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An Ecological Characterization of Fish Assemblages in Mosquito Lagoon, Florida

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Abstract - Coastal marine ecosystems are increasingly threatened by urbanization, land-based sources of pollution, and climate change. Changes in the environment due to these pressures could lead to shifts in community composition and dynamics. To address this issue, we sampled the fish assemblage of a coastal lagoon to assess species richness, rates of occurrence, and relative abundance. We caught 176,136 individuals representing 87 taxa. We compared our results to the last published survey of the study area conducted during the mid-1990s. Compared to historic data, there have been large shifts in percent occurrence in some economically important taxa, such as *Lagodon rhomboides* (Pinfish) increasing from 4% to 53% and *Anchoa* spp. (anchovies) increasing from 23% to 66%. These findings possibly indicate changes in the fish assemblage, essential fish habitat, or environment over the past 2 decades. As environmental and anthropogenic stressors continue to impact this complex coastal ecosystem, continued monitoring will be critical to detecting and understanding changes in the fish community in Mosquito Lagoon.

Introduction

Estuarine habitats are some of the most productive and diverse marine systems. Many species use estuaries for foraging, reproduction, and as nursery habitat for part or all of their life stages (Gillanders 2002, Szedlmayer and Able 1996). Species' distributions in estuaries are driven by differences in environmental conditions, available habitat, and biotic interactions (Blaber and Blaber 1980). In particular, coastal estuaries are at risk due to increasing urbanization, nutrient inputs, sea-level rise, and broad-scale warming that may ultimately alter species' distributions and ranges (Amorim et al. 2018, Barile 2018, Daufresne et al. 2009, Troast et al. 2020). Far-field pressures such as climate change in addition to near-field anthropogenic stressors (e.g., eutrophication, sedimentation, shifts in freshwater inflow) can also contribute to the loss of essential fish habitat (EFH) within coastal ecosystems, resulting in impacts on fish communities and the ecosystem services they provide (Cook et al. 2014, Peterson et al. 2000). By assessing the distribution and abundance of fish species in relation to these EFH types, we can gain a better understanding of how fishes interact with their environment and how those interactions may change over time (Rilov and Schiel 2011). Protracted monitoring of estuarine ecosystems

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is critical to enabling assessments of broad-scale spatial and/or temporal shifts in species assemblages over time (Karnauskas et al. 2015).

Over the past 2 decades, numerous estuaries and coastal lagoons have continued to experience significant losses of EFH, including losses in seagrass, mangroves, and oyster reefs (Short et al. 2011). Seagrass beds have seen massive declines in part due to eutrophication-related increases in turbidity and algal growth (Connell et al. 2017, Orth et al. 2006, Udy et al. 1999, Waycott et al. 2009). While some temperate and subtropical coastal systems are experiencing turnover from saltmarsh communities to mangroves, other subtropical and tropical regions are experiencing losses of mangroves due to sea-level rise, habitat loss, and additional urbanization-related pressures (Duke et al. 2007, Field 1995). Global losses of mangrove habitat are estimated at 1–2% annually; however, realized impacts and changes in relative abundance of mangroves will be dependent on local conditions (Polidoro et al. 2010, Ward et al. 2016). Oyster reefs within estuarine systems are also experiencing dramatic losses due to pollution and overharvesting, with an estimated loss of 85% of shellfish reefs globally (Beck et al. 2011). All 3 of these EFH types are at risk of continued degradation and loss within coastal systems.

While there are many efforts to restore these coastal habitats, it is vital to assess fish communities within these habitats to accurately document potential losses, changes, or gains in species assemblages over time either due to habitat loss or restoration of habitat (Beck et al. 2001, Coen et al. 2007, Lewis 2005, Troast et al. 2020, van Katwijk et al. 2009). In this study ,we examined fish assemblages in Mosquito Lagoon, FL, over 2 years to document relative abundance and species composition among predominant EFH types, and by comparing these results with the last peer-reviewed published survey of the region from the mid-1990s, we highlight changes in the fish assemblage over the past 2 decades.

Field-site Description

The Indian River Lagoon (IRL) is one of the largest subtropical estuaries in the United States, spanning more than 250 km along the east coast of Florida. It is connected to the Atlantic Ocean by 5 inlets and contains a variety of EFH types, such as seagrass beds, oyster reefs, drift/fixed algal beds, and mangrove shorelines (Gilmore et al. 1977, Virnstein and Carbonara 1985). Consequently, the IRL is home to a variety of estuarine species, as well as species commonly associated with the nearshore subtropical and more southerly tropical waters carried north by the Gulf Stream (Gilmore 1995, Snelson 1983). For these reasons, the IRL is one of the most diverse estuaries in North America (Gilmore 1995).

The IRL is comprised of 3 smaller distinct, but connected bodies of water: Mosquito Lagoon, Banana River, and the Indian River proper. Mosquito Lagoon is a shallow, saltwater basin located on the east coast of Central Florida, within Volusia and Brevard counties (Fig. 1). It is the northernmost sub-region of the IRL and is connected to the Atlantic Ocean by Ponce de Leon Inlet in the north, and it was connected to the Indian River proper by a man-made canal near its southern terminus, Haulover Canal, which was constructed in 1852. The Mosquito Lagoon is economically valuable to Florida's fishing industry; landings data indicate that the Mosquito Lagoon and the upper Indian River complex are the most productive fishing areas in the northeast coastal region of Florida (ECFRFPC and TCRPC 2016, Provancha and Scheidt 2000).

The primary benthic habitats of Mosquito Lagoon change with latitude and are characterized by a mosaic of mud–sand, unvegetated substrate, and intertidal oyster reefs to the north, and seagrass to the south with intertidal mangroves occurring throughout the lagoon (ECFRFPC and TCRPC 2016, Paperno et al 2001). Coastal wetland vegetation, referenced throughout this study as "living shoreline", is characterized by mangroves (*Rhizophora mangle* L. [Red Mangrove], *Laguncularia racemosa* (L.) C.F. Gaertn [White Mangrove], *Avicennia germinans* (L.) L. [Black Mangrove]), and to a lesser degree *Spartina* spp. (cordgrasses) and *Juncus* spp. (rushes). In the south of Mosquito Lagoon, patchy seagrass beds are comprised of *Halodule wrightii* Asch. (Shoal Grass), *Ruppia maritima* L. (Widgeon Grass), and *Syringodium filiforme* Kütz. (Manatee Grass) (Provancha and Scheidt 2000, Provancha et al. 1992).

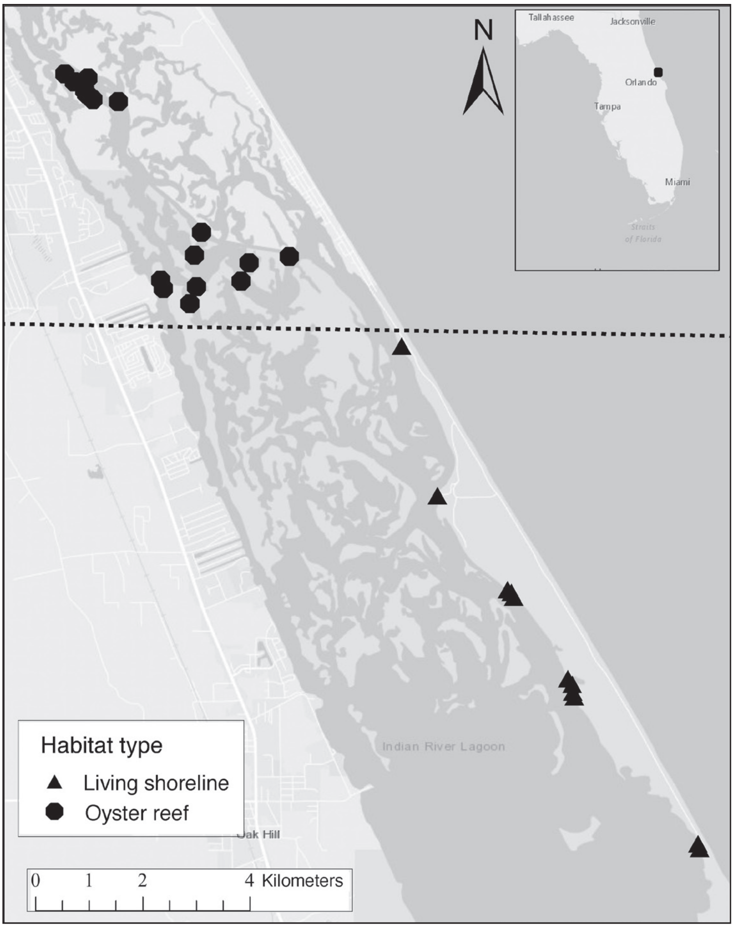

Figure 1. Sampling sites in Mosquito Lagoon 2017–2019. Dashed line at ~26°56'N, 80°51'W indicates a transition from primarily oyster reefs in the north to seagrass in the south. Oyster habitat was primarily oyster reef and adjacent mangrove habitat, while living-shoreline sites were predominantly mangrove habitat with patchy fringing seagrass. The study region is ~9 km from Ponce Inlet to the North and ~13 km from Haulover Canal to the South. Inset map: black square identifies study location within Florida.

Unfortunately, in recent years the primary benthic habitat types (i.e., oyster reef and seagrass) have been degraded by a combination of natural and anthropogenic pressures including hurricanes, algal blooms, boating activities, and land-based sources of pollution (Kamerosky et al. 2015, Paperno et al. 2006, Steward et al. 2005). While there is an abundance of information on fish assemblages of the IRL proper (Gilmore et al. 1977, Paperno et al. 2018, Tremain and Adams 1995), the Mosquito Lagoon is relatively understudied, with only 1 published survey on the fish assemblages since Snelson's (1983) seminal work almost 4 decades ago (Fig. 2; Paperno et al. 2001). Paperno et al. (2001) sampled the fish assemblage of the Mosquito Lagoon from 1993 to 1996. In the ensuing 25 years, the region has continued to experience large losses of EFH due to natural disturbances such as hurricanes, potential impacts of climate change, and anthropogenic-related stressors like land-based sources of pollution and algal blooms (Morris et al. 2018). In this assessment, we compare the fish assemblage sampled between 1993 and 1996 with the current assemblage while considering potential environmental shifts that may have contributed to observed changes.

Methods

Sampling methods

We sampled a combination of live, dead, and restored oyster reefs as well as restored and natural stretches of living shoreline seasonally (*n* = 4) throughout the study region from 2017–2019 (Fig. 1, Appendix 1). Hereafter, we refer to first quarter as winter, second quarter as spring, third quarter as summer, and fourth quarter as fall. We analyzed seasonally due to quarterly sampling bias based on funding and logistics (i.e., there was greater sampling effort in the third quarter than other quarters). We sampled the fish assemblage with seines and otter trawls. Seines were 21.3 m in length and 2 m high, with a 2 m × 2 m center bag. Seines consisted of

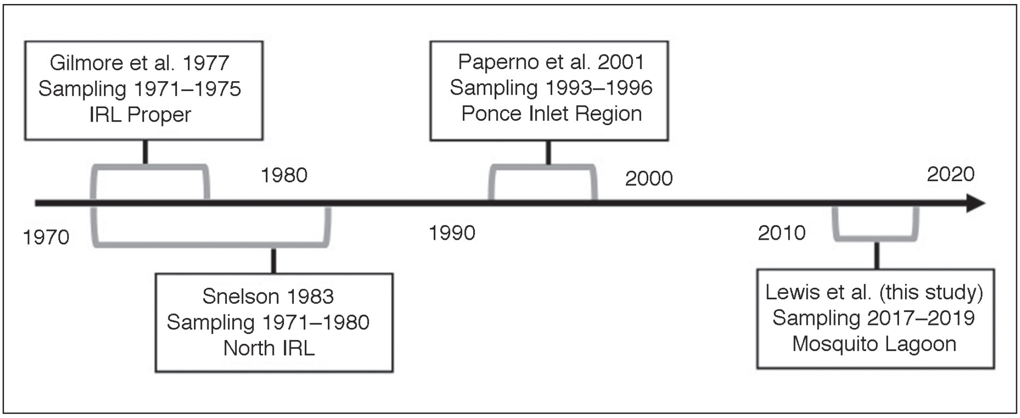

Figure 2. A timeline of peer-reviewed publications that have surveyed Indian River Lagoon or regions near Mosquito Lagoon. Publication first authors are on top, followed by years and the region in which samples were collected. Gray brackets indicate the approximate duration of sampling.

3.2-mm nylon netting with a float line along the top and a lead line along the bottom and were dragged ~35 m at each site. We used seines to sample the water column and benthic habitat directly adjacent to oyster reefs and living shorelines, capturing species using the habitat presumably for foraging and shelter.

The otter trawl used in sampling was 2.1 m (33 cm × 50 cm doors, 3.5-m headrope length, 6-mm heavy delta mesh body, and 2-mm delta mesh in the cod end). We towed the trawl for 2 minutes at ~2 m/s to sample ~500 m^2. Trawling occurred as close to the shoreline as logistically possible, and we centered the length of each trawl relative to the target oyster reef or stretch of living shoreline. Trawls sampled open water and captured soft-sediment species as well as species moving between patches of benthic habitat. We collected samples during daylight and identified and enumerated them in the field. If field identification was not possible, voucher specimens were preserved in 95% ethanol, and brought to the lab for identification.

Statistical methods

We calculated summary statistics for abiotic conditions in the study region including temperature (°C), dissolved oxygen (DO; mg L^{-1}), salinity (ppt), and secchi depth (m; as a proxy for turbidity) using measurements taken each time a sample was collected, including multiple sites within each habitat type. We assessed significant differences among seasons and also habitat types using one-way ANOVAs and posthoc Tukey HSD tests. We assessed normality using Shapiro–Wilk tests and homogeneity of variance utilizing Levene's test. We log-transformed environmental data to better meet assumptions of normality. We calculated smoothed conditional means and 95% confidence intervals for each variable to visualize seasonal variation using the R package 'ggplot' (Wickham et al. 2016). We calculated a rarefaction curve in R package 'iNEXT' to assess the likelihood that our sampling effort captured all species within our study region (Hsieh et al. 2019). We calculated percent of catch by species by dividing the number of individuals of a given taxa over the total number of individuals captured at a given habitat type, and percent occurrence by dividing the presence (if at least 1 individual was captured in a sample) of a taxa by the number of hauls for a given habitat type, season, or gear type to determine how often a taxa was captured. We calculated species richness, which solely accounts for the number of taxon, and Pielou's evenness, which determines how balanced the abundance is for each taxa present (Pielou 1966), using the package 'vegan' in program R (Okansen et al. 2019). For species evenness analyses, we omitted *Anchoa* spp. due to their numerical abundance and overwhelming proportion of the catch. Finally, we calculated catch per unit effort (CPUE) for each habitat type by dividing the number of individuals captured by sampling effort (number of samples) in that habitat type. Similar ratios of seines and trawls in both habitat types were collected, therefore all samples collected were quantified using CPUE (Harley et al. 2001). We conducted all statistical analyses in Rstudio using R language for statistical computing (R Core Team 2019, RStudio Team 2018).

Results

Abiotic environment

For the overall study region, the mean (± sd) annual water temperature was 27.15 °C ± 4.65, DO was 6.44 ± 1.39 mg L^{-1}, salinity was 33.80 ± 4.03 ppt, and secchi depth was 0.69 ± 0.25 m (Table 1). Sampling occurred more frequently in the summer than any other season, resulting in greater variance in environmental data in fall and winter months (Fig. 3, Appendix 1). Water temperatures were similar in spring, summer, and fall, but water temperatures in winter were significantly lower than in all other seasons. Temperature was highest in the summer (mean ± sd = 30.17 ± 1.55 °C), and lowest in the winter (mean = 17.7 ± 2.38 °C). Being inversely related to temperature, dissolved oxygen was higher in the winter months than in other seasons (mean ± sd = 8.65 ± 0.84 mg L^{-1}) and was significantly lower in summer than in spring months ($P < 0.05$). Salinity was significantly lower in fall (the end of the wet season) than in summer ($P < 0.001$), and in spring ($P < 0.05$; the end of the dry season). Secchi depths were significantly different between spring and fall as well as between summer and

Table 1. Environmental metrics with means, standard deviations (SD), and ranges broken down by habitat type and season with all samples used to calculate the rows. Environmental values for Paperno et al. (2001) derived from 11 sampling stations throughout the Mosquito Lagoon years 1993–1996. DO = Dissolved Oxygen, ppt = parts per thousand. "-" indicates values not taken.

		Temperature (°C)	DO (mg L^{-1})	Salinity (ppt)	Secchi (m)
2017–2019	Mean	27.15	6.44	33.80	0.69
	SD	4.65	1.39	4.03	0.25
	Min–max	14.10–37.70	3.49–9.81	24.00–45.00	0.22–1.86
Spring	Mean	24.8 4	6.84	36.35	0.71
	SD	2.66	0.94	2.40	0.31
	Min–max	18.00–29.70	4.52–8.75	31.00–40.00	0.30–1.80
Summer	Mean	30.17	6.02	33.74	0.65
	SD	1.55	1.30	3.41	0.18
	Min–max	26.10–37.70	3.49–9.72	26.00–41.00	0.26–1.40
Fall	Mean	25.92	6.17	30.24	0.73
	SD	4.21	1.23	4.19	0.26
	Min–max	18.90–31.30	3.89–8.65	24.00–37.00	0.22–1.60
Winter	Mean	17.70	8.65	35.16	0.79
	SD	2.38	0.84	5.03	0.34
	Min–max	14.10–21.70	6.29–9.81	29.00–45.00	0.22–1.86
Oyster reef	Mean	27.12	6.528	33.91	0.72
	SD	4.76	1.39	3.98	0.24
	Min–max	14.10–37.70	3.72–9.81	25.00–43.00	0.22–1.86
Living shoreline	Mean	27.23	6.22	33.56	0.62
	SD	4.39	1.38	4.16	0.26
	Min–max	14.20–34.70	3.49–9.07	24.00–45.00	0.22–1.80
Paperno et al. 2001 (1993–1996)	Mean	23.90	6.80	30.30	-
	SD	5.81	1.35	4.52	-
	Min–max	9.90–31.90	3.90–9.70	31.00–38.00	-

fall ($P < 0.05$). Oyster reefs and living-shoreline sites were not significantly different in any of the environmental metrics except salinity, which was significantly higher at oyster reefs compared to living-shoreline sites ($P < 0.05$).

During the study, we used seines and trawls to catch 176,136 individuals representing 87 taxa. Seines (n = 344 sampling events) accounted for 156,653 individuals captured. In total, 151 trawl hauls collected the remaining 19,483 individuals. Rarefaction curves reached asymptotes, suggesting project sampling achieved appropriate coverage of the taxa present in Mosquito Lagoon (Fig. 4). The top 5 most abundant taxa captured from all hauls (i.e., seines and trawls combined) were *Anchoa* spp. (anchovies), *Eucinostomus* spp. (mojarra), *Leiostomus xanthurus* (Spot), *Menidia* spp. (silversides), and *Diapterus auratus* (Irish Pompano); these 5 taxa represented ~83% of the all individuals collected (Table 2). This combined haul result was primarily driven by seine sampling, which had the same top 5 most abundant species accounting for 82% of the total individuals captured in seines. The most abundant taxa captured in trawl hauls include anchovies, *Harengula jaguana* (Scaled Sardine), *Bairdiella chrysoura* (Silver Perch), Irish Pompano, and *Lagodon rhomboides* (Pinfish). These 5 taxa accounted for 91% of the individuals captured in trawls. Hauls by oyster reefs accounted for 62% (n = 108,769) of the total captures, and hauls by living-shoreline sites accounted for the remaining 38% (n = 67,367). The top 5 most abundant taxa at oyster reefs were anchovies, mojarra, Spot, Scaled Sardine, and Pinfish, in total accounting for 88% of the catch. The top 5 most abundant taxa captured at living-shoreline sites were anchovies, silversides, Silver Perch, Irish Pompano, and mojarra, accounting for 84% of individuals collected (Appendix 2). The top 5 most commonly occurring taxa, based on percent

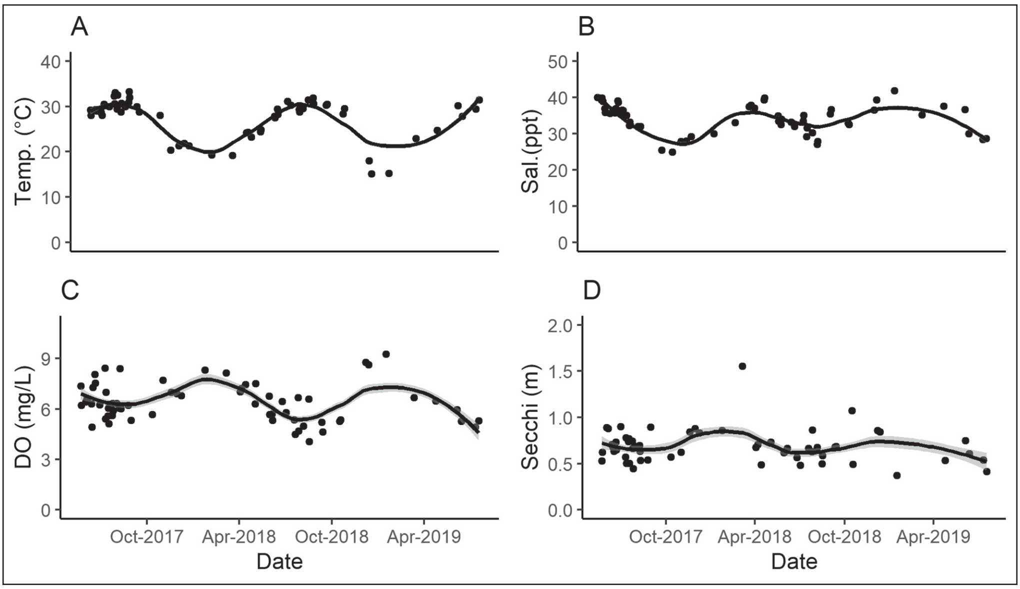

Figure 3. Season variation of (A) temperature, (B) salinity, (C) dissolved oxygen, and (D) Secchi depth with individual sampling events (black circles) and smoothed conditional mean lines (black line with 95% confidence invervals [gray shading]).

occurrence, at all sites were mojarra (69%), anchovies (69%), *Eucinostomus harengulus* (Tidewater Mojarra; 58%), Pinfish (53%), and *Eucinostomus gula* (Silver Jenny; 49%).

Seasonal results

The CPUE was highest in the summer, followed by fall and spring. The CPUE was lowest in the winter. While total number of individuals collected was higher

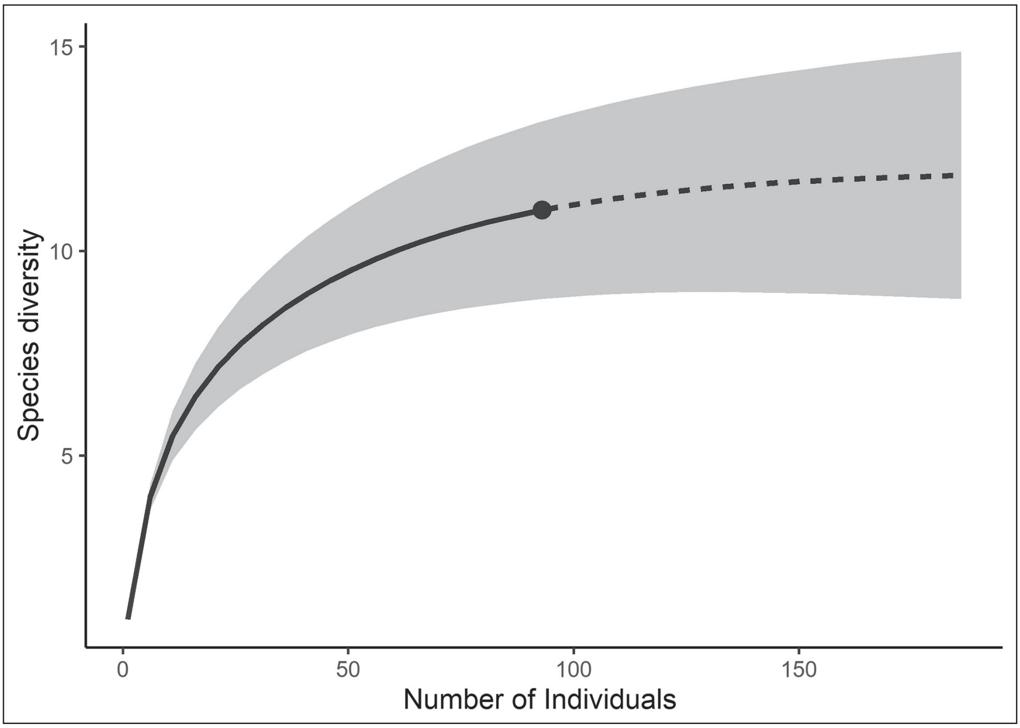

Figure 4. Rarefaction curve illustrating representative nature of project sampling effort with respect to mean species diversity (i.e., richness) per catch including a 95% confidence interval (gray shading). Solid black line represents mean number of species captured per haul and dashed line represents extrapolated capture data.

Table 2. Total catch of top 5 numerically abundant taxa (total catch of all taxa from all hauls at all sites was 176,136 individuals; Appendix 2). Percent of catch is number of individuals of a taxa over total number of individuals collected. Percent occurrence is the presence of a species over total number of hauls.

Taxon	Count	Percent of catch	Percent occurrence
Anchoa spp.(anchovies)	110,807	62.91%	69.09%
Eucinostomus spp. (mojarras)	15,241	8.65%	69.29%
Leiostomus xanthurus (Spot)	6886	3.91%	24.85%
Menidia spp. (silversides)	6,824	3.87%	21.21%
Diapterus auratus (Irish Pompano)	5483	3.11%	39.80%
Total count of top 5 taxa	145,241	82.45%	

at oyster reefs (due to greater sampling effort and more sites; Appendix 1) than at living-shoreline habitat, the latter had the highest CPUE except in fall (Table 3, Appendix 2). Mean daily abundance was higher in the summer, and species richness spiked in the spring and summer months (Fig. 5). Seasonal trends were similar among habitat types, with living-shoreline sites having higher species richness in the summer when compared to oyster reefs. Anchovies and mojarra were the most commonly captured species in every season except spring, when Pinfish were captured more frequently (Appendix 2).

Discussion

Multiple tropical storms, hurricanes, algal blooms, and anthropogenic inputs have impacted Mosquito Lagoon (Feller et al. 2015, Hu et al. 2006, Lapointe et al. 2015, Steward et al. 2005) since the last peer-reviewed survey of the fish assemblage was published (Paperno et al. 2001). All of these disturbances have had various impacts on water quality, submerged aquatic vegetation, and related benthic habitats (La and Cooke 2011, Yarbro and Carlson 2016). In the northern portion of the IRL, percent cover of seagrass increased from 1996 to 2011 (Morris et al. 2018); however, due to a large phytoplankton "super bloom" in 2011, there was a widespread loss in seagrass cover throughout the IRL (Morris et al. 2018). This phytoplankton bloom was caused by *Aureoumbra lagunensis* D.A.Stockwell, DeYoe, Hargraves, & P.W.Johnson, a novel phytoplankton not recorded in this system prior to this bloom (Kang et al. 2015). While percent cover of seagrass has increased since the die-off in 2011, areal cover has yet to return to pre-bloom levels (Yarbro and Carlson 2016). Exacerbating this issue and slowing the recovery of seagrass in Mosquito Lagoon was another large bloom of *A. lagunensis* in 2016, which dwarfed the original "super bloom" of 2011. Almost annual algal blooms, primarily phytoplankton events, have occurred since 2011 with many surpassing the algal concentrations of the initial "super bloom" (Morris et al. 2018). Many of these algal blooms resulted in large fish kill events that potentially impacted the IRL fish community (Adams et al. 2019, Backer et al. 2015, FFWCC 2019). Overall, algal blooms of varying intensities are increasing in frequency throughout the IRL, and while they may not be as prevalent or widespread in Mosquito Lagoon, the region's hydrologic connectivity to the IRL proper could bring about shifts in assemblage composition or species abundance (Lapointe et al. 2015). Furthermore,

Table 3. Total number of individuals collected (*n*) by habitat type and season. Catch per unit effort (CPUE) calculated by number of individuals collected divided by sampling effort.

	Living shoreline sites		Oyster reefs		Total	
Season	*n*	CPUE	*n*	CPUE	*n*	CPUE
Spring	6439	280	17,196	242	23,635	251
Summer	55,577	639	68,097	366	123,674	453
Fall	4638	186	22,590	403	27,228	336
Winter	713	59	886	25	1599	34

climate change may be altering the frequency and intensity of algal blooms in this region, further exacerbating losses of seagrass habitat due to changes in water quality and/or related disturbance events (Hallegraeff 2010, Poff 1992, Short and

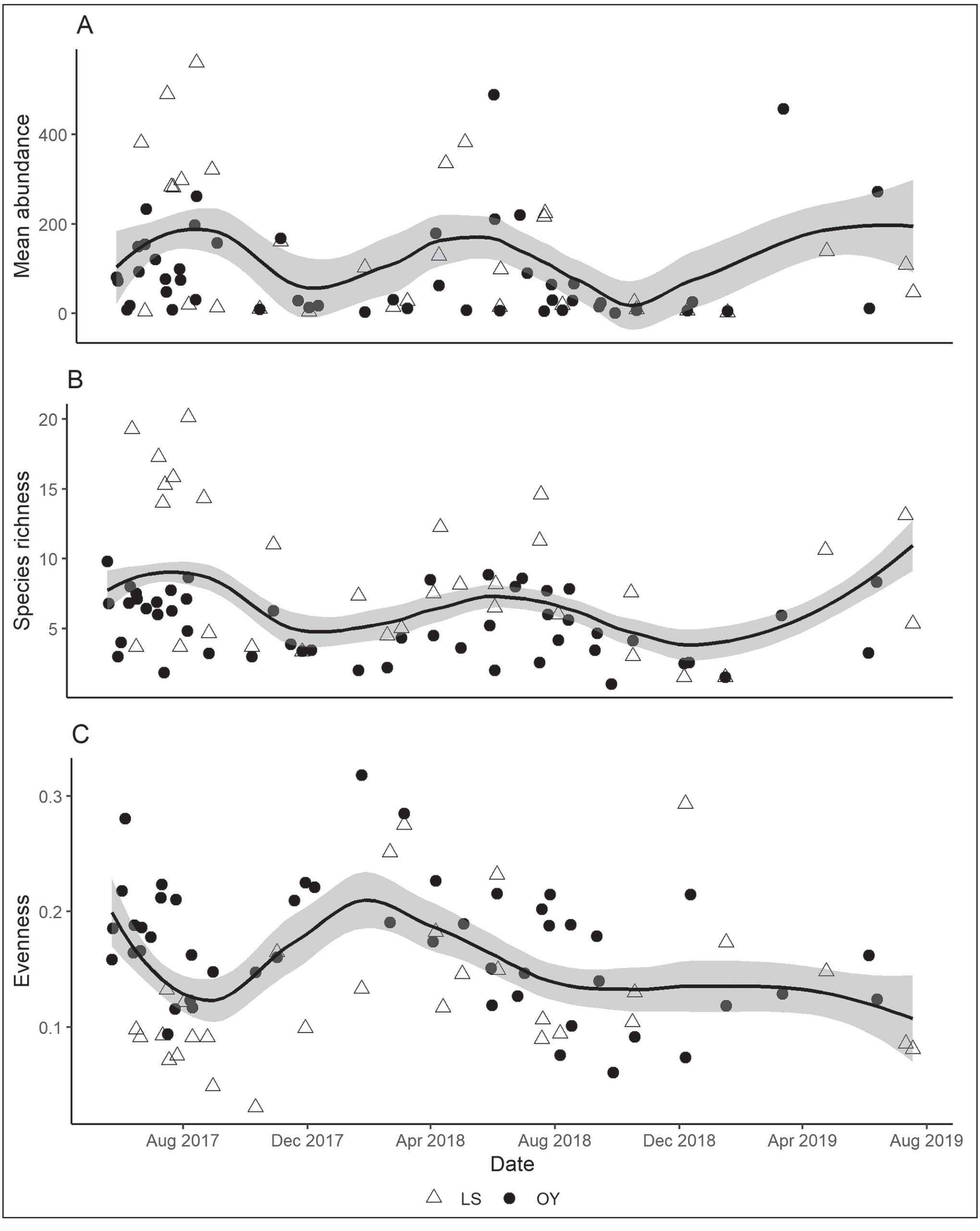

Figure 5. Community diversity metrics with points indicating mean values of samples collected on a given date by habitat type with trend lines and 95% confidence intervals (gray shading) over time. (A) daily mean abundance over time, (B) daily mean species richness, and (C) daily mean species evenness. Closed circles represent oyster reef (OY) samples, and open triangles represent living-shoreline (LS) samples.

Wyllie-Echeverria 1996). As anthropogenic and natural impacts continue to degrade EFH in the IRL, identifying sources of risk and understanding components of the community experiencing shifts over time will be critical to the future management of this system.

The last published survey of the fish assemblage in this region was generated from data collected January 1993–December 1996 (Paperno et al. 2001). Paperno et al. (2001) used an identical seine technique and similar but larger trawl to sample the Mosquito Lagoon as we used in this study, but they collected more samples over a 4-yr period (434,530 individuals in 1464 hauls vs. the 176,136 individuals captured in 495 hauls over 2 years of this study). The results of this study indicated *Lucania parva* (Rainwater Killifish) has decreased in percent occurrence (from 21% to 11%) over the past ~25 years; this change in abundance could be potentially due to the increase in salinity (from a mean of 30.3 ppt in the mid-1990s to 33.8 in this study) and this species' habitat preference for waters with salinities lower than that of marine water, ~35.0 ppt (Fuller et al. 2007). However, some of the most commonly occurring species have increased markedly in that same period, including anchovies (from 23% to 66% occurrence), Pinfish (from 4% to 53%), and mojarra (from 1.5% to 69%). Currently mojarra are one of the most commonly occurring and abundant species in the Mosquito Lagoon. Seasonal changes in abundance and CPUE were observed likely due to shifts in environmental metrics (e.g., warmer temperature in summer) and species life histories (e.g., time of spawning and settlement of young of the year; Table 3; Potter et al. 1986). While collection methods and exact sampling sites differed between these 2 studies, the sampling region and annual catch effort were similar. As such, sampling differences do not appear to be an adequate explanation for the relatively large changes in percent occurrence and potential assemblage homogenization. These changes could be due to losses of EFH and/or related changes in abiotic environment including an increase in water temperature, decrease in DO, and increase in salinity observed over the past ~25 years (Troast et al. 2020). All of these decadal scale shifts would be expected to continue with future climate and urbanization projections. Furthermore, 6 unique taxa not collected by Paperno et al. (2001) were captured during this study (Table 4).

Some of these 6 unique taxa may have been present but not collected in the 1990s. However, given the higher sampling effort and total number of unique fish

Table 4. Unique species captured within the Mosquito Lagoon proper in present study (2017–2019) but not captured in 1993–1996 survey of the same region within Mosquito Lagoon, and their abundance by habitat type. LS = living shoreline sites, OY = oyster reefs.

Taxon	Common name	LS	OY	Total
Ancylopsetta ommata	Ocellated Flounder	0	1	1
Caranx latus	Horse-eye Jack	1	2	3
Cynoscion arenarius	Sand Seatrout	8	1	9
Haemulon spp.	Grunt	1	0	1
Scomberomorus cavalla	King Mackerel	0	3	3
Trinectes maculatus	Hogchoker	2	0	2

taxa captured during the 1990s sampling program (n = 108), this result could indicate the fish assemblage composition may have changed over the past 25 years, as has been documented in the broader IRL region (Troast et al. 2020). Of the 108 fish taxa captured by Paperno et al. (2001), there were 28 taxa not captured in this study. Similar to the current study, the unique taxa collected by Paperno et al. were relatively rare; all were represented by fewer than 10 individuals collected over the 4 years of sampling that occurred in the mid-1990s. As the IRL has a dynamic tropical/subtropical biogeographic break at ~28°N, there are differences in species assemblages over latitude, with more southern species shifting north over the past 2 decades, possibly accounting for some of the unique taxa observed in this survey (Gilmore 1995, Troast et al. 2020).

As they are relatively rare ($n \leq 3$), it is unclear whether the unique taxa captured in this study have established populations in the lagoon and/or if shifts in environmental conditions, particularly winter low temperatures, are great enough to enable these novel species to persist after having dispersed into the region. Relatively common species captured in this study such as *Cynoscion arenarius* (Sand Seatrout), historically rare along Florida's east coast, may indicate changes in environmental conditions, benthic habitat quality, and/or species assemblages are allowing these species to persist in regions that they did not formerly inhabit. Juvenile Sand Seatrout prefer unvegetated substrate on the west coast of Florida, but remain understudied on Florida's east coast (Purtlebaugh and Rogers 2007). Changes in the benthic habitat mosaic in the Mosquito Lagoon, such as shifts from seagrass to mud bottom following algal blooms, could result in a greater proportion of bare benthic habitat enabling the persistence of species such as Sand Seatrout, which prefer bare substrate and/or are better adapted to it than relatively common native species in the Mosquito Lagoon such as *Cynoscion nebulosus* (Spotted Seatrout) that have a preference for seagrass habitat (Knapp and Purtlebaugh 2008, MacRae and Cowan 2010). Hence, pressures related to urbanization and climate change, coupled with disturbances such as algal blooms, may perturb the IRL to such an extent that the benthic habitat mosaic shifts sufficiently to enable the establishment of formerly rare, novel, or invasive species with unknown repercussions for the existing fish assemblage.

Long-term monitoring of fish abundance and community assemblages is often required to accurately assess the health of coastal estuaries, particularly those in close proximity to human populations reliant on recreational and commercial fishing opportunities. This study complements previous surveys in the region and advances our knowledge of changes within the fish community in this coastal lagoon. Additionally, it identifies species that may be increasing in abundance and/or (re)establishing populations in the area and provides an updated assessment of community assemblage on which future studies can build. A large change in percent occurrence of Rainwater Killifish, anchovies, and mojarra over the past 25 years are indicative of shifts in the community assemblage, but further studies focused on these species could elucidate the drivers behind these specific changes. As Florida's coastal estuaries continue to be impacted by myriad near-field and far-field pressures (Cook et al. 2014), continued monitoring will be critical to understanding how the fish community responds to future disturbances and overall long-term environmental changes in these complex coastal ecosystems.

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Appendix 1. Sampling effort by habitat type and gear utilized. LS = living shoreline sites, OY = oyster reefs, SE = Seine, TR = Trawl.

Season	Trawl	Seine	LS TR	LS SE	OY TR	OY SE	LS	OY	Total
Spring	21	73	7	16	14	57	23	71	94
Summer	74	199	22	65	52	134	87	186	273
Fall	32	49	9	16	23	33	25	56	81
Winter	24	23	7	5	17	18	12	35	47
Total	151	344	45	102	106	242	147	348	495

Appendix 2. Total counts and percent occurrence calculated for all taxa and by habitat type, gear type, and season. LS = Living Shoreline, OY = Oyster Reef, SE = Seine, TR = Trawl.

	Total	Percent Occurrence in Catch								
Taxon	Count	LS	OY	SE	TR	Spring	Summer	Fall	Winter	Total
Achirus lineatus (L.) (Lined Sole)	43	14.97	1.72	6.98	2.65	3.19	5.86	7.41	6.38	5.66
Acanthostracion quadricornis (L.) (Scrawled Cowfish)	1	0.00	0.29	0.29	0.00	0.00	0.00	1.23	0.00	0.20
Anchoa spp.	110,807	82.99	63.22	69.77	67.55	56.38	79.12	72.84	29.79	69.09
Ancylopsetta ommata (Jordan & Gilbert) (Ocellated Flounder)	1	0.00	0.29	0.00	0.66	1.06	0.00	0.00	0.00	0.20
Archosargus probatocephalus (Walbaum) (Sheepshead)	181	42.86	8.62	22.97	9.27	26.60	19.05	17.28	4.26	18.79
Ariopsis felis (L.) (Hardhead Catfish)	20	4.08	2.01	2.03	3.97	1.06	3.30	2.47	2.13	2.63
Bairdiella chrysoura (Lacepède) (Silver Perch)	4964	60.54	3.74	21.51	18.54	11.70	25.64	17.28	14.89	20.61
Brevoortia spp.	94	3.40	0.57	2.03	0.00	3.19	1.47	0.00	0.00	1.41
Carangidae spp.	1	0.00	0.29	0.29	0.00	0.00	0.37	0.00	0.00	0.20
Caranx hippos (L.) (Crevalle Jack)	3	0.68	0.57	0.87	0.00	0.00	1.10	0.00	0.00	0.61
Caranx latus (Agassiz) (Horse-eye Jack)	3	0.68	0.57	0.87	0.00	1.06	0.73	0.00	0.00	0.61
Centropomus undecimalis (Bloch) (Common Snook)	34	10.20	1.72	5.81	0.66	3.19	4.40	6.17	2.13	4.24
Chaetodipterus faber (Broussonet) (Atlantic Spadefish)	8	2.72	0.86	0.58	3.31	0.00	1.83	2.47	0.00	1.41
Chasmodes saburrae (Jordan & Gilbert) (Florida Blenny)	1	0.68	0.00	0.29	0.00	0.00	0.37	0.00	0.00	0.20
Chilomycterus schoepfii (Walbaum) (Striped Burrfish)	9	2.04	1.44	2.33	0.00	0.00	2.56	1.23	0.00	1.62
Chloroscombrus chrysurus (L.) (Atlantic Bumper)	7	0.00	1.15	0.58	1.32	0.00	1.10	1.23	0.00	0.81
Citharichthys spilopterus (Günther) (Bay Whiff)	93	14.29	5.46	10.76	1.99	14.89	7.33	4.94	4.26	8.08
Clupeidae spp.	2422	13.61	14.66	19.19	3.31	24.47	14.65	9.88	0.00	14.34
Ctenogobius (Gobionellus) boleosoma (Jordan & Gilbert) (Darter Goby)	74	0.00	7.76	7.85	0.00	10.64	4.76	3.70	2.13	5.45
Ctenogobius (Gobionellus) smaragdus (Valenciennes) (Emerald Goby)	2	0.68	0.29	0.00	1.32	0.00	0.73	0.00	0.00	0.40
Cynoscion arenarius (Ginsburg) (Sand Seatrout)	9	3.40	0.29	0.00	3.97	0.00	1.10	2.47	2.13	1.21
Cynoscion nebulosus (Cuvier) (Spotted Seatrout)	1165	35.37	0.57	13.95	3.97	2.13	16.48	8.64	0.00	10.91
Diapterus auratus (Ranzani) (Irish Pompano)	5396	59.86	31.32	47.09	23.18	25.53	1.83	1.23	8.51	39.80
Elops saurus (L.) (Ladyfish)	172	6.80	6.90	7.27	5.96	8.51	56.41	30.86	21.28	6.87
Eucinostomus gula (Quoy & Gaimard) (Jenny Mojarra)	1945	25.85	59.20	61.34	21.85	39.36	60.07	38.27	25.53	49.29
Eucinostomus harengulus (Goode & Bean) (Tidewater Mojarra)	2944	44.22	63.22	70.64	27.81	44.68	75.46	33.33	21.28	57.58
Eucinostomus jonesii (Günther) (Slender Mojarra)	16	0.00	1.15	1.16	0.00	3.19	0.00	1.23	0.00	0.81

	Total	Percent Occurrence in Catch								
Taxon	Count	LS	OY	SE	TR	Spring	Summer	Fall	Winter	Total
Eucinostomus spp.	15,235	68.03	69.83	82.56	39.07	46.81	84.98	60.49	38.30	69.29
Floridichthys carpio (Günther) (Goldspotted Killifish)	69	7.48	0.29	3.49	0.00	1.06	1.47	2.47	10.64	2.42
Fundulus grandis (Baird & Girard) (Gulf Killifish)	27	7.48	0.57	3.78	0.00	3.19	2.93	0.00	4.26	2.63
Fundulus majalis (Walbaum) (Striped Killifish)	12	1.36	0.29	0.29	1.32	1.06	0.73	0.00	0.00	0.61
Fundulus spp.	5	1.36	0.29	0.87	0.00	0.00	1.10	0.00	0.00	0.61
Gambusia holbrooki (Girard) (Eastern Mosquitofish)	1	0.68	0.00	0.29	0.00	0.00	0.00	1.23	0.00	0.20
Gobiosoma bosc (Lacepède) (Naked Goby)	27	4.08	1.72	3.49	0.00	1.06	3.30	1.23	2.13	2.42
Gobiosoma robustum (Code Goby) (Ginsburg)	112	19.73	4.02	9.59	6.62	19.15	6.23	3.70	10.64	8.69
Gobiosoma spp.	648	45.58	8.05	23.84	8.61	9.57	23.44	16.05	19.15	19.19
Gymnura micrura (Bloch & Schneider) (Smooth Butterfly Ray)	1	0.00	0.29	0.00	0.66	0.00	0.00	1.23	0.00	0.20
Haemulon spp.	1	0.68	0.00	0.29	0.00	0.00	0.37	0.00	0.00	0.20
Harengula jaguana (Poey) (Scaled Sardine)	3807	19.73	11.78	17.44	6.62	7.45	20.51	8.64	0.00	14.14
Hemiramphidae spp.	2	0.68	0.00	0.29	0.00	0.00	0.37	0.00	0.00	0.20
Hypanus sabinus (Dasyatis sabina) (Lesueur) (Atlantic Stingray)	13	5.44	1.15	3.49	0.00	2.13	2.93	1.23	2.13	2.42
Hypanus (Dasyatis) say (Lesueur) (Bluntnose Stingray)	2	0.68	0.29	0.58	0.00	1.06	0.00	1.23	0.00	0.40
Hyporhamphus meeki (Banford & Collette) (American Halfbeak)	19	2.04	0.00	0.87	0.00	0.00	1.10	0.00	0.00	0.61
Lagodon rhomboides (L.) (Pinfish)	3567	51.70	53.74	64.53	27.15	80.85	57.88	27.16	14.89	53.13
Leiostomus xanthurus (Lacepède) (Spot Croaker)	6883	35.37	20.40	30.81	11.26	53.19	26.37	1.23	0.00	24.85
Lucania parva (Baird & Girard) (Rainwater Killifish)	3096	28.57	3.16	11.92	7.95	34.04	4.76	4.94	8.51	10.71
Lutjanus griseus (L.) (Gray Snapper)	280	34.69	25.86	38.37	5.96	20.21	34.80	30.86	4.26	28.48
Lutjanus spp.	32	5.44	0.29	2.33	0.66	1.06	7.69	6.17	0.00	1.82
Lutjanus synagris (L.) (Lane Snapper)	77	0.68	7.47	6.98	1.99	0.00	2.56	2.47	0.00	5.45
Membras martinica (Valenciennes) (Rough Silverside)	112	14.97	0.00	6.10	0.66	4.26	6.23	1.23	0.00	4.44
Menidia spp.	6824	45.58	10.92	29.65	1.99	29.79	24.54	8.64	6.38	21.21
Menticirrhus americanus (L.) (Southern Kingfish)	1	0.68	0.00	0.00	0.66	0.00	0.00	0.00	2.13	0.20
Microgobius gulosus (Girard) (Clown Goby)	2044	45.58	11.21	29.94	1.99	4.26	34.07	9.88	2.13	21.41
Microgobius thalassinus (Jordan & Gilbert) (Green Goby)	7	2.72	0.00	0.87	0.66	0.00	0.73	2.47	0.00	0.81
Micropogonias undulatus (L.) (Atlantic Croaker)	339	12.93	6.32	5.81	13.91	19.15	6.59	2.47	6.38	8.28
Mugil cephalus (L.) (Striped Mullet)	95	21.77	3.45	12.50	0.66	2.13	12.82	7.41	2.13	8.89
Mugil curema (Valenciennes) (White Mullet)	244	27.89	14.37	26.45	0.00	21.28	20.51	12.35	10.64	18.38

	Total	Percent Occurrence in Catch								
Taxon	Count	LS	OY	SE	TR	Spring	Summer	Fall	Winter	Total
Mugil spp.	29	3.40	0.00	1.45	0.00	2.13	0.37	2.47	0.00	1.01
Myrophis platyrhynchus (Breder) (Broadnose Worm Eel)	2	0.00	0.57	0.58	0.00	1.06	0.37	0.00	0.00	0.40
Oligoplites saurus (Bloch and Schneider) (Leatherjack)	265	27.89	4.31	15.99	0.66	0.00	19.41	3.70	0.00	11.31
Opisthonema oglinum (Lesueur) (Atlantic Thread Herring)	299	1.36	5.46	5.23	1.99	3.19	6.59	0.00	0.00	4.24
Opsanus tau (L.) (Oyster Toadfish)	7	3.40	0.29	1.74	0.00	3.19	0.37	2.47	0.00	1.21
Orthopristis chrysoptera (L.) (Pigfish)	910	38.78	18.10	29.65	11.92	41.49	26.74	9.88	0.00	24.24
Paralichthys albigutta (Jordan & Gilbert) (Gulf Flounder)	37	6.80	6.32	6.69	5.96	7.45	7.33	4.94	2.13	6.46
Poecilia latipinna (Lesueur) (Sailfin Molly)	10	2.04	0.00	0.87	0.00	2.13	0.00	0.00	2.13	0.61
Pogonias cromis (L.) (Black Drum)	8	3.40	0.29	1.45	0.66	1.06	1.83	0.00	0.00	1.21
Prionotus tribulus (Cuvier) (Bighead Searobin)	7	2.72	0.29	0.87	1.32	2.13	0.73	1.23	0.00	1.01
Sciaenops ocellatus (L.) (Red Drum)	4	1.36	0.57	0.87	0.66	1.06	0.73	1.23	0.00	0.81
Sciaenidae spp.	1	0.68	0.00	0.29	0.00	0.00	0.37	0.00	0.00	0.20
Scomberomorus cavalla (Cuvier) (King Mackerel)	3	0.00	0.57	0.58	0.00	0.00	0.73	0.00	0.00	0.40
Selene vomer (L.) (Lookdown)	2	0.00	0.57	0.58	0.00	0.00	0.73	0.00	0.00	0.40
Sphoeroides nephelus (Goode & Bean) (Southern Puffer)	22	7.48	2.30	4.65	1.99	0.00	0.73	0.00	0.00	3.84
Sphyraena barracuda (Edwards) (Great Barracuda)	2	0.68	0.29	0.58	0.00	3.19	4.76	3.70	0.00	0.40
Stephanolepis (Monacanthus) hispidus (L.) (Planehead Filefish)	6	0.68	1.44	0.87	1.99	2.13	0.37	3.70	0.00	1.21
Strongylura marina (Walbaum) (Atlantic Needlefish)	73	10.20	3.45	7.85	0.00	7.45	7.33	0.00	0.00	5.45
Strongylura notata (Poey) (Redfin Needlefish)	394	42.18	8.33	26.45	0.00	4.26	27.84	12.35	2.13	18.38
Strongylura timucu (Walbaum) (Timucu)	1	0.68	0.00	0.29	0.00	1.06	0.00	0.00	0.00	0.20
Symphurus plagiusa (L.) (Blackcheek Tonguefish)	14	10.20	1.44	3.49	5.30	2.13	3.30	0.00	2.13	4.04
Syngnathus louisianae (Günther) (Chain Pipefish)	25	4.08	1.72	3.49	0.00	8.51	4.03	0.00	2.13	2.42
Syngnathus scovelli (L.) (Gulf Pipefish)	148	23.13	3.74	6.69	15.89	19.15	8.79	0.00	10.64	9.49
Syngnathus spp.	3	0.68	0.29	0.29	0.66	0.00	0.37	1.23	0.00	0.40
Synodus foetens (L.) (Inshore Lizardfish)	28	3.40	4.60	5.52	1.32	4.26	5.86	1.23	0.00	4.24
*Trachinotus carolinus** (L.) (Florida Pompano)	2	0.00	0.57	NA	NA	0.00	0.73	0.00	0.00	NA
Trachinotus falcatus (L.) (Permit)	9	2.04	0.00	0.87	0.00	0.00	1.10	0.00	0.00	0.61
Trinectes maculatus (Bloch & Schneider) (Hogchoker)	2	0.00	0.29	0.00	0.73	0.00	0.73	0.00	0.00	0.20

*Species was incidentally captured during trawling near oyster habitat in summer months i.e. individuals jumped directly into skiff to avoid capture in trawl and are therefore not counted toward totals.