

2013

The Spacial and Temporal Community Structure of Ichthyoplankton in a Northeast Florida Estuary : A Study of Ingress at a Faunal Boundary

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THE SPATIAL AND TEMPORAL COMMUNITY STRUCTURE OF
ICHTHYOPLANKTON IN A NORTHEAST FLORIDA ESTUARY: A STUDY OF
INGRESS AT A FAUNAL BOUNDARY

Breanna Marie Korsman

A thesis submitted to the Department of Biology
in partial fulfillment of the requirements for the degree of

Master of Science in Biology

University of North Florida

August 2013

CERTIFICATE OF APPROVAL

The Spatial and Temporal Community Structure of Ichthyoplankton in a Northeast
Florida Estuary: A Study of Ingress at a Faunal Boundary

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ACKNOWLEDGEMENTS

Foremost, I would like to thank my advisor Dr. Matt Kimball for providing guidance in designing and carrying out the project that would become my M.S. thesis. Your motivation and high expectations are qualities that I hope to carry with me through the rest of my career. Additional thanks go out to my committee members: Dr. Courtney Hackney, Dr. Eric Johnson and Dr. Frank Hernandez. Thanks for listening to theories and ideas, and for providing great advice on data analysis. Frank – your lab at DISL provided an excellent environment for someone just beginning to learn how to identify larval fish. Thanks to all of you!

Thanks to everyone who helped make my field work possible. Wendy Eash-Loucks, Tom Harding, and the rest of the research staff at the Guana-Tolomato-Matanzas NERR were instrumental in the process. Kurt Foote, Andrew Rich, and Sam Adukiewicz – thanks so much for working with me in establishing and gaining access to my field sites. Your support is appreciated!

To my regulars in the field: Blake Thomas, Cora Johnston and Jessica Landkrohn – thank you so much! You all put in more than your fair share of early mornings, and helped make the work fun. Thanks as well to all of the rest of my volunteers. Many hours of sleep were given up in order to help me complete this project.

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ABSTRACT

Estuaries are widely recognized as important habitats for the early life history stages of commercially and recreationally important marine fish species. In general the estuaries of northeast Florida are understudied, and there is a need to characterize the ichthyoplankton community at this important faunal boundary between temperate and tropical marine zones. To determine community structure and temporal patterns in the distribution and abundance of larval fish ingressing in to the Guana-Tolomato-Matanzas (GTM) estuary through its two inlets (St. Augustine and Matanzas), ichthyoplankton were sampled bi-weekly for one year at both inlets during nighttime spring flood tides beginning in March 2012. Samples were collected with a plankton net (1 m diameter with 1mm mesh) suspended 1 m below the surface in the water column. Over 30,000 individuals were collected, representing 74 taxa. Four families made up 90 % of the collection: Gobiidae (34.8 %), Sciaenidae (26.1 %), Engraulidae (19.3 %), and Gerreidae (9.3 %). Examination of the ichthyoplankton community revealed seasonal trends in species richness and in larval fish density; species richness and larval fish density were generally greatest during the protracted summer season. Spring and summer pulses in recruitment were evident in nearshore summer spawners (e.g., gobiids and engraulids), and winter peaks in recruitment were evident in marine spawned species (e.g., sciaenids, sparids, haemulids). The variety of taxa collected, and the patterns in the seasonal species assemblage of the ichthyoplankton community of the GTM estuary align with its geographical position near a faunal boundary.

INTRODUCTION

Estuaries support abundant and diverse assemblages of fishes and invertebrates, and are broadly recognized as important nursery grounds for the larval and juvenile life history stages of many species (Boehlert and Mundy 1988, Warlen and Burke 1990, Rountree and Able 1997, Able *et al.* 2006). Estuarine environments exhibit high levels of both primary and secondary production, which provide ample food resources for early life history stage organisms (Boesch and Turner 1984, Kneib 1997, Holt and Holt 2000). Additionally, shallow depths, relatively low salinity, and structural complexity provided by estuarine vegetation and oyster reefs may offer protection from predation (Boesch and Turner 1984, Warlen and Burke 1990, Paperno and Brodie 2004). Early life history stage fishes may function as important trophic links between primary production and larger transient (often economically valuable) species (Boesch and Turner 1984, Kneib 1997). Large horizontal transfers of energy take place as many of these species emigrate to spawning grounds or adult habitat in continental shelf waters (Deegan 1993).

Many commercially and recreationally important marine fish species exhibit a wide range of life history strategies, and depend on estuarine habitats for a portion of their development (Able and Fahay 2010). Coastal residents (e.g., gobies, anchovies) are of ecological importance, representing essential forage for larger piscivorous, and recreationally important species found in estuaries (e.g., *Sciaenops ocellatus*, *Cynoscion nebulosus*). A subset of species found temporally in estuaries emigrate from the habitat as juveniles or adults to reproduce in continental shelf waters (e.g., *Brevoortia tyrannus*, *Micropogonias undulatus*, paralichthyid flounders and lutjanid snappers), and are targeted by recreational and commercial fishermen (Able 2005, Able and Fahay 2010).

Newly-spawned larvae or juveniles of these species must be transported across the continental shelf and then into an estuary through a combination of physical and behavioral processes (Sherman *et al.* 1984, Checkley *et al.* 1988, Pietrafesa and Janowitz 1988, Blanton *et al.* 1999, Hare *et al.* 2005, Able and Fahay 2010).

Temporal patterns in abundance of early life history stage estuarine species are dependent on numerous factors. Changes in water temperature are known to trigger spawning events (Olney and Boehlert 1988, Warlen and Burke 1990, Stegmann *et al.* 1999), which could lead to recruitment pulses of larval fishes into estuaries. Climatic and weather events may generate seasonal or episodic wind and circulation patterns that favor onshore movement by early life history stage marine organisms (Checkley *et al.* 1988, Pietrafesa and Janowitz 1988, Hare *et al.* 1999, Epifanio and Garvine 2001). Additionally, seasonal changes in salinity (Sullivan *et al.* 2006), and the cyclic fluctuations in food resource abundance (Stegmann *et al.* 1999) may also contribute to temporal community structure within estuaries. As a result, seasonal shifts in the community structure of ingressing larval fishes should be relatively predictable on broad time scales.

Coastal inlets function as critical corridors, connecting the coastal and open ocean environments to essential fish habitats within estuaries. Many marine fish species must pass through inlets into estuaries as eggs, larvae or early juveniles in order to reach appropriate nursery habitat. Previous studies have documented correlations between the abundance of larval and juvenile fishes at the ocean side of an inlet with abundance within the estuary (Hettler and Hare 1998, Taylor *et al.* 2009), emphasizing the importance of the inlets for movements of large numbers of fishes. Maximum ingress of

early life stage fishes often occurs on nighttime spring tides, when tidal range, and therefore the horizontal advection of water, are greatest (Boehlert and Mundy 1988, Epifanio 1988, Valle-Levinson *et al.* 2009).

Oceanic and atmospheric circulation in the South Atlantic Bight (SAB) is complex and has been most studied in the northern portion of the Bight, in coastal Georgia and the Carolinas (Weber and Blanton 1980, Pietrafesa and Janowitz 1988, Werner *et al.* 1997, Blanton *et al.* 1999, Stegmann *et al.* 1999), while studies examining the Atlantic coast of Florida are fewer in number (Atkinson *et al.* 1983, Hare and Walsh 2007, Leshner 2008). The SAB continental shelf varies in width from a minimum of 30 km off Cape Hatteras, NC, at the northern limit, to 50 km off Cape Canaveral at the southern end, with a maximum of 120 km off Savannah, GA. Circulation conditions on the outer shelf vary with Gulf Stream events, but because of the great distance between the shelf break and the coastline in some locations along the SAB, such as northeast Florida, these events infrequently influence coastal hydrography. Mid- and inner-shelf circulation patterns in this region are primarily impacted by winds, freshwater inflow and pressure gradients (Atkinson *et al.* 1983, Werner *et al.* 1997).

A two-step process has been suggested that allows for the estuarine ingress of larval and juvenile fishes spawned in continental shelf waters or in nearshore environments (Boehlert and Mundy 1988). The first step involves cross-shelf transport to coastal waters and ultimately to the tidal prism of an inlet from the spawning grounds by largely passive mechanisms, such as wind-generated currents, Ekman transport and winter cooling of surface water (Weber and Blanton 1980, Werner *et al.* 1997, Epifanio and Garvine 2001). Once ichthyoplankton reach the inner continental shelf, various

environmental cues (e.g., diel cycles, turbulence associated with tidal oscillations) trigger behavioral changes that enhance the likelihood that the larvae will reach potential nursery grounds (Weinstein *et al.* 1980, Pietrafesa and Janowitz 1988, Forward and Tankersley 2001). These behaviors, coupled with transport by the predominantly southward flowing longshore current, periodic onshore winds, and tidal fluctuations, move the organisms to the vicinity of inlets. Results from particle-tracking models suggest that larvae generally move in through an inlet from a narrow band of water that runs parallel to shore on either side of the inlet, and generally do not enter by direct cross-shelf movements (Blanton *et al.* 1999, Brown *et al.* 2004). Beyond this general pattern, however, it is difficult to broadly describe the movement of organisms through inlets, as several factors interact, making larval ingress a complex process. The orientation of the specific inlet, anthropogenic modifications to the inlet, and the near-inlet bathymetry must be considered in addition to climatic and oceanographic conditions (Seabergh 1988, Werner *et al.* 1997, Hettler and Hare 1998, Hare *et al.* 1999).

US east coast estuaries are dominated by salt marshes, and within the SAB, *Spartina alterniflora* is the predominate emergent intertidal vegetation. Seagrasses are present in the northern and southern portions of the bight, and along the southern extent of the SAB, on the coast of north-central Florida, mangrove stands begin to mix with, and then replace *Spartina* in the emergent zone. As one moves south into Florida, mangrove stands begin to mix with and then replace *Spartina* in the emergent zone (Dame *et al.* 2000, Williams *et al.* in review). Studies spanning a great portion of the SAB have demonstrated the importance of these estuarine environments for the early life history stages of coastal fish species through examination of the seasonal patterns of species

diversity and abundance (Weinstein *et al.* 1980, Hettler and Chester 1990, Allen and Barker 1990, Hettler and Barker 1993, Rountree and Able 1997, Reyier and Shenker 2007). Despite this, the estuaries of northeast Florida have received little attention and thus little is known regarding the ichthyoplankton of the region.

In northeast Florida, toward the southern end of the SAB, the faunal boundary between tropical and temperate marine species occurs (Briggs 1974). The Guana-Tolomato-Matanzas (GTM) estuary, a sub-tropical lagoonal estuary (Valle-Levinson *et al.* 2009) that extends along the northeast coast, is known to host juvenile and adult species common to both marine regions, such as *Centropomus undecimalis*, *Megalops atlanticus*, *Lutjanus griseus*, *Mycteroperca microlepis* and *B. tyrannus* (Turtora and Schotman 2010). Along the Florida coastline, research has disproportionately focused on the Indian River Lagoon of central Florida (Gilmore 1977, Tremain and Adams 1995, Paperno *et al.* 2001, Solomon *et al.* 2006, Reyier and Shenker 2007), but it is unknown whether these species also utilize the GTM estuary in their earliest life history stages. The estuaries of northeast Florida are understudied, and to date there have been no quantitative or qualitative studies of the ichthyoplankton communities in the region.

To better understand the ichthyoplankton community of northeast Florida, early life history stage fishes entering the Guana-Tolomato-Matanzas estuary through its two inlets were sampled on nighttime spring flood tides. The primary objectives of this study were 1) to determine the spatial and temporal assemblage structure of larval fish transported into the estuary; and 2) to relate the observed larval fish recruitment patterns to those reported for geographically proximate estuaries. Examination of the ichthyoplankton community in northeast Florida will provide valuable data for the

southern extent of the SAB and serve to better define the faunal boundary along the southeast US Atlantic coast. Information on the seasonality, abundance, and assemblage structure of ichthyoplankton will provide a baseline to evaluate theories regarding alterations in the timing of migrations and the impacts of the environment and anthropogenic actions on nearshore fish communities (Beck *et al.* 2001). Combined with studies on juvenile and adult nekton in the region, information on ichthyoplankton would also document connectivity between larval, juvenile, and adult habitats in order to more accurately define essential fish habitat.

METHODS

Study Area

Located along the northeast Florida coast, the Guana-Tolomato-Matanzas (GTM) estuary is a narrow and relatively shallow (average depth 2.7 m) lagoonal estuary with two inlets (St. Augustine and Matanzas), connecting it to the Atlantic Ocean (Valle-Levinson *et al.* 2009). The estuary spans approximately 60 km of coast from south of Jacksonville to Marineland, and consists of *Spartina*-dominated marshes as well as mixed marsh-mangrove areas (primarily red and black mangroves). Three main tributaries form the GTM estuary: the Guana and Tolomato Rivers to the north, and the Matanzas River to the south. The Tolomato and Matanzas Rivers also serve as the Intracoastal Waterway for this portion of Florida. The entire GTM estuary is generally well-mixed (Webb *et al.* 2007) with a flushing time (time to exchange 50% of water volume) of about two weeks (Sheng *et al.* 2008). Compared to other estuaries along the US east coast (Neuse River, NC, Winyah Bay, SC, Indian River Lagoon, FL), the GTM estuary receives little

freshwater input and is very narrow east-to-west, which results in a well-mixed water column throughout most of the estuary (Dame *et al.* 2000, Valle-Levinson *et al.* 2009). Both the St. Augustine and Matanzas inlets experience semi-diurnal tides of approximately 1.5 m (Powell *et al.* 2006).

The St. Augustine inlet (29.910089 N, 81.287617 W) is located approximately 2 km north and east of the city of St. Augustine (Fig. 1). The inlet is an important area for boat traffic, and the Army Corps of Engineers maintains the channel at a depth of approximately 5 m. The St. Augustine inlet is a naturally occurring inlet that was cut and stabilized with jetties in 1941 and again in 1957 to prevent the filling of the channel (Dean and O'Brien 1987). Flood tides enter the inlet through the channel and then trifurcate into the Tolomato River, the Matanzas River and Salt Run. The tidal prism for the St. Augustine inlet is approximately $2.5 \times 10^7 \text{ m}^3$ (Powell *et al.* 2006), and the flushing time for the inlet is 2-3 days (Sheng *et al.* 2008).

The Matanzas inlet (29.704889 N, 81.227433 W) lies at the mouth of the Matanzas River, 21 km south of the St. Augustine inlet (Fig. 1). It is one of the only unstructured inlets on the Atlantic coast of Florida, and is characterized by heavy shoaling and the presence of a broad ocean sand bar 1-2 m deep that renders the channel unnavigable for most watercrafts (Dean and O'Brien 1987). Today, the inlet is spanned by a small bridge, which prevents its southward migration. Ninety-five percent of the flood tide prism moves through the channel and into the north arm of the Matanzas River (Davis and Fox 1981). The tidal prism of the Matanzas inlet is approximately $1.4 \times 10^7 \text{ m}^3$ (Powell *et al.* 2006) and the average flushing time for the inlet is 3-4 days (Sheng *et al.* 2008).

Both inlets are primarily tidally-driven, with lesser and intermittent forcing by winds and freshwater inflow (Sheng *et al.* 2008, Valle-Levinson *et al.* 2009). The flow of the longshore current on the ocean side of the inlets is generally to the south, with frequent reversals during the summer months due to shifting wind patterns (Dean and O'Brien 1987). Tidally-driven inlets, such as the St. Augustine and Matanzas inlets, experience flood tides that enter through the channel, and ebb tides that exit over the shoals (Li and O'Donnell 2005). Additionally, the combined impact of tides and a lack of freshwater input results in stronger exchange flows during spring tides, which is different from other inlets in the northern portion of the SAB (Valle-Levinson *et al.* 2009). Along this portion of the northeast Florida coastline the continental shelf is generally wide (approximately 100 km to the shelf break and Gulf Stream).

General Field Sampling Methodology

Ichthyoplankton abundance and community structure were examined by sampling larval and early juvenile fishes (hereafter referred to as larvae) entering the St. Augustine and Matanzas inlets on new and full moon spring tides (i.e., bi-weekly) between March 2012 and February 2013. All sampling was conducted at night, during mid-flood tide, unless otherwise noted (see below). For all field sampling activities, fishes were collected with a General Oceanics circular plankton net (1 m diameter with 1 mm mesh) equipped with a General Oceanics mechanical flowmeter. The flowmeter was mounted in the mouth of the net to record both current speed and volume of water filtered. In addition to the standard bi-weekly sampling, other factors that could potentially influence ichthyoplankton catches, such as sampling location, time of day, sampling depth, and sample duration were also examined at various intervals during the study period.

Ichthyoplankton collections were transported to the laboratory for fixation in 85% ethanol, identification, and quantification. Specimens were identified to the lowest possible taxonomic unit using a stereomicroscope. Standard length (SL) of a random sample of twenty flexion and post-flexion fish of each species or lowest taxonomic group was recorded to the nearest 0.5 mm using digital calipers. Taxon-specific catch was converted to a number of fish per 100 m³ water, and the three replicate samples were averaged by site for each collection date. During each sampling event, data were also collected on abiotic factors including water temperature, salinity, and dissolved oxygen using a handheld YSI at the same depth as sample collection.

Standard Sampling

For the primary focus of this study, ichthyoplankton were sampled at each inlet every two weeks during nighttime spring flood tides from March 2012 through February 2013. Collections were taken from the Fort Matanzas dock, located 1.5 km northwest of the Matanzas inlet, and at the St. Augustine municipal marina dock, located 2 km southwest of the St. Augustine inlet (Fig. 1). The plankton net was suspended 1 m below the surface of the water, in the current, from a fixed point. Three replicate samples were collected during each sampling event, each filtering approximately 100 m³ water.

Trial Sampling

A series of trial sampling efforts were undertaken to examine multiple factors such as sampling location, time of day, sampling depth, and sample duration that may potentially influence larval fish catches.

Inlet Channel Sampling

In order to determine whether sampling inland (1.5-2.0 km) from the inlet provided an accurate sample of the larval fish community (e.g., taxa richness and larval density), fishes were sampled from the middle of the St. Augustine inlet channel proper (300 m wide channel; 0.5 km from the Atlantic Ocean). Water passes the station prior to trifurcating into the Tolomato River, Matanzas River, and Salt Run. Three replicate samples were collected during these events, which occurred on the same dates as standard sampling, during the nighttime flood tide, at intervals of eight weeks beginning in July 2012, for a total of four sampling dates. The Matanzas inlet was not sampled in a similar manner due to safety concerns associated with navigating the shoals at night.

Diel Sampling

To assess diel differences in larval collections, daytime sampling events were conducted from the St. Augustine municipal marina and Fort Matanzas docks for four consecutive bi-weekly collection dates beginning in September 2012. Three replicate samples were collected at each inlet following the standard sampling protocol, and took place on the morning immediately following standard sampling events, during mid-flood tide, commencing after sunrise.

Depth Sampling

A single sample at a depth of 3 m at Fort Matanzas, and 4 m at St. Augustine, which represent water depth at slack low tide, was taken every four weeks during standard sampling events for four months beginning in August 2012, to determine if there was a significant difference in the density of fish, or in taxa richness collected at depth versus the standard 1 m sampling depth.

Extended Sampling Duration

A single ichthyoplankton sample of longer duration (filtering 250 m³ water) was taken every four weeks during standard sampling events at both inlets for four months beginning in September 2012 in order to determine whether the standard sampling protocol (filtering 100 m³ water) was accurately assessing the taxa richness at a depth of 1 m in the water column.

Data Analysis

Ichthyoplankton Data Preparation

Individual specimens were identified to the lowest possible taxonomic unit. Larval engraulids and gobiids less than 8 mm SL, and all gerreids, were especially problematic to identify due to overlapping meristic characteristics and a lack of detailed published descriptions, so individuals of these taxa were identified only to family. Hybridization between the sciaenids *Cynoscion arenarius* and *Cynoscion regalis* has been documented in the study area (Tringali *et al.* 2011), therefore these two species were considered to represent a single species complex for the purpose of this study.

Statistical Analyses

Taxon-specific abundance data were standardized to concentration as a count per 100 m³ water, and averaged by inlet for each sample date. Diversity was measured as taxonomic richness (taxa per sample). The mean monthly concentrations of the top 20 most abundant taxa were classified using non-metric multi-dimensional scaling (MDS). Prior to these analyses, density data were fourth root transformed in order to down-weight the effects of abundant taxa (e.g., engraulids and gobiids), and allow less common taxa to contribute to sample discernment (Thorne *et al.* 1999). A Bray-Curtis similarity matrix (Bray and Curtis 1957) was constructed from the transformed density data prior to

the MDS and further analyses. One-way analyses of similarity (ANOSIM) tests were used to evaluate separation between the ichthyoplankton assemblage at each inlet, and between seasons. MDS was also used to construct an ordination based on taxa to classify seasonal catch based on literature-derived reproductive strategies for each taxon (e.g., shelf-spawned vs. spawned nearshore). All multivariate procedures were performed using PRIMER 6.0 statistical software.

Transformed mean monthly larval densities ($\ln[x+1]$) and taxa richness values for collections were examined using two-way analyses of variance (ANOVA) with inlet and month as factors. Two-way ANOVAs were also conducted to test for differences in abundance of individual taxa at each inlet. Paired t-tests were used to compare the taxa richness of samples filtering 100 m³ vs. 250 m³ water, as well as to compare taxa richness and larval density values of collections made at the surface vs. at depth, between collections obtained during nighttime vs. daytime hours, and between collections from the dock vs. the main channel at the St. Augustine inlet. The paired aspect of this test provides greater statistical power over an unpaired t-test or ANOVA. Multivariate analysis of variance (MANOVA) was employed to examine taxa density differences resulting from location, diel and depth sampling.

RESULTS

Environmental Variables

Surface water temperature, salinity, and dissolved oxygen were similar between the St. Augustine and Matanzas inlets (Kruskal-Wallis, temperature: $p = 0.954$, salinity: $p = 0.193$, dissolved oxygen: $p = 0.273$). Mean water temperature ranged from a low of

16.6 °C in January 2013 to a high of 27.1 °C in September 2012 (Fig. 2). Salinity remained largely euhaline, ranging between 32 and 38 ppt, with observations highest in the spring during prolonged drought conditions (Fig. 2). Dissolved oxygen levels decreased throughout the spring and summer of 2012 to a low of 4.9 mg/L before rising again in the fall (Fig. 2).

Trial Sampling

Inlet Channel Sampling

There were no significant differences in either taxa richness or larval density between samples collected from the channel at the St. Augustine inlet or samples collected from the dock near the St. Augustine inlet (Table 1). One-way MANOVA results comparing concentrations of individual taxa of fish that were represented in all four sampling events (*A. hepsetus*, *A. mitchilli*, *C. boleosoma*, *Gobiosoma* spp., *Gerreidae* spp. and *Symphurus plagiusa*) indicated that no single taxa differed statistically in density when collected at either the dock or the inlet ($F = 3.47$, global $p = 0.097$).

Diel Sampling

Taxa richness and ichthyoplankton density were significantly greater at night than during the day (Table 1). Data were pooled between the inlets, and individual taxa were tested for diel differences in density. Many taxa, including *A. hepsetus*, *Gerreidae* spp., *C. boleosoma*, *Gobiosoma* spp., and *M. undulatus* were caught in greater numbers at night than during the day ($F = 3.69$, global $p = 0.017$, post-hoc tests $p < 0.05$). The two exceptions to this pattern were *A. mitchilli* ($p = 0.092$) and *S. ocellatus* ($p = 0.10$). The average density of ichthyoplankton caught during the day amounted to only 40 % of the

average density caught during nighttime sampling events. Only three taxa (*S. ocellatus*, *M. undulatus* and *Gerreidae* spp.) were present in densities greater than 5 larvae / sample during daytime collections. Average lengths of individuals in the diel collections did not differ significantly between collection times, with the exception of *C. boleosoma*, which was slightly larger at night (ANOVA, $F = 4.90$, $p = 0.049$).

Depth Sampling

Paired t-test results indicated no differences between larval densities or taxa richness observed in samples taken in surface waters vs. those taken deeper in the water column (Table 1). MANOVA results yielded no significant differences ($F = 0.26$, global $p = 0.952$) for any single taxon between the near-surface samples and the deeper-water samples for taxa that were collected during all sampling events: *A. hepsetus*, *A. mitchilli*, *Gerreidae* spp., *Gobiosoma* spp., *C. boleosoma*, *S. ocellatus* and *M. undulatus*.

Extended Sampling Duration

Taxa richness in samples filtering 100 m³ water was compared with taxa richness in samples filtering 250 m³ water to assess whether samples following standard protocol were of sufficient duration to account for the true taxa richness. Tests for differences between taxa richness in standard vs. extended duration samples resulted in non-significant p -values (Table 1).

Standard Sampling

Species Composition

A total of 34,406 larvae were collected during the 12-month study period, representing 74 distinct taxa in 38 families (Tables 2 and 3). Most specimens (82 %) were identifiable to the level of genus or species. A further 17 % were identified to the

family level. Less than 1 % were identifiable only to order, or were not able to be identified at all due to damage to the fish or taxonomic ambiguity. Most taxa (68 %) were shared between the two inlets. Four families comprised 90 % of the total fish caught: Gobiidae (34.8 %), Sciaenidae (26.1 %), Engraulidae (19.3 %), and Gerreidae (9.3 %) (Table 4). Family Sciaenidae was the most speciose, with nine representatives. Twenty-nine taxa were represented by fewer than six individuals. Only 11 taxa comprised more than 1 % of the total catch: the gobies *Ctenogobius boleosoma* (3.43 %), and *Gobiosoma* spp. (27.27 %); the sciaenids *Micropogonias undulatus* (18.10 %), *L. xanthurus* (4.03 %), and *S. ocellatus* (1.76 %); the engraulids *Anchoa hepsetus* (12.71 %), and *Anchoa mitchilli* (2.08 %), the clupeid *B. tyrannus* (2.37 %); gerreids (9.33 %); the sparid *Lagodon rhomboides* (1.18 %), and the haemulid *Orthopristis chrysoptera* (1.65 %). Because species representing gobiid and gerreid genera are present in the study area as juveniles and adults (Turtora and Schotman 2010), the *Gobiosoma* spp. grouping likely represented a combination of *Gobiosoma bosc* and *Gobiosoma ginsburgi*, and the gerreids were likely a mix of species in the genera *Eucinostomus* and *Diapterus*. Individuals identified as *Clupeidae* spp., *Engraulidae* spp., *Gobiidae* spp., or *Sciaenidae* spp. were omitted from abundance rankings, as these taxa likely represented a mix of species, and could have masked other trends in the ichthyoplankton community structure (Tables 2 and 3).

Ichthyoplankton Community Structure and Seasonality

Mean monthly larval concentrations ranged from a low of 19.9 larvae / 100 m³ in October to a high of 144.0 larvae / 100 m³ in August at the St. Augustine inlet and from a low of 27.5 larvae / 100 m³ in June to a high of 3169.4 larvae / 100 m³ in April at the

Matanzas inlet during the study period (Fig. 2). Average taxa richness was lowest in March (4.0) and highest in August (15.0) at the St. Augustine inlet, and was lowest in November (6.0) and highest in May (21.2) at the Matanzas inlet (Fig. 3). Multimodal peaks in larval density and taxa richness were seen over the course of the year (Fig. 3). ANOSIM results indicated that larval assemblages differed significantly between seasons (Global $R = 0.788$, $p < 0.001$). Ordination largely separated the samples according to month or season rather than inlet (Fig. 4). Changes in the taxa assemblage demonstrated a strong seasonal cycle characterized by winter (November - February), spring (March - May), and summer (June - September) ingress periods, with an attenuated fall ingress period of relatively low larval density (October). Taxa sharing similar reproductive patterns were typically collected together (Fig. 5). Shelf-spawning taxa dominated larval collections in the colder months of the year (Fig. 6). Nearshore resident taxa such as engraulids, gobiids, and gerreids dominated collections in the summer months (Fig. 7). *Elops saurus* leptocephali and *Bairdiella chrysoura* larvae were among the few abundant spring-recruiting species. *Sciaenops ocellatus* was the single dominant species collected in the short period of late September through October, defined as the fall season. The paralichthyid *Citharichthys spilopterus* and the goby *C. boleosoma* were collected throughout the year, with peak densities in May for both (Fig. 8).

Winter-Spawning Taxa

Six species (*Archosargus probatocephalus*, *B. tyrannus*, *L. rhomboides*, *L. xanthurus*, *M. undulatus*, and *O. chrysoptera*) spawn in continental shelf waters in cooler months, and peak recruitment of larvae is subsequently observed in SAB estuaries October through March. Three species within the genus *Paralichthys* (*P. albigutta*, *P.*

dentatus, *P. lethostigma*) also recruit from continental shelf waters at this time, but did not make up a significant portion of the total catch (0.25 %) in this study (Fig. 6).

Winter collections were dominated by the sciaenids *M. undulatus* (representing 18.1 % of the total catch) and *L. xanthurus* (4.0 % of total catch). *Micropogonias undulatus* exhibited a protracted spawning season, with larvae ingressing into the GTM estuary between October and May. Recruitment to the GTM estuary resulted in bimodal peaks in density in November (93.48 larvae / 100 m³ at the Matanzas inlet and 127.54 larvae / 100 m³ at the St. Augustine inlet), and April (81.00 larvae / 100 m³) at the Matanzas inlet and February (13.68 larvae / 100 m³) at the St. Augustine inlet. Larval sizes for *M. undulatus* ranged from 5.0 mm to 25.5 mm SL. The recruitment season for *L. xanthurus* extended from December through April, with peak ingress occurring in January at the Matanzas inlet (77.0 larvae / 100 m³) and in February at the St. Augustine inlet (38.1 larvae / 100 m³). Size at ingress for *L. xanthurus* ranged from 5.5 to 15.5 mm SL.

Ingress of *B. tyrannus* larvae into the GTM estuary began in January and extended through May. Peak ingress occurred in January at the Matanzas inlet (54.9 larvae / 100 m³) and in March at the St. Augustine inlet (2.65 larvae / 100 m³). Larval size of *B. tyrannus* ranged between 8.0 and 28.5 mm SL.

Sciaenops ocellatus exhibited a brief period of larval ingress between August and October. Ingress peaked in October at both inlets (maximum density 43.08 larvae / 100 m³ at Matanzas, 13.07 larvae / 100 m³ at St. Augustine). Larval size ranged between 2.5 and 10.5 mm SL for *S. ocellatus*, which was smaller than the other winter-spawning species.

Summer-Spawning Taxa

Recruitment to the GTM estuary in the warmer months of the year (March through September) was characterized by larvae of estuarine and nearshore resident species. Ingress generally increased as water temperature increased. Bimodal peaks in recruitment were evident for species that reproduce throughout the warmer months, with the first peak generally occurring in late spring (April-May), and the second peak in mid-late summer (July-August). This pattern was illustrated by the gobies *Gobiosoma* spp. and *C. boleosoma*, engraulids in the genus *Anchoa*, and species within the family gerreidae (Figs. 7 and 8). Single peaks in abundance were seen in the spring-time recruiting species *E. saurus* and *B. chrysoura*, and the summer-recruiting *Stellifer lanceolatus* (Figs. 7 and 8). Small, pre-settlement size classes were consistently obtained between the months of April and September for most of these taxa.

Inlet Differences

Ichthyoplankton collections from both the St. Augustine and Matanzas inlets followed the same general patterns with regard to the seasonality of the species assemblage, however, differences in taxa richness and larval concentrations were observed during the study period (Fig. 3). A large number of taxa ($n = 50$) occurred at both inlets, while 17 taxa were unique to the Matanzas inlet and 7 taxa were unique to the St. Augustine inlet. Two-way ANOVA results suggested that mean monthly larval concentration ($F = 12.41$, $p < 0.01$) and mean monthly taxa richness ($F = 9.88$, $p < 0.01$) were significantly different between inlets. The two inlets showed differences in the abundance rankings for many taxa (Tables 2 and 3). Monthly density values for the 11 taxa that comprised greater than 1 % of the total catch were analyzed by two-way

ANOVA. Results indicated that densities of *A. hepsetus* ($F = 5.13$, $p < 0.05$), *B. tyrannus* ($F = 20.85$, $p < 0.01$), *C. boleosoma* ($F = 4.58$, $p < 0.05$), *Gerreidae* spp. ($F = 6.49$, $p < 0.05$), *L. rhomboides* ($F = 9.62$, $p < 0.01$), *L. xanthurus* ($F = 4.71$, $p < 0.05$), and *O. chrysoptera* ($F = 5.77$, $p < 0.05$) were significantly greater at the Matanzas inlet than at the St. Augustine inlet. The remaining four taxa (*A. mitchilli*, *Gobiosoma* spp., *M. undulatus*, *S. ocellatus*) had similar densities at both inlets ($p > 0.05$).

DISCUSSION

This study of the ichthyoplankton community of the GTM estuary was the first to target ingressing larval fishes in northeast Florida. Further, it was distinctive since the GTM estuary is positioned near the boundary between temperate and tropical marine ichthyofauna and includes species representing both zones. Finally, it was unique because the GTM estuary receives little freshwater inflow and is well-mixed by tidal oscillations, making it physically different from geographically proximate (both north and south) estuaries. When compared with other estuaries within the SAB (Table 4), the ichthyoplankton community of the GTM estuary stands out with regard to the number of dominant taxa. Though the ichthyoplankton community of the GTM estuary was driven by relatively few taxa overall, in the present study, 20 taxa comprised 90 % of the overall catch. An examination of ichthyoplankton communities in other SAB estuaries generally found that 10-15 taxa accounted for >90 % of the total catch (see Table 4; Allen and Barker 1990, Hettler and Chester 1990, Hettler and Barker 1993, Reyier and Shenker 2007).

Within the GTM estuary, the densities of ingressing larvae of seven taxa (representatives of the family Gerreidae, the sparid *A. probatocephalus*, the haemulid *O. chrysoptera*, gobies of the genus *Gobiosoma*, as well as three species with leptocephalus larval stages: *E. saurus*, *Albula vulpes*, and *Megalops atlanticus*) were greater than densities seen at other SAB estuaries (Allen and Barker 1990, Hettler and Chester 1990, Hettler and Barker 1993, Reyier and Shenker 2007). Further, and these taxa, though present in the GTM estuary as adults, are not highly abundant (Turtora and Schotman 2010). *Archosargus probatocephalus* is a popular species with recreational anglers in the southeast US and is also regulated commercially in south Atlantic waters. Surveys of juvenile and adult fishes in the northern Indian River Lagoon, the St. Marys River estuary (FL/GA border), and the GTM estuary have documented large numbers of gerreids in later life history stages, but not in larval form (Tremain and Adams 1995, Paperno *et al.* 2001, Solomon *et al.* 2006, Turtora and Schotman 2010). The only other study to document abundant ingressing gerreids was conducted at the Sebastian inlet, FL, located to the south of the study area (Ferrell 1999). Though not recreationally important, gerreids and haemulids like *O. chrysoptera* are key forage fish for larger species (Heupel and Hueter 2002). Abundance values for *E. saurus*, *M. atlanticus*, and *A. vulpes* aligned much more closely with those found for the northern Indian River Lagoon (Reyier and Shenker 2007) than with other estuaries located to the north of the study area. These three species are popular sportfish in the central and southern portions of Florida, and are not common in northeast Florida estuaries as adults. The number of recruits ingressing to the GTM estuary suggests that it may function as an important nursery habitat for these species. Finally, gobies were present in larval collections at extremely high densities

during April 2012. Most local gobies reproduce during the warmer months of the year within the estuary or in the nearshore environment (Dahlberg and Conyers 1973, Able and Fahay 1998). Gobies of the genus *Gobiosoma* are common throughout the SAB, but only one other study, conducted in South Carolina, documented densities as high as those seen in the GTM estuary, particularly at the Matanzas inlet (Allen and Barker 1990). The large number of larval *Gobiosoma* spp. ingressing through the Matanzas inlet in April 2012 likely resulted from sampling coinciding with a period of strong ingress.

A large number of rare taxa, those represented by fewer than 6 individuals, were collected in the GTM estuary during the study period. These rare taxa can be divided into two categories: those that were likely expatriates and would not typically utilize north Florida estuaries as nursery habitat, and those that, though rare as larvae, are present as juveniles and adults. The GTM estuary lacked many tropical species. Of 74 unique taxa, only 3 could possibly be considered to be of tropical origin (*Abudefduf saxatilis*, *Acanthostracion quadricornis*, *Microdesmus bahiana*); each of these species was represented by a single individual. Other rare taxa that were likely strays from other marine regions such as lower or higher latitudes, the pelagic realm, or deep water environments included *Ammodytes* sp., *Bregmaceros houdei*, *Chaetodipterus faber*, *Histrion histrio*, *Kyphosus incisor* and *Sphyrna barracuda*. Wind events and fluctuations in the pathways of oceanic currents may account for the collection of some of these organisms. It is not uncommon for tropical and boreal species to be found in estuarine environments outside of their normal latitudinal ranges (e.g., butterflyfishes; McBride and Able 1998). However, they often cannot survive either the colder winter months or warmer summer months, as they likely lack the ability to cope with the

temperature fluctuations, and thus are not commonly found in such estuaries as adults (Solomon *et al.* 2006, Able and Fahay 2010, Turtora and Schotman 2010).

Some taxa common to the GTM estuary as juveniles and adults were absent, or nearly absent from larval collections, including benthic species (*Gobiesox strumosus*, *Hippocampus erectus*, and *Opsanus tau*), as well as seabasses of the genus *Centropristis*, lutjanids (*Lutjanus griseus*, *L. synagris*), and sciaenids of the genus *Cynoscion*. The benthic species may have been poorly represented in larval collections due to their reproductive and early life history strategies; brooding behaviors and demersal nests may have rendered them less vulnerable to collections taken near the surface of the water column compared to other ingressing species. This reasoning may also extend to species within the *Cynoscion* genus. For example, a study by Rowe and Epifanio (1994) documented that *C. regalis* larvae tended to remain lower in the water column throughout the tidal and diel cycles than other species did.

Oceanic circulation patterns off the southeast US coast may partially account for the low abundance of larvae from offshore reef-spawning taxa, namely lutjanids and serranids. Drifter studies have documented that particles released from known spawning locations throughout SAB shelf waters rarely end up along the northeast Florida coast, and are instead advected toward the coast of North Carolina (Hare and Walsh 2007, Leshner 2008). The Gulf Stream is a major transportation route for newly spawned eggs and larvae of reef-associated taxa, however, St. Augustine, FL is located nearly 100 km from the shelf break, and Gulf Stream interactions with nearshore waters are rare (Atkinson *et al.* 1983, Werner *et al.* 1997). Further north in the SAB, the Gulf Stream passes a deep-water bottom feature, the Charleston Bump, which can cause large eddies

to diverge from the Gulf Stream and propagate toward shore (Hare *et al.* 2002, Hare and Walsh 2007). In the northern portion of the SAB, southward-flowing polar currents interact with the Gulf Stream and can generate similar eddies, and both phenomena can result in the transport of larvae across the continental shelf. Like northeast Florida, South Carolina and Georgia may be too far south to experience significant effects from Gulf Stream eddies, and studies focused on larval and juvenile fishes in these areas have also collected few reef-spawned taxa (Allen and Barker 1990, Marancik *et al.* 2005). To further support this point, studies of post-larval and juvenile fishes in North Carolina estuaries have collected greater numbers of reef-associated species than those observed in the present study (Hettler and Chester 1990, Hettler and Barker 1993, Ross and Moser 1995).

Net extrusion, high variability in larval population dynamics, and variations in reproductive and settlement patterns may also explain some of the disparity between larval and juvenile/adult community assemblages. High levels of variance in catches of larval fishes between years, and also between samples, are typical of studies focusing on ichthyoplankton (Hettler and Chester 1990, Hettler *et al.* 1997, Rice *et al.* 1999). In the present study, variance among three samples from a single site on a single sampling date ranged from < 1 to 6.1×10^5 individuals with an average of 8.7×10^3 individual larvae. Larval fishes have been documented to form aggregations in pre-settlement life history stages (Breitburg *et al.* 1995). The degree of variation among replicate samples may reflect larval patchiness in the water column, and it is possible that these patches were not thoroughly sampled. Additionally, it is possible that larvae of some of these species, such as *Centropristis striata*, are settling in nearshore habitats and are

undergoing a secondary dispersal period as post-larvae or juveniles (Reyns *et al.* 2006, Able *et al.* 2006), which could decrease vulnerability to the gear.

The St. Augustine and Matanzas inlets share many features - environmental factors, positioning along the coast of Florida, general patterns in larval density and diversity - but did not exhibit identical species distributions. The ichthyoplankton community ingressing to the estuary through the Matanzas inlet was consistently greater in overall larval density, taxa richness, and the densities of the most abundant taxa. Of the 20 most abundant taxa, only *A. mitchilli*, *S. lanceolatus*, and *S. plagiusa* were more abundant at the St. Augustine inlet. It is possible that the individuals arriving at each of the two inlets derived from separate spawning locations, which could represent different spawning populations. This is improbable though, especially for shelf-spawned larvae, due to the short distance (21 km) between the inlets. It is more likely that nearshore circulation patterns may not be consistent between the two inlets, resulting in unequal rates of ingress. The two inlets do differ substantially in their degrees of human impact. The St. Augustine inlet channel is maintained through semi-regular dredging by the Army Corps of Engineers, and the inlet is bound by jetties, whereas the Matanzas inlet is not modified by dredging or stabilized by jetties. Earlier studies in the northern SAB have attempted to examine how jetties may impact near-inlet circulation and movements of planktonic organisms. Jetties may generate larger eddies on the ocean side of inlets than would form naturally, which could potentially disrupt the pathway of ichthyoplankton in the longshore current moving toward an inlet (Lawler *et al.* 1988, Seabergh 1988, Wang 1988). It is also possible that the jetty material provides structurally complex habitat for organisms occupying several trophic levels (Lindquist *et*

al. 1985, Van Dolah *et al.* 1987). The effects of increased biomass near the inlet may have resulted in fewer larval fishes entering the estuary through the St. Augustine inlet due to increased predation. Concrete conclusions regarding the observed differences between larval density and diversity at these inlets are difficult to discern, especially since coastal circulation studies are lacking for this understudied portion of the southeast US coast. Despite the close proximity of the St. Augustine and Matanzas inlets, the differences in observed larval densities at each suggests that it is important to include all ocean connections when examining the spatial distribution of the larval community ingressing into the GTM estuary.

While generally accepted and similar sampling protocols are commonly employed in estuaries to examine ingressing ichthyoplankton (e.g., Hettler and Chester 1990, Rice *et al.* 1999, Reyier and Shenker 2007, Taylor *et al.* 2009), larval catches may be influenced by a number of factors (e.g., sample depth, time of day, sampling location, sample duration). Some fish taxa are known to favor particular depths in the water column that may vary with tidal cycle. Larval *L. xanthurus*, *L. rhomboides*, and flounders of the genus *Paralichthys* undergo selective tidal stream transport, rising in the water column on nighttime flood tides in order to move up-estuary (Weinstein *et al.* 1980, Hare *et al.* 2005, Hare and Govoni 2005). Previous studies have documented that *M. undulatus* and *C. regalis* remain low in the water column throughout diel and tidal cycles (Weinstein *et al.* 1980, Lawler *et al.* 1988, Rowe and Epifanio 1994). Sampling at depth may have allowed for the collection of species that might have otherwise been missed during standard sampling protocols. No significant differences in the densities of individual species were observed in surface samples when compared to deeper samples in

the present study. One possible explanation for this is that the turbulent waters associated with inlets may have overwhelmed the swimming abilities of ingressing larvae, which could have disrupted patterns of vertical migration that might be observed further up-estuary (Forward *et al.* 1999). Alternatively, it is possible that the difference between the two sampling depths (e.g., 1 m vs. 4 m) was not large enough to observe vertical stratification of larvae.

Previous studies have shown that sampling at night results in greater species richness and larval densities than sampling during the day (Weinstein *et al.* 1980, Hettler and Barker 1993, Raynie and Shaw 1994, Forward *et al.* 1999). This is likely due to environmental cues that cause larval and juvenile fishes to migrate deeper in the water column to avoid predation during daylight hours (Olney and Boehlert 1988, Holt and Holt 2000). Additionally, sampling in the present study was a passive process, and collecting during nighttime hours may have decreased incidences of gear avoidance (Thayer *et al.* 1983, Powell *et al.* 1989). Nighttime samples resulted in significantly greater taxa richness and greater densities of larvae compared with daytime samples. Daytime samples were dominated by a small number of species (1-3) in the present study, findings which are corroborated by a study of the Oregon and Ocracoke inlets of North Carolina by Hettler and Barker (1993). These results confirm that sampling the nighttime flood tide likely resulted in a more accurate representation of the ingressing ichthyoplankton community than daytime sampling would have. Combining these results with those from sampling in the inlet and conducting samples of extended duration, it seems that the standard sampling protocols used in the present study accurately sampled the ingressing community.

Strong seasonal patterns were evident in the species composition of the ichthyoplankton community ingressing into the GTM estuary. Larval density and taxa richness both increased with increasing water temperature. The ichthyoplankton community of the GTM estuary experienced a pronounced seasonal shift in composition between transient species that spawn primarily in winter over the continental shelf and coastal resident species that reproduce in estuarine or nearshore waters during the warmer months of the year. Similar seasonal shifts have been documented in estuaries in both North and South Carolina (Hettler *et al.* 1997, Allen and Barker 1990). Convergent evolution has resulted in shared life history strategies among marine fish taxa; groups of species may spawn at a time of year that increases the likelihood of successful transport of their young to estuarine nursery grounds, or at a time when there is an adequate supply of food for first-feeding offspring (Parrish *et al.* 1981, Sherman *et al.* 1984, Stegmann *et al.* 1999). These shared reproductive patterns can result in predictable seasonal pulses of eggs and larval and juvenile fishes arriving at coastal nursery habitats.

The winter ingressing larval fish community was dominated by the sciaenids *M. undulatus* and *L. xanthurus*, as well as *B. tyrannus*, which recruited in large numbers through the Matanzas inlet. These species are known to spawn in deeper waters over the continental shelf, and the larger sizes of individuals of these species compared to those ingressing during the summer months suggest a longer pre-ingress transit period. Several mechanisms facilitating cross-shelf transport may be utilized by these species. In the fall and winter months, the SAB experiences predominantly northeast winds, which tend to pull surface waters and ichthyoplankton toward shore (Weber and Blanton 1980, Epifanio and Garvine 2001). Sinking of coastal water as a result of winter cooling has been

documented in the SAB, which may aid in drawing surface waters onshore, providing another cross-shelf transport mechanism for winter-spawned larvae (Werner *et al.* 1997). Offshore winter storm events may provide a third mechanism to enhance cross-shelf transport to estuaries by shelf-spawning species, as demonstrated by *B. tyrannus* in a study conducted by Checkley *et al.* (1988).

Summer-spawning nearshore resident species of the GTM estuary and the greater SAB consist mainly of engraulids, smaller sciaenids, gobiids and gerreids. These species exhibit patterns of maximum recruitment during the warmest months of the year. Bimodal peaks in recruitment, in late spring and in late summer, have been documented for *Anchoa* spp., *Eucinostomas* spp., and *Gobiosoma* spp. (Allen and Barker 1990, Hettler and Barker 1993, Reyier and Shenker 2007, this study), which may indicate repeated spawning events for an individual species within the season. Larvae of nearshore resident species are likely able to make use of productive estuarine waters, initiated by the increase in primary productivity as days lengthen (Sherman *et al.* 1984, Philips *et al.* 2004). These summer-spawning taxa function as important trophic links in the estuarine environment, acting as important primary consumers and providing forage for species at higher levels, which then supply commercially and recreationally important species within the estuary, as well as in nearby coastal and pelagic waters.

Though engraulids represented a significant portion of the ingressing larvae in the summer months, the proportion of the total catch was much lower than has been documented in other SAB estuaries (Hettler and Chester 1990, Paperno and Brodie 2004, Solomon *et al.* 2006). The locally occurring engraulid species are known to reproduce near inlets (Hildebrand and Cable 1930), and as a result, would be expected in

collections. It is possible that the gear used in this study (1 mm mesh net) extruded individuals of the smallest size classes, which may have resulted in an underestimate of the actual ingressing engraulid population. In a similar study in North Carolina, Hettler and Chester (1990) found that a 0.5 mm net collected significantly more summer spawned larval than did a 0.8 mm net. Though the smallest size classes may not have been as effectively sampled, the larger mesh likely provided a more robust estimate of the late larval and early juvenile stages of fishes ingressing into the estuary.

Ecologically important members of the sciaenid family were represented in summer ichthyoplankton collections, and warrant discussion here because of the strong representation by the family in overall catches. The periods of peak ingress into the GTM estuary during the spring and summer seasons were consistent with those documented for sciaenids throughout the SAB (Hettler and Chester 1990, Allen and Barker 1990, Hettler and Barker 1993, Reyier and Shenker 2007). The consistently small sizes (e.g., 3.0 mm to 5.0 mm) of the spring and summer recruiters, *B. chrysoura*, *S. lanceolatus*, and members of the *Cynoscion* genus (*C. arenarius/regalis*, *C. nebulosus*, *C. nothus*) suggest that these species spawn within the estuary or in the nearshore waters.

Reproductive timing varies greatly among the teleost taxa of the southeast US coast, with the ichthyoplankton of the GTM estuary displaying a wide range of strategies. Some, such as *S. ocellatus* recruited in large numbers for a short period of time, while, in contrast, recruits of species like *A. hepsetus* and *M. undulatus* were present in collections for 6 months or more, with multiple peaks in ingressing larval density. The strategies demonstrated by these taxa are variations on the common theme of iteroparity seen amongst marine fish taxa (Murphy 1968). Repeated spawning throughout a life cycle

helps to assure survival of some offspring in what can be a very heterogeneous spatial environment (Winemiller and Rose 1992).

Taxa richness and variety of teleosts observed in the GTM estuary were comparable to those observed in estuaries throughout the SAB (Table 4). Seventy-four unique taxa, representing 38 families of teleost fish, were collected during this study. In two separate 12-month studies in North Carolina, Hettler and Chester (1990) collected 74 taxa representing 34 families at the Beaufort inlet, and Hettler and Barker (1993) collected 71 taxa representing 41 families between the Oregon and Ocracoke inlets. In the northern Indian River Lagoon to the south of the study area, Reyier and Shenker (2007) collected 58 taxa in 28 families during a two-year ichthyoplankton study, and Ferrell (1999) obtained 69 taxa from 40 families in a one-month period in the fall at the Sebastian Inlet. The southern portion of the Indian River Lagoon tends to be more speciose, with as many as 275 species (though not all present in larval form) associated with inlets (Gilmore 1977). Combined, these results suggest a faunal boundary between the northern and southern portions of the Indian River Lagoon, as the number of unique taxa in the estuaries north of this line is fairly consistent. It should be noted, however, that comparing results of different surveys with varied goals and methodologies can be problematic. Variations in (among others) the type of gear used, in net mesh size, and in time of day samples are collected can influence catch composition.

The ichthyoplankton community of the GTM estuary aligns with its geographical position near a faunal boundary. Seasonal trends in species composition are consistent across the Bight, likely due to similar climate and shared offshore circulation patterns and available habitat types. Numerous temperate species of commercial and/or recreational

importance were collected in the estuary, as were some species that are not seen in large numbers farther north (e.g., *E. saurus*, *M. atlanticus*, *Gerreidae* spp.). When compared directly with other SAB estuaries (Table 4), the GTM estuary shared the most individual species in common with the northern Indian River Lagoon (IRL). Unlike the northern IRL, however, the ichthyoplankton community of the GTM estuary is more heavily populated by marine-spawned species (35 % of total catch vs. 1 % documented by Reyier and Shenker [2007] in the northern IRL) and experiences more pronounced seasonal shifts in larval community assemblage structure. Both of these observations are likely due to the fact that the GTM is a narrow estuary and is strongly influenced by tidal oscillations, whereas the northern portion of the IRL has limited connectivity with the Atlantic Ocean. Flushing time within the northern IRL can be as long as 1 year (Smith 1993), compared with 2 weeks for the GTM estuary (Sheng *et al.* 2008). Thus it seems that the GTM estuary may represent the northern extent of a mixing zone between the tropical and temperate marine regions. As it stands, this study provides the first set of data on the spatial and temporal patterns of the larval fish community ingressing into the GTM estuary during the course of a full year. The results of this study help fill a large data gap that existed along the southeast US coastline and has helped further refine the boundary between tropical and temperate marine ichthyofauna in the region.

Table 1. Summary of results from paired t-tests on species richness and larval density values from diel, depth, duration, and location sampling protocols. Mean values of density (number of fish / 100 m³) and species richness (taxa / sample) are presented (\pm 1 SE). Diel, depth, and duration sampling took place at both inlets and data were combined. Location sampling occurred only at St. Augustine inlet.

Variable		Density	Richness
Diel	<i>df</i>	23	23
	<i>p</i>	0.000035	0.00085
	Day	31.77 (6.07)	5.00 (0.55)
	Night	108.39 (13.92)	8.50 (0.49)
Depth	<i>df</i>	7	7
	<i>p</i>	0.789	0.522
	Surface	171.81 (61.26)	11.25 (2.30)
	Deep	159.46 (42.66)	10.5 (1.96)
Duration	<i>df</i>	N/A	7
	<i>p</i>	N/A	0.1389
	100 m ³	N/A	8.25 (0.77)
	250 m ³	N/A	10 (0.80)
Location	<i>df</i>	11	11
	<i>p</i>	0.793	0.806
	Inlet	70.45 (12.74)	7.25 (0.93)
	Dock	79.54 (16.78)	7.42 (0.99)

Table 2. Average monthly densities as number of larvae per 100 m³ of all taxa collected with a 1 mm mesh plankton net ingressing into the GTM estuary through the St. Augustine inlet between March 2012 and February 2013. Abundance rankings were calculated for the St. Augustine inlet and the Matanzas inlet (SA Rank, M Rank) for all taxa represented by > 5 individuals. Rare taxa (in rankings = R) were those represented by ≤ 5 individuals. Taxa collected only at the Matanzas inlet (*) or the St. Augustine inlet (^) are identified (in rankings, NC = no catch). Selected mixed taxa were exempted (E) from abundance rankings. Monthly larval densities represent sums of mean densities and were not used in statistical analyses.

Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Albulidae															
<i>Albula vulpes</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	40
Elopidae															
<i>Elops saurus</i>	--	0.14	2.62	2.57	--	--	--	0.48	--	--	--	--	5.81	19	16
Megalopidae															
<i>Megalops atlanticus</i>	--	--	--	--	--	2.57	0.67	3.02	0.18	--	--	--	6.44	15	20
Anguillidae															
<i>Anguilla rostrata</i>	--	--	--	--	--	--	--	--	0.14	--	0.39	--	0.53	R	R
Ophichthidae															
<i>Myrophis punctatus</i>	0.38	--	--	--	--	--	0.09	--	0.33	--	1.45	0.82	3.07	20	23
<i>Ophichthus gomesii</i> [^]	--	--	--	--	1.59	--	--	--	--	--	--	--	1.59	R	NC
<i>Ophichthidae</i> sp.	--	--	--	--	--	--	--	0.15	--	--	--	--	0.15	R	NC
Clupeidae															
<i>Brevoortia tyrannus</i>	1.03	0.16	2.65	0.35	--	0.79	--	--	--	--	--	--	4.98	17	6
<i>Harengula jaguana</i>	--	--	0.42	0.35	--	--	0.12	--	--	--	--	--	0.89	32	18
<i>Opisthonema oglinum</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
<i>Sardinella aurita</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	25
<i>Clupeidae</i> spp.	0.12	--	0.50	--	--	--	--	--	--	--	--	--	0.62	E	E
Engraulidae															
<i>Anchoa hepsetus</i>	--	0.137	4.50	56.1	1.83	6.46	14.89	53.66	19.40	1.61	--	--	158.59	2	3
<i>Anchoa mitchilli</i>	--	--	--	4.42	--	2.74	12.46	15.03	9.04	1.61	3.34	--	48.64	5	12
<i>Engraulis eurystole</i>	--	--	1.00	--	--	0.11	0.30	--	--	--	--	--	1.41	28	24
<i>Engraulidae</i> spp.	--	0.39	1.00	11.58	3.04	0.17	8.36	24.38	12.99	--	--	--	61.91	E	E
Synodontidae															
<i>Synodus foetens</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Bregmacerothidae															
<i>Bregmaceros houdei</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Batrachoididae															
<i>Opsanus tau</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Gobiesocidae															
<i>Gobiesox strumosus</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Ophidiidae															
<i>Ophidiidae</i> sp.*	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Atherinidae															
<i>Menidia</i> sp.*	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R

Table 2. Continued.															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Antennariidae															
<i>Histrio histrio</i> ^A	--	--	--	--	--	--	--	--	--	0.30	--	--	0.30	R	NC
Hemiramphidae															
<i>Hyporhamphus meeki</i> [*]	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Syngnathidae															
<i>Hippocampus erectus</i> [*]	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
<i>Syngnathus</i> spp.	--	--	0.45	--	0.16	0.36	0.09	--	--	--	--	--	1.06	32	39
Carangidae															
<i>Selene setapinnis</i> [*]	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
<i>Caranx hippos</i>	--	--	--	--	--	--	0.18	--	--	--	--	--	0.18	R	R
<i>Chloroscombrus chrysurus</i>	--	--	--	--	--	--	0.48	0.48	0.14	--	--	--	1.10	27	R
<i>Oligoplites saurus</i>	--	--	--	--	--	--	0.1	--	--	--	--	--	0.10	R	R
<i>Trachinotus falcatus</i>	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Lutjanidae															
<i>Lutjanus analis</i> [*]	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
<i>Lutjanus synagris</i>	--	--	--	--	--	--	--	0.17	0.41	--	--	--	0.58	33	27
Gerreidae															
<i>Gerreidae</i> spp.	--	--	--	3.10	0.77	0.17	14.48	16.68	7.35	1.40	8.68	--	52.63	4	4
Haemulidae															
<i>Orthopristis chrysoptera</i>	0.12	0.55	2.60	--	4.07	--	--	--	--	--	--	--	7.34	16	8
Kyphosidae															
<i>Kyphosus incisor</i> ^A	--	0.33	--	--	--	--	--	--	--	--	--	--	0.33	R	NC
Sciaenidae															
<i>Bairdiella chrysoura</i>	--	--	--	3.44	5.86	1.47	1.00	0.17	--	--	--	--	11.94	11	13
<i>Cynoscion</i>															
<i>arenarius/regalis</i>	--	--	--	--	--	--	0.54	1.60	--	1.07	--	--	3.21	18	34
<i>Cynoscion nothus</i>	--	--	--	--	--	--	0.40	1.11	0.40	--	--	--	1.91	24	32
<i>Cynoscion nebulosus</i>	--	--	--	0.52	--	--	0.10	0.17	--	0.59	--	--	1.38	26	35
<i>Cynoscion</i> spp.	--	--	--	--	--	--	0.10	0.19	--	--	--	--	0.29	E	E
<i>Leiostomus xanthurus</i>	24.04	38.09	1.67	--	--	--	--	--	--	--	--	2.20	66.00	7	5
<i>Menticirrhus</i>															
<i>americanus</i>	--	--	--	--	--	--	--	--	0.20	--	--	--	0.20	R	R
<i>Menticirrhus</i> spp.	--	--	--	--	--	0.36	0.63	--	--	--	--	--	0.99	25	36
<i>Micropogonias undulatus</i>	25.27	48.50	3.02	13.68	3.87	--	--	--	--	27.54	127.54	63.05	312.47	1	2
<i>Pogonias cromis</i>	--	1.21	0.92	--	--	--	--	--	--	--	--	--	2.13	R	26
<i>Sciaenops ocellatus</i>	--	--	--	--	--	--	--	0.16	0.42	13.06	--	--	13.64	9	9
<i>Stellifer lanceolatus</i>	--	--	--	--	--	7.32	9.15	2.63	0.14	--	--	--	19.24	8	19
<i>Sciaenidae</i> spp.	1.62	0.27	--	2.16	1.59	--	0.10	0.51	--	0.77	--	--	7.02	E	E

Table 2. Continued..															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Serranidae															
<i>Centropristis striata</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Sparidae															
<i>Archosargus probatocephalus</i>	--	--	--	2.97	1.59	--	--	--	--	--	--	--	4.56	22	14
<i>Lagodon rhomboides</i>	1.83	0.76	--	--	--	--	--	--	--	0.44	2.12	2.37	7.52	12	10
<i>Sparidae</i> spp.	--	--	--	--	0.27	--	--	--	--	--	--	--	0.27	E	E
Pomacentridae															
<i>Abudefduf saxatilis</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Mugilidae															
<i>Mugil cephalus</i>	0.13	--	--	--	--	--	--	--	--	--	--	--	0.13	R	32
<i>Mugil curema</i>	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Sphyraenidae															
<i>Sphyraena barracuda</i> ^	--	--	--	--	--	--	0.18	--	--	--	--	--	0.18	R	NC
Ammodytidae															
<i>Ammodytes</i> sp.^	0.16	--	--	--	--	--	--	--	--	--	--	--	0.16	R	NC
Blennidae															
<i>Hypsoblennius hentz</i>	--	--	--	1.03	--	--	--	0.16	0.21	--	--	--	1.40	29	31
<i>Blennidae</i> sp.*	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Ephippidae															
<i>Chaetodipterus faber</i> *	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Eleotridae															
<i>Eleotris pisonis</i>	0.14	--	--	--	--	--	--	0.64	--	--	0.22	--	1.00	31	37
Gobiidae															
<i>Ctenogobius boleosoma</i>	--	0.28	--	--	4.94	--	--	4.60	8.46	2.15	7.26	--	27.69	6	7
<i>Ctenogobius saepapellans</i> ^	--	--	--	--	--	--	11.38	0.17	--	--	--	1.91	13.46	R	NC
<i>Gobionellus oceanicus</i>	--	--	0.42	0.29	--	--	0.39	1.90	1.47	--	0.66	0.53	5.66	14	15
<i>Gobiosoma ginsburgi</i>	--	--	--	--	--	--	--	0.33	1.40	0.14	0.50	--	2.37	R	33
<i>Gobiosoma</i> spp.	--	--	--	22.26	3.96	23.76	11.30	4.79	25.99	0.68	0.50	--	93.24	3	1
<i>Gobiidae</i> spp.	--	0.26	4.58	2.13	11.08	8.11	9.63	4.80	5.85	0.75	--	0.18	47.37	E	E
<i>Microgobius</i> sp.*	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
Microdesmidae															
<i>Microdesmus bahiana</i> ^	--	--	--	--	--	--	--	0.15	--	--	--	--	0.15	R	NC
<i>Microdesmus longipinnis</i>	--	--	--	--	--	--	0.19	--	--	--	--	--	0.19	R	22
Triglidae															
<i>Prionotus tribulus</i>	--	--	--	--	--	--	--	--	--	0.15	--	--	0.15	R	R
<i>Prionotus</i> spp.	--	0.13	--	--	--	--	--	--	--	0.31	--	--	0.44	35	38

Table 2. Continued.															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Bothidae															
<i>Citharichthys spilopterus</i>	0.56	0.52	--	1.03	--	--	--	1.30	--	--	3.33	1.52	8.26	13	11
<i>Citharichthys</i> spp.	--	--	--	--	--	--	--	--	--	--	--	0.36	0.36	R	R
<i>Etropus</i> spp.	--	0.30	--	--	--	--	--	0.15	--	--	--	--	0.45	37	29
<i>Paralichthys</i> spp.	0.20	0.25	--	--	0.27	--	--	--	--	--	0.90	0.24	1.61	21	21
Cynoglossidae															
<i>Symphurus civitans</i>	--	--	--	--	--	--	--	--	--	--	--	--	NC	NC	R
<i>Symphurus plagiusa</i>	--	--	--	--	4.93	--	4.33	4.12	0.33	--	--	--	13.71	10	17
Balistidae															
<i>Stephanolepis hispidus</i>	--	--	--	--	--	--	--	--	0.95	4.20	2.02	--	7.17	23	28
Tetradontidae															
<i>Sphoeroides</i> spp.	--	--	--	--	--	--	--	--	--	0.19	--	--	0.19	36	30
Monthly Larval Densities	55.60	92.28	26.35	127.98	49.82	54.39	101.64	143.70	95.80	56.96	158.91	73.18	1036.06		

Table 3. Average monthly densities as number of larvae per 100 m³ of all taxa collected with a 1 mm mesh plankton net ingressing into the GTM estuary through the Matanzas inlet between March 2012 and February 2013. Abundance rankings were calculated for the St. Augustine inlet and the Matanzas inlet (SA Rank, M Rank) for all taxa represented by > 5 individuals. Rare taxa (in rankings = R) were those represented by ≤ 5 individuals. Taxa collected only at the Matanzas inlet (*) or the St. Augustine inlet (^) are identified (in rankings, NC = no catch). Selected mixed taxa were exempted (E) from abundance rankings. Monthly larval densities represent sums of mean densities and were not used in statistical analyses.

Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Albulidae															
<i>Albula vulpes</i> *	--	--	0.14	--	0.29	--	--	--	--	--	--	0.12	0.55	NC	40
Elopidae															
<i>Elops saurus</i>	0.24	1.64	1.28	12.11	1.85	0.52	0.24	0.79	--	0.11	--	--	18.78	19	16
Megalopidae															
<i>Megalops atlanticus</i>	--	--	--	--	--	0.22	3.07	0.36	5.92	--	0.12	--	9.69	15	20
Anguillidae															
<i>Anguilla rostrata</i>	--	--	0.11	--	--	--	--	--	--	--	--	--	0.11	R	R
Ophichthidae															
<i>Myrophis punctatus</i>	--	0.66	1.21	0.85	--	0.11	--	--	0.17	--	0.98	0.68	4.66	20	23
<i>Ophichthus gomesii</i> ^	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
<i>Ophichthidae</i> sp.	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
Clupeidae															
<i>Brevoortia tyrannus</i>	54.93	8.89	23.17	38.43	1.29	0.26	--	--	--	--	--	--	126.97	17	6
<i>Harengula jaguana</i>	--	0.64	0.68	9.61	3.40	4.21	--	--	--	0.14	0.14	--	18.82	32	18
<i>Opisthonema oglinum</i> *	--	--	--	--	0.91	--	--	--	--	--	--	--	0.91	NC	R
<i>Sardinella aurita</i> *	--	0.34	0.52	1.75	--	1.78	--	--	--	--	--	--	4.39	NC	25
<i>Clupeidae</i> spp.	1.64	0.45	0.97	2.38	5.68	1.05	--	--	--	--	--	--	12.17	E	E
Engraulidae															
<i>Anchoa hepsetus</i>	--	3.44	24.17	55.01	34.12	3.76	56.32	117.22	47.43	6.63	0.39	--	348.49	2	3
<i>Anchoa mitchilli</i>	--	--	--	7.15	2.29	1.29	1.08	10.79	1.00	0.82	0.19	--	24.61	5	12
<i>Engraulis eurystole</i>	--	--	2.62	--	0.18	--	0.52	2.23	--	--	--	--	5.55	28	24
<i>Engraulidae</i> spp.	--	3.61	6.42	5.51	8.80	1.92	24.03	36.16	25.62	0.14	0.91	--	113.12	E	E
Synodontidae															
<i>Synodus foetens</i> *	--	--	--	--	0.11	--	--	0.33	--	--	--	--	0.44	NC	R
Bregmacerotidae															
<i>Bregmaceros houdei</i> *	--	0.41	--	--	--	--	--	--	--	--	--	--	0.41	NC	R
Batrachoididae															
<i>Opsanus tau</i> *	--	--	--	--	--	--	--	0.17	--	--	--	--	0.17	NC	R
Gobiesocidae															
<i>Gobiesox strumosus</i> *	--	--	--	--	--	--	--	0.17	--	--	--	--	0.17	NC	R
Ophidiidae															
<i>Ophidiidae</i> sp.*	--	--	--	--	--	--	0.16	--	--	--	--	--	0.16	NC	R
Atherinidae															
<i>Menidia</i> sp.*	--	--	--	--	--	--	--	--	--	--	0.20	--	0.20	NC	R

Table 3. Continued															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Antennariidae															
<i>Histrio histrio</i> ^A	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
Hemiramphidae															
<i>Hyporhamphus meeki</i> *	--	--	--	--	--	--	--	--	--	0.15	--	--	0.15	NC	R
Syngnathidae															
<i>Hippocampus erectus</i> *	--	--	--	0.11	0.13	--	--	--	--	--	--	--	0.24	NC	R
<i>Syngnathus</i> spp.	--	--	0.13	0.11	--	--	--	0.17	--	--	--	--	0.41	32	39
Carangidae															
<i>Selene setapinnis</i> *	--	--	--	--	--	--	--	--	--	0.18	--	--	0.18	NC	R
<i>Caranx hippos</i>	--	--	--	--	--	--	--	--	0.17	--	--	--	0.17	R	R
<i>Chloroscombrus chrysurus</i>	--	--	--	--	0.09	--	0.26	--	--	--	--	--	0.35	27	R
<i>Oligoplites saurus</i>	--	--	--	--	--	0.35	--	--	--	--	--	--	0.35	R	R
<i>Trachinotus falcatus</i>	--	--	--	--	--	--	0.11	--	--	--	--	--	0.11	NC	R
Lutjanidae															
<i>Lutjanus analis</i> *	--	--	--	--	--	--	--	--	--	0.27	--	--	0.27	NC	R
<i>Lutjanus synagris</i>	--	--	--	--	--	--	2.07	1.63	0.46	0.17	--	--	4.33	33	27
Gerreidae															
<i>Gerreidae</i> spp.	--	--	2.08	19.13	14.36	1.94	123.04	88.98	23.06	20.34	10.02	--	302.95	4	4
Haemulidae															
<i>Orthopristis chrysoptera</i>	0.64	27.83	43.83	2.85	11.65	--	--	--	--	--	--	--	86.80	16	8
Kyphosidae															
<i>Kyphosus incisor</i> ^A	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
Sciaenidae															
<i>Bairdiella chrysoura</i>	--	1.55	0.72	15.34	8.22	2.61	1.71	0.60	--	--	--	--	30.75	11	13
<i>Cynoscion arenarius/regalis</i>	--	--	--	--	0.50	--	--	0.30	0.41	--	--	--	1.21	18	34
<i>Cynoscion nothus</i>	--	--	--	--	--	0.19	--	--	--	0.97	--	--	1.16	24	32
<i>Cynoscion nebulosus</i>	--	--	--	0.24	0.61	--	--	0.44	--	0.15	--	--	1.44	26	35
<i>Cynoscion</i> spp.	--	1.02	--	--	--	--	--	0.16	0.17	--	--	--	1.35	E	E
<i>Leiostomus xanthurus</i>	77.09	37.57	26.74	2.26	--	--	--	--	--	--	--	--	143.66	7	5
<i>Menticirrhus americanus</i>	--	--	--	--	--	--	--	--	0.13	--	--	--	0.13	R	R
<i>Menticirrhus</i> spp.	--	--	0.33	--	0.89	--	0.33	0.17	--	--	--	--	1.72	25	36
<i>Micropogonias undulatus</i>	7.49	77.79	50.50	81.00	17.60	--	--	--	--	27.32	93.48	43.19	398.37	1	2
<i>Pogonias cromis</i>	--	1.69	3.51	--	--	--	--	--	--	--	--	--	5.20	R	26
<i>Sciaenops ocellatus</i>	--	--	--	--	--	--	--	0.17	2.09	43.08	--	--	45.34	9	9
<i>Stellifer lanceolatus</i>	--	--	--	0.11	0.99	0.33	1.11	2.42	0.17	--	--	--	5.13	8	19
<i>Sciaenidae</i> spp.	0.12	--	0.76	0.11	1.10	--	--	0.50	0.13	--	--	--	2.72	E	E
Serranidae															
<i>Centropomus striata</i> *	--	--	--	--	--	--	--	0.17	--	--	--	--	0.17	NC	R

Table 3. Continued															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Sparidae															
<i>Archosargus probatocephalus</i>	0.15	1.37	3.02	22.92	0.85	0.36	--	--	--	--	--	0.22	28.89	22	14
<i>Lagodon rhomboides</i>	14.28	2.75	11.82	2.62	--	0.19	--	--	--	0.32	0.75	13.93	46.66	12	10
<i>Sparidae</i> sp.	--	--	--	0.13	--	--	--	--	--	--	--	--	0.13	E	E
Pomacentridae															
<i>Abudefduf saxatilis</i> *	--	--	--	--	--	--	--	--	--	0.15	--	--	0.15	NC	R
Mugilidae															
<i>Mugil cephalus</i>	0.27	2.34	--	--	--	--	--	--	--	--	--	--	2.61	R	32
<i>Mugil curema</i>	--	--	--	--	0.13	--	--	--	0.14	--	--	--	0.27	NC	R
Sphyraenidae															
<i>Sphyraena barracuda</i> ^	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
Ammodytidae															
<i>Ammodytes</i> sp.^	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
Blennidae															
<i>Hypsoblennius hentz</i>	--	--	--	1.04	0.25	1.55	--	0.15	0.17	0.11	--	--	3.27	29	31
<i>Blennidae</i> sp.*	--	--	--	--	--	--	--	--	--	--	0.26	--	0.26	NC	R
Ephippidae															
<i>Chaetodipterus faber</i> *	--	--	--	0.11	--	--	--	--	--	--	--	--	0.11	NC	R
Eleotridae															
<i>Eleotris pisonis</i>	--	--	--	--	--	--	0.26	0.63	--	--	--	--	0.89	31	37
Gobiidae															
<i>Ctenogobius boleosoma</i>	0.69	0.51	--	1.27	25.57	14.98	12.42	12.29	2.78	4.45	13.21	4.34	92.51	6	7
<i>Ctenogobius saepapellans</i> ^	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
<i>Gobionellus oceanicus</i>	--	--	0.86	3.88	7.11	1.47	2.07	4.02	0.33	0.11	0.19	0.39	20.43	14	15
<i>Gobiosoma ginsburgi</i>	--	--	--	--	--	--	--	--	0.14	0.21	0.38	--	0.73	R	33
<i>Gobiosoma</i> spp.	--	0.68	--	1424.64	8.04	1.45	1.66	6.27	1.13	0.66	0.38	--	1444.91	3	1
<i>Gobiidae</i> spp.	--	9.28	9.17	10.36	62.68	22.15	5.47	3.65	3.97	0.09	1.36	0.34	128.52	E	E
<i>Microgobius</i> sp.*	--	--	0.13	--	--	--	0.62	--	--	--	--	--	0.75	NC	R
Microdesmidae															
<i>Microdesmus bahiana</i> ^	--	--	--	--	--	--	--	--	--	--	--	--	NC	R	NC
<i>Microdesmus longipinnis</i>	--	--	2.07	--	2.00	3.93	1.03	0.33	--	--	--	--	9.36	R	22
Triglidae															
<i>Prionotus tribulus</i>	--	--	--	--	--	--	0.20	--	--	--	--	--	0.20	R	R
<i>Prionotus</i> spp.	--	0.51	0.28	--	0.31	--	--	--	--	0.11	--	--	1.21	35	38

Table 3. Continued															
Scientific Name	Month												Annual Total	Rank	
	J	F	M	A	M	J	J	A	S	O	N	D		SA	M
Bothidae															
<i>Citharichthys spilopterus</i>	4.68	4.55	4.19	5.77	9.01	0.69	0.46	2.32	0.62	--	0.18	2.88	35.35	13	11
<i>Citharichthys</i> spp.	--	--	--	0.11	--	--	--	--	--	--	--	--	0.11	R	R
<i>Etropus</i> spp.	--	1.83	--	--	1.59	0.17	0.23	0.17	--	--	--	--	3.99	37	29
<i>Paralichthys</i> spp.	2.16	3.05	0.50	--	0.44	--	0.13	--	--	--	--	--	6.28	21	21
Cynoglossidae															
<i>Symphurus civitans</i>	--	--	--	0.90	--	--	--	--	--	--	--	--	0.90	NC	R
<i>Symphurus plagiusa</i>	--	--	--	--	10.70	0.19	3.21	1.45	0.17	0.49	--	--	16.21	10	17
Balistidae															
<i>Stephanolepis hispidus</i>	--	--	--	--	0.11	--	0.13	--	0.33	0.77	0.18	--	1.52	23	28
Tetradontidae															
<i>Sphoeroides</i> spp.	--	--	--	--	0.11	--	--	--	--	1.01	0.23	--	1.35	36	30
Monthly Larval Densities	164.38	194.40	221.93	1727.81	243.96	67.67	241.94	295.21	116.71	108.95	123.55	66.09	3572.60		

Table 4. Summary (expressed as a percentage of the total catch along with rank in parentheses) of the dominant families of ichthyoplankton collected ingressing into the Guana-Tolomato-Matanzas estuary during the March 2012 – February 2013 study period, along with summaries of the dominant families from other similar surveys elsewhere in the South Atlantic Bight presented geographically from north to south. Family groups representing a negligible portion of the overall catch (*) or not caught (--) are indicated. Percent shared taxa refers to the proportion of total taxa shared with the present study.

Family	Estuary				
	Ocracoke Inlet, NC ¹	Beaufort Inlet, NC ²	North Inlet, SC ³	GTM, FL	Northern IRL, FL ⁴
Gobiidae	5.6 (4)	2.1 (4)	83.8 (1)	34.8 (1)	17.4 (2)
Sciaenidae	7.3 (2)	13.7 (2)	7.3 (2)	26.1 (2)	4.9 (3)
Engraulidae	69.7 (1)	74.7 (1)	4.8 (3)	19.3 (3)	74.0 (1)
Gerreidae	0.2 (*)	0.0 (*)	--	9.3 (4)	0.01
Clupeidae	6.8 (3)	2.3 (3)	0.0 (*)	3.0 (5)	0.5 (6)
Sparidae	0.8 (8)	0.4 (9)	0.6 (*)	1.8 (6)	0.01 (*)
Haemulidae	1.3 (6)	1.9 (5)	0.0 (*)	1.6 (7)	--
Paralichthyidae	0.8 (8)	1.9 (5)	0.1 (*)	1.2 (8)	--
Ophichthidae	0.2 (*)	1.4 (6)	1.04 (4)	0.3 (11)	0.01 (*)
% Shared Taxa	67.1	67.7	88.6		73.5

¹ Hettler & Barker (1993): Samples were collected monthly at night at Ocracoke Inlet from October 1988 through September 1989. Surface and bottom waters were simultaneously fished with 0.5 mm mesh nets.

² Hettler & Chester (1990): Samples were collected every two weeks at night at Beaufort Inlet from August 1986 through July 1987. Bow-mounted pushnets with 0.5 and 0.8 mm mesh were used to collect samples.

³ Allen & Barker (1990): Samples were collected every two weeks at North Inlet from January 1981 through January 1985. An epibenthic sled with a 0.365 mm plankton net was used to collect fishes during daylight hours. Specimens were often identified to genus level groupings.

⁴ Reyier & Shenker (2007): Samples were collected bi-monthly at night in the northern Indian River Lagoon from August 2002 through July 2004. A neuston net with 0.5 mm mesh was used to collect samples.

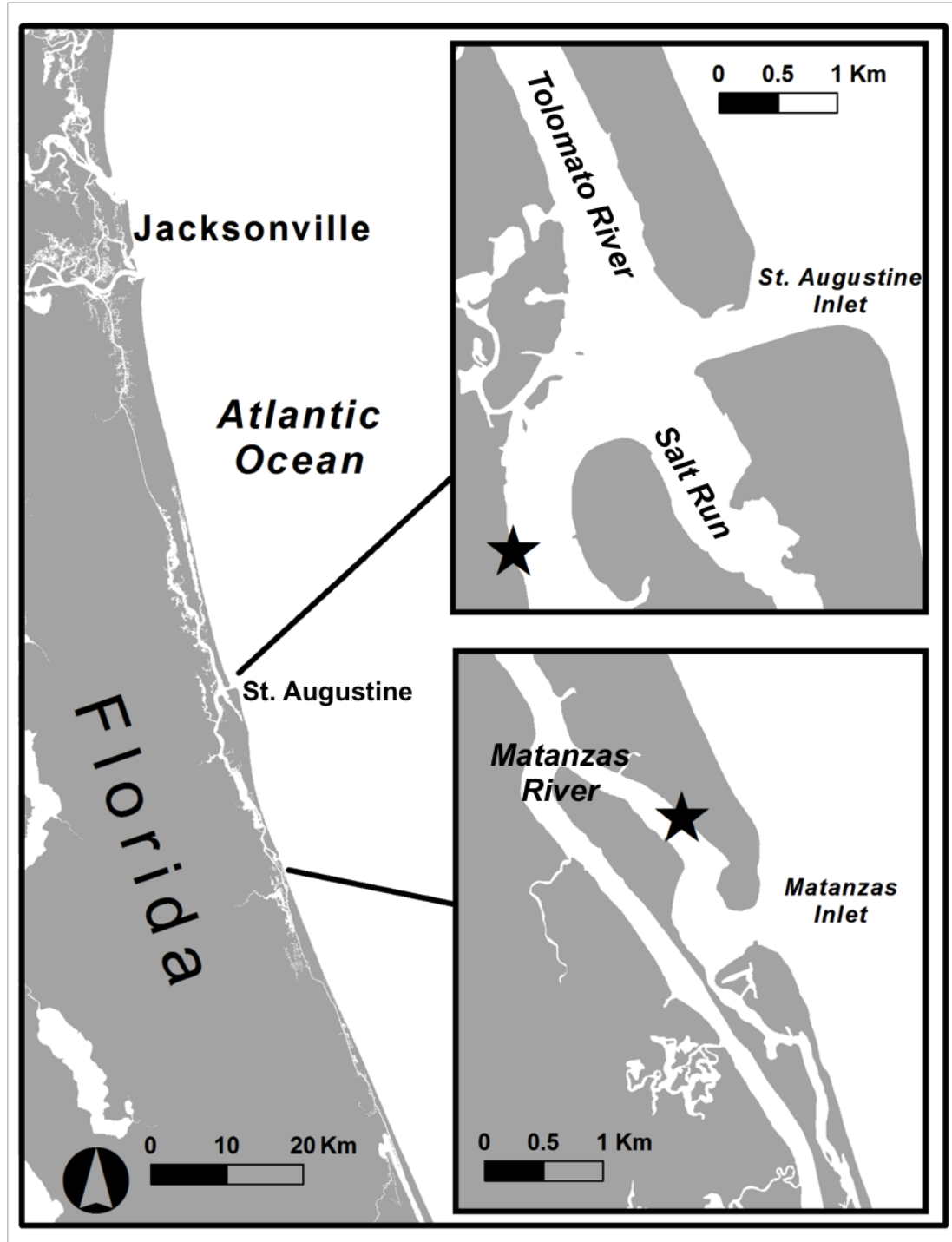


Figure 1. The St. Augustine and Matanzas inlets of the Guana-Tolomato-Matanzas estuary along the US Atlantic coast in northeast Florida. Primary ichthyoplankton sampling locations for each inlet are marked with stars.

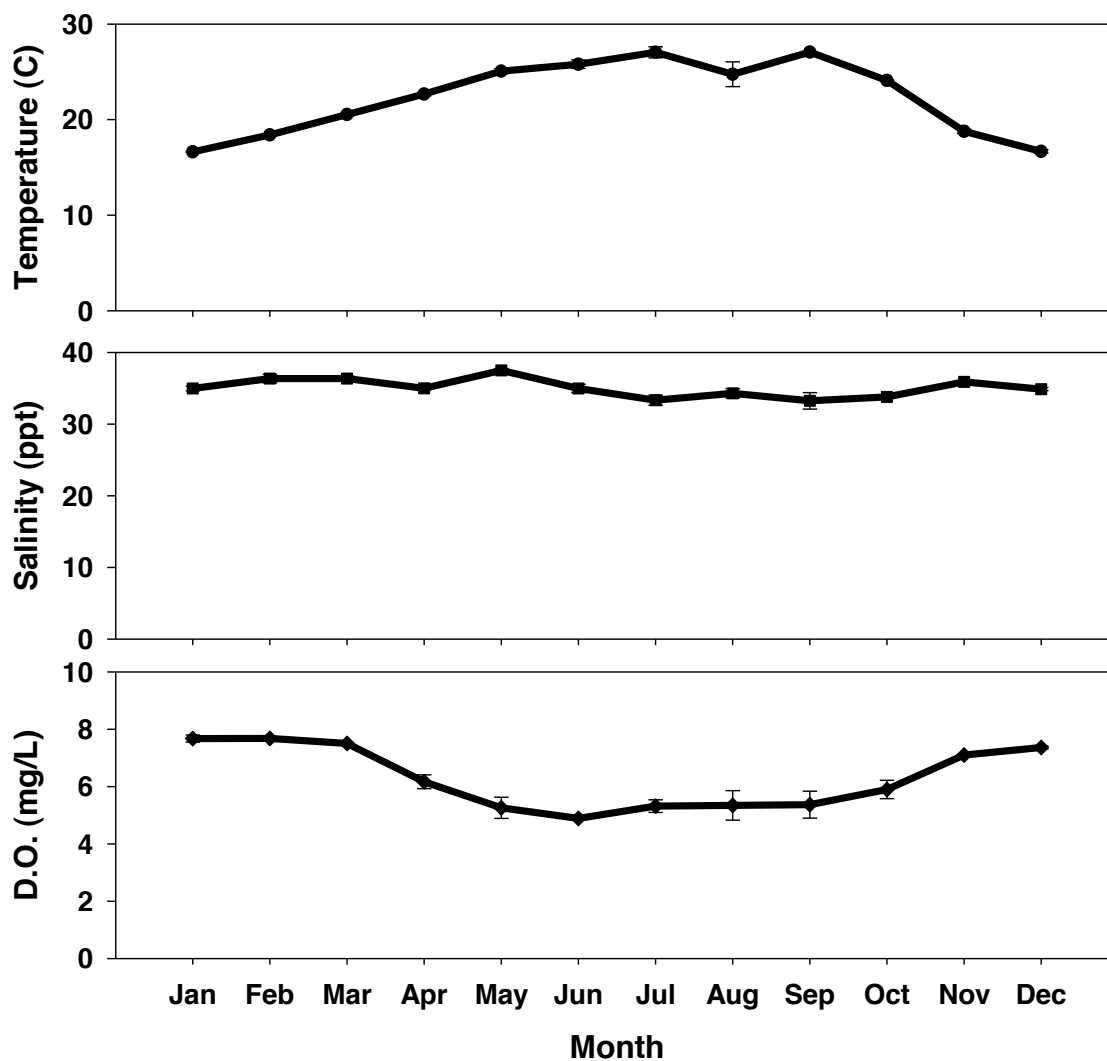


Figure 2. Mean (± 1 SE) temperature, salinity and dissolved oxygen (D.O.) for the GTM estuary March 2012 through February 2013. Data for the inlets were pooled, as no major differences existed between them during any sampling event (Kruskal-Wallis, temp: $p = 0.954$, salinity: $p = .193$, dissolved oxygen: $p = .273$).

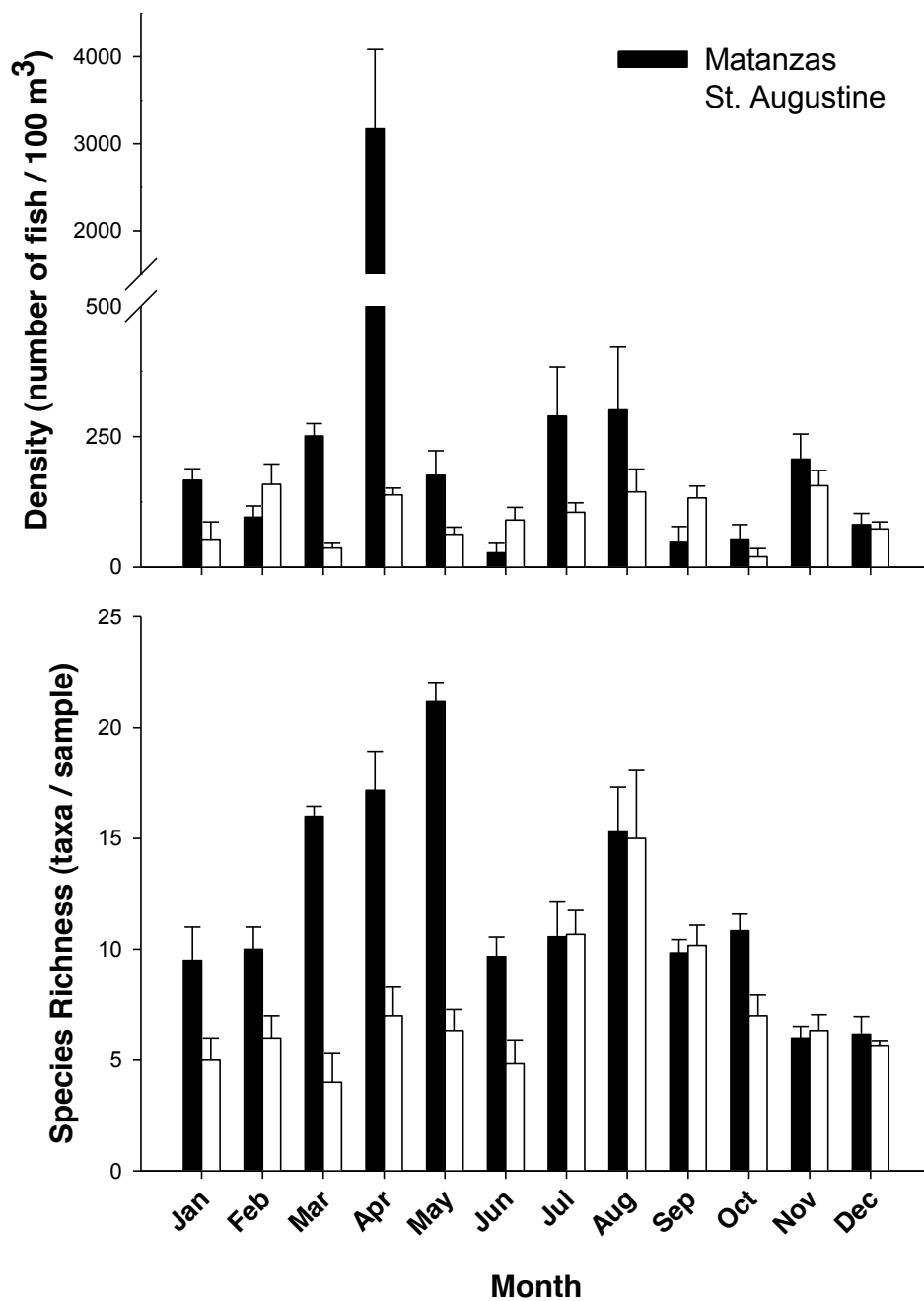


Figure 3. Monthly average species richness (taxa sample⁻¹) and monthly average density (number of fish / 100 m³; ± 1 SE), for the Matanzas inlet (filled bars) and St. Augustine inlet (open bars) between March 2012 and February 2013. Note that the y-axis scales differ.

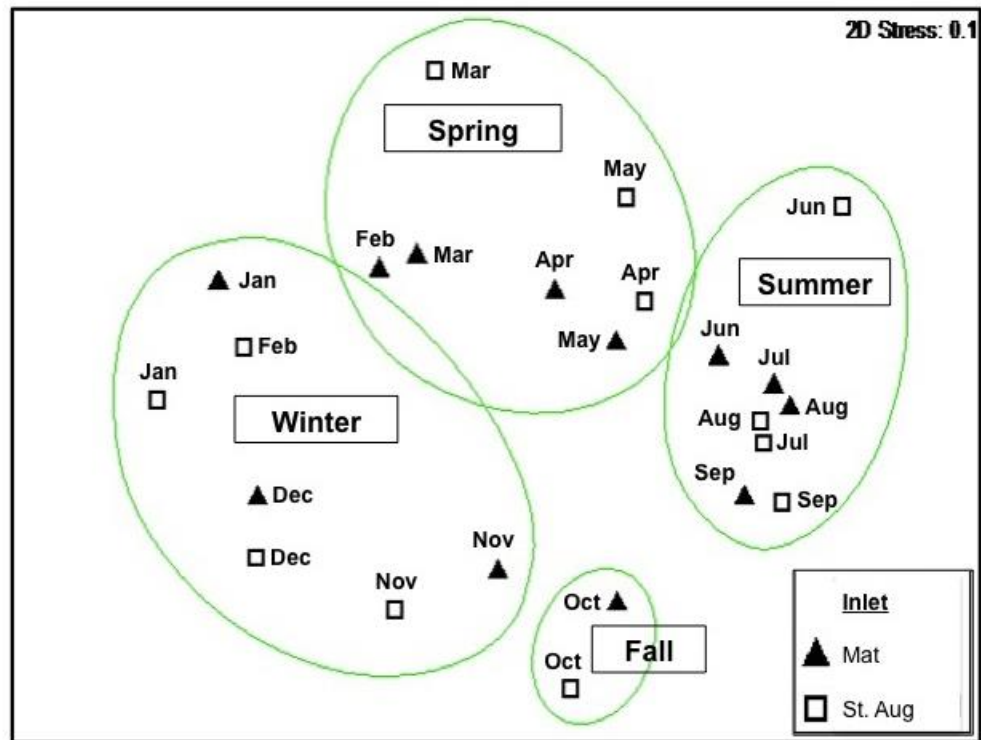


Figure 4. Spatial differences demonstrated by non-metric multidimensional scaling in ichthyoplankton community structure at each of the two inlets that open to the Guana-Tolomato-Matanzas estuary, FL. Collections were taken between March 2012 and February 2013 with a 1 mm mesh plankton net. Each data point represents the density and diversity of the larval fish assemblage by month for each inlet. Ovals classify monthly assemblages into seasonal groups based on degree of similarity. Data were fourth root transformed prior to analyses. Similarity: 45, 2-D stress: 0.1

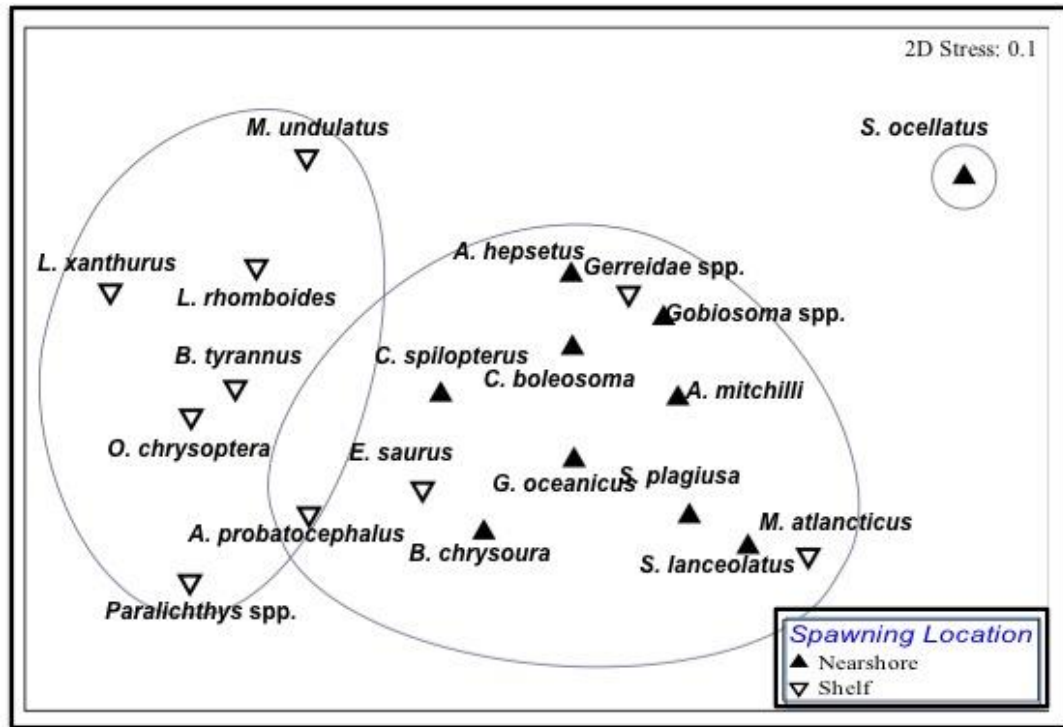


Figure 5. Temporal species associations for collections made at the inlets connecting the Atlantic Ocean with the Guana-Tolomato-Matanzas estuary, FL between March 2012 and February 2013, as demonstrated by non-metric multidimensional scaling. Collections were taken with a 1 mm mesh plankton net. Each data point represents the density of a single species by month for the two inlets combined. Species clustered together were often collected together. Data were fourth root transformed prior to analyses. Similarity: 50, 2-D stress: 0.1.

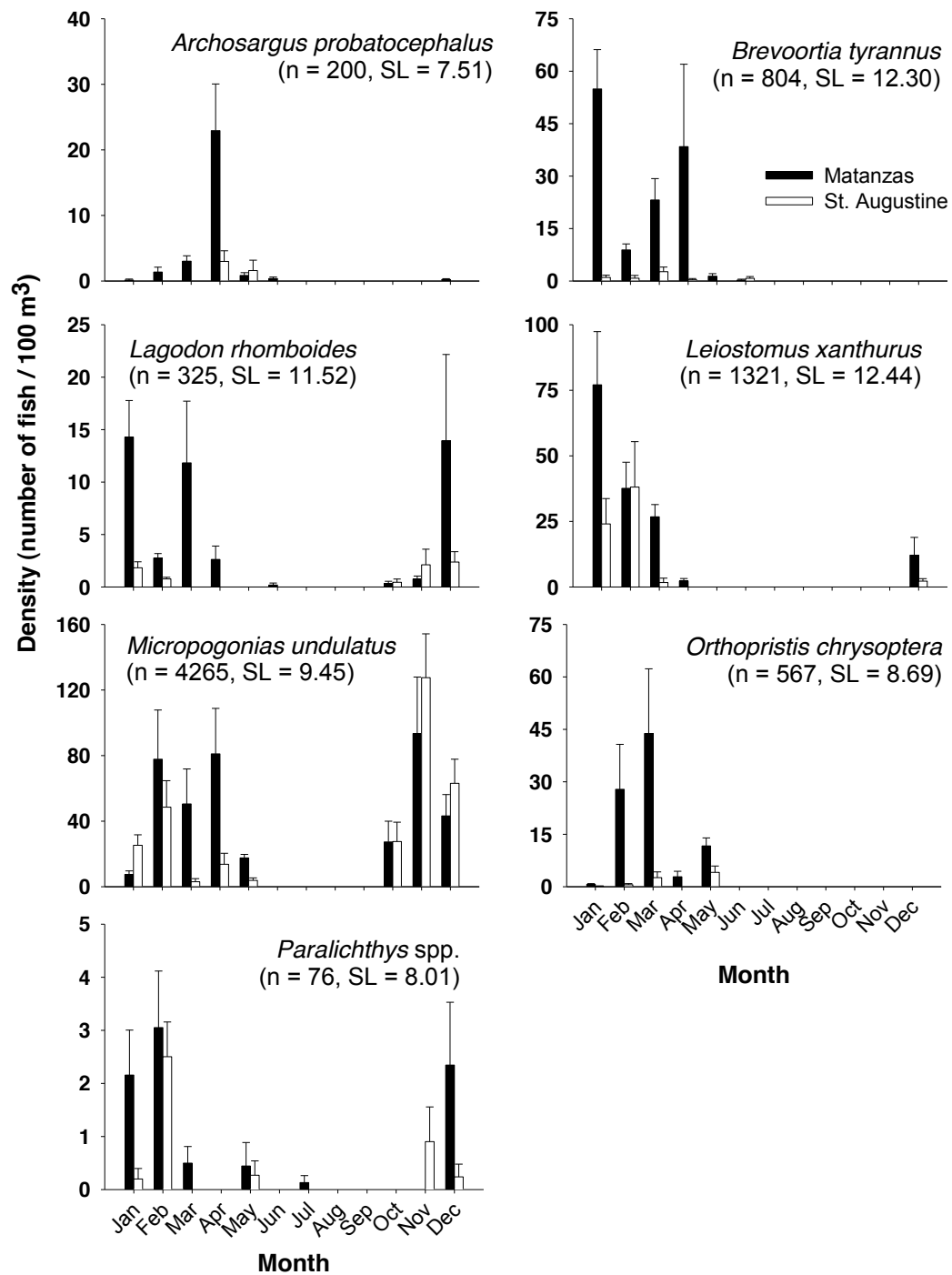


Figure 6. Winter-recruiting taxa mean larval concentrations (number of fish / 100 m³; \pm 1 SE). Total numbers of scaled individuals and mean standard length (SL) given for abundant winter-recruiting taxa entering the GTM estuary between March 2012 and February 2013. Mean length is reported as standard length (mm). Note that the y-axis scales vary.

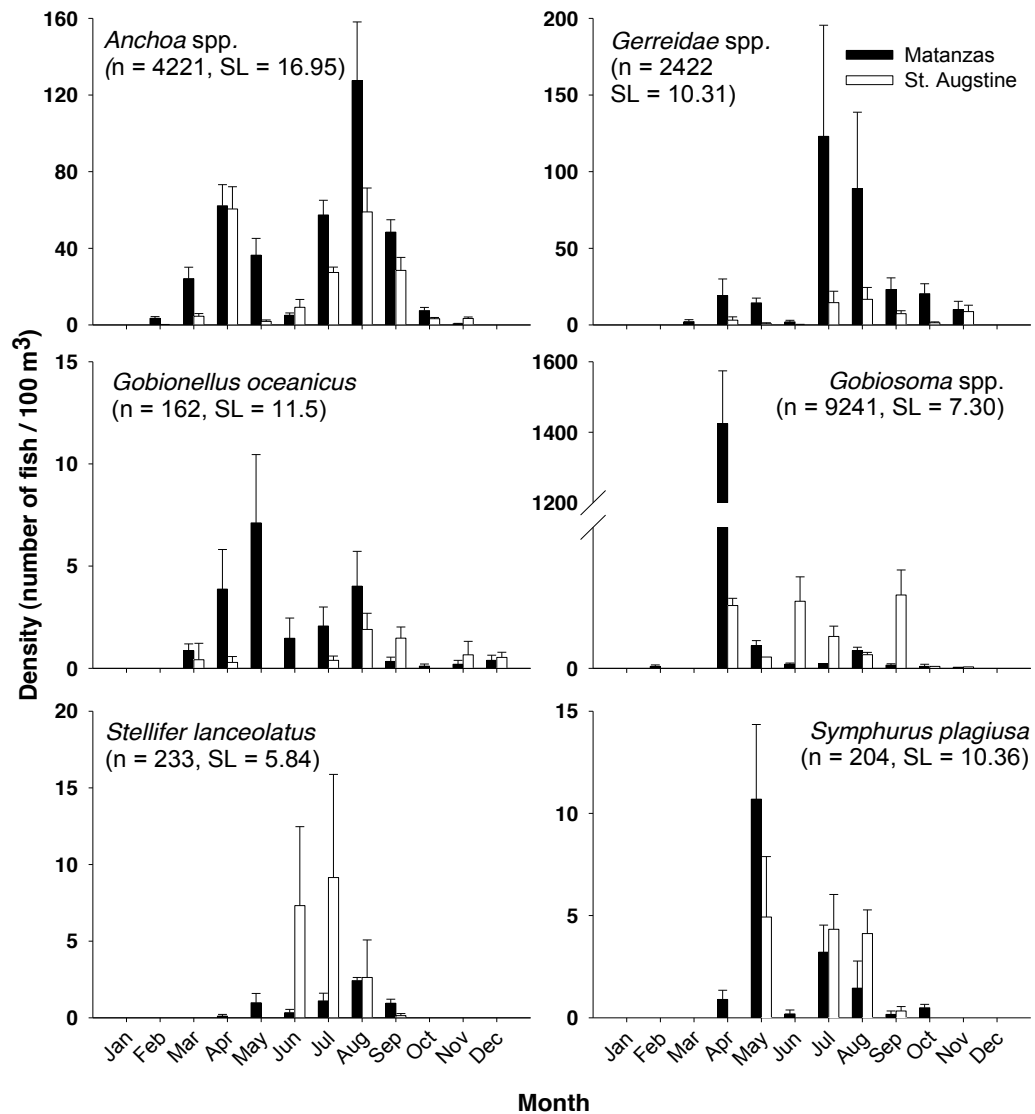


Figure 7. Summer-recruiting taxa mean larval concentrations (number of fish / 100 m³; ± 1 SE). Total numbers of scaled individuals and mean standard length (SL) given for abundant summer-recruiting taxa entering the GTM estuary between March 2012 and February 2013. Mean length is reported as standard length (mm). Note that the y-axis scales vary.

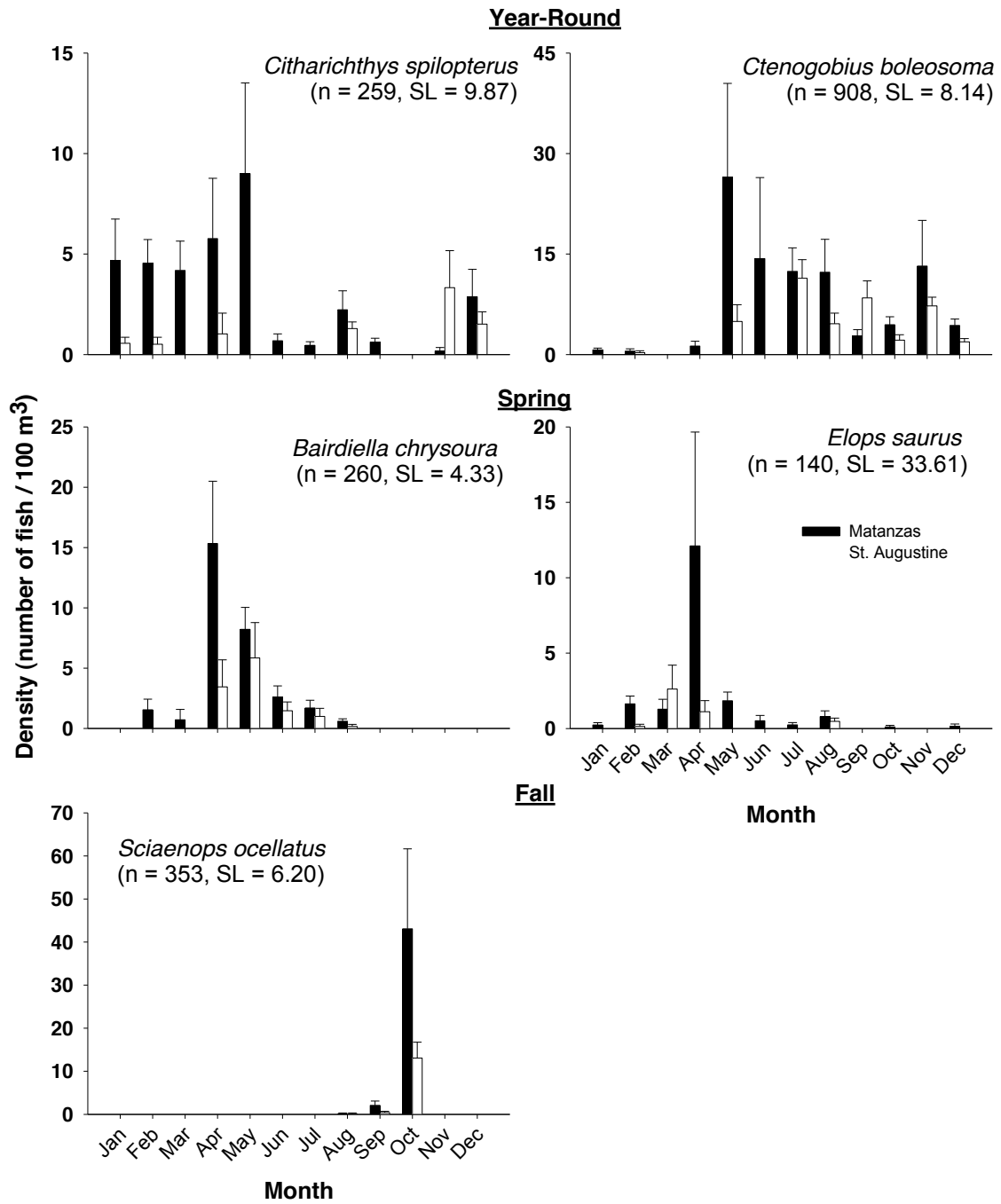


Figure 8. Year-round-, spring-, and fall-recruiting mean larval concentrations (number of fish / 100 m³; \pm 1 SE). Total numbers of scaled individuals and mean standard length (SL) given for abundant taxa entering the GTM estuary March 2012 through February 2013. Mean length is reported as standard length (mm). Note that the y-axis scales vary.

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CURRICULUM VITAE

Breanna Korsman

Future Interests and Objectives

I will complete the requirements for a Master of Science degree in Biology through the Coastal Biology Program at the University of North Florida in August 2013, after which I plan to begin the Biology Ph.D. program at the University of Louisiana at Lafayette in August 2013. My research at ULL will focus on population genetics of recruiting ichthyoplankton in the northern Gulf of Mexico.

Education

- University of North Florida, M.S. Biology 2011 - 2013
 - University of Florida, M.Ed. Secondary Science Education 2005 - 2007
 - The College of William and Mary, B.S. Biology and Environmental Science 2001 - 2005
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Professional Experience

- Adjunct Lecturer, University of North Florida 2012 - 2013
 - Graduate Teaching Assistant, University of North Florida 2011 - 2012
 - High School Science Teacher, St. Johns County, FL 2006 - 2011
 - Undergraduate Research Assistant, VA Institute of Marine Science 2004 - 2005
 - Undergraduate Research Assistant, The College of William and Mary 2002 - 2003
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Grants, Fellowships & Scholarships

- SEERS Student Travel Grant 2013
 - University of North Florida Coastal Biology Travel Grant 2012
 - Northeast Florida Association of Environmental Professionals Scholarship 2012
 - University of North Florida Travel Grant 2011
 - Oscar and Catherine A. Munoz Presidential Fellowship 2011 - 2013
 - Ponte Vedra Education Foundation Grant 2006, 2008, 2009
 - Enhancing Education Through Technology Grant 2007
 - Virginia Institute of Marine Science REU 2004
 - The College of William and Mary REU 2002
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Presentations

- B. Korsman, M.E. Kimball. SEERS Meeting. April 2013
 - B. Korsman, M.E. Kimball. UF Marine Biology Symposium. January 2013
 - B. Korsman, M.E. Kimball. SEERS Meeting. October 2012
 - B. Korsman, J.E. Duffy, J.P. Richardson. Benthic Ecology Meeting. April 2005
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