IMPACTS OF A NEW TIDAL INLET ON ESTUARINE NEKTON:
Fisheries recruitment assessment of Packery Channel post-opening in Corpus Christi, Texas

Publication CBBEP – 57
Project Number – 0720
December 2008

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Acknowledgements

We would like to thank the Coastal Bend Bays and Estuaries Program (CBBEP) for funding this research. We would also like to thank the staff of CBBEP, particularly Jace Tunnell, for their help and support throughout this study. We also thank Deidre Williams and Lanmon Aerial Photography, Inc. for providing aerial photography. This project would not have been possible without the members of the Fisheries Ecology Lab at TAMU-CC and their numerous hours of field and laboratory help. We particularly would like to thank Sarah Bayer, Heather Barackman, Annette Cardona, Rafael Calderon, Alyssa Dailey, Ryan Fikes, John Froeschke, Todd Neahr, and Brooke Stanford.

Packery Channel – Post Opening – Fisheries Recruitment Assessment (Nekton)

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Executive Summary

The US Army Corps of Engineers dredged and permanently reopened Packery Channel, historically a natural tidal inlet, to allow water exchange between the Gulf of Mexico and the Laguna Madre, Texas. The main objective of this study was to assess the impact of opening this channel on estuarine-dependent recruitment and community structure in seagrass habitats adjacent to Packery Channel pre- and post-channel opening. During Phase I of this study we sampled fish and crustacean abundance using an epibenthic sled in *Halodule wrightii* seagrass meadows in both control and impact locations over one-year before the opening of Packery Channel (October 2004-May 2005) and one-year after (July 2005-April 2006). During Phase II, which is the focus of this report, we continued sampling seagrass habitats seasonally from February 2007 – July 2008. In the first phase we found significantly fewer overall nekton abundance post-channel opening. However, we found significantly higher mean densities of newly-settled estuarine-dependent species (*Sciaenops ocellatus, Micropogonias undulatus, Lagodon rhomboides, Callinectes sapidus*, and penaeid shrimp) post-opening. We monitored these same areas during 2007 and 2008, and these estuarine-dependent species also occurred at high densities post-channel opening. Multivariate analyses showed significant community assemblage changes post-opening for both phases of the study with increased contribution of estuarine-dependent species post-opening. Our results show that estuarine-dependent nekton are using Packery Channel as a means of ingress into areas of the upper Laguna Madre's seagrass meadows that were previously inaccessible, which will translate into higher fisheries productivity for some of these economically and ecologically important fishery species such as *S. ocellatus*, penaeid shrimp, and *C. sapidus*. Moreover, we found continued high densities of estuarine-dependent species over the 2-year study period, possibly resulting in increased fisheries productivity long-term.

Introduction

Many nekton occurring in coastal waters share a common life history strategy characterized by near-shore spawning with larvae migrating through tidal inlets into shallow estuarine "nursery" grounds (Weinstein 1979; Baltz et al. 1993; Kneib 1993; Minello 1999; Heck et al. 2003). Therefore, access to high quality habitat in estuarine areas via tidal inlets is critical for reproduction, growth, survival, and sustainability of these populations. Access to nursery habitats has both ecological and economic implications because as much as 75% of commercially or recreationally important species in the Gulf of Mexico are estuarine-dependent (Chambers 1991).

In an effort to restore flow between the Gulf of Mexico and the upper Laguna Madre, TX, the United States Army Corps of Engineers (USACE) completed a project in 2005, named North Padre Island Storm Damage Reduction and Environmental Restoration Project, that permanently reopened the Packery Channel, a historic tidal inlet. The tidal inlet was periodically open until the 1930s, but has since remained closed due to natural sedimentation until the completion of the USACE project. The new inlet is approximately 4 m deep and 37 m wide, and extends 5.6 km from the seaward end of the jetties to the Gulf Intracoastal Waterway (GIWW) (United States Army Corps of Engineers 2003). Impacts of the new inlet to the upper Laguna Madre were mathematically modeled to extend north into Corpus Christi Bay and south towards Baffin Bay (United States Army Corps of Engineers 2003). The USACE (2003) predicted that hypersaline conditions in the upper Laguna Madre negative estuarine complex would be periodically reduced due to the new connection to the Gulf of Mexico; however, overall changes in hydrodynamics were expected to be minimal to the system.

For estuarine-dependent nekton, Packery Channel creates a direct link between the Gulf of Mexico and nearby habitats (e.g., primarily seagrass meadows) in the upper Laguna Madre. The new channel is 35 km from the nearest tidal inlet (Aransas Pass), and a new means of ingress into the estuarine system may result in higher fisheries productivity, since these adjacent nursery habitats were previously inaccessible to nekton recruiting from other inlets (Bushon 2006). The upper Laguna Madre is a highly productive hypersaline estuary because of its shallowness (average depth 75 cm) with extensive seagrass meadows (Quammen and Onuf 1993). Submerged aquatic vegetation (SAV) 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). Therefore, the upper Laguna Madre could potentially sustain higher densities of newly recruiting fisheries species, support rapid growth rates, and ultimately increase survival of juveniles that may subsequently contribute to adult populations (Minello 1999; Beck et al. 2001; Heck et al. 2003).

A new tidal inlet may influence fishery productivity and impact the nekton community structure of the upper Laguna Madre. Changes in physical (distance from tidal inlets, salinity, water depth, etc.) and biotic factors (food abundance, predation, competition, and life history traits) have been shown to impact nekton abundance and community assemblages (Hoff and Ibara 1977; Weinstein et al. 1980; Rozas and Hackney 1984;

Kneib 1993; Levin et al. 1997). The opening of Packery Channel may cause both physical and biological changes. In particular, variation in seasonal migrations of estuarine-dependent species through the new tidal inlet has the potential to influence community structure.

Few studies have related estuarine species composition and abundance to the open/closed period of tidal inlets along the Texas coast. Reid (1957) published the only Texas study assessing the impact of dredging and reopening a tidal inlet on estuarine organisms by examining the impacts of opening Rollover Pass in Galveston Bay, Texas from 1954-1956. Reid (1957) suggested that stenohaline marine forms were immigrating into the estuary after opening of the inlet due to higher salinity levels. Simmons and Hoese (1959) studied Cedar Bayou Pass in Mesquite Bay, Texas during periods when the inlet was open and when it naturally closed due to sedimentation. They determined that when open, it was important to the migration and development of young penaeid shrimp, *Sciaenops ocellatus*, and *Paralichthys lethostigma*. More recently, several studies have been conducted in southern Australia on intermittently open/closed tidal inlets and their impact to nekton densities and assemblages. Most of these studies have shown that after opening a previously closed inlet there are increased densities of estuarine-dependent species (Griffiths and West 1999; Griffiths 2001; Jones and West 2005) and nekton community changes, which may be attributed to the increase of tidal flow and a closer distance to the ocean (Young and Potter 2003).

In 2004 and 2005 we conducted a study (Phase I) determining the immediate impact of opening Packery Channel on estuarine-dependent species. The goal was to determine if Packery Channel provides a means of ingress to nursery habitats of the upper Laguna Madre that were previously inaccessible for many estuarine-dependent species, such as red drum, penaeid shrimp, and blue crabs (Reese et al. 2008). We also assessed differences in community composition post-opening due to seasonal migrations of juvenile estuarine-dependent species. The purpose of this study (Phase II) is to assess the impact of Packery Channel on ecologically and economically important nekton several consecutive years post-channel opening, and compare our finding to results from Phase I of this large project.

Methods

<u>Study Location</u>

The Laguna Madre is a bar-built coastal lagoon and one of the largest hypersaline systems in the world (Javor 1989). It extends approximately 200 km south from Corpus Christi Bay to the Mexico border (McKee 2008) and is separated into two sub-units (the upper Laguna Madre and lower Laguna Madre) by the Land Cut south of Baffin Bay (Tunnell et al. 2002). Salinities in the upper Laguna Madre are typically 40 ppt, but historically salinities have reached >100 ppt (Quammen and Onuf 1993). Seagrass meadows (primarily *Halodule wrightii*) are the predominant habitat type due to its ability to tolerate high salinities (Britton and Morton 1989).

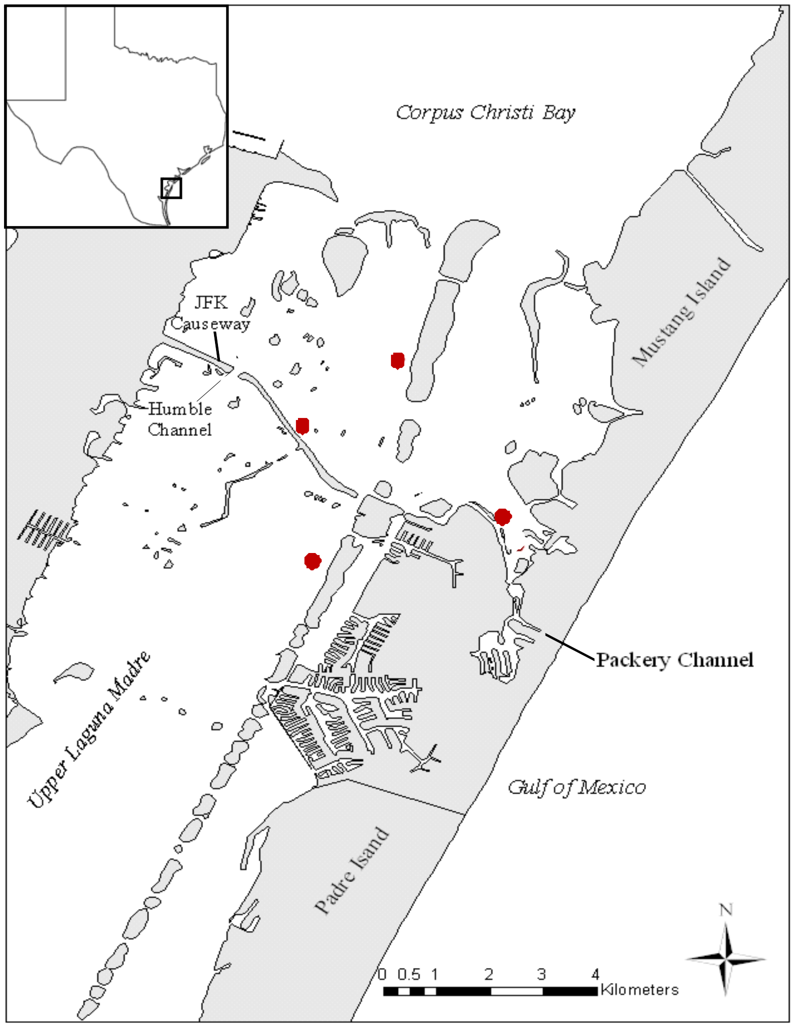

Figure 1. Study map representing the four sampling locations in the upper Laguna Madre, Texas from 2007 – 2008.

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

We established four sampling locations at varying distances from Packery Channel (Fig. 1) with two sampling sites in each location based on Phase I sampling of Packery Channel (Reese et al. 2008). We collected nekton triplicate samples at each location using an epibenthic sled. 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. It 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). Samples were collected seasonally from February 2007 – July 2008; twice in the winter and fall, and once in the spring and summer. Samples were rough-sorted in the field and pre-served in 10% formalin. In the laboratory, 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 or total length (TL) for shrimp. If more than 20 individuals were caught for each species, the largest and smallest and 20 other random individuals were measured. Post-larval brown shrimp (*F. aztecus*), pink shrimp (*F. duorarum*), and white shrimp (*Litopenaeus setiferus*) that were collected at an unidentifiable size range (10 – 18 mm TL) were all were grouped into "penaeid shrimp" (Rozas and Minello 1998).

At each of the locations (4 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 was also recorded during each sampling period.

<u>Statistical Analysis</u>

Phase I Analysis

Data were analyzed with ANOVA using SAS 9.1 in a before-after-control-impact (BACI) design to identify nekton density changes due to an environmental change (Stewart-Oaten and Murdoch 1986), such as opening Packery Channel. We used a partially-nested hierarchical ANOVA model with before-after (BA) and control-impact (CI) as fixed main effects and locations as random effects. Sampling dates were nested within the before and after (BA) treatment, and sampling locations were nested within the control and impact (CI) treatment (Keough and Mapstone 1997). We used the RANDOM statement in the general linear model procedure (GLM), which calculates the expected mean squares and correct F-values for mixed models with fixed and random effects (Montagna and Ritter 2006). The distribution of the residuals were analyzed using the UNIVARIATE procedure and data were transformed ($\log_{10}$ (x+1), ln (x+1), or 4^{th} root) to ensure homogeneity of variance and normality of the residuals.

We tested for differences in pre- and post-opening density and abundance of economically important estuarine-dependent species during their peak recruitment period in the impact locations only. These species were: *Sciaenops ocellatus*, *Lagodon rhomboides*, *Micropogonias undulatus*, *Callinectes sapidus*, and penaeid shrimp (*F. aztecus*, *F. duorarum*, and *L. setiferus*). *S. ocellatus* mean densities and sizes were calculated from fall samples only (Holt et al. 1983). *L. rhomboides* mean densities (Levin et al. 1997; Patillo et al. 1997) and sizes, as well as *M. undulatus* mean densities (Petrik et al. 1999; Poling and Fuiman 1999; Ditty et al. 2005) and sizes were calculated from winter samples. *C. sapidus* mean densities and sizes were calculated by combining fall, winter, and spring samples (Pile et al. 1996; Blackmon and Eggleston 2001). Penaeid shrimp mean densities and sizes were calculated by combining all seasons (Zein-Eldin and Renaud 1986; Patillo et al. 1997).

Phase II Analysis

We calculated mean densities (#/m^2 ± SE) and size (mm) (mean ± SE) of all nekton collected seasonally from 2007 and 2008. All sampling locations were combined for overall mean densities and size by season. Mean densities were calculated annually from a total of 24 samples in the fall and winter, and 12 samples in the spring and summer. Mean sizes (standard length for fish, total length for shrimp, and carapace width for crabs) were calculated from n number of species measured each year. Data were not collected in the fall 2008, as the project was completed July 2008. We also calculated the relative abundance (RA) seasonally for fishes and crustaceans for 2007. 2008, and overall

(2007 and 2008 combined). The change in relative abundance (RA % Change) was also calculated for each species and group of nekton seasonally. The 2008 RA (%) was subtracted from the 2007 RA (%) to calculate the change.

We used a multivariate analysis (PRIMER v.6; Clarke and Gorley 2006) to test for significant differences in community assemblages between pre- and post-opening samples (Dawson Shepherd et al. 1992; Greenstreet and Hall 1996; Fisher and Frank 2002). We examined the mean densities of each species collected by date (24 total) for pre- (2004) and post-opening (2005 – 2008). Data were 4^{th} root transformed prior to analysis to reduce the differential effects of dominant species and differentiate between pre- and post-opening with having many or few rare species (Clarke and Green 1988). Community assemblage between pre- and post-opening was further explored using non-metric multidimensional scaling (MDS) based on Bray-Curtis similarity with Bray-Curtis cluster groups superimposed for interpretation (Clarke and Warwick 2001).

Results

Physical Parameters

Water depth ranged from 21 cm (spring 2004 pre-opening) to 40 cm (summer 2008 post-opening), with some seasonal differences pre- and post-opening. Dissolved oxygen was fairly consistent throughout Phase I and Phase II of the study ranging between 5.08 mg l^{-1} and 8.53 mg l^{-1}. Both salinity and temperature were higher 2005 post-opening over all seasons, both peaking during the summer (33.4 ˚C and 40 ppt, respectively). However, temperature was consistent between 2007 and 2008, with slightly lower temperatures observed in winter 2008. Salinity was much higher in summer 2008 (43‰) as compared to 2007 (29‰) (Table 1).We did not measure flow nor changes to habitat types, but during 2005 post-opening sampling large differences were observed in water movement and physical alterations to habitat (i.e., extensive seagrass loss on exposed sand bars) most likely a result of more extreme tidal fluctuations. We observed similar tidal fluctuations in Phase II, however did not observe any additional seagrass loss.

Table 1. Seasonal mean physical parameters (with standard error, SE) for 2007 and 2008. Measurements were not taken in fall 2008 (as indicated by a dash), because sampling was complete in summer 2008.

	2007			2008		
Parameter	Mean	SE	n	Mean	SE	n
Winter						
Dissolved oxygen (mg/L)	6.16	(0.3)	8	7.67	(0.5)	8
Water temperature (°C)	20.0	(0.4)	8	15.7	(1.4)	8
Salinity (‰)	32	(0.2)	8	32	(0.6)	8
Spring						
Dissolved oxygen (mg/L)	6.57	(0.2)	4	7.47	(0.4)	4
Water temperature (°C)	24.2	(0.2)	4	25.2	(0.4)	4
Salinity (‰)	33	(1.2)	4	34	(1.2)	4
Summer						
Dissolved oxygen (mg/L)	5.08	(0.5)	4	6.87	(0.4)	4
Water temperature (°C)	30.5	(0.3)	4	29.0	(0.2)	4
Salinity (‰)	29	(2.2)	4	43	(1.7)	4
Fall						
Dissolved oxygen (mg/L)	8.53	(0.8)	8	-	-	-
Water temperature (°C)	20.6	(1.3)	8	-	-	-
Salinity (‰)	27	(0.7)	8	-	-	-

Total Nekton Density

Phase I

We examined the overall differences in nekton with the opening of Packery Channel and found significantly fewer nekton post-opening in impact locations (mean = 15.88 m^{-2} ± 1.37 SE) than pre-opening impact sites (mean = 59.12 m^{-2} ± SE = 5.69; BA x CI interaction $F_{1,567} = 50.81$; $p < 0.001$) (Table 2, Fig. 2). Crustaceans dominated nekton total catch pre- and post-opening, 95% and 89% respectively. *Palaemonetes* sp. dominated the crustacean abundance both pre- and post-opening, 83% and 52% respectively. Because of this numerically dominant species, we separated nekton into three broad taxonomic categories, fish, crustaceans, and *Palaemonetes* sp. to determine density changes post-opening. Although there were higher mean densities of fish post-opening in impact locations (mean = 2.40 m^{-2} ± 0.26 SE) versus pre-opening (mean = 1.95 m^{-2} ± 0.12 SE), there was no significant difference (BA x CI interaction $F_{1,567}$ = 1.29; $p = 0.2564$) (Table 2, Fig. 2). However, there were significantly fewer crustaceans and *Palaemonetes* sp. (BA x CI interaction $F_{1,567} = 60.00$; $p < 0.001$; $F_{1,567} = 59.63$, $p < 0.001$, respectively) in impact locations post-opening (mean = 13.48 m^{-2} ± 1.23 SE; mean = 7.71 m^{-2} ± 1.04 SE, respectively) versus pre-opening (mean = 57.17 m^{-2} ± 5.64 SE; mean = 51.48 m^{-2} ± 5.58 SE, respectively) (Table 2, Fig. 2).

Table 2. Analysis of Variance nested model (overall, fish, crustacean, and grass shrimp) for Phase I (2004 – 2005) of Packery Channel project, with date as a nested factor within the before and after (BA) treatment and sampling locations as a nested factor within the control and impact (CI) treatment.

SOURCE	df	SUM OF SQUARES	MEAN SQUARE	F VALUE	P VALUE
OVERALL					
BA	1	16.963	16.963	135.650	<0.001
Date (BA)	12	16.504	1.375	11.000	<0.001
CI	1	0.856	0.856	6.850	0.0090
Location (CI)	5	9.001	1.800	14.400	<0.001
BA x CI	1	6.353	6.353	50.810	<0.001
Error	567	70.900	0.125		
FISH					
BA	1	0.858	0.858	3.240	0.0722
Date (BA)	12	23.863	1.987	7.510	<0.001
CI	1	1.782	1.782	6.730	0.0097
Location (CI)	5	37.627	7.525	28.440	<0.001
BA x CI	1	0.342	0.342	1.290	0.2564
Error	567	150.030	0.265		
CRUSTACEANS					
BA	1	103.712	103.712	152.910	<0.001
Date (BA)	12	90.292	7.524	11.090	<0.001
CI	1	4.205	4.205	6.200	0.0131
Location (CI)	5	45.250	9.050	13.340	<0.001
BA x CI	1	40.697	40.697	60.000	<0.001
Error	567	384.571	0.678		
GRASS SHRIMP					
BA	1	82.318	82.318	271.190	<0.001
Date (BA)	12	73.699	6.142	20.230	<0.001
CI	1	1.338	1.338	4.410	0.0362
Location (CI)	5	2.070	6.414	21.130	<0.001
BA x CI	1	18.099	18.099	9.630	<0.001
Error	567	172.106	0.304		

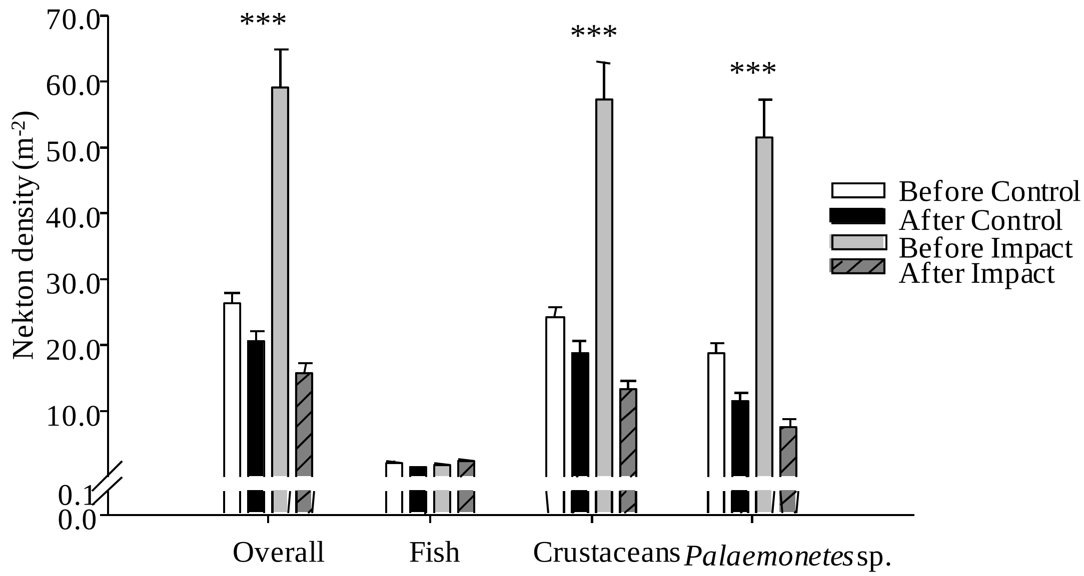

Figure 2. Overall mean density (m^{-2}) of nekton, fish, crustaceans, and *Palaemonetes* sp. in control and impact locations over all seasons pre- and post-opening 2004-2005. Before-after-control-impact ANOVA model was used to test each group; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Phase II

We collected a total of 2,528 individual fishes representing 26 species from 16 families, and 28,229 individual crustaceans representing at least 6 species during 2007 post-opening sampling of Packery Channel between February and November 2007. During 2008 sampling of Packery Channel we collected a total of 2,511 individual fishes representing at least 29 species with 17 families, and 10,688 individual crustaceans representing 7 species between February and July 2008. For some taxa, juveniles were only identified to family. Samples were examined seasonally because we found seasonal differences in nekton composition and density in locations adjacent to Packery Channel, and mean density, size, total catch, and relative abundance (RA%) were calculated for each species or family (Table 3). Habitats adjacent to Packery Channel supported high abundances of *Gobionellus boleosoma*, *Lagodon rhomboides*, and *Micropogonias undulatus* during winter 2007 (27.5%, 49.6%, and 9.5% respectively), with very little change observed in 2008. We also found similar abundances of *L. rhomboides* and *G. boleosoma* during both the spring and summer seasons in 2007 and 2008. However, densities of *Eucinostomus argenteus* greatly increased in summer 2008 as compared to 2007. During the only fall season we sampled in 2007, we found that *G. boleosoma, Sciaenops ocellatus,* and *Syngnathus* sp. were the most abundant fishes. *Palaemonetes* sp. were the most abundant crustaceans over all seasons during both 2007 and 2008 sampling, with at least 68.5% relative abundance (Table 3).

Table 3. Mean densities (#/m^2; SE = Standard Error) and mean size (mm) of all nekton collected seasonally from 2007 and 2008. Data were not collected in fall 2008. The relative abundance (RA) is listed seasonally for fishes and crustaceans for 2007, 2008, and overall (2007 and 2008 combined). The change in relative abundance (RA % Change) was also calculated for each species and group of nekton seasonally. A negative value shows a decline in abundance, and a positive number indicated an increase in abundance.

	2007						2008								
Species	Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Winter															
FISHES															
Total Fishes	3.53	(0.42)			832		2.15	(0.49)			511		1343		
Brevoortia patronus	0.00	(0.00)	12.8	(0.0)	1	0.1	0.00	(0.00)	10.3	(0.0)	1	0.2	2	0.1	0.1
Citharichthys spilopterus	0.01	(0.01)	11.3	(0.1)	3	0.4	0.05	(0.02)	10.9	(0.8)	11	2.2	14	1.0	1.8
Cyprinodon variegatus	0.04	(0.02)	25.9	(1.2)	10	1.2	0.03	(0.02)	33.6	(1.6)	8	1.6	18	1.3	0.4
Fundulus grandis	0.00	(0.00)	18.5	(0.0)	1	0.1	0.00	(0.00)	51.9	(0.0)	1	0.2	2	0.1	0.1
Gobiidae	0.14	(0.06)	9.5	(0.1)	33	4.0	0.17	(0.05)	9.3	(0.1)	40	7.8	73	5.4	3.9
Gobionellus boleosoma	0.95	(0.23)	18.5	(0.5)	229	27.5	0.73	(0.20)	17.1	(0.6)	174	34.1	403	30.0	6.5
Gobiosoma bosc	0.00	(0.00)	0.0	(0.0)	0	0.0	0.00	(0.00)	23.5	(0.0)	1	0.2	1	0.1	0.2
Gobiosoma robustum	0.03	(0.02)	16.1	(1.6)	6	0.7	0.05	(0.03)	16.2	(2.0)	13	2.5	19	1.4	1.8
Hippocampus zosterae	0.01	(0.01)	22.9	(2.0)	2	0.2	0.01	(0.01)	25.4	(1.1)	2	0.4	4	0.3	0.2
Lagodon rhomboides	1.72	(0.25)	16.1	(0.2)	413	49.6	0.68	(0.26)	16.4	(0.7)	164	32.1	577	43.0	-17.5
Leiostomus xanthurus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.00	(0.00)	26.9	(0.0)	1	0.2	1	0.1	0.2
Lucania parva	0.03	(0.02)	16.5	(1.7)	8	1.0	0.00	(0.00)	0.0	(0.0)	0	0.0	8	0.6	-1.0
Menidia menidia	0.00	(0.00)	0.0	(0.0)	0	0.0	0.05	(0.04)	16.9	(0.8)	13	2.5	13	1.0	2.5
Menticirrhus littoralis	0.00	(0.00)	0.0	(0.0)	0	0.0	0.00	(0.00)	3.1	(0.0)	1	0.2	1	0.1	0.2
Micropogonias undulatus	0.39	(0.12)	15.6	(0.5)	79	9.5	0.23	(0.07)	14.6	(0.9)	48	9.4	127	9.5	-0.1
Mugil cephalus	0.02	(0.02)	23.0	(0.2)	5	0.6	0.00	(0.00)	25.0	(0.0)	1	0.2	6	0.4	-0.4
Paralichthys lethostigma	0.01	(0.01)	16.2	(0.9)	2	0.2	0.02	(0.01)	12.3	(2.6)	4	0.8	6	0.4	0.5
Pogonias cromis	0.00	(0.00)	0.0	(0.0)	0	0.0	0.00	(0.00)	28.5	(0.0)	1	0.2	1	0.1	0.2
Prionotus rubio	0.00	(0.00)	0.0	(0.0)	0	0.0	0.00	(0.00)	44.4	(0.0)	1	0.2	1	0.1	0.2
Symphurus plagiusa	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	28.4	(12.5)	2	0.4	2	0.1	0.4
Symphurus sp.	0.00	(0.00)	52.6	(0.0)	1	0.1	0.00	(0.00)	8.8	(0.0)	1	0.2	2	0.1	0.1
Syngnathus sp.	0.16	(0.04)	63.4	(3.5)	39	4.7	0.10	(0.04)	74.6	(3.9)	23	4.5	62	4.6	-0.2
CRUSTACEANS															
Total Crustaceans	43.82	(11.98)			10517		11.14	(1.67)			2671		13188		
Callinectes sapidus	3.73	(1.02)	7.6	(0.3)	894	8.5	1.91	(0.73)	8.3	(0.5)	458	17.1	1352	10.3	8.6
Farfantepenaeus sp.	0.11	(0.04)	20.4	(1.7)	26	0.2	1.21	(0.38)	26.7	(1.3)	291	10.9	317	2.4	10.6
Litopenaeus setiferus	0.11	(0.08)	15.6	(1.4)	27	0.3	0.03	(0.03)	24.7	(3.5)	6	0.2	33	0.3	0.0
Palaemonetes sp.	32.83	(12.38)	14.3	(0.2)	7878	74.9	4.79	(1.33)	14.6	(0.3)	1150	43.1	9028	68.5	-31.9
Penaeid Shrimp	5.13	(0.78)	12.5	(0.2)	1230	11.7	2.30	(0.74)	12.8	(0.3)	552	20.7	1782	13.5	9.0
Tozeuma sp.	0.39	(0.16)	25.2	(0.4)	94	0.9	0.58	(0.34)	33.4	(4.8)	140	5.2	234	1.8	4.3
Xanthidae	1.53	(0.32)	4.7	(0.2)	368	3.5	0.31	(0.08)	4.3	(0.3)	74	2.8	442	3.4	-0.7

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Table 3 continued.

	2007						2008								
Species	Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Spring															
FISHES															
Total Fishes	7.14	(1.57)			857		12.86	(5.79)			1541		2398		
Bairdiella chrysoura	0.00	(0.00)	0.0	(0.0)	0	0.0	0.05	(0.04)	13.4	(2.2)	6	0.4	6	0.3	0.4
Cynoscion nebulosus	0.01	(0.01)	11.8	(0.0)	1	0.1	0.00	(0.00)	0.0	(0.0)	0	0.0	1	0.0	-0.1
Eucinostomus argenteus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.17	(0.17)	11.5	(0.2)	20	1.3	20	0.8	1.3
Gobiidae	0.08	(0.04)	9.0	(0.2)	10	1.2	0.06	(0.03)	8.8	(0.3)	7	0.5	17	0.7	-0.7
Gobionellus boleosoma	2.12	(0.58)	19.6	(0.5)	254	29.6	1.88	(0.45)	18.1	(0.5)	225	14.6	479	20.0	-15.0
Gobiosoma robustum	0.14	(0.06)	21.0	(1.1)	17	2.0	0.03	(0.03)	12.5	(0.5)	4	0.3	21	0.9	-1.7
Hippocampus erectus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	12.0	(0.0)	1	0.1	1	0.0	0.1
Hippocampus zosterae	0.00	(0.00)	0.0	(0.0)	0	0.0	0.02	(0.01)	11.6	(3.5)	2	0.1	2	0.1	0.1
Lagodon rhomboides	4.53	(1.08)	18.5	(0.4)	543	63.4	10.34	(5.33)	16.9	(0.5)	1241	80.5	1784	74.4	17.2
Leiostomus xanthurus	0.03	(0.01)	46.2	(3.7)	3	0.4	0.00	(0.00)	0.0	(0.0)	0	0.0	3	0.1	-0.4
Lucania parva	0.03	(0.02)	20.0	(1.2)	3	0.4	0.00	(0.00)	0.0	(0.0)	0	0.0	3	0.1	-0.4
Menidia menidia	0.01	(0.01)	9.9	(0.0)	1	0.1	0.00	(0.00)	0.0	(0.0)	0	0.0	1	0.0	-0.1
Micropogonias undulatus	0.01	(0.01)	33.6	(0.0)	1	0.1	0.01	(0.01)	37.1	(0.0)	1	0.1	2	0.1	-0.1
Ophichthus gomesii	0.01	(0.01)	95.2	(0.0)	1	0.1	0.00	(0.00)	0.0	(0.0)	0	0.0	1	0.0	-0.1
Orthopristis chrysoptera	0.01	(0.01)	21.2	(0.0)	1	0.1	0.13	(0.07)	13.1	(1.0)	16	1.0	17	0.7	0.9
Paralichthys lethostigma	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	33.0	(0.0)	1	0.1	1	0.0	0.1
Stellifer lanceolatus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.03	(0.03)	7.3	(0.9)	4	0.3	4	0.2	0.3
Syngnathus sp.	0.18	(0.05)	65.7	(4.8)	22	2.6	0.11	(0.04)	52.9	(7.9)	13	0.8	35	1.5	-1.7
CRUSTACEANS															
Total Crustaceans	55.47	(11.52)			6656		32.21	(9.04)			3859		10515		
Callinectes sapidus	0.34	(0.11)	14.0	(1.7)	41	0.6	0.30	(0.14)	6.3	(1.1)	36	0.9	77	0.7	0.3
Farfantepenaeus sp.	1.70	(0.46)	31.1	(1.2)	204	3.1	4.19	(1.37)	26.4	(1.2)	503	13.0	707	6.7	10.0
Litopenaeus setiferus	0.53	(0.47)	21.8	(1.5)	64	1.0	0.14	(0.14)	24.1	(2.0)	17	0.4	81	0.8	-0.5
Ogyrides sp.	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	9.4	(0.0)	1	0.0	1	0.0	0.0
Palaemonetes sp.	45.73	(10.48)	13.1	(0.3)	5487	82.4	25.16	(8.49)	13.3	(0.5)	3019	78.2	8506	80.9	-4.2
Penaeid Shrimp	5.88	(1.05)	14.2	(0.4)	706	10.6	1.03	(0.47)	15.6	(1.5)	123	3.2	829	7.9	-7.4
Tozeuma sp.	0.82	(0.37)	21.8	(1.0)	98	1.5	0.62	(0.16)	13.5	(0.5)	74	1.9	172	1.6	0.4
Xanthidae	0.47	(0.13)	4.6	(0.5)	56	0.8	0.72	(0.58)	3.5	(0.4)	86	2.2	142	1.4	1.4

Table 3 continued.

Species	2007 Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	2008 Mean Density (#/m^2)	SE	Mean Size (mm)	SE	Total Catch	RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Summer															
FISHES															
Total Fishes	3.04	(0.49)			364		3.78	(1.10)			450		814		
Bairdiella chrysoura	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	6.5	(0.0)	1	0.2	1	0.1	0.2
Cynoscion nebulosus	0.02	(0.02)	6.7	(0.7)	2	0.5	0.03	(0.01)	12.6	(3.3)	3	0.7	5	0.6	0.1
Dormitator maculatus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	20.1	(0.0)	1	0.2	1	0.1	0.2
Eucinostomus argenteus	0.27	(0.15)	9.3	(0.5)	31	8.5	0.88	(0.45)	10.4	(0.4)	103	22.9	134	16.5	14.4
Evorthodus lyricus	0.01	(0.01)	32.8	(0.0)	1	0.3	0.00	(0.00)	0.0	(0.0)	0	0.0	1	0.1	-0.3
Gobionellus boleosoma	1.09	(0.41)	20.1	(0.8)	131	36.0	1.46	(0.60)	21.6	(0.7)	175	38.9	306	37.6	2.9
Gobiosoma bosc	0.02	(0.02)	34.9	(0.3)	2	0.5	0.00	(0.00)	0.0	(0.0)	0	0.0	2	0.2	-0.5
Gobiosoma robustum	0.23	(0.09)	28.1	(1.3)	27	7.4	0.37	(0.19)	25.9	(0.7)	44	9.8	71	8.7	2.4
Hippocampus zosterae	0.00	(0.00)	0.0	(0.0)	0	0.0	0.02	(0.01)	13.4	(2.1)	2	0.4	2	0.2	0.4
Lagodon rhomboides	1.13	(0.32)	31.5	(0.6)	136	37.4	0.66	(0.15)	89.0	(59.6)	79	17.6	215	26.4	-19.8
Lutjanus griseus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.03	(0.02)	35.8	(13.2)	3	0.7	3	0.4	0.7
Menidia menidia	0.01	(0.01)	9.8	(0.0)	1	0.3	0.00	(0.00)	0.0	(0.0)	0	0.0	1	0.1	-0.3
Ophichthus gomesii	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	148.0	(0.0)	1	0.2	1	0.1	0.2
Scorpaena plumieri	0.00	(0.00)	0.0	(0.0)	0	0.0	0.01	(0.01)	30.6	(0.0)	1	0.2	1	0.1	0.2
Symphurus plagiusa	0.00	(0.00)	0.0	(0.0)	0	0.0	0.02	(0.02)	20.6	(0.4)	2	0.4	2	0.2	0.4
Syngnathus sp.	0.28	(0.07)	57.4	(6.1)	33	9.1	0.29	(0.09)	55.1	(6.3)	35	7.8	68	8.4	-1.3
CRUSTACEANS															
Total Crustaceans	13.66	(3.87)			1639		34.66	(15.80)			4158		5797		
Callinectes sapidus	0.07	(0.05)	10.9	(3.7)	8	0.5	0.02	(0.02)	2.8	(1.0)	2	0.0	10	0.2	-0.4
Farfantepenaeus sp.	0.70	(0.15)	40.1	(1.9)	84	5.1	0.36	(0.13)	46.1	(1.9)	43	1.0	127	2.2	-4.1
Litopenaeus setiferus	0.00	(0.00)	0.0	(0.0)	0	0.0	0.22	(0.20)	12.3	(1.0)	26	0.6	26	0.4	0.6
Palaemonetes sp.	10.55	(2.90)	17.9	(0.4)	1266	77.2	27.75	(14.32)	15.4	(0.5)	3330	80.1	4596	79.3	2.8
Penaeid Shrimp	1.03	(0.43)	10.0	(0.3)	123	7.5	1.06	(0.28)	10.4	(0.4)	127	3.1	250	4.3	-4.5
Tozeuma sp.	1.16	(0.84)	29.8	(1.0)	139	8.5	5.17	(1.94)	20.2	(0.7)	620	14.9	759	13.1	6.4
Xanthidae	0.16	(0.11)	5.6	(0.9)	19	1.2	0.08	(0.07)	5.3	(0.7)	10	0.2	29	0.5	-0.9

Table 3 continued.

Species	2007 Mean Density ($\#/m^2$)	2007 SE	2007 Mean Size (mm)	2007 SE	2007 Total Catch	2007 RA (%)	2008 Mean Density ($\#/m^2$)	2008 SE	2008 Mean Size	2008 SE	2008 Total Catch	2008 RA (%)	Overall Total Catch	Overall RA (%)	RA % Change
Fall															
FISHES															
Total Fishes	1.91	(0.26)			459										
Citharichthys spilopterus	0.01	(0.01)	13.2	(2.9)	3	0.7									
Cyprinodon variegatus	0.03	(0.02)	29.8	(3.7)	7	1.5									
Eucinostomus argenteus	0.09	(0.03)	23.2	(3.0)	22	4.8									
Gobiidae	0.08	(0.04)	9.5	(0.2)	19	4.1									
Gobionellus boleosoma	0.91	(0.24)	18.9	(0.6)	219	47.7									
Gobiosoma robustum	0.03	(0.01)	15.9	(1.2)	6	1.3									
Hippocampus zosterae	0.00	(0.00)	25.0	(0.0)	1	0.2									
Lagodon rhomboides	0.14	(0.04)	42.5	(2.2)	34	7.4									
Lutjanus griseus	0.00	(0.00)	30.9	(0.0)	1	0.2									
Micropogonias undulatus	0.01	(0.01)	16.3	(4.1)	3	0.7									
Ophichthus gomesii	0.00	(0.00)	121.2	(0.0)	1	0.2									
Prionotus rubio	0.00	(0.00)	11.5	(0.0)	1	0.2									
Sciaenops ocellatus	0.28	(0.05)	8.3	(0.2)	66	14.4									
Symphurus civitatium	0.00	(0.00)	12.1	(0.0)	1	0.2									
Symphurus plagiusa	0.02	(0.02)	14.0	(4.2)	5	1.1									
Symphurus sp.	0.00	(0.00)	21.8	(0.0)	1	0.2									
Syngnathus sp.	0.29	(0.07)	39.6	(4.1)	69	15.0									
CRUSTACEANS															
Total Crustaceans	39.29	(5.20)			9417										
Callinectes sapidus	0.48	(0.23)	6.9	(0.9)	114	1.2									
Farfantepenaeus sp.	1.17	(0.43)	34.5	(1.0)	280	3.0									
Litopenaeus setiferus	0.03	(0.02)	27.7	(2.6)	7	0.1									
Palaemonetes sp.	34.02	(5.03)	12.4	(0.2)	8165	86.7									
Penaeid Shrimp	0.83	(0.27)	9.6	(0.3)	198	2.1									
Tozeuma sp.	2.45	(0.79)	21.2	(0.5)	588	6.2									
Xanthidae	0.27	(0.10)	3.2	(0.3)	65	0.7									

Selected Fishes and Crustaceans

Phase I

In general, we found higher densities of estuarine-dependent species with the opening of Packery Channel. Several estuarine-dependent species that had recently settled into the seagrass meadows from their planktonic phase had significantly higher mean densities post-opening. Specifically, we found significantly higher densities of newly-settled *S. ocellatus* ($p < 0.01$; $t = -3.55$; $df = 94$), *L. rhomboides* ($p = 0.005$; $t = -2.85$; $df = 94$), *M. undulatus* ($p < 0.001$; $t = -3.90$; $df = 94$), *C. sapidus* ($p < 0.001$; $t = -5.01$; $df = 286$) and penaeid shrimp ($p < 0.001$; $t = -4.83$; $df = 334$) in the impact locations (Table 4, Fig. 3). Of the identifiable penaeid shrimp, *F. aztecus* were the predominant species.

In addition to the increase of individuals to locations adjacent to Packery Channel, we also observed distinct size differences for all size classes of estuarine-dependent species, with the general pattern of significantly smaller individuals post-opening in 2005. All of the estuarine-dependent species analyzed were significantly smaller post-opening: *S. ocellatus* ($p < 0.001$; $t = 6.71$; $df = 26$), *L. rhomboides* ($p < 0.001$; $t = 15.49$; $df = 497$), *M. undulatus* ($p < 0.001$; $t = 5.62$; $df = 247$), *C. sapidus* ($p < 0.001$; $t = 14.90$; $df = 1053$), and penaeid shrimp ($p < 0.001$; $t = 10.23$; $df = 6201$) (Table 4, Fig. 4).

Phase II

We found continued high densities of estuarine-dependent species in locations near the opening of Packery Channel. *Sciaenops ocellatus* had a nearly ten-fold increase in density from 2005 ($0.03\ m^{-2} \pm 0.01$) to 2007 (0.28 ± 0.05), and blue crabs had an even larger increase in density in both 2008 and 2007 (Table 4). Penaeid shrimp and *M. undulatus* densities were similar to the initial 2005 post-opening densities, but are still much greater than pre-opening (Table 4, Fig. 4). We also observed similar size patterns to Phase I sampling, with smaller individuals post-opening in 2007 and 2008. All of the species from Phase II were smaller than pre-opening, with the only exception being *M. undulatus*. This could be due to a longer recruitment season (November – February), so there was a greater mix of large and small individuals. (Table 4, Fig. 5).

Table 4. Mean densities (#/m^{-2}) and mean size (mm) of selected fishes and crustaceans (SE = Standard Error) for 2004 pre-opening and all post-opening sampling are summarized below. The mean densities of the species selected were calculated during their recruitment seasons.

	Pre-opening			Post-opening								
	2004			2005			2007			2008		
Species	Mean	S.E.	n	Mean	S.E.	n	Mean	S.E.	n	Mean	S.E.	n
Density												
Sciaenops ocellatus	0.00	0.00	48	0.03	0.01	48	0.28	(0.05)	24	-	-	-
Lagodon rhomboides	0.23	0.05	48	1.11	0.31	48	1.72	(0.25)	24	0.68	(0.26)	24
Micropogonias undulatus	0	0	48	0.415	0.12	48	0.39	(0.12)	24	0.23	(0.07)	24
Callinectes sapidus	0.00	0.00	144	0.07	0.02	144	1.75	(0.46)	60	1.37	(0.50)	36
Penaeid Shrimp	2.715	0.27	168	4.37	0.38	168	4.08	(0.42)	72	1.67	(0.40)	48
Size												
Sciaenops ocellatus	23.02	3.26	10	8.80	0.51	18	8.3	(0.2)	61	-	-	-
Lagodon rhomboides	16.10	0.25	247	12.10	0.16	550	16.1	(0.2)	341	16.4	(0.7)	127
Micropogonias undulatus	16.64	0.57	10	12.17	0.16	471	15.6	(0.5)	93	14.6	(0.9)	53
Callinectes sapidus	15.37	0.34	208	9.94	0.28	94	8.0	(0.3)	504	8.0	(0.4)	271
Penaeid Shrimp	24.56	0.27	2688	21.21	0.2	3515	12.2	(0.1)	940	12.7	(0.3)	463

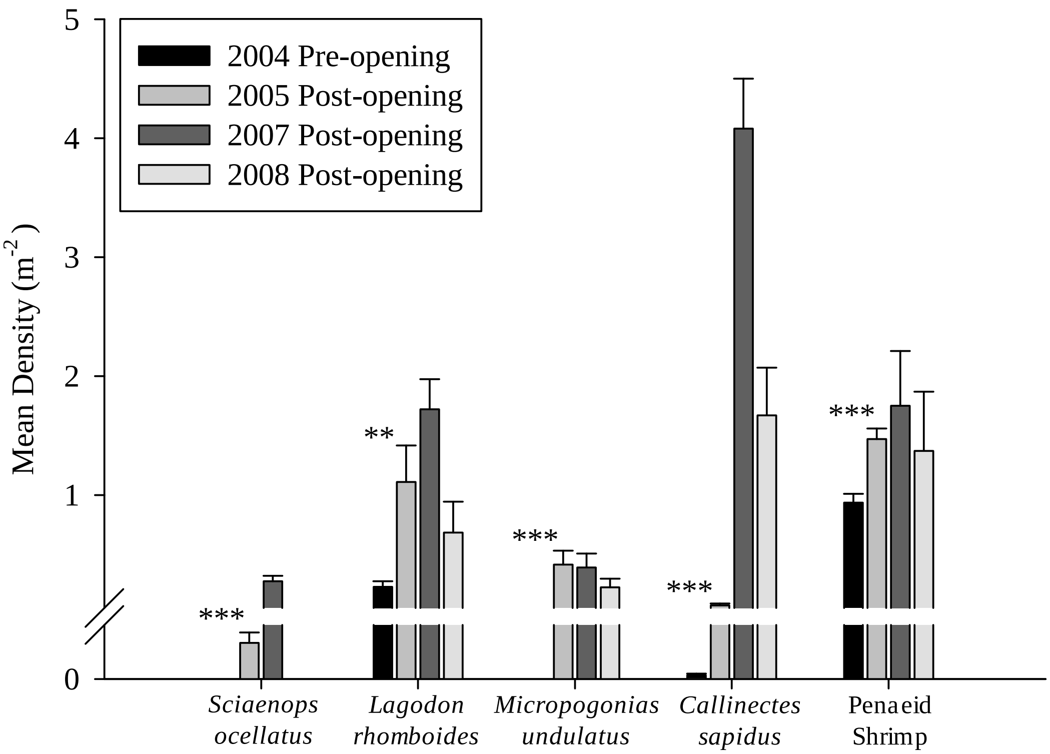

Figure 3. Mean densities (#/m^2) of selected fishes and crustaceans during their peak recruitment season from pre-opening (2004) sampling, as well as all post-opening sampling (2005, 2007, and 2008). Samples were not collected in 2008 for *S. ocellatus* due to project completion. Student's *t*-test was performed on the selected fishes and crustaceans from 2004 pre-opening versus 2005 post-opening only; ** $p < 0.01$, *** $p < 0.001$.

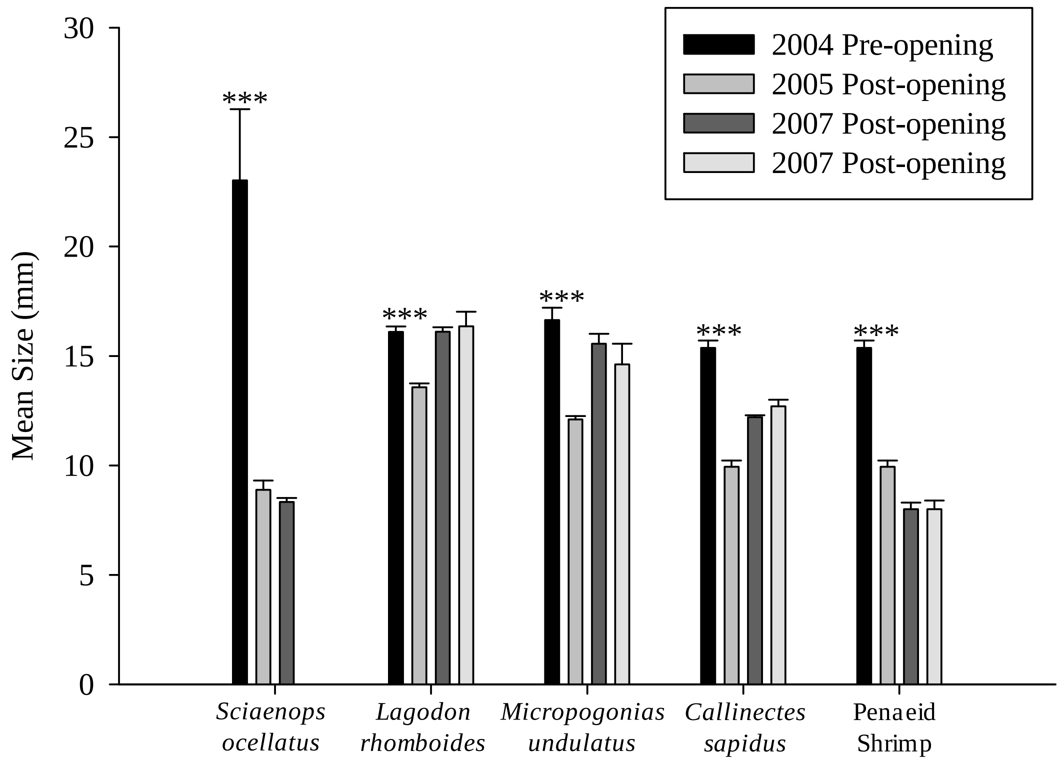

Figure 4. Mean size (mm) of selected fishes and crustaceans during their peak recruitment season from pre-opening (2004) sampling, as well as all post-opening sampling (2005, 2007, and 2008). Samples were not collected in 2008 for *S. ocellatus* due to project completion. Student's *t*-test was performed on the selected fishes and crustaceans 2004 pre-opening versus 2005 post-opening only; *** $p < 0.001$.

<u>Community Assemblage</u>

Our community analysis revealed differences in community assemblage seasonally pre- versus post-opening. The MDS analysis had a slightly high stress value (0.17), therefore we superimposed the Bray-Curtis analysis to strengthen our interpretation (Clarke and Warwick 2001). The Bray-Curtis cluster analysis superimposed on the MDS plot reveal three distinct clusters at the 67% similarity level, with a pre-opening group and three post-opening groups (Fig. 5). The three post-opening groups are grouped generally by season over all three years.

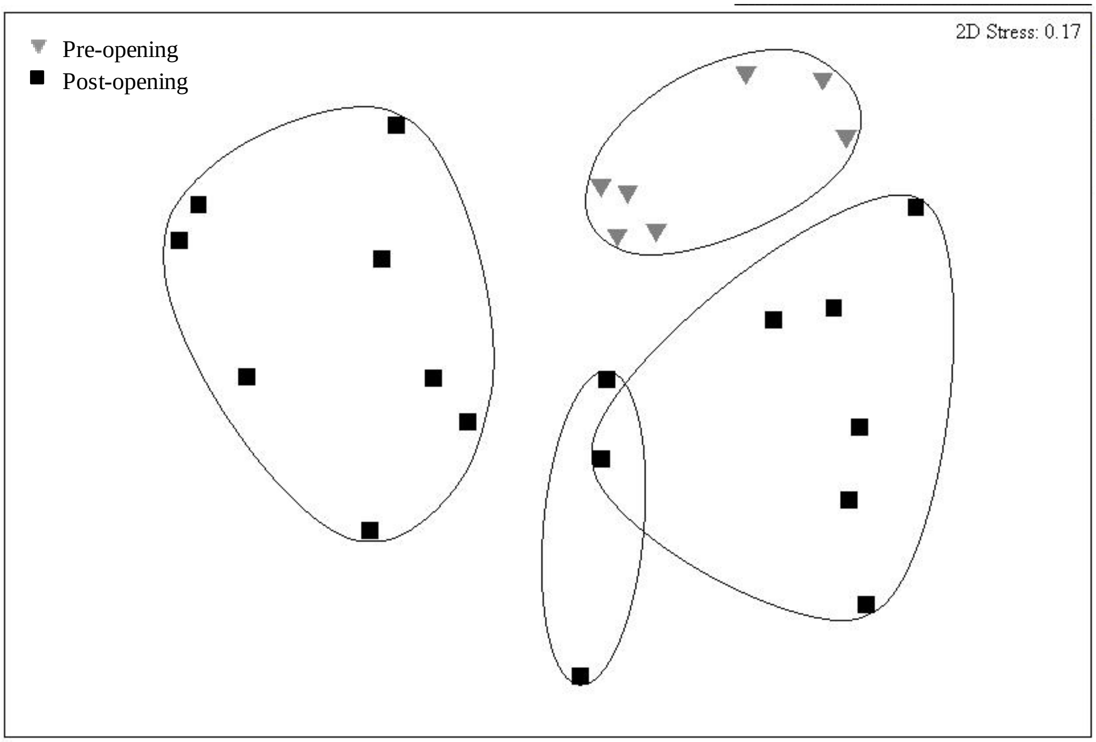

Figure 5. MDS ordination of nekton density (m^{-2}) from pre- and post-opening samples over all seasons. Densities were averaged among locations by date for a total of 24 samples from 2004 – 2008.

Discussion

This study was designed to assess the impact of opening a tidal inlet by determining density patterns and community structure for estuarine-dependent and estuarine-resident species. We found strong evidence that opening new tidal inlets may have wide-ranging impacts on nekton recruitment at both the individual species and community levels. Overall, we observed striking differences in density patterns and lengths for many species as well as changes to the community structure. These data show that the opening of tidal inlets, particularly tidal inlets at great distances from other inlets, may increase fisheries productivity for some ecologically and economically important species that would not normally have access to these areas.

Nekton density and abundance

During Phase I of the project, we observed numerous differences in nekton density and abundance for a variety of species and these were most likely due to the opening of Packery Channel. Overall, there were fewer nekton present 2005 post-opening, which appears to be caused by the decline of *Palaemonetes* sp. in seagrass habitats directly adjacent to the new inlet. *Palaemonetes* sp. are an essential part of estuarine communities and are found throughout estuaries along the Gulf coast (Morgan 1980). Once Packery Channel was opened and flowing, the impact locations adjacent to Packery Channel changed from backwater lagoons with little tidal fluctuation to locations with increased tidal energy and current. With larger tidal fluctuations and flow post-opening there were long periods of seagrass exposure, and we observed but did not quantify, a decrease (and loss in one area) in seagrass cover in locations nearest the inlet. *Palaemonetes* sp. select for seagrass cover to forage for food and to decrease predation (Morgan 1980; Orth et al. 1984). Therefore, the observed seagrass loss in the areas very near the inlet most likely caused *Palaemonetes* sp. mean densities to sharply decrease post-opening with fewer seagrass beds available for cover. The dramatic change in *Palaemonetes* sp. (an estuarine-resident species) densities post-opening with the observed loss of seagrass cover, demonstrate that Packery Channel could potentially have a large impact on other estuarine-resident and estuarine-dependent species that use seagrass meadows as nursery habitat (Sheridan 2004).

There did not appear to be major differences in seasonal fish and crustacean abundances during Phase II of the project from 2007 and 2008 in the surrounding habitats of Packery Channel. The relative abundances of fish over each season show little change in composition. *Gobionellus boleosoma* and *L. rhomboides* were both predominant in the winter, spring and summer samples with little change in abundance from 2007 to 2008. We only sampled in the fall during 2007 because the project was completed in July 2008. However, we found very high abundances of *S. ocellatus.* Post-opening in 2005 Packery Channel was not completely dredged to its contracted depth, therefore in 2007 there was much more water flowing, which could be a reason why there were much higher densities of this estuarine-dependent species.

We found evidence that suggests density-dependent species are recruiting to the previously inaccessible seagrass meadows of the Laguna Madre via Packery Channel immediately after opening, and have continued to recruit several years post-opening. *Sciaenops ocellatus*, *L. rhomboides*, *M. undulatus*, *C. sapidus*, and penaeid shrimp all have varied seasonal recruitment patterns, but 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 are 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 (35 km) from the nearest tidal inlet (Aransas Pass to the north). We found evidence suggesting that estuarine-dependent species are recruiting to the Laguna Madre via Packery Channel. For example, before Packery Channel was open there were very low densities of *M. undulatus* present, but in the winter 2005 post-opening they were one of the most abundant species collected. We also found continued high densities of these estuarine-dependent species in 2007 and 2008 providing very strong evidence that Packery Channel provides a means of ingress to the upper Laguna Madre. 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 these habitats of the upper Laguna Madre may ultimately increase the survival of juveniles that could contribute to adult populations (Rozas and Minello 1998; Minello 1999; Beck et al. 2001).

Examining the mean size of fish and crustaceans pre- versus post-opening provides additional support that estuarine-dependent species are using 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. Thus, significantly larger individuals of many estuarine-dependent species were collected pre-opening in 2004. All of the estuarine-dependent species examined for this study were significantly smaller post-opening in 2005. Juvenile *S. ocellatus* settle into seagrass meadows between 6-8 mm SL (Holt et al. 1983; Rooker and Holt 1997), and were rarely in this size range pre-opening. However, the mean size of *S. ocellatus* post-opening in the upper Laguna Madre was approximately 9 mm SL suggesting that *S. ocellatus* were recruiting to these habitats via Packery Channel. *L. rhomboides*, *M. undulatus*, penaeid shrimp, and *C. sapidu*s were also significantly smaller post-opening, and we collected these species at lengths of first settlement post-opening. This trend continued with smaller estuarine-dependent individuals in habitats adjacent to Packery Channel in Phase II of the project as well. These data suggest these estuarine-dependent fishes and crustaceans are using Packery Channel as a means of recruitment to the nursery grounds of the upper Laguna Madre. This may increase fishery productivity for some of these economically and ecologically important fishery species.

Community structure

We observed changes to community structure with the opening of Packery Channel when examining each sampling date. The overall community change appears to have corresponded with the opening of Packery Channel with the arrival of estuarine-dependent species, providing evidence that these immigrating species are using Packery Channel as a means of ingress to the upper Laguna Madre. Although post-opening estuarine-resident species had the most variation in species abundance, our data shows that increases in estuarine-dependent species contributed to the overall change in community assemblage.

Seasonal migrations of small, juvenile estuarine-dependent species have an impact on the communities of the upper Laguna Madre because some species historically have not occurred in these seagrass habitats. Interpretation of the MDS ordination shows evidence of increased recruitment of several species post-opening. Pre-opening all the samples are grouped, whereas post-opening there are three groups that are separated seasonally. Clearly, the separation of pre- and post-opening samples suggests that we have detected the varied recruitment patterns of estuarine-dependent species with changes in species assemblages throughout the year with this trend continuing in both 2007 and 2008. In a similar study, Akin et al. (2003) also concluded seasonal occurrence of estuarine-dependent species is an important factor influencing community assemblages. These data suggest that the increase in estuarine-dependent species may have impacted the community structure in seagrass habitats of the upper Laguna Madre.

Conclusions

The opening of Packery Channel has caused changes to nekton densities and overall community structure in seagrass habitats of the Laguna Madre. Overall, this study provides evidence that this new tidal inlet provides a means of ingress to the productive nursery habitats of the upper Laguna Madre that were previously inaccessible for many estuarine-dependent species, such as *S. ocellatus*, penaeid shrimp, and *C. sapidus*. The second phase provides additional evidence because we found continued high densities of estuarine-dependent species over time, possibly resulting in increased fisheries productivity long-term. This study examined density patterns and community changes, but it is also critical to document changes to the functionality of the newly available estuarine nursery habitats. Future studies should examine changes in growth and mortality rates, fine- and large-scale movement patterns, and subsequent movement to adult population for nekton accessing and using these areas as their nursery grounds.

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