	0.2					3	0.1	-0.2
Orthopristis chrysoptera	0.004	(0.000)	3	0.2	0.001	(0.000)	1	0.1	4	0.1	-0.1
Paralichthys lethostigma	0.001	(0.000)	1	0.1	0.001	(0.000)	1	0.1	2	0.1	0.0
Prionotus tribulus					0.001	(0.000)	1	0.1	1		0.1
Symphurus plagiusa					0.004	(0.000)	3	0.2	3	0.1	0.2
Syngnathus spp.	0.098	(0.013)	82	4.2	0.058	(0.013)	49	3.0	131	3.7	-1.2
Synodus foetens	0.001	(0.000)	1	0.1	0.002	(0.000)	2	0.1	3	0.1	0.1
CRUSTACEANS											
Total Crustaceans	47.185	(4.688)	39635		10.871	(0.558)	9132		48767		
Alpheus heterochaelis	0.011	(0.009)	9						9		0.0
Callinectes sapidus	0.438	(0.043)	368	0.9	0.317	(0.188)	266	2.9	634	1.3	2.0
Palaemonetes spp.	38.901	(9.349)	32677	82.4	2.580	(0.659)	2167	23.7	34844	71.4	-58.7
Penaeid Shrimp	5.867	(0.750)	4928	12.4	7.301	(0.519)	6133	67.2	11061	22.7	54.7
Tozeuma carolinense	1.206	(0.225)	1013	2.6	0.576	(0.269)	484	5.3	1497	3.1	2.7
Xanthidae	0.762	(0.100)	640	1.6	0.098	(0.036)	82	0.9	722	1.5	-0.7

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
<u>Summer</u>											
FISHES											
Total Fishes	1.945	(0.135)	817		1.629	(0.086)	684		1501		
Anchoa mitchilli	0.040	(0.050)	17	2.1					17	1.1	-2.1
Blenniidae					0.002	(0.000)	1	0.1	1	0.1	0.1
Citharichthys spilopterus	0.002	(0.000)	1	0.1					1	0.1	-0.1
Cynoscion nebulosus					0.002	(0.000)	1	0.1	1	0.1	0.1
Eucinostomus argenteus					0.381	(0.138)	160	23.4	160	10.7	23.4
Fundulidae	0.148	(0.086)	62	7.6	0.074	(0.036)	31	4.5	93	6.2	-3.1
Gobionellus boleosoma	0.031	(0.016)	13	1.6	0.452	(0.141)	190	27.8	203	13.5	26.2
Gobiosoma robustum	0.398	(0.077)	167	20.4	0.267	(0.037)	112	16.4	279	18.6	-4.1
Unidentified Gobiidae					0.012	(0.000)	5	0.7	5	0.3	0.7
Hippocampus zosterae	0.014	(0.000)	6	0.7					6	0.4	-0.7
Lagodon rhomboides	1.062	(0.232)	446	54.6	0.195	(0.028)	82	12.0	528	35.2	-42.6
Leiostomus xanthurus	0.026	(0.012)	11	1.3	0.002	(0.000)	1	0.1	12	0.8	-1.2
Lutjanus griseus					0.007	(0.000)	3	0.4	3	0.2	0.4
Lutjanus spp.	0.019	(0.022)	8	1.0	0.002	(0.000)	1	0.1	9	0.6	-0.8
Menidia beryllina					0.002	(0.000)	1	0.1	1	0.1	0.1
Microgobius gulosus	0.014	(0.007)	6	0.7	0.010	(0.009)	4	0.6	10	0.7	-0.1
Opsanus beta	0.002	(0.000)	1	0.1	0.010	(0.000)	4	0.6	5	0.3	0.5
Orthopristis chrysoptera	0.038	(0.017)	16	2.0	0.002	(0.000)	1	0.1	17	1.1	-1.8
Paralichthys lethostigma	0.002	(0.000)	1	0.1					1	0.1	-0.1
Syngnathus spp.	0.140	(0.026)	59	7.2	0.202	(0.053)	85	12.4	144	9.6	5.2
Synodus foetens	0.007	(0.000)	3	0.4					3	0.2	-0.4
Unidentified fish					0.005	(0.000)	2	0.3	2	0.1	0.3

Table 2 cont.

	Pre				Post						
Species	Mean	S.E.	Total Catch	RA (%)	Mean	S.E.	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
CRUSTACEANS											
Total Crustaceans	32.943	(2.872)	13836		15.533	(1.267)	6524		20360		
Alpheus heterochaelis	0.005	(0.000)	2		0.005	(0.000)	2		4		0.0
Callinectes sapidus	0.040	(0.008)	17	0.1	0.048	(0.018)	20	0.3	37	0.2	0.2
Palaemonetes spp.	23.040	(5.028)	9677	69.9	11.157	(1.444)	4686	71.8	14363	70.5	1.9
Penaeid Shrimp	3.095	(0.261)	1300	9.4	0.826	(0.198)	347	5.3	1647	8.1	-4.1
Tozeuma carolinense	6.331	(1.011)	2659	19.2	3.369	(1.431)	1415	21.7	4074	20.0	2.5
Xanthidae	0.431	(0.106)	181	1.3	0.129	(0.133)	54	0.8	235	1.2	-0.5

Table 3. Mean sizes, mm, (with standard errors, S.E.) for all species or groups caught pre-opening, October 2004-July 2005, and post-opening, July 2005-April 2006, are listed seasonally. Mean sizes (standard length for fish, total length for shrimp, and carapace width for crabs) were calculated from n number of species measured each season pre- and post-opening. If more than 20 individuals were caught for each species or group, the largest and smallest and 20 other random individuals were measured.

	Pre			Post		
Species	Mean	S.E.	N	Mean	S.E.	N
Fall						
FISHES						
Anchoa mitchilli				24.7	(0.73)	4
Citharichthys spilopterus	12.0	(0.00)	1			
Cynoscion nebulosus	26.8	(0.00)	1	8.9	(0.00)	1
Eucinostomus argenteus				23.9	(1.34)	10
Fundulidae	18.6	(0.63)	681	17.4	(0.47)	130
Gobionellus boleosoma	28.5	(1.05)	29	18.7	(0.63)	510
Gobiosoma bosc				20.2	(0.00)	1
Gobiosoma robustum	15.5	(0.57)	282	14.9	(0.39)	83
Gobiidae				20.7	(1.33)	2
Hippocampus zosterae	19.2	(0.58)	13	17.1	(0.41)	2
Hypsoblennius hentz	32.8	(2.47)	4	61.0	(0.00)	1
Lagodon rhomboides	66.2	(0.70)	8	62.1	(1.07)	15
Lobotes surinamensis				48.3	(0.00)	1
Lutjanus griseus				71.7	(4.71)	2
Menidia beryllina	19.3	(0.89)	45	27.9	(0.52)	12
Microgobius gulosus	23.2	(0.90)	13	29.6	(0.62)	2
Opsanus beta	55.3	(1.29)	6	33.4	(0.00)	1
Scartella cristata	40.3	(0.00)	1			
Sciaenops ocellatus	23.0	(1.12)	10	8.9	(0.24)	27
Symphurus plagiusa	31.0	(0.59)	3	17.2	(0.91)	11
Syngnathus spp.	46.4	(2.16)	451	47.8	(2.32)	348
Synodus foetens				79.6	(0.00)	1
Unidentified fish				10.4	(0.00)	1
CRUSTACEANS						
Alpheus heterochaelis	20.2	(0.97)	14	19.4	(0.02)	2
Callinectes sapidus	15.9	(0.85)	208	8.7	(0.73)	94
Libinia spp.	19.0	(0.00)	1			
Palaemonetes spp.	14.5	(0.53)	1816	13.3	(0.44)	1726
Penaeid Shrimp	26.7	(2.04)	797	28.4	(1.20)	1326
Tozeuma carolinense	24.2	(0.67)	669	21.3	(0.66)	752
Xanthidae	9.5	(0.46)	131	7.3	(0.44)	74

Table 3 cont.

Species	Mean	Pre- S.E.	N	Mean	Post S.E.	N
Winter						
FISHES						
Anchoa mitchilli	19.0	(0.10)	2			
Chasmodes bosquianus	49.7	(0.00)	1			
Citharichthys spilopterus	17.8	(1.00)	7	15.9	(0.80)	41
Fundulidae	20.6	(0.57)	468	24.3	(0.50)	167
Gobionellus boleosoma	16.8	(0.61)	44	19.3	(0.64)	370
Gobiosoma robustum	16.9	(0.52)	205	19.7	(0.60)	12
Gobiidae	9.5	(0.04)	4	9.5	(0.07)	53
Hippocampus zosterae	22.1	(0.18)	11			
Lagodon rhomboides	16.9	(0.47)	408	13.6	(0.46)	588
Menidia beryllina	19.2	(0.14)	5	29.7	(0.00)	1
Micropogonias undulatus	17.8	(0.40)	17	12.1	(0.29)	311
Mugil cephalus	22.5	(0.09)	3	23.1	(0.19)	39
Opsanus beta				39.3	(0.00)	1
Paralichthys lethostigma	11.7	(0.42)	6	10.7	(0.35)	7
Sciaenops ocellatus	68.8	(0.00)	1	67.50	(1.16)	2
Symphurus plagiusa				32.6	(0.86)	4
Syngnathus spp.	69.4	(1.47)	103	66.6	(2.19)	103
Synodus foetens				11.5	(0.00)	1
Unidentified fish	8.8	(0.00)	1			
CRUSTACEANS						
Alpheus heterochaelis	22.6	(1.38)	3			
Callinectes sapidus	14.4	(0.93)	203	9.2	(0.66)	370
Palaemonetes spp.	14.4	(0.52)	1718	14.9	(0.48)	1139
Penaeid Shrimp	20.6	(1.36)	452	16.3	(0.82)	1457
Tozeuma carolinense	28.4	(0.44)	550	29.0	(0.53)	258
Unidentified crab	6.3	(0.00)	1			
Xanthidae	5.6	(0.36)	171	5.0	(0.26)	106

Table 3 cont.

		Pre-			Post	
Species	Mean	S.E.	N	Mean	S.E.	N
Spring						
FISHES						
Anchoa mitchilli				11.5	(0.08)	4
Citharichthys spilopterus	25.9	(0.93)	9	18.2	(1.02)	17
Fundulidae	22.1	(0.62)	348	20.2	(0.25)	24
Gobionellus boleosoma	20.0	(0.84)	128	20.0	(0.83)	479
Gobiosoma robustum	21.2	(0.59)	301	22.3	(0.74)	21
Gobiidae	10.1	(0.11)	4	10.0	(0.06)	81
Hippocampus zosterae	24.5	(0.29)	13			
Hyporhamphus unifasciatus				15.1	(0.00)	1
Lagodon rhomboides	19.1	(0.85)	668	18.3	(0.72)	540
Leiostomus xanthurus	33.7	(0.60)	29	36.3	(1.05)	41
Menidia beryllina	17.4	(0.94)	14	17.2	(0.21)	19
Microgobius gulosus	38.2	(0.34)	4			
Micropogonias undulatus	24.7	(0.45)	5	15.7	(1.08)	23
Mugil cephalus				25.2	(0.00)	1
Ophichthus gomesi				172.3	(1.50)	2
Opsanus beta	72.1	(1.07)	3			
Orthopristis chrysoptera	14.3	(0.25)	3	10.5	(0.00)	1
Paralichthys lethostigma	25.7	(0.00)	1	8.8	(0.00)	1
Prionotus tribulus				48.6	(0.00)	1
Symphurus plagiusa				47.4	(0.29)	3
Syngnathus spp.	65.6	(2.91)	82	63.1	(2.14)	49
Synodus foetens	72.4	(0.00)	1	62.4	(3.84)	2
CRUSTACEANS						
Alpheus heterochaelis	24.6	(0.64)	9			
Callinectes sapidus	17.0	(1.01)	362	11.9	(0.59)	171
Palaemonetes spp.	15.4	(0.63)	1755	15.2	(0.53)	708
Penaeid Shrimp	22.4	(1.23)	2003	19.6	(1.18)	2517
Tozeuma carolinense	30.6	(0.59)	566	25.3	(0.86)	272
Xanthidae	6.1	(0.35)	568	6.1	(0.33)	82

Table 3 cont.

	Pre-			Post		
Species	Mean	S.E.	N	Mean	S.E.	N
Summer						
FISHES						
Anchoa mitchilli	16.8	(0.22)	15			
Blenniidae				8.0	(0.00)	1
Citharichthys spilopterus	54.9	(0.00)	1			
Cynoscion nebulosus				10.1	(0.00)	1
Eucinostomus argenteus				9.7	(0.16)	138
Fundulidae	19.9	(0.39)	62	21.4	(0.63)	31
Gobionellus boleosoma	24.1	(0.73)	13	9.1	(0.20)	173
Gobiosoma robustum	23.5	(0.38)	166	22.1	(0.58)	112
Gobiidae				8.8	(0.06)	4
Hippocampus zosterae	19.7	(0.70)	6			
Lagodon rhomboides	25.2	(0.60)	328	38.3	(0.93)	82
Leiostomus xanthurus	44.4	(1.01)	11	50.3	(0.00)	1
Lutjanus griseus				15.5	(0.15)	3
Lutjanus spp.	18.4	(0.55)	8	24.7	(0.00)	1
Menidia beryllina				16.7	(0.00)	1
Microgobius gulosus	42.6	(0.56)	6	22.6	(0.73)	4
Opsanus beta	15.6	(0.00)	1	73.9	(4.20)	4
Orthopristis chrysoptera	20.6	(0.45)	16	50.9	(0.00)	1
Paralichthys lethostigma	102.0	(0.00)	1			
Syngnathus spp.	45.7	(3.14)	59	59.0	(2.31)	85
Synodus foetens	60.3	(1.67)	3			
CRUSTACEANS						
Alpheus heterochaelis	23.3	(0.35)	2	18.7	(0.52)	2
Callinectes sapidus	16.4	(0.72)	17	7.3	(0.84)	20
Palaemonetes spp.	14.9	(0.60)	847	17.8	(0.56)	829
Penaeid Shrimp	34.9	(1.42)	817	22.3	(2.07)	305
Tozeuma carolinense	24.2	(0.70)	679	22.3	(0.89)	239
Xanthidae	4.7	(0.35)	174	7.2	(0.35)	47

Seven species of fishes and crustaceans with different seasonal recruitment patterns and that may not have been dominant in all seasons, were then analyzed seasonally to detect specific differences in densities pre- verses post-opening: red drum (*Sciaenops ocellatus*), pinfish (*Lagodon rhomboids*), Atlantic croaker (*Leiostomus xanthurus*), southern flounder (*Paralichthys lethostigma*), killifish (Fundulidae), blue crab (*Callinectes sapidus*), and penaeid shrimp (brown shrimp *Farfantepenaeus aztecus*, pink shrimp *Farfantepenaeus duorarum*, and white shrimp *Litopenaeus setiferus*).

In the fall, there were significantly higher mean densities of red drum post-opening (P = 0.011; t = -2.579; *df* = 166) than pre-opening. In the winter I also found significantly higher mean densities of pinfish (P = 0.030; t = -2.185; *df* = 166) and Atlantic croaker (P<0.001; t = -4.137; *df* = 166) post-opening. There was no significant difference in southern flounder mean densities in the winter pre- verses post-opening (P = 0.826; t = -0.220; *df* = 166; 1-β = 0.050). Killifish densities were analyzed over all seasons, and there were significantly fewer killifish post-opening (P<0.001; t = 8.331; *df* = 586). There was no significant difference in blue crab mean densities pre- verses post-opening when combining fall, winter, and spring densities (P = 0.075; t = 1.783; *df* = 502; 1- β = 0.296). Penaeid shrimp were analyzed over all seasons both pre- and post-opening, and there were significantly higher mean densities of penaeid shrimp post-opening (P<0.001; t = -4.379; *df* = 586) (Fig. 8, Table 4).

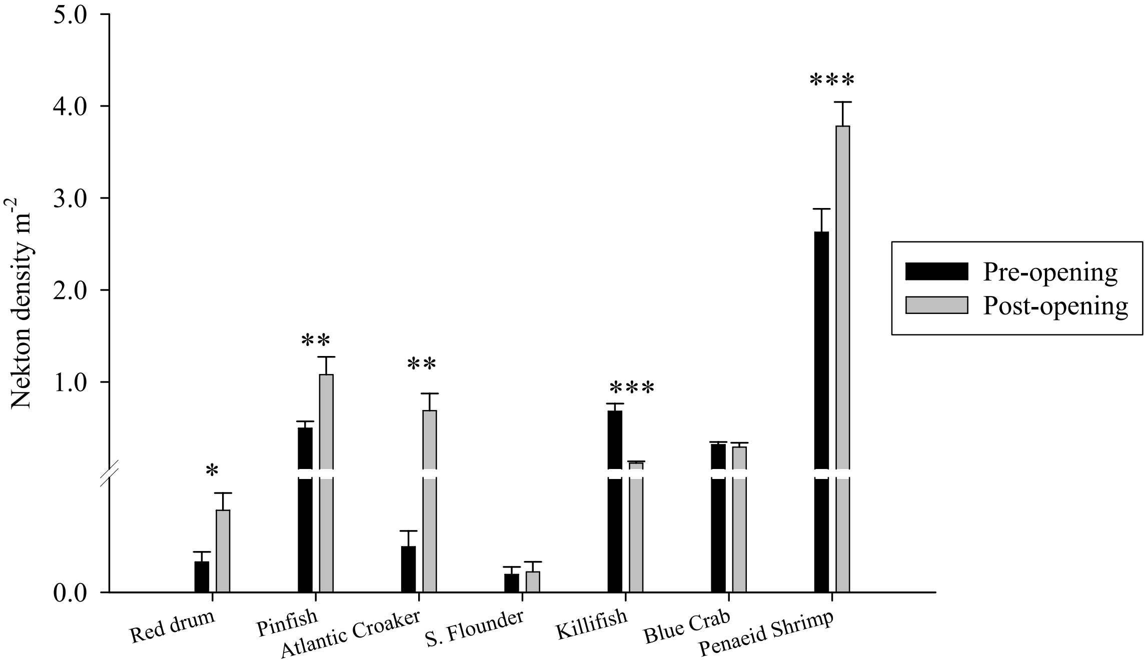


Figure 8. Mean densities of selected fishes and crustaceans pre- and post-opening for all locations. The mean densities of the species selected were calculated during their peak recruitment season. S. Flounder = Southern Flounder. Red drum mean densities were calculated from fall samples, pinfish and Atlantic croaker mean densities were calculated from winter samples, southern flounder mean densities were calculated from winter samples, killifish and penaeid shrimp mean densities were calculated over all seasons, and blue crab densities were calculated from fall, winter, and spring samples. Student's *t*-test was performed on the selected fishes and crustaceans pre- verses post-opening; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4. Mean densities, in number per m^2, of selected fish and crustaceans (with standard error, S.E.) for both pre-opening and post-opening are summarized below. The mean densities of the species selected were calculated during their peak recruitment season. Red drum mean densities were calculated from fall samples; pinfish and Atlantic croaker mean densities were calculated from winter samples; southern flounder mean densities were calculated from winter samples; killifish mean densities were calculated by combining all seasons; blue crab mean densities were calculated by combing fall, winter, and spring densities; penaeid shrimp mean densities were calculated by combining all seasons. Results of the comparison between pre- and post-opening using a Student's *t*-test (P-value) for each species are also listed. An * listed indicates that the value was significant.

	Pre-		Post		
Species	Mean	S.E.	Mean	S.E.	P
Red drum *Sciaenops ocellatus*	0.012	(0.004)	0.032	(0.007)	0.011*
Pinfish *Lagodon rhomboides*	0.498	(0.075)	1.080	(0.194)	0.030*
Atlantic croaker *Micropogonias undulatus*	0.018	(0.006)	0.690	(0.185)	0.001*
Southern flounder *Paralichthys lethostigma*	0.007	(0.003)	0.008	(0.004)	0.826
Killifish Fundulidae	0.682	(0.083)	0.119	(0.019)	0.001*
Blue crab *Callinectes sapidus*	0.319	(0.030)	0.294	(0.046)	0.075
Penaeid Shrimp	2.628	(0.256)	3.782	(0.262)	0.001*

The mean size of the selected fish and crustacean species differed pre- verses post-opening. In the fall, red drum were significantly smaller post-opening than pre-opening ($P < 0.001$; $t = 7.608$; $df = 35$). Pinfish and Atlantic croaker were also significantly smaller in the winter ($P = 0.030$; $t = 13.521$; $df = 994$; $P < 0.001$; $t = 8.910$; $df = 326$). There was no difference in size of southern flounder pre- verses post-opening ($P = 0.628$; $t = 0.499$; $df = 11$; $1- \beta = 0.050$). Size differences of blue crabs were analyzed over fall, winter, and spring as with the mean densities. Blue crabs were significantly smaller post-opening ($P < 0.001$; $t = 18.486$; $df = 1406$). Penaeid shrimp were also significantly smaller post-opening over all seasons ($P < 0.001$; $t = 17.110$; $df = 9671$) (Fig. 9, Table 5). Fundulidae were excluded from the size analyses because of variability in size due to the grouping of multiple species.

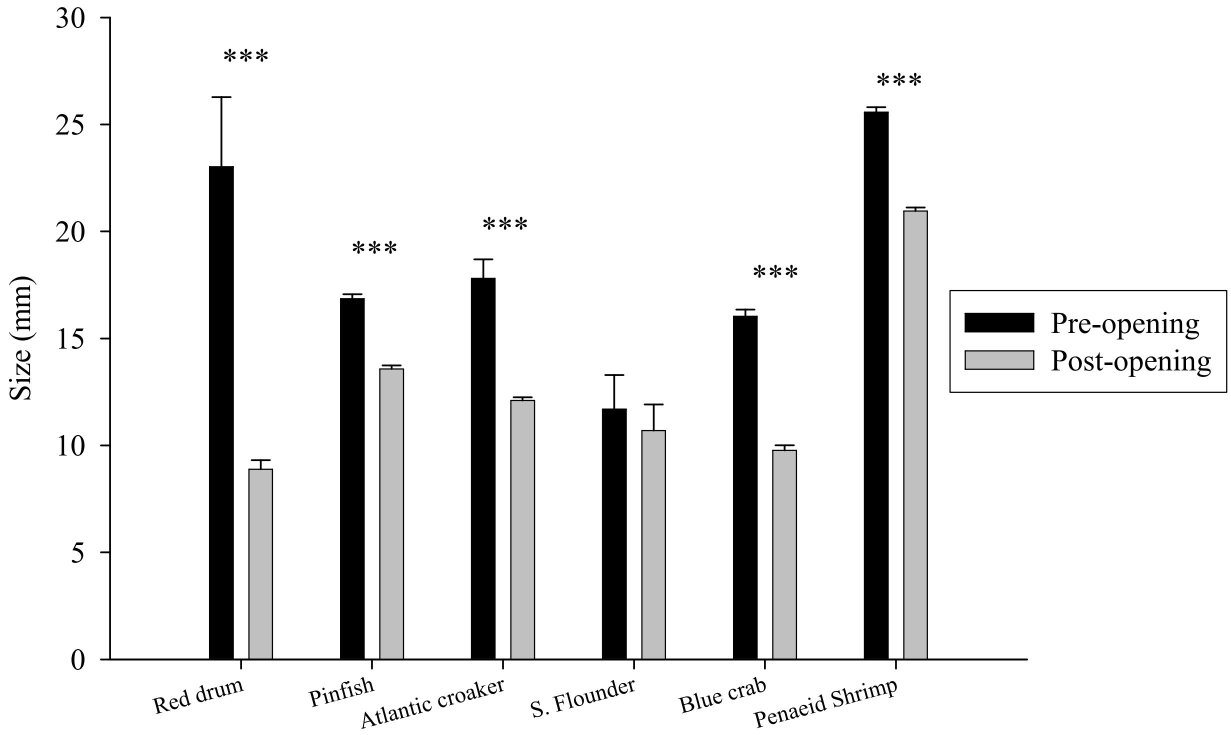
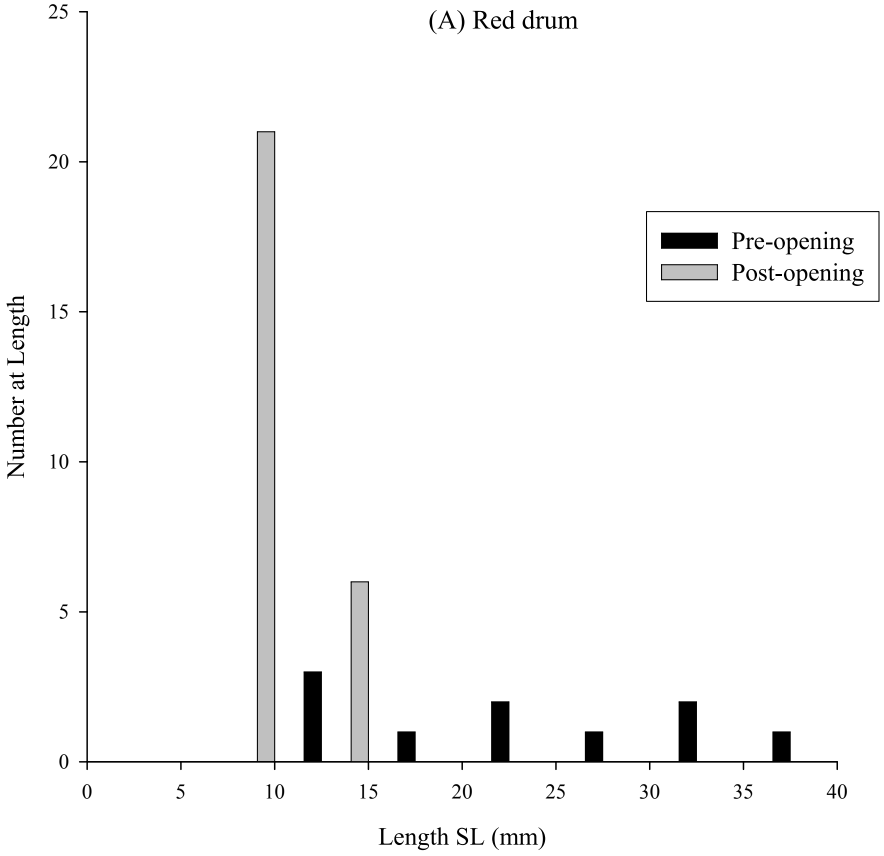


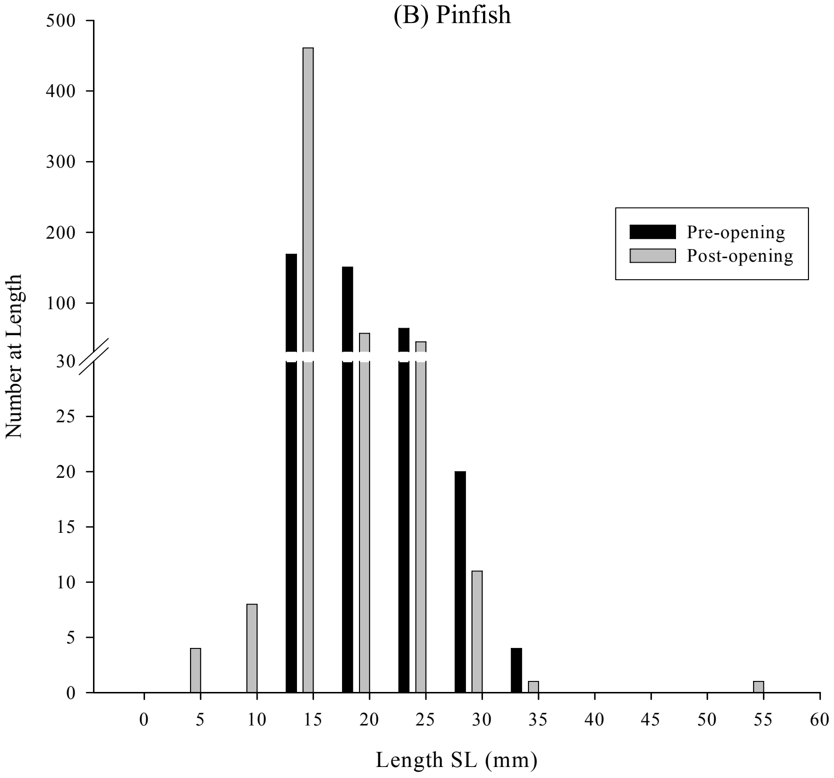
Figure 9. Mean sizes of selected fishes and crustaceans pre- and post-opening over all locations and different seasons. S. Flounder = Southern Flounder. Red drum mean sizes were calculated from fall samples; pinfish, Atlantic croaker, and southern flounder mean sizes were calculated from winter samples; blue crab sizes were calculated from fall, winter, and spring samples; penaeid shrimp mean sizes were calculated over all seasons. Student's *t*-test was performed on the selected fishes and crustaceans; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

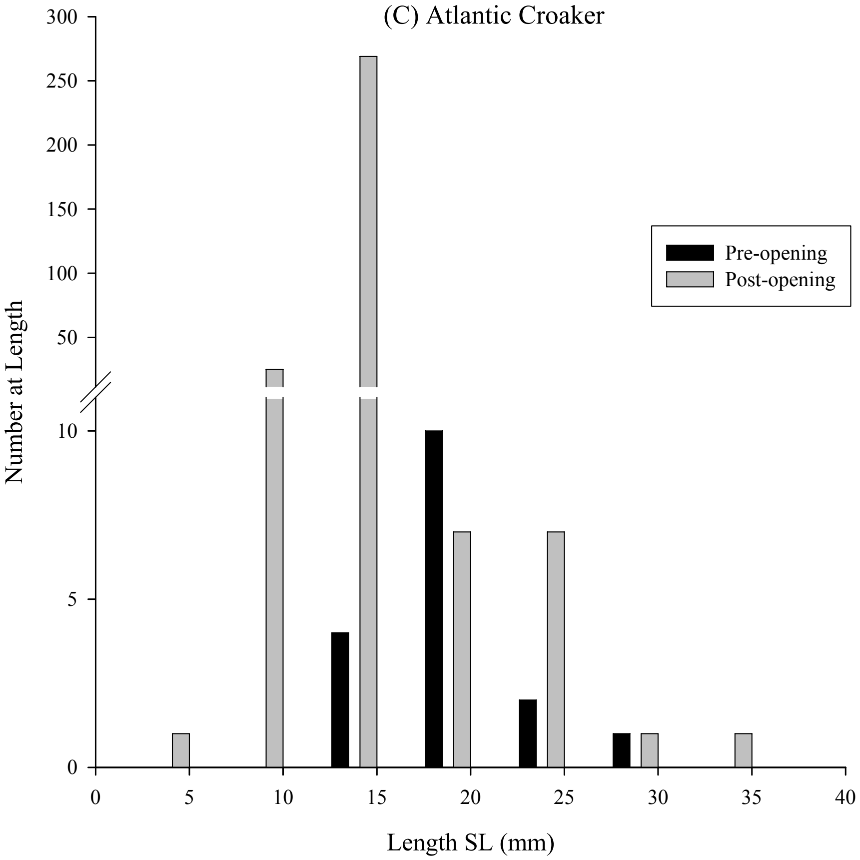
Table 5. Mean sizes, mm, of selected fish and crustaceans (with standard error, S.E.) for both pre-opening, October 2004-July 2005, and post-opening, July 2005-April 2006, are listed below. Mean sizes (standard length for fish, total length for shrimp, and carapace width for crabs) were calculated from N number of species measured each season pre- and post-opening. If more than 20 individuals were caught for each species or group, the largest and smallest and 20 other random individuals were measured. Red drum mean sizes were calculated from fall samples; pinfish, Atlantic croaker, and southern flounder mean sizes were calculated from winter samples; blue crab mean sizes were calculated by combing fall, winter, and spring densities; penaeid shrimp mean sizes were calculated by combining all seasons. Results of the comparison between pre-opening and post-opening using a Student's *t*-test (P-value) for each species are also listed. An * listed indicates that the value was significant.

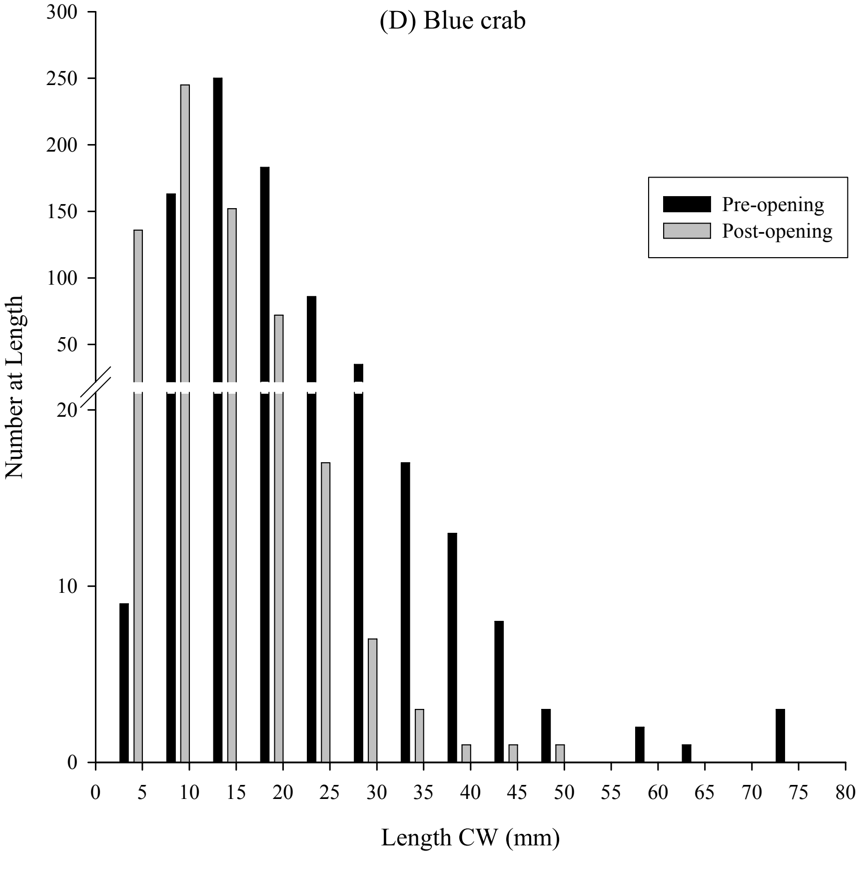
	Pre			Post			
Species	Mean	S.E.	N	Mean	S.E.	N	P
Red drum *Sciaenops ocellatus*	23.02	(3.26)	10	8.88	(0.43)	27	0.001*
Pinfish *Lagodon rhomboides*	16.85	(0.22)	408	13.57	(0.17)	588	0.001*
Atlantic croaker *Micropogonias undulatus*	17.81	(0.89)	17	12.10	(0.15)	311	0.001*
Southern flounder *Paralichthys lethostigma*	13.70	(2.41)	7	10.46	(1.07)	8	0.236
Blue crab *Callinectes sapidus*	16.03	(0.31)	208	9.84	(0.24)	94	0.001*
Penaeid Shrimp	25.58	(0.23)	4069	20.96	(0.16)	5605	0.001*

Length frequency distributions of the selected fishes and crustaceans are illustrated in Fig. 10. In general, there were greater abundances of estuarine-dependent fishes in the smaller size classes post-opening of Packery Channel. Sizes classes of red drum (Fig. 10 A) were different pre- verses post-opening. The majority of red drum post-opening were between 5-10 mm and there were no fish that size pre-opening. Both pinfish (Fig. 10 B) and Atlantic croaker (Fig. 10 C) had many more fish that were in the smaller size classes post-opening. Blue crab (Fig. 10 D) and penaeid shrimp (Fig. 10 E) had similar distributions pre- verses post-opening, but there were many more individuals that were in the smallest size classes post-opening. Southern flounder are not shown, since so few individuals were collected.


(A) Red drum
Number at Length
0
5
10
15
20
25
Length SL (mm)
0
5
10
15
20
25
30
35
40
Pre-opening
Post-opening


(B) Pinfish
Number at Length
0
5
10
15
20
25
30
100
200
300
400
500
Length SL (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
Pre-opening
Post-opening


(C) Atlantic Croaker
Number at Length
Length SL (mm)
Pre-opening
Post-opening
0
5
10
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40


(D) Blue crab
Number at Length
Length CW (mm)
Pre-opening
Post-opening
0
10
20
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

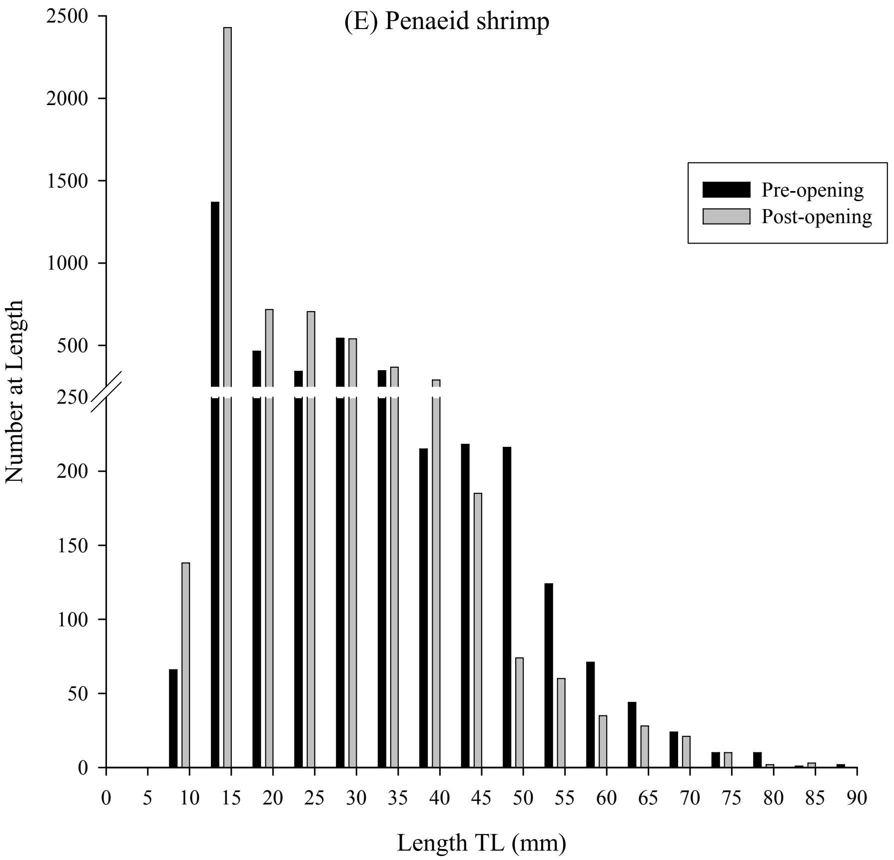


Figure 10. Length-frequency distribution of the selected fishes and crustaceans; (A) red drum, (B) pinfish, (C) Atlantic croaker, (D) blue crab, and (E) penaeid shrimp both pre- and post-opening. Red drum sizes are from fall samples; pinfish and Atlantic croaker sizes are from winter samples; blue crab sizes are from fall, winter, and spring densities; penaeid shrimp sizes are from all seasons.

The mean densities of red drum collected both pre- and post-opening in habitats adjacent to Packery Channel were compared to densities of red drum from areas where they are know to occur in high densities. During peak red drum recruitment in fall 2005 red drum were collected in the extensive seagrass meadows of the northeast part Corpus Christi Bay near the Corpus Christi Ship Channel, and in Aransas Bay in the seagrass meadows at the North end of the Lydia Ann Channel (see Fig. 2). Mean densities were calculated for these two locations and compared with mean densities collected near Packery Channel (upper Laguna Madre) pre- and post-opening (Fig. 11). Clearly, the densities of red drum are significantly higher in both Corpus Christi Bay and Aransas Bay (mean = 0.617 ± 0.261 SE, mean = 0.945 ± 0.383 SE) than in the upper Laguna Madre both pre- and post-opening (mean = 0.011 ± 0.003 SE, mean = 0.032 ± 0.007 SE) ($P < 0.001$; $F = 29.45$; *df* = 3, 187). Mean densities of red drum were similar in Corpus Christi Bay and Aransas Bay, and mean densities were similar between pre- and post-opening. It should be noted that in the earlier analysis of red drum densities pre- verses post-opening were significantly different. However, with very high densities of red drum collected in Corpus Christi and Aransas Bays as compared to the Packery Channel area, the differences were not detected by the ANOVA analysis for pre- verses post-opening.

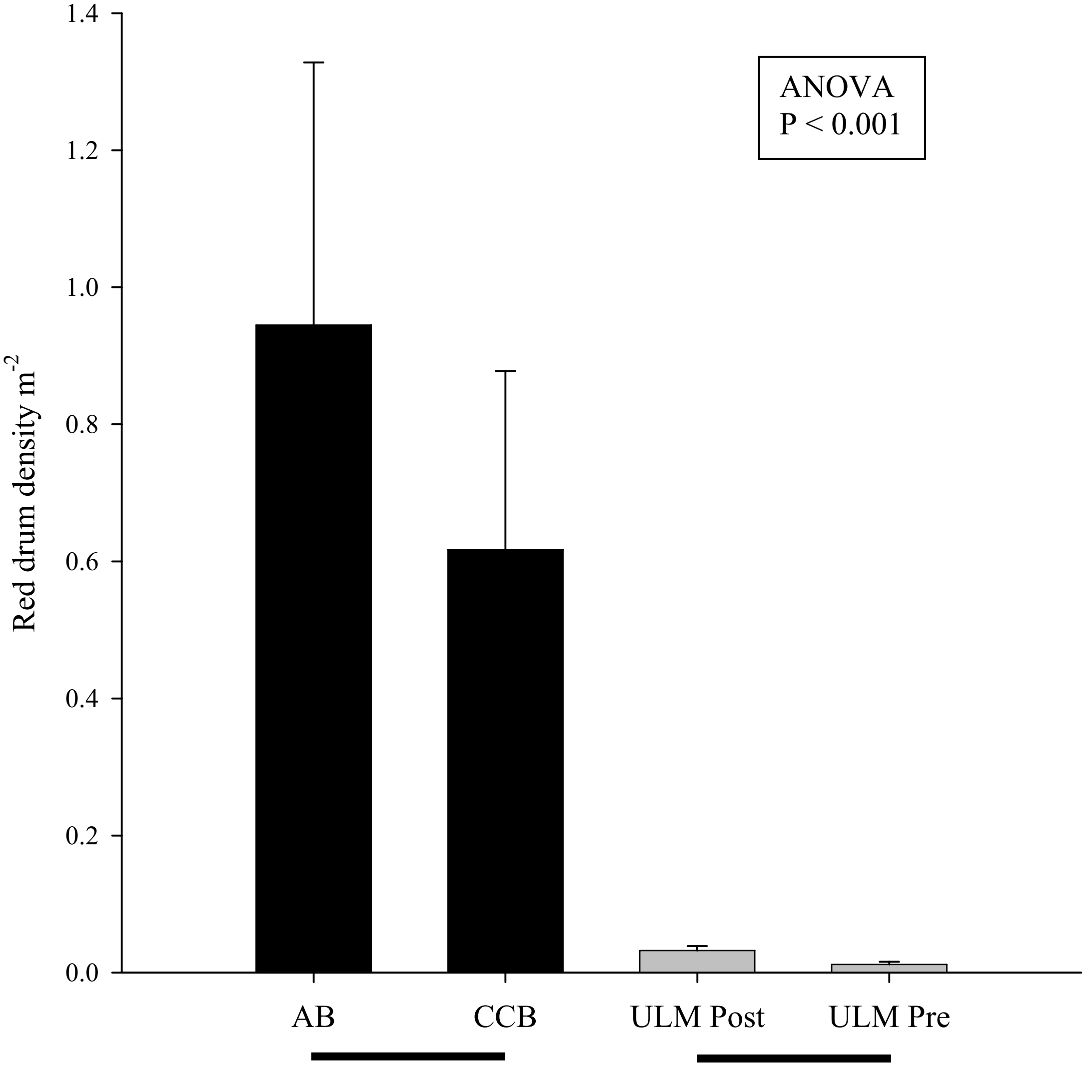


Figure 11. Mean densities of red drum collected with an epibenthic sled during the fall recruitment season, October 2005 – November 2005. AB = Aransas Bay. CCB = Corpus Christi Bay. ULM Post = upper Laguna Madre post-opening. ULM Pre = upper Laguna Madre pre-opening. Red drum from Aransas Bay were collected in seagrass meadows just after Lydia Ann Channel. Corpus Christi Bay red drum were collected after the Corpus Christi Ship Channel in the seagrass meadows of Corpus Christi Bay. Red drum densities from the upper Laguna Madre represent the previous red drum densities data from the sampling locations adjacent to Packery Channel.

Community assemblages

To assess impacts to the community dynamics of the habitats adjacent to Packery Channel several analyses were conducted. Community structure was first assessed using change in relative abundance (Table 2). Species or groups that had a large change in RA (> 10%) during any season are illustrated seasonally in Figure 12. Species with a positive RA (above the x-axis) showed an increase in RA post-opening. Species with a negative RA (below the x-axis) showed a decrease in RA post-opening. Killifish, code gobies, and grass shrimp all showed a negative change in RA, thus a marked decrease in abundance. Darter gobies, spotfin mojarra (*Eucinostomus argenteus*), Atlantic croaker, pinfish (fall and winter), penaeid shrimp, and arrow shrimp (*Tozeuma carolinense*) all had a positive change in RA, showing an increase in abundance.

The reciprocal of the Simpson index (1/D) was used so that the value calculated relates to the number of species required for that community to have equally frequent species (Peet 1974, Lande 1996). Both the Shannon and Simpson indices followed the same pattern over the sampling timeframe. Diversity increased slightly after the opening of Packery Channel in July 2005. The diversity values for the fall collections (October 2004 and 2005) are approximately the same both pre-and post-opening, but diversity is higher for all other post-opening sampling seasons (Fig. 13). The Simpson diversity mean pre-opening was 1.547 (SE = 0.143), and the mean post-opening was 2.993 (SE = 0.319). The Shannon diversity mean pre-opening was 0.318 (SE = 0.045), and post-opening was 0.550 (SE = 0.036). Both the Simpson and Shannon indices indicate that diversity was significantly higher post-opening (P = 0.001; t = -4.360; *df* = 11; P = 0.002; t = -3.934; *df* = 11 respectively).

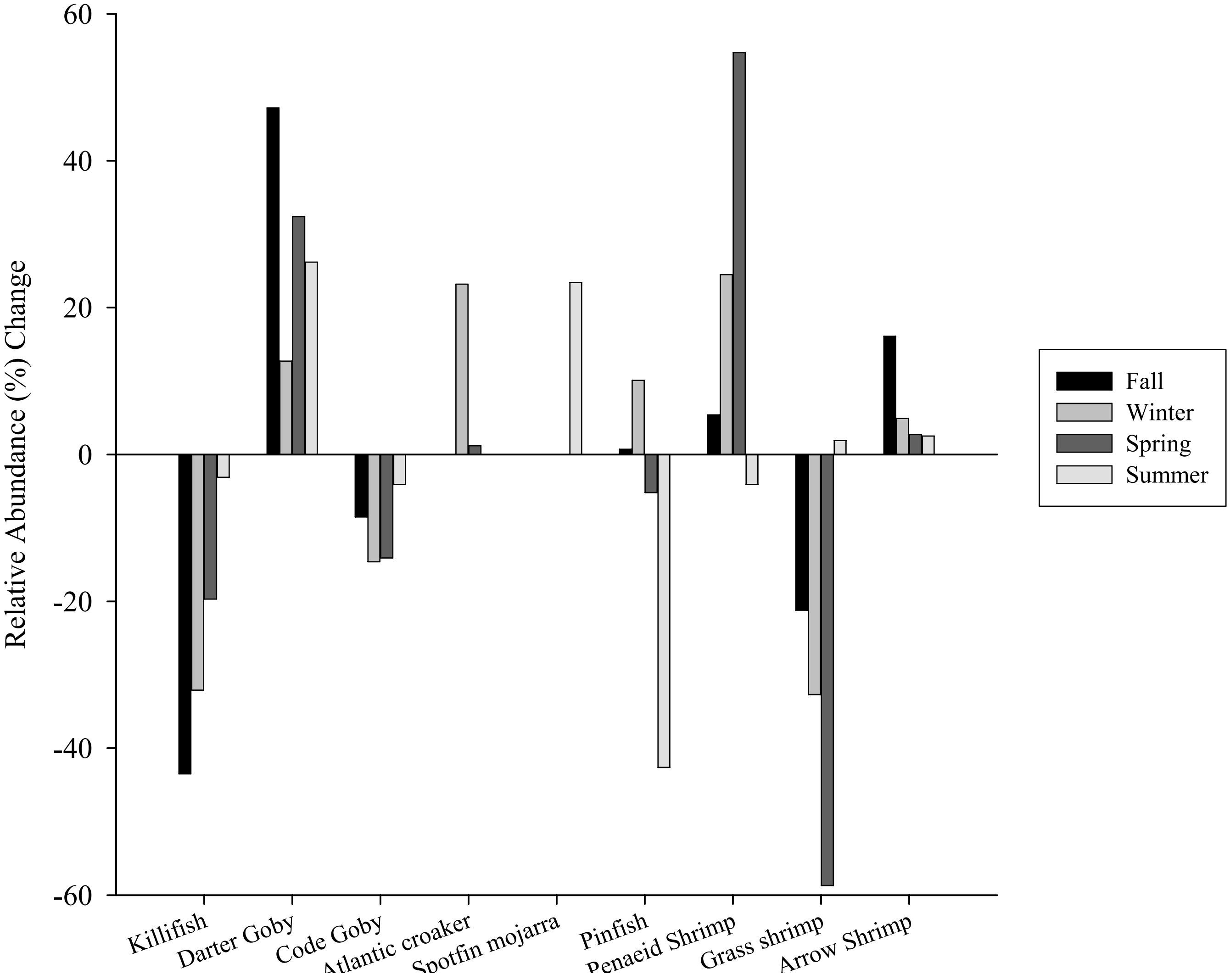


Figure 12. Change in relative abundance (RA) of species or groups that had a large change in RA (> 10%) during any season. The post opening RA (%) was subtracted from the pre-opening RA (%) to calculate the change. A negative value shows a decline in relative abundance, and a positive number indicated an increase in relative abundance. Values of RA % Change are shown in Table 2.

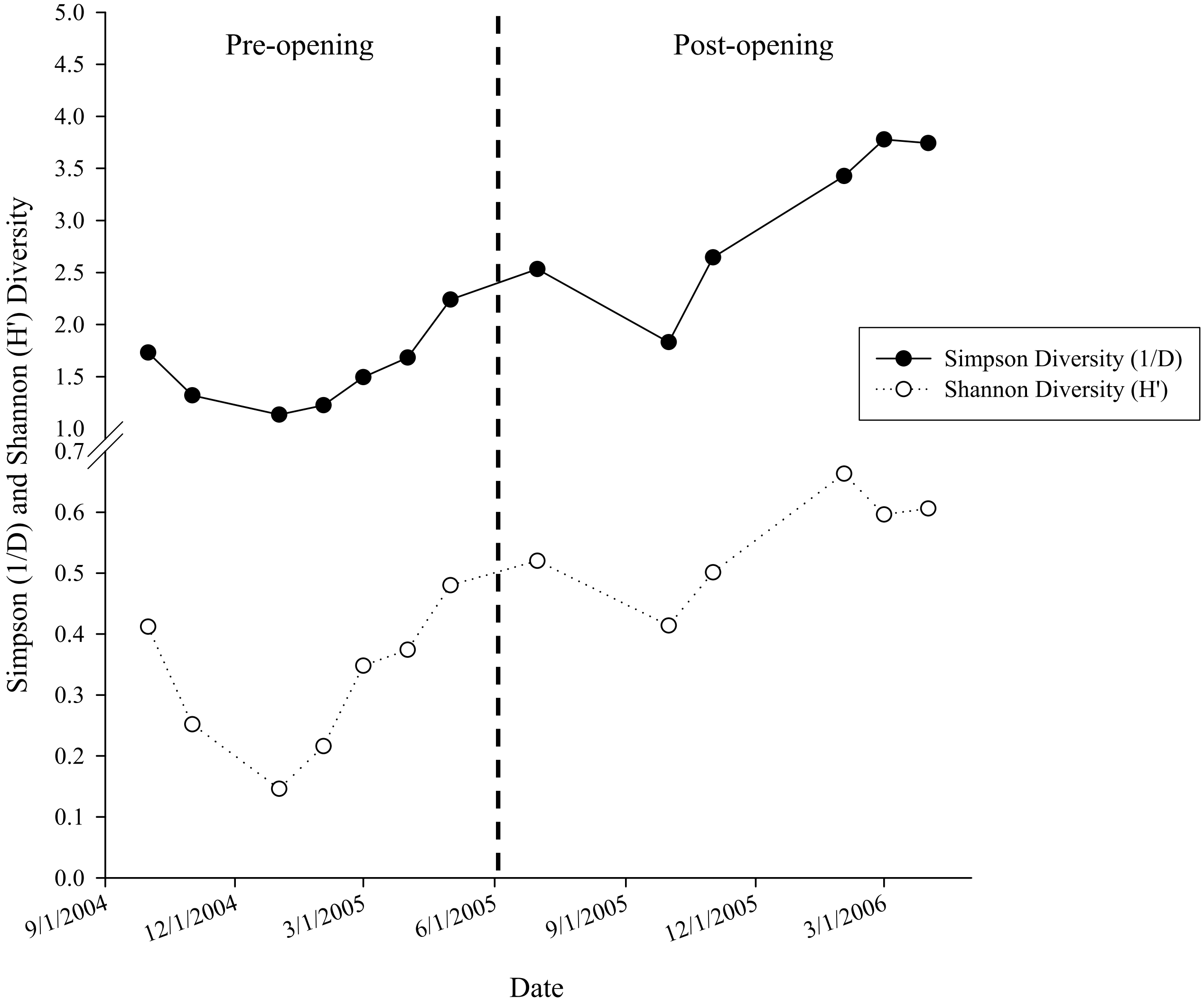


Figure 13. Indices of species diversity for nekton by sampling date with all locations combined. The solid line represents the reciprocal of the Simpson index (1/D) and the dashed line represents the Shannon index (H'). The dashed vertical line divides pre-opening (October 2004 – May 2005) from post-opening (July 2005-April 2006).

The Bray-Curtis similarity index was used to assess whether pre- and post-opening communities at each location had similar species composition and abundance. Mean densities of the individual species over all seasons were used in the analysis. The locations I expected to be similar due to proximity and distance from Packery Channel were first grouped for pre- and post-opening. Locations 1 and 2 were combined (named Packery) since they are along Packery Channel. Locations 3 and 4 were combined (named GIWW N) because they are both north of Packery Channel, with location 3 being on the GIWW and location 4 being just off the GIWW in Corpus Christi Bay. Locations 6 and 7 were combined (named GIWW S) since they are south of Packery Channel and are adjacent to the GIWW. Location 5 (named Humble) was not combined with any other locations because I expected it to be potentially the least impacted by Packery Channel since it is near the Humble Channel along the JKF Causeway (see Fig. 1). The similarity cluster (Fig. 14) showed no clear groupings distinguishing pre- and post-opening communities. Packery Pre (locations 1 and 2) and GIWW S Pre (locations 6 and 7) were somewhat similar (62.6%). Packery Post was not similar to Packery Pre indicating that community assemblages in these locations may have changed post-opening.

Another Bray-Curtis similarity cluster was used to assess similarity among locations pre- and post-opening (Fig. 15). The only locations that were grouped both pre- and post-opening were locations 1 and 2 (91.8% and 89.1% similarity, respectively). However, these groups were not very similar to each other pre- verses post-opening. There were no other clear location groupings to distinguish changes in community structure pre- verses post-opening.

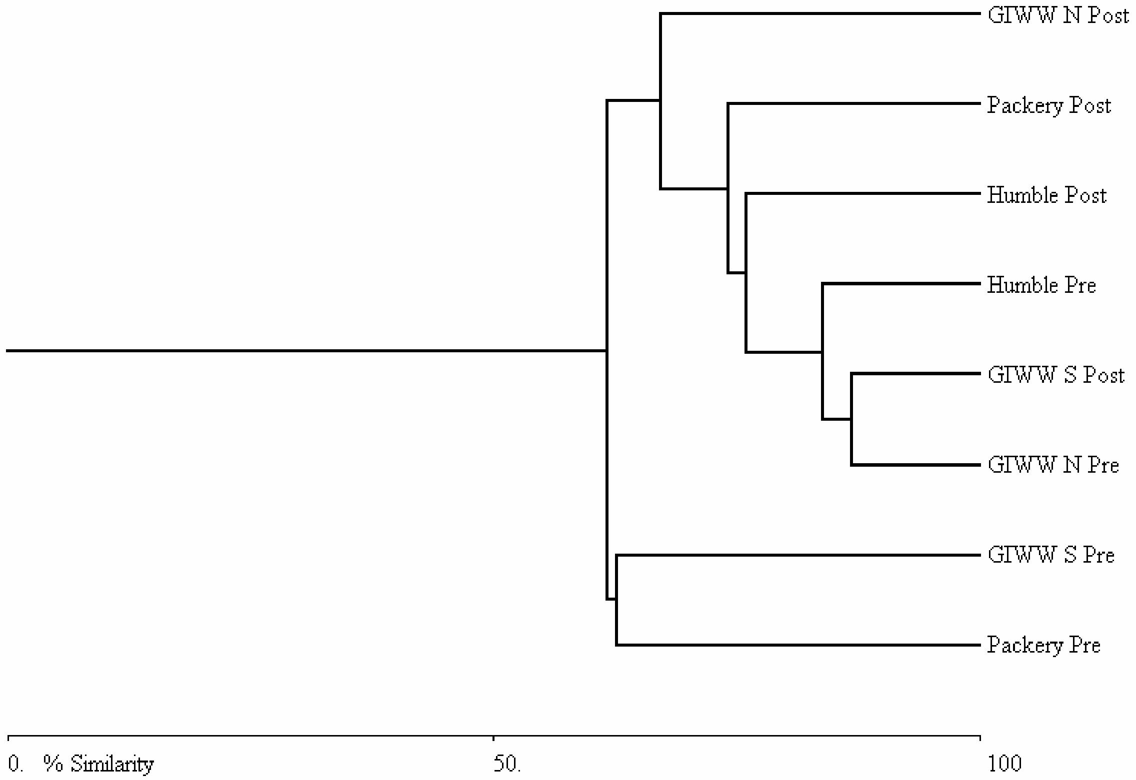


Figure 14. Bray-Curtis similarity cluster of combined locations. Locations 1 and 2 were combined (named Packery) since they are along Packery Channel. Locations 3 and 4 were combined (named GIWW N) because they are both north of Packery Channel with location 3 being on the GIWW and location 4 being just off the GIWW in Corpus Christi Bay. Locations 6 and 7 were combined (named GIWW S) since they are south of Packery Channel and are adjacent to the GIWW. Location 5 (named Humble) was not combined with any other locations. Pre = pre-opening (October 2004-May 2005). Post = post-opening (July 2005-April 2006).

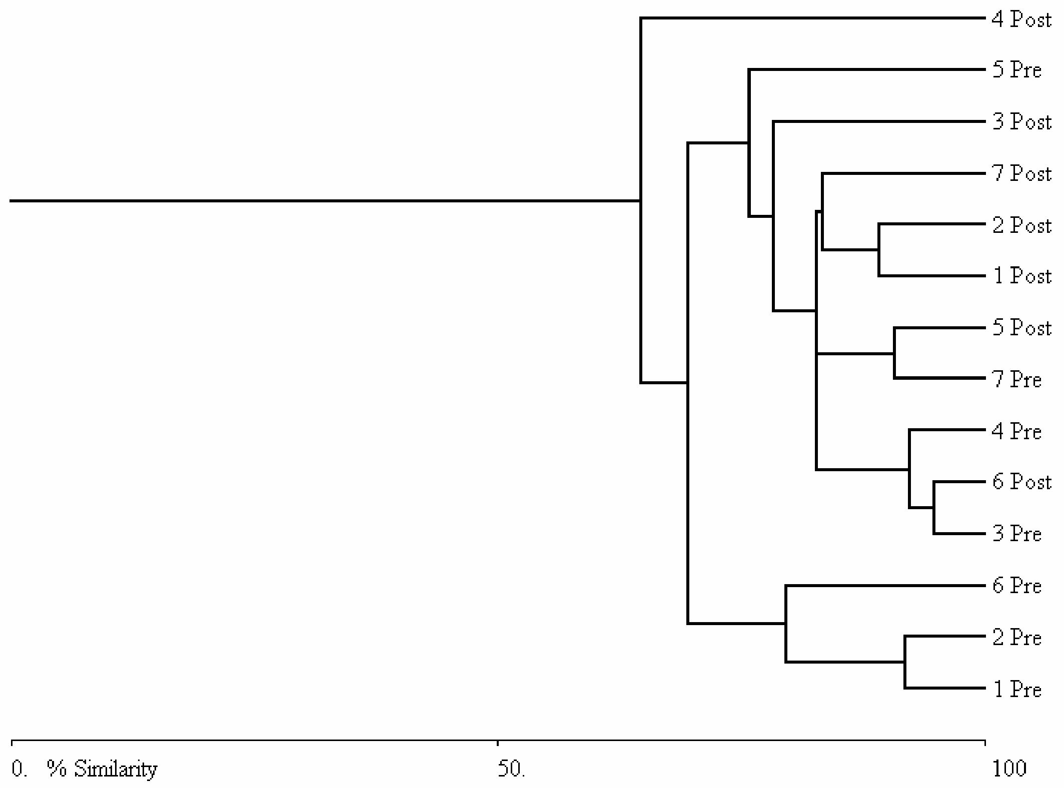


Figure 15. Bray-Curtis similarity cluster of each sampling location. Mean densities of individual species in each location over all seasons were combined and used in the analysis. Pre = pre-opening (October 2004-May 2005). Post = post-opening (July 2005-April 2006).

Otolith Analysis

I examined a total of 53 red drum otoliths from three different bay systems in Texas; 17 from Aransas Bay, 20 from Corpus Christi Bay, and 16 from the upper Laguna Madre. The overall mean age of red drum was 20.8 (SE = 0.37) d. There was a significant age difference between bay systems. Aransas Bay and Corpus Christi Bay were similar and the mean age in days was 21.6 (SE = 0.41) and 21.5 (SE = 0.66), respectively. Red drum from the upper Laguna Madre were significantly younger and had a mean age of 19.0 d (SE = 0.626) (P = 0.005; F = 6.051; *df* = 2,50). The overall average size of red drum was 12.6 mm SL (SE = 0.30). There was a significant size difference between bay systems. Aransas Bay and Corpus Christi Bay were similar and the mean size was 13.1 mm SL (SE = 0.33) and 13.4 mm SL (SE = 0.50), respectively. Red drum from the upper Laguna Madre were significantly smaller and had a mean size of 11.2 mm SL (SE = 0.50) (P = 0.005; F = 5.843; *df* = 2,50).

I used ANCOVA to determine differences in juvenile red drum growth rates between the different bay systems. I found a significant age-length relationship when using length (SL) as the dependent variable and age in days as the covariate ($P < 0.001$; F = 620.408; *df* = 1,49). There was no significant interaction (ANCOVA P = 0.832; F = 0.185; *df* = 2,47; 1-β = 0.077) between bay and age indicating that the slopes of the regression lines were not different among bay systems. There was no significant difference between bay systems (the independent factor) (ANCOVA P = 0.171; F = 1.832; *df* = 2,49; 1-β = 0.352) indicating that size-at-age was not different among bay systems (Fig. 16).

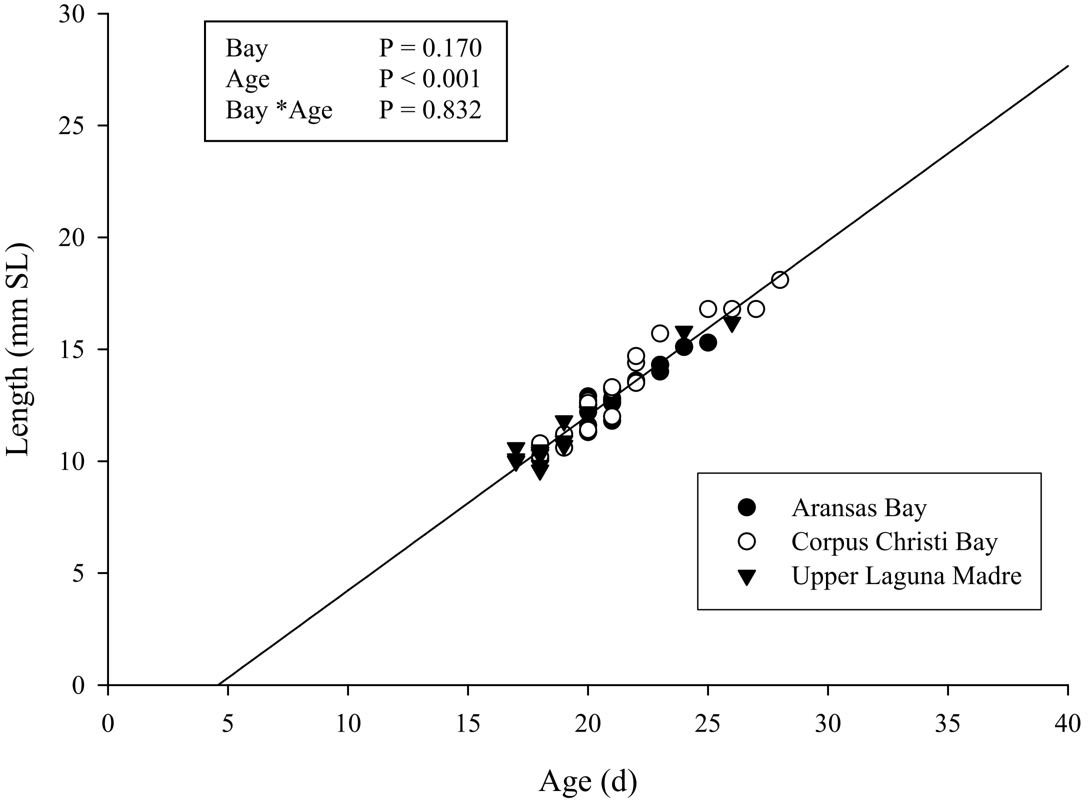


Figure 16. The relationship between age (d) and the length (SL) of red drum from Aransas Bay, Corpus Christi Bay, and the upper Laguna Madre, Texas. The ANCOVA results in the box compare the slopes of the age-length regression lines and show that there is no significant difference in the slopes of the age-length relationship in the different bay systems. The regression line shown is from the pooled age-length relationship from all three bay systems. $SL = -3.584 + 0.781$ (Age); $N = 52$; $R^2 = 0.936$; $P < 0.001$.

I also examined recent post-settlement growth of red drum collected from the three different bay systems. I found a significant relationship between red drum length and otolith diameter ($R^2 = 0.831$; $N = 53$; $P < 0.001$); therefore, otolith increment widths was used for the last 7 d of growth as a proxy for somatic growth (Fig. 17). Red drum growth rates were not related to age using this restricted age range ($R^2 = 0.07$; $N = 53$; $P = 0.054$; $1-\beta = 0.488$). Mean increment widths were 3.199 μm (SE = 0.064) for Aransas

Bay, 3.270 μm (SE = 0.069) for Corpus Christi Bay, and 3.064 μm (SE = 0.070) for the upper Laguna Madre (Fig 18). Recent post-settlement growth rates were 0.304 mm d^{-1} (SE = 0.001) for Aransas Bay, 0.304 mm d^{-1} (SE = 0.001) for Corpus Christi Bay, and 0.306 mm d^{-1} (SE = 0.001) for the upper Laguna Madre. There was no significant difference in mean increment widths for the last 7 d of growth among bay systems (P = 0.110; F = 2.310; *df* = 2,50; 1-β = 0.260).

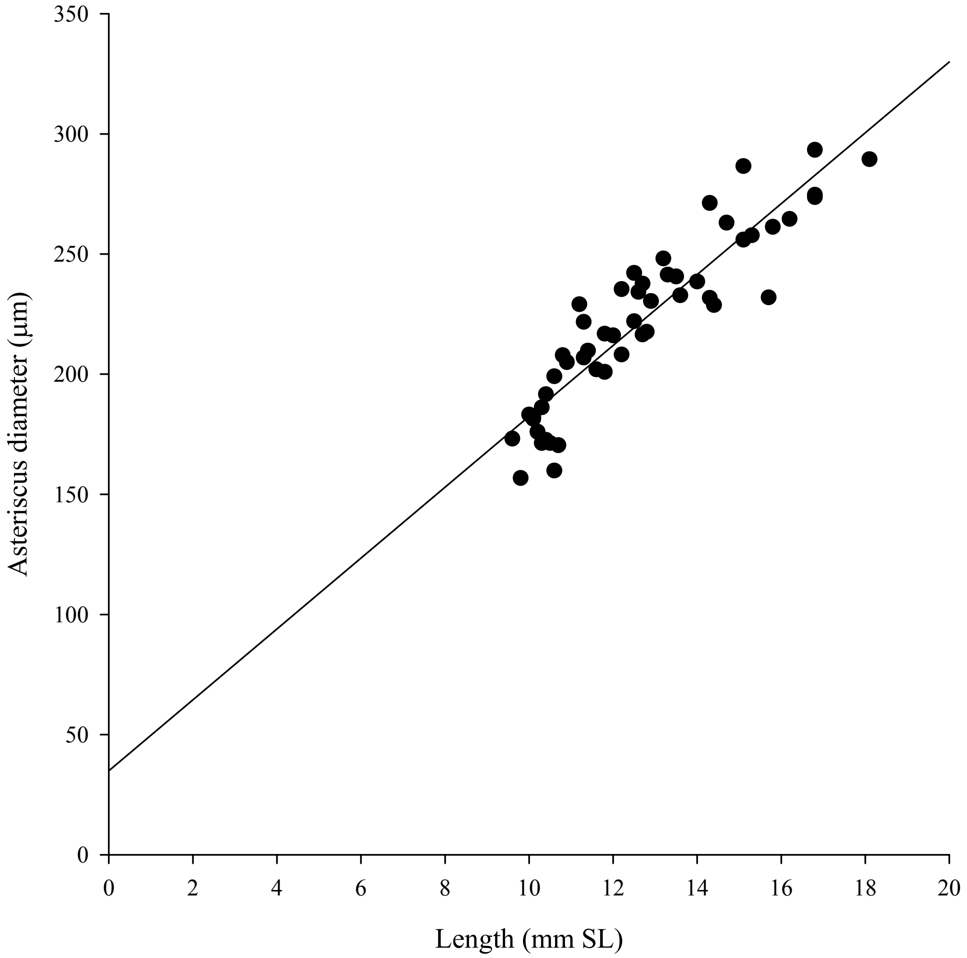


Figure 17. The relationship between the length (mm SL) and otolith diameter (μm) of the right asteriscus of juvenile red drum collected from Aransas Bay, Corpus Christi Bay, and the Upper Laguna Madre, Texas. Regression model: diameter = 34.631 + 14.752 (SL); N = 53; $R^2 = 0.831$; $P < 0.001$.

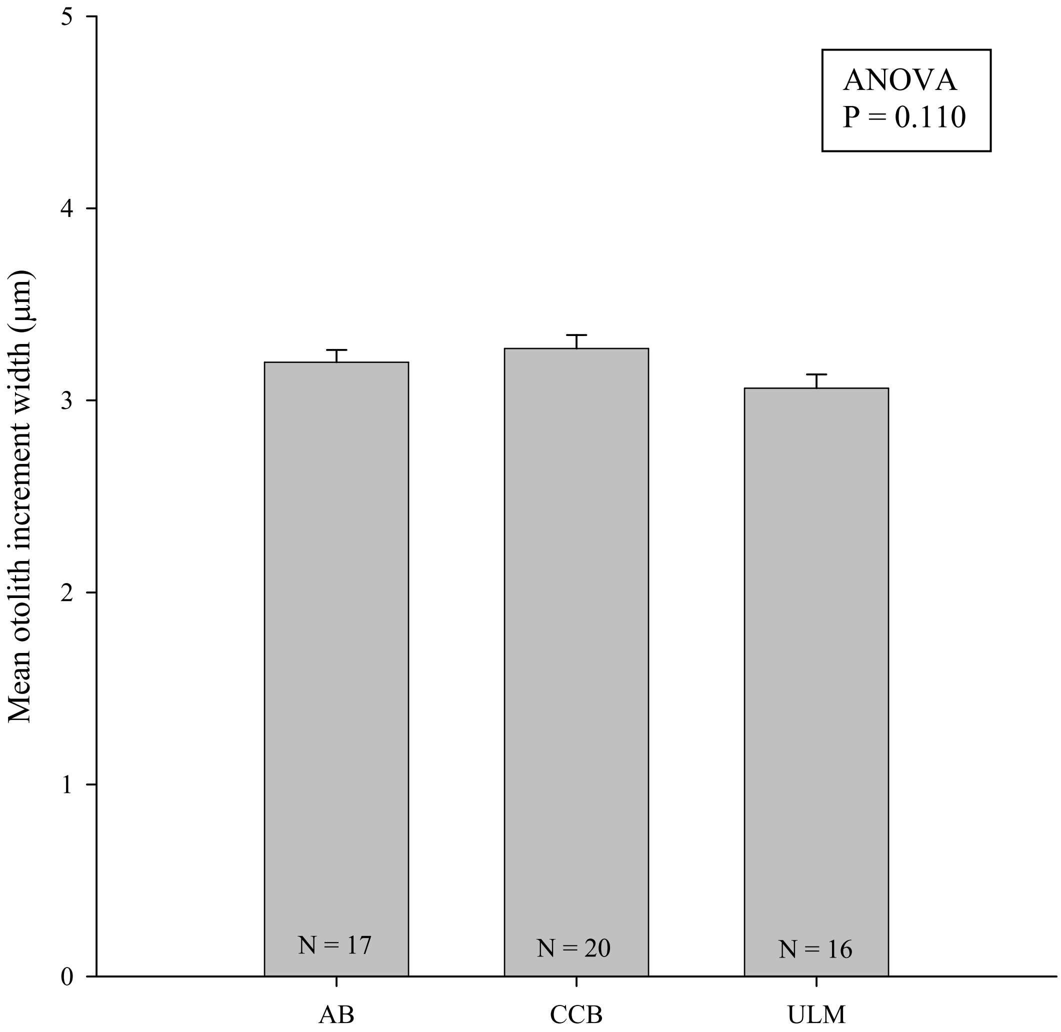


Figure 18. Mean otolith increment widths (± SE) for the last 7 d of growth for juvenile red drum collected from three Texas Bay systems. AB = Aransas Bay, CCB = Corpus Christi Bay, ULM = upper Laguna Madre. The number (N) of red drum used from each bay system is indicated at the bottom of each bar.

Discussion

This study was designed to assess the impact of opening Packery Channel on estuarine nekton in adjacent habitats. I assessed density patterns of many estuarine-dependent fish as well as determined changes in community structure and diversity patterns. I also assessed physical changes to habitats in the upper Laguna Madre since the FEIS by the USACE predicted minimal changes to the area (2003). Many differences were seen post-opening physically and biologically in terms of nekton density and community structure. Overall the opening of a new tidal inlet may have caused changes to estuarine nekton densities and associated communities in the habitats of the upper Laguna Madre. However, some of the changes documented may have been due to annual environmental fluctuations and not caused by Packery Channel (Blaber and Blaber 1980, Loneragan 1987, Moser and Gerry 1989, Garcia et al. 2001, Akin et al. 2003). Data also suggest that the opening of Packery Channel may increase fisheries productivity for some ecologically and economically important species.

Physical Parameters

Packery Channel appears to have altered certain hydrological parameters measured in this study such as depth, temperature, and salinity. Some of the physical changes to the area were unexpected. Water depth was significantly higher post-opening during the fall and spring seasons, whereas it was significantly lower post-opening in the winter and summer seasons. An increase in tidal fluctuations associated with the opening of Packery Channel may have caused the water depth changes observed, especially in the areas that are closest to the channel. However, water depth changes may also be due to regional or interannual tidal fluctuations. Packery Channel did not appear to change the dissolved oxygen levels post-opening in the surrounding area because they were similar in the fall, winter, and spring. Water temperature and salinity were significantly higher post-opening in fall, winter, and spring, which contradicts the FEIS by the US Army Corps of Engineers (2003) that projected periods of reduced hypersaline conditions in the upper Laguna Madre. The significance of increased salinity post-opening may be attributed to local annual meteorological changes since there was a decrease in precipitation over the post-opening sampling. While these events may be due to random variability and intertidal fluctuations, it is unclear if the physical changes observed were caused by the opening of Packery Channel. However, physical changes are important to document because changes in salinity and other physical variables may impact nekton assemblages and community structure (Hoff and Ibara 1977, Weinstein et al. 1980, Cyrus and Blaber 1992).

Nekton density and abundance

Many differences in nekton density and abundance were found after the opening of Packery Channel. There were significant differences in overall abundance of nekton pre- verses post-opening at all locations and sites combined. Overall, there were significantly fewer nekton present post-opening; however, fish and crustacean abundances (excluding grass shrimp) were not significantly different pre- verses post-opening. Reid (1957) also found that fish populations were not significantly affected with the opening of Rollover Pass in Galveston Bay, TX from 1954 - 1956. However, there were significantly fewer grass shrimp post-opening. The overall decline of grass shrimp appears to be driving the low overall densities of nekton post-opening. Overall nekton and grass shrimp densities showed the same distinct pattern of density decline in locations nearest the tidal inlet. This suggests that the overall difference in nekton density seen post-opening was driven by the decline in grass shrimp densities post-opening.

Grass shrimp densities in locations closest to Packery Channel were the most altered post-opening. Grass shrimp are an essential part of estuarine communities and are found throughout estuaries along the Gulf coast (Morgan 1980). They are a food source for many recreational and commercially important species such as red drum and spotted seatrout (Wood 1967). Grass shrimp are abundant throughout the year in seagrass habitats and usually exhibit peak abundances and growth rates from July to October with high water temperature, increased salinity, and abundant food from epiphytes on seagrass blades (Wood 1967, Morgan 1980). Post-opening both salinity and temperature were significantly higher than pre-opening indicating that grass shrimp densities should have increased. Pre-opening the areas directly adjacent to Packery Channel were backwater lagoons covered with dense seagrass meadows that experienced little tidal fluctuations and current. Once Packery Channel was open these locations changed from backwater lagoons with little tidal fluctuation to locations with increased tidal energy and current. With increased tidal fluctuations post-opening there were long periods of seagrass exposure, and I observed, but did not quantify, a decrease in seagrass cover in locations nearest the inlet. Grass shrimp select for seagrass cover to forage for food and to decrease predation (Morgan 1980; Orth et al. 1984), therefore the observed seagrass loss in some areas may have caused grass shrimp densities to sharply decrease post-opening. The dramatic change in grass shrimp (a resident estuarine species) densities post-opening demonstrate that Packery Channel could also potentially have a large impact on other estuarine-dependent species that use estuaries as nursery habitats (Sheridan 2004).

Red drum, pinfish, Atlantic croaker, southern flounder, blue crab, and penaeid shrimp are ecologically and economically important species that have varied seasonal recruitment patterns. In order to determine patterns of recruitment via Packery Channel their mean densities were compared pre- verses post-opening. All of these species generally follow the same life history pattern, where the adults spawn offshore in the Gulf of Mexico, typically near tidal inlets. Their eggs, larvae, and juveniles recruit via tidal inlets into estuarine nursery habitats where there is high productivity, survival, and growth rates of juveniles to adults (Minello 1999, Beck et al. 2001). Newly settled juveniles had very limited access to the extensive nursery habitats of the upper Laguna Madre prior to Packery Channel due to the great distance from the nearest tidal inlet (Aransas Pass to the north and Port Mansfield Pass to the south) (Bushon 2006). A new means of ingress to the upper Laguna Madre via Packery Channel allowed me to assess changes in seasonal densities of some estuarine-dependent species in the nearby habitats of Packery Channel.

Recruitment of economically and ecologically important fish species to the upper Laguna Madre via Packery Channel were assessed during their respective peak recruitment season(s). Red drum peak recruitment occurs from October through November (Rooker et al. 1998). Significantly higher densities of juvenile red drum in habitats adjacent to Packery Channel were observed post-opening. Similar patterns were seen for pinfish, Atlantic croaker, and penaeid shrimp. Peak recruitment for both pinfish and Atlantic croaker occurs in the winter (Patillo et al. 1997). Although pinfish were found in areas near Packery Channel pre-opening, there were significantly higher densities post-opening. Atlantic croaker showed the most dramatic density increase post-opening of all species analyzed during winter. Before Packery Channel was open there were very low densities of Atlantic croaker present, but in the winter post-opening they were one of the most abundant species found. Southern flounder juveniles recruit to estuaries from late winter through spring (Patillo et al. 1997). However, was no difference in their densities post-opening. This may be attributed to the low densities captured (6 individuals pre-opening and 7 individuals post-opening), therefore no difference was detected. These data suggest that Packery Channel may result in higher fisheries productivity since the nursery habitats of the upper Laguna Madre are now accessible to numerous estuarine-dependent species. Because seagrass meadows typically sustain high densities of newly recruiting fisheries species and support rapid growth rates, access to the habitats of the upper Laguna Madre may ultimately increase the survival of juveniles that could contribute to adult populations (Rozas and Minello 1997, Minello 1999, Beck 2001).

Penaeid shrimp also showed similar recruitment patterns to the upper Laguna Madre via Packery Channel. All three species of penaeid shrimp were combined for analysis and were analyzed over all seasons because of their variable recruitment patterns. Brown shrimp postlarvae move into estuaries from February to April and have been found to recruit year round; pink shrimp postlarvae recruit into estuaries during summer months; white shrimp postlarvae migrate into estuaries from May to November with peaks in June and September (Patillo et al. 1997). There were fairly high densities of penaeid shrimp in the areas around Packery Channel pre-opening, however post-opening there was a large increase in their densities. Although my data suggest that penaeid shrimp were able to disperse to the upper Laguna Madre via other tidal inlets, it also suggests that they may be recruiting via Packery Channel since higher densities were observed post-opening. Packery Channel may also increase penaeid shrimp productivity with increased access to the upper Laguna Madre, however the increase may be hard to detect since shrimp were able to recruit to these areas in large numbers even before Packery Channel was open.

Because I saw an increase in penaeid shrimp densities post-opening, I expected to observe a similar trend with blue crab densities. Blue crabs also have a very complex life cycle, and their larvae are able to disperse great distances. Larvae are released near tidal inlets, but then move out over the continental shelf where the larvae develop. Tidal current transports postlarvae into estuaries where they disperse (Etherington and Eggleston 2000). It has been suggested that blue crabs may disperse up to 300 km (Patillo et al. 1997). Blue crab peak recruitment into estuaries occurs during the fall and spring, but have been documented to recruit year round (Patillo et al. 1997, Etherington and Eggleston 2000). I found that blue crab densities were not different pre- and post-opening, suggesting that blue crabs easily dispersed 35 km from Aransas Pass to habitats near Packery Channel before the inlet was open. This provides supporting evidence that blue crabs have a wide dispersal pattern, and that Packery Channel may have little impact to the overall productivity of the blue crab fishery. However, it does appear that blue crabs are recruiting to the upper Laguna Madre via Packery Channel since post-opening juvenile blue crab were much smaller. Because blue crabs are able to disperse such great distances other physical, and biological interactions may play a greater role in determining their overall dispersal and recruitment success.

Larval settlement and dispersal within estuaries is due to the interaction of many physical and biological processes (Brown et al. 2005). I found that some species of fish and especially crustaceans were able to disperse approximately 35 km from Aransas Pass to habitats in the upper Laguna Madre at fairly high densities before Packery Channel was open. These data are consistent with typical particle circulation patterns in Corpus Christi Bay (Brown et al. 2005). These authors created a circulation model and physical transport model of the Corpus Christi Bay/Redfish Bay/Aransas Bay complex to determine settlement patterns of red drum that recruit via Aransas Pass. Their model found that particles (larvae) accumulate along the southern boundary of Corpus Christi Bay and the upper Laguna Madre, which is near Packery Channel. This helps explain how juvenile penaeid shrimp and blue crabs were able to disperse to habitats adjacent to Packery Channel before the inlet was open. Because crustaceans appear to be able to disperse to these habitats from Aransas Pass, it may be more difficult to determine how much of the density increase post-opening was due to the opening of Packery Channel.

Examining the mean size of fish and crustaceans pre- verses post-opening provides additional support for the hypothesis that estuarine-dependent species will use Packery Channel to access the habitats of the upper Laguna Madre. The species that were able to reach areas near Packery Channel before the inlet was open were most likely growing while they were dispersing. In general species found near Packery Channel pre-opening should be larger than species that would recruit via Packery Channel and quickly settle into seagrass meadows. All of the economically important species examined for this study, with the exception of southern flounder, were significantly smaller post-opening. Juvenile red drum settle into seagrass meadows between 6-8 mm SL (Holt et al. 1983, Rooker and Holt 1997), and I observed very few in this size range pre-opening. However, the mean size of red drum post-opening in the upper Laguna Madre was approximately 9 mm SL suggesting that red drum were recruiting to these habitats via Packery Channel. Although densities of blue crabs were not significantly different pre-verses post-opening, the blue crabs collected post-opening were significantly smaller suggesting they also were recruiting to the upper Laguna Madre via Packery Channel. Southern flounder were collected at such low densities that differences in their mean size pre- and post-opening were not detected. Pinfish, Atlantic croaker, and penaeid shrimp all had the same size pattern as with red drum in that they were significantly smaller post-opening. This pattern suggests that economically important fishes are using Packery Channel as a means of recruitment to the nursery grounds of the upper Laguna Madre.

Clearly, there is strong evidence to suggest that many estuarine-dependent species are accessing the extensive seagrass meadows of the upper Laguna Madre via Packery Channel. However, it has not been established how densities of these species compare with other established tidal inlets. Aransas Pass is the closest tidal inlet to Packery Channel, which is a permanent tidal inlet approximately 35 km north that provides water exchange between the Gulf of Mexico and Aransas and Corpus Christi Bays. Water is transported to Aransas Bay via the Lydia Ann Channel (~6 m deep and 40 m wide), and to Corpus Christi Bay via the Corpus Christi Ship Channel (14 m deep and ~150 m wide) (Brown et al. 2000). Using red drum as a “model” species for recruiting nekton, their mean densities from the upper Laguna Madre (Packery Channel) both pre- and post-opening were compared to densities from Corpus Christi Bay and Aransas Bay. Red drum recruitment and settlement via Aransas Pass has been well documented and it is established that high densities of newly settled red drum occur in Aransas and Corpus Christi Bays (Holt et al. 1983, Holt et al. 1989, Rooker and Holt 1997, Rooker et al. 1997, Rooker et al. 1998, Herzka et al. 2002, Bushon 2006). Red drum mean densities observed post-opening in the upper Laguna Madre (0.03 m^{-2}) did not compare in magnitude to the mean densities found in Aransas and Corpus Christi Bays (approximately 0.6 – 1.0 m^{-2}), which are typical densities found in these areas (Rooker et al. 1998). This suggests that Packery Channel may not be delivering as many recruits as a natural inlet in terms of nekton recruitment or these new recruits are not surviving. The low densities may be attributed to the incompletion of the Packery Channel project during the fall post-opening sampling. There was water exchange with the Gulf of Mexico to the upper Laguna Madre, however the inlet was not fully dredged. Future sampling once the project is fully complete is needed to determine if project incompletion was the cause of low red drum densities in the upper Laguna Madre as compared to Aransas Bay and Corpus Christi Bay, or if there is a functional difference between the habitats in Aransas and Corpus Christi Bays compared to the upper Laguna Madre.

Although densities of nekton are a good predictor of habitat quality, it is also essential to understand the functionality of nursery habitats (Heck et al. 1997, Minello 1999, Beck et al. 2001). The functionality of seagrass meadows in Aransas Bay, Corpus Christi Bay, and the upper Laguna Madre (Packery Channel) was determined using growth rates of juvenile red drum. Generally, high quality habitats will support rapid growth rates so as to reduce the time juvenile fish and invertebrates spend at sizes most vulnerable to predation (Chambers and Leggett 1987, Houde 1987, Bertram and Leggett 1994, Levin et al. 1997, Stunz et al. 2002*b*). Using red drum as a model species I collected fish from three bay systems to determine differences in habitat functionality. I found a significant relationship between otolith diameter and length of the fish, which allowed me to use otoliths proxy for recent growth, since there is a direct relationship between otoliths and somatic growth (Campana and Nielson 1985, Secor and Dean 1989). I examined age-length relationships of fish from the different bay systems and found no difference in growth history over the life of the fish between bays. Since red drum settle into nursery habitats at approximately 6-8 mm SL (Holt et al. 1983, Rooker and Holt 1997), I also examined recent growth (last seven d) to determine bay-related growth rates. The overall post-settlement growth rate of red drum was 0.31mm SL day^{-1}, which is similar to red drum growth rates measured in other studies. Red drum average growth rates in Aransas Bay are between 0.50-0.80 mm SL d^{-1} (Rooker and Holt 1997, Rooker et al. 1997) and 0.45 mm SL d^{-1} in Galveston Bay (Stunz et al. 2002*b*). I found no difference in recent growth between bay systems indicating that seagrass meadows among these bays do not function differently. High red drum recruitment to Aransas and Corpus Christi Bays has been well documented and growth rates established (Holt et al. 1983, Holt et al. 1989, Rooker and Holt 1997, Rooker et al. 1997, Rooker et al. 1998, Herzka et al. 2002). The upper Laguna Madre supports similar growth rates for newly settled red drum as with Aransas and Corpus Christi Bays, indicating that the habitats adjacent to Packery Channel function as nursery habitats for red drum. From a fishery prospective it indicates that the upper Laguna Madre may potentially contribute to the overall red drum fishery. The low red drum densities found near Packery Channel are therefore most likely due to the inlet not being fully open, and not due to the functionality of the adjacent habitats.

Because many economically important fish require access to estuaries for nursery grounds for their early life stages, tidal inlets play a critical role in this process. Packery Channel now provides access to the very productive upper Laguna Madre as nursery grounds for nekton that recruit through inlets such as red drum, blue crabs, and penaeid shrimp. The opening of Packery Channel could potentially translate into higher fisheries productivity. At the conclusion of this study, the Packery Channel had substantial flow, but was still under construction. Further dredging is planned to deepen and widen the channel. These activities will dramatically increase flow and likely result in higher recruitment potential for nekton that rely on these tidal currents for access to estuarine nursery habitats.

Community assemblage

There did not appear to be major impacts on the overall fish densities in the surrounding habitats of Packery Channel pre- verses post-opening. With all species, seasons, and locations combined there was not a significant difference in fish density post-opening. Even the relative abundances of fish over each season showed little change in composition. Killifish and pipefish were both predominant in the fall samples both pre- and post-opening. In the winter, spring, and summer killifish, pinfish, and either darter or code gobies were the dominant species both pre- and post-opening. Although generally the same dominant species were present each season, the change in relative abundance of some species changed dramatically. In all seasons, killifish relative abundances decreased dramatically. Although they were still the most dominant group post-opening, there were fewer individuals. Darter goby abundances increased post-opening while code gobies decreased over all seasons. Gobies were also very dominant in the overall abundances seasonally, but post-opening a shift occurred from the code goby to the darter goby. Changes in grass shrimp densities were previously discussed, but there were also dramatic changes in their relative abundance seasonally. During fall, winter, and spring there was a large decline in relative abundance. Summer was the only season where grass shrimp abundances increased. The summer post-opening sampling occurred during the same year and took place directly after Packery Channel opened, so changes in grass shrimp abundances may not have been detected. Overall, the shifts in nekton relative abundances illustrate shifts in community assemblages post-opening, which may be influenced by the new tidal inlet.

Killifish, darter gobies, code gobies, and grass shrimp are all estuarine residents, meaning they complete their life cycle within the estuary (Day et al. 1989). Abundance changes in these species may not be attributed to the opening of Packery Channel. Numerous studies have documented how changes in physical parameters can alter nekton assemblages (Blaber and Blaber 1980, Loneragan et al. 1987, Moser and Gerry 1989, Peterson and Ross 1991, Cyrus and Blaber 1992, Garcia et al. 2001, Akin et al. 2003). The changes in physical parameters seen post-opening is most likely due to annual cycles rather than Packery Channel, as discussed earlier. Garcia et al. (2001) attributed differences in estuarine fish assemblages to varying environmental changes caused by years of high and low precipitation. Cyrus and Blaber (1992) reported similar findings, in that salinity is one of the most important physical factors that may affect fish distribution. However, killifish losses may be attributed to the increased current and wave action of locations directly adjacent to Packery Channel post-opening. Jenkins et al. (1997) found that disturbance due to wave action may be a major physical factor for variation in fish abundance. Once Packery Channel was open areas very near the inlet experienced much greater energy due to increased current and flow, and also due to increased wave action from boating activities. Increases in these physical stresses may have caused a decrease in killifish abundance post-opening. Therefore, Packery Channel may not have caused the changes in relative abundance of some estuarine resident species because salinity and other physical factors directly influence nekton assemblages.

Atlantic croaker, pinfish, spotfin mojarra, and penaeid shrimp all showed increases in relative abundances post-opening, indicating seasonal variation in recruitment and migration. It has been well documented that changes in abundance of estuarine fishes can be largely attributed to seasonal fluctuations of estuarine-dependent species (Dalhberg and Odum 1970, McErlean et al. 1973, Weinstein et al. 1980). As previously discussed, there is evidence that these species recruited to the estuarine habitats of the upper Laguna Madre, resulting in small seasonal shifts in diversity and therefore community assemblage.

Two diversity indices were used to analyze the community structure of the areas adjacent to Packery Channel. Diversity was calculated during each sampling period since shifts in diversity due to seasonal and environmental fluctuations were seen (Livingston 1976). Both the Shannon-Weiner and the reciprocal of the Simpson’s index were used to assess assemblage differences, considering both dominant and rare species. Both indices followed the same pattern over all sampling dates. Post-opening diversity was higher although shifts in seasonal diversity are somewhat similar pre- and post-opening. Diversity decreased from fall to winter and then steadily increased towards the summer months. This same general trend was observed post-opening. My results are similar to those of Livingston (1976) who found that diversity peaked with periods of elevated salinity and temperature. The highest diversity was seen during the summer sampling concurrent with both high water temperature and salinity. I also saw increased salinity post-opening, which may explain the higher diversity post-opening. However, Packery Channel may have influenced the higher diversity post-opening. I saw increased densities of estuarine-dependent species, which may have translated into increased species richness since many of those species (red drum and Atlantic croaker) had limited access to the upper Laguna Madre pre-opening. Such increases may have affected diversity levels post-opening.

A multivariate analysis was used to evaluate species composition and abundance, to identify areas that may have experienced the greatest influence from Packery Channel, and also to characterize community assemblage patterns in locations that were at varying distances from Packery Channel. Sampling locations were first grouped by locality to determine the areas that may have showed the greatest impact to Packery Channel. The Bray-Curtis similarity matrix showed no clear groupings of the different sampling areas. I predicted that the Humble Channel category would be similar pre- and post-opening since it was one of the farthest areas sampled from Packery Channel and was the most dissimilar from the other locations since it was not located on the GIWW or directly adjacent to Packery Channel. However, the Humble Channel category was not grouped and was dissimilar pre- and post-opening. This suggests that other environmental or seasonal variables were affecting community dynamics in the upper Laguna Madre. The pre-opening Packery category was grouped with GIWW south, which supports my previous density results, suggesting that pre-opening locations 1 and 2, and possibly 6 were very different from all other locations both pre- and post-opening. To analyze this further another Bray-Curtis similarity matrix was used to analyze all individual locations. The only locations that were grouped with high similarity both pre- (91.8%) and post-opening (89.1%) were locations 1 and 2. This substantiates the initial location groupings. There are no other clear trends among locations or between pre- and post-opening. As seen with overall nekton and grass shrimp densities, locations 1, 2, and 6 were altered the greatest post-opening. Location 6 was not grouped with 1 and 2 post-opening, indicating that it may not be as similar to these locations as previously thought. With no other distinct groupings, the zone of influence of Packery Channel may not be as large as initially hypothesized. Habitats not directly adjacent to the inlet were most likely influenced by other physical and biological dynamics, which seem to shape the faunal communities of the upper Laguna Madre. Habitats directly adjacent to Packery Channel were most impacted by the nearness to the inlet, which may be the extent of the zone of influence of the opening of this new tidal inlet.

Packery Channel may not have affected the community structure of the upper Laguna Madre except for areas directly adjacent to the inlet. The diversity indices showed that there was increased diversity post-opening with all sampling location combined. Diversity of seagrass-associated nekton varies both locally and geographically with physical structure and complexity being some of the most influencing factors on community structure (Heck and Orth 1980). The structure and complexity of seagrass in these areas may have changed because of increased wave action, boating activities, and tidal range once the inlet was open, therefore causing severe disturbances in areas directly adjacent to Packery Channel. These disturbances may have caused an increase in the heterogeneity of the environment and therefore an increase in diversity post-opening (Pielou 1966, Heck and Orth 1980). This is substantiated by a multivariate Bray-Curtis analysis showing that Packery Channel most likely influenced community dynamics in areas closest to the inlet. It is important to document diversity and community changes long-term in these areas to understand the full impact of Packery Channel on nekton residing in the habitats of the upper Laguna Madre.

Conclusions

Very few studies have examined the impact of opening a tidal inlet on estuarine nekton. The information provided by Reid (1957) is the only published work describing the estuarine effects of opening Rollover Pass in Galveston, Texas. The opening of Packery Channel has revealed some expected and unexpected trends in nekton densities and overall community changes. There is strong evidence to suggest that many estuarine-dependent species, such as red drum, penaeid shrimp, and blue crabs are recruiting to the productive seagrass meadows of the upper Laguna Madre via Packery Channel. This may increase fishery productivity for some of these economically and ecologically important species. However, the overall impact on community structure of these habitats is less clear. Initially, it was hypothesized that Packery Channel would have a large zone of influence due to the FEIS by the USACE. However, the community similarity analysis showed only one clear location grouping post-opening indicating that overall differences seen in community assemblage were most likely due to an annual or environmental affect rather than to the opening of Packery Channel. Locations closest to Packery Channel appeared to be the most affected by the opening of the inlet because I observed a loss of seagrass in these areas and fewer grass shrimp post-opening. The changes found in these locations may be attributed to a shift from a low energy backwater lagoon pre-opening to a high-energy habitat adjacent to an inlet post-opening. Although there was higher diversity after Packery Channel was open, it is not clear whether this was due to the inlet or to other environmental variables. Future studies are necessary to determine what influence Packery Channel will have to these habitats and the community structure over time. Overall, there is evidence to suggest that opening Packery Channel may provide a means of increased fishery productivity for many estuarine-dependent species, such as red drum, penaeid shrimp, and blue crabs, because of new means of access to the productive nursery habitats of the upper Laguna Madre.

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