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## Response of barrier island fish assemblages to impacts from multiple hurricanes: assessing resilience of Chandeleur Island fish assemblages to hurricanes Ivan (2004) and Katrina (2005)

Mark Chad Ellinwood  
*University of New Orleans*

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Response of barrier island fish assemblages to impacts from multiple hurricanes: assessing resilience of Chandeleur Island fish assemblages to hurricanes Ivan (2004) and Katrina (2005)

A Thesis

Submitted to the Graduate Faculty of the  
University of New Orleans  
in partial fulfillment of the  
requirements for the degree of

Master of Science  
in  
Earth and Environmental Sciences

by

Mark “Chad” Ellinwood

B.S. Southeastern Louisiana University, 2003

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## Dedication

I dedicate this manuscript to my pawpaw, Charles Cuthbert “Cut” Nunez. He has been a grandfather, father, teacher, hunting and fishing partner, and most importantly a great friend.

While we spent a lot of time together doing what we love most, hunting and fishing in South Louisiana, the days he and I spent together squirrel hunting in the Honey Island Swamp are my most cherished memories.

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Nunez, have been the greatest positive influence in my life. My mawmaw and pawpaw's unconditional love and incredible cooking have made my life inconceivably wonderful. My sister, Amber Ellinwood, has always been supportive and honest and has also played a major positive role in my life. She and her daughter, Kayla, are always there for me when I need a good laugh. Ted Harris who has been at my side during many of my most fun and educational adventures has nourished my understanding of science and contributed to the curiosities I have of the world. Lastly, the rest of my family including my Aunts, Uncles, cousins and step father have been supportive of my career, helpful and loving throughout my life. I would also like to show my gratitude to others who have supported me and been great friends throughout my graduate career. They are Ricardo "Ricky" Botello, Byron Humphrey, and Jennifer Klobas. Thank you all very much!

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## Abstract

Hurricanes can temporarily disrupt seasonal patterns of fish assemblage change or result in permanent changes in fish assemblages. I studied the effects of two hurricanes on fish assemblages at the Chandeleur Islands and the possible influence that storm-generated tidal channels may have on the composition of local fish assemblages. I also compared recently collected data to historic ichthyofaunal survey data collected over thirty years ago at the Chandeleur Islands. Near shore fish assemblages changed the most after hurricanes but changes in species composition were primarily due to increases in abundance and diversity. During July 2007 there was no significant difference between fish assemblages in channel and seagrass habitats, although significant differences among wash-over channels existed. Loss of habitat and the increased intensity and frequency of recent storms may explain why current fish assemblages at the Chandeleur Islands are less diverse (as measured by taxonomic distinctness) than assemblages collected during 1969-1971.

Keywords: fish assemblage, hurricane impact, disturbance, intermediate disturbance hypothesis, barrier island, tidal channel, Chandeleur Islands, Gulf of Mexico

## Introduction

Hurricanes often impact coastal regions with strong winds, heavy rainfall, and tidal surges that may directly or indirectly alter environmental and chemical conditions of aquatic habitats (Steward et al., 2006). The composition of fish assemblages in aquatic habitats is typically determined by biological interactions, habitat characteristics, and physiological environmental factors (Modde and Ross, 1981; Kneib, 1987; Rakocinski et al., 1992; Greenwood, 2007). While estuarine fish assemblages often undergo predictable annual changes largely attributable to periods of recruitment of marine species (Livingston, 1976; Tsou and Matheson, 2002; O'Connell et al., 2006), the impact of a hurricane may result in anomalous hydrologic conditions (e.g., hypoxia, decreased or increased salinity or temperature, and decreased water clarity) disrupting seasonal patterns of fish assemblage change (Greenwood et al., 2006; Switzer et al., 2006; Paperno et al., 2006). Finally, the destructive forces of hurricanes may alter or destroy aquatic habitat resulting in long-term fish assemblage changes (Van Vrancken, 2007).

Assemblage changes immediately following large storms are often attributed to decreased salinity from heavy rains (Hoese and Moore, 2005; Paperno et al., 2006). Following Tropical Storm Agnes in 1972, fishes that normally occupy salinity  $\geq 3$  parts per thousand (‰) were displaced downstream in the James, York, and Rappahannock Rivers of Virginia (Hoagman and Wilson, 1977). The same storm also caused the movement of demersal fishes in mid-Chesapeake Bay to deeper waters in response to decreased salinity (Ritchie, 1977). Within one month, salinity had returned to normal and demersal species were again taken from all depths sampled and assemblages in the rivers had returned to normal. After Hurricane Isabel in 2003, Chesapeake Bay fish assemblages were again similarly altered due to a large occurrence of

freshwater species in the bay (Houde et al., 2005). Following four hurricanes during the summer of 2004, estuarine fish assemblages in Florida, although initially severely altered, generally showed rapid recoveries following the increased salinity of estuarine waters and the return of marine species (Greenwood et al., 2006; Paperno et al., 2006; Stevens et al., 2006; Switzer et al., 2006).

During high energy storm events, coastal fish assemblages may also quickly change when local fishes are displaced, injured, or killed. While larger fishes may avoid undesirable hydrologic conditions, less mobile smaller fishes unable to avoid low salinity water may suffer osmotic shock and subsequent mortality. Storm surge and associated high water velocity may sweep fishes inland where they become stranded (personal observation). High discharge following a storm surge or heavy rain may also physically displace fishes, particularly larval and juvenile stages, into a bay or further offshore (Tabb and Jones, 1962; Hoagman and Merriner, 1977; Hoese and Moore, 2005; Greenwood et al., 2006). Young fishes may also be flushed into less productive portions of the estuary and face starvation (Moyle and Cech, 2004).

Additionally, following Hurricane Andrew in 1992 deaths of freshwater fishes in Southeastern Louisiana were attributed to low dissolved oxygen concentration (Harris and Darensbourg, 1992) while the deaths of coastal fishes may have been a result of gill damage (Robins, 1957; Tabb and Jones, 1962; Lovelace and McPherson, 1996).

A more indirect impact of a hurricane is when a storm surge washes organic material into the water column of nearby aquatic habitats. This usually results in increased decomposition of these materials, local oxygen depletion, and these hypoxic and anoxic conditions may cause direct mortality of aquatic fauna. For example, Hurricane Hugo in 1989 caused anoxic waters in the French West Indies that led to considerable local fish mortality (Bouchon et al., 1994). The

Neuse River and western Pamlico Sound ecosystems also experienced massive fish kills from oxygen depletion following Hurricane Fran in 1996 (Burkholder et al., 2004). While low dissolved oxygen concentration does not always result in mortality, it may cause major assemblage changes within an aquatic ecosystem. Extensive hypoxia in Charlotte Harbor, Florida, following Hurricane Charley (2004) and in St. Lucie estuary, Florida, following Hurricane Francis and Jeanne (2004) resulted in estuarine fish assemblages being replaced by a few highly resilient species (Stevens et al., 2006; Switzer et al., 2006). Following Hurricane Katrina (2005), hypoxic conditions in the Pascagoula River, Mississippi, and Bayou Lacombe, Louisiana, were correlated to fish kills and fish assemblage changes (Schaefer et al., 2006; Van Vrancken, 2007).

Habitats in shallow coastal regions are often the most severely impacted because hurricane wave surge is greater in shallow versus deep water (Glynn et al., 1964; Woodley et al., 1981). Additionally, shoreline erosion may be more severe in some areas than others because the severity of impact is influenced by the storm's intensity, the direction and speed of approach, and the point of landfall (Sallenger et al., 2006; Weisberg and Zheng, 2006). The destruction or alteration of habitat may contribute greatest to long-term fish assemblage changes (Kaufman, 1983; Pfeffer and Tribble, 1985; Fenner, 1991; Van Vrancken, 2007). Following the passage of Hurricane Charley, a shoreline fish assemblage in Charlotte Harbor, Florida, is thought to have changed due to damaged vegetated shorelines that decreased fish survival through a reduction in feeding and refuge habitat (Greenwood et al., 2006). The destruction of shallow coral reef habitats by hurricanes have also been shown to result in fish assemblage changes (Pfeffer and Tribble, 1985; Fenner, 1991). Low-profile barrier islands often consist of a thin beach and respond to storm surges and high wave energies by wash-over events and reopening of tidal

channels (Boyd and Penland, 1981). During these events, seagrass beds may be destroyed due to scouring or burial (Eleuterius, 1987; Franze, 2002) when the displaced sediment forms a fan shaped distribution on the back marsh and bay area (Shabica et al., 1983). Majuro (2007) observed fish assemblage structure changes following the physical alteration and decreased area of submersed aquatic vegetation (SAV) habitat in the Biloxi Marshes, Louisiana. Habitat alteration may also be caused by changes in salinity or water clarity, as Bouchon et al. (1994), in the French West Indies, reported seagrass fish assemblages changed months after Hurricane Hugo due to the delayed mortality of turtle grass (*Thalassia testudinum*), a species that requires average salinity at or above 25 ‰ for survival (Zieman, 1975).

Environmental changes resulting from hurricanes may also prove positive for some species. The abundance of some fishes has been observed to increase following wet years or years of higher than average rainfall. Following a wet year in Chesapeake Bay, abundance of young of the year (YOY) anadromous fishes (e.g., striped bass, *Morone saxatilis* and white perch, *M. americana*) and Atlantic croaker (*Micropogonias undulatus*) were above the decadal mean with *M. undulatus* being 30 times higher the decadal mean (Houde et al., 2005). An increased abundance of YOY red drum (*Sciaenops ocellatus*) was reported along the Louisiana coast following Hurricane Beulah in 1967 (Matlock, 1987). Wet years may also alter other aspects of fish life history. Four species of estuarine killifishes in a North Carolina marsh were found to change in abundance, sex ratio, and biomass between wet and dry years (Schwartz, 1999).

Within recorded history, many tropical storms and hurricanes have made landfall in the Southeastern United States. Although winter storms are common in the northern Gulf of Mexico (GOM), tropical and extra-tropical storms in late summer and fall are often most destructive to

the coastal shoreline and barriers such as the Chandeleur Islands (Figure 1). On 16 September 2004, the western eye-wall of Hurricane Ivan (a Category Three Hurricane) passed 150 km to the east of the Chandeleur Islands (Figure 2). Presently, the most destructive storm to strike the northern GOM in recorded history was Hurricane Katrina (a Category Four Hurricane). Hurricane Katrina's eastern eye-wall passed within 90 km to the west of the islands (Figure 3) before making landfall on August 29, 2005 at the Louisiana-Mississippi gulf coast border. The Chandeleur Islands, Louisiana, experienced major geomorphic changes and habitat loss during both hurricanes Ivan and Katrina (Martinez et al., 2005; Bethel et al., 2007). Although the Chandeleur Islands are located 45 km from land assuring salinity remains near 25 ‰, the island's seagrass beds, the largest expanse of seagrass in Louisiana, were decreased by approximately 20 percent, or 212 hectares, during Hurricane Katrina (Bethel et al., 2007). The islands seagrass beds and other habitat types were likely buried by displaced sediment or destroyed due to scouring by strong water velocity from storm surge and wind driven waves. Prior to both storms, the Chandeleur Islands had a nearly continuous beach (Martinez et al., 2006) but Hurricane Katrina, in particular, created and reopened tidal and wash-over channels that contributed to the overall decrease of the islands supra- and inter-tidal land by 70 percent, or 915 hectares (Martinez et al., 2005). In post-storm periods, wave and tidal driven processes generally reincorporate sediment into the landward migrating island to fill and repair wash-over and tidal channels (Boyd and Penland, 1981; Michot and Wilson, 2004; Figure 4). While initial beach accretion may be rapid, subsequent tropical storm and winter storm front events can slow or prevent tidal channel closure (Boyd and Penland, 1981; Kahn, 1986). While increased wave heights and storm frequency exacerbates erosion on barrier islands, the Chandeleur Islands are also being affected by high relative sea level rise rates and a negative sediment budget resulting



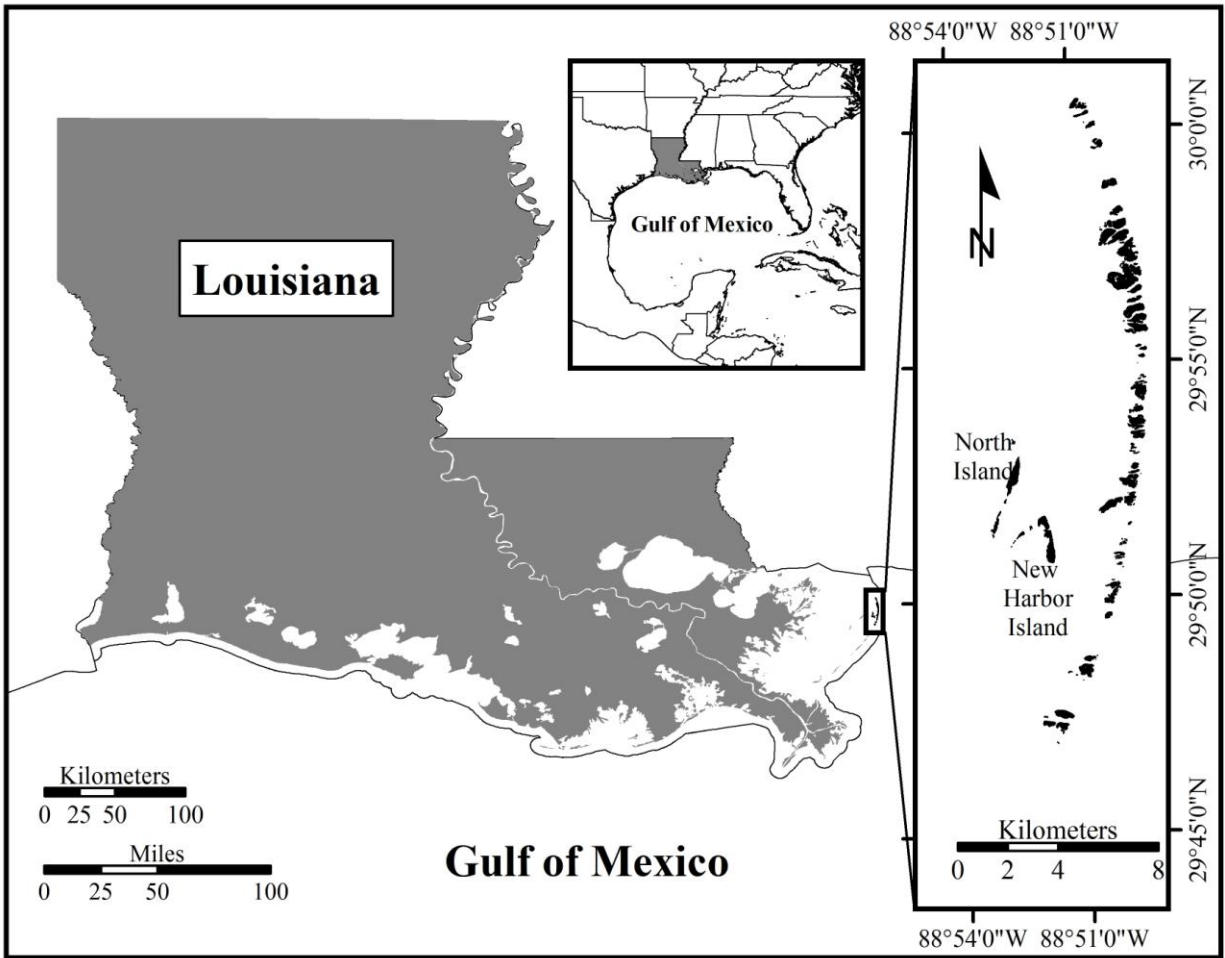


Figure 1. Location of the Northern Chandeleur Islands, Louisiana, USA, in the north-central Gulf of Mexico.

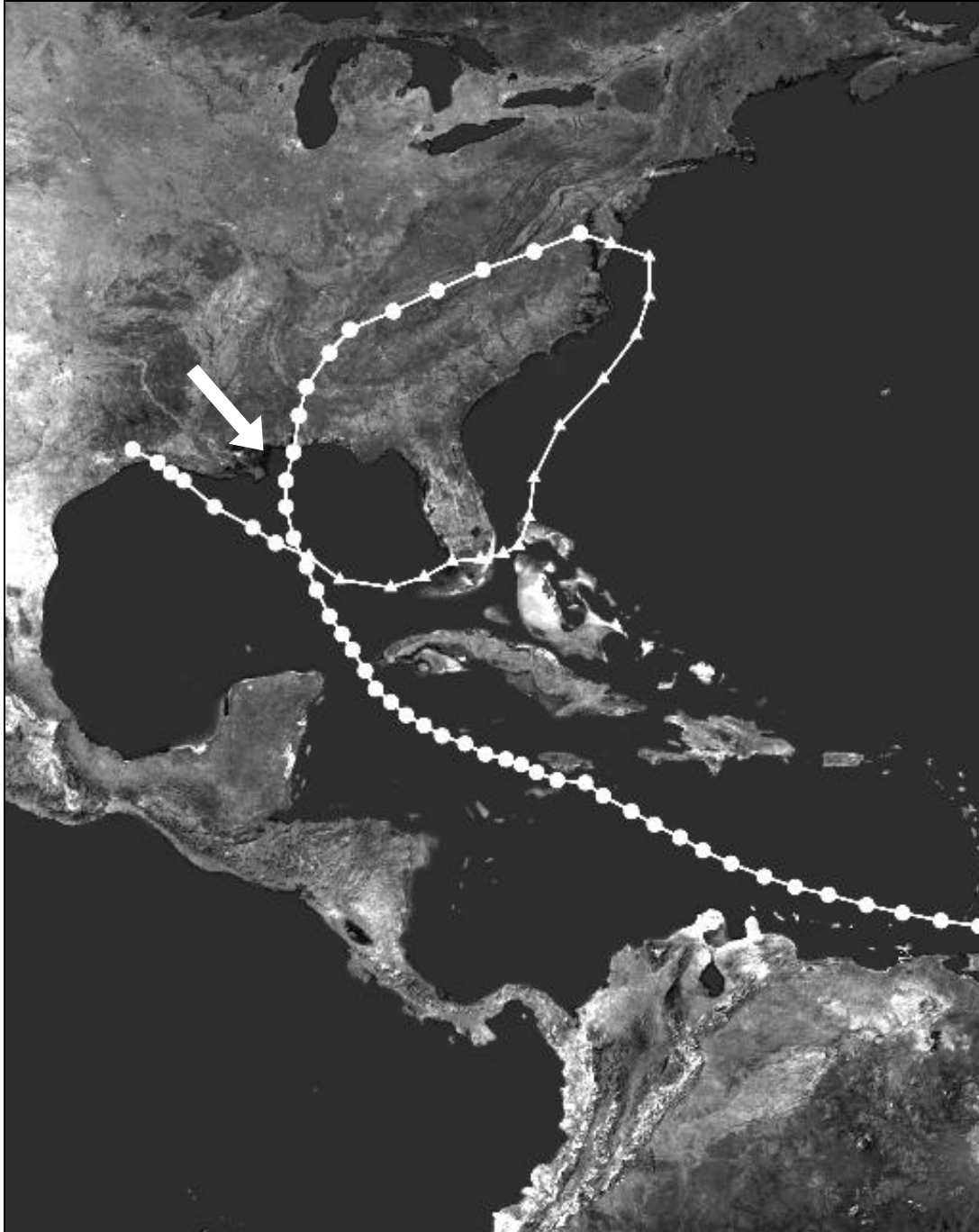


Figure 2. Path of Hurricane Ivan a Category 3 hurricane that made landfall on 16 September 2004 at Gulf Shores, Alabama. The circles represent hurricane strength winds  $>119.1$  km/h and the triangles represent winds  $<119.1$  km/h. The Chandeleur Islands location is marked approximately by the tip of the arrow. Hurricane Ivan's eastern eyewall passed 150km to the east of the Chandeleur Islands. Image modified from [http://en.wikipedia.org/wiki/Image:Ivan\\_2004\\_track.png](http://en.wikipedia.org/wiki/Image:Ivan_2004_track.png)



Figure 3. Path of Hurricane Katrina a Category 4 Hurricane that made final landfall on August 29, 2005 at the Louisiana / Mississippi gulf coast border. The circles represent hurricane strength winds  $>119.7$  km/h while the triangles represent winds  $<119.7$  km/h. Hurricane Katrina's eastern eyewall passed within 90km to the west of the Chandeleur Islands. The Chandeleur Islands location is marked approximately by the tip of the arrow. Image modified from [http://www.usasac.army.mil/SAEC/Katrina/katrina\\_files/image002.gif](http://www.usasac.army.mil/SAEC/Katrina/katrina_files/image002.gif)

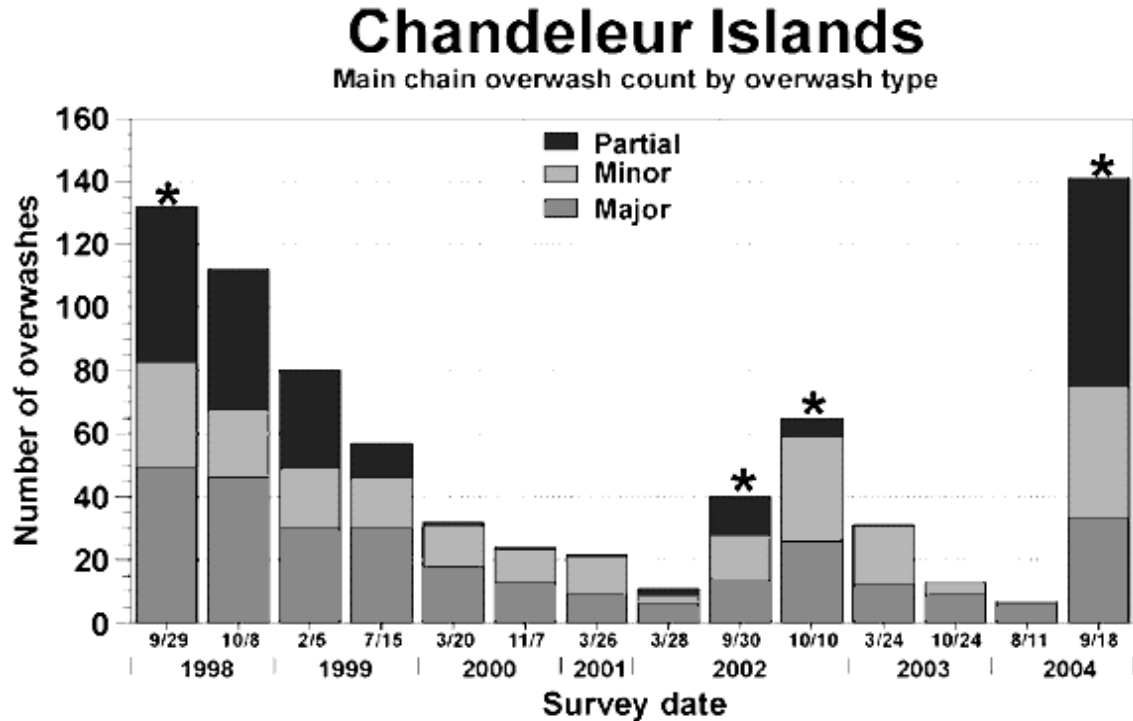


Figure 4. Results of aerial surveys conducted from 1998 to 2004 to count over-wash channels per type at the Chandeleur Islands, Louisiana. Surveys conducted immediately after the passage of a hurricane or tropical storm are noted (\*). These hurricanes or storms are as follows: 9/29/1998 Hurricane Georges (landfall 9/28/1998); 9/30/2002 Tropical Storm Isidore (landfall 9/28/2002); 10/10/2002 Hurricane Lili (landfall 10/2/2002); and 9/18/2004 Hurricane Ivan (landfall 9/16/2004). A partial channel is an over-wash channel that cuts into the island from the Gulf of Mexico (gulf), but does not go completely through to Chandeleur Sound. A minor channel is a narrow over-wash channel that cuts through an island and tracks a curved or meandering course from the gulf to the sound. A major channel is a wide over-wash channel that separates two islands in the main chain and tracks a straight course from the gulf to the sound. Image modified from Michot and Wilson (2004).

in a gulfside shore that retreats faster than the bay shoreline, ultimately reducing the islands width (Penland and Boyd, 1981; Penland and Ramsey, 1990; McBride et al., 1993; Georgiou et al., 2005). Natural erosional processes have contributed to the islands radically altered and increasingly dynamic geomorphology that is unique when compared to other northern GOM habitats. As of fall 2008, the recovery progress of the Chandeleur Islands has been slow and the barrier island chain remains disintegrated.

My review of barrier island literature suggests that only one previous study has investigated the effects of a major storm on the ichthyofaunal assemblage of a barrier island habitat (Blanke, 2006). Blanke (2006) and other past studies have shown that ecological components of southeastern United States estuaries and coastal systems are quite resilient to the effects of hurricanes (Tabb and Jones, 1962; Burkholder et al., 2004; Greenwood et al., 2006; Greening et al., 2006). Also, the ecological effects of major disturbances from storms are often studied in isolation of each other. Due to an increase in hurricane landfalls and hurricane intensity in the southeastern United States that is predicted to continue into the next decade (Goldenberg et al., 2001; Emanuel, 2005; Webster et al., 2005; Elsner et al., 2008), the opportunity to study these events as cumulative disturbances has emerged (Bortone, 2006). This project began as an ichthyofaunal survey of multiple habitats of the Chandeleur Island's; however, the impact by two major storms provided an opportunity to interpret two natural experiments on how hurricanes impact barrier island fish assemblages. This study addressed the effects of two hurricanes on the fish assemblages of three barrier island habitat types; protected bay shoreline (near shore; bag seine samples), demersal seagrass (trawl samples), and deep intertidal seagrass (gill net samples). Also, the combination of reopening and "mending" of tidal channels could have ecological implications for local fish assemblages if fishes are shown to use

these storm-generated channels as corridors. Therefore, I tested to determine if the reopening of tidal channels appear to have affected local fish assemblages of the Chandeleur Island's seagrass and bay shoreline habitats. Finally, I compared historic ichthyofaunal survey data collected over 35 years ago at the Chandeleur Islands (Laska, 1973) to data recently collected by myself and other members of the University of New Orleans Nekton Research Lab in order to determine if current assemblages are different from historical assemblages. The historical survey was conducted from March 1969 to November 1971 in three primary habitat types at the Chandeleur Islands: isolated and semi-isolated pools, the surf, and seagrass habitats (Laska, 1973). It should be noted that this survey also took place during a period of recovery, after Hurricane Camille had passed nearby.

In particular my specific objectives were to:

- A. Determine if fish assemblages of the Chandeleur Islands (as collected in the protected bay shoreline (near shore), demersal seagrass, and deep intertidal seagrass habitats) were significantly impacted by two major hurricanes;
- B. Determine if fishes use hurricane-reopened tidal channels at the Chandeleur Islands as corridors to seagrass beds; and
- C. Determine if current ichthyofaunal assemblages at the Chandeleur Islands are different from historical ichthyofaunal assemblages collected during a 1969-1971 study.

## Materials and Methods

### *Study Location*

The Chandeleur Islands are located in the eastern Lake Pontchartrain drainage basin, St. Bernard Parish, and constitute Louisiana's eastern-most boundary in the subtropical northern GOM (Figure 1). These islands are a transgressive barrier arc derived from the St. Bernard delta which was deposited between 1,000 and 2,800 years ago (Penland et al., 1988; Ritchie et al., 1992). The Chandeleurs have an oblique northeast-southwest orientation and a dominant southeasterly wave approach resulting in bi-directional long-shore transport patterns and decreased wave energies that ultimately provide the northern end of the barrier chain with more sandy sediment, increasing its width (Penland and Boyd, 1981), and resulting in substrates composed primarily of shell fragments at the southern end of the barrier chain (Ritchie et al., 1992). The Chandeleurs are divided into two groups based on geomorphic characteristics: North and South. The Northern Chandeleur Islands, the location of this study, consist of a crescent shaped barrier island chain encompassing a group of smaller islands (Figure 1).

The Chandeleur Islands have similarities to other barrier island systems similar to those found in southern Texas bays and the Tampa Bay area. All of these barrier islands offer habitats such as sandy beaches, back barrier marsh with mud bottomed lagoons, and shallow grassy-bottomed protected bays. Similar to the Chandeleurs, other barrier islands in the northern GOM respond to storm surge and high wave energies by inundation and wash over events (Penland et al., 1989; Ritchie and Penland, 1989; Froede, 2006). Within the northern GOM, the Chandeleur Islands are most dissimilar to the barrier islands found between the Mississippi River and the Louisiana-Texas border which have predominantly muddy substrates. The Chandeleur Island chain has been protected since 1904 as part of the Breton National Wildlife Refuge. In

1975, it became a part of the National Wilderness Preservation System (US Fish and Wildlife Service, 2008). Due to its protected status and location, 48 km from the main coast, the Chandeleur Islands appear to be the least affected by anthropogenic disturbance of all the Gulf coast barrier islands. The Chandeleur Islands, while sharing similar fauna to coastal localities, have their own distinct marine fauna, likely due to their remote location from land. The protected bays provide a range of habitat types, environments and ecotones unlike that found in open GOM waters nearby. In the bays throughout the western, or leeward, side of the islands, seagrass beds form an extensive but discontinuous underwater ‘meadow’ which consist predominantly of *T. testudinum*, star grass (*Halophila engelmanni*), shoal grass (*Halodule wrightii*), and manatee grass (*Syringodium filiforme*). In 1989 Handley (1995), using aerial surveys, estimated that 5,650 hectares of seagrasses were present throughout the bays of the Chandeleur Islands. Although the Northern Chandeleur Islands seagrass habitat has decreased by 85% from 1989 to 2006, these meadows still constitute the largest expanse of seagrass in Louisiana (Handley, 1995; Bethel et al., 2007).

### *Sampling Methods and Data Analyses*

A survey of Chandeleur Island’s ichthyofauna assemblages was conducted intermittently from October 2003 to May 2008 (Table 1). Three primary collecting sites were used along the leeward shore of the Northern Chandeleur Islands and at each site, three habitat types were sampled: protected bay shoreline (near shore), demersal seagrass, and deep intertidal seagrass (Figure 5). The deep intertidal and demersal seagrass habitat sampling stations, per site, were approximately perpendicular to the near shore habitat sampling station and bay shoreline. Initially, collections were sampled monthly from October 2003 through August 2005 (Table 1).



Table 1. Sampling dates of an ichthyofaunal survey at the Chandeleur Islands from 2003 to 2008. No sampling was conducted during December of any year. Dates of sampling that occurred just prior to a major hurricane impact on the islands are indicated by an (\*); these hurricanes were Hurricane Ivan which made landfall on 16 September 2004 and Hurricane Katrina which made landfall on 29 August 2005.

	2003	2004	2005	2006	2007	2008
January		13-15	5-7			
February			11-12			
March		6-7, 28-29	23-24			
April		6-8	14-15			
May		10-12	18-19	15-17	21-22	24-26
June		8-10	16-17	18-20		
July		6-8			2-3	
August		3-4	8-9*	25-27		
September		9-10*		15-16	2-3	
October	14-16					
November	10-12	8-9				

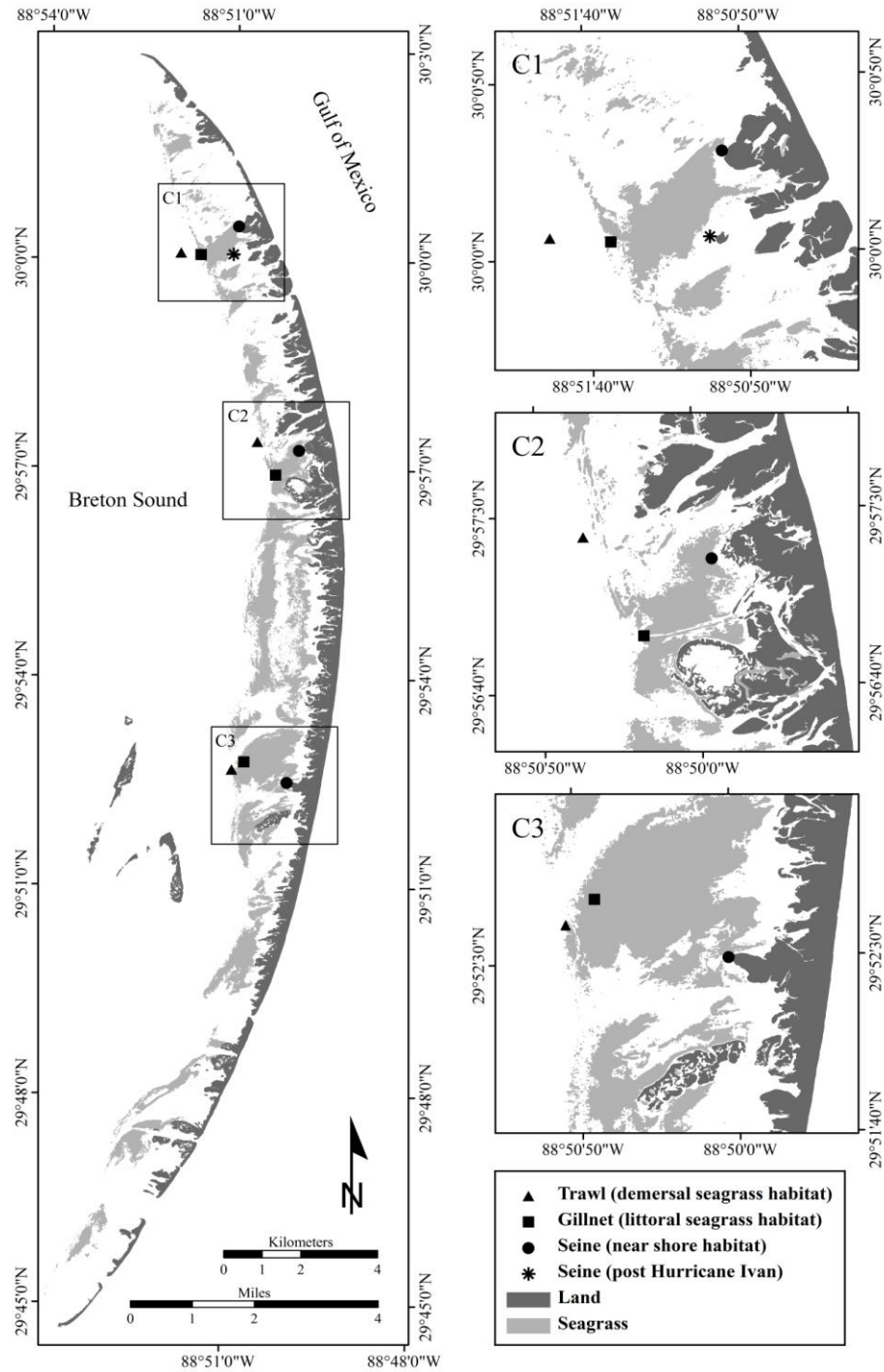


Figure 5. Ichthyofaunal survey sampling sites (C1, C2, and C3) at the northern Chandeaur Islands pre-Hurricane Katrina (October 2003 to August 2005). Within each site, the sampling stations of three different habitat types are shown: ● = protected bay shoreline (near shore; seine), ▲ = demersal seagrass (trawl), and ■ = deep intertidal seagrass habitat (littoral; gillnet). The near shore habitat sampling station at site C1 was relocated after Hurricane Ivan and is represented by (\*). The base maps used to generate this map are from January 2005 satellite photographs.

This first part of the survey was conducted for one year when Hurricane Ivan passed within 150 km of the islands. Sampling was missed in October 2004 but resumed in November 2004. The near shore habitat sampling station of the northernmost site, C1, was relocated due to erosion caused by Hurricane Ivan; however, the deep intertidal and demersal seagrass stations remained the same (Figure 5; inset C1). The survey continued until one year post Hurricane Ivan when sampling was again interrupted by Hurricane Katrina. Post Hurricane Katrina sampling resumed monthly during the summers of 2006 and 2007, and in May 2008. Hurricane Katrina radically changed the islands geomorphology (e.g., compare Figure 5 versus Figure 6) and in May 2006 site C1 was abandoned as a sampling site for all three gear types. A new location (C4) was selected between sites C2 and C3 (Figure 6). The near shore station at C4 had to be relocated again during the first trip of 2007 while the deep intertidal and demersal seagrass stations remained the same (Figure 6; inset C4).

To sample the near shore habitat, a 15.2 m X 1.83 m bag seine with 9.5 mm mesh was pulled for 50 m perpendicular and onto the shore. Triplicate seine hauls were conducted per station. All seine hauls started over seagrass habitat although the amount of bare substrate adjacent to shore, usually sand or mud, varied between station and individual hauls. At Sites C2 and C3, the shoreline is salt marsh edge consisting predominantly of smooth cordgrass (*Spartina alterniflora*). While the near shore sampling station at site C1/C4 was moved four times throughout the study, the alternate stations were chosen to best match the habitat of the original station; a shoreline consisting predominantly of sandy beach. To sample demersal seagrass habitats, a 4.9 m otter trawl was towed at 1.8 m/s for 10 min covering a distance of about 1.2 km. Triplicate tows were conducted per station. All tows were made in an oscillating pattern to reduce the effect of the boat's prop wash on the trawl. While GPS was used to consistently

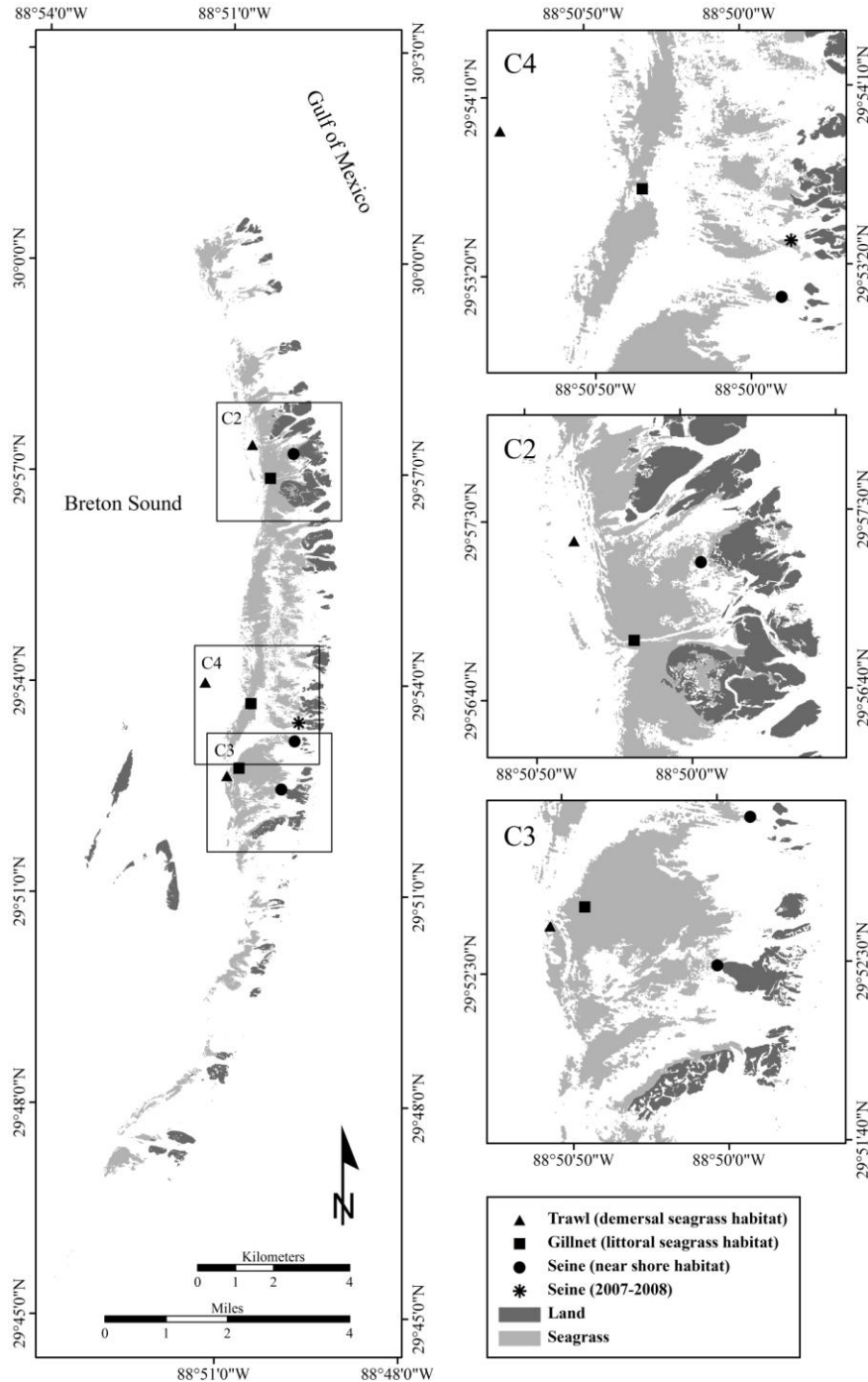


Figure 6. Ichthyofaunal survey sampling sites (C1, C2, and C3) at the northern Chandeleur Islands post-Hurricane Katrina (May 2006 to May 2008). Note: Site C1 has been relocated from its location prior to Hurricane Katrina (see fig. 5) and renamed C4. Within each site, the sampling stations of three different habitat types are shown: ● = protected bay shoreline (near shore; seine), ▲ = demersal seagrass (trawl), and ■ = deep intertidal seagrass habitat (littoral; gillnet). The near shore habitat station at site C4 was relocated in 2007 and is represented by \*. The base maps used to generate this map are from October 2005.

sample the same area per station, individual tows were not spatially similar per trip. To sample deep intertidal seagrass habitats, a gill net 100 m in length and 2 m in height, containing six alternating panels of 5.1 and 24.4 cm mesh, was set for one hour. All gill net sampling stations were over seagrass habitats and a GPS was used to determine consistent placement of the gill net. Fishes were separated by panel (gillnet) or replicate haul (seine and trawl) then identified to species (Robins et al., 1986; Murdy, 1995; Hoese and Moore, 2005) and abundance, total wet weight (grams) and standard length (SL; mm) range were recorded. Adjacent panels of 5.1 and 24.4 cm mesh are combined for all gill net collections: resulting in triplicate samples each consisting of a 5.1 and 24.4 cm mesh panel. For all collections, fish were stored on ice until processing could be conducted. Water quality data for near shore and deep intertidal collections were taken at the deep intertidal sampling station while water quality data for the demersal collections were taken at the demersal sampling station. Water quality measurements were recorded using a YSI-85 (Yellow Springs Instrument) meter. Temperature (°C), dissolved oxygen (mg/liter), conductivity (Siemens, S), specific conductivity (Siemens, S) and salinity (‰) were recorded. A secchi disk was used to determine water clarity and depth (0.25 m increments).

All data were analyzed with PRIMER-E® (PRIMER-E, Ltd., Plymouth, England; Clarke and Warwick, 2001). This software package offers several advantages when analyzing large, multivariate environmental databases because more realistic assumptions of normality (which are rarely met in environmental data sets) are not necessary and the exploratory options available provide an added dimension to hypotheses testing in an existing database. Assemblage data per habitat type were square root transformed and a Bray-Curtis similarity matrix was calculated. While it is recommended to omit all of the rarer species (“usually at least half of the species set”)

which tend to confuse or disrupt the patterns in any subsequent clustering or ordination analysis (Clarke and Warwick, 2001), I chose not to omit these rare species from the data matrix. Many of the rarer (or less abundant) species appeared or became absent following the storm impacts and likely played some role in the observed before-after assemblage changes. Also clustering analyses were used to interpret patterns in direction of assemblage change, in multivariate space, over time and not used to determine similarities among assemblages. Non-metric multidimensional scaling (MDS) plots are used to represent multi-dimensional relationships in a typical two dimensional graph. In MDS plots, assemblages that are more similar in species composition appear closer together. Additionally, a stress value is calculated for each MDS plot which represents the relative effectiveness of the two dimensional graph in representing the multivariate relationships of the data. I constructed MDS plots for all assemblages per habitat type and removed outliers to achieve a stress value of  $\leq 0.20$  before further analyses were run. The removed outliers generally included those assemblages with the rarer species and low overall abundance. I then used a one way analysis of similarity (ANOSIM;  $p = 0.05$ ) to test for significant differences among fish assemblages from same months of different years for each habitat type (Clarke, 1993). The ANOSIM index or  $R$  represents the similarity between samples being compared and ranges from +1 and -1. An  $R$  value of zero represents no difference between a pair of assemblages. When  $R$  is near 1, assemblages are different in composition while an  $R$  near -1 (which is rarely seen in natural data) means greater similarity exists between assemblages being compared than within assemblages. When significant differences were observed, MDS plots were generated to show directional patterns of fish assemblage changes, in multivariate space, over time. Stress values per MDS plot represent fish assemblages sampled at all sampling stations per habitat type during each month of different years. I also used a similarity percentage

(SIMPER) analysis to determine which species contributed most to dissimilarities among assemblages (Clarke, 1993). Finally, I used the BIO-ENV routine to determine relative relationship strengths between assemblage change and measured environmental data. During this routine, environmental variables were log transformed and used to form a similarity matrix based on normalized Euclidean distance. Then Spearman rank correlation coefficients were calculated to determine which environmental variables were most associated with the measured change in fish assemblages over time.

To determine use of tidal channels by fishes, four channels (Figure 7) were sampled diurnally from 6-16 July 2007 and one channel was sampled again during 4-5 September 2007 (Table 2). A total of 21 hours of sampling was conducted during July and 3 hours of sampling were conducted during September for a total of 24 net hours sampled in channels. Samples collected in deep intertidal seagrass habitats were used (gillnet samples) to compare between assemblages collected in channel and seagrass habitats. Gill nets identical to those used to sample deep intertidal seagrass habitats for the assemblage analyses (see above) were deployed in each channel perpendicular to the channel shores and a GPS was used to determine consistent placement of the gill net in each channel. The net was collected after one hour set time and fishes were separated by panel then identified to species (Robins et al., 1986; Murdy, 1995; Hoese and Moore, 2005) and abundance, total wet weight, and SL range were recorded. All fishes were stored on ice until processing was conducted and fishes were not discarded in or near the channels being sampled, avoiding the possibility of attracting scavenging species. A secchi disk was used to determine water clarity (0.25 m increments) and atmospheric data was recorded from weather reports broadcasted on VHF channel 2. At all channel sampling locations, two-dimensional bathymetric profiles were constructed between shorelines in the approximate

locations the net was placed. Adjacent panels of 5.1 and 24.4 cm mesh are combined for all gill net collections: resulting in triplicate samples each consisting of a 5.1 and 24.4 cm mesh panel. I tested for significant differences (ANOSIM;  $p = 0.05$ ) among fish assemblages collected during July in all channels and for significant differences (ANOSIM;  $p = 0.05$ ) between assemblages collected in channels and seagrass beds during July and September. MDS plots were then constructed for those assemblages exhibiting significant differences. SIMPER analysis was used to determine which species contribute most to dissimilarities between channels and between channels and seagrass beds.

To test for possible assemblage changes over thirty five years, I used historical data collected at the Chandeleur Islands from March 1969 to November 1971 (Laska, 1973). The study was conducted in eight trips during all seasons of the year and multiple habitat types were sampled, although only the following data was used for comparison. Thirty-seven collections were made in seagrass habitats during all seasons using a boat towing a beam trawl with 3 cm stretched mesh with a 6 mm stretched mesh cod end. The net opening was 0.914 m in height and 1.829 m in width and each collection consisted of one haul that lasted from 5 to 15 minutes. A total of 3 collections were made in the surf during June and July of 1970 using a 30.5 m nylon bag seine with 2 cm stretched mesh and a 1.2 cm stretched mesh bag that was 3.5 m in width, 2 m in height and 2 m deep. Each haul began about 60 m from shore and three to six hauls pulled perpendicular and onto the shore constituted a collection. Nineteen collections were made in lagoons and isolated and semi-isolated pools during June and July of 1970 and May 1971 using seines and dip-nets after applying a rotenone based asphyxiating chemical.



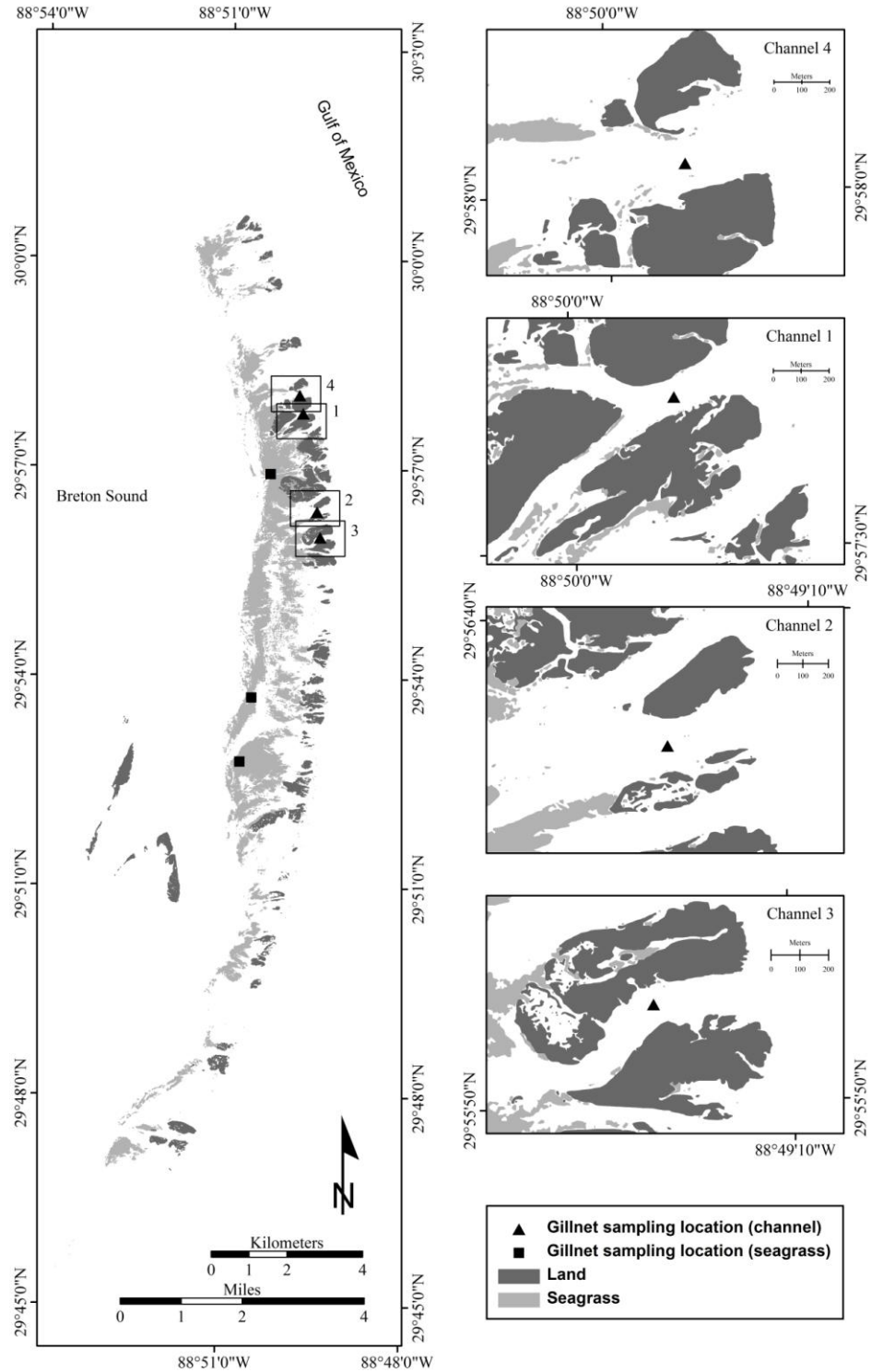


Figure 7. Location of tidal channel sampling sites (channels 1, 2, 3, and 4) during summer 2007 at the northern Chandeleur Islands, Louisiana. Diurnal sampling was conducted from July 6-16 and diel sampling occurred September 3-5 in channel 1 only. ▲ = channel gillnet sampling locations and ■ = seagrass habitat gillnet sampling locations. The base maps used to generate this map are from October 2005.

Table 2. Dates gill net sampling was conducted in channels at the Chandeleur Islands during two trips; 6-16 July 2007 and 4-5 September 2007. Numbers of collections conducted per channel per day are given in parenthesis while the times collections began (i.e. the net was set) is reported (24 hr format).

Sampling Date	Channel			
	1	2	3	4
6 July 07		(2) 0936, 1634		
7 July 07			(4) 0651, 0952 1146, 1625	
8 July 07	(2) 1038, 1212	(1) 1706		
9 July 07	(1) 0739			(1) 1058
10 July 07				
11 July 07			(1) 1752	
12 July 07	(1) 0808			
13 July 07		(1) 0622	(2) 0809, 0935	
14 July 07			(2) 0603, 0756	
15 July 07	(1) 0604			
16 July 07		(1) 0610	(1) 0745	
-----				
4 Sept 07	(2) 0700, 0836			
5 Sept 07	(1) 0532			

The recent data used in this comparison to the historical data were collected at the Chandeleur Islands from October 2003 to June 2008 and include all near shore habitat collections from the previously mentioned survey work and collections made during additional sampling. Additional sampling conducted by myself and other UNO Nekton Research Lab personnel included collections from sixteen connected or isolated pools sampled during 25-27 May 2008, four connected or isolated pools sampled during 24 June 2008, and two beach sampling stations sampled during 24-25 June 2008 (Figure 8). Pool N was sampled during both trips. Smaller pools were sampled with a 4.25 m X 2.2 m seine with 7 mm mesh while larger pools and the surf were sampled with a 15.2 m X 1.83 m bag seine with 9.5 mm mesh. Two or more tows were conducted when using the smaller seine but only one tow was made when using the bag seine. Collections made at each surf zone station consisted of triplicate hauls following similar methods of the surveys near shore habitat sampling and were conducted between 0930 and 1230. All fishes were preserved as above then identified to species (Robins et al., 1986; Murdy, 1995; Hoese and Moore, 2005). Abundance, total wet weight, and SL range were also recorded. Because of inconsistencies in sampling techniques, all assemblage data used for comparison between historic and current collections were converted to presence-absence matrices and analyzed following the methods of Chávez-López et al. (2005). A taxonomic distinctness index was constructed and 'ellipse' plots were used to determine if a decrease in taxonomic distinctness (taxonomic diversity) had occurred since the early 1970s.

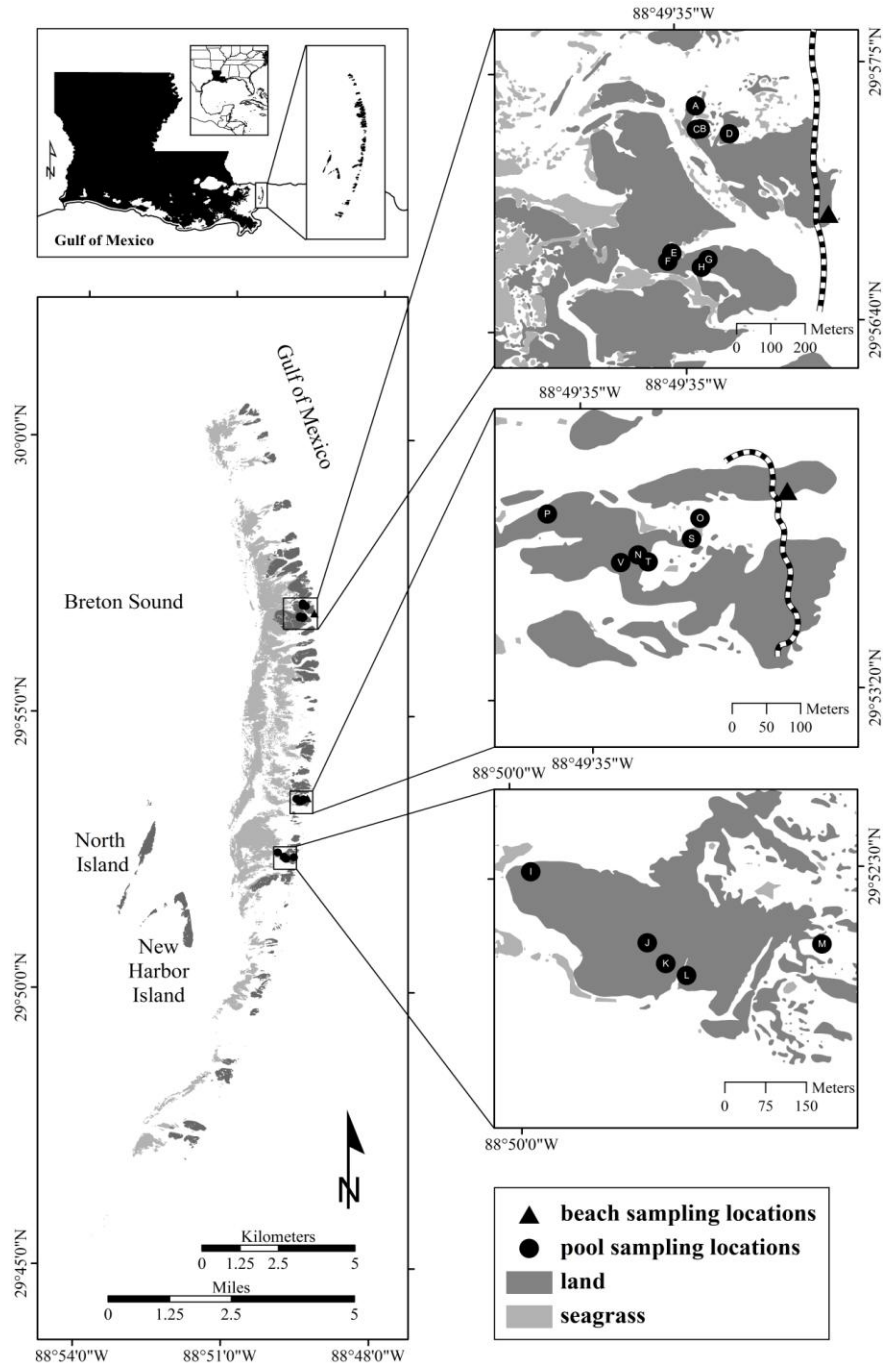


Figure 8. Map of sampling sites conducted in pool and surf zone habitats at the northern Chandeleur Islands, Louisiana. ● = pools and ▲ = beach sampling stations. Pools A through P were sampled on 25-27 May, 2008 and pools N, S, T and V were sampled on 24 June 2008. Pool N was sampled during both trips. The surf zone was sampled during 24-25 of June 2008. The base map used is from October 2005 and the channels in the right upper and right middle insets have closed forming a continuous beach near the surf zone sampling stations. The dotted line in the top two insets are the beach shoreline locations as observed in an aerial photograph from August 27, 2007. The beach shoreline locations during June 2008 appeared similar.

## Results

### *Fish assemblage comparisons: the near shore habitat*

During the ichthyofaunal survey, 49,971 total fishes comprising 100 species from 44 families were collected in three habitat types (Appendix I). In the near shore habitat 29,737 fishes comprising 71 species from 36 families were collected while 24 of these taxa were unique to this habitat type (Appendix I). Pinfish (*Lagodon rhomboides*) which comprised 47.2% of the assemblage were the most abundant species collected in the near shore habitat. During the survey this species was the greatest contributor to dissimilarities among fish assemblages collected in near shore habitats during same months of different years. Other species commonly collected in the near shore habitat were silver jenny (*Eucinostomus gula*; 12.2% of total composition), inland silverside (*Menidia beryllina*; 9.7%), white mullet (*Mugil curema*; 6.8%) and spot (*Leiostomus xanthurus*; 5.2%).

Fish assemblages collected in the near shore habitat during 10-12 November 2003 and 8-9 November 2004 were significantly different (ANOSIM;  $R = 0.575$ ;  $p = 0.012$ ). It is important to note, though, that sampling of the near shore habitat during November 2004 was conducted only at site C2. Additionally, one sampling attempt at site C1 during November 2003 produced no fishes. Despite the decreased sampling effort during November 2004, overall abundance increased although species richness decreased (Figures 9 and 10). When comparing fish assemblages collected only at site C2 during November of 2003 and 2004 an increase in overall abundance was also observed (from 74 to 156 fishes) while species richness declined markedly from 17 to 7 species. An MDS plot shows clustering of assemblages collected during November 2003 and changes among fish assemblages collected at site C2 during November 2003 and

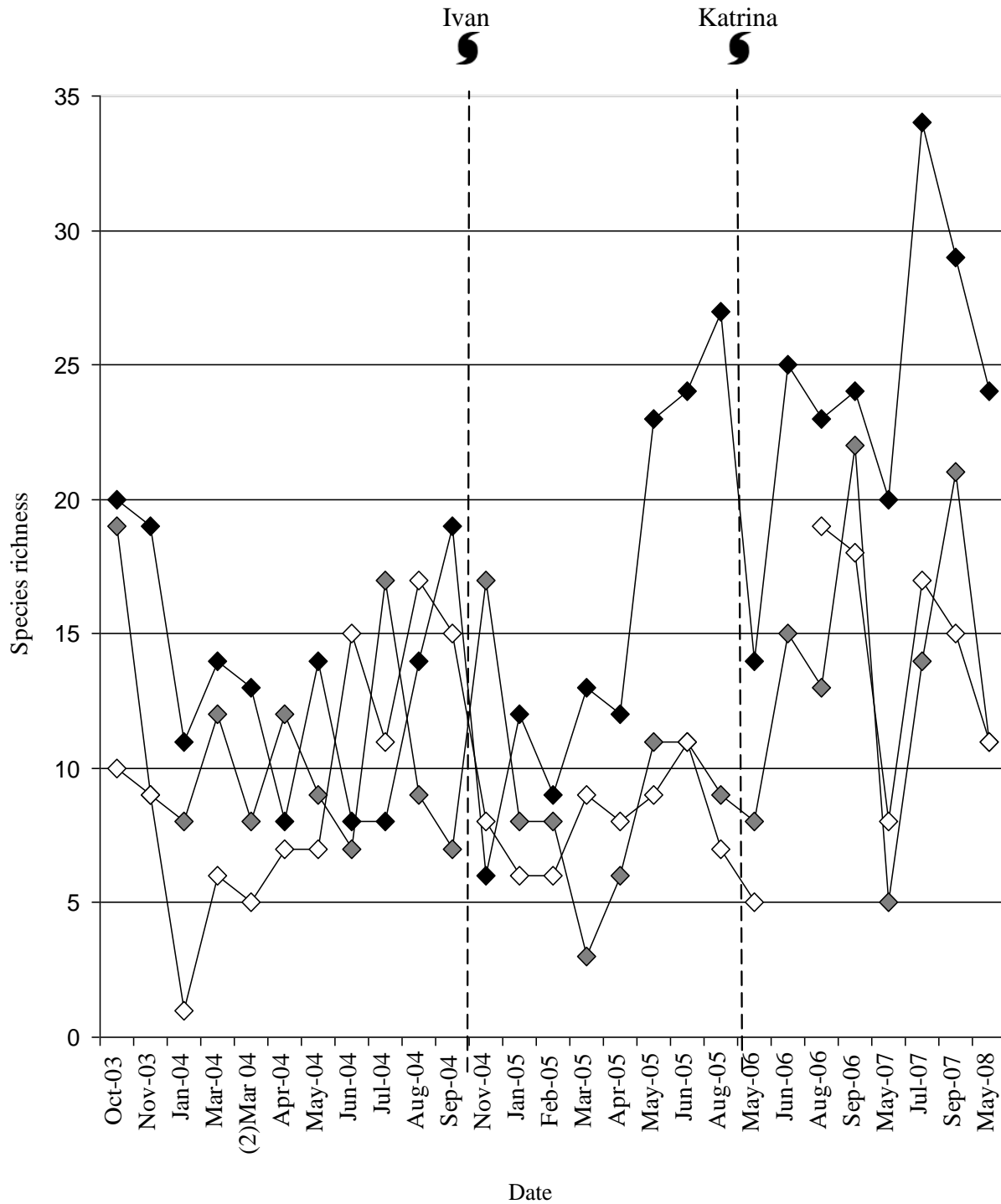


Figure 9. Species richness (number of species) from three habitat types sampled from October 2003 to May 2008 at the Chandeleur Islands, Louisiana. Species richness was calculated as total richness across all three sampling stations per habitat type for that sampling period. Symbols represent habitat type; ◆ = near shore habitat; ◇ = demersal seagrass habitat; ◇ = deep intertidal seagrass habitat. June 2006 deep intertidal habitat samples are not available. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by 5.

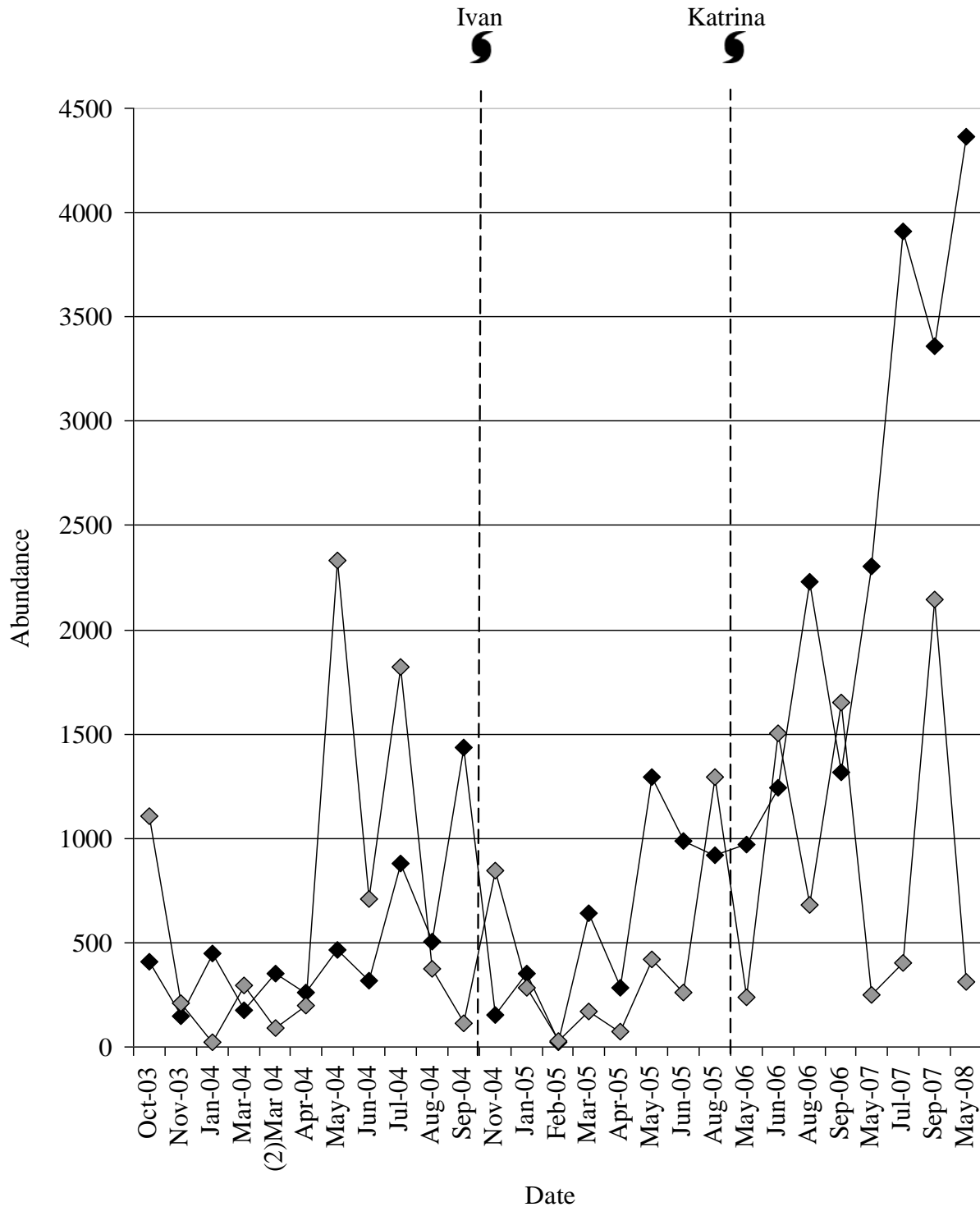


Figure 10. Overall abundance of fishes from two habitat types sampled from October 2003 to May 2008 at the Chandeleur Islands, Louisiana. Species abundance was calculated as the sum of abundances from all three sampling stations per habitat type for that sampling period. Symbols represent habitat type; ◆ = near shore seagrass habitat; ◇ = demersal seagrass habitat. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

November 2004 (Appendix II). *Lagodon rhomboides*, which increased in abundance during this period, contributed most (42.48%) to the dissimilarity between the November assemblages (Table 3). Additionally, when comparing assemblages from site C2 only, *L. rhomboides* comprised just 16.2% of the assemblage collected during November 2003 but 92.3% during November 2004. All other species contributed markedly less to the observed dissimilarity between November samples (Table 3). For example, the species contributing the second most to dissimilarity was *E. gula* which provided only 15.12% of the dissimilarity observed (Table 3). Additionally, the near shore fish assemblage collected during 13-15 January 2004 was not significantly different than the assemblage collected during 5-7 January 2005 (ANOSIM;  $R=0.026$ ;  $p=0.335$ ).

While near shore fish assemblages collected during 6-7 March 2004 and 28-29 March 2004 were not significantly different (ANOSIM;  $R=0.01$ ;  $p=0.01$ ), fish assemblages collected during 23-24 March 2005 were significantly different than assemblages collected during 6-7 March 2004 (ANOSIM;  $R=0.645$ ;  $p=0.002$ ) and 28-29 March 2004 (ANOSIM;  $R=0.122$ ;  $p=0.037$ ). No collections were made at site C1 during the first March 2004 trip. While species richness remained similar in the near shore habitat from March 2004 to March 2005, the overall abundance of fishes increased (Figures 9 and 10). MDS plots show the assemblages at site C1 became more similar during March 2005 while similar directions of assemblage change occurred at sites C2 and C3 (Appendix II). Again, *L. rhomboides* contributed most (32.11% and 33.75%) to the dissimilarity between assemblages collected during March 2004 and March 2005 (Table 4). With abundance values from both March 2004 trips combined, this species still increased in abundance by 1,025% during March 2005. *Leiostomus xanthurus* contributed to 12.57% of the dissimilarity between the assemblages collected during 6-7 March 2004 and March 2005 and



Table 3. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during November of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>Nov 2003 Mean Abundance</u>	<u>Nov 2004 Mean Abundance</u>	<u>% Contribution</u>
November 2003 vs. November 2004	0.58	0.012	<i>Lagodon rhomboides</i>	4.13	48.00	42.48
			<i>Eucinostomus gula</i>	6.00	0.00	15.12
			<i>Fundulus grandis</i>	1.50	1.00	6.33
			<i>Syngnathus floridae</i>	1.50	0.00	5.08
			<i>Chasmodes saburrae</i>	0.00	1.00	4.91

Table 4. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during March of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
6-7 March 2004 vs. March 2005	0.645	0.002	<i>Lagodon rhomboides</i>	1.83	45.11	32.11
			<i>Leiostomus xanthurus</i>	4.50	14.11	12.57
			<i>Lucania parva</i>	5.17	0.22	10.11
			<i>Cyprinodon variegatus</i>	8.83	4.78	9.38
			<i>Fundulus similis</i>	5.00	2.89	7.64
28-29 March 2004 vs. March 2005	0.122	0.037	<i>Lagodon rhomboides</i>	6.11	45.11	33.75
			<i>Leiostomus xanthurus</i>	17.11	14.11	19.14
			<i>Cyprinodon variegatus</i>	10.78	4.78	11.51
			<i>Fundulus similis</i>	1.67	2.89	7.04
			<i>Menidia beryllina</i>	0.78	1.33	6.25

19.14% of the dissimilarity between the assemblages collected during 28-29 March 2004 and March 2005 (Table 4). The near shore assemblages collected during both March 2004 sampling periods were not significantly different than the assemblage collected during 11-12 February 2005 (ANOSIM;  $R = 0.067$  and  $p = 0.225$ ;  $R = 0.05$  and  $p = 0.243$ ).

Fish assemblages collected in the near shore habitat during 10-12 May 2004 were significantly different than assemblages collected during 18-19 May 2005 (ANOSIM;  $R = 0.262$ ;  $p = 0.004$ ), 15-17 May 2006 (ANOSIM;  $R = 0.156$ ;  $p = 0.054$ ), 21-22 May 2007 (ANOSIM;  $R = 0.228$ ;  $p = 0.019$ ) and 24-26 May 2008 (ANOSIM;  $R = 0.622$ ;  $p = 0.001$ ). Near shore fish assemblages collected during 18-19 May 2005 were significantly different than assemblages collected during 15-17 May 2006 (ANOSIM;  $R = 0.299$ ;  $p = 0.003$ ) while near shore fish assemblages collected during 15-17 May 2006 were significantly different than assemblages collected during 21-22 May 2007 (ANOSIM;  $R = 0.221$ ;  $p = 0.035$ ). Lastly, near shore fish assemblages collected during 21-22 May 2007 were not significantly different than the assemblage collected during 24-26 May 2008 (ANOSIM;  $R = 0.118$ ;  $p = 0.056$ ). It is important to note that two replicates from site C1/C4 during May 2006 appeared as outliers and were removed prior to analysis. MDS plots show, in multivariate space, patterns of cyclic assemblage change (Mathews, 1998) at sites C1/C4 and C3 but a unidirectional pattern of assemblage change at site C2 while all sites showed similar directions of assemblage change (Figures 11, 12, and 13). Near shore fish assemblages collected during May of different years show similar patterns of species richness and abundance through time: an increase from May 2004 to May 2005, a decrease from May 2005 to May 2006, and increases from May 2006 to May 2007 and from May 2007 to May 2008 (Figures 9 and 10). An increase in overall abundances of 279.5% occurred in near shore habitats from May 2004 to May 2005 but the increase in overall

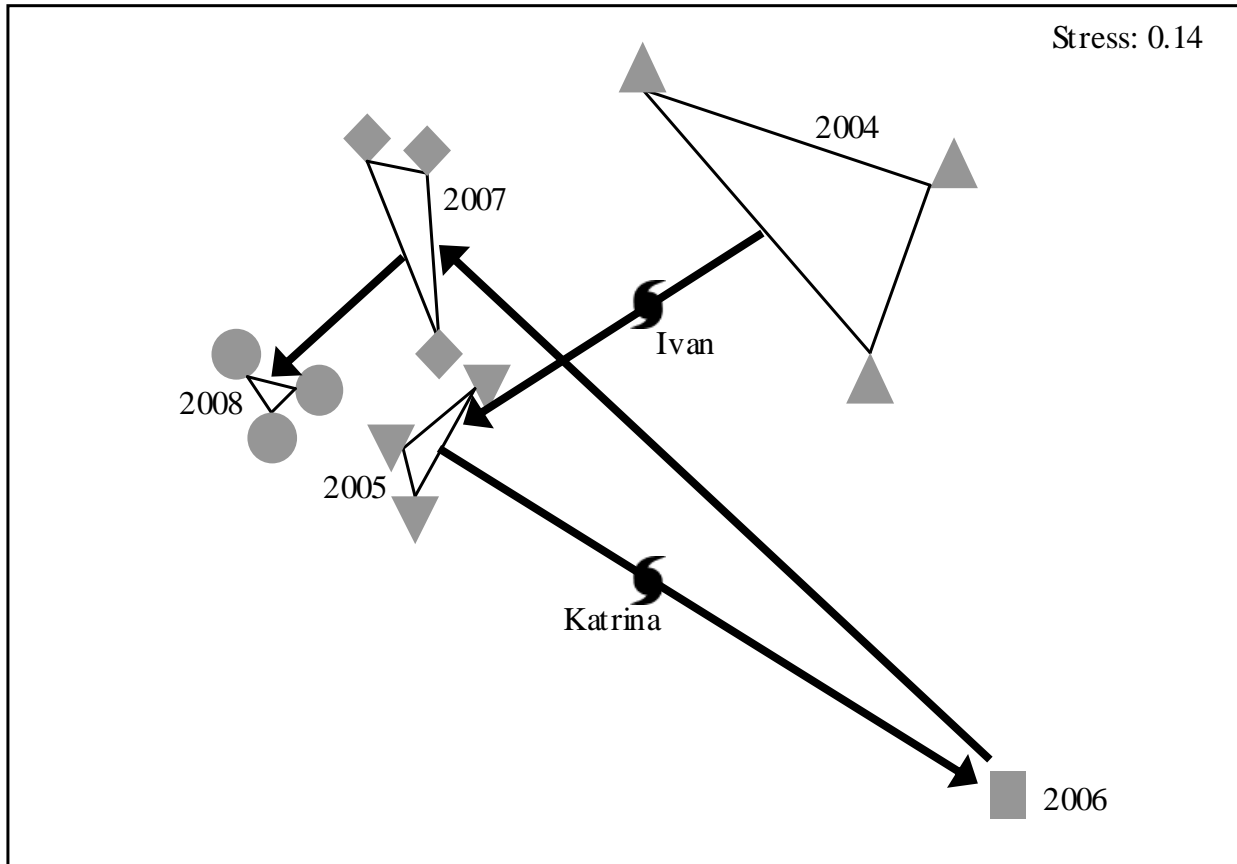


Figure 11. Multidimensional scaling plot of fish assemblages collected at site C1/C4 in the near shore habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. Two replicates from May 2006 appeared as outliers and were removed. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

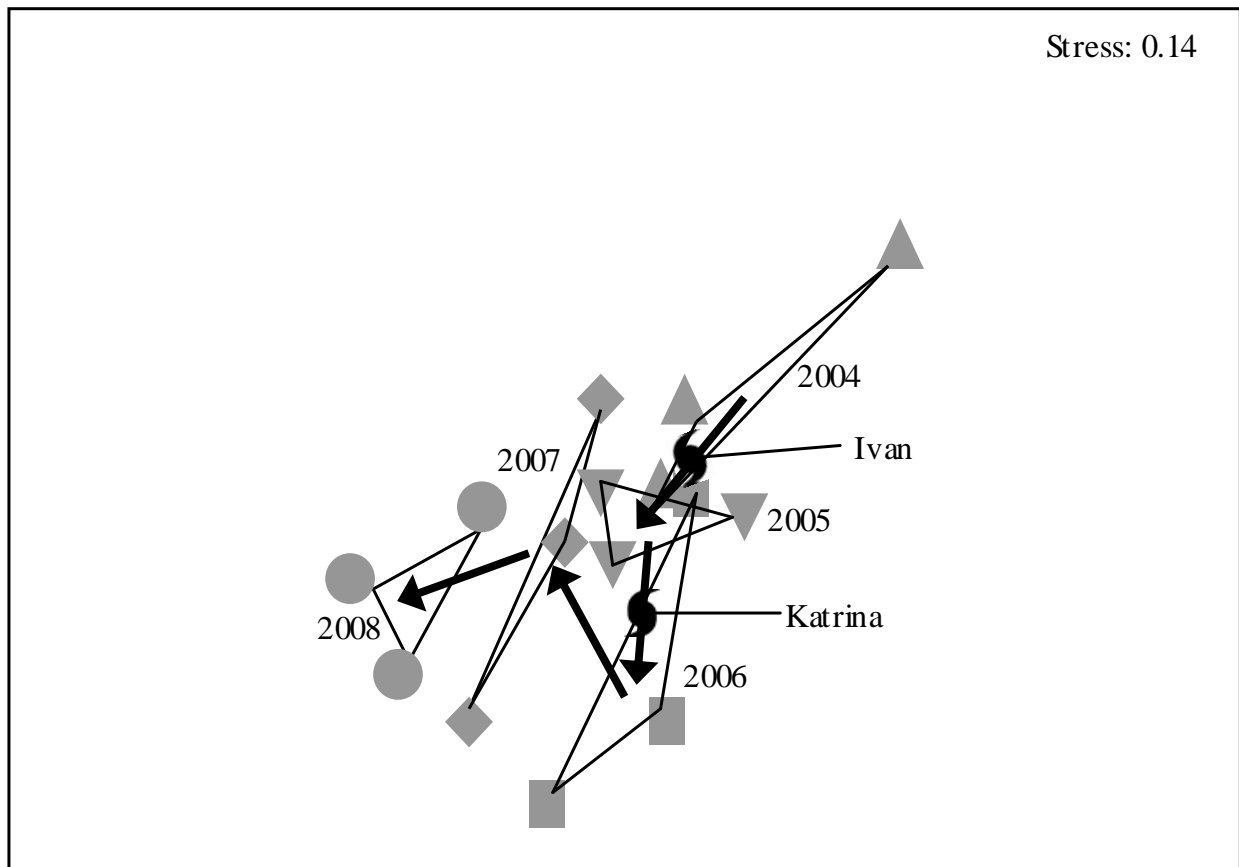


Figure 12. Multidimensional scaling plot of fish assemblages collected at site C2 in the near shore habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ●.

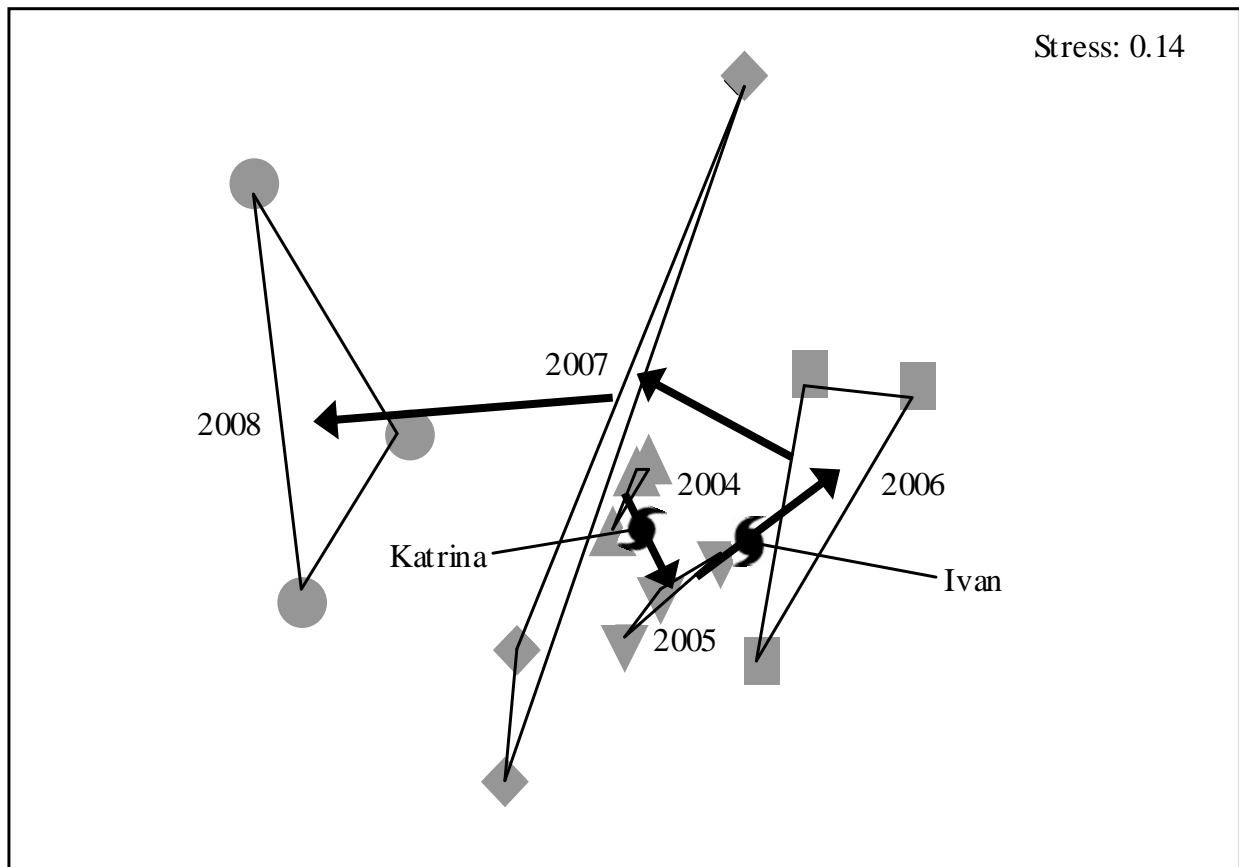


Figure 13. Multidimensional scaling plot of fish assemblages collected at site C3 in the near shore habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

abundance from May 2004 to May 2008 was 942% (Figure 10). While 292 *L. rhomboides* were collected during May 2004, an increase in the abundance of this species was observed during all years resulting in a 597.0% increase from May 2004 to 2008. This species contributed most to the dissimilarity observed between assemblages collected during May of different but proximate years (Table 5). Within the near shore habitat during May 2004, 65% of *L. rhomboides* were collected at site C3 while only 3.4% were collected at site C1. During May 2005, though, only 25% were collected at C3 and 50% were collected at site C1. Silver perch (*Bairdiella chrysoura*) appeared in May collections for the first time during 2008 and the freshwater goby (*Ctenogobius shufeldti*) was captured for the first time at the Chandeleur Islands during May 2008. A total of 152 *B. chrysoura* were collected during May 2008 with 69.7% of them collected at site C2. *Ctenogobius shufeldti* were also collected with 124 collected at site C1/C4 and the remainder at site C3. Additionally, near shore fish assemblages collected during May 2004 were not significantly different than assemblages collected during 23-24 March 2005 (ANOSIM;  $R = 0.02$ ;  $p = 0.329$ ) and 14-15 April 2005 (ANOSIM;  $R = 0.056$ ;  $p = 0.151$ ).

Near shore fish assemblages collected during 8-10 June 2004 were significantly different than assemblages collected during 16-17 June 2005 (ANOSIM;  $R = 0.15$ ;  $p = 0.023$ ) while near shore fish assemblages collected during 16-17 June 2005 were significantly different than assemblages collected during 18-20 June 2006 (ANOSIM;  $R = 0.251$ ;  $p = 0.018$ ). MDS plots show fish assemblages from site C1/C4 changed most from June 2004 to June 2005 while fish assemblages at sites C2 and C3 changed most from June 2005 to June 2006 (Appendix II). Additionally, similar directions of assemblage change occurred at all sites from June 2005 to June 2006 (Appendix II). Species richness increased 100% from June 2004 to June 2005 but remained similar from June 2005 to June 2006 while overall abundance increased from June

Table 5. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during May of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
May 2004 vs. May 2005	0.262	0.004	<i>Lagodon rhomboides</i>	32.44	99.56	26.48
			<i>Anchoa mitchilli</i>	1.00	10.44	9.41
			<i>Leiostomus xanthurus</i>	13.78	8.56	9.13
			<i>Citharichthys spilopterus</i>	0.00	1.67	6.27
			<i>Fundulus similis</i>	0.67	4.33	6.06
May 2005 vs. May 2006	0.299	0.003	<i>Lagodon rhomboides</i>	99.56	120.00	24.76
			<i>Anchoa mitchilli</i>	10.44	1.29	8.65
			<i>Leiostomus xanthurus</i>	8.56	2.14	7.68
			<i>Anchoa hepsetus</i>	0.00	8.29	6.66
			<i>Citharichthys spilopterus</i>	1.67	0.14	5.05
May 2006 vs. May 2007	0.221	0.035	<i>Lagodon rhomboides</i>	120.00	152.11	27.75
			<i>Menidia beryllina</i>	1.43	16.22	11.60
			<i>Mugil curema</i>	0.00	19.00	9.60
			<i>Leiostomus xanthurus</i>	2.14	13.78	8.57
			<i>Anchoa hepsetus</i>	8.29	16.78	8.53
May 2007 vs. May 2008	0.118	0.056	<i>Lagodon rhomboides</i>	152.11	193.67	21.02
			<i>Mugil curema</i>	19.00	94.44	13.16
			<i>Menidia beryllina</i>	16.22	70.67	10.06
			<i>Leiostomus xanthurus</i>	13.78	59.67	9.03
			<i>Bairdiella chrysoura</i>	0.00	16.89	7.11



2004 to June 2005 (313%) and from June 2005 to June 2006 (26%; Figures 9 and 10). *Lagodon rhomboides* increased in abundance from June 2004 to June 2005 but decreased from June 2005 to June 2006. This species contributed most to the dissimilarity between assemblages collected during June 2004 and June 2005 (26.11%) and second between the June 2005 and 2006 assemblages (17.03%; Table 6). Specimens of *E. gula* were absent in collections during June 2004 but 211 and 494 fish were collected during June 2005 and June 2006, respectively, contributing greatly to the dissimilarities among those assemblages (Table 6).

Near shore fish assemblages collected during 6-8 July 2004 and 2-3 July 2007 were significantly different (ANOSIM;  $R = 0.704$ ;  $p = 0.001$ ). MDS plots show similar directions of assemblage change over time at all sites (Figure 22). From July 2004 to July 2007, species richness increased by 325% and overall abundance increased by 446% (Figures 9 and 10). Only 18 *M. beryllina* were collected during July 2004 but 754 fish were collected during July 2007 (Table 7). This species contributed most to the dissimilarity observed between assemblages collected during July 2004 and July 2007 (17.0%).

Fish assemblages collected in the near shore habitat during 3-4 August 2004 were significantly different than assemblages collected during 8-9 August 2005 (ANOSIM;  $R = 0.263$ ;  $p = 0.013$ ) while near shore fish assemblages collected during 8-9 August 2005 were significantly different than assemblages collected during 25-27 August 2006 (ANOSIM;  $R = 0.132$ ;  $p = 0.058$ ). MDS plots show similar directions of assemblage change over time at all sites (Appendix II). An increase in overall abundance of fishes occurred from August 2004 to August 2005 (82%) and from August 2005 to August 2006 (143%) while species richness also increased (from 14 to 27 species) from August 2004 to August 2005 but remained similar during August 2006 (Figures 9 and 10). An increase in abundance of *E. gula* occurred during all years resulting

Table 6. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during June of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
June 2004 vs. June 2005	0.15	0.023	<i>Lagodon rhomboides</i>	56.56	67.00	26.11
			<i>Eucinostomus gula</i>	0.00	23.44	14.32
			<i>Menidia beryllina</i>	0.44	4.67	8.17
			<i>Mugil cephalus</i>	0.00	3.78	7.81
			<i>Leiostomus xanthurus</i>	2.67	1.22	6.92
June 2005 vs. June 2006	0.251	0.018	<i>Eucinostomus gula</i>	23.44	54.89	17.03
			<i>Lagodon rhomboides</i>	67.00	53.33	12.42
			<i>Bairdiella chrysoura</i>	2.22	11.11	9.01
			<i>Menidia beryllina</i>	4.67	0.22	5.55
			<i>Harengula jaguana</i>	0.00	6.44	5.52

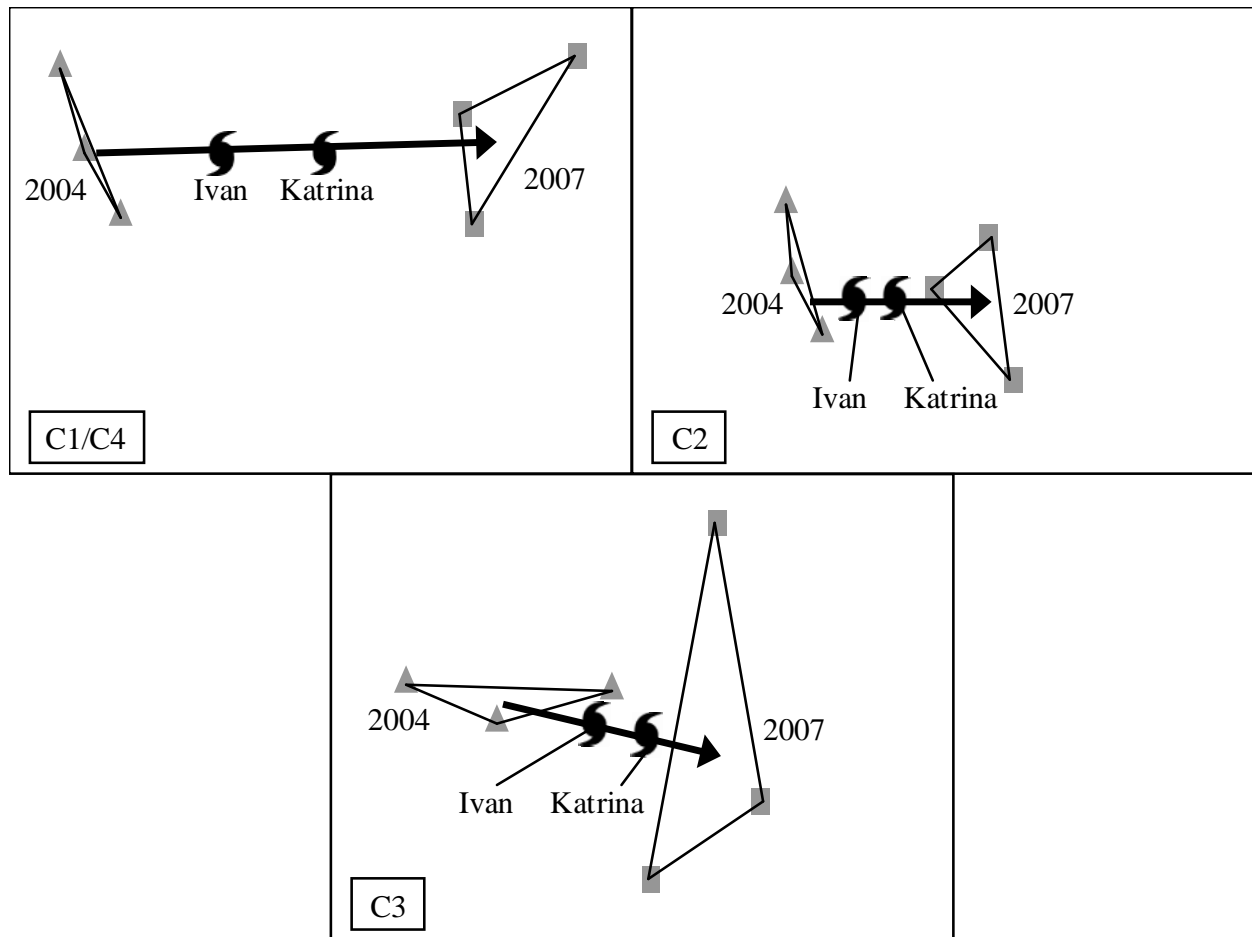


Figure 14. Multidimensional scaling plots of fish assemblages collected at sites C1/C4, C2, and C3 in the near shore habitat during July of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 6-8 July 2004; ■ = 2-3 July 2007. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪. The stress value for all plots is 0.11.

Table 7. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during July of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
July 2004 vs. July 2007	0.704	0.001	<i>Menidia beryllina</i>	2.00	83.78	17.00
			<i>Lagodon rhomboides</i>	81.89	156.56	13.65
			<i>Mugil curema</i>	0.00	69.00	10.26
			<i>Bairdiella chrysoura</i>	0.11	16.67	6.55
			<i>Eucinostomus gula</i>	0.22	18.11	5.86

in a 1,643% increase in abundance of this species from August 2004 to 2006. This species contributed to 15.72% and 15.62% of the dissimilarity between assemblages (Table 8). Near shore fish assemblage collected during 9-10 September 2004 were significantly different than assemblages collected during 15-16 September 2006 (ANOSIM;  $R = 0.466$ ;  $p = 0.001$ ) while near shore assemblages collected during 15-16 September 2006 were significantly different than assemblages collected during 2-3 September 2007 (ANOSIM;  $R = 0.197$ ;  $p = 0.019$ ). MDS plots show similar directions of assemblage change over time at sites C1/C4, C2 and C3 (Figure 15). Species richness increased from September 2004 to September 2006 (from 19 to 24 species) and from September 2006 to September 2007 (from 24 to 29 species) while overall abundance decreased slightly from September 2004 to September 2006 but increased from September 2006 to September 2007 (from 1,318 to 3,357 fish; Figures 9 and 10). *Eucinostomus gula* and *L. rhomboides* contributed to 21.48% and 20.55% of the dissimilarity, respectively, between assemblages collected during September 2004 and September 2006 and 12.07% and 17.76% of the dissimilarity, respectively, between assemblages collected during September 2006 and September 2007 (Table 9).

Sampling stations per site were initially chosen to similarly represent the three habitat types, although I found that microhabitat differences did exist resulting in assemblage differences among sites. Because of this, fish assemblages per site in each habitat type were not compared within each month (per sampling trip) but were compared within periods. During the pre Hurricane Ivan period (from October 2003 to September 2004) fish assemblages collected in the near shore habitat at site C1 were significantly different than assemblages collected at sites C2 (ANOSIM;  $R = 0.08$ ;  $p = 0.01$ ) and site C3 (ANOSIM;  $R = 0.077$ ;  $p = 0.011$ ) while fish assemblages collected at sites C2 and C3 during this period were not significantly different

Table 8. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during August of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
August 2004 vs. August 2005	0.263	0.013	<i>Eucinostomus gula</i>	5.11	28.56	15.73
			<i>Lagodon rhomboides</i>	38.33	34.78	13.96
			<i>Menidia beryllina</i>	1.56	19.78	11.84
			<i>Bairdiella chrysoura</i>	0.00	3.89	7.47
			<i>Fundulus similis</i>	0.89	2.67	5.45
August 2005 vs. August 2006	0.132	0.058	<i>Eucinostomus gula</i>	28.56	84.00	15.62
			<i>Menidia beryllina</i>	19.78	68.78	15.36
			<i>Lagodon rhomboides</i>	34.78	36.67	8.19
			<i>Harengula jaguana</i>	0.22	26.11	7.93
			<i>Bairdiella chrysoura</i>	3.89	9.44	6.95

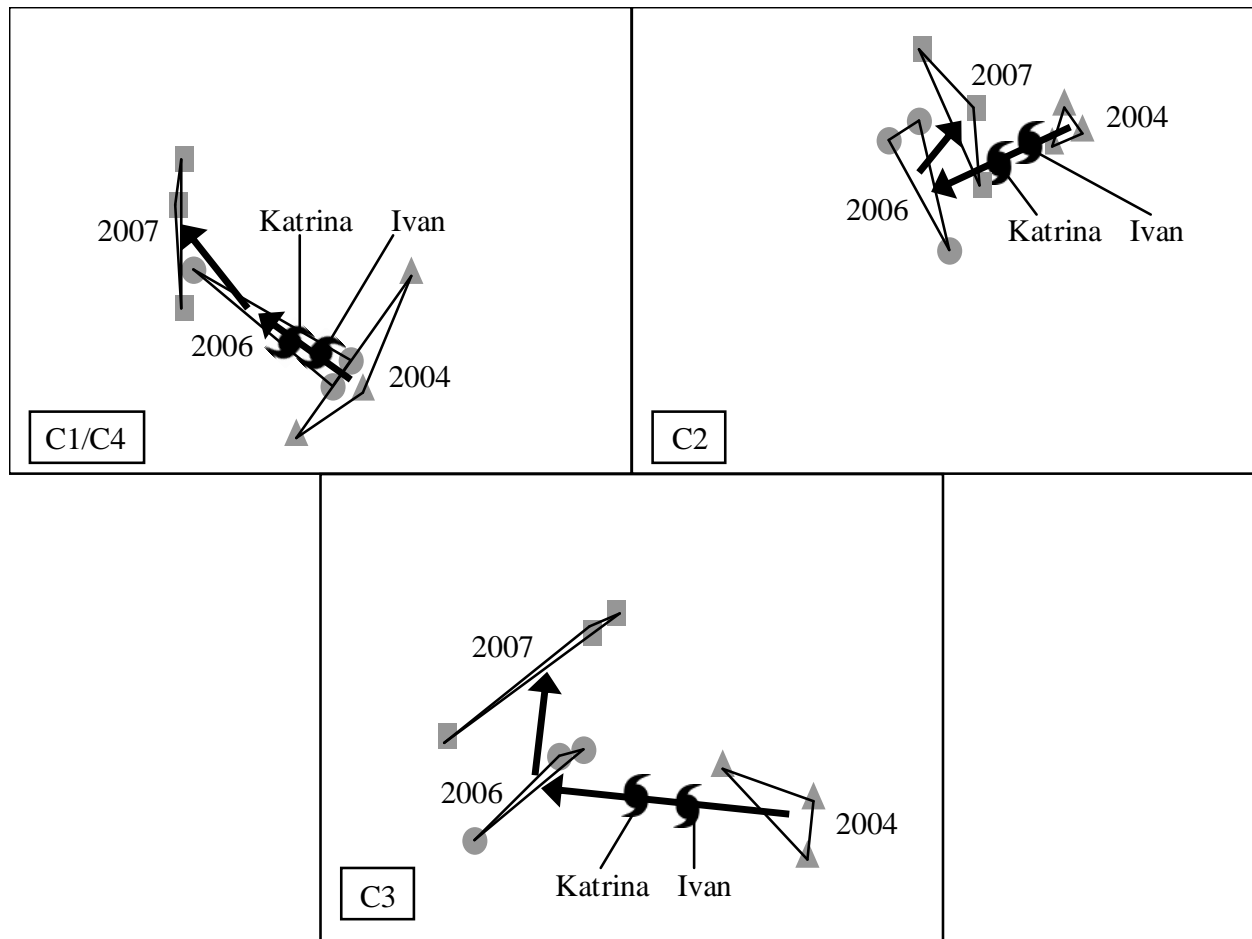


Figure 15. Multidimensional scaling plot of fish assemblages collected at sites C1/C4, C2 and C3 in the near shore habitat during September of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made:  $\blacktriangle$  = 9-10 Sep 2004;  $\bullet$  = 15-16 Sep 2006;  $\blacksquare$  = 2-3 Sep 2007. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by  $\bullet$ . The stress value for all plots is 0.18.

Table 9. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the near shore habitat during September of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
September 2004 vs. September 2006	0.466	0.001	<i>Eucinostomus gula</i>	5.78	69.44	21.48
			<i>Lagodon rhomboides</i>	123.78	41.00	20.55
			<i>Lutjanus griseus</i>	0.00	11.33	11.10
			<i>Menidia beryllina</i>	5.00	3.22	6.86
			<i>Bairdiella chrysoura</i>	0.67	4.22	6.09
September 2006 vs. September 2007	0.543	0.001	<i>Lagodon rhomboides</i>	41.00	199.44	17.76
			<i>Eucinostomus gula</i>	69.44	75.56	12.07
			<i>Harengula jaguana</i>	0.56	33.67	9.66
			<i>Fundulus similis</i>	5.67	15.67	7.36
			<i>Menidia beryllina</i>	3.22	6.78	5.31



(ANOSIM;  $R = 0.013$ ;  $p = 0.171$ ). *Lagodon rhomboides* comprised 60% of all fishes collected during this period and contributed most to the dissimilarity between sites C1 and C2 (29.54%) and sites C1 and C3 (23.24%). In the near shore habitat during this period, 350 *L. rhomboides* were collected at site C1 while 1,016 and 2,048 specimens were collected at sites C3 and C2, respectively. *Eucinostomus gula* was the second greatest contributor to the dissimilarity between sites C1 and C3 (11.20%) and fourth between sites C1 and C2 (8.02%). At site C1, 124 specimens of this species were collected while 54 and 39 were collected at sites C3 and C2, respectively. *Leiostomus xanthurus* was the third greatest contributor to the dissimilarity between assemblages at sites C1 and C2 (11.18% and 9.06%). This species was most abundant at site C3 (315 fish) but only 79 and 76 specimens were collected at sites C2 and C1, respectively.

From November 2004 to August 2005 (post Hurricane Ivan period) there were no significant differences between near shore fish assemblages collected at sites C2 and C3 (ANOSIM;  $R = 0.03$ ;  $p = 0.136$ ) and sites C1 and C3 (ANOSIM;  $R = 0.038$ ;  $p = 0.098$ ) while there were significant differences between fish assemblages collected at sites C1 and C2 (ANOSIM;  $R = 0.139$ ;  $p = 0.003$ ). Specimens of *L. rhomboides* (which comprised 54% of all fishes collected in the near shore habitat during this period) were collected in greatest abundance at site C1 (1,020 specimens). At site C2, this species was also collected in high abundance (949 specimens) but it was collected less at site C3 (526 specimens). *Lagodon rhomboides* contributed most to the dissimilarity between sites C1 and C2 (23.72 %) while *M. beryllina* was the second greatest contributor (10.36%). In addition, the greatest abundance of *L. rhomboides*, *M. beryllina*, *E. gula*, and longnose killifish (*Fundulus similis*) were collected at site C1.

From May 2006 to September 2006 (immediate post Hurricane Katrina period) there were no significant differences between fish assemblages collected in the near shore habitat at sites C2 and C3 (ANOSIM;  $R = 0.091$ ;  $p = 0.076$ ) and sites C3 and C4 (ANOSIM;  $R = 0.091$ ;  $p = 0.076$ ) while there were significant differences between assemblages at sites C2 and C4 (ANOSIM;  $R = 0.263$ ;  $p = 0.006$ ). Specimens of *E. gula* were collected 989 times at site C4 and 140 times at site C2 contributing to 17.36% of the dissimilarity between those sites. *Lagodon rhomboides* was collected 1,299 times at site C2 and 351 times at site C4 contributing to 14.5% of the dissimilarity. No *M. beryllina* were collected at site C4 and contributed to 9.66% of the dissimilarity but in contrast the scaled sardine (*Harengula jaguana*) was collected in greatest abundance at site C4 and contributed to 9.66% of the dissimilarity.

There were also significant differences between the assemblages collected in the near shore habitat from May 2007 to May 2008 at sites C2 and C3 (ANOSIM;  $R = 0.136$ ;  $p = 0.01$ ), sites C2 and C4 (ANOSIM;  $R = 0.489$ ;  $p = 0.001$ ), and sites C3 and C4 (ANOSIM;  $R = 0.198$ ;  $p = 0.013$ ). Over 4,300 *L. rhomboides* were collected at site C2 during this period while 1,493 were collected at site C3 and 522 were collected at site C4. This species contributed most to the dissimilarity between assemblages collected at sites C2 and C3 (22.87%) and sites C2 and C4 (20.08%) but was second between assemblages at sites C3 and C4 (10.73%). *Eucinostomus gula* was collected 471 times at site C4 but only 150 and 222 times at sites C2 and C3, respectively, while *L. xanthurus* was also collected in greatest abundance at site C4 (375 specimens) compared to 171 and 197 specimens collected at sites C2 and C3, respectively.

### *Fish assemblage comparisons: the demersal seagrass habitat*

During this survey 17,839 fishes comprising 61 species from 31 families were collected in the demersal seagrass habitat while 13 of these taxa were unique to this habitat type (Appendix I). However, for 9 species of these unique taxa only one or two specimens were collected each. *Lagodon rhomboides* comprised 52% of fishes collected in the demersal seagrass habitat while 18% of the total assemblage was *E. gula*. Other species commonly collected in the demersal seagrass habitat were *B. chrysoura* (7.4% of total assemblage), striped anchovy (*Anchoa hepsetus*; 7.2%), and bay anchovy (*Anchoa mitchilli*; 4.8%).

Fish assemblages collected in the demersal seagrass habitat during 10-12 November 2003 and 8-9 November 2004 were significantly different (ANOSIM;  $R = 0.455$ ;  $p = 0.004$ ) although it is important to note that all replicates at site C1 during November 2004 contained no fishes. MDS plots show similar directions of assemblage change over time at sites C2 and C3 (Appendix II). *Lagodon rhomboides* which increased in abundance from November 2003 to November 2004 (from 73 to 671 specimens) contributed to 37.98% of the dissimilarity between those assemblages (Table 10). During November 2003, the greatest abundance of *L. rhomboides* was collected at site C2 (93%) but during November 2004, 79% of this species was collected at site C3. *Anchoa mitchilli* was absent from collections during November 2003 but was collected during November 2004 (99 specimens). Demersal fish assemblages collected during 14-16 October 2003 and 8-9 November 2004 were not significantly different (ANOSIM;  $R = 0.078$ ;  $p = 0.187$ ).

Fish assemblages collected in the demersal seagrass habitat during 13-15 January 2004 and 5-7 January 2005 were significantly different (ANOSIM;  $R = 0.938$ ;  $p = 0.028$ ). During January 2004 two collections from site C1/C4, two collections from site C2, and one collection

Table 10. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the demersal seagrass habitat during November of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R-value</u>	<u>p-value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
November 2003 vs. November 2004	0.455	0.004	<i>Lagodon rhomboides</i>	8.11	111.83	37.98
			<i>Eucinostomus gula</i>	8.33	0.00	11.62
			<i>Anchoa mitchilli</i>	0.00	16.50	10.91
			<i>Chloroscombrus chrysurus</i>	3.00	2.33	8.32
			<i>Anchoa hepsetus</i>	1.67	2.17	7.02

from site C3 appeared as outliers and were removed prior to analysis. Additionally, during January 2004, one collection each from sites C1 and C2 contained no fishes and the same occurred during January 2005 for two collections from site C1/C4. In the demersal seagrass habitat, low species richness was observed during January but the collection of 234 *A. mitchilli* contributed to an increase in overall abundance during this time (Figure 10). *Anchoa mitchilli* and *L. rhomboides* were absent during January 2004 but were collected during January 2005 contributing first and second, respectively, to the dissimilarity between those assemblages (Table 11).

Fish assemblages collected in the demersal seagrass habitat during 23-24 March 2005 were not significantly different than assemblages collected during 6-7 March 2004 (ANOSIM;  $R = -0.038$ ;  $p = 0.46$ ) or 28-29 March 2004 (ANOSIM;  $R = 0.203$ ;  $p = 0.151$ ). Also, there were no significant differences between demersal assemblages collected during 6-7 March 2004 and 11-12 February 2005 (ANOSIM;  $R = 0.032$ ;  $p = 0.328$ ), 28-29 March 2004 and 11-12 February 2005 (ANOSIM;  $R = -0.008$ ;  $p = .437$ ), 6-7 March 2004 and 14-15 April 2005 (ANOSIM;  $R = 0.092$ ;  $p = 0.246$ ), or during 28-29 March 2004 and 14-15 April 2005 (ANOSIM;  $R = -0.022$ ;  $p = 0.532$ ). Fish assemblages collected in the demersal seagrass habitat during 6-8 April 2004 and 14-15 April 2005 (ANOSIM;  $R = 0.135$ ;  $p = 0.136$ ) were also not significantly different.

Significant differences did not exist between fish assemblages collected in the demersal seagrass habitat during 10-12 May 2004 and 18-19 May 2005 (ANOSIM;  $R = 0.096$ ;  $p = 0.158$ ), 18-19 May 2005 and 15-17 May 2006 (ANOSIM;  $R = 0.005$ ;  $p = 0.377$ ), and 21-22 May 2007 and 24-26 May 2008 (ANOSIM;  $R = -0.022$ ;  $p = 0.503$ ). There were, however, significant differences between demersal fish assemblages collected during 15-17 May 2006 and 21-22 May 2007 (ANOSIM;  $R = 0.44$ ;  $p = 0.024$ ). At site C1/C4, no collections were made during May 2006

Table 11. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the demersal seagrass habitat during January of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
January 2004 vs. January 2005	0.938	0.028	<i>Anchoa mitchilli</i>	0.00	33.43	39.59
			<i>Lagodon rhomboides</i>	0.00	5.57	18.38
			<i>Chilomycterus schoepfi</i>	1.00	0.14	12.06
			<i>Citharichthys spilopterus</i>	0.50	0.00	7.10
			<i>Dasyatis sabina</i>	0.00	0.57	6.41

and one replicate from May 2007 appeared an outlier and was removed. At site C2, one collection attempt from May 2006 produced no fish while another from May 2007 appeared an outlier and was removed from further analysis. Additionally, at site C3, two collection attempts from May 2007 produced no fish. MDS plots of these assemblages suggest cyclicity in the temporal assemblage change and similar directions of assemblage change at all sites (Figures 16, 17, and 18). From May 2004 to May 2005, species richness increased slightly but then decreased until May 2007 before increasing during May 2008 (Figure 9). Overall abundance was greatest during May 2004 (2,334 fishes) but decreased by 82% during May 2005 and remained low through 2008 (Figure 10). During May 2004, greater than 94% of all fishes captured were *L. rhomboides* although this species decreased in abundance from May 2004 to May 2008. This species contributed most to the dissimilarity between assemblages collected during May 2006 and May 2007 assemblages (53.01%; Table 12). During May 2004 greater than 96% of *L. rhomboides* were collected at site C3 while none were collected at site C1. During May 2005, however, greater than 99% of this species was collected at site C2. During May 2006, *L. rhomboides* was collected only at site C3 but during May 2007, only 60% of this species was collected at site C3 and during May 2008 only 3.1% was collected there. Fish assemblages collected in the demersal seagrass habitat during 8-10 June 2004 were not significantly different than assemblages collected during 16-17 June 2005 (ANOSIM;  $R = -0.134$ ;  $p = 0.848$ ) and demersal fish assemblages collected during 16-17 June 2005 were not significantly different than assemblages collected during 18-20 June 2006 (ANOSIM;  $R = 0.132$ ;  $p = 0.099$ ).

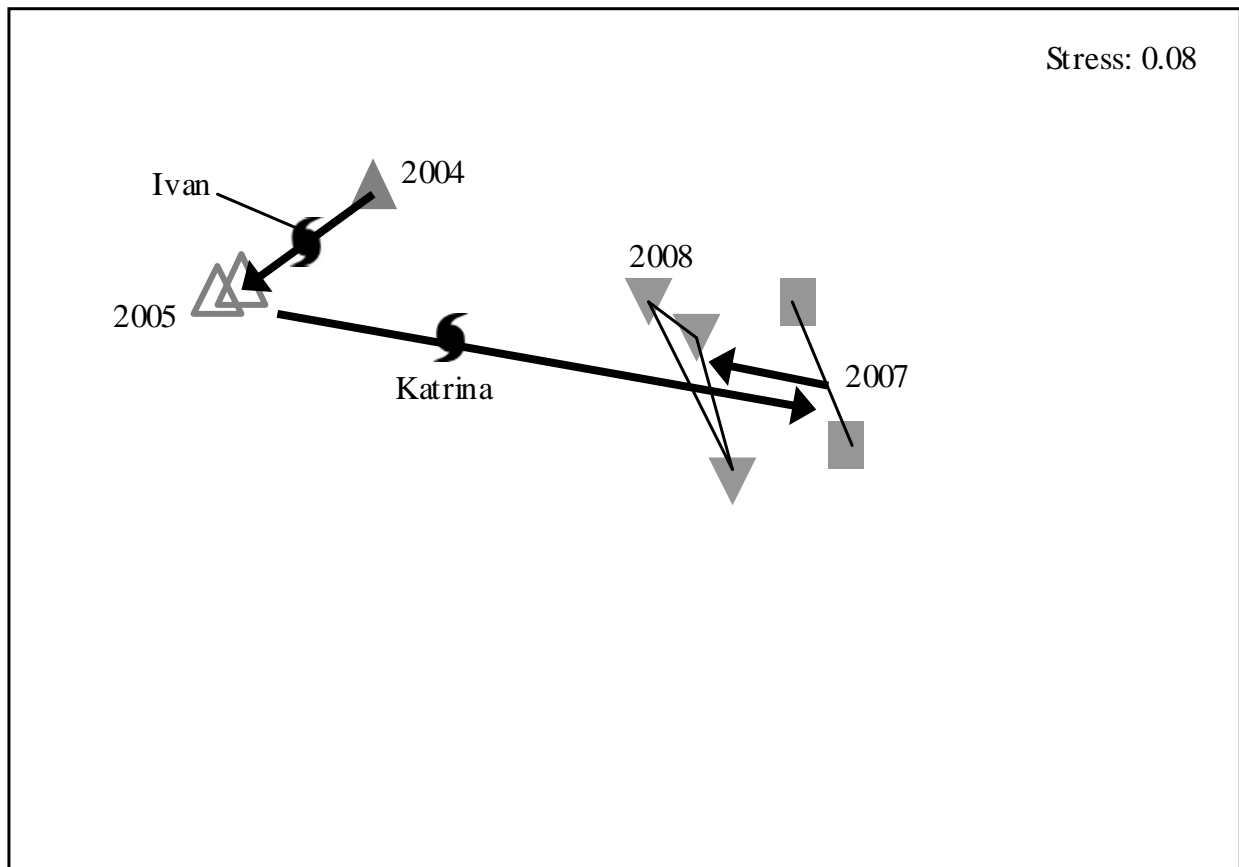


Figure 16. Multidimensional scaling plot of fish assemblages collected at site C1/C4 in the demersal seagrass habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; △ = 18-19 May 2005; ■ = 21-22 May 2007; ▼ = 24-26 May 2008. Two replicates from May 2004 and one replicate from May 2005 were empty. No collections were made during May 2006. One replicate from May 2007 appeared an outlier and was removed. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.



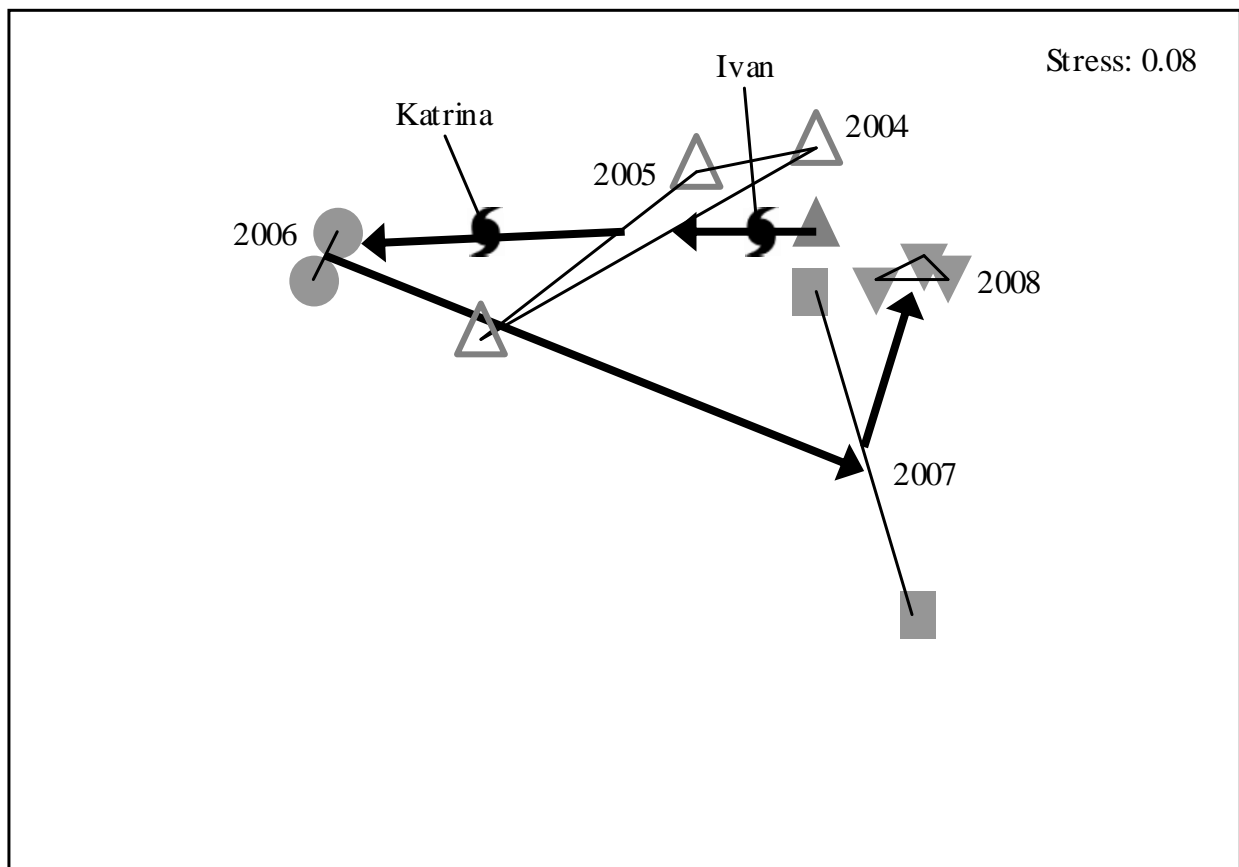


Figure 17. Multidimensional scaling plot of fish assemblages collected at site C2 in the demersal seagrass habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; △ = 18-19 May 2005; ● = 15-17 May 2006; ■ = 21-22 May 2007; ▼ = 24-26 May 2008. One replicate from May 2004 was empty while another appeared an outlier and was removed. One replicate from May 2006 was empty while one replicate from May 2007 appeared an outlier and was removed. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

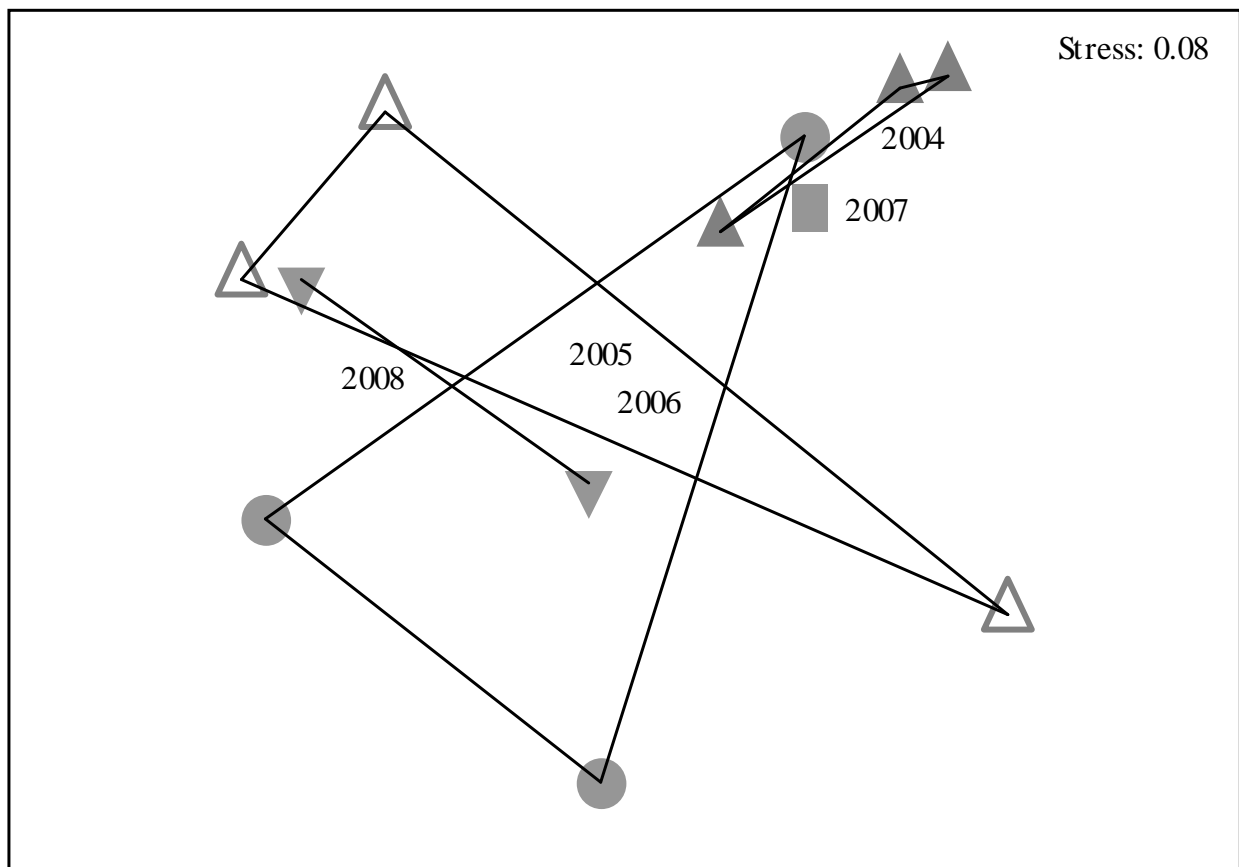


Figure 18. Multidimensional scaling plot of fish assemblages collected at site C3 in the demersal seagrass habitat during May of different years. Symbols represent dates collections were made: ▲ = 10-12 May 2004; △ = 18-19 May 2005; ● = 15-17 May 2006; ■ = 21-22 May 2007; ▼ = 24-26 May 2008. Two replicates from May 2007 and one replicate from May 2008 were empty. Hurricane Ivan made landfall on 16 September 2004 and Hurricane Katrina made landfall on 29 August 2005.

Table 12. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the demersal seagrass habitat during May of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
May 2004 vs. May 2005	0.096	0.158	<i>Lagodon rhomboides</i>	440.60	36.88	56.69
			<i>Chloroscombrus chrysurus</i>	2.40	13.75	16.58
			<i>Orthopristis chrysoptera</i>	14.20	0.75	10.61
			<i>Leiostomus xanthurus</i>	8.00	0.13	8.78
May 2005 vs. May 2006	0.005	0.377	<i>Lagodon rhomboides</i>	36.88	39.20	30.51
			<i>Chloroscombrus chrysurus</i>	13.75	1.80	30.05
			<i>Selene setapinnis</i>	0.00	2.60	9.55
			<i>Anchoa hepsetus</i>	0.00	0.40	8.35
			<i>Orthopristis chrysoptera</i>	0.75	1.20	4.28
May 2006 vs. May 2007	0.44	0.024	<i>Lagodon rhomboides</i>	39.20	43.40	53.01
			<i>Chloroscombrus chrysurus</i>	1.80	0.00	14.98
			<i>Orthopristis chrysoptera</i>	1.20	5.80	12.53
			<i>Selene setapinnis</i>	2.60	0.00	7.06
			<i>Anchoa hepsetus</i>	0.40	0.00	5.33
May 2007 vs. May 2008	- .022	0.503	<i>Lagodon rhomboides</i>	43.40	20.25	37.33
			<i>Orthopristis chrysoptera</i>	5.80	7.63	18.65
			<i>Leiostomus xanthurus</i>	0.20	4.88	11.63
			<i>Chloroscombrus chrysurus</i>	0.00	1.00	10.73
			<i>Anchoa hepsetus</i>	0.00	3.63	10.73

Fish assemblages collected in the demersal seagrass habitat during 3-4 August 2004 and 8-9 August 2005 were significantly different (ANOSIM;  $R = 0.376$ ;  $p = 0.002$ ) and between 8-9 August 2005 and 25-27 August 2006 (ANOSIM;  $R = 0.127$ ;  $p = 0.036$ ). MDS plots suggest some cyclicity in assemblage changes at all sites (Appendix II). From August 2004 to August 2005, species richness increased but then decreased during August 2006 while overall abundance remained similar from May 2004 to May 2005 but increased during August 2006 (Figures 9 and 10). From August 2004 to August 2005, *E. gula* increased in abundance (from 114 to 935 fish) and contributed to 47.51% of the dissimilarity between those assemblages but decreased in abundance during August 2006 (614 fish) contributing to 43.48% of the dissimilarity between the assemblages collected during August 2005 and August 2006 (Table 13). Fish assemblages collected in the demersal seagrass habitat were not significantly different between 9-10 September 2004 and 15-16 September 2006 (ANOSIM;  $R = 0.118$ ;  $p = 0.087$ ) and between 15-16 September 2006 and 2-3 September 2007 (ANOSIM;  $R = 0.015$ ;  $p = 0.343$ ).

From October 2003 to September 2004 (pre impact period) there were no significant differences between fish assemblages collected in the demersal seagrass habitat at sites C2 and C3 (ANOSIM;  $R = -0.031$ ;  $p = 0.774$ ) and sites C1 and C3 (ANOSIM;  $R = 0.036$ ;  $p = 0.189$ ) but there were significant differences between fish assemblages collected at sites C1 and C2 (ANOSIM;  $R = 0.234$ ;  $p = 0.001$ ). *Lagodon rhomboides* and *E. gula* were collected in greatest abundance at sites C2 and contributed to 56.71% of the dissimilarity between sites C1 and C2. From November 2004 to August 2005 (post Hurricane Ivan period) there were significant differences between assemblages collected at sites C1 and C2 (ANOSIM;  $R = 0.126$ ;  $p = 0.025$ ) and sites C1 to C3 (ANOSIM;  $R = 0.101$ ;  $p = 0.038$ ) but there were no significant differences between assemblages at sites C2 and C3 (ANOSIM;  $R = -0.003$ ;  $p = 0.477$ ). With the exception

Table 13. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the demersal seagrass habitat during August of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
August 2004 vs. August 2005	0.376	0.002	<i>Eucinostomus gula</i>	16.29	103.67	47.51
			<i>Chloroscombrus chrysurus</i>	0.71	11.00	19.02
			<i>Lagodon rhomboides</i>	34.43	0.89	13.32
			<i>Anchoa hepsetus</i>	0.14	26.78	9.25
			<i>Bairdiella chrysoura</i>	0.29	0.33	1.78
August 2005 vs. August 2006	0.127	0.036	<i>Eucinostomus gula</i>	103.67	68.22	43.48
			<i>Chloroscombrus chrysurus</i>	11.00	0.89	19.25
			<i>Anchoa hepsetus</i>	26.78	2.89	12.99
			<i>Lagodon rhomboides</i>	0.89	1.22	5.92
			<i>Ariopsis felis</i>	0.00	1.22	4.79

of two species, *M. beryllina* and Gulf butterfish (*Peprilus burti*), site C1 had the lowest abundance of all other species. From May 2006 to September 2006 (immediate post Hurricane Katrina period) there were no significant differences between the assemblages collected at sites C2 and C3 (ANOSIM;  $R = 0.027$ ;  $p = 0.302$ ), sites C2 and C4 (ANOSIM;  $R = 0.071$ ;  $p = 0.164$ ), or sites C3 and C4 (ANOSIM;  $R = -0.013$ ;  $p = 0.541$ ) and from May 2007 to May 2008 there were no significant differences between the assemblages at sites C2 and C3 (ANOSIM;  $R = 0.095$ ;  $p = 0.10$ ), sites C2 and C4 (ANOSIM;  $R = 0.062$ ;  $p = 0.116$ ), or sites C3 and C4 (ANOSIM;  $R = -0.068$ ;  $p = 0.876$ ).

#### *Fish assemblage comparisons: the deep intertidal seagrass habitat*

During this survey 2,395 fishes comprising 36 species from 20 families were collected in the deep intertidal seagrass habitat while eight of these species were unique to this habitat type (Appendix I). Hardhead catfish (*Ariopsis felis*) which comprised 26.5% of fishes collected in the deep intertidal habitat was the most abundant species for this habitat type. In addition to *A. felis*, other species that comprised the five most abundant fishes were *L. xanthurus* (15.6% of total assemblage), *L. rhomboides* (14.6%), Atlantic thread herring (*Opisthonema oglinum*; 9.2%), and *H. jaguana* (6.2%).

Fish assemblages collected in the deep intertidal seagrass habitat during 10-12 November 2003 and 8-9 November 2004 were not significantly different (ANOSIM;  $R = 0.043$ ;  $p = 0.44$ ). Deep intertidal habitat fish assemblages collected during 23-24 March 2005 were also not significantly different than the assemblages collected during 6-7 March 2004 (ANOSIM;  $R = -0.097$ ;  $p = 0.796$ ) or 28-29 March 2004 (ANOSIM;  $R = 0.069$ ;  $p = 0.255$ ). Fish assemblages

collected in the deep intertidal seagrass habitat during 6-8 April 2004 and 14-15 April 2005 were also not significantly different (ANOSIM;  $R = -0.051$ ;  $p = 0.74$ ).

Fish assemblages collected in the deep intertidal seagrass habitat during 10-12 May 2004 were significantly different than assemblages collected during 18-19 May 2005 (ANOSIM;  $R = 0.576$ ;  $p = 0.001$ ), 15-17 May 2006 (ANOSIM;  $R = 0.213$ ;  $p = 0.027$ ), 21-22 May 2007 (ANOSIM;  $R = 0.191$ ;  $p = 0.03$ ), and 24-26 May 2008 (ANOSIM;  $R = 0.381$ ;  $p = 0.001$ ). Deep intertidal fish assemblages collected during 18-19 May 2005 were significantly different than assemblages collected during 15-17 May 2006 (ANOSIM;  $R = 0.356$ ;  $p = 0.007$ ) while deep intertidal fish assemblages collected during 15-17 May 2006 were not significantly different than assemblages collected during 21-22 May 2007 (ANOSIM;  $R = 0.149$ ;  $p = 0.058$ ). Additionally, there were significant differences between intertidal fish assemblages collected during 21-22 May 2007 and 24-26 May 2008 (ANOSIM;  $R = 0.339$ ;  $p = 0.004$ ). At site C1/C4 two collection attempts during May 2005, one during May 2006, and one during May 2008 produced no fishes while one collection during May 2006 appeared an outlier and was removed from further analysis. MDS plots show similar directions of assemblage change and suggest cyclicity in assemblage change at all sites (Figures 19, 20, and 21). From May 2004 to May 2005, species richness in the deep intertidal seagrass habitat remained similar (typically about 8 species) but decreased during May 2006 (5 species) before increasing during May 2007 and May 2008 (8 and 11 species, respectively; Figure 9). Overall abundance in the deep intertidal seagrass habitat decreased by 42% from May 2004 to May 2005 (from 66 to 36 fishes) and remained similar through May 2007 but increased 336% during May 2008 (144 fishes; Figure 22). *Ariopsis felis* contributed most to the dissimilarity between assemblages collected during May 2004 and May 2005 (30.38%) and between May 2007 and May 2008 (34.4%; Table 14). This species

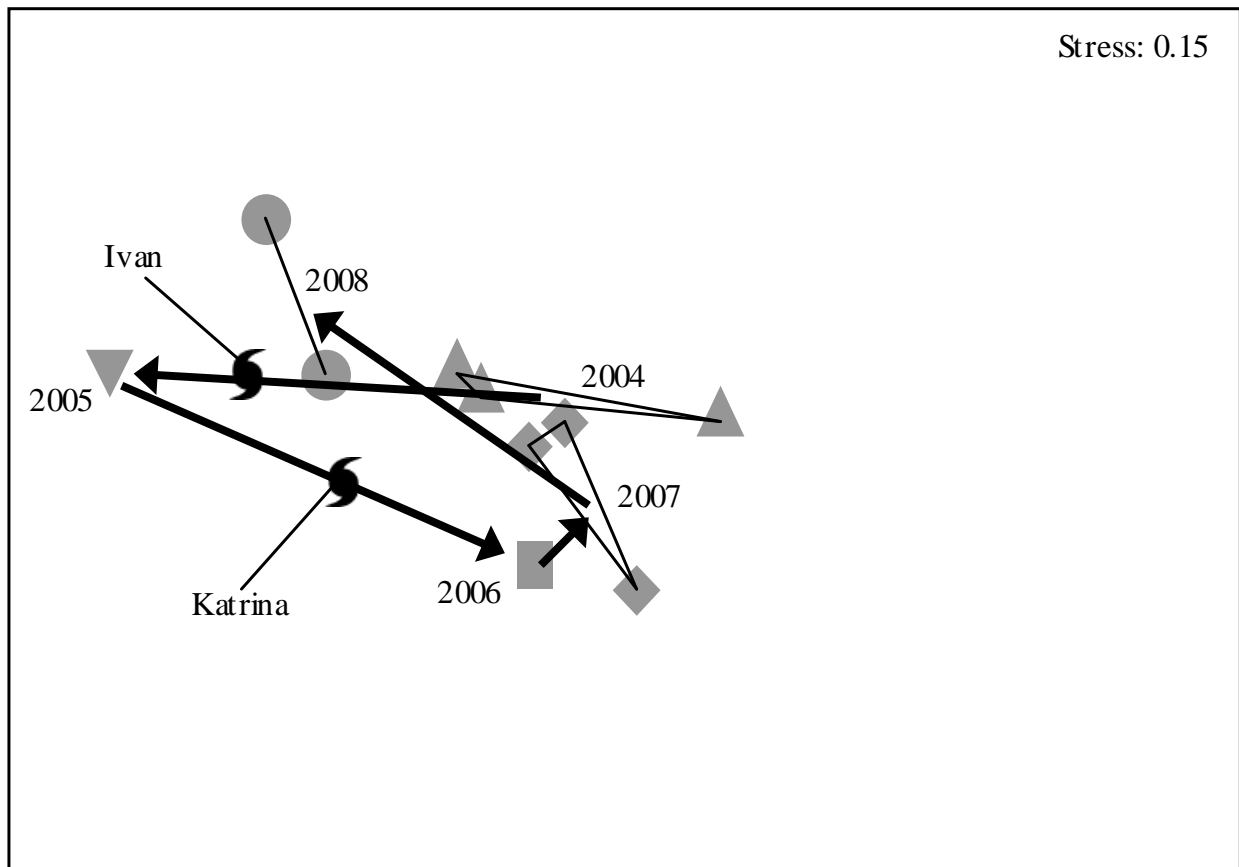


Figure 19. Multidimensional scaling plot of fish assemblages collected at site C1/C4 in the deep intertidal seagrass habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. Two replicates in May 2005, one replicate in May 2006, and one replicate in May 2008 were empty while one replicate in May 2006 appeared an outlier and was removed. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.



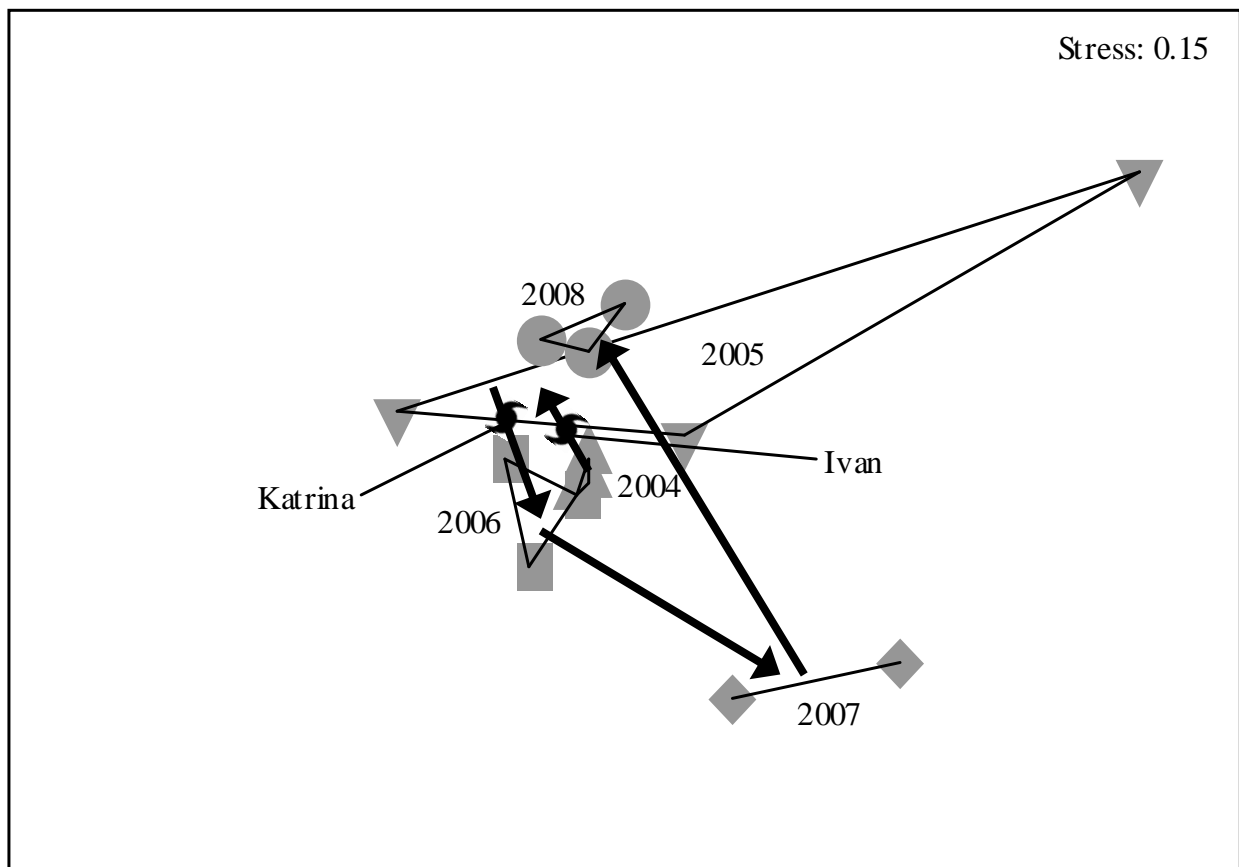


Figure 20. Multidimensional scaling plot of fish assemblages collected at site C2 in the deep intertidal seagrass habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. One replicate in May 2007 was empty. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ●.

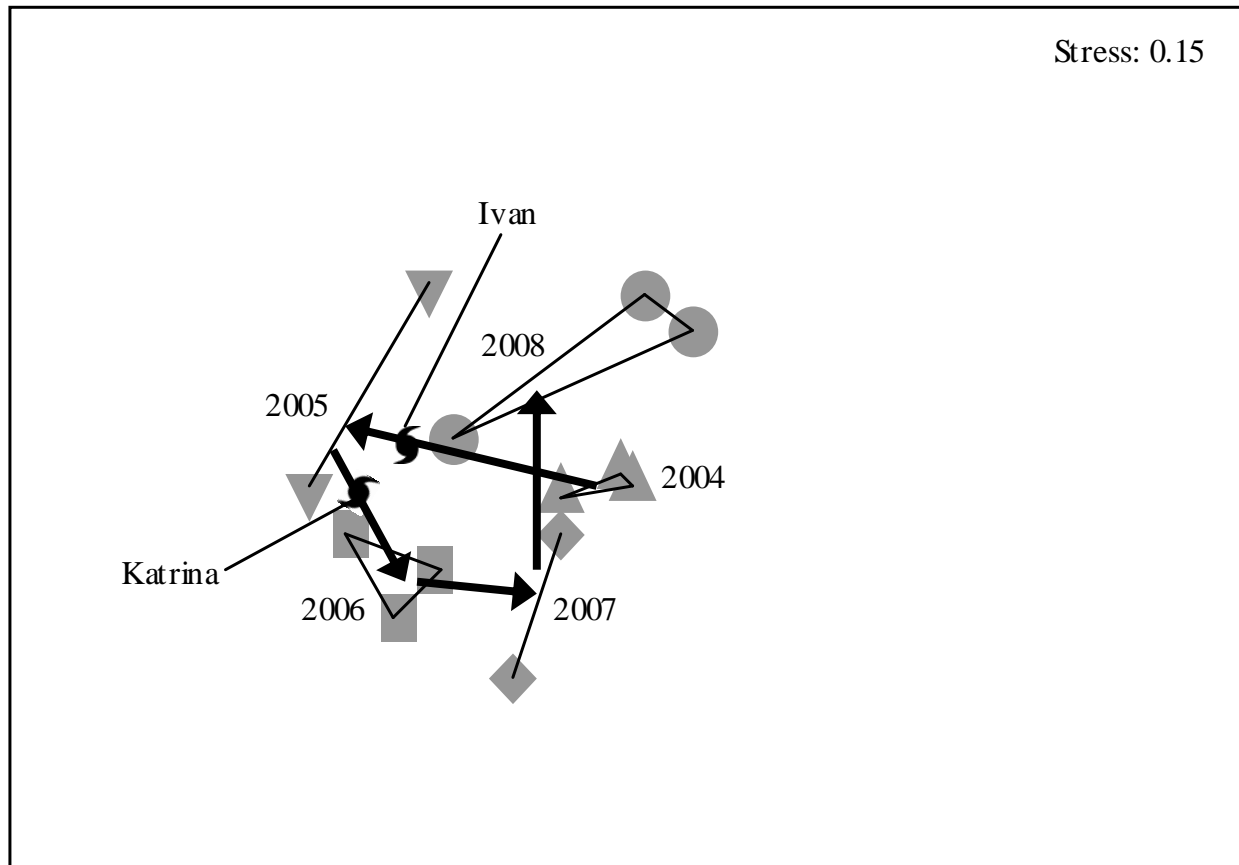


Figure 21. Multidimensional scaling plot of fish assemblages collected at site C3 in the deep intertidal seagrass habitat during May of different years. The arrows show direction of assemblage change over time. Symbols represent dates collections were made: ▲ = 10-12 May 2004; ▼ = 18-19 May 2005; ■ = 15-17 May 2006; ◆ = 21-22 May 2007; ● = 24-26 May 2008. One replicate in May 2005 and another in May 2007 were empty. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

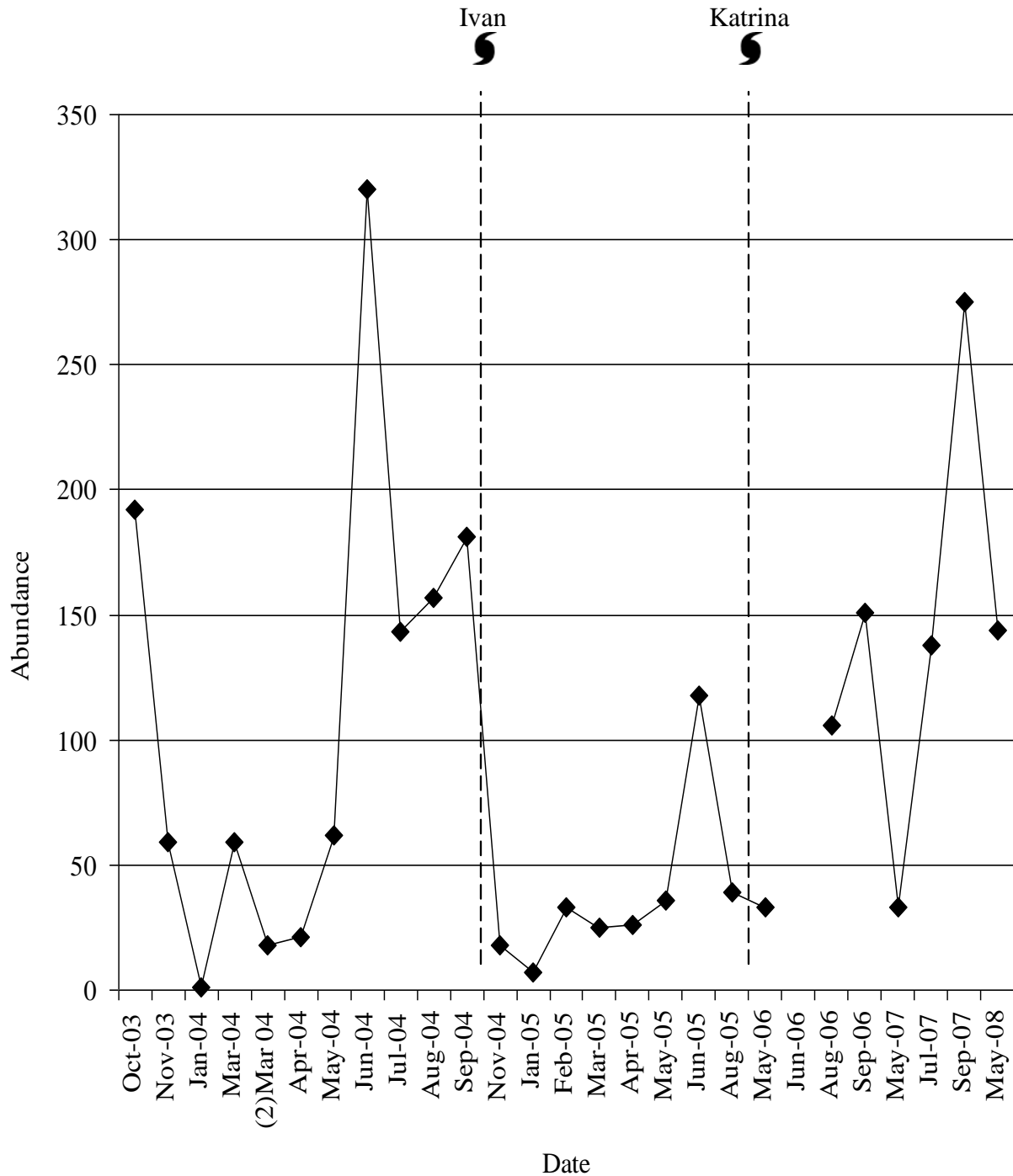


Figure 22. Species abundance from the deep intertidal seagrass habitat sampled from October 2003 to May 2008 at the Chandeleur Islands. Species abundance was calculated as the sum of abundances from all three sampling stations for that sampling period. June 2006 littoral seagrass habitat samples are not available. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by ☪.

Table 14. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the deep intertidal seagrass habitat during May of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
May 2004 vs. May 2005	0.576	0.001	<i>Ariopsis felis</i>	5.56	1.83	30.38
			<i>Oligoplites saurus</i>	0.00	1.83	21.66
			<i>Rhinoptera bonasus</i>	0.11	0.50	9.35
			<i>Lagodon rhomboides</i>	0.22	0.67	8.48
			<i>Sphyrna lewini</i>	0.00	0.33	7.17
May 2005 vs. May 2006	0.356	0.007	<i>Oligoplites saurus</i>	1.83	0.13	24.16
			<i>Ariopsis felis</i>	1.83	2.50	23.44
			<i>Chloroscombrus chrysurus</i>	0.17	1.13	14.03
			<i>Rhinoptera bonasus</i>	0.50	0.00	10.21
			<i>Lagodon rhomboides</i>	0.67	0.25	8.86
May 2006 vs. May 2007	0.149	0.058	<i>Ariopsis felis</i>	2.50	2.57	26.41
			<i>Chloroscombrus chrysurus</i>	1.13	0.00	16.22
			<i>Sphyrna tiburo</i>	0.00	0.43	11.70
			<i>Cynoscion nebulosus</i>	0.00	0.43	11.29
			<i>Lagodon rhomboides</i>	0.25	0.29	9.99
May 2007 vs. May 2008	0.339	0.004	<i>Ariopsis felis</i>	2.57	13.63	34.40
			<i>Harengula jaguana</i>	0.00	1.88	9.08
			<i>Lagodon rhomboides</i>	0.29	0.63	8.82
			<i>Oligoplites saurus</i>	0.00	0.38	6.36
			<i>Rhizoprionodon terraenovae</i>	0.00	0.50	6.17

decreased in abundance from May 2004 to May 2005 (from 50 to 11 fish) and remained low until May 2008 when 109 fish were collected. Additionally, the leatherjacket (*Oligoplites saurus*) was second in contribution to the dissimilarity between assemblages collected during May 2004 and May 2005 (21.66%) and during May 2005 and May 2006 (24.16%; Table 14).

Fish assemblages collected in the deep intertidal habitat during 18-19 May 2005 were not significantly different than assemblages collected during 6-7 March 2004 (ANOSIM;  $R = 0.178$ ;  $p = 0.081$ ) or 28-29 March 2004 (ANOSIM;  $R = 0.299$ ;  $p = 0.052$ ). Deep intertidal fish assemblages collected during 8-10 June 2004 and 16-17 June 2005 were also not significantly different (ANOSIM;  $R = 0.113$ ;  $p = 0.075$ ) while no collections were made in deep intertidal habitats during June 2006. Fish assemblages collected in the deep intertidal seagrass habitat during 6-8 July 2004 were not significantly different than assemblages during 2-3 July 2007 (ANOSIM;  $R = 0.116$ ;  $p = 0.097$ ).

Fish assemblages collected in the deep intertidal seagrass habitat during 3-4 August 2004 were significantly different than assemblages collected during 8-9 August 2005 (ANOSIM;  $R = 0.275$ ;  $p = 0.007$ ) while intertidal fish assemblages collected during 8-9 August 2005 were significantly different than assemblages collected during 25-27 August 2006 (ANOSIM;  $R = 0.301$ ;  $p = 0.006$ ). At site C2, one collection attempt during Aug 2005 produced no fishes. MDS plots suggest cyclicity in assemblage change and similar directions of assemblage change at all sites (Appendix II). Species richness and overall abundance in the deep intertidal seagrass habitat decreased from August 2004 to August 2005 before increasing during August 2006 (Figures 9 and 22). *Leiostomus xanthurus* decreased in abundance from August 2004 to August 2005 and contributed most to the dissimilarity between those assemblages (20.92%; Table 15)

Table 15. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the deep intertidal seagrass habitat during August of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
August 2004 vs. August 2005	0.275	0.007	<i>Leiostomus xanthurus</i>	8.78	1.50	20.92
			<i>Ariopsis felis</i>	1.22	2.50	13.11
			<i>Lagodon rhomboides</i>	1.33	0.25	10.93
			<i>Oligoplites saurus</i>	1.44	0.00	8.91
			<i>Scomberomorus maculatus</i>	0.89	0.00	7.93
August 2005 vs. August 2006	0.301	0.006	<i>Lagodon rhomboides</i>	0.25	2.44	17.16
			<i>Ariopsis felis</i>	2.50	3.00	16.60
			<i>Leiostomus xanthurus</i>	1.50	0.78	14.44
			<i>Oligoplites saurus</i>	0.00	1.44	10.84
			<i>Harengula jaguana</i>	0.25	1.00	7.96

while *Lagodon rhomboides* increased in abundance from August 2005 and August 2006 and contributed to the dissimilarity most (17.16%) between those assemblages (Table 15).

Fish assemblages collected in the deep intertidal seagrass habitat during 9-10 September 2004 were not significantly different than assemblages collected during 15-16 September 2006 (ANOSIM;  $R = 0.165$ ;  $p = 0.062$ ) while deep intertidal fish assemblages collected during 15-16 September 2006 were significantly different than assemblages collected during 2-3 September 2007 (ANOSIM;  $R = 0.305$ ;  $p = 0.003$ ). MDS plots show patterns of semi-cyclic assemblage change but similar directions of assemblage change at all sites (Appendix II). Species richness in the deep intertidal seagrass habitat increased by 20% from September 2004 to September 2006 but decreased during September 2007 while overall abundance in the deep intertidal seagrass habitat decreased 20% from September 2004 to September 2006 but increased 82% from September 2006 to September 2007 (Figures 9 and 22). *Leiostomus xanthurus* contributed most to the dissimilarity between intertidal fish assemblages collected during September 2006 and September 2007 (21.08%; Table 16).

There were significant differences between fish assemblages collected in the deep intertidal habitat from October 2003 to September 2004 (pre impact period) at sites C1 and C2 (ANOSIM;  $R = 0.085$ ;  $p = 0.016$ ) and at sites C1 and C3 (ANOSIM;  $R = 0.156$ ;  $p = 0.001$ ) while there were no significant differences between fish assemblages collected at sites C2 and C3 during this period (ANOSIM;  $R = 0.01$ ;  $p = 0.284$ ). From October 2003 to September 2004 *A. felis* contributed most to the dissimilarity between assemblages collected at sites C1 and C2 (16.29%) and sites C1 and C3 (17.18%). From November 2004 to August 2005 (post Hurricane Ivan period) there were significant differences between the deep intertidal fish assemblages collected at sites C1 and C2 (ANOSIM;  $R = 0.122$ ;  $p = 0.02$ ), sites C1 and C3 (ANOSIM;  $R =$

Table 16. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in the deep intertidal seagrass habitat during September of different years. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Time Period Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Month Mean Abundance</u>	<u>2nd Month Mean Abundance</u>	<u>% Contribution</u>
September 2004 vs. September 2006	0.165	0.062	<i>Leiostomus xanthurus</i>	7.89	3.44	16.09
			<i>Orthopristis chrysoptera</i>	5.00	0.00	14.22
			<i>Lagodon rhomboides</i>	3.11	2.11	11.00
			<i>Ariopsis felis</i>	1.44	4.67	9.48
			<i>Opisthonema oglinum</i>	0.00	1.56	7.10
September 2006 vs. September 2007	0.305	0.003	<i>Leiostomus xanthurus</i>	3.44	13.56	21.08
			<i>Cynoscion arenarius</i>	0.33	5.44	11.09
			<i>Ariopsis felis</i>	4.67	2.00	9.62
			<i>Harengula jaguana</i>	1.89	2.44	8.72
			<i>Lagodon rhomboides</i>	2.11	3.00	8.67



0.078;  $p = 0.03$ ), and sites C2 and C3 (ANOSIM;  $R = 0.137$ ;  $p = 0.028$ ). The species contributing most to the dissimilarity between all assemblages during this period was *A. felis* which was collected 68 times at site C2 but only 17 and 21 times at sites C1 and C3, respectively. From May 2006 to September 2006 (the immediate post Hurricane Katrina period) there were no significant differences between the deep intertidal fish assemblages collected at sites C4 and C2 (ANOSIM;  $R = 0.014$ ;  $p = 0.379$ ), sites C4 and C3 (ANOSIM;  $R = 0.1$ ;  $p = 0.132$ ) and sites C2 and C3 (ANOSIM;  $R = 0.09$ ;  $p = 0.108$ ) and from May 2007 to May 2008 there were no significant differences between fish assemblages collected at sites C4 and C2 (ANOSIM;  $R = 0.009$ ;  $p = 0.48$ ), sites C4 and C3 (ANOSIM;  $R = 0.004$ ;  $p = 0.415$ ) and sites C2 and C3 (ANOSIM;  $R = 0.088$ ;  $p = 0.092$ ).

#### *Environmental variables and assemblage change*

Results of BIO-ENV analysis indicate water temperature contributed most to seasonal fish assemblage changes in the near shore habitat and was strongly correlated (Spearman Correlation = 0.413; Table 17). Similarly, water temperature contributed most to seasonal fish assemblage changes in the demersal seagrass habitat but was intermediately correlated (Spearman Correlation = 0.219). While results of the BIO-ENV analysis for the deep intertidal seagrass habitat indicate that, singularly, water temperature contributed strongly to assemblage changes (Spearman Correlation = 0.338), a combination of the factors water temperature and water depth contributed most to assemblage changes (Spearman Correlation = 0.340). The mean water depth for all sites in the deep intertidal seagrass habitat during the survey was 1.93 m while the mean water depth at site C2, the shallowest site, was 1.82 m and the mean depth at site C1/C4, the deepest site, was 2.04 m. Additionally, BIOENV analysis for the near shore habitat

Table 17. Results of BIO-ENV analysis for the near shore habitat which indicate water temperature contributed most to seasonal fish assemblage changes in this habitat type. A strong correlation between water temperature and changes in fish assemblages existed. The five water quality variables measured were water temperature, secchi depth, salinity, specific conductivity, dissolved oxygen.

Number of Variables	Spearman Correlation	Selections
1	0.413	water temperature
2	0.405	water temperature, secchi depth
3	0.403	water temperature, secchi depth, specific conductivity
2	0.401	water temperature, specific conductivity
3	0.398	water temperature, secchi depth, salinity
2	0.394	water temperature, salinity
4	0.385	water temperature, secchi depth, salinity, specific conductivity
3	0.377	water temperature, secchi depth, specific conductivity
4	0.371	water temperature, secchi depth, specific conductivity, dissolved oxygen
4	0.367	water temperature, secchi depth, salinity, dissolved oxygen
1	0.077	dissolved oxygen
1	0.070	specific conductivity
1	0.051	Salinity
1	0.026	secchi depth

per month during the months May through September indicate no distinct driver of assemblage change existed across these months (Table 18). While salinity was correlated strongly with assemblage changes observed in the near shore habitat during July (Spearman Correlation = 0.443), the range of the mean salinity per year was 2.7 ‰. While water temperature was strongly correlated with fish assemblage changes in the near shore habitat during August (Spearman Correlation = 0.431) and September (Spearman Correlation = 0.326), the range in water temperature recorded during August (30.3 to 31.6 °C) and September (30.06 to 32.03 °C) was small.

Table18. Results of BIO-ENV analysis for the near shore habitat per month indicates which factors contributed most to assemblage changes. Additionally, the top singular factor was included if it was not within the top three. The five water quality variables measured were water temperature, salinity, specific conductivity, dissolved oxygen, secchi depth.

Month	Number of Variables	Spearman Correlation	Selections
May	3	0.225	water temperature, secchi depth, dissolved oxygen
	4	0.212	water temperature, secchi depth, salinity, dissolved oxygen
	1	0.148	secchi depth
June	2	0.234	secchi depth, dissolved oxygen
	3	0.233	water temperature, secchi depth, dissolved oxygen
	1	0.193	dissolved oxygen
July	1	0.443	Salinity
	2	0.443	secchi depth, salinity
	2	0.388	salinity, dissolved oxygen
August	1	0.431	water temperature
	2	0.406	water temperature, dissolved oxygen
	3	0.397	water temperature, salinity, dissolved oxygen
September	2	0.360	water temperature, specific conductivity
	3	0.356	water temperature, salinity, specific conductivity
	1	0.326	water temperature

### *Channel and deep intertidal seagrass habitat fish assemblage comparisons*

There were significant differences between fish assemblages collected during July 2007 in channel 1 and channel 2 (ANOSIM;  $R = 0.189$ ;  $p = 0.005$ ), in channel 1 and channel 3 ( $R = 0.309$ ;  $p = 0.001$ ), and in channel 2 and channel 3 (ANOSIM;  $R = 0.166$ ;  $p = 0.004$ ). There were no significant differences between fish assemblages collected during July 2007 in channel 4 and assemblages collected in channel 1 (ANOSIM;  $R = -0.001$ ;  $p = 0.416$ ), channel 2 (ANOSIM;  $R = -0.106$ ;  $p = 0.695$ ), or channel 3 (ANOSIM;  $R = -0.118$ ;  $p = 0.671$ ). The greatest number of collections were made in channel 3 ( $n = 10$  or  $30$  samples) while the least collections were made in channel 4 ( $n = 1$  or  $3$  samples; Table 2). An MDS plot exhibits weak clustering of fish assemblages collected in channels 1, 2, 3, and 4 (Figure 23). Bathymetric profiles showed channel 1, the deepest channel, had a maximum depth of  $4.63$  m and a mean depth of  $3.2$  m while channel 2, the second deepest channel, had a maximum depth of  $3$  m and a mean depth of  $1.6$  m and channel 3, the shallowest channel, had a maximum depth of  $2.35$  m and a mean depth of  $1.54$  m. Additionally, channel 1 had the greatest complexity (i.e., number of habitat types, amount of channel shoreline) while channel 3 was the second most complex and channels 2 and 4 were the least complex (Figure 7). Channel 1 had the largest mean abundance per sample ( $> 15$  fishes) and the greatest species richness (17 species) while Channel 3 had the lowest mean abundance per sample ( $< 5.5$  fishes) but the second greatest species richness (12 species). The assemblage of channel 2 contained 10 species and a mean of  $9.43$  fishes per sample. Channel 4 had a mean abundance of 10 fishes comprising 6 species. The mean dissimilarity between fish assemblages collected in channels 1 and 2 and in channels 1 and 3 were similar (85.49% and 85.48%) while there was less dissimilarity between assemblages collected in channels 2 and 3 (77.33%). *Ariopsis felis* contributed most to the dissimilarity between assemblages collected in

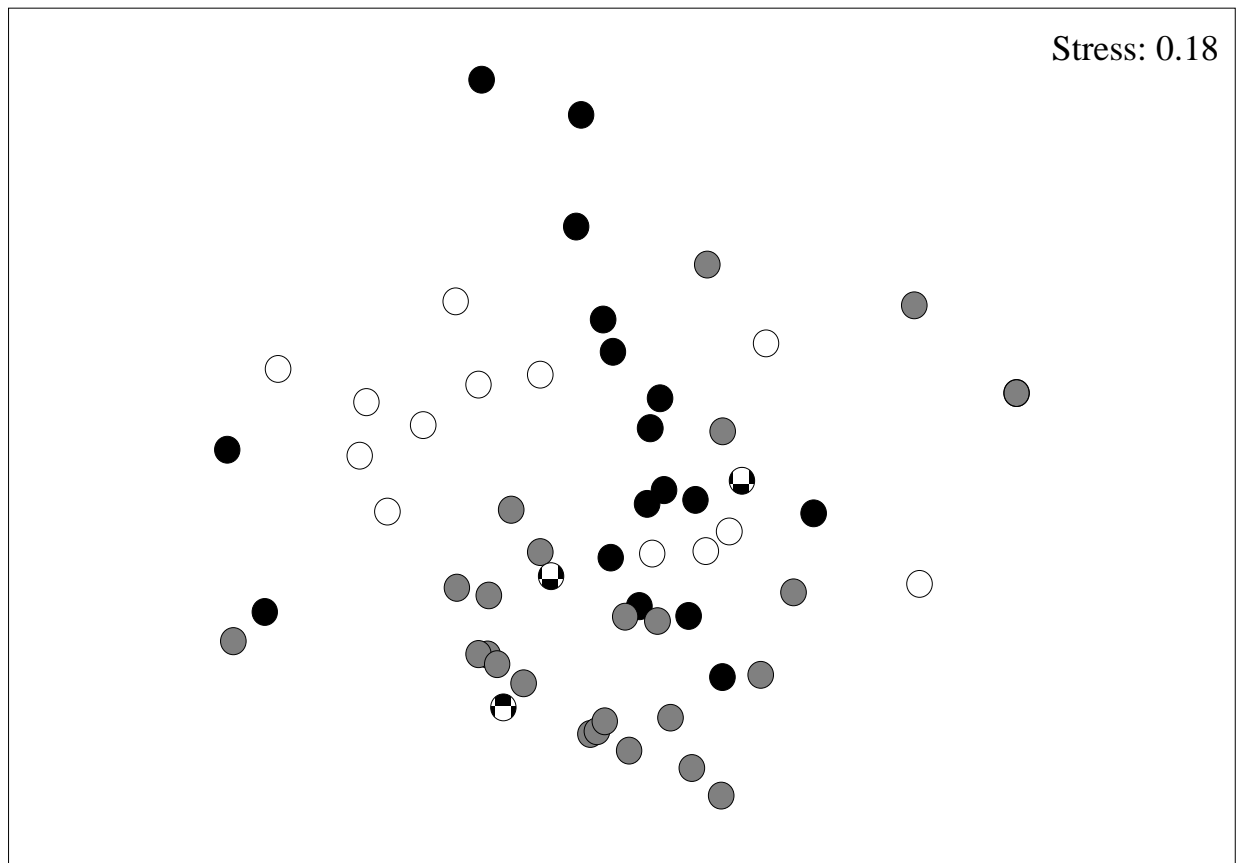


Figure 23. Multidimensional scaling plot of fish assemblages collected in four channels during July 2007. Symbols represent the channel where collections were made: ○ = channel 1, ● = channel 2, ● = channel 3, and ◐ = channel 4.

channels 2 and 3 (26.50%) but was the second greatest contributor to the dissimilarity between assemblages collected in channels 1 and 2 (13.97%) and channels 1 and 3 (20.31%; Table 20). Southern kingfish (*Menticirrhus americanus*) was the fourth greatest contributor to the dissimilarity between assemblages collected in channels 2 and 3 (10.63%) but contributed most to the dissimilarity between assemblages collected in channels 1 and 2 (35.66%) and channels 1 and 3 (40.27%; Table 19). *Oligoplites saurus* was fifth in percent dissimilarity contribution between the assemblages collected in channels 2 and 3 (10.36%) but third in contribution between channels 1 and 2 (13.77%) and channels 1 and 3 (15.80%; Table 19). Atlantic bumper (*Chloroscombrus chrysurus*) was ranked second in dissimilarity contribution between assemblages collected in channels 2 and 3 (16.06%) and fourth between channels 1 and 2 (11.35%) and channels 1 and 3 (11.28%; Table 19). Spanish mackerel (*Scomberomorus maculatus*) was third in percent dissimilarity contribution between the assemblages collected in channels 2 and 3 (13.29%; Table 19).

There were no significant differences between fish assemblages collected during July 2007 in channel and deep intertidal seagrass habitats (ANOSIM;  $R = -0.072$ ;  $p = 0.763$ ) but there were significant differences between fish assemblages collected during September 2007 in channel and deep intertidal seagrass habitats (ANOSIM;  $R = 0.502$ ;  $p = 0.001$ ). An MDS plot exhibits a lack of clustering between fish assemblages collected during July 2007 in channel and the deep intertidal seagrass habitats (Figure 24) while another MDS plot shows distinct clustering between fish assemblages collected during September 2007 in channel and deep intertidal habitat (Figure 25). During September 2007, *L. xanthurus* was collected in greater abundance in the deep intertidal seagrass habitat and contributed most to the dissimilarity between assemblages collected in channel and seagrass habitats (35.87%; Table 20). Sand

Table 19. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in channels during July 2007. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Channel Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>1st Channel Mean Abundance</u>	<u>2nd Channel Mean Abundance</u>	<u>% Contribution</u>
Channel 1 vs. Channel 2	0.189	0.005	<i>Menticirrhus americanus</i>	24.64	0.29	35.66
			<i>Ariopsis felis</i>	1.21	2.53	13.97
			<i>Oligoplites saurus</i>	1.71	1.12	13.77
			<i>Chloroscombrus chrysurus</i>	1.14	2.06	11.35
			<i>Scomberomorus maculatus</i>	0.07	1.88	8.91
Channel 1 vs. Channel 3	0.309	0.001	<i>Menticirrhus americanus</i>	24.64	1.00	40.27
			<i>Ariopsis felis</i>	1.21	3.13	20.31
			<i>Oligoplites saurus</i>	1.71	0.46	15.80
			<i>Chloroscombrus chrysurus</i>	1.14	0.79	11.28
			<i>Elops saurus</i>	0.36	0.17	2.92
Channel 2 vs. Channel 3	0.166	0.004	<i>Ariopsis felis</i>	2.53	3.13	26.50
			<i>Chloroscombrus chrysurus</i>	2.06	0.79	16.06
			<i>Scomberomorus maculatus</i>	1.88	0.08	13.29
			<i>Menticirrhus americanus</i>	0.29	1.00	10.63
			<i>Oligoplites saurus</i>	1.12	0.46	10.36



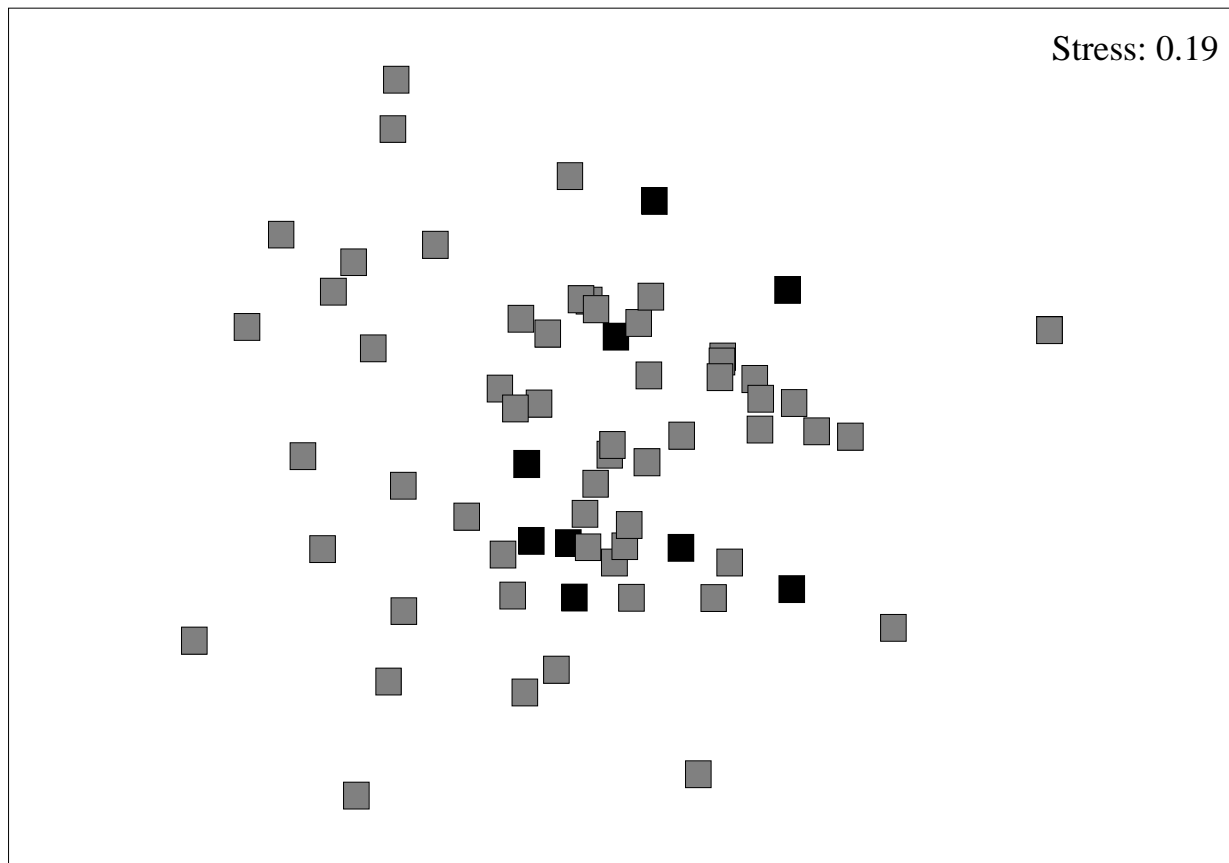


Figure 24. Multidimensional scaling plot of fish assemblages collected in channel and deep intertidal seagrass habitats during July 2007. Symbols represent the habitat types where collections were made: ■ = channel habitat and ■ = deep intertidal seagrass habitat.

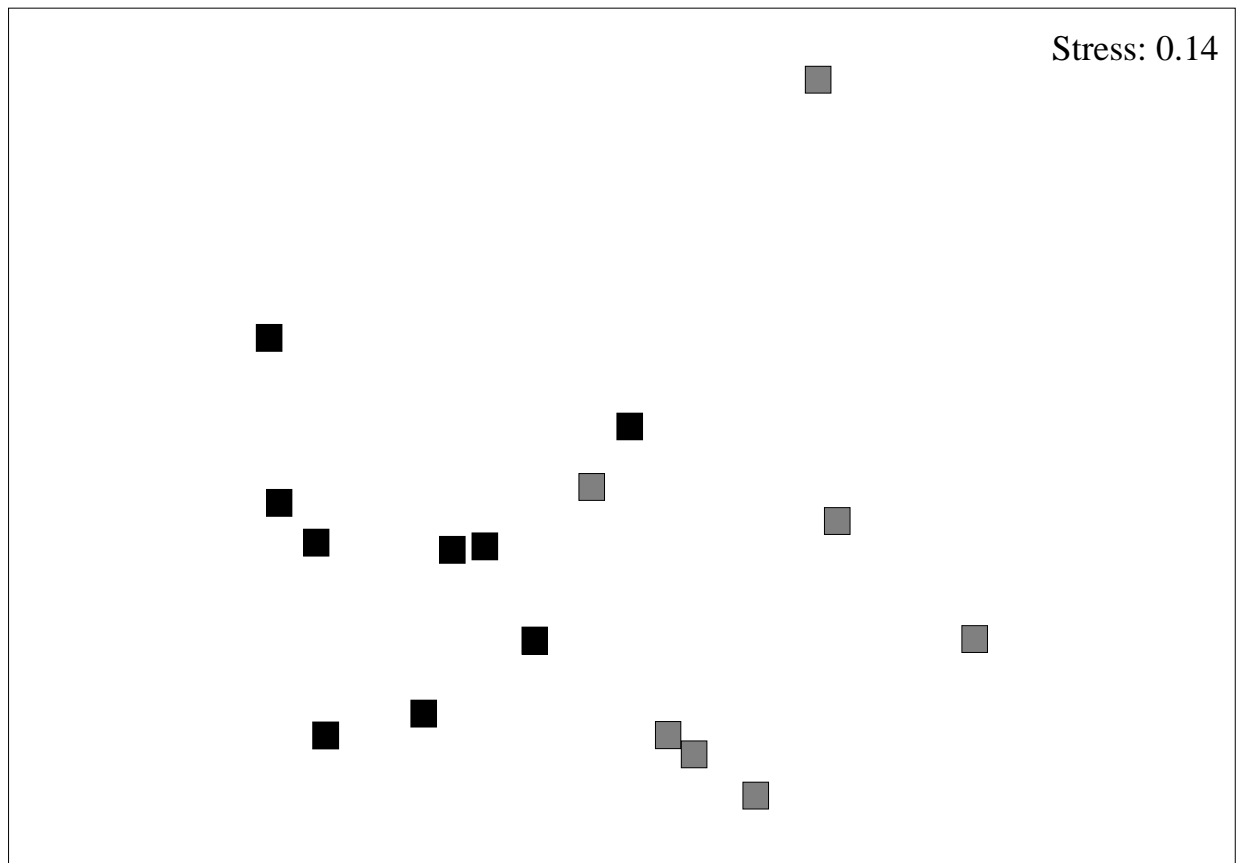


Figure 25. Multidimensional scaling plot of fish assemblages collected in channel and deep intertidal seagrass habitats during September 2007. Symbols represent the habitat types where collections were made: ■ = channel habitat and ■ = deep intertidal seagrass habitat.

Table 20. Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fish assemblages collected in channel and deep intertidal seagrass habitats during September 2007. Only the top five species associated with the greatest change between sampling periods are listed. Values in the last column are the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

<u>Habitat Comparison</u>	<u>R- value</u>	<u>p- value</u>	<u>Species</u>	<u>Channel 1 Mean Abundance</u>	<u>Seagrass Mean Abundance</u>	<u>% Contribution</u>
Channel vs. Seagrass	0.502	0.001	<i>Leiostomus xanthurus</i>	0.71	13.56	35.87
			<i>Cynoscion arenarius</i>	9.00	5.44	26.51
			<i>Lagodon rhomboides</i>	0.14	3.00	8.75
			<i>Ariopsis felis</i>	0.57	1.78	6.42
			<i>Harengula jaguana</i>	1.00	1.67	5.97

seatrout (*Cynoscion arenarius*) which was collected in greatest abundance in channels was the second greatest contributor to the dissimilarity between channel and seagrass habitats (26.51%; Table 20).

### *Historical comparisons of assemblages*

The historical ichthyofaunal survey of the Chandeleur Islands (March 1969 - November 1971) yielded 86 species (Laska, 1973). By comparison, the more recent survey efforts by the University of New Orleans (UNO) yielded 82 species (Appendix III). When these species lists are combined, 108 species of fishes have been collected at the Chandeleur Islands (Appendix III). The average taxonomic distinctiveness ( $\Delta+$ ) and variation in taxonomic distinctiveness ( $\Lambda+$ ) value for the historic survey was within the simulated 95% confidence limits (Figure 26). The ( $\Delta+$ ,  $\Lambda+$ ) value for the recent survey lies outside the 95% confidence interval suggesting there has been a decrease in taxonomic distinctness (taxonomic diversity) since the early 1970s at the Chandeleur Islands (Figure 27). The recent survey had lower values of taxonomic distinctness and variation in taxonomic distinctiveness than the historic survey (compare Figures 26 and 27).

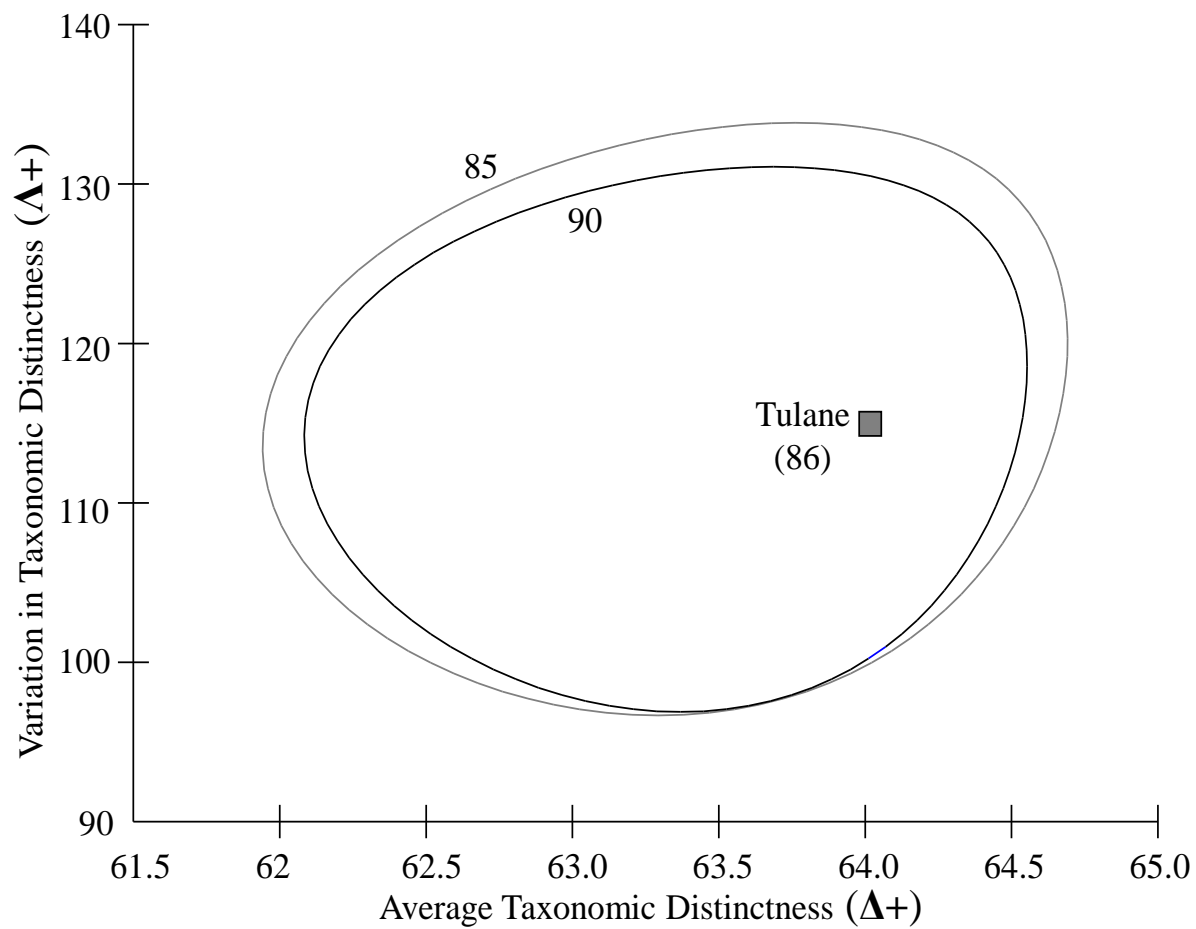


Figure 26. 'Ellipse' plots of 95% probability regions for the range of sublist sizes: 85 species (grey line); 90 species (black line). The ( $\Delta+$ ,  $\Delta+$ ) value for the Tulane University ichthyofaunal study (Laska, 1973) is represented by ■. The value shown in parenthesis on the plot is the number of actual species from the Tulane survey (Laska, 1973) used in the comparison; 86 species.

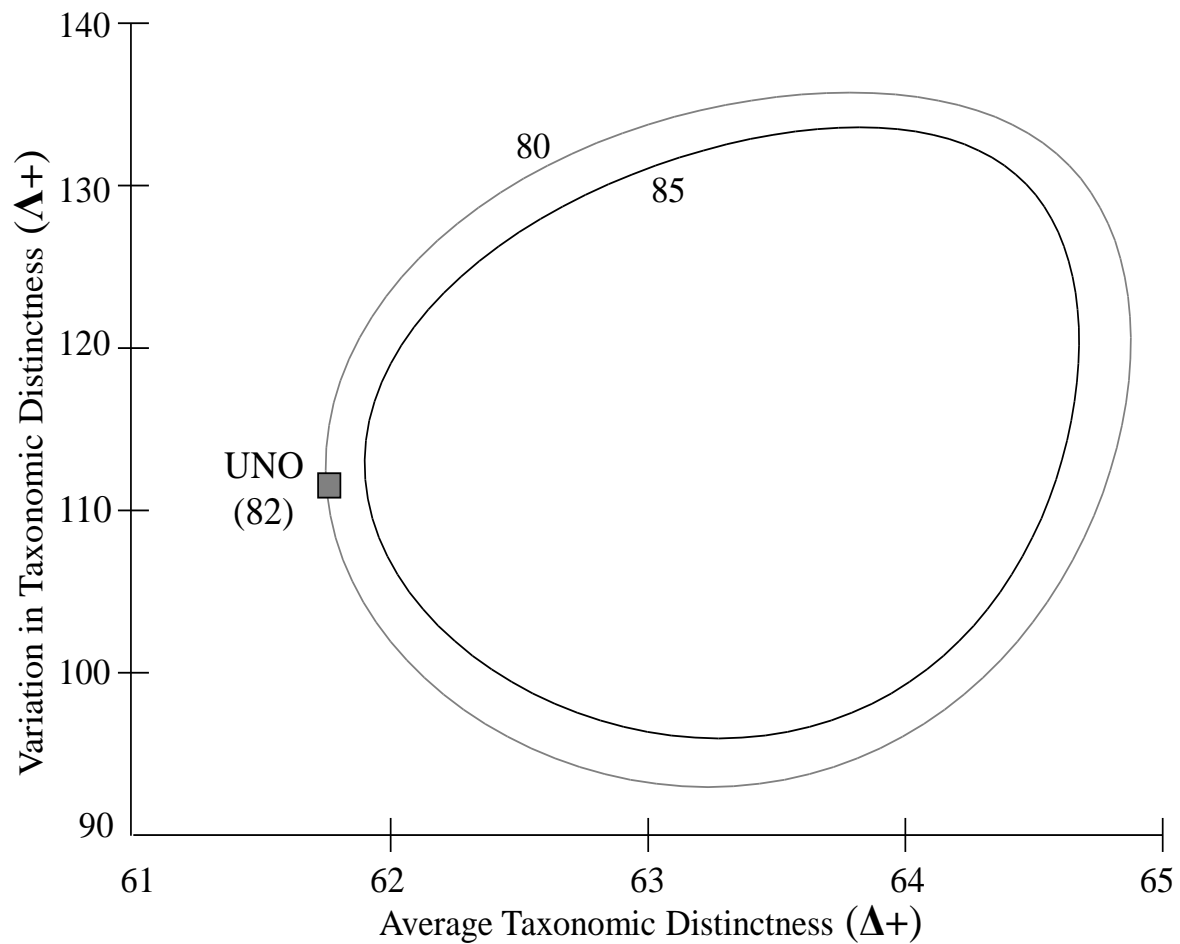


Figure 27. ‘Ellipse’ plots of 95% probability regions for the range of sublist sizes: 80 species (grey line); 85 species (black line). The ( $\Delta+$ ,  $\Delta+$ ) value for the UNO ichthyofaunal study is represented by ■. The value shown in parenthesis is the number of actual species from the UNO survey used in the comparison; 82 species. The ( $\Delta+$ ,  $\Delta+$ ) value lies outside the 95% confidence interval suggesting there has been a decrease in taxonomic distinctness (taxonomic diversity) since the early 1970’s at the Chandeleur Islands.

## Discussion

There were significant changes among fish assemblages in all habitat types at the Chandeleur Islands associated with hurricanes Ivan and Katrina. While these changes in fish assemblages were measured just after the hurricanes when fishes moved from impacted areas, other delayed assemblage changes occurred well after the storms. Fish assemblage changes were more common in the protected bay shoreline (near shore) habitat where hurricanes Ivan and Katrina appeared to cause the greatest impact. Also, near shore habitat fish assemblages generally increased in overall abundance and species richness following the disturbances while, in comparison, overall abundance of fishes in the demersal seagrass habitat decreased after Hurricane Ivan and remained low throughout the remainder of the study. Through my channel sampling, I determined that fishes use hurricane-reopened tidal channels at the Chandeleur Islands and different channels had significantly different fish assemblages. My results also show that during July 2007 there was no significant difference between fish assemblages collected in channels and the deep intertidal seagrass habitat. While the severe loss of overall habitat at the Chandeleur Islands may be affecting the long term resilience of fish assemblage diversity, the increased intensity and frequency of recent storms may also explain why current fish assemblages at the Chandeleur Islands appear to be less diverse (as measured by taxonomic distinctness) than assemblages collected during 1969-1971. I conclude that, while hurricanes Ivan and Katrina affected fish assemblages of all habitat types differently, overall the fish assemblages of the Chandeleur Islands appear highly resilient to the impact of hurricanes.

### *Fish assemblage comparisons*

Fish assemblage changes in the near shore and demersal seagrass habitat immediately following Hurricane Ivan, during November 2004, were due, in part, to an increase in overall abundance and species richness in the demersal seagrass habitat and a decrease in species richness in the near shore habitat. Additionally, while there were no significant changes among near shore fish assemblages collected during January following Hurricane Ivan, there were significant changes in demersal fish assemblages during this time. During these months, the increase in abundance of *L. rhomboides* and *A. mitchilli* in demersal habitats contributed most to the assemblage changes in the demersal seagrass habitat although *L. rhomboides* also increased in abundance in the near shore habitat. The apparent movement of fishes to the demersal seagrass habitat during November and the lack of significant changes seen in the near shore habitat during January suggests that fishes associated with the near shore habitat retreated to the safety of deep water during Hurricane Ivan contributing to early seasonal fish assemblage changes. In a natural experiment at the Chandeleur Islands, Blanke (2006) found seagrass associated fish and invertebrate assemblages changed significantly immediately following the passage of Hurricane Ivan. Blanke (2006) also observed a greater abundance of *L. rhomboides* following the storm but a decreased abundance of the hermit crab (*Pagurus* spp.), blue crab (*Callinectes sapidus*), and brown shrimp (*Farfantepenaeus aztecus*). His results suggested that fish assemblages were more resilient to hurricane impacts than invertebrate assemblages whereas unlike most invertebrates, fishes can react to degrading conditions by abandoning an area quickly to seek refuge in deeper waters. Rather than a habitat disturbance effect, Blanke's (2006) results suggest that fishes return to seagrass habitats more quickly than invertebrates and that he likely observed the same post hurricane movement of fishes to deeper water that I report here.



The greatest number of fish assemblage changes occurred in the near shore habitat. While the immediate fish assemblage changes (November and January post-Hurricane Ivan) in the near shore habitat were due to the retreat of fishes to deeper water, other less immediate assemblage changes (observed during 2005 and 2006) were likely due to the acute geomorphic changes that appeared most prominent in the near shore habitat following both storms. Additionally, the delayed assemblage changes that occurred two and three years after the impact of Hurricane Katrina were likely due to the regular geomorphic changes that the islands shorelines experience. Because some of the islands shorelines were more dynamic than others, the near shore sampling stations were affected differently by acute effects of the storms impacts and long-term geomorphic processes. For example, site C2, which consisted of an edge that was predominantly *S. alterniflora* salt marsh, appeared to be the least affected while, conversely, site C1/C4, which consisted predominantly of sandy beach and had to be moved three times throughout the study due to erosion of the shoreline, proved to be the most dynamic of the near shore habitat sampling stations. Additionally, fish assemblage variability among sites was most prominent in the near shore habitat and was likely due to the diversity of local habitat characteristics within this habitat type (microhabitats). For example, during the post Hurricane Katrina periods (May 2006 to September 2006; May 2007 to May 2008), significant differences among fish assemblages collected at different sites were observed only in near shore habitats. These assemblage differences appeared to be driven most by the dominance of individual species at different sites. For example, in the near shore habitat during most sampling periods (i.e., pre-impact, post Hurricane Ivan, etc.), *L. rhomboides* were often collected in greatest abundance at site C2 while *L. xanthurus* were collected in greatest abundance at site C3 and *E. gula* were collected in greatest abundance at site C1/C4. Also, in the demersal habitat during May of

different years, greater than 96% of *L. rhomboides* were collected at site C3 during 2004 while during May 2005 greater than 99% of this species were collected at site C2 and during May 2006 *L. rhomboides* were collected only at site C3. While the dominance of these species varied temporally and spatially in the near shore and demersal habitats during the survey, *L. rhomboides*, *L. xanthurus* and *E. gula* were also generally not collected in greatest abundance at the same site per sampling trip. Also, large numbers of *B. chrysoura* collected in demersal habitats were generally always collected at the same site whereas during November 2003, 379 *B. chrysoura* were collected from site C2 while none were collected at the other sites. Similarly, during June 2006, 291 *B. chrysoura* were collected from site C3 and during August 2006, 557 fish were collected from site C2 while no fish of this species were collected in other demersal collections during these sampling trips. These examples of assemblage variability among sites show the diversity of microhabitats at the Chandeleur Islands and the importance of these microhabitats on species richness and overall abundance. Species found predominantly in the near shore habitat are more associated with the physical habitat. In other words, small near shore fishes are generally found in greater abundance over shallow-sloped banks than steeper banks and along shore edge that has a greater abundance of emergent vegetation due to the increased protection these microhabitat differences offer from predators (McIvor and Odum, 1988; Rakocinski et al., 1992). While the near shore sampling station at site C2 had the steepest shore-face slope, it also had the greatest amount of emergent *S. alterniflora* and attracted species generally associated with the salt marsh habitat. In contrast site C1/C4 had no emergent vegetation but had the shallowest shore-face slope and attracted species generally associated with the bare, sandy shoreline habitat. While the dynamic nature of the islands shorelines and the differences in microhabitats at each near shore sampling station and in adjacent habitats may

explain the large number of changes and large amount of variability observed among near shore fish assemblages, fish assemblage changes were spatially similar. Fish assemblages more sensitive to environmental or habitat changes may lack seasonal cyclicity following a disturbance, meaning species composition does not return to a similar point, in multivariate space, over some period of time (Mathews, 1998). If an assemblage is displaced, or changes in composition over time, the point will move progressively further away from the original condition. While distinct patterns of fish assemblage changes, in multivariate space, were observed in all habitat types during the survey, similar patterns of fish assemblage change (direction in multivariate space) were generally observed at all sites per month. For example, similar (in direction) patterns of cyclicity were observed at all sites during May sampling in the demersal seagrass habitat and in the deep intertidal seagrass habitat (Figures 16, 17, 18, 19, 20, and 21). Also, in the near shore habitat during May sampling, similar patterns of cyclicity were seen at sites C1/C4 and C3 although site C2 appeared to undergo a unidirectional pattern of assemblage change (Figures 11, 12, and 13). This is counterintuitive because the near shore sampling station at site C2 appeared to be the least physically dynamic with the least microhabitat changes over time. It is possible that, due to the relative stability of this near shore sampling stations shoreline and microhabitats, assemblage change over time is more accurately detected at this sampling station. Despite the unidirectional pattern observed at site C2, it is important to note that overall assemblage changes at all near shore sampling stations during May were similar, moving from upper-right to bottom-left in multivariate space. Although microhabitat and fish assemblage differences among sampling stations in all habitat types existed, the observation of similar directions and patterns of assemblage changes among sampling stations per habitat type suggests the different fish assemblages are undergoing

spatially similar temporal assemblage changes that often suggest cyclicity or a return to a previous state.

The high rates of physical disturbance in the near shore habitat likely contributed to the increases in overall abundance and species richness observed in this habitat type suggesting the impacts of these storms were advantageous for many fish species associated with this habitat type. The intermediate disturbance hypothesis states that because ecological communities seldom reach an equilibrium state, disturbances that kill or damage individuals set back the process of competition by opening bare, or partially bare, patches (uninhabited space) for colonization by less competitive individuals (Wilson, 1994; Townsend and Scarsbrook, 1997). This allows the coexistence of species with different life history strategies. Many small fish species collected in the near shore habitat at the Chandeleur Islands have r-selected life histories meaning these species produce many offspring quickly allowing them to opportunistically exploit bare patches. For example, *L. rhomboides* may grow up to 110 mm and spawn in their first year of life (Hansen, 1970; Muncy, 1984). Smaller-bodied sciaenids that were collected during this study such as *B. chrysoura* are also considered r-selected (Waggy et al., 2006). Additionally, eight species of Gobiidae were collected at the Chandeleur Islands while seven of these were exclusive to the near shore habitat. While all gobies are small fishes and considered to have r-selected life histories (Robins et al., 1986; Wyanski and Targett, 2000), the two most abundant gobies collected during this study, *C. shufeldti* and darter goby (*Ctenogobius boleosoma*), were collected only in the near shore habitat and increased in abundance following the impacts of the hurricanes. Such a response in these and other r-selected species would explain the increase in species richness and overall abundance observed in the near shore habitat. Additionally, many species such as *L. rhomboides*, chain pipefish (*Syngnathus louisianae*), *E.*

*gula*, and *B. chrysoura* feed primarily on small invertebrates (i.e., amphipods and mysids) during different life stages (i.e., juvenile and adult; Muncy, 1984; Kerschner et al., 1985; Robins et al., 1986; Waggy et al., 2007). In the Northern Baltic Sea, Bostrom and Bonsdorff (2000) showed that wind disturbance affects led to an increase in copepod abundance and invertebrate diversity in seagrass beds. After hurricanes Ivan and Katrina, a similar disturbance effect may have contributed to an increase in invertebrate abundance and diversity in the Chandeleur Islands seagrass beds. While Blanke (2006) saw a decrease in the abundance of invertebrates following Hurricane Ivan, his study concluded in May 2005, seven months after Hurricane Ivan, and likely did not document the recovery of the seagrass invertebrate assemblage. Additionally, he used passive minnow traps which, due to their mesh size, selectively sample only medium sized invertebrates. While the recent survey did not include invertebrates in the analysis, brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and blue crab (*Callinectes sapidus*), when collected in the near shore and demersal habitats, were recorded. While *C. sapidus* and *L. setiferus* only slightly increased in abundance over time, *F. aztecus* increased 132 fold from May 2006 to May 2008 with an overall increase of 190 fold from May 2004 to May 2008. While the increase in available resources following each storm (e.g., food, uninhabited space) likely contributed to the increase in species richness and abundance observed in the near shore habitat, it is important to note that Hurricane Georges (landfall 28 September 1998), Tropical Storm Isidore (landfall 28 September 2002), and Hurricane Lili (landfall 2 November 2002) also recently impacted the islands and that the “pre-impact” sampling period for this study may be considered a time of recovery from these storms. Additionally, two of these storms, Tropical Storm Isidore and Hurricane Lili, made landfall only four days apart in 2002. The intermediate disturbance hypothesis also states that, while local disturbance must

occur frequently enough so that competitive exclusion does not occur over the whole area, if disturbances occur too frequently, most species may be eliminated (Wilson, 1994). The species richness and overall abundance observed during 2004 sampling may have been low due to the impact of those back to back storms in 2002. Also, while the severity of Hurricane Katrina likely had immediate negative effects on many fish species, the timing of the storm, which occurred eleven months after Hurricane Ivan, may have exacerbated the impact on fish assemblages whereas, although sampling did not resume until nine months after the impact of Hurricane Katrina, a decrease in abundance and species richness was observed in all habitat types during May 2006. Although the high impact frequency of storms during the last decade has likely not allowed fish assemblages to recover as they did in the past, an increased amount of uninhabited space available over a longer time than usually occurs may be resulting in an assemblage comprising a greater number of species.

During this survey, eight species were absent from collections after the impact of Hurricane Ivan while 16 species appeared to increase in abundance following both disturbances. Six species which were not collected until 2007 or 2008 are the sergeant major (*Abudefduf saxatilis*), spadefish (*Chaetodipterus faber*), permit (*Trachurus falcatus*), red snapper (*Lutjanus campechanus*), northern kingfish (*Menticirrhus saxatilis*), and sargassum fish (*Histrion histrio*). The observation of these sporadic species, some of which are considered to be tropical (i.e., *A. saxatilis*, *T. falcatus*, and *C. faber*), may be due to the proximity of the Chandeleur Islands in relation to the Gulf of Mexico's Loop Current, which distributes warm tropical waters into the Gulf of Mexico. Additionally, Hurricanes Katrina's path appeared to follow the Gulf Loop Current into the northern GOM and therefore many of these tropical sporadic species may have been transported to the islands as larvae or juveniles by the additional water currents generated

by the storm. In south-western Australia, high species richness in some near shore fish assemblages was attributed to their location nearer the warm Leeuwin Current (Ayvazian and Hyndes, 1995). It is also possible that these tropical species exist in the waters surrounding the Chandeleur Islands but, like many other species, increased in abundance following the disturbances which increased the chances of their capture. *Ctenogobius shufeldti*, which was also collected for the first time at the Chandeleur Islands during May 2008, comprised almost half of the total abundance of all gobies collected in near shore habitats. This species was collected in greatest abundance at site C4 (124 fish) but only 2 fish were collected at site C3 and none were collected at site C2. The large abundance of this species and its concentration at site C4 may be considered as another example of microhabitat differences among near shore sampling stations, but also suggests that a colonization event may have taken place. For example, Beckett et al. (1992) captured three *Lepomis* species (all freshwater species) within the inland waters of Horn Island, Mississippi while Franks (1970), who sampled much thoroughly 23 years earlier, captured none. Beckett et al. (1992) suggested that colonization of the islands inland pools by freshwater species likely takes place during spring when high river flow lowers salinities in offshore waters. Subsequently these freshwater species may later be extirpated due to a storm surge filling the islands ponds with high salinity water. This same colonization mechanism may explain the presence of sporadic species or species generally found in less saline waters collected historically or more recently at the Chandeleur Islands (Laska, 1973). While the disturbance associated with hurricanes Ivan and Katrina may have extirpated some species from the Chandeleur Islands, other species appeared to benefit from the impact of these storms.

While fish assemblages in all habitat types generally initially decreased in species richness and overall abundance following the impact of hurricanes Ivan and Katrina, long-term

negative effects (i.e., decreases in species richness and overall abundance) were most obvious among demersal seagrass habitat fish assemblages. The overall abundance of fishes collected in the demersal habitat during May of different years decreased following Hurricane Ivan and remained low throughout the remainder of the survey. However, in contrast, during September sampling in the demersal habitat, an increase in abundance occurred following Hurricane Katrina but was due primarily to a large abundance of *B. chrysoura* collected during September 2006, a large abundance of *A. hepsetus* collected during September 2007, and large abundances of *E. gula* and *L. rhomboides* collected during September 2006 and 2007. It is important to note that, due to a large amount of variability within the trawl collections, microhabitat differences within the demersal habitat were likely observed during this study. While seagrass beds exist in demersal habitats, they are fragmented and it is likely that the trawl was sampling bare substrate at times. For example, at site C1 during November 2004 all collections were empty except for sea star (*Luidia* spp.) which prefer sandy bottom habitats (Meinkoth, 1998). Throughout the survey, fishless trawl samples appeared to occur equally at sites C1/C4 and C2 but were observed less frequently at site C3. While hurricanes Ivan and Katrina may have contributed to the fragmentation or reduction in the area of the Islands' demersal seagrass beds, variability in trawl samples was also observed prior to the impact of Hurricane Ivan when overall abundance of fishes was greatest. Due to predation risks, most species of fishes collected during this study and particularly those collected in greatest abundance in near shore and demersal habitats during the survey (i.e., *L. rhomboides*, *L. xanthurus*, and *E. gula*) are generally collected in greater abundance over seagrass habitat than bare substrate (Jordan et al., 1996; Blanke, 2006). An example of this from the demersal habitat that has already been mentioned is the large numbers of *B. chrysoura* that were generally always collected at the same site and in large abundances. It



appears this species may colonize selected patches of demersal seagrass. While the increased resources in the shallow seagrass beds and the near shore habitat may have proved to be a more suitable habitat resulting in a migration of fishes away from the demersal seagrass habitat, hurricane associated deterioration and further fragmentation of demersal seagrass beds likely caused most of the observed decrease in abundance of fishes in the demersal seagrass habitat although the variability of fish assemblages in this habitat was present prior to these storms.

Due to gear type differences, fish assemblages targeted in the deep intertidal seagrass habitat were comprised of larger-bodied fishes than those targeted in the near shore and demersal seagrass habitat. Because of the increased mobility of the deep intertidal seagrass habitat fishes and their ability to retreat to the safety of deeper water at the onset of degrading conditions, these assemblages appeared least affected by the immediate impact of these storms. The delayed changes observed in deep intertidal fish assemblages may be due, in part, to a response to changes in “prey” rather than a habitat disturbance effect. In other words, as prey resources such as *F. aztecus* and *A. mitchilli* become more available, large-bodied fishes likely moved into these habitats to forage on these species. For example, from May 2004 to May 2005, *O. saurus* (a small carangid piscivore) in the deep intertidal seagrass habitat increased in abundance but then decreased during May 2006. A similar pattern in abundance was observed in other habitat types for *A. mitchilli*, a small fish associated with shallow open water habitats and a “prey” item for many species (Robinette, 1983). There was also a significant change between deep intertidal fish assemblages collected during May 2007 and 2008 due to a large increase in abundance of *A. felis*. This species which is an opportunistic feeder that commonly consumes crustaceans and fishes may also be attracted to the seagrass flats due the increase in abundance of prey (Muncy, 1983). Other biological interactions also likely played a role in assemblage differences observed

per site in all habitat types. Life history differences between species such as *L. rhomboides*, *L. xanthurus*, *E. gula*, and others collected during this survey, decrease competition among them. For example, in Port Aransas Bay, Texas, post-settlement patterns of the sciaenid's *B. chrysoura*, spotted seatrout (*Cynoscion nebulosus*), *L. xanthurus*, *S. ocellatus*, and Atlantic croaker (*Micropogonius undulatus*) to seagrass habitat were partitioned temporally with little overlap whereas YOY *B. chrysoura*, *C. nebulosus*, and *S. ocellatus* inhabited seagrass beds during spring and summer while *L. xanthurus* and *M. undulatus* were present in the late fall and winter (Rooker et al., 1998). Additionally, *L. rhomboides* adults generally move to deeper water to spawn during fall while *E. gula* move into shallow seagrass beds during this period (Muncy, 1984). During this study, *L. rhomboides* was the numerically dominant species throughout the survey although *E. gula* was generally numerically dominant in the near shore habitat during June, August, and September. Increases in the abundance of most species, particularly in the near shore habitat, likely increased spatial and temporal interactions among different species.

Water temperature, which is often the primary driver of fish assemblage change in year round or seasonal sampling (Modde and Ross, 1981; Ross et al., 1987), contributed most to seasonal fish assemblage changes in all habitat types during the survey although, in the deep intertidal seagrass habitat, a combination of water temperature and water depth were also correlated strongly to assemblage changes. In contrast to my findings, Blanke (2006) found only a weak correlation between changes in biotic assemblages and water temperature in seagrass beds at the Chandeleur Islands following Hurricane Ivan. While Blanke's (2006) sampling sites were similar in habitat to the deep intertidal habitat sampled in this survey, his gear type targeted smaller fishes that are less mobile and more associated with seagrass. Also, per month in the near shore habitat, no distinct environmental driver of assemblage change appeared consistently

during the months May to September although water temperature, in combination with other factors, appeared to have the greatest influence. Additionally, due to high variability of the most influential factors, May-July appear to be transitional months between the winter and summer seasons. In addition to low sample numbers, many other factors such as high river discharge from the Mississippi and Pearl Rivers and influence of the Gulf Loop Current may have also contributed to the inconclusiveness of the results. While salinity was correlated strongly with assemblage changes in the near shore habitat during July, the range of the mean salinity per sampling trip was small (2.7 ppt). Similarly, while water temperature was strongly correlated with fish assemblage changes in the near shore habitat during August and September, the range in water temperature was small, although, during these summer months, temperatures are near the maximum thermal tolerance level of many species and the difference of only a few degrees may have contributed to the movement of less tolerant species to deeper, cooler water. Because environmental data used for the near shore habitat assemblage analysis was collected at the deep intertidal seagrass sampling station, water temperature for the near shore habitat, which is often the warmest due to solar radiation warming of the shallow water, was likely not accurately documented.

#### *Channel and deep intertidal seagrass habitat assemblage comparisons*

Channels sampled, which were geomorphically different from one another, contained significantly different fish assemblages. For example, *A. felis* was collected in greatest abundance in the shallowest channel while *M. americanus* and *C. arenarius* were collected in greatest abundance in the deepest channel. During one collection in the deepest channel, 293 *M. americanus* were collected comprising an approximately equal ratio of males and females and all

fishes were gravid. This species is thought to spawn largely or entirely offshore in 9-36 m of water (Irwin, 1970). Additionally, *C. arenarius* is believed to spawn in shallow lower-estuarine waters so their larvae may be carried into the estuary or nursery habitat with tidal and wind driven currents (Sutter and McIlwain, 1987). The observed congregation of gravid *M. americanus* suggests spawning among this species may also occur in or near these deep barrier island tidal channels. Also, due to the collection of juvenile *C. arenarius* in the near shore and demersal seagrass habitats during this survey, it is possible this species may also spawn in the waters around the Chandeleur Islands tidal channels. While species richness was greater in channels with increased complexity, the overall abundance of fishes in channels appeared to be positively correlated with channel depth. Because barrier island tidal channels often “mend” as littoral and aeolian processes add sediment to the beach shore face and dunes reforming a continuous shoreline, it is likely fish assemblages in over-wash channels may be determined by the geomorphology of channels and the time passed since the last major disturbance.

Because there were no significant differences between fish assemblages collected during July in channels and the deep intertidal seagrass habitat, it is likely that, during post-impact periods when connectivity is greatest between tidal channels and other habitats, fishes move among the channels, surf zone and the more diverse seagrass habitat types. Additionally, the ANOSIM generated *R* value between fish assemblages collected in channels and the deep intertidal seagrass habitat was negative. Chapman and Underwood (1999) found that negative *R* values generally occur when replicates were variable but each sample had similar amounts of variability among replicates or if individual species have a heavily clustered spatial distribution. My results may be due to the low number of collections made in seagrass habitat, the low number of species generally collected with gill nets, or the large amount of assemblage

variability observed among channels. Also, when comparing among channels in July, negative  $R$  values were generated between channel 4 and the other channels. This was likely due to the low number of collections in channel 4 and, again, the large amount of fish assemblage variability observed in the channels. Other abundant species collected in channels were *O. saurus*, *C. chrysurus*, *S. maculatus*, bluefish (*Pomatomus saltatrix*), and ladyfish (*E. saurus*). These taxa, which are known to prey on small fishes, were also abundant in the surf and seagrass habitat at the Chandeleur Islands (personal observation). I observed that larger abundances of these fishes were collected per sample when “prey” species (particularly juvenile *H. jaguana*) were present and “schooling” in channels. Many of these predator fishes collected in channels during July are generally associated with open water and likely enter channels in pursuit of prey. The significant differences between fish assemblages collected in channels and the deep intertidal seagrass habitat during September 2007 may have been due to low collection numbers and the lack of spatial and temporal variability in channel samples. In comparison to July sampling of channel habitats, four channels were sampled which resulted in a more diverse assemblage whereas only one channel was sampled during September. Additionally, during July 2007, 21 collections were conducted over eleven days while during September only three collections were conducted over two days.

Fish assemblages in other habitat types also appeared to be affected by hurricane-reopened tidal channels. Prior to Hurricane Ivan, there was a nearly continuous shoreline along the beach which would have required fishes to swim around the northern or southern portions of the islands to access seagrass beds. During September 2007, *M. americanus* were collected in high abundance in the near shore and deep intertidal habitat at site C4 which was located on a sandy spit near a tidal channel. Additionally, Florida pompano (*Trachinotus carolinus*) which

are also generally associated with surf zone habitats (Gilbert, 1986) were collected in greatest abundance in the near shore habitat following the impact of hurricanes Ivan and Katrina. Increases in the abundance and size of wash-over channels following these storms increased the connectivity between surf zone and seagrass habitats allowing fishes to travel more easily between habitat types. Also, the increase in number of channels transgressing the islands may lead to earlier recruitment events and reduced predation during migration to nursery areas. For example, fish assemblages collected in near shore habitats during both March 2004 sampling periods were not significantly different than the assemblage collected during February 2005. Similarly, fish assemblages collected in near shore habitats during May 2004 were not significantly different than near shore fish assemblages collected during March 2005 and April 2005. *Lagodon rhomboides* adults spawn in offshore surface waters and juveniles migrate into estuaries in the spring and summer (Muncy, 1984). During the recent survey, the largest increase in the abundance of this species was observed in the near shore habitat. While many larval and juvenile fishes may travel through wash-over channels with tidal currents, the near shore habitat is likely one of the habitat types first accessed when larval or juvenile fishes traverse the islands, particularly if they remain in shallow waters of the high bank to avoid predators. In addition to increasing connectivity among habitat types, the increase in abundance and size of over-wash channels likely altered hydrologic conditions in aquatic habitats of the islands. During pre-impact flood and ebb tides, water currents flowed around the islands whereas now they flow through the islands. This means that water velocities (energy per unit area/length) and direction of tidally-influenced currents are different in seagrass habitats post-impact, particularly nearest to over-wash channels. Additionally, water ‘stand up’, caused by northwesterly wind events, would be decreased, limiting the amount of marsh surface accessible to fishes.

To my knowledge no other study has addressed the use of tidal channels by fishes. While my study did not address this question directly, I now have a better understanding of the larger-bodied fish assemblages found in tidal channels at the Chandeleur Islands and how these assemblages may change over time. In Texas, tidal inlets to coastal lagoons are sometimes limited due to low river flow or well developed (“mended”) barrier beaches. Hoese and Moore (2005) mentioned that fishes become concentrated in these passes creating an “impressive sight and phenomenon” and that these passes become highly efficient places to “harvest” fishes. Additionally, Hoese and Moore (2005) added that “it does not necessarily follow that creating more tidal passes means more fish.” Although the creation or reopening of tidal channels generally results in an overall decrease in barrier island area and habitat, their repeated openings and closings likely plays a significant role in microhabitat diversity resulting in greater species and habitat richness.

#### *Historical comparisons of assemblages*

My comparison of historical data (Laska, 1973) with current fish collections conducted over the last six years suggests that there has been a decrease in taxonomic distinctness (taxonomic diversity) at the Chandeleur Islands since the early 1970s. That is, current fish assemblages at the Chandeleur Islands are different from historical fish assemblages whereas the more recent survey data had lower values of average taxonomic distinctness and variation in taxonomic distinctiveness than the 1970s survey. These measures, average taxonomic distinctness and variation in taxonomic distinctiveness, were developed to incorporate the taxonomic relatedness of species into their calculation (Clarke and Warwick, 1998). While the historic and recent surveys appear to have similar species richness (86 and 82 species,

respectively), it is likely that the increased frequency of the recent storms is keeping Chandeleur Island fish assemblages in earlier successional stages that are comprised of species that are more closely related. Similar to the recent data, the historical data were collected during a period of recovery from the impact of a hurricane however; other differences between historic and recent fish assemblages may also be associated with the different collecting gear whereas the assemblage of fishes observed often reflects what sampling technique was utilized (Gray and Bell, 1986). While seines have been shown to be less effective at capturing bottom dwelling species (Ross et al., 1987), Laska's (1973) use of rotenone as an asphyxiate likely makes his method of pool sampling more effective than the gear types more recently used at the Chandeleur Islands. The use of rotenone may also explain the large number of speckled worm eel (*Myrophis punctatus*), a burrowing species, collected by Laska (1973). A total of 644 *M. punctatus* were collected in the historical survey in pool and seagrass habitats while only two individuals were collected by Blanke (2006) and none were collected during the recent survey. Additionally, while Blanke (2006) collected 23 species of fishes sampling with passive minnow traps in seagrass and bare substrate habitats, three of these species were not collected during the recent survey. Additionally, while sampling differences did exist between the historic and recent surveys, collections during the recent survey were made over a longer period of time, increasing the likelihood of capturing sporadic species and a more accurate representation of species richness.



## Summary

Overall, fish assemblages of the Chandeleur Islands appear highly resilient to recent hurricane impacts. The high resilience observed by fish assemblages at the Chandeleur Islands is likely a reflection of adaptation by local species to regular hurricane impacts. While the disturbance associated with hurricanes Ivan and Katrina was most prominent in the near shore habitat, an increase in species richness and overall abundance was observed following the storms in this habitat type suggesting the storms impacts proved positive for some species. The hurricanes likely increased the amount of uninhabited space available for colonization by less competitive species. Additionally, hurricane-reopened tidal channels have increased connectivity between habitat types at the islands. My results suggest these corridors between habitat types have major implications on the dynamics of fish assemblages by altering environmental conditions, habitat availability, and settlement patterns. Long-term changes in fish assemblages at the Chandeleur Islands have also occurred whereas there has been a decrease in taxonomic distinctness (taxonomic diversity) since the early 1970s. Witman (1992) studying the impact of hurricanes Hugo and Gilbert on fringing reefs found Hurricane Hugo, the most severe of the two storms, caused less damage to exposed reef than protected reef because the exposed reef was still in recovery from the storm the previous year. Witman's (1992) study shows the importance of interpreting recent disturbances in light of the history of past disturbances. Decreased dune elevations, a fragmented beach shoreline, and increased abundance and sizes of over-wash channels contribute to greater energy per unit area/length in the protected back-bay habitats. In other words, less extreme storm events may cause an equal or greater amount of disturbance to the islands aquatic habitats that are generally protected. While the decrease in taxonomic distinctness among Chandeleur Island's fish assemblages may be due

to the overall loss of habitat since the early 1970s, it may also be due to the increased frequency of storms to impact the islands in the last century and the increased intensity of these impacts. The loss of sub-, inter-, and supra-tidal habitats, which is generally recognized as the leading threat to biodiversity (Dobson et al., 1997), in combination with the high frequency of recent disturbances may be affecting the ability of the Chandeleur Islands fish assemblage to recover as they once did over thirty years ago resulting in assemblages comprised of earlier successional stages of more closely related species.

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Appendix I. Abundance of all fishes collected during an ichthyofaunal survey at the Chandeleur Islands. Dates of collections are given per month followed by days in parenthesis. Gear type = habitat type; S = seine (near shore seagrass habitat); T = trawl (demersal seagrass habitat); G = gill net (littoral seagrass habitat). Gear type was shown only if a species was captured in the associated habitat during the survey. Vertical dotted lines separate samples collected before or after Hurricane Ivan which made landfall on 16 September 2004 and Hurricane Katrina which made landfall on 29 August 2005.

		2003	2004										2005						2006			2007			2008				
		October (14-16)	November (10-12)	January (13-15)	March (6-7)	March (28-29)	April (6-8)	May (18-19)	June (8-10)	July (6-8)	August (3-4)	September (9-10)	November (8-9)	January (5-7)	February (11-12)	March (23-24)	April (14-15)	May (18-19)	June (16-17)	August (8-9)	May (15-17)	June (18-20)	August (25-27)	September (15-16)	May (21-22)	July (2-3)	September (2-3)	May (24-26)	
Carcharhinidae																													
	<i>Carcharhinus leucas</i>	G				1	1		1		3					1													
	<i>Carcharhinus limbatus</i>	G	3		3						1	1										1				2		1	
	<i>Negaprion brevirostris</i>	S						1											2									1	
	<i>Rhizoprionodon terraenovae</i>	G	3				2		9		7	6	1			1	2		1				1		1	1	3	4	
Sphyrnidae																													
	<i>Sphyrna lewini</i>	G																2											
	<i>Sphyrna tiburo</i>	T																		1									
		G								1		2				1			1				1		3				
Dasyatidae																													
	<i>Dasyatis sabina</i>	T				1					1			4	4											1	1		
		G	1		1				3															1				1	
Rhinopteridae																													
	<i>Rhinoptera bonasus</i>	T																								2			
		G				6	11	1	1					1		5	5	3					1		5				
Elopidae																													
	<i>Elops saurus</i>	S										3											3				1		
		G	1						2	1	3	4	2						1				5	6		4	1		
Engraulidae																													
	<i>Anchoa hepsetus</i>	S																		58			15		151	41		25	
		T	50	15			1	5			12	1					2		71	241	2	23	26	17	1	1	770	29	
	<i>Anchoa mitchilli</i>	S						2	9							5	51	94		3	9				239	26			
		T				251	35	5					99	234	2	165	58	2				3							
Clupeidae																													
	<i>Alosa chrysochloris</i>	G													1														
	<i>Brevoortia patronus</i>	S					1													6		1							
	<i>Harengula jaguana</i>	S																		2	1	58	235	5	1	171	303		
		T									7									4			1	1	11				
		G						1		45	19	7					2		2	2				9	17		7	22	15
	<i>Opisthonema oglinum</i>	T	12					9					2					1		1									
		G								176	1	1			21				6				1	14					
	<i>Sardinella aurita</i>	S																	13										
		T	2																										

# Appendix I (continued)

	2003		2004										2005							2006				2007			2008	
	October (14-16)	November (10-12)	January (13-15)	March (6-7)	March (28-29)	April (6-8)	May (18-19)	June (8-10)	July (6-8)	August (3-4)	September (9-10)	November (8-9)	January (5-7)	February (11-12)	March (23-24)	April (14-15)	May (18-19)	June (16-17)	August (8-9)	May (15-17)	June (18-20)	August (25-27)	September (15-16)	May (21-22)	July (2-3)	September (2-3)	May (24-26)	
Ariidae																												
<i>Ariopsis felis</i>	S						2				3	4						2	1	3				1	3	1	1	
	T	8	6		3	1	4		2		4	11					1			20	11	2		2	1			
	G	3	1		25	4	12	50	56	70	11	13	2		4	10	11	59	20	20		27	42	18	50	18	109	
Synodontidae																												
<i>Synodus foetens</i>	S	2	1														5		1	1	1			2	2		5	
	T	3	9	5						1							1				2	2	7		4	4	2	
Phycidae																												
<i>Urophycis floridana</i>	T				1		1																					
Batrachoididae																												
<i>Opsanus beta</i>	S	3									2																	
Antennariidae																												
<i>Histrio histrio</i>	S																										1	
Mugilidae																												
<i>Mugil cephalus</i>	S		9	1		5			6	15			1	1	2	10	2	34	12	11		5	1	3		13		
<i>Mugil curema</i>	S			17				1			15	6		11			59		15		34	9	1	171	621	86	850	
	G																				1							
Atherinopsidae																												
<i>Menidia beryllina</i>	S	20		45	6	7	2	13	4	18	44	62	1	126		12	37	18	42	178	10	2	619	29	146	754	61	636
	T			9	3									5														
Belonidae																												
<i>Strongylura marina</i>	S									1			1								4				2			
	G							1									1						1				1	
Hemiramphidae																												
<i>Hyporhamphus meeki</i>	S						4	6			3					5	4	1	12	10	10	4	6			1		
	G	1																		1				1				
Fundulidae																												
<i>Adinia xenica</i>	S	26		4	4				2																			
<i>Fundulus grandis</i>	S	12	12	37	4	1			2		6	3	48	1	3	1	2				3		26			17		
<i>Fundulus similis</i>	S	19	2	77	30	15	3	6	12	8	4		14		26	5	39	11	24				51	61	139	141	166	
<i>Lucania parva</i>	S			5	31	3	1	1	5	2	7				2		6	3	1							2	1	
Poeciliidae																												
<i>Poecilia latipinna</i>	S		2	2					1																			
Cyprinodontidae																												
<i>Cyprinodon variegatus</i>	S	9	3	256	53	97		3	21	19	36		114	4	43	3	24	3							116	4	25	
Syngnathidae																												
<i>Hippocampus erectus</i>	S																	1										
	T			1									2														1	
<i>Hippocampus zosterae</i>	S				1																							
<i>Syngnathus floridae</i>	S		12											1			16	6										
	T					4																						
<i>Syngnathus louisianae</i>	S	2															1	3	3			28	8	2	3		27	
	T	1						1		1							1			8		1	2		9	9	6	

Appendix I (continued)

	2003		2004										2005								2006				2007			2008
	October (14-16)	November (10-12)	January (13-15)	March (6-7)	March (28-29)	April (6-8)	May (18-19)	June (8-10)	July (6-8)	August (3-4)	September (9-10)	November (8-9)	January (5-7)	February (11-12)	March (23-24)	April (14-15)	May (18-19)	June (16-17)	August (8-9)	May (15-17)	June (18-20)	August (25-27)	September (15-16)	May (21-22)	July (2-3)	September (2-3)	May (24-26)	
<i>Syngnathus scovelli</i>	S	3	2	2				1					1			2		9		1	3	5		2	1			
	T			3	2			2				1					1										1	
Triglidae																												
<i>Prionotus scitulus</i>	T																					1						
<i>Prionotus tribulus</i>	S	1																										
	G																							1				
Serranidae																												
<i>Diplectrum bivittatum</i>	S																				6							
	T	1																			2	1	2					
<i>Mycteroperca bonaci</i>	T																								1			
<i>Mycteroperca microlepis</i>	T																					1						
Pomatomidae																												
<i>Pomatomus saltatrix</i>	S									1																		
	G							2	1						1											2		
Echeneidae																												
<i>Echeneis naucrates</i>	S																							1				
	T						1		1	3								1										
	G	1			1					2								1			1			1				
Rachycentridae																												
<i>Rachycentron canadum</i>	T									1																		
Carangidae																												
<i>Caranx crysos</i>	T															1												
	G							2		1																		
<i>Caranx hippos</i>	S								1								1				5			1	11	1	2	
	T																				1							
	G																					1						
<i>Chloroscombrus chrysurus</i>	S																				1				1			
	T	20	27	1			12	5	8	5	46	14		1		2	110	20	99	9	1	8	9		4	21	8	
	G						1	3	1						1	1	10		9						7	1	2	
<i>Oligoplites saurus</i>	S								3		1							8			16	44	20		81	42		
	G						5	12	13							11	8		1		13	1		13		3		
<i>Selene setapinnis</i>	T										1								13						1			
<i>Selene vomer</i>	S																	1										
	T	1						1																		2		
<i>Trachinotus carolinus</i>	S																1		7	1	1		2					
	T																									17		
<i>Trachinotus falcatus</i>	S																							4				
<i>Trachurus lathami</i>	T					1																						
Lutjanidae																												
<i>Lutjanus campechanus</i>	T																				1							
<i>Lutjanus griseus</i>	S	5																19			1	102		3	77			
	T	1																				57			12			

Appendix I (continued)

		2003		2004										2005							2006			2007			2008	
		October (14-16)	November (10-12)	January (13-15)	March (6-7)	March (28-29)	April (6-8)	May (18-19)	June (8-10)	July (6-8)	August (3-4)	September (9-10)	November (8-9)	January (5-7)	February (11-12)	March (23-24)	April (14-15)	May (18-19)	June (16-17)	August (8-9)	May (15-17)	June (18-20)	August (25-27)	September (15-16)	May (21-22)	July (2-3)	September (2-3)	May (24-26)
<i>Lutjanus synagris</i>	S																		1		6	22	10		8	8		
	T	6																	2			5	85			58		
	G																						3					
Gerreidae																												
<i>Eucinostomus gula</i>	S	69	48						60	46	52							211	257		494	756	625		163	680		
	T	90	75	1					23	114	29							1	935		2	614	565			810		
Haemulidae																												
<i>Orthopristis chrysoptera</i>	S										33											60		4	11	24	7	
	T	6					71	6	53	7		6					6	5		6	25		14	29	125	47	61	
	G	3								1	45							2				4					2	
Sparidae																												
<i>Archosargus probatocephalus</i>	S	5			1				1									9	5		5		1	2	76	3	9	
	T	1																					1			2		
<i>Lagodon rhomboides</i>	S	187	33	1	11	55	130	292	276	737	345	1127	144	16	7	406	120	896	603	313	840	480	330	369	1369	1409	1795	1743
	T	515	73		26	47	170	2203	682	1624	241	27	671	39	12	1	2	295	155	8	196	1105	11	305	217	234	369	162
	G	159	32					2	2	11	12	28	2	1				4	7	2	2		22	19	2	11	27	5
Sciaenidae																												
<i>Bairdiella chrysoura</i>	S	13			2			2	1		7					4			20	35		100	85	38		150	20	152
	T	379		2	1				51	2	1	11	1		4			4	3	3	291		557			9		
	G							1				1	2			1							1	1	4	1		1
<i>Cynoscion arenarius</i>	S																2											
	T	1				1						1																
<i>Cynoscion nebulosus</i>	G	5								3				2	1	2							2	3			49	
	S	12									1	2					1		2	9		1	3	8		6	5	
	T				1								1		1													
<i>Leiostomus xanthurus</i>	G	9	1			1	2	3	10	1	2	3	1	4		1	1	10	1			3	5	3	7	7		
	S	1		27	154	119	124	24	6	4	77		4	7	122	45	77	11	1	15	4		1	124	74	8	537	
	T	4					40	15	19			6	3	1			1	2			23		7	1	5		39	
<i>Menticirrhus americanus</i>	G	6	1					5	16	79	71	4	1	5				10	12				7	31		3	122	
	S																					1				31		
	T											1																
<i>Menticirrhus littoralis</i>	G								4	1				1								2	2	1	5	10		
	T			1																								
<i>Menticirrhus saxatilis</i>	G																										2	
	T																					1	2			1		
<i>Micropogonias undulatus</i>	G									1												3	1		3	4		
	T																											
<i>Pogonias cromis</i>	G				4									1		5												
<i>Sciaenops ocellatus</i>	S	3	4		7		3	1					12	1	10		2	2									3	
<i>Stellifer lanceolatus</i>	T											2																
Pomacentridae																												
<i>Abudefduf saxatilis</i>	S																									1	1	


Appendix I (continued)





	2003		2004										2005							2006				2007			2008
	October (14-16)	November (10-12)	January (13-15)	March (6-7)	March (28-29)	April (6-8)	May (18-19)	June (8-10)	July (6-8)	August (3-4)	September (9-10)	November (8-9)	January (5-7)	February (11-12)	March (23-24)	April (14-15)	May (18-19)	June (16-17)	August (8-9)	May (15-17)	June (18-20)	August (25-27)	September (15-16)	May (21-22)	July (2-3)	September (2-3)	May (24-26)
Blenniidae																											
<i>Chasmodes saburrae</i>	S	15		1							3									1							
	T				1			5																1	1		
<i>Hypsoblennius henz</i>	S																					1					
	T						1															1					
Gobiidae																											
<i>Bathygobius soporator</i>	S	1																							16	10	
<i>Ctenogobius boleosoma</i>	S	9		4											1	21								14	1	14	
<i>Ctenogobius shufeldti</i>	S																									126	
<i>Evorthodus lyricus</i>	S	1	2														1	1				5		1			
<i>Gobionellus oceanicus</i>	S								1					4							1						
<i>Gobiosoma bosc</i>	S	1																									
<i>Gobiosoma robustum</i>	S	3					2						1			2	2					2					7
	T					1		1																			
<i>Microgobius gulosus</i>	S		3		5	2	1																				
Ephippidae																											
<i>Chaetodipterus faber</i>	T																				1						
	G																				1						
Sphyraenidae																											
<i>Sphyraena barracuda</i>	S									1	1					2	1	1				2	1	1			
	T						2								1	1											
<i>Sphyraena guachancho</i>	S								1											1	1			2	6		
	T					1																					
Scombridae																											
<i>Scomberomorus maculatus</i>	G	4	16		14	1	3	5	7	1	8	3	2		5	4		4			2	2		17	5	2	
Stromateidae																											
<i>Peprilus burti</i>	S				1																						
	T			1		2									8												
<i>Peprilus paru</i>	S																	1									
Paralichthyidae																											
<i>Ancylosetta quadrocellata</i>	T															1											
	S	2							1				1	1		3	15	3	2	1	3		1	10	7		31
<i>Citharichthys spilopterus</i>	T	1	1																						1	1	
	S						2													1							
<i>Etropus crossotus</i>	S	1				1									1		1							1			
	T								1																		
Cynoglossidae																											
<i>Symphurus plagiusa</i>	S	2																						1			3
	T			1																							
Monacanthidae																											
<i>Aluterus scriptus</i>	T							2																	2		
<i>Stephanolepis hispidus</i>	S																4				6	2	1		1		
	T	1						1	4			2						2			1		3		8	8	1

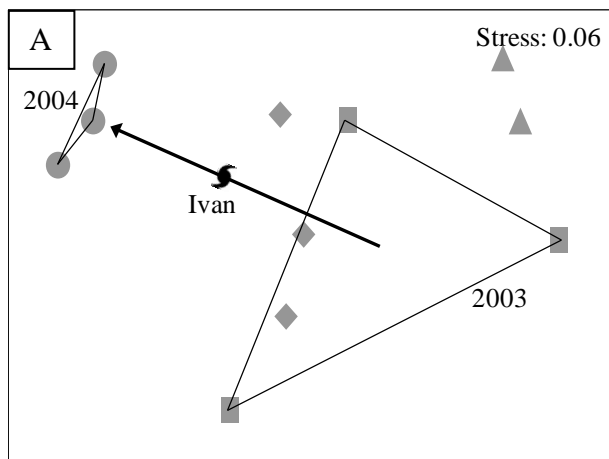




Appendix I (continued)

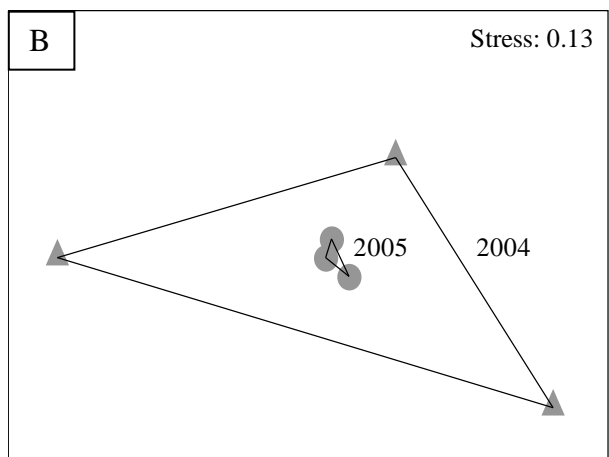
		2003	2004										2005					2006			2007			2008
		October (14-16) November (10-12) January (13-15) March (6-7) March (28-29) April (6-8) May (18-19) June (8-10) July (6-8) August (3-4) September (9-10) November (8-9)																						
Ostraciidae																								
	<i>Acanthostracion quadricornis</i>	T		1	1															3				
	<i>Lactophrys trigonus</i>	T	3																					
Tetraodontidae																								
	<i>Sphoeroides parvus</i>	S			1								1											1
		T					1				1								2					
Diodontidae																								
	<i>Chilomycterus schoepfii</i>	S						1										1			2			
		T	4	2			3		6		4	1	3			1		1			7	2		




Appendix II. Multidimensional scaling (MDS) plots of fish assemblages collected at different sites and habitat types during same months of different years. The arrows show direction of assemblage change, in multivariate space, over time. Landfalls of hurricanes Ivan (16 September 2004) and Katrina (29 August 2005) are represented by  when indicated.

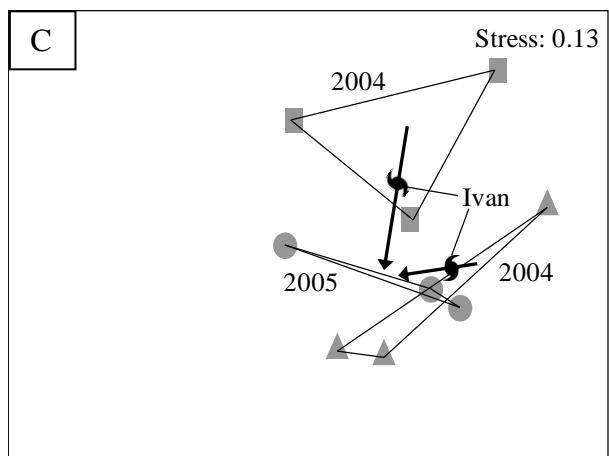
A) MDS plot of fish assemblages collected at sites C1, C2, and C3 in near shore habitats during November of different years. Symbols represent sites and dates collections were made:  = site C1, 10-12 Nov 2003;  = site C2, 10-12 Nov 2003;  = site C3, 10-12 Nov 2003;  = site C2, 8-9 Nov 2004. One sampling attempt at site C1 during Nov 2003 produced no fishes. No collections were made at site C1 and C3 during November 2004 due to inclement weather conditions.



B) MDS plot of fish assemblages collected at site C1 in near shore habitats during March of different years. Symbols represent dates collections were made:  = 28-29 Mar 2004;  = 23-24 Mar 2005. Landfall of Hurricane Ivan occurred on 16 September 2004.

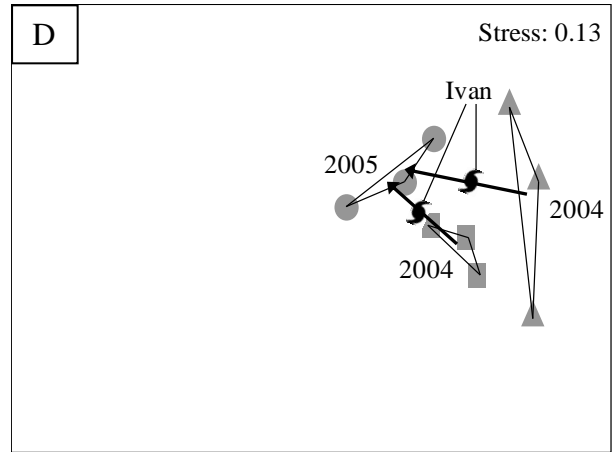


C) MDS plot of fish assemblages collected at site C2 in near shore habitats during March of different years. Symbols represent sites and dates collections were made:  = 6-7 Mar 2004;  = 28-29 Mar 2004;  = 23-24 Mar 2005.

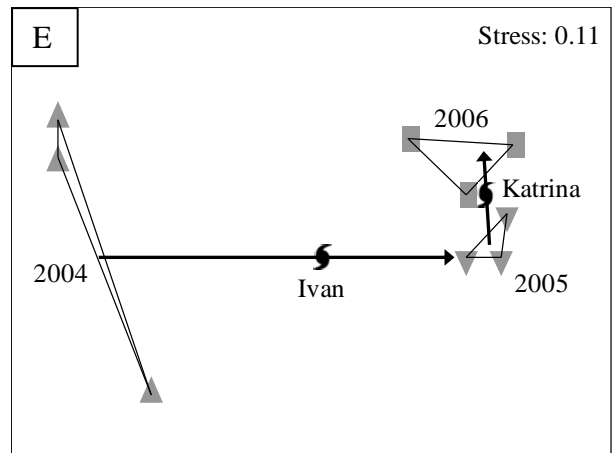


Appendix II (continued)

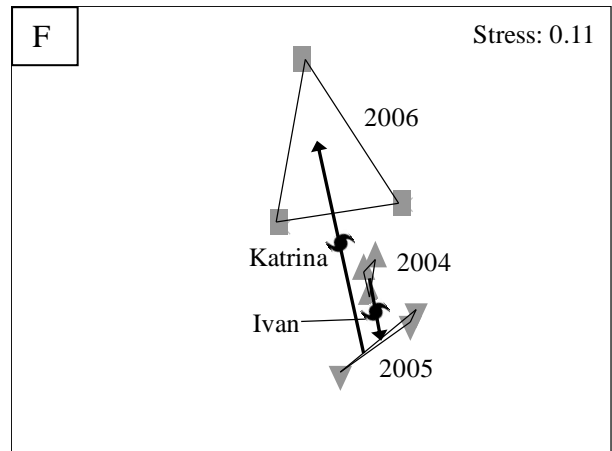
D) MDS plot of fish assemblages collected at site C3 in near shore habitats during March of different years. Symbols represent sites and dates collections were made: ▲ = 6-7 Mar 2004; ■ = 28-29 Mar 2004; ● = 23-24 Mar 2005.



E) MDS plot of fish assemblages collected at site C1 in near shore habitats during June of different years. Symbols represent dates collections were made: ▲ = 8-10 Jun 2004; ▼ = 16-17 Jun 2005; ■ = 18-20 Jun 2006.

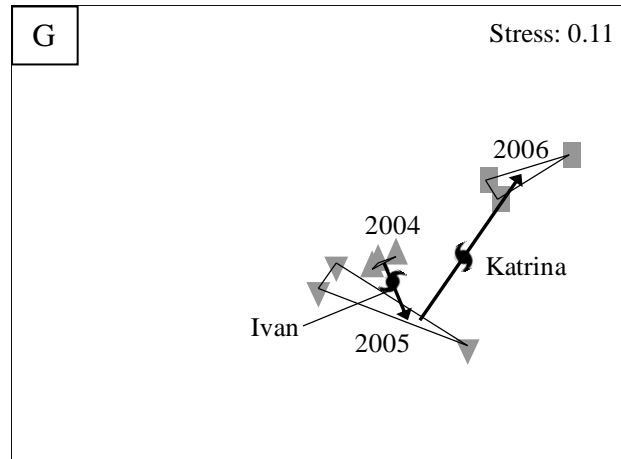


F) MDS plot of fish assemblages collected at site C2 in near shore habitats during June of different years. Symbols represent dates collections were made: ▲ = 8-10 Jun 2004; ▼ = 16-17 Jun 2005; ■ = 18-20 Jun 2006.

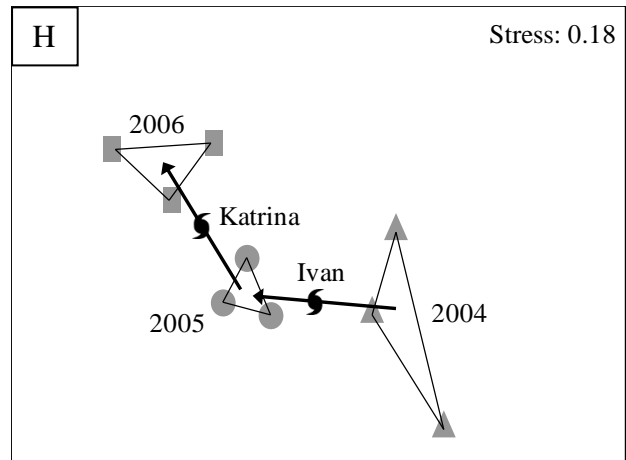


Appendix II (continued)

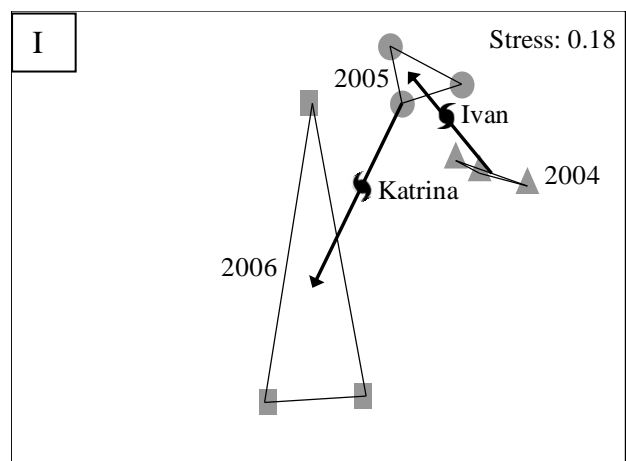
G) MDS plot of fish assemblages collected at site C3 in the near shore habitat during June of different years. Symbols represent dates collections were made: ▲ = 8-10 Jun 2004; ▼ = 16-17 Jun 2005; ■ = 18-20 Jun 2006.



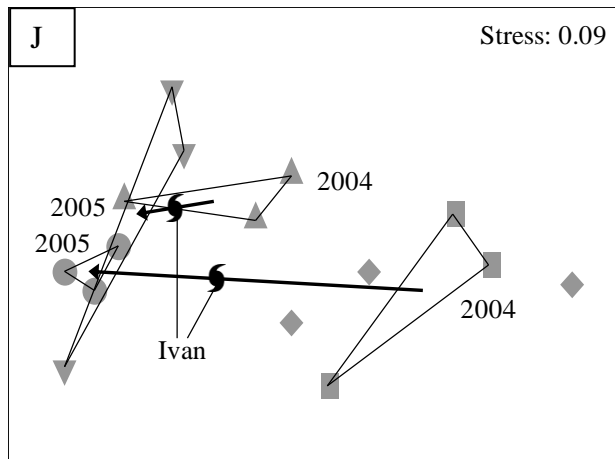
H) MDS plot of fish assemblages collected at site C1/C4 in the near shore habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ● = 8-9 Aug 2005; ■ = 25-27 Aug 2006.



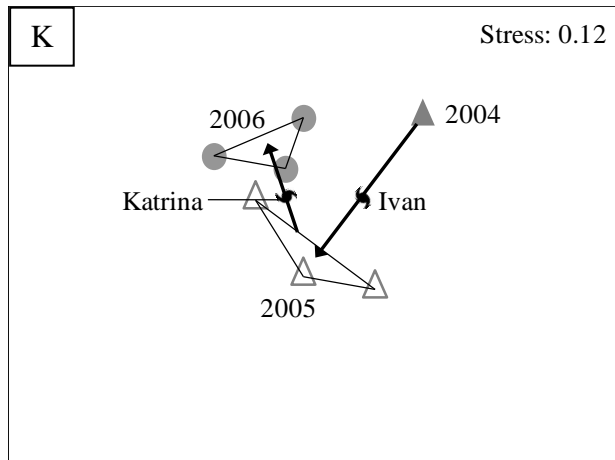
I) MDS plot of fish assemblages collected at site C2 in the near shore habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ● = 8-9 Aug 2005; ■ = 25-27 Aug 2006.



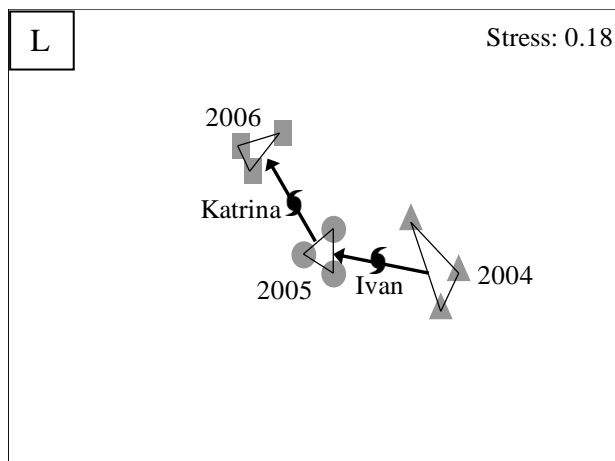
J) MDS plot of fish assemblages collected at site C2 in the near shore habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ● = 8-9 Aug 2005; ■ = 25-27 Aug 2006.



K) MDS plot of fish assemblages collected at sites C1, C2 and C3 in the demersal seagrass habitat during November of different years. Symbols represent sites and dates collections were made: ▲ = site C2, 14-16 Nov 2003; ■ = site C3, 14-16 Nov 2003; ▼ = site C2, 8-9 Nov 2004; ● = site C3, 8-9 Nov 2004. Additionally, ◆ = site C1, 14-16 Nov 2003; however, site C1 collections during November 2004 were empty.

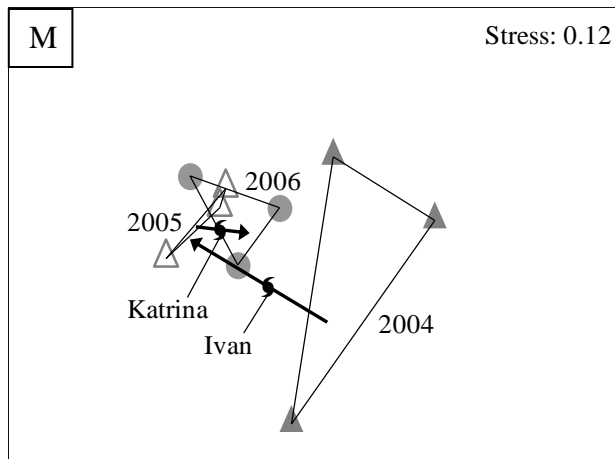


L) MDS plot of fish assemblages collected at site C1/C4 in the demersal seagrass habitat during the months of August. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; △ = 8-9 Aug 2005; ● = 25-26 Aug 2006. Two replicates from August 2004 were empty.

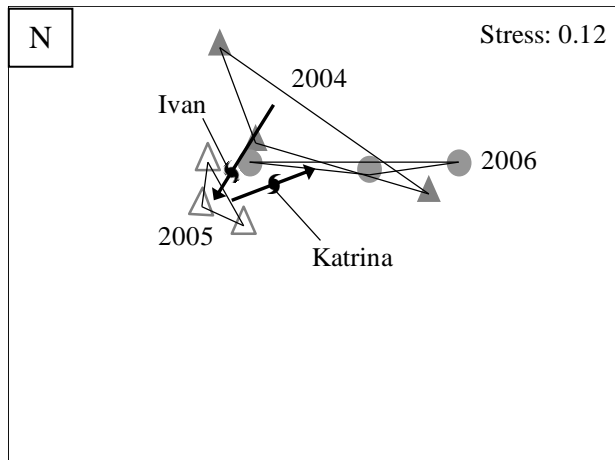


Appendix II (continued)

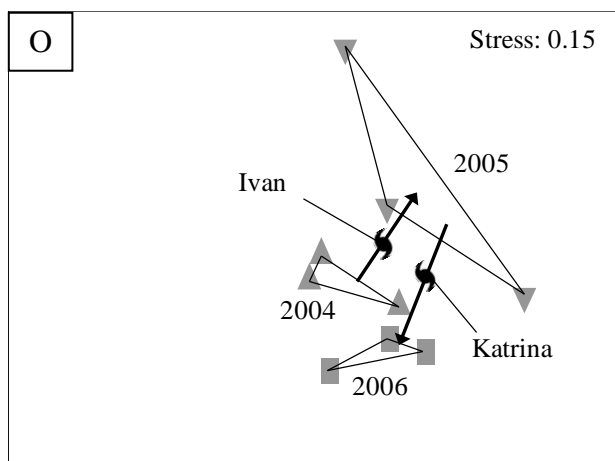
M) MDS plot of fish assemblages collected at site C2 in the demersal seagrass habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; △ = 8-9 Aug 2005; ● = 25-26 Aug 2006.



N) MDS plot of fish assemblages collected at site C3 in the demersal seagrass habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; △ = 8-9 Aug 2005; ● = 25-26 Aug 2006.

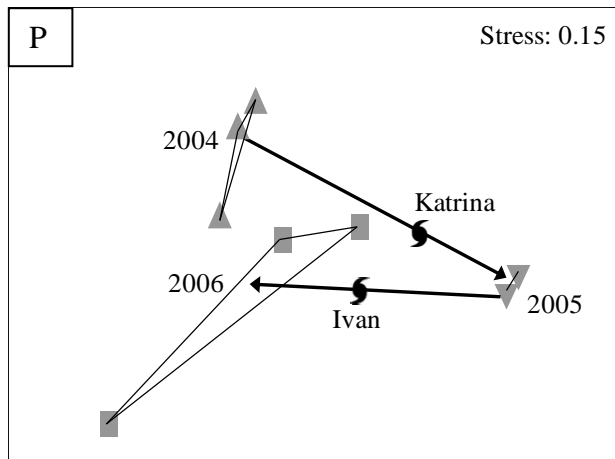


O) Multidimensional scaling plot of fish assemblages collected at site C1/C4 in the deep intertidal seagrass habitat during August of different years. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ▼ = 8-9 Aug 2005; ■ = 25-27 Aug 2006.

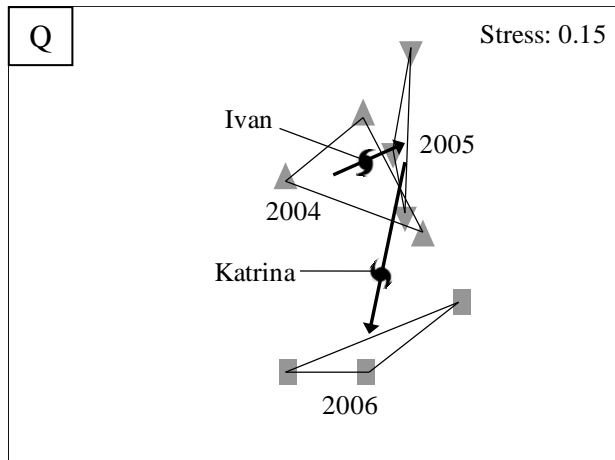


Appendix II (continued)

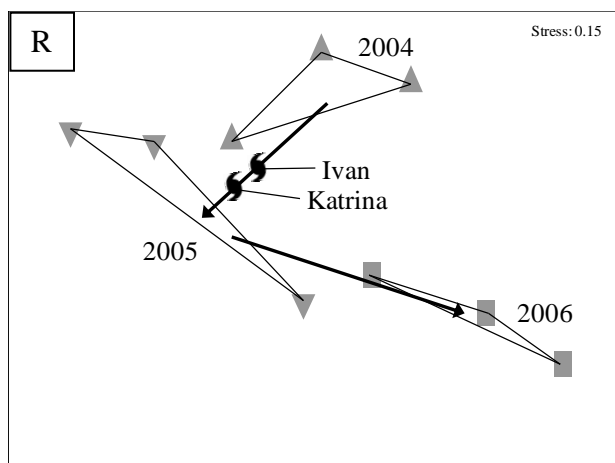
P) MDS plot of fish assemblages collected at site C2 in the deep intertidal seagrass habitat during the months of August. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ▼ = 8-9 Aug 2005; ■ = 25-27 Aug 2006. One replicate during Aug 2005 was empty.



Q) MDS plot of fish assemblages collected at site C3 in the deep intertidal seagrass habitat during the months of August. Symbols represent dates collections were made: ▲ = 3-4 Aug 2004; ▼ = 8-9 Aug 2005; ■ = 25-27 Aug 2006.

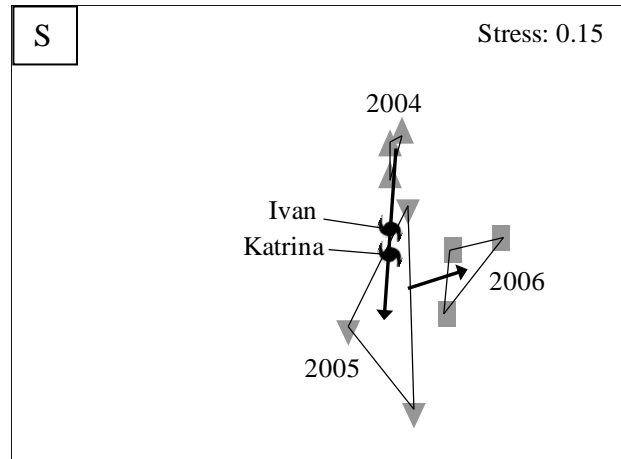


R) MDS plot of fish assemblages collected at site C1 in the deep intertidal seagrass habitat during the months of September. Symbols represent dates collections were made: ▲ = 9-10 Sep 2004; ▼ = 15-16 Sep 2006; ■ = 2-3 Sep 2007.

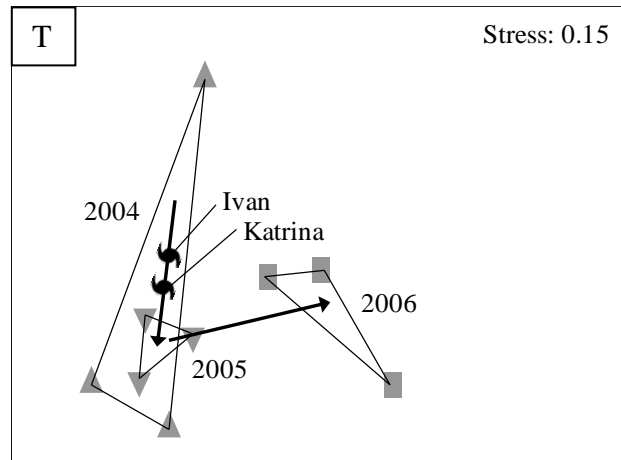


## Appendix II (continued)

S) MDS plot of fish assemblages collected at site C2 in the deep intertidal seagrass habitat during September of different years. Symbols represent dates collections were made: ▲ = 9-10 Sep 2004; ▼ = 15-16 Sep 2006; ■ = 2-3 Sep 2007.



T) MDS plot of fish assemblages collected at site C3 in the deep intertidal seagrass habitat during September of different years. Symbols represent dates collections were made: ▲ = 9-10 Sep 2004; ▼ = 15-16 Sep 2006; ■ = 2-3 Sep 2007.





Appendix III. Fish species collected from the Chandeleur Islands during two ichthyofaunal surveys: 1) Tulane University from March 1969-November 1971 (Laska, 1973) and 2) University of New Orleans (UNO) from October 2003-June 2008. Only samples collected by Laska (1973) in seagrass or during May, June, or July in beach, pool or lagoon habitats were used. Samples used by UNO were those collected in the near shore seagrass habitat during a recent ichthyofaunal survey and additional samples that were collected by UNO in beach, pool, and lagoon habitats during May and June 2008. Species occurrence in a collection is denoted by an X with non-occurrences denoted by an O.

<b>Family</b>	<b>Species</b>	<b>Tulane</b>	<b>UNO</b>
Carcharhinidae	<i>Negaprion brevirostris</i>	X	X
	<i>Rhizoprionodon terraenovae</i>	X	O
Dasyatidae	<i>Dasyatis sabina</i>	X	O
Gymnuridae	<i>Gymnura micrura</i>	X	O
Rhinopteraidae	<i>Rhinoptera bonasus</i>	O	X
Elopidae	<i>Elops saurus</i>	X	X
Ophichthidae	<i>Myrophis punctatus</i>	X	O
Engraulidae	<i>Anchoa cubana</i>	X	O
	<i>Anchoa hepsetus</i>	X	X
	<i>Anchoa lyolepis</i>	X	O
	<i>Anchoa mitchilli</i>	X	X
Clupeidae	<i>Brevoortia patronus</i>	X	X
	<i>Harengula jaguana</i>	X	X
	<i>Sardinella aurita</i>	O	X
Ariidae	<i>Ariopsis felis</i>	X	X
Synodontidae	<i>Synodus foetens</i>	X	X
Ophidiidae	<i>Ophidion marginatum</i>	X	O
Phycidae	<i>Urophycis floridana</i>	X	O
Batrachoididae	<i>Opsanus beta</i>	X	X
Antennariidae	<i>Histrio histrio</i>	O	X
Mugilidae	<i>Mugil cephalus</i>	X	X
	<i>Mugil curema</i>	X	X
Atherinopsidae	<i>Membras martinica</i>	X	X
	<i>Menidia beryllina</i>	X	X
Belonidae	<i>Strongylura marina</i>	X	X
Hemiramphidae	<i>Hemirampus brasiliensis</i>	X	O
	<i>Hyporhamphus meeki</i>	O	X
Fundulidae	<i>Adinia xenica</i>	X	X
	<i>Fundulus grandis</i>	X	X
	<i>Fundulus jenkinsi</i>	X	O
	<i>Fundulus pulvereus</i>	X	O
	<i>Fundulus similis</i>	X	X
	<i>Lucania parva</i>	X	X
Poeciliidae	<i>Poecilia latipinna</i>	X	X

Appendix III (continued)

Family	Species	Tulane	UNO
Cyprinodontidae	<i>Cyprinodon variegatus</i>	X	X
Syngnathidae	<i>Anarchopterus criniger</i>	X	O
	<i>Hippocampus erectus</i>	O	X
	<i>Hippocampus zosterae</i>	X	X
	<i>Syngnathus floridae</i>	X	X
	<i>Syngnathus louisianae</i>	X	X
	<i>Syngnathus scovelli</i>	X	X
Triglidae	<i>Prionotus rubio</i>	X	O
	<i>Prionotus tribulus</i>	X	X
Serranidae	<i>Diplectrum bivittatum</i>	O	X
Pomatomidae	<i>Pomatomus saltatrix</i>	O	X
Echeneidae	<i>Echeneis naucrates</i>	O	X
Rachycentridae	<i>Rachycentron canadum</i>	O	X
Carangidae	<i>Caranx hippos</i>	X	X
	<i>Chloroscombrus chrysurus</i>	X	X
	<i>Oligoplites saurus</i>	X	X
	<i>Selene setapinnis</i>	X	O
	<i>Selene vomer</i>	O	X
	<i>Trachinotus carolinus</i>	X	X
	<i>Trachinotus falcatus</i>	O	X
Lutjanidae	<i>Lutjanus campechanus</i>	O	X
	<i>Lutjanus griseus</i>	X	X
	<i>Lutjanus synagris</i>	O	X
Gerreidae	<i>Eucinostomus gula</i>	X	X
Haemulidae	<i>Orthopristis chrysoptera</i>	X	X
Sparidae	<i>Archosargus probatocephalus</i>	X	X
	<i>Lagodon rhomboides</i>	X	X
Polynemidae	<i>Polydactylus octonemus</i>	X	O
Sciaenidae	<i>Bairdiella chrysoura</i>	X	X
	<i>Cynoscion arenarius</i>	X	X
	<i>Cynoscion nebulosus</i>	X	X
	<i>Larimus fasciatus</i>	X	X
	<i>Leiostomus xanthurus</i>	X	X
	<i>Menticirrhus americanus</i>	X	X
	<i>Menticirrhus littoralis</i>	X	X
	<i>Menticirrhus saxatilis</i>	X	X
	<i>Micropogonias undulatus</i>	X	O
	<i>Pogonias cromis</i>	X	X
	<i>Sciaenops ocellatus</i>	X	X
Pomacentridae	<i>Abudefduf saxatilis</i>	O	X
Blenniidae	<i>Chasmodes saburrae</i>	X	X
	<i>Hypsoblennius hentz</i>	X	X
	<i>Hypsoblennius ionthas</i>	X	O

## Appendix III (continued)

<b>Family</b>	<b>Species</b>	<b>Tulane</b>	<b>UNO</b>
Eleotridae	<i>Eleotris amblyopsis</i>	X	O
	<i>Erotelis smaragdus</i>	X	O
Gobiidae	<i>Bathygobius soporator</i>	O	X
	<i>Ctenogobius boleosoma</i>	X	X
	<i>Ctenogobius shufeldti</i>	O	X
	<i>Evorthodus lyricus</i>	X	X
	<i>Gobionellus oceanicus</i>	X	X
	<i>Gobiosoma bosc</i>	X	X
	<i>Gobiosoma robustum</i>	X	X
	<i>Microgobius gulosus</i>	X	X
Ephippidae	<i>Chaetodipterus faber</i>	X	X
Sphyraenidae	<i>Sphyraena barracuda</i>	X	X
	<i>Sphyraena guachancho</i>	O	X
Trichiuridae	<i>Trichiurus lepturus</i>	X	O
Scombridae	<i>Scomberomorus maculatus</i>	X	X
Stromateidae	<i>Peprilus burti</i>	O	X
	<i>Peprilus paru</i>	O	X
Paralichthyidae	<i>Ancylopsetta quadrocellata</i>	X	O
	<i>Citharichthys macrops</i>	X	O
	<i>Citharichthys spilopterus</i>	X	X
	<i>Etropus crossotus</i>	O	X
	<i>Paralichthys albigutta</i>	X	O
	<i>Paralichthys dentatus</i>	O	X
	<i>Paralichthys lethostigma</i>	X	X
Cynoglossidae	<i>Symphurus plagiosa</i>	X	X
Monacanthidae	<i>Aluterus schoepfii</i>	X	O
	<i>Monacanthus ciliatus</i>	X	O
	<i>Stephanolepis hispidus</i>	X	X
Ostraciidae	<i>Acanthostracion quadricornis</i>	X	O
Tetraodontidae	<i>Sphoeroides parvus</i>	O	X
Diodontidae	<i>Chilomycterus schoepfii</i>	X	X

## Vita

Mark Chadwick Ellinwood (“Chad”) was born March 20, 1980 in New Orleans, Louisiana. Chad attended Salmen High School where he played on the soccer and golf teams while spending his weekends hunting and fishing with his grandfather Charles “Cut” Nunez in the Honey Island Swamp and lower Lake Pontchartrain basin. In 2003, Chad received his B.S. in secondary biology education from Southeastern Louisiana University in Hammond, Louisiana. During the summer of 2004, Chad worked under Dr. Ron Kneib as an intern with the University of Georgia Marine Institute on Sapelo Island, Georgia. Chad’s graduate career began in the University of New Orleans Biology Department as a research assistant in Dr. Bernard Rees’ lab. Chad took a year off school after Hurricane Katrina to help rebuild family and friends houses in Slidell before taking a 3 month sailing and scuba diving trip in the Western Pacific Ocean. He returned to UNO as a research assistant in the Pontchartrain Institute for Environmental Sciences Nekton Research Lab where he worked throughout the remainder of his graduate career. Chad’s hobbies include scuba diving, under water and terrestrial photography, hiking, camping, playing tennis and traveling.