Packery Channel Post-Opening Fisheries Recruitment Project

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<u>Principal Investigator</u>

Scott A. Holt, Research Associate

University of Texas at Austin
Marine Science Institute
750 Channel View Drive
Port Aransas, TX 78373
(361) 749-6715 voice
(361) 749-6777 fax

Submitted to:
Coastal Bend Bays & Estuaries Program
1305 N. Shoreline Blvd., Suite 205
Corpus Christi, TX 78401

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Executive Summary

Packery Channel transects Mustang Island, connecting the Gulf of Mexico to the upper portion of the Laguna Madre but has been silted closed for the past 50 or more years. The US Army Corp of Engineers completed dredging and jetty construction to permanently open the channel in the fall of 2006, although the inlet was prematurely breeched in July 2006 by Hurricane Emily. This study was undertaken to determine the effects of opening the channel to the Gulf of Mexico on larval stages of fishes and macroinvertebrates (collectively referred to as meroplankton) in the vicinity of Packery Channel. Plankton samples were taken with an epibenthic sled at seven stations in and around the Packery Channel tidal inlet. Some sample locations in the Intercoastal Waterway (ICWW) were moved closer to the confluence with Packery Channel beginning with the August 2007 collections (and continuing until the end of the study) to provide a more detailed assessment of the impact of larval immigration through the channel and into the ICWW. The two station configurations are referred to as the "expanded" (pre August 2007) and contracted (post August 2007) sampling schemes. Sample dates were chosen to target specific species of recreational or commercial importance so most sampling was concentrated in the fall, winter, and spring seasons with little sampling in the mid-summer. The premature opening of the channel by Hurricane Emily truncated the period of pre-opening collections to the winter and spring seasons. Analysis of the entire meroplankton assemblage by cluster analysis showed that the species assemblage of the Packery Channel area could be divided into "warm" season and "cool" groups. The cool season assemblage dominated by estuarine dependent marine species that primarily spawn off shore and the larvae recruit to estuarine nursery areas through the tidal inlet while the warm season assemblage was dominated by species that spawn within the estuary, or near the tidal inlet and are not dependent on the inlet for access to the nursery sites. The same analysis did not show a clear differentiation of pre and post- opening collections that would have indicated large-scale changes in the meroplankton community with opening of the inlet. Cluster analysis of sample locations for three periods, the pre-opening period and the expanded and contracted sampling periods, showed that the species assemblage from the sample site within the Packery Channel tidal inlet was very dissimilar from all other sampling sites for the two post-opening periods but not the pre-opening period. The wide dissimilarity was due to much higher diversity and, for many species, higher density at the Packery Channel site. Detailed assessment of the distribution and abundance of selected species showed that most offshore spawned species that depend on the tidal inlet for access to the estuarine nursery grounds were much more abundant after the inlet was opened but in many cases they occurred almost exclusively within the tidal inlet. Estuarine resident species were wide-spread throughout the study area and seldom at elevated densities within the tidal inlet. The ultimate impact on fisheries resources due to the opening of Packery Channel could not be derived directly from these data but it seems intuitive

that increasing the utilization of potential nursery habitat in the area by increasing larval supply from offshore should increase production of these estuarine-dependent species. In addition, there does not seem to be either a positive or negative effect of the inlet on estuarine resident species, many of which are small, cryptic species such as code gobies but also include important recreational species such as spotted seatrout and black drum.

Introduction

Packery Channel transects Mustang Island, connecting the Gulf of Mexico to the upper portion of the Laguna Madre. This tidal pass was a natural inlet that opened to the Gulf of Mexico for short periods of time following tropical cyclones and occasional over-wash by very high astronomical tides. When the Aransas Pass Ship Channel was completed at the northern end of Mustang Island in 1912 Packery Channel completely silted in.

Federal funding was obtained in 2003 to permanently open the pass as a component of a beach erosion control project for North Padre Island (USACE 2003). Construction began in late 2003 with completion scheduled for the fall of 2006. The plan was to essentially dredge the entire channel with the exception of a sand plug at the beach line, then finish construction of the jetties before opening the inlet. However, the storm surge from Hurricane Emily breached the inlet on 22 July 2006 and created a permanent, albeit shallow, opening to the Gulf. Channel construction was officially completed in the winter of 2006/2007.

Many commercially and recreationally important fish and invertebrate species in the Upper Laguna Madre and Corpus Christi Bay have a life cycle where adults spawn in the coastal ocean and their eggs, larvae, and/or juveniles recruit to the bay system through tidal inlets (Kneib 1993; Heck et al. 2003). For many of these species, only the juvenile stages reside in the estuary; the adults live offshore and only occasionally enter the estuary. These species are often referred to as estuarine dependent marine species and their larvae are important components of the meroplankton (the planktonic larval stage of species whose juvenile and adult stages are nektonic or benthic). With the opening of Packery Channel, a new permanent means of ingress to the local estuarine system became available to these estuarine dependent marine species (Reese et al. 2008). This could result in more fish productivity from habitats that were once remote from passes and potentially underutilized as nursery habitat. The purpose of this project is to determine the continued effect of Packery Channel on larval stages of fish and crustaceans in the vicinity of the pass.

Study Area

The study area (Fig. 1) is in an estuarine/lagoon system on the South Texas coast in the north end of the Upper Laguna Madre and the southeastern corner of Corpus Christi Bay. Packery Channel is situated approximately in the middle of the study area. In addition to the Packery Channel tidal inlet, two other dredged channels, the Intracoastal Waterway (ICWW) and Causeway Channel, transect the study area. The ICWW runs perpendicular to Packery Channel and the two intersect where Packery Channel terminates in the bay. Causeway Channel is a short channel that begins almost directly across the ICWW from Packery Channel and extends across an area of shallow water.

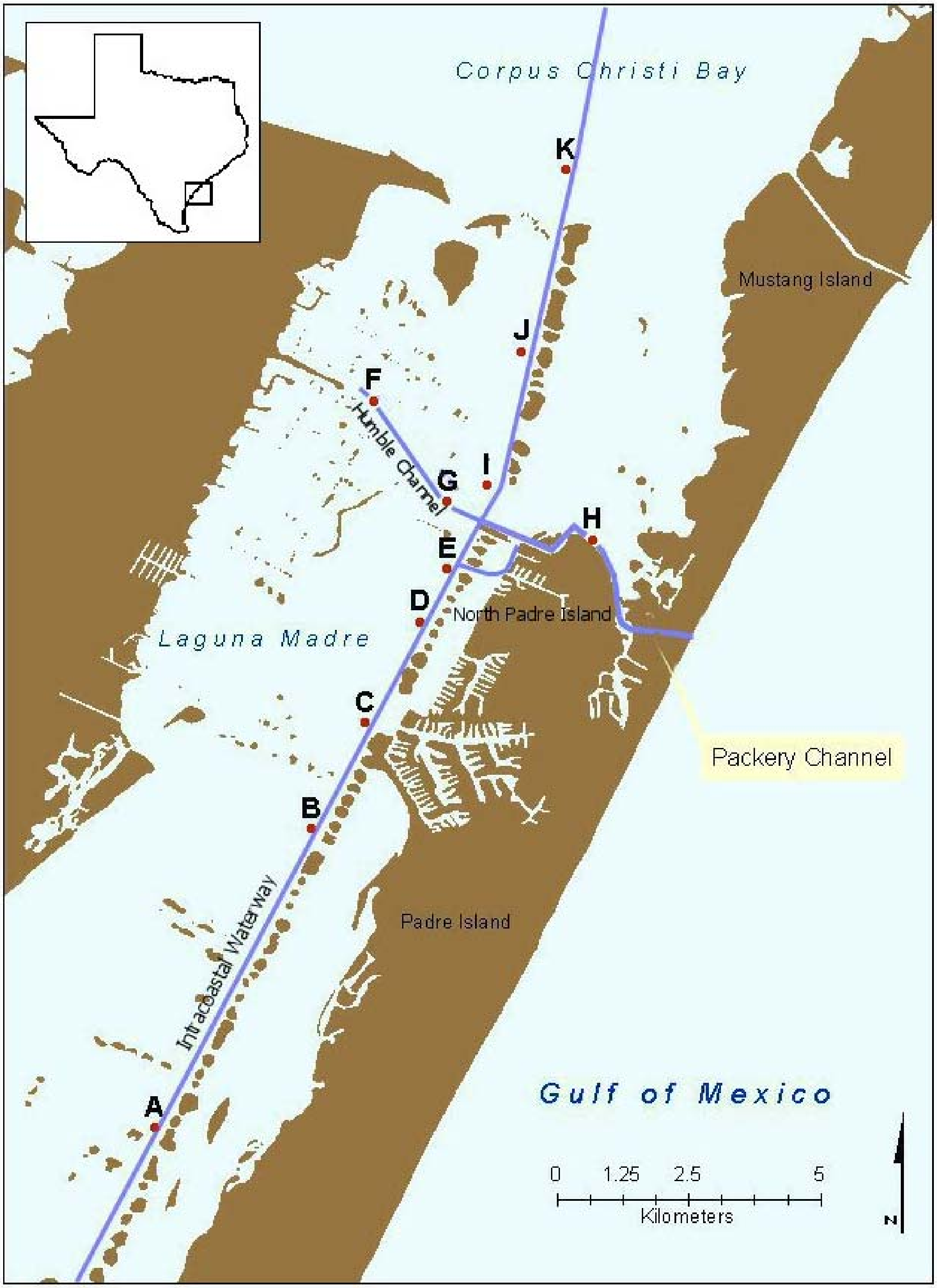

Figure 1. Map of study showing location of Packery Channel and sample sites.

Materials and Methods

Sampling

Sampling stations were established within the 3 channels in the study area to monitor larval migration from the Gulf of Mexico (GOM) into the estuary via Packery Channel (Fig. 1). Samples were taken before and after Packery Channel opened. Pre-opening samples were collected during 3 trips in 2005 (7 Feb, 30 Mar, and 7 Jun). Post-opening samples were taken during 18 trips: 3 in 2005 (19 Aug, 19 Oct, & 30 Nov), 2 in 2006 (2 Mar & 20 Sep), 9 in 2007 (9 & 13 Feb, 20 Apr, 3 & 8 May, 10 Aug, 20 & 26 Sep, 19 Dec), and 4 in 2008 (29 Jan, 14 Feb, 8 & 21 May). Seven fixed sampling sites were initially established within the three dredged channels transecting the study site: one station was located in the southern edge of Corpus Christi Bay just west of the ICWW (K), one station was north of Packery Channel in the ICWW (J), one station was inside Packery Channel near the Highway 361 bridge (H), one west of Packery Channel in Causeway Channel (F), and three were south of Packery Channel in the ICWW (A, B, and C). An assessment of larval fish densities from the first year of post-opening data indicated there was little influence of Packery Channel on meroplankton composition or density at the farthest reaches of the study area. Beginning with the 10 Aug 2007 collections, we eliminated the four stations most distant from Packery Channel (stations A, B, F, and K), and added four stations near the confluence of Packery Channel with the ICWW (D, E, G, and I), thus concentrating sampling closer to Packery Channel's intersection with the ICWW and Causeway Channel to discern any finer scale affects of Packery Channel. The two sampling schemes are thus identified as the expanded scheme and concentrated scheme, respectively. In order to accommodate data analysis we named all 11 stations alphabetically beginning with the southernmost station and moving northward; thus station names, but not location, have been changed from the first report.

Meroplankton was collected using a 1 m, 500 micron mesh net mounted on an epibenthic sled set to fish 20 cm off the bottom. A net mounted flowmeter recorded volume of water filtered through the net. Sampling at the Packery Channel site was timed to coincide with the time of maximum flood tide. All other stations were sampled without regard to tidal stage. Samples were preserved in 5% formalin, and later sorted to species or lowest taxonomic level possible. In some instances the condition and/or poor pigmentation of the specimen prevented specific identification. Once sorted, each taxon was enumerated.

Environmental conditions were recorded at every station for each sampling event using a YSI 650 MDS data-logger and 6950 Datasonde. Parameters measured included water temperature, salinity, dissolved oxygen, pH, turbidity and depth.

To determine the spatial extent of the tidal prism flowing into the estuary through Packery Channel from the Gulf of Mexico (GOM), we ran survey transects profiling surface water conditions from the base of the jetties at Packery Channel to the confluence with the ICWW, both north and south in the ICWW, in Causeway Channel, and from the bridge along Kennedy Causeway where Packery Channel interfaces with the canals serving the waterfront community of North Padre Island (NPI) out to the Laguna Madre (Fig. 1). Transects were run 6 times (17 & 20

May and 4 & 8 Oct in 2007 and 13 Feb and 29 Apr in 2008) during diurnal tidal periods. Sampling was initiated in Packery Channel at the time of maximum flood tide and required about 2 h to complete.

The YSI system was programmed to measure and record water temperature, salinity, pH and turbidity every 4 seconds and it was interfaced with a Garmin GPSMap 76/CSx to collect and record latitude and longitude as we moved along the transect. Water delivered by way of a wash down pump run into a tub on deck and continually bathed the sensors. Preliminary analysis showed that no parameter except dissolved oxygen was modified by transit through the pump. Dissolved oxygen was not measured in the study. Wind speed and direction were measured and recorded on each trip.

Analysis

Results from water profile surveys were downloaded into ESRI ArcMap 9.0. The program classified the georeferenced water-quality parameters into 5 bins or categories. This information was then mapped using graduated colors to visually show the measurements. The spatial extent of the effect of Packery channel was determined visually from these plots and could be followed from near the jetties through Packery Channel into the Laguna Madre, either as a uniform value or as a gradient. The limit of the spatial effect of the Packery Channel tidal excursion could be determined as that location where the value of a water parameter value became uniform or varied in a random or non-uniform manner, i.e having the same value at several spatially separated locations with no clear gradient connecting them.

Hierarchical cluster analysis was used to examine both temporal and spatial patterns in the biological data to determine whether there was an observable change in meroplankton community as a result of opening Packery Channel. Cluster analysis is a multivariate procedure for detecting natural groupings in data. The input data is a matrix of “entities” (e.g stations or dates) and the “attributes” (e.g. density of each species collected at that date or station). The analysis is a two step process where a similarity matrix is computed for all possible pairs of objects to be clustered and then a linkage procedure is employed to sequentially link all the separate entities (or attributes) into progressively inclusive groups. The results are displayed as a tree diagram, or dendrogram, that shows the relationship among groups. Clustering can be applied to the entities, to determine the natural relationship among locations, for instance, or to the attributes to determine the natural groupings of species, for instance, to show their association with various locations or dates. Clusters were subjectively defined at a single distance value within each analysis. Each cluster was identified by entity or attribute name and by sequential letter (e.g. Station Group A or Species Group B) and within each analyses, group naming began with “A”. Finally, the original data matrix can be rearranged into a cross-tabulation matrix based on the position of the entities and attributes in the dendrogram to provide a visual assessment of the relationship between the two patterns produced by the cluster analysis. The mean density of each species was computed for each station group (or date group for the temporal analysis) in each analysis as a measure to the species’ fidelity to that group. For example, if a species occurred at stations in only one group the mean density, or “fidelity”, for that group would be 100%. In the cross-tabulation tables, fidelity values >50% were shaded for emphasis.

To examine temporal changes, all collections (stations) from each date were pooled and the resulting collections for date were clustered based on the density of each species observed on those dates and clustering of species was done based on the dates on which they occurred. For the spatial analysis, the study period was divided into three periods: pre-opening, post-opening with expanded station arraignment, and post-opening with concentrated station arraignment. Separate analyses were run for each period and both station and species clusters were produced. In all cases, the data were 4th root transformed to reduce the influence of highly abundant species (Young and Potter 2002). The analysis was run in SYSTAT (SYSTAT Software Inc., San Jose CA).

Results

Water Quality Surveys

Turbidity was generally not a useful indicator for distinguishing between the different bodies of water. In most cases, windy conditions combined with the shallow waters of our study area overwhelmed any physical trait the water might have exhibited due to incoming GOM water. Turbidity tended to fluctuate widely in unprotected locations.

For the other three water quality parameters, offshore water entering Packery Channel could generally be distinguished from the resident Laguna Madre water in the other channels based on GIS plots. In four of the six surveys (Figs. 2-5), the water quality parameters within Packery Channel were fairly homogenous with little to no change along the length of the channel. Water in the North Padre Island Channel was often similar to the Packery channel water in these surveys but the water quality characteristics in the North Padre Island Channel did not extend any distance into the ICWW where the two channels intersect, suggesting little net transport through the North Padre Island Channel. Surveys 3 and 4 (Figs. 6 and 7) were exceptions to this pattern, showing an increase in temperature and pH and a decrease in salinity with increasing distance from the GOM within Packery Channel.

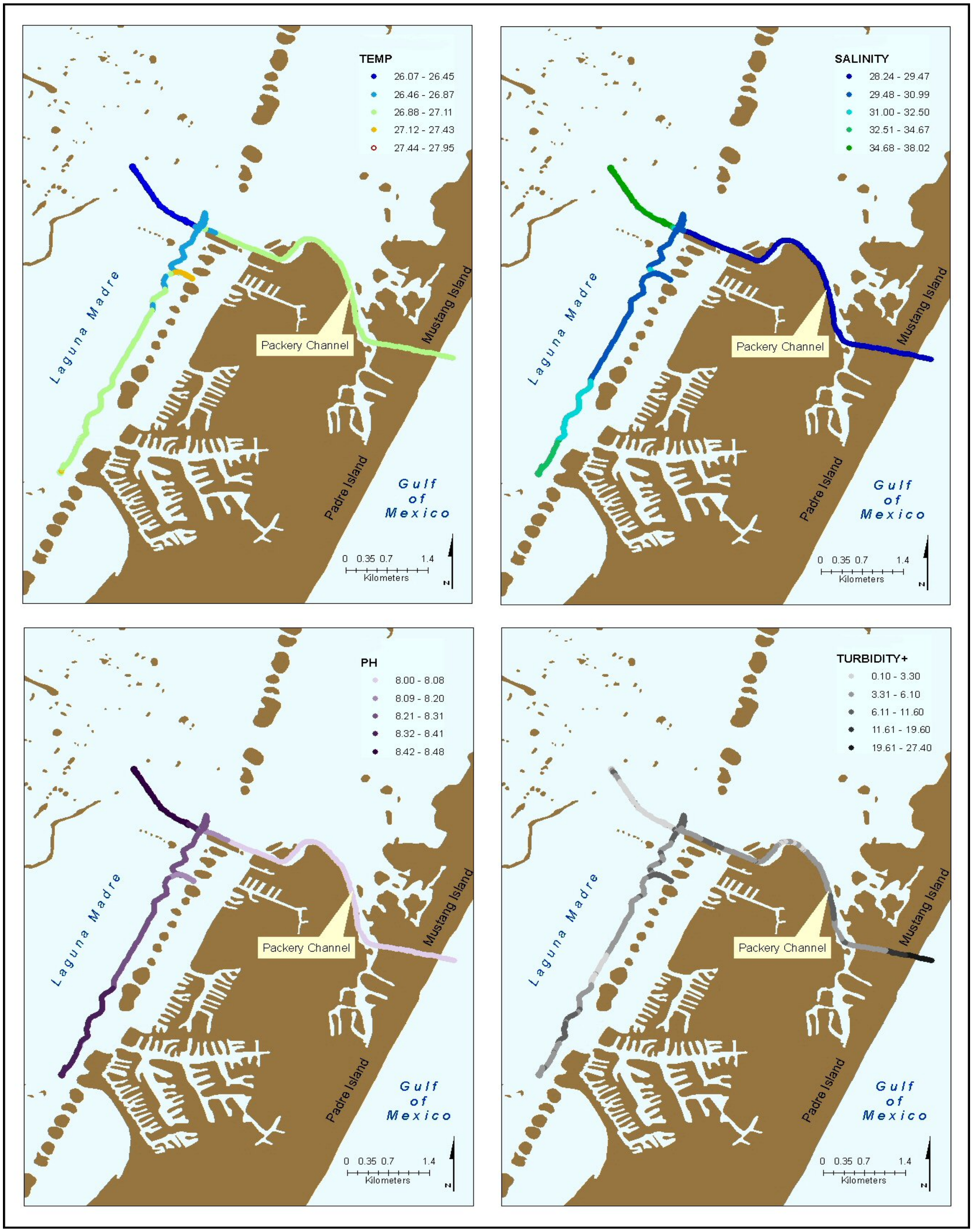

Figure 2. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 17 May 2007 (Survey 1).

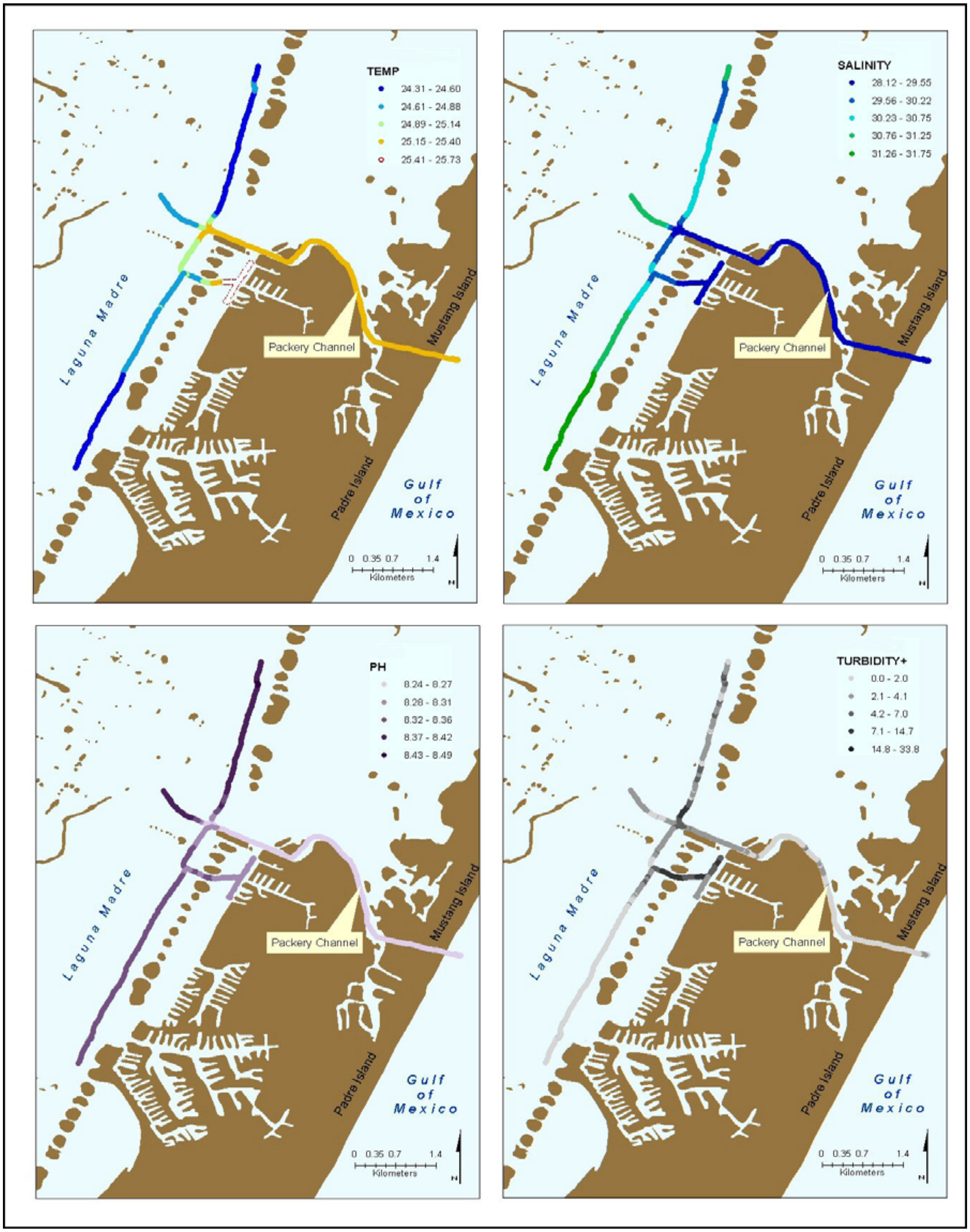

Figure 3. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 20 May 2007 (Survey 2).

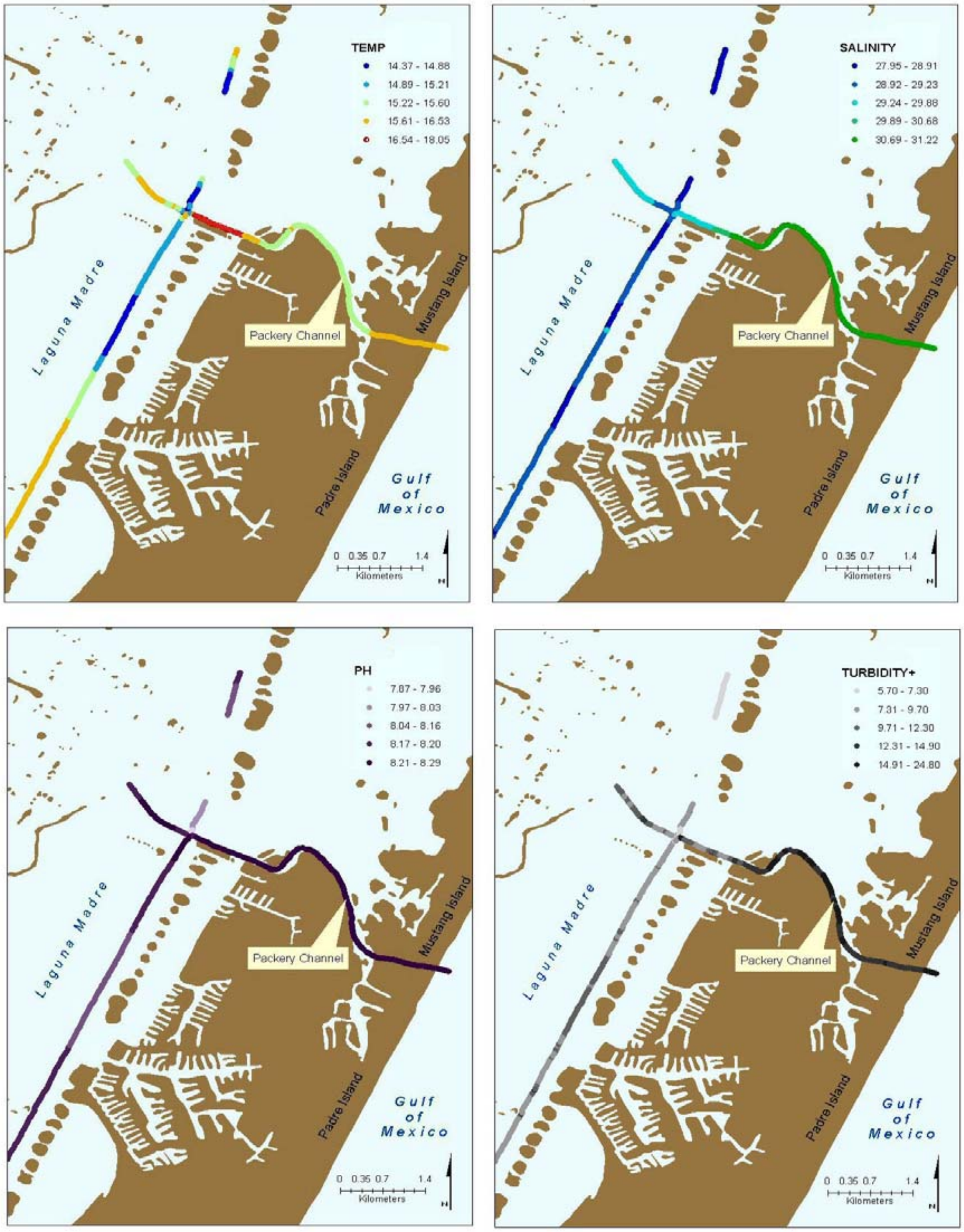

Figure 4. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 13 February 2008 (Survey 5).

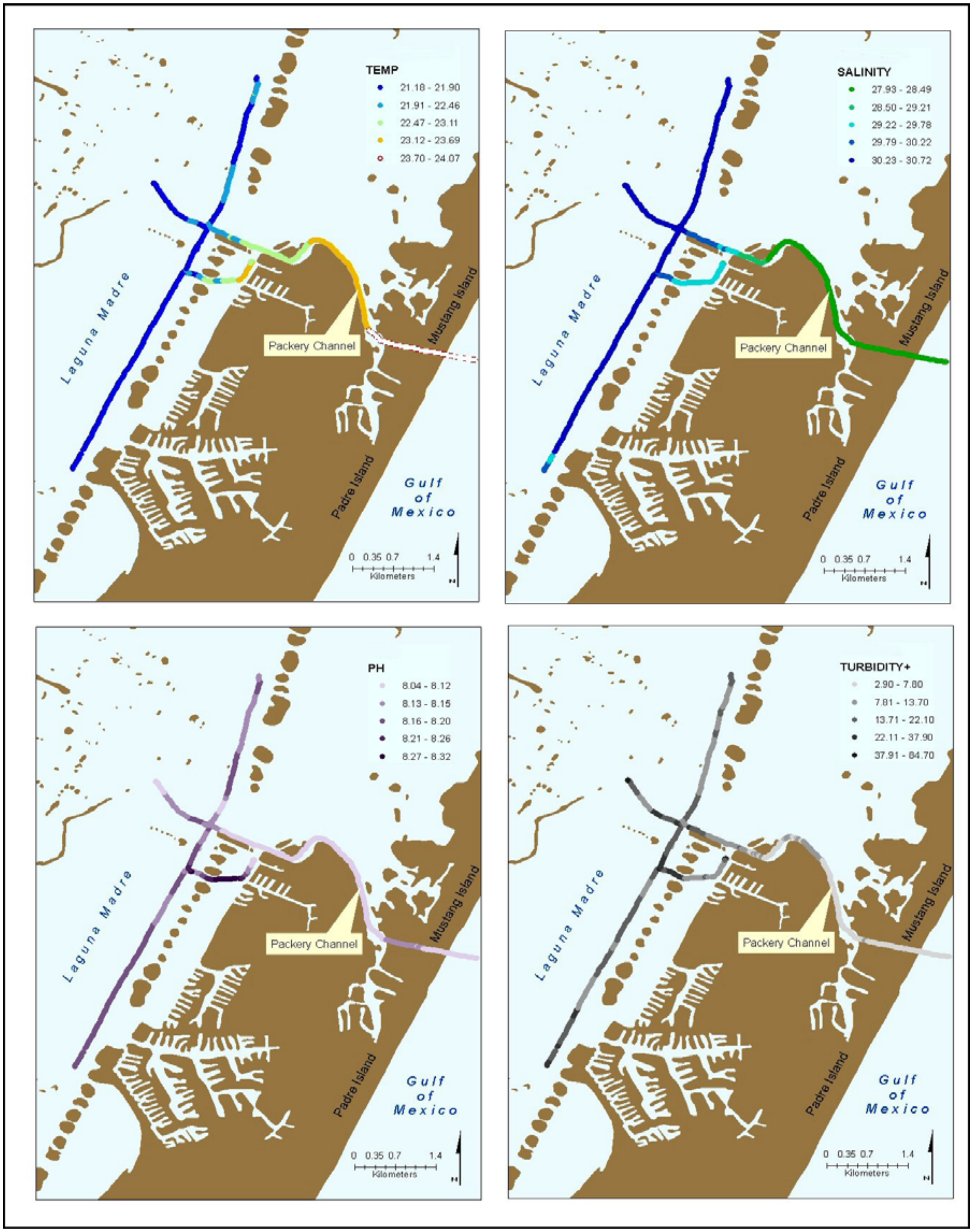

Figure 5. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 29 April 2008 (Survey 6).

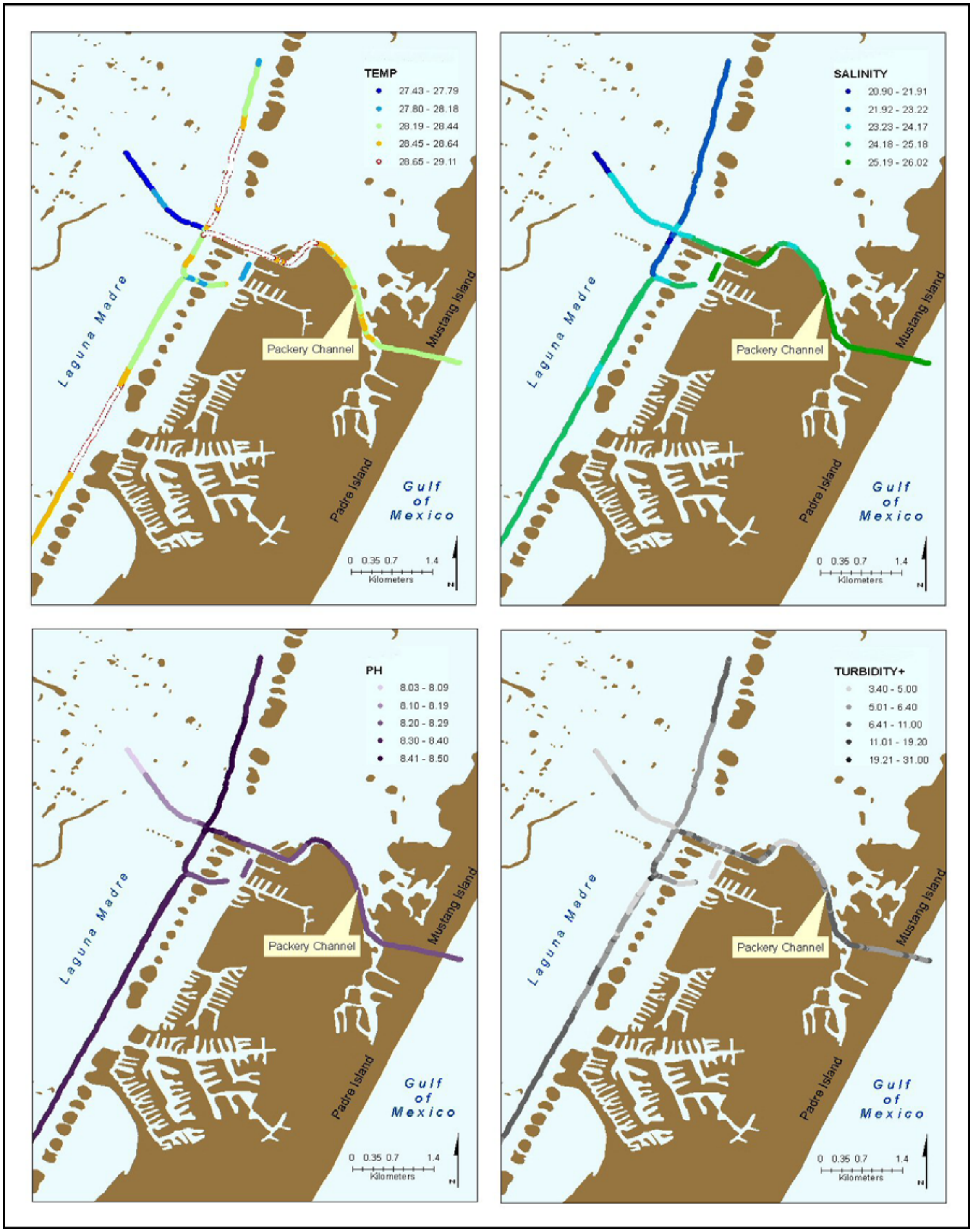

Figure 6. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 4 October 2007 (Survey 3).

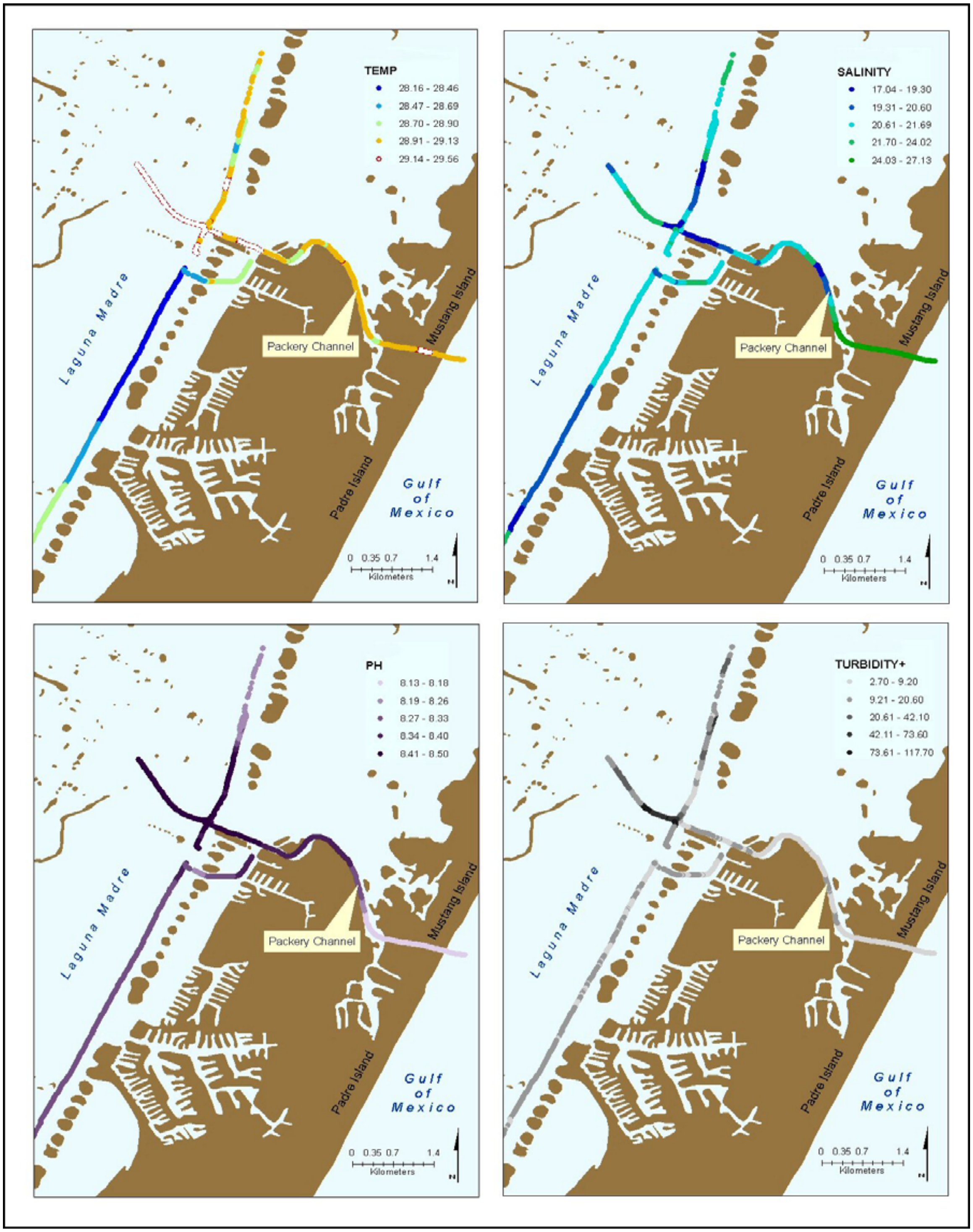

Figure 7. Graphical representation of water quality survey results from the Packery Channel region of the Upper Laguna Madre. Panels show color coded representation of the spatial distribution of temperature, salinity, pH, and turbidity on 08 October 2008 (Survey 4).

In four of the six surveys it appears that offshore water stopped at or before the juncture with the ICWW. On the first survey (Fig 2) water in the ICWW south of Packery Channel had similar from the GOM within Packery channel. Coincidentally, these two surveys were taken under conditions with the lowest wind speeds, ESE at 2-12 mph and ENE at 0-15 mph, respectively salinities but the pH and temperature were different. Again, on survey 3, (Fig. 6) only salinity values were comparable north of Packery Channel in the ICWW, and on survey 5 (Fig. 4) pH was the only equivalent value in the 2 channels.

Causeway Channel water conditions resembled Packery Channel water on only one survey, survey 4 (Fig. 7) And NPI appeared ineffective at transporting offshore water any distance away from its intersection with Packery Channel.

From these surveys, it appears that offshore water entering Packery channel on flood tide is largely contained within Packery Channel itself and is seldom seen in the channels of the ICWW or the Causeway Channel crossing the Laguna Madre. There is no doubt there is some mixing of offshore water with Laguna Madre water but the direct effect of Packery Channel on Laguna Madre water quality characteristics is spatially limited.

Meroplankton Surveys

Over 547,600 individual invertebrates and fish from 48 taxa were captured in the study (Table 1). Two invertebrate species dominated the catches, including 280,118 blue crab megalops (51.1% og the total catch) and 63,055 (11.5%) penaeid shrimp post-larvae (mostly brown shrimp). Among fish larvae, anchovy, mostly bay anchovy, was the most common taxa, comprising 18.8% of the catch. Anchovies typically dominate meroplankton catches, not only in the Laguna Madre (Holt et al 1990), but in most Gulf and Atlantic estuarine systems of the U.S. Code goby was the second most common meroplankton taken in the study, accounting for 6.9% of the total catch. These were followed by spot (2.4%), darter goby (1.64%), Atlantic croaker (1.64%), green goby (1.26%) and unidentified gobies (1.09%). The unidentified gobies were mostly small or damaged specimens and probably were representatives of one of the species mentioned above. The remaining species each comprised less than 1% of the catch. Several recreationally or commercially important fish species were collected in the study, including spotted seatrout (757 ind.), southern flounder (335 ind.), red drum (160 ind.), and black drum (158 ind.).

Temporal assessment of the data by cluster analysis showed produced a dendrogram that could clearly be divided into two groups (Fig. 8). One group, the “warm” season collections, included all collections taken from April through September in all years plus the March 2005 collection. The second group, the “cool” season collections, included all collections taken from November

Table 2. Taxa collected in Packery Channel study area from Feb 2005 through May 2008.

Common name/taxa	**total catch**	**mean density/1000 m3**	**% rank in abundance**
Blue crab (Megalops) *Callinectes sapidus*	280,118	2,393.05	45.9792
Anchovy *Anchoa sp.*	102,682	852.36	16.8544
Penaeid shrimp (Post larval) *Penaeidae*	63,055	613.97	10.3500
Goby A (All gobies combined) *Gobiidae*	61,197	521.98	10.0450
Code Goby *Gobiosoma robustum*	37,634	288.84	6.1773
Spot *Leiostomus xanthurus*	13,011	134.11	2.1357
Darter goby *Gobionelllus boleosoma*	8,969	109.90	1.4722
Atlantic croaker *Micropogonias undulatus*	8,936	89.54	1.4668
Green goby *Microgobius thalassinus*	6,873	57.72	1.1281
Goby B (unidentifiable to species) *Gobiidae*	5,987	49.58	0.9827
Pipefish sp. *Syngnathidae*	3,734	30.78	0.6129
Herring *Clupeidae*	3,641	28.60	0.5976
Gulf menhaden *Brevoortia patronus*	3,574	30.63	0.5866
Silver perch *Bairdiella chrysoura*	2,414	20.73	0.3962
Pinfish *Lagadon rhomboides*	1,168	9.73	0.1917
Eel (Leptocephallus) *Ophichthidae*	832	9.18	0.1366
Spotted seatrout *Cynoscion nebulosus*	757	6.17	0.1243
Sand seatrout *Cynosion arenarius*	661	5.84	0.1085
Ladyfish (Leptocephallus) *Elops saurus*	548	4.42	0.0899
Naked goby *Gobiosoma bosc*	469	4.23	0.0770
Blenny A (All blennies combined) *Blenniidae*	379	3.02	0.0622
Bay whiff *Citharichthys spilopterus*	354	5.03	0.0581
Southern flounder *Paralichthys lethostigma*	335	3.66	0.0550
Lined sole *Achirus lineatus*	274	2.03	0.0450
Violet goby *Gobioides broussoneti*	249	2.28	0.0409
Blenny B (Unidentifiable to species) *Blenniidae*	201	1.68	0.0330
Feather blenny *Hypsoblennius hentz*	178	1.35	0.0292
Silversides *Atherinidae*	169	1.38	0.0277
Red drum *Scianops occellatus*	160	1.40	0.0263
Black drum *Pogonias cromis*	158	1.77	0.0259
Whiting *Menticirrhus sp.*	149	1.88	0.0245
Skilletfish *Gobiesox strumosus*	74	0.59	0.0121
Hogchoker *Trinectes maculatus*	50	0.46	0.0082
Sheepshead *Archosargus probatocephalus*	47	0.58	0.0077
Lizardfish *Synodontidae*	39	0.26	0.0064
Leatherjacket *Oligoplites saurus*	29	0.36	0.0048
Seahorse *Hippocampus sp.*	25	0.20	0.0041
Gulf black sea bass *Centropristis striata*	17	0.16	0.0028
Frillfin goby *Bathygobius soporator*	16	0.16	0.0026
Mullet *Mugilidae*	14	0.11	0.0023
Bothid *Bothidae*	13	0.14	0.0021
Jack *Carangidae*	11	0.20	0.0018
Drum *Sciaenidae*	8	0.06	0.0013
Least puffer *Sphoeroides parvus*	5	0.04	0.0008
Gulf butterfish *Peprilus burti*	5	0.04	0.0008
Halfbeak *Exocotetidae*	3	0.02	0.0005
Pigfish *Orthopristis chrysoptera*	2	0.02	0.0003
Wrasse *Labridae*	2	0.02	0.0003
Tarpon (Leptocephallus) *Megalops atlanticus*	1	0.01	0.0002
Gulf toadfish *Opsanus beta*	1	0.01	0.0002

through February in all years plus the March 2006 collection. It is significant that the collections taken prior to Packery Channel being opened were not grouped separate from the post-opening collections but were integrated within the appropriate seasonal group. Within each of these two seasonal groups, the collections can be further subdivided into two sub-groups. Within the warm season group, all the collections from 2005 are in a cluster distinct from all the 2006, 2007 and 2008 collections. Within the cool season group, the two collections from 2005 plus the March collection from 2006 are in a cluster distinct from all other collections. The species (i.e. attribute) dendrogram from the seasonal analysis could be divided into three distinct clusters (Fig. 9).

Examination of the resulting cross-tabulation table from the temporal analysis (Table 2) gives a clear indication of the temporal occurrence of meroplankton in the study area. Species Group A was composed of species taken primarily in the cool season and is characterized by high fidelity of estuarine-dependent marine species such as southern flounder, pinfish, Atlantic croaker, and spot. Blue crab megalops and penaeid shrimp, also members of this group, have high densities during the cool season but were also taken abundantly in the warm, season. Black drum, an estuarine and coastal spawner and is also a member of this species group and characteristic of the cool season fauna. Species group C was composed of species taken primarily in the warm season and included species such as spotted seatrout, whiting, naked goby, silver perch, and pigfish. Species Group B was composed of species that were also taken primarily in the warm season but most were taken in relatively lower abundance and at fewer occasions than most species in Species Group C. The sub-groups in each seasonal cluster, representing primarily the 2005 collections, are not characterized so much by distinct species assemblages as by relatively lower mean abundances for most species in the 2005 collections.

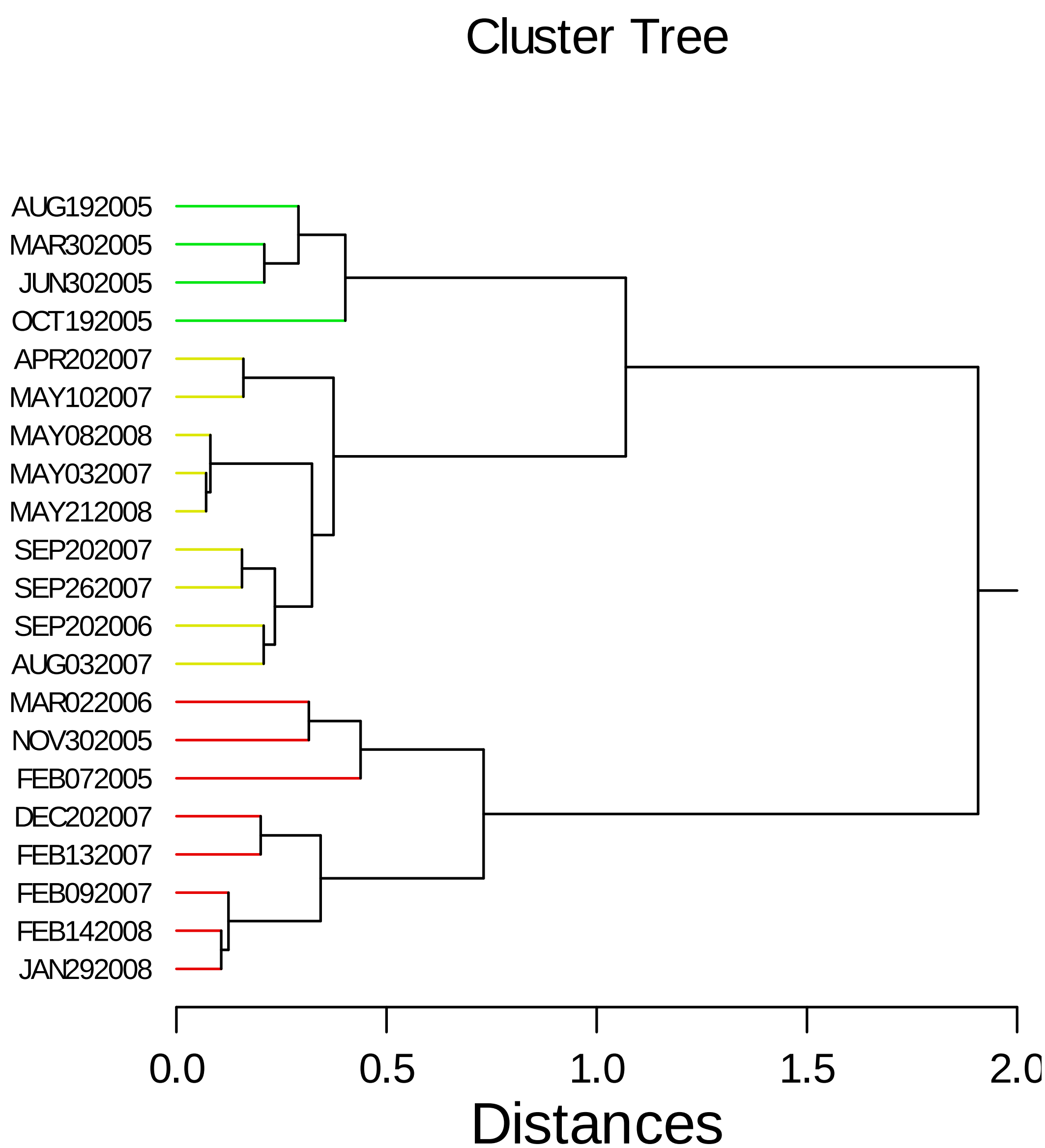

Figure 8. Dendrogram from temporal cluster analysis of all collections pooled by date.

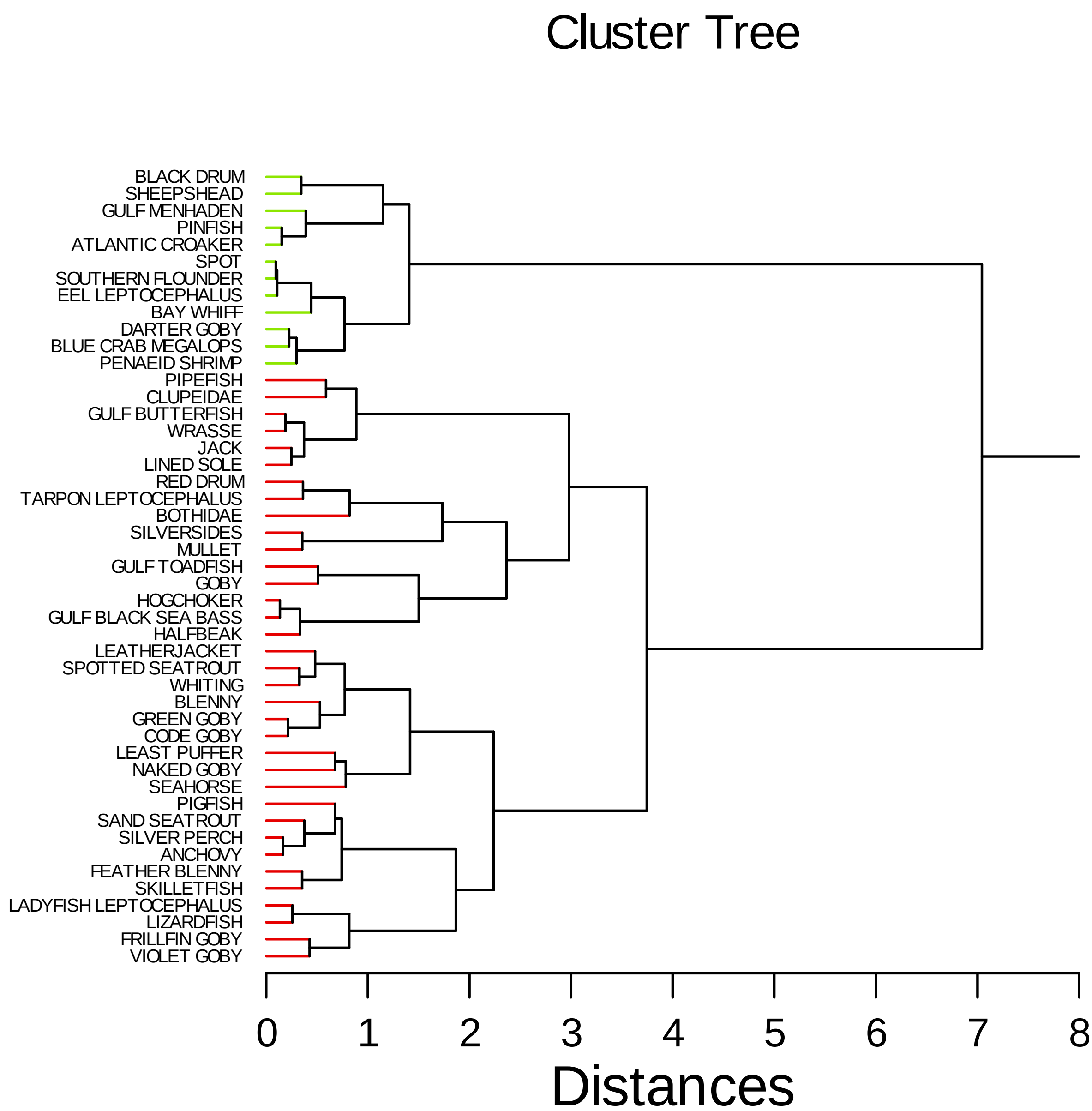

Figure 9. Dendrogram from cluster analysis of all Packery channel collections based on species composition of each station pooled over all pre-opening dates.

Table 2. Cross-tabulation table of temporal cluster analysis results. Dashes in the table, "-", were inserted to improve readability and represent measured zeros and not missing data. Shaded cells indicate ≥ 50% fidelity in that cell (see text for full description).

Species	Temporal Group	A "Warm"		B "Cool"	
Group	Species	A1	A2	B1	B2
A	BLACK DRUM	0.10	0.14	0.08	0.69
	SHEEPSHEAD	0.16	0.01	0.07	0.76
	GULF MENHADEN	0.07	0.12	0.28	0.53
	PINFISH	0.00	0.00	0.21	0.79
	ATLANTIC CROAKER	0.00	-	0.50	0.50
	SPOT	0.01	-	0.00	0.99
	SOUTHERN FLOUNDER	-	-	0.05	0.95
	EEL LEPTOCEPHALUS	0.00	-	0.00	1.00
	BAY WHIFF	-	0.00	0.00	1.00
	DARTER GOBY	-	0.23	0.00	0.77
	BLUE CRAB MEGALOPS	0.00	0.36	0.01	0.63
	PENAEID SHRIMP	0.03	0.28	0.06	0.63
	PIPEFISH	0.08	0.58	0.16	0.18
B	CLUPEIDAE	-	0.60	0.01	0.39
	GULF BUTTERFISH	-	1.00	-	-
	WRASSE	-	1.00	-	-
	JACK	-	0.96	0.04	-
	LINED SOLE	-	1.00	-	-
	RED DRUM	-	0.99	0.01	-
	TARPON LEPTOCEPHALUS	-	1.00	-	-
	BOTHIDAE	-	0.06	0.94	-
	SILVERSIDES	-	0.06	0.83	0.11
	MULLET	-	-	1.00	-
	GULF TOADFISH	1.00	-	-	-
	GOBY	1.00	0.00	-	-
	HOGCHOKER	0.95	0.05	-	-
	GULF BLACK SEA BASS	1.00	-	-	-
	HALFBEAK	0.76	0.24	-	-
C	LEATHERJACKET	0.05	0.95	-	-
	SPOTTED SEATROUT	0.26	0.74	-	-
	WHITING	0.10	0.90	-	-
	BLENNY	0.11	0.86	0.03	-
	GREEN GOBY	0.06	0.93	0.00	-
	CODE GOBY	-	1.00	-	-
	LEAST PUFFER	-	1.00	-	-
	NAKED GOBY	0.85	0.15	-	-
	SEAHORSE	0.26	0.44	0.23	0.07
	PIGFISH	-	1.00	-	-
	SAND SEATROUT	0.04	0.95	-	0.01
	SILVER PERCH	0.09	0.91	-	-
	ANCHOVY	0.31	0.69	0.00	0.00
	FEATHER BLENNY	0.55	0.45	-	-
	SKILLETFISH	0.76	0.24	-	-
	LADYFISH LEPTOCEPHALUS	0.08	0.75	0.01	0.16
	LIZARDFISH	0.13	0.87	-	-
	FRILLFIN GOBY	-	1.00	-	-
	VIOLET GOBY	-	0.78	0.01	0.21

Cluster analysis of the pre-opening period, where all collection dates were pooled by station, produced a dendrogram divided into three groups (Fig. 10) but among-group distances (i.e. the relative difference between clusters) are relatively small, suggesting no clear differentation among sites or groups of sites. Group A contains the station in the ICWW north of Packery Channel (station J) and the Causeway Channel, station K., Group B contains the ICWW stations south of Packery Channel (Stations C, B, and A) and group C includes the station in Packery Channel (Station H) and the open bay station (Station K). The dendrogram from cluster analysis of species for the pre-opening period was divided into three clear groups with a clear separation between the goby-anchovy couplet and all other species, although the remaining species show a clear separation into two groups (Fig. 11). The resulting cross-tabulation table (Table 3) shows that goby and anchovy were taken at all station groups in relatively even diatribution, as were spotted seatrout and skilletfish in species group B (goby and anchovy were strongly separated from the rest of the species due to high absolute abundance which is not indicated in the table). Station group B had fewer species than the other stations groups and few fish with high fidelity there. The majority of species from all species groups had the highest fidelity at station group A.

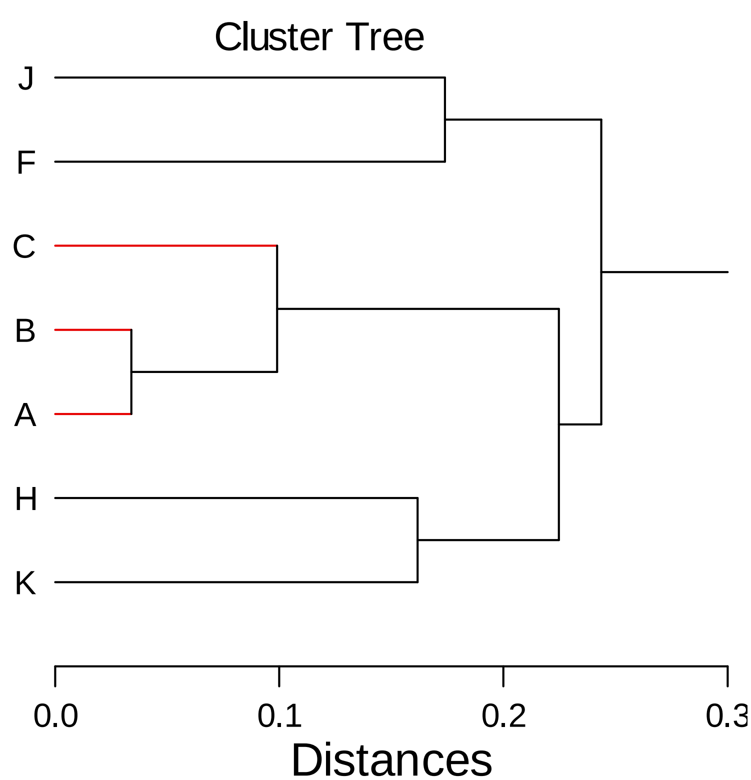

Figure 10. Dendrogram of station groups from spatial cluster analysis of all pre-opening collections based on species composition of each station pooled over all pre-opening dates.

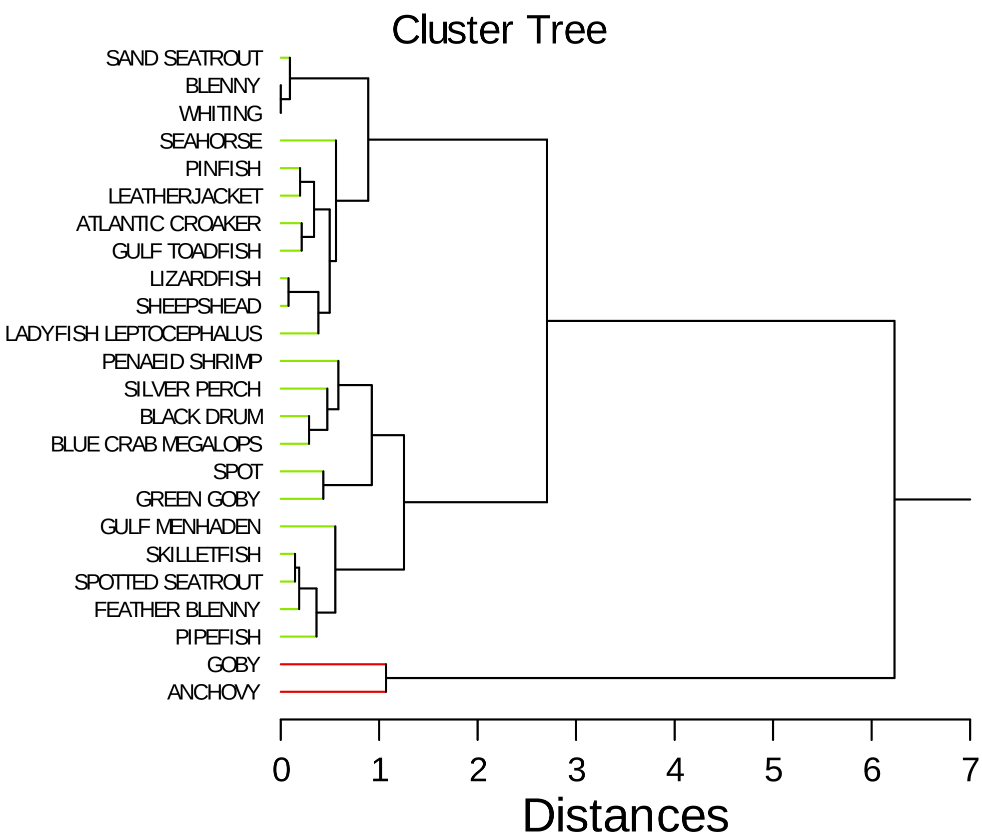

Figure 11. Dendrogram of species groups from cluster analysis of all pre-opening Packery Channel collections based on stations where each species occurred and pooled over all stations for each species.

Table 3. Cross-tabulation table of pre-opening cluster analysis results. Dashes in the table, “-“, were inserted to improve readability and represent measured zeros and not missing data. Shaded cells indicate ≥ 50% fidelity in that cell (see text for full description).

Species Group	Station Group	A	B	C
	Species			
A	SAND SEATROUT	-	-	1.00
	BLENNY	-	-	1.00
	WHITING	-	-	1.00
	SEAHORSE	-	0.79	0.21
	PINFISH	0.58	-	0.42
	LEATHERJACKET	1.00	-	-
	GULF TOADFISH	1.00	-	-
	ATLANTIC CROAKER	1.00	-	-
	LIZARDFISH	0.29	-	0.71
	SHEEPSHEAD	0.42	-	0.58
	LADYFISH LEPTOCEPHALUS	0.59	-	0.41
B	PENAEID SHRIMP	0.98	-	0.02
	SILVER PERCH	0.59	0.03	0.38
	BLACK DRUM	0.68	-	0.32
	BLUE CRAB MEGALOPS	0.76	0.06	0.18
	SPOT	0.02	-	0.98
	GREEN GOBY	-	0.02	0.98
	GULF MENHADEN	0.05	0.08	0.88
	SKILLETFISH	0.33	0.23	0.45
	FEATHER BLENNY	0.57	0.16	0.28
	SPOTTED SEATROUT	0.35	0.39	0.26
	PIPEFISH	0.67	0.14	0.19
C	GOBY	0.50	0.21	0.29
	ANCHOVY	0.39	0.16	0.45

The Dendrogram from cluster analysis of stations for the expanded (or original) station location scheme (Fig. 12) can be divided into three groups. The Packery Channel station (H) is shown as widely dissimilar from all other station in an arrangement clearly different from the pre-opening analysis. The other two groups are not strongly differentiated but the two stations in Station Group A are the stations in the ICWW north and south of the junction with Packery Channel. The remaining stations are in Station Group B. The dendrogram from the cluster analysis of species for this period (Fig. 13) can be divided into three groups. Group C has very low within-group dissimilarity and is strongly dissimilar from the other two groups. The cross-tabulation table for these two analyses (Table 4) shows that Station Group C (the Packery Channel site) is characterized by high fidelity of a majority of species in these collections. Species in Species group C were take almost exclusively in Packery Channel while species in Species Group B also had high fidelity to that Station Group but were also taken in moderate numbers in the other Station Groups as well. Only species in Species Group A had higher fidelity to either of the other two Station Groups (ladyfish leptocephalus was considered misclassified and reassigned to Species Group A) and most of those had high fidelity to Station Group A.

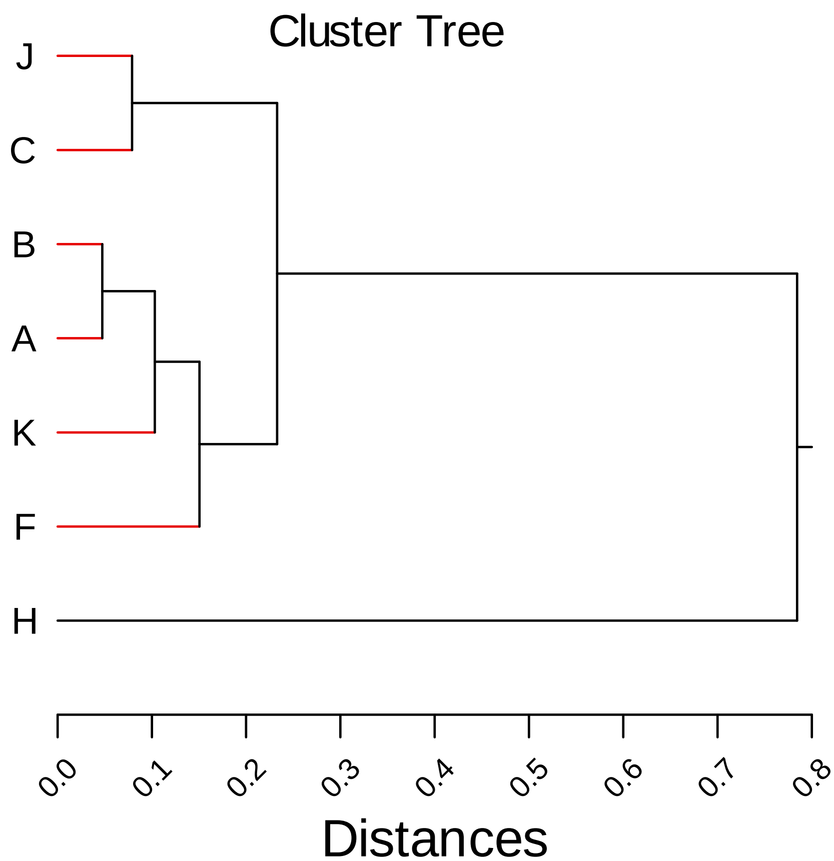

Figure 12. Dendrogram of station groups from spatial cluster analysis of all post-opening, expanded station scheme collections based on species composition of each station pooled over all appropriate post-opening dates.

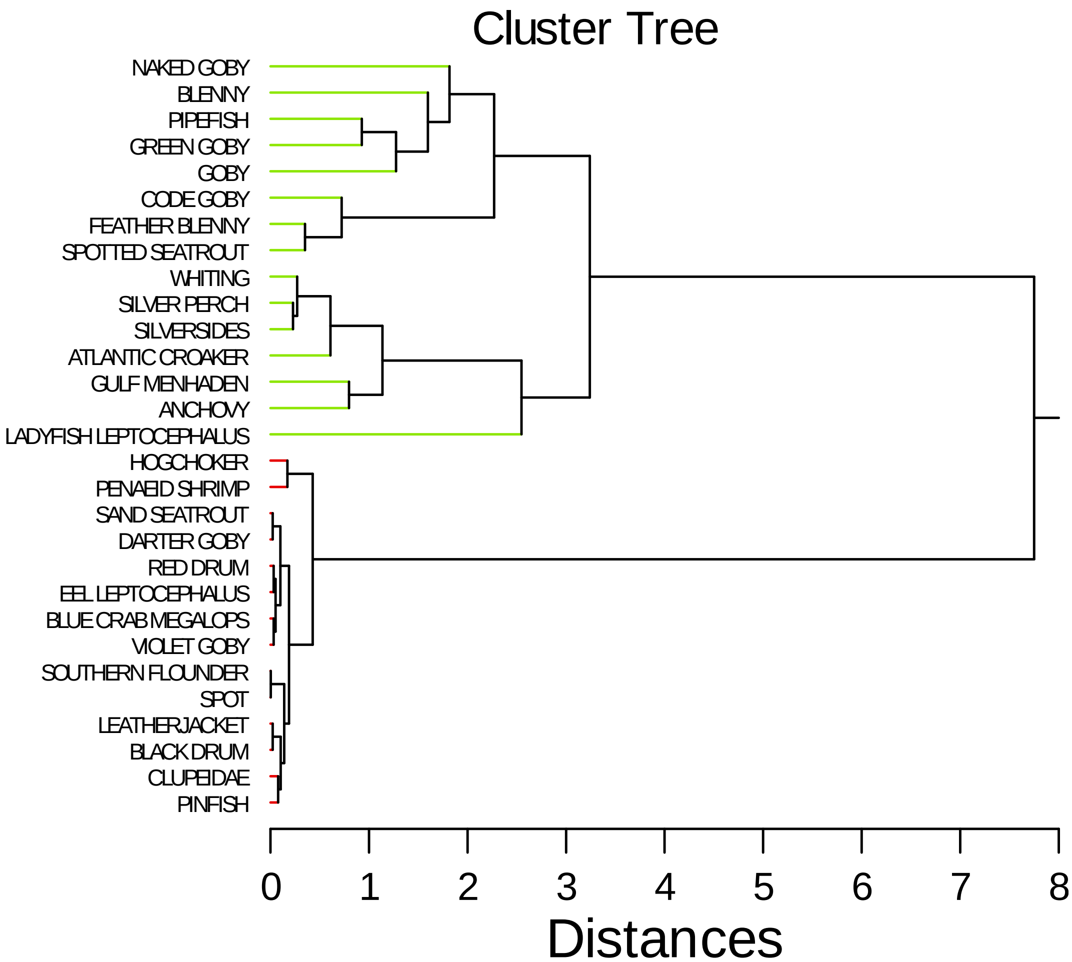

Figure 13. Dendrogram of species groups from spatial cluster analysis of the post-opening, expanded station scheme based on stations where each species occurred and pooled over all appropriate post-opening dates.

Table 4. Cross-tabulation table of results from post-opening cluster analysis of the expanded station location scheme. Dashes in the table, "-", were inserted to improve readability and represent measured zeros and not missing data. Shaded cells indicate ≥ 50% fidelity in that cell (see text for full description).

Species Group	Station Group	A	B	C
	Species			
A	NAKED GOBY	0.01	0.89	0.10
	BLENNY	0.24	0.43	0.32
	PIPEFISH	0.36	0.49	0.15
	GREEN GOBY	0.74	0.24	0.03
	GOBY	0.90	0.06	0.04
	CODE GOBY	0.77	0.23	0.00
	FEATHER BLENNY	0.74	0.20	0.06
	SPOTTED SEATROUT	0.71	0.17	0.12
	LADYFISH LEPTOCEPHALUS	0.73	0.04	0.23
B	WHITING	0.14	0.17	0.69
	SILVER PERCH	0.11	0.17	0.72
	SILVERSIDES	0.15	0.18	0.67
	ATLANTIC CROAKER	0.19	0.22	0.60
	GULF MENHADEN	0.35	0.02	0.62
	ANCHOVY	0.49	0.13	0.39
C	HOGCHOKER	0.06	0.05	0.89
	PENAEID SHRIMP	0.03	0.05	0.92
	SAND SEATROUT	0.02	0.03	0.95
	DARTER GOBY	0.02	0.03	0.95
	RED DRUM	0.01	0.02	0.97
	EEL LEPTOCEPHALUS	-	0.03	0.97
	BLUE CRAB MEGALOPS	0.01	0.02	0.97
	VIOLET GOBY	-	0.02	0.98
	SOUTHERN FLOUNDER	-	-	1.00
	SPOT	0.00	-	1.00
	LEATHERJACKET	-	0.03	0.97
	BLACK DRUM	-	0.02	0.98
	CLUPEIDAE	0.03	-	0.97
	PINFISH	0.03	0.01	0.96

The idea behind adjusting the station locations to a more concentrated arraignment near the Packery Channel's confluence with the ICWW was to better determine the spatial extent of larval immigration through Packery Channel into the ICWW. The dendrogram from spatial analysis of the data for the post-opening concentrated station scheme produced a slightly different arraignment of stations within station groups than seen for the expanded scheme (Fig. 14). As with the expanded scheme, the Packery Channel station is in a Station Group by itself and is strongly dissimilar to the other Stations Groups. However, although the other stations are similarly divided into two groups, the low dissimilarity, outlying group (Station Group B in this case) was not composed of the stations closest to the confluence of the Packery channel with the

ICWW but contains the two stations in the ICWW to the north of Packery Channel. The remaining stations compose the final Station Group A. The dendrogram from the species analysis of this data set (Fig. 15) is similar to the one for the expanded scheme in showing two highly dissimilar clusters with one group of very low within-group dissimilarity and the other group divided into two clusters of moderately low within-group dissimilarity.

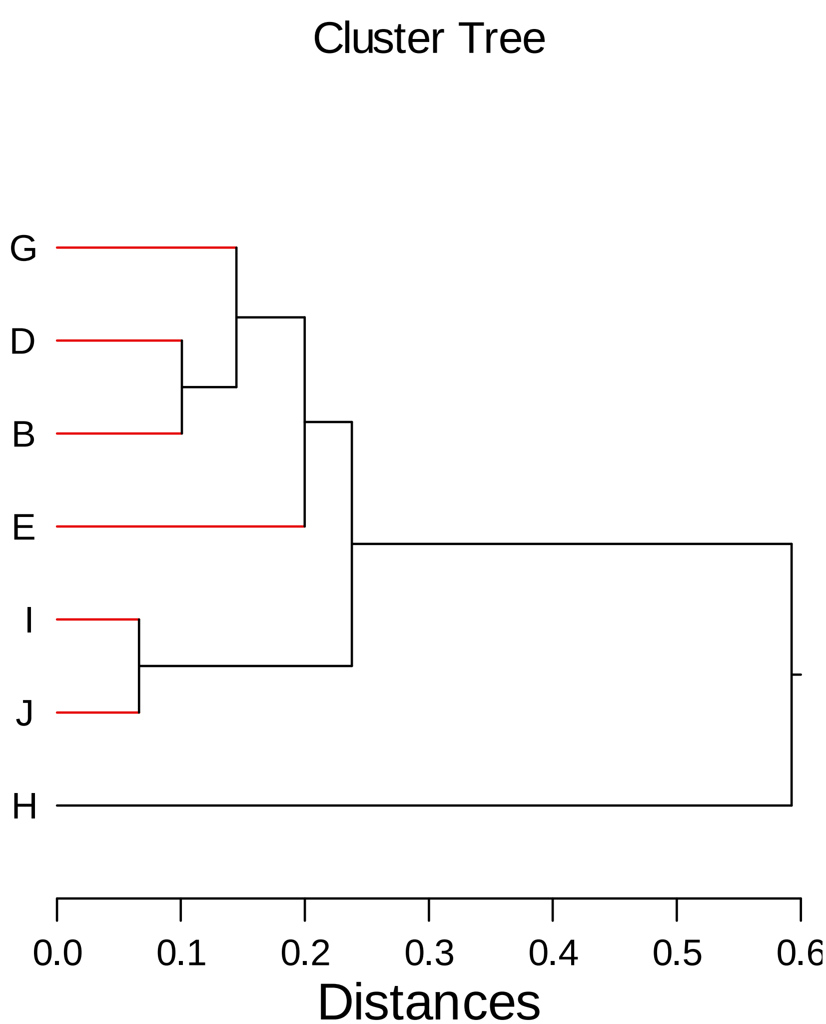

Figure 14. Dendrogram of station groups from spatial cluster analysis of all post-opening, contracted station scheme collections based on species composition of each station pooled over all appropriate post-opening dates.

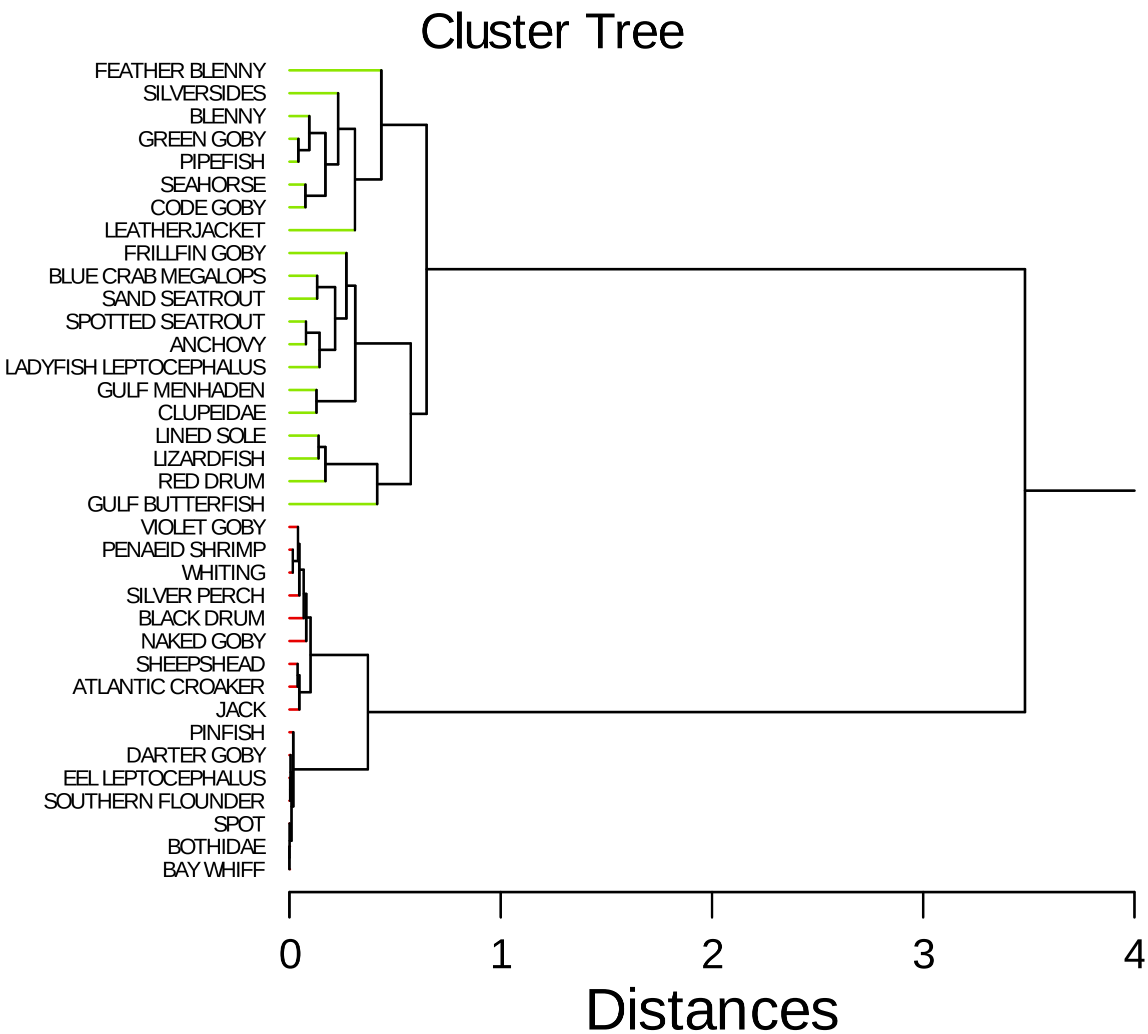

Figure 15. Dendrogram of species groups from spatial cluster analysis of the post-opening, contracted station scheme collections based on stations where each species occurred and pooled over all appropriate post-opening dates.

The cross-tabulation table from this analysis (Table 5) shows results similar to the analysis of the expanded scheme but with subtle differences. As seen in the preceding analysis, there is one group of species (Species Group C) with high fidelity to the Packery Channel station (Station Group C) but this is a smaller percentage of the total collection than seen in the expanded scheme analysis. The remaining species mostly have high fidelity at one or the other of the remaining Station Groups and many species, especially those in Species Group B, are distributed across two or even all three Station Groups.

Table 5. Cross-tabulation table of results from post-opening cluster analysis of the contracted station location scheme. Dashes in the table, "-", were inserted to improve readability and represent measured zeros and not missing data. Shaded cells indicate ≥ 50% fidelity in that cell (see text for full description).

Species Group	Station Group / Species	A	B	C
A	FEATHER BLENNY	0.19	0.81	-
	SILVERSIDES	0.74	0.26	-
	BLENNY	0.73	0.13	0.14
	GREEN GOBY	0.75	0.24	0.01
	PIPEFISH	0.76	0.21	0.02
	SEAHORSE	0.78	0.22	-
	CODE GOBY	0.82	0.18	0.00
	LEATHERJACKET	1.00	-	-
B	FRILLFIN GOBY	0.40	-	0.60
	BLUE CRAB MEGALOPS	0.07	0.39	0.53
	SAND SEATROUT	0.13	0.53	0.34
	SPOTTED SEATROUT	0.40	0.35	0.25
	LADYFISH LEPTOCEPHALUS	0.59	0.05	0.36
	ANCHOVY	0.59	0.20	0.21
	GULF MENHADEN	0.38	0.03	0.59
	CLUPEIDAE	0.63	0.02	0.35
	LINED SOLE	0.94	0.06	-
	LIZARDFISH	0.77	0.23	-
	RED DRUM	0.95	0.05	-
	GULF BUTTERFISH	0.20	0.80	-
C	VIOLET GOBY	0.11	0.08	0.81
	PENAEID SHRIMP	0.10	0.08	0.82
	WHITING	0.08	0.12	0.81
	SILVER PERCH	0.09	0.15	0.75
	BLACK DRUM	0.16	0.07	0.77
	NAKED GOBY	0.18	-	0.82
	SHEEPSHEAD	0.08	-	0.92
	ATLANTIC CROAKER	0.03	0.08	0.88
	JACK	-	0.11	0.89
	PINFISH	0.02	0.02	0.97
	DARTER GOBY	0.01	0.01	0.98
	EEL LEPTOCEPHALUS	0.01	0.01	0.99
	SOUTHERN FLOUNDER	0.01	-	0.99
	SPOT	0.00	0.00	1.00
	BOTHIDAE	-	-	1.00
	BAY WHIFF	-	-	1.00

Multivariate analysis provides an assessment of the general pattern of meroplankton distribution within the study area. Additional insight into the impact of opening the tidal inlet can be gained from detailed assessment of the distribution of individual species. Seventeen taxa were sufficiently abundant and/or economically important to reasonably assess their individual temporal and spatial distribution in the context of opening Packery Channel. Examination of the composition of the species groups from cluster analysis described above and visual assessment of the temporal and spatial distribution of these taxa (Figs. 16 – 22) shows that they can be subjectively divided into three general groups, although there is a continuum of distribution patterns among taxa within groups.

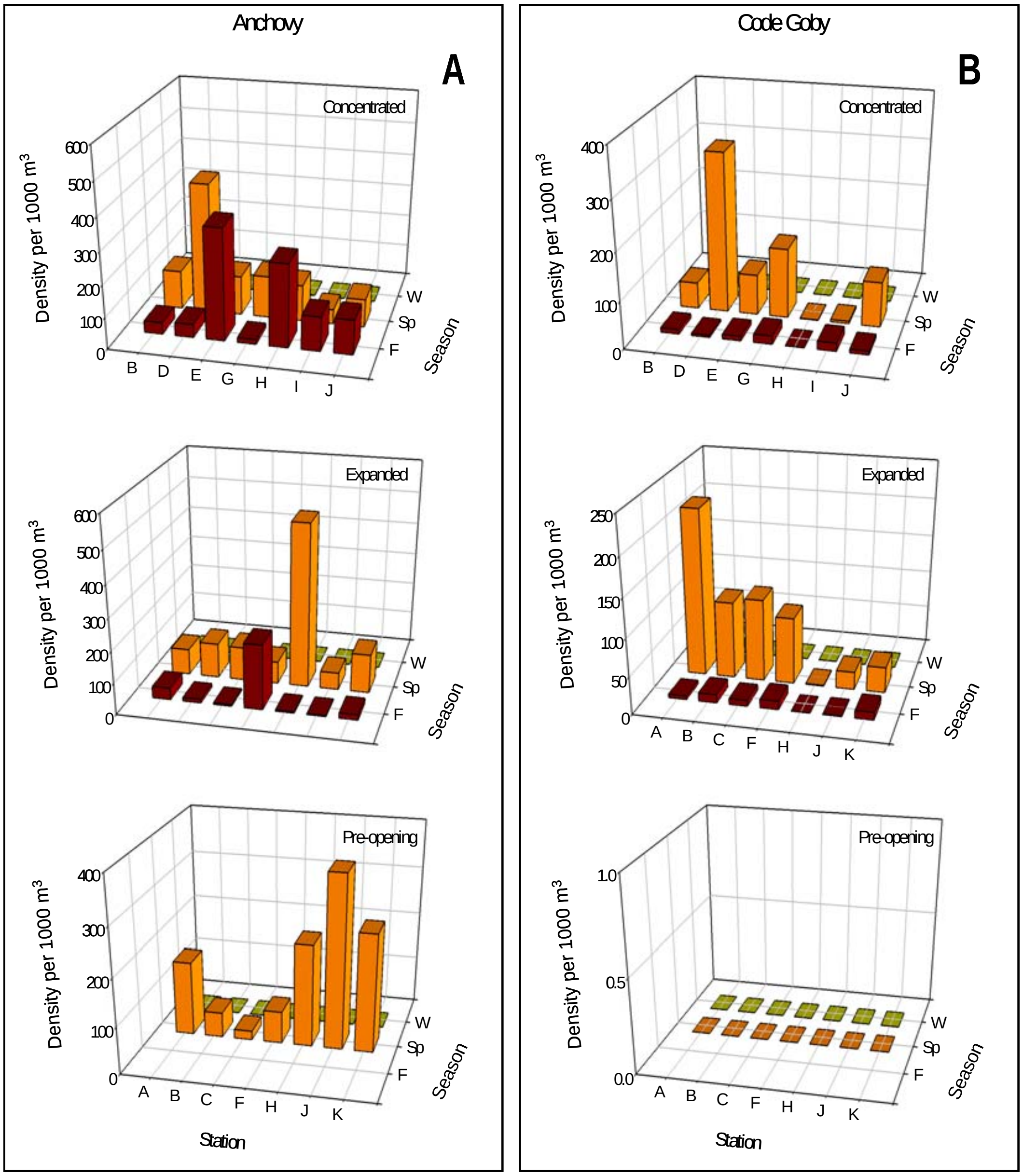

Figure 16. Mean density of anchovy (left panel) and code goby (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. The bottom panel in each plot represents collections made before Packery Channel was open. The middle panel, labeled “Expanded” represents collections taken after Packery Channel was opened and the stations were in the same physical locations as the pre-opening collections. The top panel, labeled “Concentrated” represents collections taken later in the study when 4 stations more distant from Packery Channel were eliminated and 4 stations were added closer to Packery Channel were added. Comparable letters among plots represent stations from the same physical location. Station H represents Packery Channel. See Figure 1 for location of other stations.

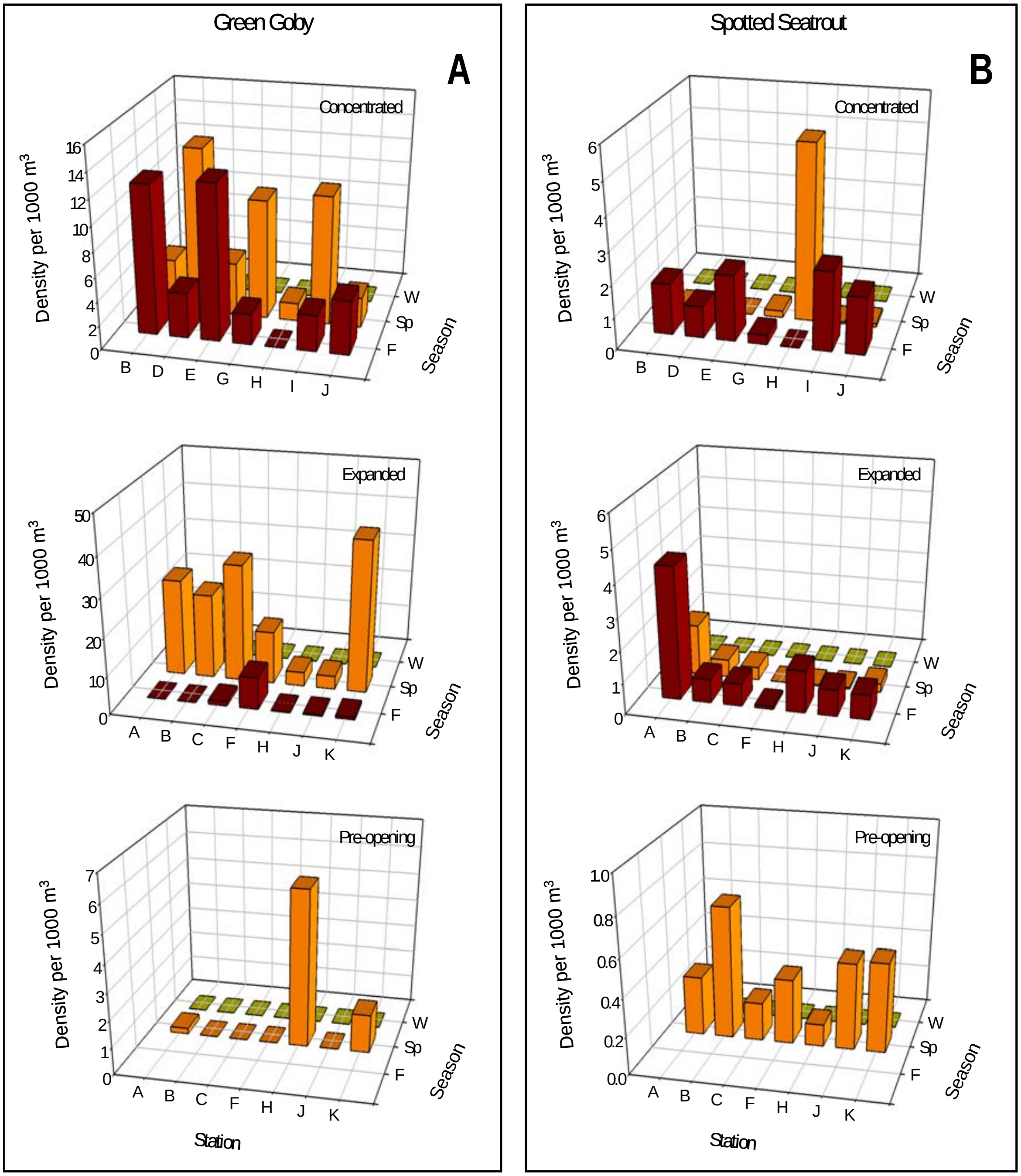

Figure 17. Mean density of green goby (left panel) and spotted seatrout (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

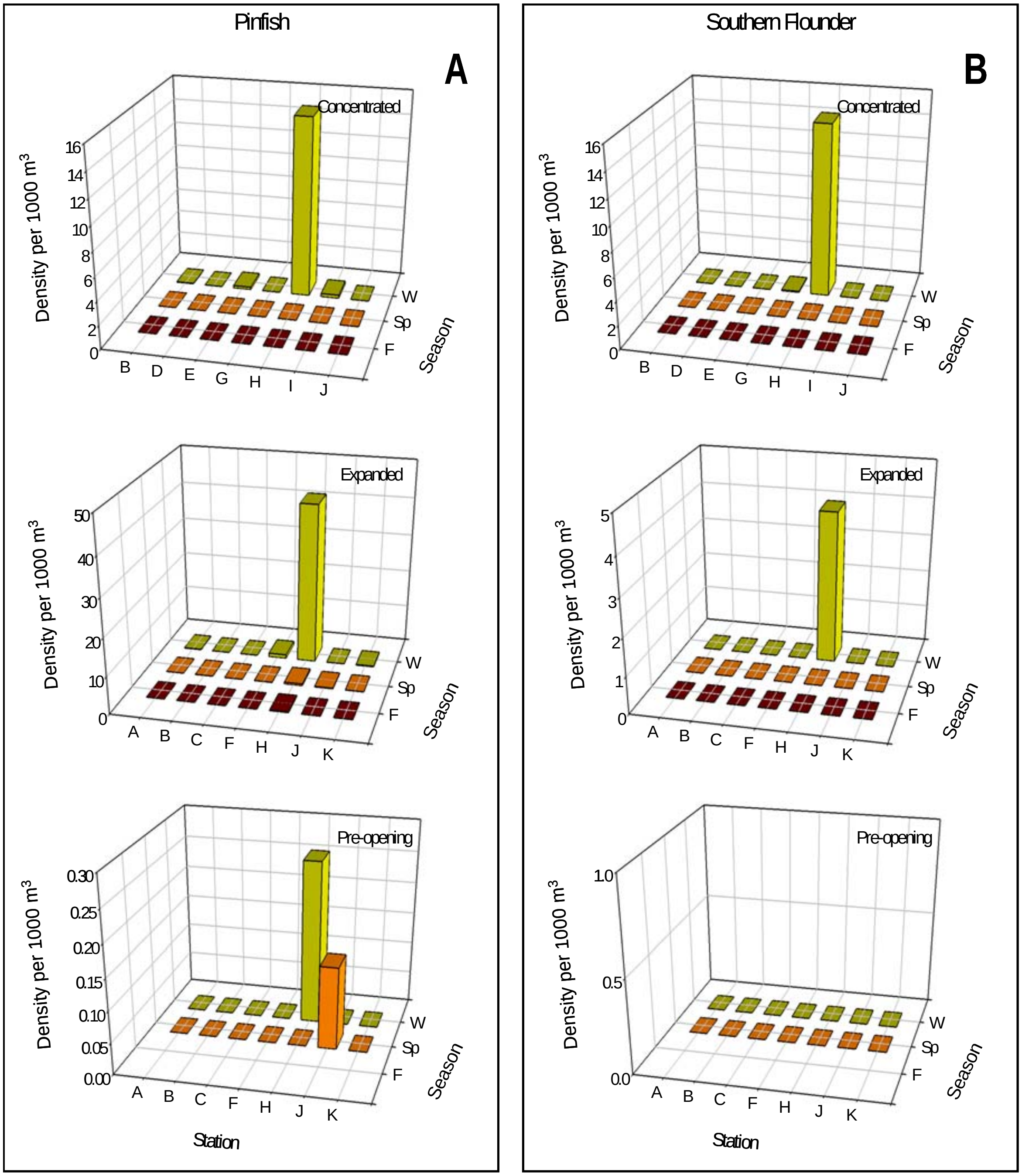

Figure 18. Mean density of pinfish (left panel) and southern flounder (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

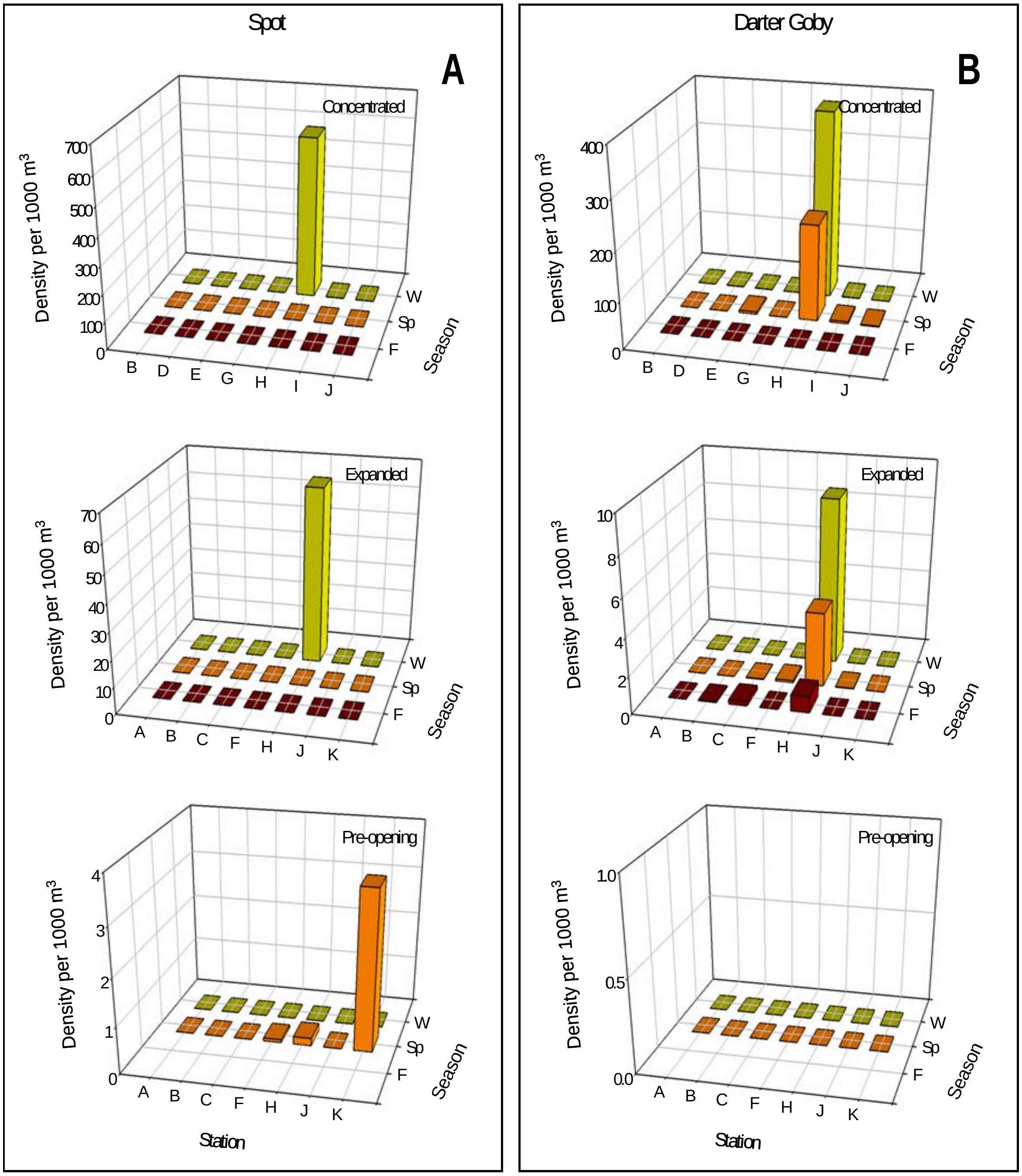

Figure 19. Mean density of spot (left panel) and darter goby (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

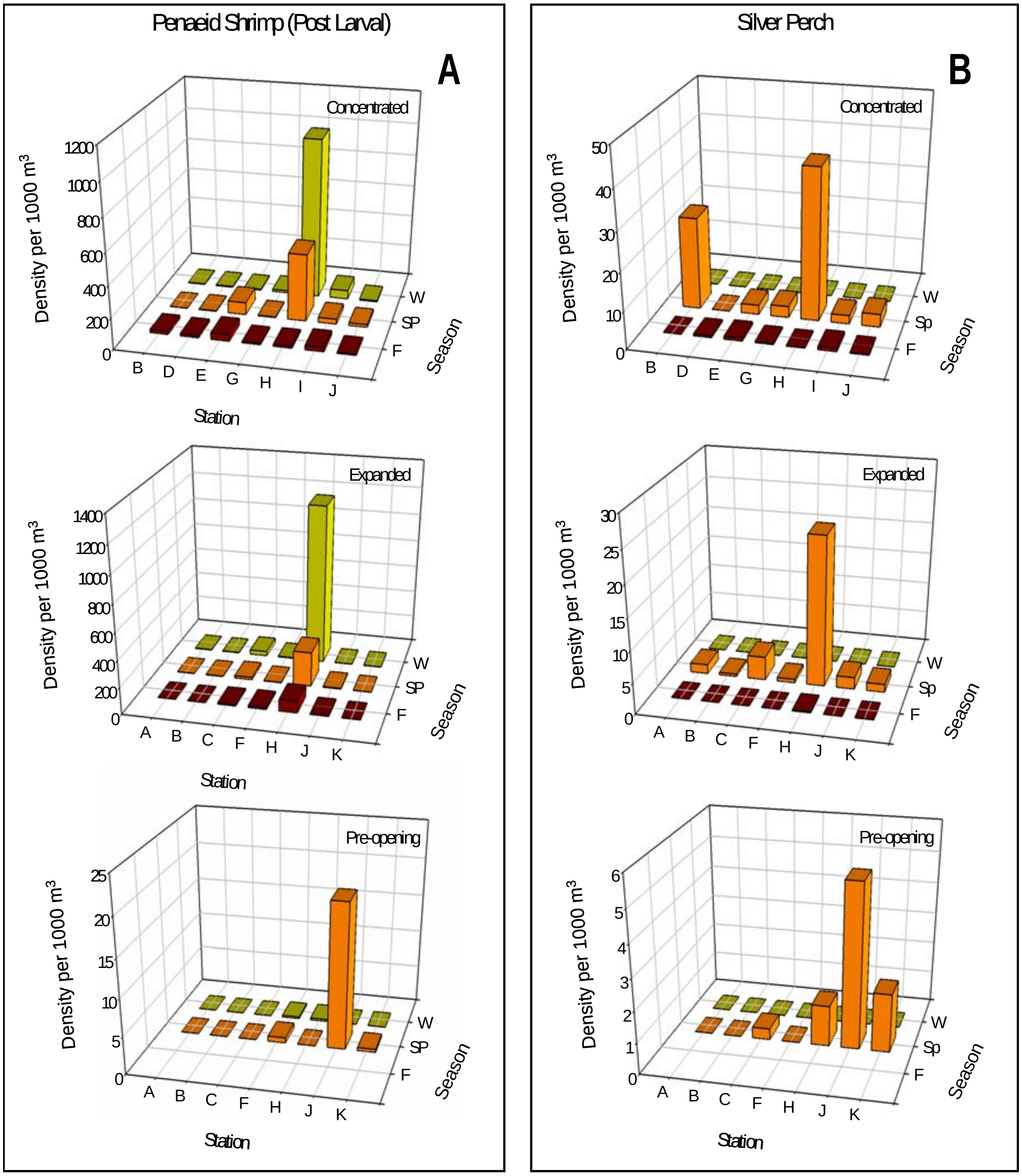

Figure 20. Mean density of penaeid shrimp (left panel) and silver perch (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

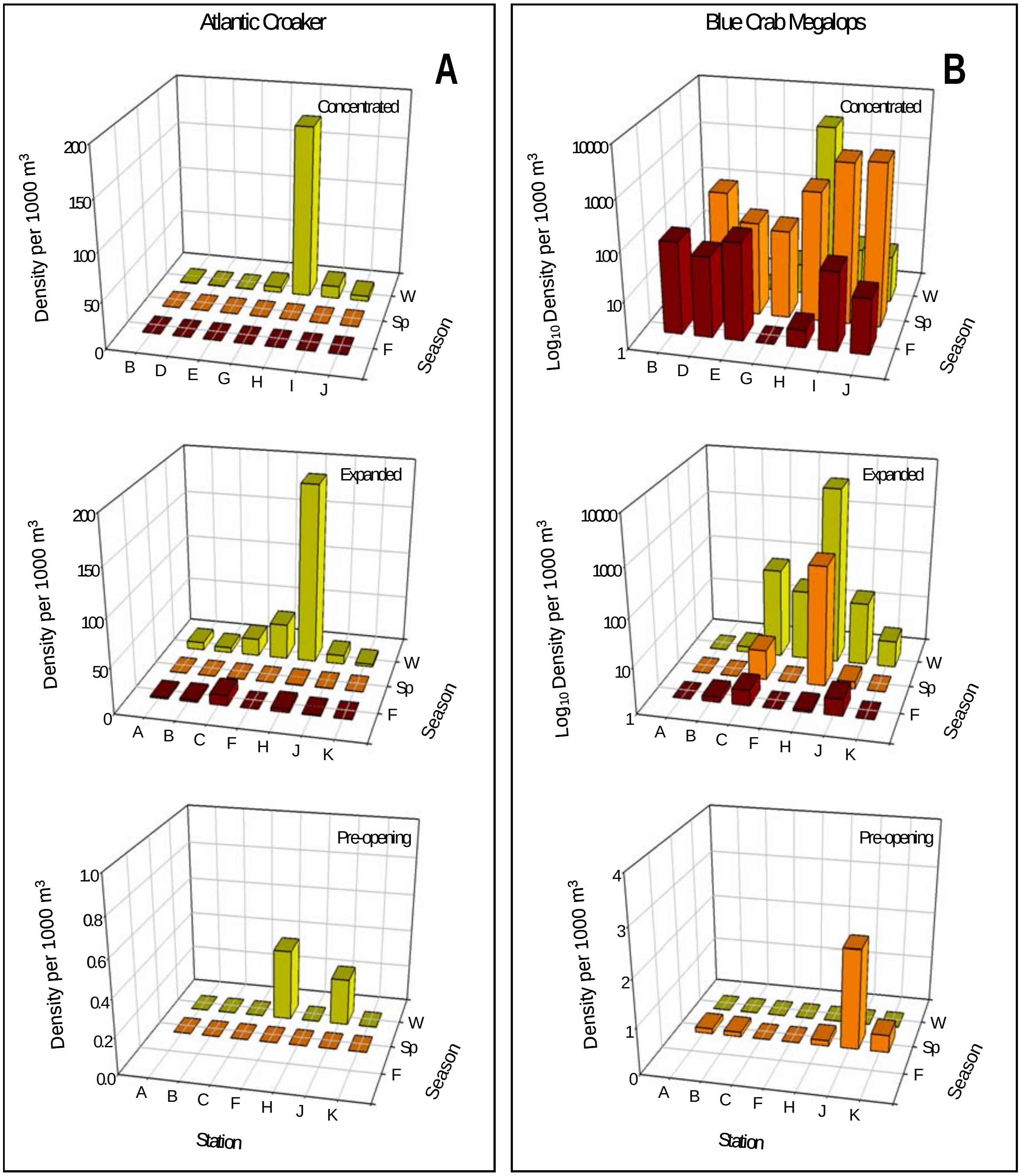

Figure 21. Mean density of Atlantic croaker (left panel) and blue crab megalops (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

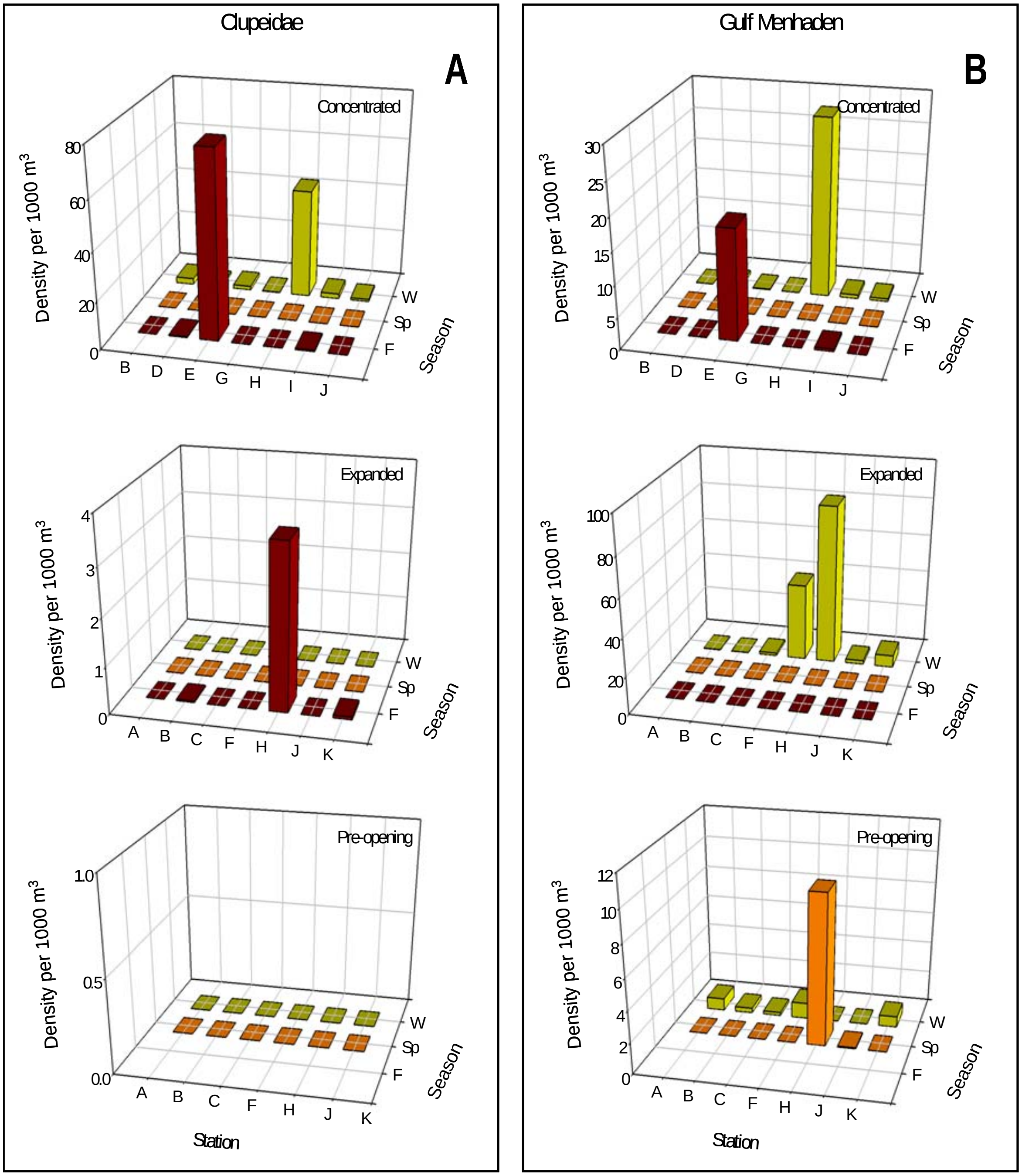

Figure 22. Mean density of clupeid (left panel) and Gulf menhaden (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

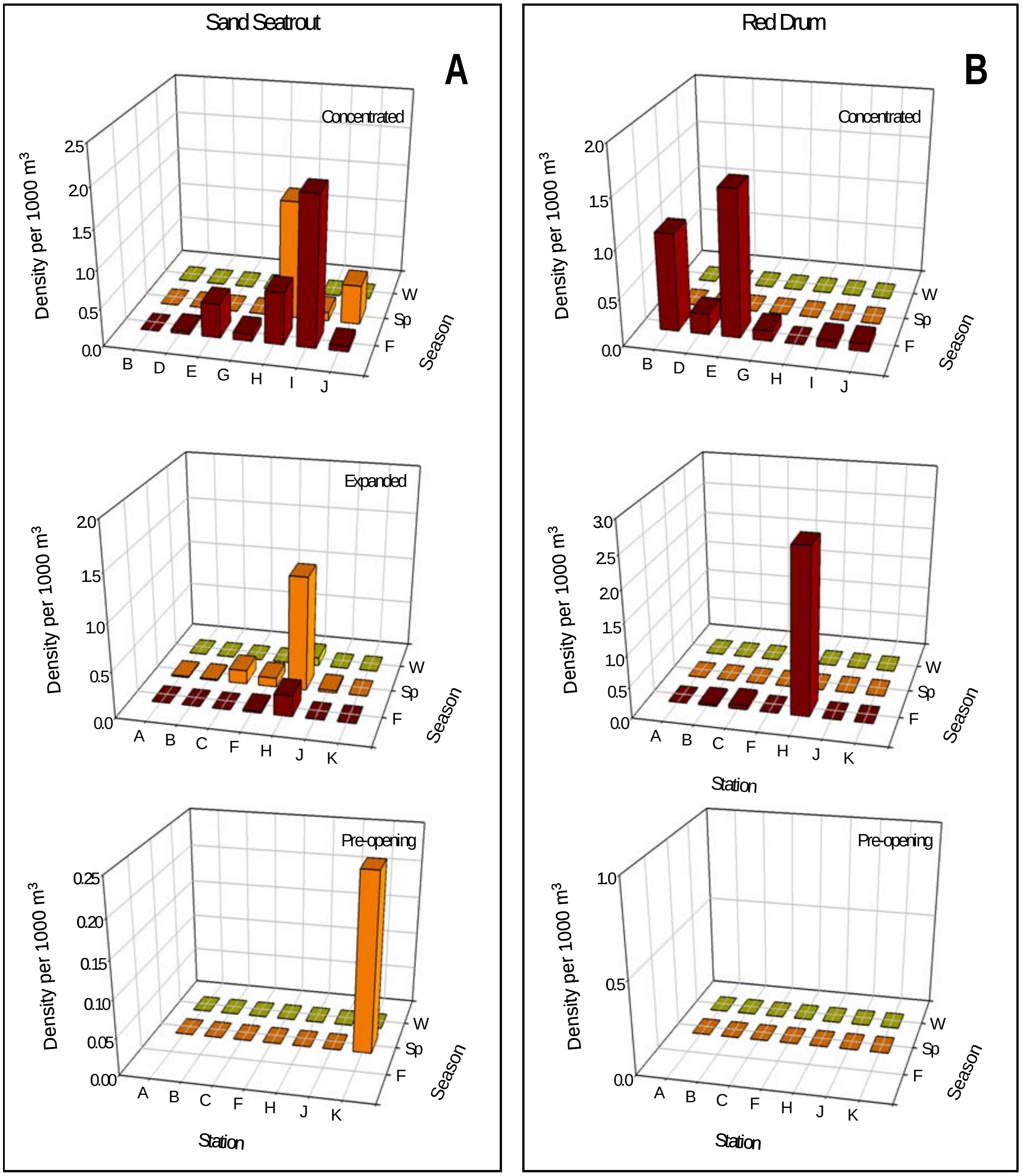

Figure 23. Mean density of sand seatrout (left panel) and red drum (right panel) at each sampling station for each season. Note that the vertical axis (density) scale varies among plots. See the legend for Figure 16 for a detailed description.

One group is comprised of species that were relatively wide spread in the study area after Packery Channel was opened and in some cases, before the channel was open as well. Although densities increased for three of the four species after the channel was opened, the distribution pattern did not suggest a direct effect of Packery Channel. The other two groups are both composed of species that increased significantly in abundance after Packery Channel was opened. One of these groups is composed of species that were found primarily only in Packery Channel. The other group is composed of species that were generally found in highest density in Packery Channel but were also found at adjacent sites as well, especially during the concentrated sampling scheme. Changes in both distribution and density of taxa in both groups suggest there were direct effects of opening Packery Channel on the spatial occurrence and abundance of these taxa in the study area.

Anchovy (Fig. 16a), code goby (Fig. 16b), green goby (Fig. 17a), and spotted seatrout (Fig. 17b) are typical of the estuarine resident group. Larvae of anchovy were found primarily during the spring and fall seasons and were distributed throughout the study area, including the open bay station K (Fig. 16a). The average density of anchovy did not change noticeably between pre and post opening collections. Spotted seatrout were also found primarily during the spring and fall period and were also distributed throughout the study area, including the open bay station K (Fig. 17b). Spotted seatrout densities are generally highest in fall collections and there were no pre-opening fall collections due to the premature opening of the inlet, thus limiting the comparison of pre and post opening densities for this species. Spotted seatrout densities did, however, change substantially between pre and post opening collections for spring samples. Mean densities ranged from 0.36 (±0.50 SD) for pre-opening collections to 0.41 (±1.20 SD) and 0.75 (±2.46 SD) for expanded and contracted post-opening samples, respectively. Although the mean density of spotted seatrout was relatively high at the Packery Channel Station in the spring, concentrated sampling scheme, the distribution of spotted seatrout in other sampling periods suggests, however, that the 2X difference in average density in spring was not attributable to opening Packery Channel. The highest densities in both the fall and spring period during the expanded sampling scheme were seen at the southern most ICWW Site A, where no evidence of Packery Channel influence was ever seen during our environmental assessment. Green goby was found primarily during spring and fall seasons and was widespread throughout the study area (Fig. 17a). Average density of green goby was higher after Packery Channel was opened but the highest pre-opening density was at the Packery channel site whereas the Packery Channel site and adjacent stations had relatively low density during both post-opening survey periods. Code goby was collected primarily during the spring (Fig 16b). They were not collected during the pre-opening survey period but were wide spread in both post-opening periods. Average densities of code gobies were lowest at the Packery Channel site, suggesting no direct influence of opening Packery Channel on code goby abundance in the study area.

Pinfish (Fig. 18a), southern flounder (Fig. 18b), spot (Fig.19a), and darter goby (Fig. 19b) are representative of taxa that were largely absent before the channel was opened, occurred at relatively high densities after the channel was opened, but were largely confined to the Packery Channel inlet site. Pinfish, southern flounder, and spot occurred almost exclusively during the winter period whereas penaeid shrimp also were taken during the spring and fall periods but as much reduced numbers compared to winter. Darter Gobies were taken in the spring and fall seasons as well as the winter season, but, with the exception of a few larvae taken at site C in the fall, were also confined to the Packery channel inlet site.

The third ecological group is composed of taxa found primarily after Packery Channel was opened and generally at the highest densities at the Packery Channel site, but they also occurred at moderate to high densities at other sites within the study area. Penaeid shrimp (Fig. 20a), silver perch (Fig. 20b), Atlantic croaker (Fig. 21a), blue crab megalops (Fig. 21b), clupeid sp. (Fig 22a), Gulf menhaden (Fig 22b), sand seatrout (Fig. 15b), and red drum (Fig. 23b) are representative of the group. Penaeid shrimp showed the narrowest distribution of this group and represents a continuum in the distribution pattern shown by this and the previous group as only a few individuals occurred in any numbers beyond the Packery Channel inlet. In the expanded sampling scheme, a few penaeid shrimp were taken at station C along the JFK Causeway near the Causeway Channel during post-opening sampling but not at sites in the ICWW. During the contracted sampling scheme, there were low numbers of penaeid shrimp (relative to the Packery Channel site) taken at Stations I and E, immediately north and south, respectively, of the junction of Packery Channel with the ICWW. Interestingly, there were none at station G immediately across the ICWW from the opening to Packery Channel. Silver perch were taken primarily in the spring season and Atlantic croaker were taken primarily in the winter season (Figs. 20b and 21a, respectively) but both have similar distribution patterns. Both were taken at relatively low densities in pre-opening collections at several ICWW sites (and in Packery Channel for silver perch). In post-opening collections, both species were most abundant at the Packery Channel site and both were taken in moderate numbers at most sites, including those along the JFK Causeway. Atlantic croaker densities were generally higher at sites closest to the junction of Packery Channel with the ICWW but silver perch densities were generally similar at all sites except for a large collection at Station B, the southernmost station in the ICWW in the contracted sampling scheme.

Blue crab megalops were taken in all seasons and were the most widely distributed taxa of this group (Fig. 21b), and except for anchovy, the most widely distributed of all taxa. In contrast to anchovy, however, blue crab megalops were virtually absent from the study area before Packery Channel was opened and extremely abundant after it was opened. Despite their widespread distribution, blue crab megalops were most abundant at the Packery Channel site and generally least abundant at the sites most distant from Packery Channel, especially during the expanded sampling scheme. The last taxa in this group are represented by clupeid sp. and Gulf menhaden. Larvae designated as clupeid sp. were generally very small and often damaged individuals that could not be identified to the species level. They are very likely small Gulf menhaden as identifiable Gulf menhaden were relatively abundant and no other identifiable clupeid was found in the collections. These two “taxa” are probably an ontogenetic series of one species and will be treated as such. Gulf menhaden were taken primarily in the fall and winter seasons with a few (presumably larger, older) individuals taken in spring at Packery Channel before the pass was opened. In post-opening collections, both stages of menhaden were most abundant at the Packery

Channel site with a few relatively large collections at other sites, primarily near the Packery Channel/ICWW confluence.

The final two species in this group are distinguished by relatively anomalous spatial or temporal distributions in this study. Neither sand seatrout (Fig. 23b) and red drum (23a) were taken in winter and red drum was only taken in fall samples. As was typical of species in this ecological group, sand seatrout were much more abundant in collections in Packery Channel than at any other site in the post opening expanded sampling scheme and in the spring samples in the concentrated sampling scheme (Fig. 23b). Unlike all others except clupeid, sand seatrout were more abundant at a site outside Packery Channel (site I in the ICWW just north of the confluence with Packery Channel) than in Packery Channel itself in the fall samples during the contracted sampling scheme. Like sand seatrout and other members of this ecological group, red drum were much more abundant at the Packery Channel site than any other site in the expanded sampling scheme. In the fall samples during the contracted sampling scheme, red drum were widespread throughout the study area, albeit at relatively low numbers compared to most other species discussed above, but none were taken at the Packery Channel site; a unique situation not seen with any other species.

Summary and Conclusions

Water entering Packery Channel from the GOM did not travel far into the estuary via the ICWW, if it entered the ICWW at all. There was evidence of interaction between Packery Channel and the ICWW on only two of the six surveys. On survey 2, there seems be some mixing at the intersection and a short distance south along the ICWW but it dampened out quickly. Survey 4 reflected possible movement of water from Packery Channel northward into the ICWW for a few kilometers and is reflected in temperature, salinity and pH values. These results are consistent with the predicted effects of the project on salinity expressed in the Final Environmental Impact Statement (USACE 2003) which expected overall existing salinity conditions to be maintained and modifications of only a few parts-per-thousand would be seen in the immediate vicinity if the inlet.

This is not to say there were no impacts of the inlet on water quality parameters in the area of the project. Gulf of Mexico water entered the inlet on each flood tide and typically encompassed the entire inlet channel up to the intersection with the ICWW. The flood tide waters also flowed out over the adjacent tidal flats (SAH, personal observation) east of the ICWW. No direct measurements were made of the spatial extent of that coverage but the data were examined to determine whether flow over the flats reached the ICWW and no evidence for that was seen. The significance of these observations is that any change in fauna outside the immediate area of the tidal inlet is unlikely to be due to changes in characteristics of the habitat (i.e. changes in quality or quantity) but due, instead, to changes in larval supply to the area. These types of indirect effects have been noticed in studies of intermittently open estuaries in Australia and elsewhere (Griffiths and West 1999, Griffiths 2001, and Young and Potter 2003).

Results of both temporal and spatial assessments of species assemblages in the vicinity of the Packery Channel inlet provide clear indications of the impact of the project on fisheries resources. Cluster analysis of the temporal distribution of meroplankton in the study area clearly showed the seasonal nature of the fauna. The cool season group is dominated by larvae of estuarine dependent marine species that spawn offshore and immigrate into the estuaries in the fall and winter. The warm season group is dominated by estuarine residents, most of which spawn near the estuarine mouth or throughout the estuary and, like spotted seatrout, have a long spawning season (Peebles and Tolley 1988). The distinct warm and cool season species assemblages in macrozooplankton (i.e. equivalent to meroplankton referred to here) shown by Holt and Strawn 1983 in Trinity Bay, Texas is very similar to the temporal partitioning seen in this study. Hettler and Chester (1990) recognized the seasonal aspects of immigrating larval fishes through the Beaufort inlet, North Carolina but classified the immigrants into three groups, recognizing a late spring group as well as winter (i.e. cool) and summer (i.e. warm) groups. These seasonal patterns are driven primarily by the reproductive season of the species involved, as clearly shown by the sequential settlement and nursery habitat occupation by several sciaenid fishes in the Aransas Bay, Texas by (Rooker et al. 1998) although (Ramos et al. 2006) suggested that spawning season may control the occurrence of temporary estuarine residents (species often referred to as estuarine dependent marine species) while environmental aspects control the occurrence of permanent estuarine resident species.

Patterns of spatial distribution in the meroplankton clearly show the effect of opening Packery Channel on the relative density of numerous species but also point out the limited spatial impact of the inlet dynamics. The spatial relationships of sampling stations prior to opening Packery Channel, based on cluster analysis of faunal assemblages, reflect a relatively homogeneous fauna composed primarily of estuarine resident species with a small contribution of estuarine dependent species that had to have come into the Laguna Madre from the Aransas Pass tidal inlet, 33 km to the north. After Packery Channel was opened, spatial relationships of species assemblages changed dramatically. In both post-opening analysis, reflecting an expanded and more concentrated scheme of station placement relative to the inlet, the faunal assemblage within the Packery Channel inlet was separated at a high level of dissimilarity from all other stations outside the inlet. Except the Packery Channel station, all other stations were separated from each other by dissimilarity levels that were about the same as the dissimilarity levels seen in the pre-opening analysis. This suggests that the community assemblage within Packery Channel changed dramatically with the opening of the inlet but the impact was relatively minor at other sites outside the inlet.

Although numerous empirical (Blackmon and Eggleston 2001, Joyeux 1998) and modeling (Wenner et al. 1998; Brown et al. 2004) studies have examined various aspects of transport to and through tidal inlets, there is little information on the effect of inlet size on the effectiveness of transport of planktonic larvae into an estuary. Modeling results, such as (Brown et al. 2004) suggest modeled particles (and by implication relatively passive fish larvae) can be mixed into estuarine waters and transported well into the estuary. Results of this study and data from the Mission/Aransas Estuary (SAH unpublished data) suggests, however, that most larval transport is limited to the extent of the tidal prism and post-settlement dispersion (Sogard 1989) is responsible for further distribution of small juveniles. The water quality component of this study, cited above, suggests the direct effect of flood tide waters was limited essentially to the Packery Channel proper and the meroplankton distribution reflects that limited scale of impact.

General assessments of faunal communities are useful to provide an overview of how ecological processes act on, or through, suites of species. A closer examination of individual species, especially those of recreational or commercial importance, can provide additional insight into the effect of substantial ecological changes, such as the opening of a new tidal inlet to connect oceanic water (and fauna) with estuarine environments.

All species examined were taken in relatively low density prior to the opening of Packery Channel. The only relatively abundant taxa were those species that reside (and hence spawn) in the estuary and are tolerant of relatively high salinities. The most obvious examples are spotted seatrout, bay anchovies, and several species of gobies. Densities at the site in Packery Channel were neither consistently higher nor lower than other sites within the study area. Several of these species show substantial increases in density in post opening samples but only weak inference can be made from these comparisons since the sample size for pre-opening collections was low and the temporal coverage limited due to the premature opening of the channel by Hurricane Emily. A more reliable assessment of the impact of Packery Channel can be made from comparing densities from the Packery Channel site (and possibly adjacent stations) with densities from sites more distant from Packery Channel. In the case of the resident species, there were occasional instances of higher densities at the Packery channel site (e.g. spotted seatrout in the spring contracted sampling scheme and anchovy in the spring expanded sampling scheme) but there was no consistent pattern suggesting any positive (or negative) effect of Packery Channel on the density of these species.

The effect of opening Packery Channel on those species that spawn offshore or near tidal inlets and whose larvae immigrate into the estuary for their juvenile phase (often referred to as “estuarine dependent marine species”) was more pronounced. Prior to the opening of Packery Channel, the only source for larval stages of these species was through the Aransas Pass tidal inlet that is 33 km to the north across Corpus Christi Bay. A few species such as spot, pinfish, Atlantic croaker, and penaeid sp. were found in the study area prior to the opening of Packery Channel. Most of these were found in relatively low numbers (compared to the post-opening collections) and were generally found in the northern portion of the study site at the Corpus Christi Bay site K or in the ICWW. Few were found in the Packery Channel site. Some species, such as southern flounder and red drum, were not found at in pre-opening samples. These observations suggest there was some transport of offshore-spawned larvae through the Aransas Pass tidal inlet and across Corpus Christi Bay but transport of individuals in the planktonic larval stage was a minor source of recruits to the Upper Laguna Madre when Packery Channel was closed.

The density of pelagic larvae of these species increased dramatically after Packery Channel was opened. Density increases were generally an order of magnitude or more over the pre-opening densities. Most of these immigrating larvae were confined to Packery Channel and occurred at surrounding Laguna Madre site in relatively low numbers. This matches the spatial pattern of direct impact of water flow through the channel determined from our water quality surveys. These observations suggest that the increase in larval supply that might drive increased recruitment of these species was not wide spread and was generally confined to the immediate vicinity of Packery Channel and the broad effect over the Upper Laguna Madre was limited.

Comparison between the Meroplankton and Nekton Studies

Concurrent assessments were conducted on the impact of opening Packery Channel on meroplankton (targeting plankton stages of resident and transient fish and crustaceans) and the nekton (targeting the early juvenile stages of resident and transient fish and crustaceans) in the Upper Laguna Madre of Texas. Results of the meroplankton study are given in Holt (2009; this study) and results of the nekton study are given in Stunz and Reese (2009). Additional information on the nekton study is contained in Reese et al (2008).

For both studies, the broad assessment of community-level changes in the fish and macroinvertebrate populations showed no dramatic changes between pre and post opening of Packery Channel. For the meroplankton component, cluster analysis of all collections by date gave a clear separation by season but pre-opening collections were not clearly separated from post-opening collections. Likewise, cluster analysis of nekton collections for 2005 and 2006 (Reese et al 2008) showed that some, but not all pre-opening collections were separated from post-opening collections. MDS ordination of the same data showed that it was the winter/spring post-opening collections that were more clearly separated from the pre-opening collections whereas the fall/summer collections were less dissimilar.

Additional MDS of all nekton collection (Stunz and Reese 2009) showed three seasonal groups (i.e. species associations or communities) for the post-opening data and a fourth group representing the pre-opening data. This result is in contrast to the meroplankton data where cluster analysis produced two seasonal groups without separating out the pre-opening data into a separate group.

A Before/After – Control/Impact (BACI) analysis of the nekton data showed that there was no significant effect of either factor on average fish densities in the area and that crustacean (minus *Palamonetes* sp) densities were significantly lower after Packery Channel was lower but significantly higher in the impact area compared to the control. No comparable parametric analysis was available for the meroplankton data but cluster analysis of collection location for pre-opening and two post-opening periods (representing two arraignments of stations) showed that the station within Packery Channel was substantially different from the other stations in post-opening analysis but not obviously different in pre-opening collections.

Examination of the data for individual species provided a clearer picture of the effects of opening Packery Channel. Analysis of red drum, pinfish, Atlantic croaker, penaeid shrimp, and blue crab data from the nekton collections showed that for all of these species, mean densities were significantly higher in post-opening collections than in pre-opening collections. Likewise, examination of density data for the meroplankton collections shows that the mean density of these and other estuarine-dependent species was substantially higher in the Packery Channel sample site than at other sites within the study area in post-opening collections. All of these species are estuarine-dependent species with offshore reproduction that rely on the inlet for access to the estuarine nursery areas and the high densities in the inlet show they are immigrating into the study through Packery Channel. These assumptions are bolstered by the fact that densities were not substantially different among sites in pre-opening collections.

In contrast, examination of the meroplankton data for estuarine resident species like spotted seatrout, anchovy, and code goby showed they were widespread in the study area both before and after Packery Channel was opened and showed no particular relationship with the Packery Channel sample site.

Taken together, these results indicate that there were no wide-spread, pervasive changes to the fish or macroinvertebrate communities seen throughout the upper Laguna Madre as a result of opening Packery Channel. Rather, there was an increase in the density of species that reproduce offshore and then recruit to estuaries as larvae or juveniles. The direct impact of this change was seen primarily in the vicinity of the tidal inlet where the planktonic larvae of these species are washed in and out of the inlet with tidal flow and where settlement of these larvae into the shallow nursery habitats produced elevated densities relative to sites more distant from the inlet. The ultimate impact on fisheries resources due to the opening of Packery Channel could not be derived directly from these data but it seems intuitive that increasing the utilization of potential nursery habitat in the area by increasing larval supply from offshore should increase production of these estuarine-dependent species. In addition, there does not seem to be either a positive or negative effect of the inlet on estuarine resident species, many of which are small, cryptic species such as code gobies but also include important recreational species such as spotted seatrout and black drum.

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