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SEASONAL VARIATIONS IN SPECIES DIVERSITY, ABUNDANCE, AND COMPOSITION OF FISH COMMUNITIES IN THE NORTHERN INDIAN RIVER LAGOON, FLORIDA

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ABSTRACT

We analyzed data from a long-term fisheries-independent monitoring program to quantitatively assess seasonal variations in species diversity, abundance, and composition of fish communities in the northern Indian River Lagoon. Between fall 1990 and 1993, over 2.24 million fish representing 108 species and 43 families were collected by using seines, trawls, and gillnets during seasonal stratified-random sampling and monthly fixed-station sampling regimes. Seasonal collections were numerically dominated by less than 10 small estuarine forage species including *Anchoa mitchilli, Menidia* spp., *Floridichthys carpio,* and *Lucania parva* which were present in high abundances throughout the year. We observed strong seasonal patterns in abundance measures for several less common or transient species collected from shallow-water habitats (e.g., *Brevoortia* spp., *Trachinotus falcatus, Caranx hippos, Cynoscion nebulosus,* and *Leiostomus xanthurus*) and from lagoon-basin habitats (e.g., *Micropogonias undulatus* and *Diapterus auratus*). Estimates of species richness and abundance were directly correlated with water temperature, reaching maxima during summer or fall and minima during winter. Species diversity (H') ranged from 0.9–1.4 and followed similar seasonal trends. This study provides baseline estimates of seasonal variations in fish communities of the northern Indian River Lagoon, based on comprehensive sampling techniques, that can be used for future comparisons of Indian River Lagoon fish communities.

Estuarine fish communities are highly variable and often experience large temporal changes in species composition and abundance (Livingston et al., 1976; Livingston, 1987; Rountree and Able, 1992). Many individual species populations exhibit predictable seasonal patterns of abundance within a given estuary (Horn, 1980; Gilmore, 1988; De Ben et al., 1990) which affect both seasonal and annual estimates of species diversity. These measures of species diversity, along with other indices of community structure and species composition, have been used to make long-term comparisons of changes in estuarine biological communities (Livingston et al., 1976; Yoklavich et al., 1991) and have also been used to assess environmental quality (Bechtel and Copeland, 1970; Haedrich, 1975; Horn, 1980; Phillips, 1983). The ability to accurately detect changes in a particular fish community requires an initial estimate to base comparisons against, as well as an understanding of inherent variations in the selected measures of that community.

The Indian River Lagoon system (IRL) on Florida's east central coast is considered one of the most diverse estuaries in North America. More than 400 fish species have been documented from the estuary and adjacent freshwater habitats (Gilmore et al., 1981; Snelson, 1983). Quantitative fish studies in the IRL have investigated the ichthyofauna of specific communities or individual habitat types such as seagrasses (Schooley, 1977, 1980; Snyder, 1984; McNeese, 1986; Gilmore, 1988), algae (Kulczycki et al., 1981; Snodgrass, 1992), channels or basins (Mulligan and Snelson, 1983), and spoil islands (Brown-Peterson and Eames, 1990). There is very little quantitative data regarding the IRL ichthyofauna based on a comprehensive investigation of multiple habitats within the lagoon. In addition, the short duration of many of these studies precludes multi-year estimates of seasonal variation. Species richness and abundance estimates may also be biased by the use of selective gear types or diel sampling periods. The data pre-

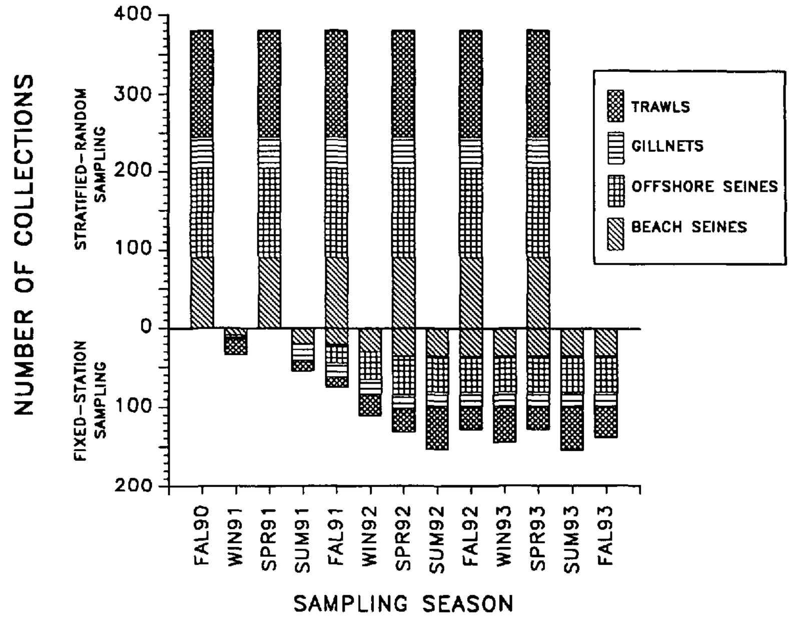


Figure 1. Seasonal allocation of fish sampling effort for beach seines, offshore seines, trawls, and gillnets in the northern Indian River Lagoon during fall 1990–fall 1993. Stratified-random sampling effort is indicated above, and fixed-station sampling effort below, the central axis.

sented below were gathered by the Florida Marine Research Institute's Marine Fisheries-Independent Monitoring Program, a comprehensive, multi-gear sampling program designed to estimate long-term trends in estuarine fish abundances.

The objectives of this study were (1) present data from the Fisheries-Independent Monitoring Program in the northern Indian River Lagoon which can be used as baseline data for future comparisons, and (2) quantitatively examine how the species diversity, abundance, and composition of the northern IRL fish community varied on a seasonal basis.

Methods and Materials

The IRL consists of three interconnected bodies of water (Mosquito Lagoon, the Indian River proper, and the Banana River lagoon). The study area encompassed the region of the IRL extending from the northern terminus of the Indian River proper (28°45′N, 80°50′W) southward to Cape Malabar (28°01′N, 80°32′W) and included the entire Banana River lagoon (Swain, et al., 1995: fig. 1). The environmental characteristics of the lagoon have been previously described by Snelson (1980), Gilmore et al. (1981), and Mulligan and Snelson (1983).

Fish were collected in the northern IRL by using two complimentary sampling strategies—seasonal stratified-random sampling (SR) and monthly fixed-station sampling (FS). We collected seasonal SR data over a 10-week period during spring (March–May) and fall (September–November) corresponding to major recruitment periods for many commercially and recreationally important fish in Florida estuaries (Reid, 1954; Wang and Raney, 1971; Comp and Seaman, 1985 and others). Sampling effort for SR sampling was nearly constant for all seasons; however, where differences existed, we excluded randomly-selected collections from the more abundant dataset to attain an equal number of samples for seasonal comparisons. A total of 380 quantitative samples for each SR sampling season from fall 1990 to spring 1993 (six seasons) were included in the analyses. Monthly FS samples were collected from 17 stations representing a variety of lagoon habitats. Fixed-station sampling was initiated in January 1991; however, all 17 stations were not sampled regularly until February 1992. In addition, we did not sample four of the fixed trawl stations during certain months of the year when sampling coincided with seasonal SR collections. We included FS data from January 1991 to December 1993 in the analyses unless otherwise indicated. Figure 1 summarizes the seasonal effort for both SR and FS sampling strategies.

All fish captured in our gear were identified in the field to the lowest practical taxon, measured, and enumerated; those fish that were positively identified were then released. Very abundant collections were subsampled and processed after large or rare species were sorted and separately processed from the sample. All unidentified species were returned to the laboratory for further processing. In addition, representative samples of fish species captured in our gears were brought back to the laboratory so that field identifications could be confirmed. Some taxa were not identified to species (*Brevoortia* spp., *Menidia* spp.) because of the possibility of hybridization in our area (Chernoff et al., 1981; Gilmore et al., 1981; Rogers and Van Den Avyle, 1983; Middaugh and Hemmer, 1992) or because they were morphologically or meristically indistinguishable at small juvenile sizes (*Eucinostomus* spp.). In the latter case, *Eucinostomus* spp. were included in species counts only when no other identified members of the genus were present in the sample. In computations of similarity or community structure, all *Eucinostomus* were pooled. Although this approach affected index results, we considered the effects to be minor due to the low overall abundance of the species. With the above exception, all species were included in the analyses of species composition, richness, and diversity (i.e., rare species were not excluded). However, specimens that could not be identified to species because of damage were not included in the analyses (N(SR) = 1,428 fish, 0.001% of SR total; N(FS) = 1,060 fish, <0.001% of FS total).

Shallow water habitats less than 1.5 m deep (near-beach and offshore) were sampled with a 23.1-m × 1.8-m nylon center-bag seine with 3-mm mesh that was hauled over a standardized area (beach seines = 377 m^2, offshore seines = 152 m^2). Beach seines were hauled immediately adjacent to the shoreline, whereas offshore seines typically sampled shallow, open-water habitats away from shoreline areas. Deeper areas of the lagoon (greater than 2.0 m) were sampled with a 6.1-m otter trawl (38-mm stretch-mesh body, 3-mm-mesh liner). Trawl tow speed was nearly constant for each haul and tow distances were computed from LORAN waypoints recorded at the start and end of each haul. Subadults and adults of larger mobile species were sampled with multi-panel experimental gillnets (180 m × 1.8-m having one 45.7-m panel each of monofilament 75-mm, 100-mm, 125-mm, and 150-mm stretch-mesh) set perpendicular to the shore for an average soaktime of approximately 2 h. During SR sampling, seines and trawls were deployed within four diel periods: morning crepuscular (crepuscular periods were defined as the period from 1 h before until 1 h after sunrise or sunset), day, evening crepuscular, and night. Gillnets were deployed within evening crepuscular and night periods. For FS sampling, seines and trawls were deployed only during the day and gillnets were deployed only during evening crepuscular periods for an average soaktime of approximately 1.5 h. Physical data including water temperature (C), salinity (‰), pH, and dissolved oxygen (ppm), were recorded with each sample by using a Hydrolab Surveyor II water quality instrument.

Data Analyses.—Due to variable catch efficiencies and selectivity of the gears used in this study, raw abundance data for each species were converted to catch per unit effort (CPUE) values for each collection. CPUEs were expressed as number 100^{-m2} for seines and trawls, and as number $soakhour^{-1}$ for gillnets. CPUE values for each species were then used as individual count data for monthly and seasonal abundance computations. In order to help normalize abundance data from contagiously distributed organisms, all individual CPUE data were log-transformed ($\log_e(x + 1)$) prior to similarity calculations, community structure analyses, and during various other statistical treatments.

Fixed-station and stratified-random datasets each present unique perspectives of the IRL fish community and, therefore, were used in separate analyses of our data. In general, analyses that required comparisons among all seasons utilized monthly FS datasets. In contrast, seasonal SR data provided more comprehensive comparisons of fish species abundance, composition, and diversity during major recruitment periods in the lagoon. We used monthly FS sampling data to examine temporal variations in both species richness (mean number of species per haul) and abundance (mean number of individuals (CPUE) per haul). To compare seasonal species composition in both FS and SR datasets, we first converted log-transformed CPUE values for each species to a percentage of the total of all species captured in a particular season. These percentages then were used to calculate the quantitative percent similarity index (PSI) which measured differences in the relative abundances of species pairs between two seasons. Percent similarity was calculated as

$$PSI = 100(1.0 - 0.5\ \Sigma|P_{ia} - P_{ib}|),$$

where P_{ia} is the proportion of the i^{th} species in sample a, with P_{ib} similarly defined for sample b (Whittaker and Fairbanks, 1958). We used Wilcoxon's signed-rank test (Sokal and Rohlf, 1981) to statistically examine differences in the species composition between seasons. A significant value of T_s ($P < 0.05$) indicated there was a difference in the relative abundance rankings of species pairs between two seasons. For more detailed seasonal comparisons of the dominant species, we first pooled FS samples by month and then calculated the number of samples in which a species was present in each month as a percentage of the total number of collections for that month (relative occurrence). This use of relative occurrence measures was necessary to standardize differences in monthly FS sampling effort.

We calculated descriptive indices of community structure recommended by Livingston (1976). These included the number of species (S); total number of individuals ($N = \Sigma CPUE$); Shannon-Wiener diversity ($H' = -\Sigma P_i \ln P_i$, where P_i = the proportion of individuals in the i^{th} species); Margalef's Richness ($D = (S - 1)/\ln N$), and relative dominance ($D_1 = N_1/N$ and $D_2 = (N_1 + N_2)/N$, where N_1 and N_2 = seasonal CPUE of the most abundant and the second most abundant species, respectively). Index calculations were based on pooled seasonal data.

Results

Environmental Factors.—We observed consistent seasonal trends for several of the environmental factors recorded during our study (Fig. 2). Mean monthly water temperatures ranged from approximately 18°C during winter to nearly 32°C during July or August each year (Fig. 2a). The trend in mean monthly salinity values was typical for the region reaching maximum levels (25–30‰) prior to the onset of the rainy season (May and June in 1992 and 1993, respectively) and generally decreasing through November (Fig. 2b). Mean salinities during summer and fall were higher in 1993 than 1992 (Fig. 2b). We did not observe any consistent seasonal patterns in our estimates of mean monthly pH (Fig. 2c). Mean monthly dissolved oxygen levels followed expected patterns, reaching maximum levels (8–10 ppm) during the colder months and minimum levels (5–7 ppm) during the warmer months for all years (Fig. 2d).

Fixed Stations.—We collected a total of 1,192,253 fish during the January 1991 to December 1993 sampling period. Members of 89 species in 38 families were represented in the collections (Table 1).The most abundant species in shallow-water seine collections included schooling planktivorous species such as *Anchoa mitchilli* and *Menidia* spp., or epibenthic detritivores such as *Floridichthys carpio* and *Lucania parva. Anchoa mitchilli* was also the most abundant species in the lagoon-basin trawl collections along with abundant members of the drift algae fish community such as *Gobiosoma robustum* (Kulczycki et al., 1981) and *Bairdiella chrysoura.* Larger size-class individuals of *Arius felis, Mugil cephalus,* and *Leiostomus xanthurus* were the most abundant fish represented in shallow water (<1.5 m) gillnet collections.

Seasonal variations in species richness were evident from our collections (Fig. 3). Monthly species richness values (mean number of species per haul) for both shallow-water and basin habitats sampled by our gears were lowest in winter during all years. Species richness was highest during summer in 1992 and during fall in 1993 with the exception of deeper areas of the lagoon which peaked in summer during both years (Fig. 3). Species richness estimates were correlated with several environmental factors (Table 2a). Mean monthly species richness estimates were positively correlated with water temperature for shallow-water seine and gillnet collections but not for lagoon-basin trawl collections. In contrast, mean monthly species richness estimates were negatively correlated with dissolved oxygen levels for both shallow-water seine collections and basin trawl collections, but not for collections of larger individuals captured in gillnets. There were no significant relationships between species richness and either salinity or pH.

Seasonal patterns in fish abundances (mean number of fish per haul) were observed in our samples; however, true differences were difficult to determine due to the large variances around the mean (Fig. 4). The considerable variances around mean monthly estimates of abundance could often be attributed to large collections of schooling species such as *Anchoa mitchilli* and *Menidia* spp. in both shallow-water and basin samples. Regardless of these variances, mean esti-

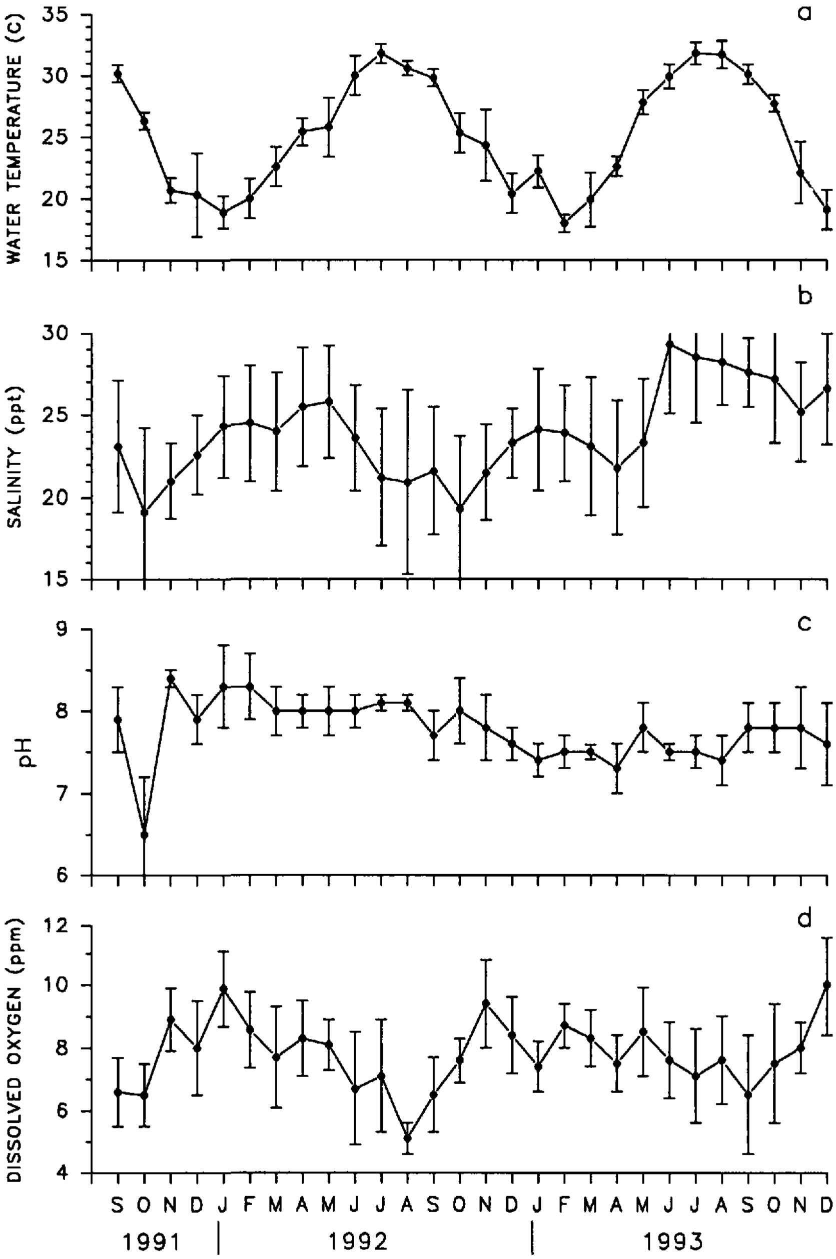


Figure 2. Variations in mean (a) water temperature, (b) salinity, (c) pH, and (d) dissolved oxygen levels in the study area between September 1991 and December 1993 based on monthly fixed-station sampling data. Vertical bars represent ± 1 SD.

mates of fish abundance followed very similar patterns for seine and trawl collections, even though each of these gear sampled different segments of the fish community. In general, maximum abundances were observed during the summer or early fall in shallow-water and basin collections. Maximum catch rates in

Table 1. List of fish species and total unadjusted seasonal abundances from stratified-random sampling in the northern Indian River Lagoon (fall 1990–spring 1993). Nomenclature follows Robins et al., 1991. † represent species that were also collected during fixed-station sampling. * Represent species collected in fixed-station sampling, but not in stratified-random sampling.

	Season						
Species	Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	Total (#)
Carcharhinidae							
†*Carcharhinus leucas*		1		3			4
Dasyatidae							
†*Dasyatis sabina*	194	155	333	153	300	111	1,246
†*Dasyatis say*	32	26	30	18	52	21	179
†*Gymnura micrura*			4	4	5	2	15
Lepisosteidae							
†*Lepisosteus platyrhincus*		3					3
Elopidae							
†*Elops saurus*	34	37	49	77	63	193	453
†*Megalops atlanticus*	2	2	10		23		37
Albulidae							
†*Albula vulpes*		3		1		1	5
Ophichthidae							
Myrophis punctatus						1	1
Ophichthus gomesi			8		1		9
Clupeidae							
†*Brevoortia* spp.	363	27,832	1,673	4,049	1,605	26,037	61,559
†*Dorosoma cepedianum*	1	1			1		3
†*Harengula jaguana*	63	4	34	6	82	6	195
†*Opisthonema oglinum*	41	2	24	8		5	80
Engraulidae							
†*Anchoa hepsetus*	16	944	6	1,724	3	72	2,765
†*Anchoa mitchilli*	21,162	173,539	34,305	18,419	61,067	40,893	349,385
Clariidae							
Clarius batrachus			2				2

Table 1. Continued

Species	Season						Total (#)
	Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	
Ariidae							
†*Arius felis*	1,003	624	989	704	859	396	4,575
†*Bagre marinus*	13	24	35	17	45	74	208
Synodontidae							
Synodus foetens						1	1
Batrachoididae							
†*Opsanus tau*	125	29	45	24	49	26	298
Antennariidae							
Histrio histrio		1					1
Gobiesocidae							
†*Gobiesox strumosus*	14	21	15	13	3	15	81
Exocoetidae							
Hemiramphus spp.	1						1
†*Hyporhamphus unifasciatus*	10	10	5	9	2	8	44
Belonidae							
†*Strongylura marina*		11		4	2	17	34
†*Strongylura notata*	1,113	1,066	861	209	837	141	4,227
†*Strongylura timucu*		59		9	35	42	145
Cyprinodontidae							
†*Cyprinodon variegatus*	2,313	1,138	3,654	16,651	2,654	2,339	28,749
†*Floridichthys carpio*	7,634	7,935	6,806	8,429	8,412	4,288	43,504
Fundulus confluentus	3						3
†*Fundulus grandis*	112	1,272		1,272	170	406	3,232
†*Fundulus majalis*	1	1	64	18	1	162	247
Jordanella floridae	1						1
Lucania goodei			1				1
†*Lucania parva*	16,858	21,589	66,348	94,318	50,519	58,673	308,305

Table 1. Continued

Species	Season						Total (#)
	Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	
Poeciliidae							
†*Gambusia holbrooki*	5	111	14	1,134	212	1	1,477
†*Heterandria formosa**							
†*Poecilia latipinna*	114	783	131	2,197	721	239	4,185
Atherinidae							
†*Membras martinica*	1		8	20	99	102	230
†*Menidia* spp.	3,409	27,209	3,777	31,846	9,773	29,404	105,418
Syngnathidae							
†*Hippocampus erectus*	14	11	8	15	2	3	53
†*Hippocampus reidi*		1					1
†*Hippocampus zosterae*	4	11	7	1	8	1	32
Syngnathus floridae	2				1		3
†*Syngnathus louisianae*	80	129	97	62	51	32	451
†*Syngnathus scovelli*	611	1,887	448	696	553	702	4,897
Triglidae							
Prionotus scitulus			1				1
†*Prionotus tribulus*	2	1					3
Centropomidae							
†*Centropomus undecimalis*	11	5	51	19	40	7	133
Serranidae							
†*Mycteroperca microlepis**							
Pomatomidae							
†*Pomatomus saltatrix*		3		4	1	2	10
Echeneidae							
Echeneis naucrates				1			1

Table 1. Continued

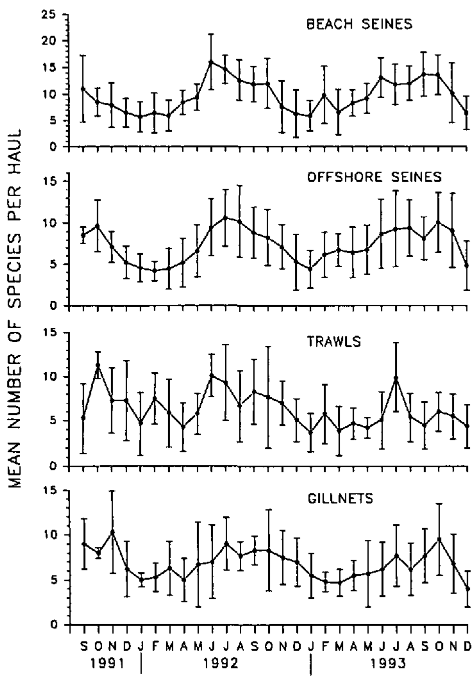
Species	Season						
	Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	Total (#)
Carangidae							
†*Chloroscombrus chrysurus**							
†*Caranx hippos*	13	18	44	20	40	6	141
†*Oligoplites saurus*	47	112	32	1	41	3	236
†*Selene setapinnis**							
†*Selene vomer*		1					1
Trachinotus carolinus	7	136		2		20	165
†*Trachinotus falcatus*	7	11	26	6	13	2	65
Lutjanidae							
†*Lutjanus griseus*	1	2	14	6	12		35
Gerreidae							
†*Diapterus auratus*	87	9	136	110	350	49	741
†*Diapterus plumieri*	92		24	2	8		126
†*Eucinostomus gula*	111	83	25	34	15	38	306
†*Eucinostomus harengulus*	645	1,362	755	481	299	366	3,908
Eucinostomus lefroyi						1	1
†*Eucinostomus* spp.	2,238	97	694	124	717	175	4,045
Gerres cinereus			1		1		2
Haemulidae							
†*Orthopristis chrysoptera*	247	556	103	556	330	562	2,354
Sparidae							
†*Calamus arctifrons**							
†*Lagodon rhomboides*	98	720	86	5,773	120	905	7,702
†*Archosargus probatocephalus*	48	15	86	69	79	19	316

Table 1. Continued

Species	Season: Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	Total (#)
Sciaenidae							
†*Bairdiella chrysoura*	504	3,673	1,025	428	1,292	339	7,261
†*Cynoscion nebulosus*	728	117	416	63	656	44	2,024
†*Cynoscion regalis*	19	266	60	2	106	116	569
†*Leiostomus xanthurus*	198	999	115	6,157	223	21,035	28,727
†*Menticirrhus americanus*	965	1,373	1,425	357	1,184	89	5,393
†*Micropogonias undulatus*	18	178	29	4,406	33	3,993	8,657
†*Pogonias cromis*	10	70	69	19	15	14	197
†*Sciaenops ocellatus*	42	20	55	33	62	31	243
Ephippidae							
†*Chaetodipterus faber*	9	17	52	16	38	6	138
Cichlidae							
†*Tilapia* spp.	3	1	1	22	5		32
Mugilidae							
†*Mugil cephalus*	132	732	374	950	192	7,305	9,685
†*Mugil curema*	199	783	230	749	335	177	2,473
Sphyraenidae							
†*Sphyraena barracuda*				1			1
Blenniidae							
Blenniidae (unidentified)			1				1
†*Chasmodes saburrae*	43	132	110	32	69	43	429
Gobiidae							
Bathygobius soporator	1						1
†*Gobionellus hastatus*			1		30	2	33
†*Gobiosoma bosc*	318	30	6	160	94	9	617
†*Gobiosoma robustum*	3,717	2,465	4,917	1,968	4,380	2,631	20,078
†*Microgobius gulosus*	1,293	177	1,376	1,767	7,148	1,251	13,012
†*Microgobius thalassinus*	2		30	11	33		76

Table 1. Continued

Species	Season: Fall 1990 (#)	Spring 1991 (#)	Fall 1991 (#)	Spring 1992 (#)	Fall 1992 (#)	Spring 1993 (#)	Total (#)
Scombridae							
†*Scomberomorus maculatus*	1	1	1	1			4
†*Scomberomorus regalis*			1				1
Bothidae							
Citharichthys macrops	2						2
†*Citharichthys spilopterus*	8	2	1	112	6	68	197
Etropus crossotus	1						1
†*Paralichthys albigutta*	1	1	1	2		1	6
†*Paralichthys lethostigma*						1	1
Soleidae							
†*Achirus lineatus*	210	174	349	263	352	193	1,541
†*Trinectes maculatus*	3	2	2		10	9	26
†*Symphurus plagiusa*		3	3		1	1	8
Balistidae							
†*Aluterus schoepfi*	1						1
†*Monacanthus hispidus*	1	2	4	2		5	14
Ostraciidae							
†*Lactophrys* spp.		2					2
Tetraodontidae							
†*Sphoeroides nephelus*	70	286	133	81	66	74	710
†*Sphoeroides spengleri*	1	1	1	1			4
†*Chilocycterus schoepfi*	254	418	184	102	109	62	1,129
Total abundance	67,757	281,527	132,841	207,023	156,715	204,068	1,049,931



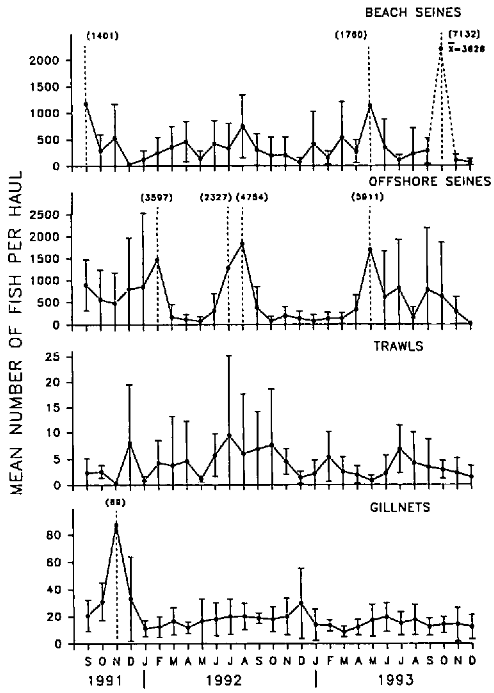


Figure 3 (left). Variations in the mean number of fish species per haul for fish caught during monthly fixed-station sampling from September 1991 to December 1993 for each gear type. Vertical bars represent ±1 SD.

Figure 4 (right). Variations in the mean number of fish (total of log-transformed CPUEs) per haul for fish caught during monthly fixed-station sampling from September 1991 to December 1993 for each gear type. Vertical bars represent ±1 SD. Values in parentheses represent ±1 SD for months with extreme variances.

Table 2. Spearman's rank correlation coefficients between environmental factors and monthly estimates of (a) species richness, calculated as the mean number of species per haul, and (b) fish abundance, calculated as the mean total CPUE per haul after $\log_e$ transformation of CPUE values for each species. Correlation coefficients are presented for each gear. Spearman's r significant at * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.

	Physical parameters			
Gear	Temp (C)	Salinity (‰)	pH	DO (ppm)
a. Mean number of species/haul				
Beach	0.80***	0.01	0.09	−0.47**
Offshore	0.77***	−0.26	−0.19	−0.61***
Trawl	0.33	−0.33	0.03	−0.42*
Gillnet	0.44*	−0.30	0.08	−0.28
b. Mean number of individuals/haul				
Beach	0.46**	−0.12	0.15	−0.43**
Offshore	0.36*	−0.18	0.45**	−0.22
Trawl	0.35*	−0.25	0.37*	−0.54**
Gillnet	0.19	−0.33	0.11	−0.06

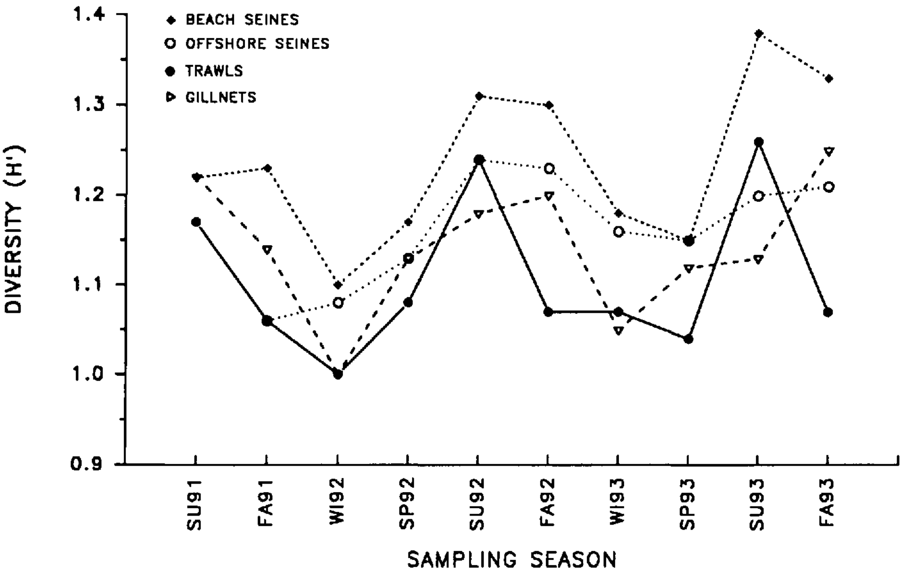


Figure 5. Seasonal variation in estimates of diversity (H') for fixed-station seine, trawl, and gillnet collections in the northern Indian River Lagoon from 1991 to 1993. Calculations of seasonal H' were based on total log-transformed CPUE values for each species.

gillnet collections were observed in winter during 1991 and 1992 but remained relatively constant throughout 1993. Rank correlations of mean monthly abundances indicated a positive association with water temperatures for both shallow-water seine and basin trawl collections (Table 2b). There was a negative correlation between fish abundance and dissolved oxygen levels for these same collections. Fish abundances were positively correlated with pH in shallow-water offshore seine collections as well as for basin trawl collections. There were no significant relationships between fish abundances and monthly salinity levels, nor between the catch rates for gillnets and any of the environmental factors we examined.

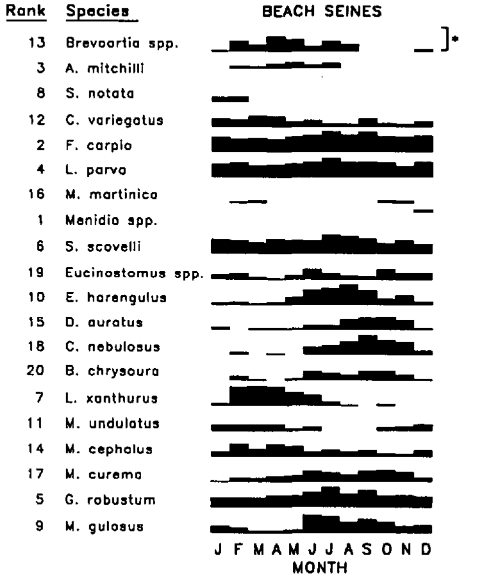
Table 3. Comparison of species composition of fish catches between seasons (1992 and 1993 pooled). Percent similarity (PSI) values for beach seines are given below, and those for offshore seines are given above, the diagonal in table (a). PSI values for trawls are given below, and those for gillnets are given above, the diagonal in table (b). Percent similarity values were calculated from percentages of total CPUE values after log-transformation. * Wilcoxon's signed-rank test, significant at $P < 0.05$.

	Winter	Spring	Summer	Fall
a.				
Winter	—	84.32	65.92	56.21
Spring	83.92	—	65.32	53.06
Summer	65.55*	63.78*	—	75.81
Fall	63.18*	60.42*	76.31	—
b.				
Winter	—	70.62	73.14	76.29
Spring	76.58	—	71.03	67.29
Summer	58.21	53.80	—	79.07
Fall	61.82	60.0	70.65	—

Shannon-Wiener (H′) estimates of species diversity based on log-transformed seasonal abundance (CPUE) data generally followed the same seasonal patterns as species richness and abundance, although H′ diversity did not vary widely between seasons (Fig. 5). Species diversity from shallow-water and basin habitats sampled with seine and trawl gears reached maximum values during summer and minimum values during winter or spring. Gillnet collections of larger size-class individuals had the highest diversity estimates during summer in 1991 and during fall in 1992 and 1993. Lowest estimates of diversity for these larger individuals were recorded during winter.

There were apparent seasonal variations in both the composition and relative abundances of fish captured from shallow-water and basin habitats. For seines and trawls, which are effective at capturing smaller individuals including the juvenile recruits of many species, percent similarity (PSI) values based on pooled species abundances from 1992 and 1993 collections indicated that winter-spring and summer-fall seasonal pairs were most similar to each other (Table 3). Other seasonal pairs were less similar to each other, and in fact, were significantly different from each other in shallow-water beach seine collections (Table 3a). The observed differences were related to the seasonal abundance patterns of several species commonly captured in these habitats. Whereas many of the small estuarine forage species such as *Anchoa mitchilli, Syngnathus scovelli, Menidia* spp., *Floridichthys carpio,* and *Lucania parva* were consistently collected throughout the year, the seasonal influx of juveniles of other species accounted for major changes in the relative abundances of fish in these shallow-water and basin habitats (Figs. 6–8). For shallow-water habitats, species such as *Brevoortia* spp., *Leiostomus xanthurus, Micropogonias undulatus,* and *Mugil cephalus* were captured in greater abundances during the late winter and spring (Figs. 6, 7), whereas species such as *Strongylura notata, Cynoscion nebulosus,* and *Bairdiella chrysoura* were captured in greater abundances during late summer and fall seasons. For deeper basin habitats, seasonality was less obvious for many of the most common species; however, the abundances of species such as *Orthopristis chrysoptera, Diapterus auratus, Cynoscion regalis,* and *Micropogonias undulatus* exhibited seasonal peaks (Fig. 8) consistent with their primary estuarine recruitment periods (Darcy, 1983; Rulifson, 1991; Szedlmayer et al., 1990). Seasonal differences in the composition and catch rates of larger individuals captured in gillnets were less evident (Table 3b). However, percent similarity estimates for seasonal comparisons indicated that summer, fall, and winter seasons were the most similar in terms of the species composition and catch rates of these larger size-class fish (Table 3b). Examination of catch rates from gillnet samples indicated that many of the transient species that exhibited strong patterns of seasonality such as *Centropomus undecimalis, Trachinotus falcatus, Caranx hippos, Lutjanus griseus,* and *Chaetodipterus faber* reached abundance peaks in summer or fall months and were often absent from winter and spring collections (Fig. 9).

Stratified-random Sampling.—A total of 1,049,931 fish were collected during the fall 1990 to spring 1993 sampling period. Members of 103 species in 42 families were represented in the collections (Table 1), although 10 species or less made up over 90% of the total catch in all seasons. In shallow-water and basin habitats sampled by our gears, species collected in SR samples were similar to those collected in FS samples. As with FS collections, small forage species collected in both types of seines numerically dominated the spring and fall catches and were species typically associated with seagrass or other shallow-water habitats. Numerically abundant species collected in basin habitats were demersal species



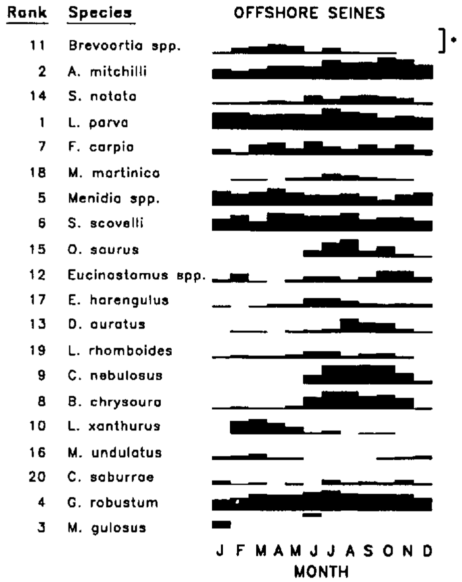


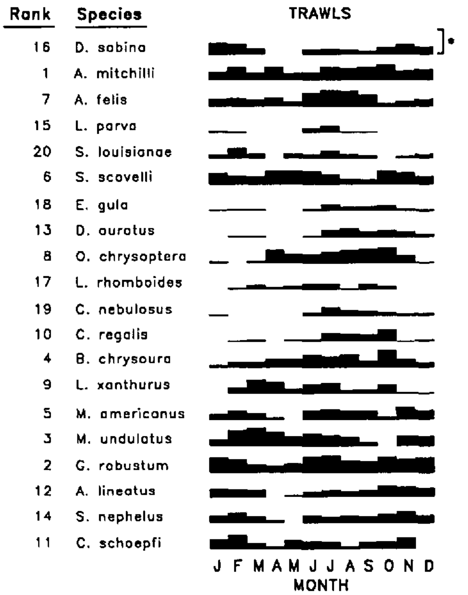
Figure 6 (left). Variations in the relative occurrence of the most abundant (total CPUE) species captured in fixed-station beach seines in the northern Indian River Lagoon. Results were pooled by month from January 1991 to December 1993. The height of the bars represents the percentage of monthly samples in which the species was present. *The height of the bracket is equal to 100% occurrence.

Figure 7 (right). Variations in the relative occurrence of the most abundant (total CPUE) species captured in fixed-station offshore seines in the northern Indian River Lagoon. Results were pooled by month from January 1991 to December 1993. The height of the bars represents the percentage of monthly samples in which the species was present. *The height of the bracket is equal to 100% occurrence.

typical of these areas (Mulligan and Snelson, 1983). Larger size-class individuals collected in gillnets included members of pelagic, epibenthic, and demersal species.

Patterns of fish abundance in seasonal SR collections were predictable based on past studies from Florida estuaries (Reid, 1954; Livingston, 1976; Livingston et al., 1976; Comp and Seaman, 1985). Total abundances (log-transformed CPUE) in both shallow-water and basin collections were generally higher in spring than in fall and, in fact, were significantly higher in shoreline-associated beach seine collections (paired t-test, $t = -3.809$, df = 4, $P < 0.02$). The opposite condition was generally true for larger size-class individuals captured in gillnets (Table 4). As with FS collections, the abundances (total number of individuals per season) of many individual species followed predictable seasonal patterns related to periods of recruitment or estuarine utilization (Table 1).

Descriptive indices of shallow-water and lagoon-basin fish communities fluctuated little between fall and spring seasons, although some consistent seasonal patterns were observed (Table 4). Species richness (D) estimates from shallow-water and basin habitats sampled with seines and trawls, respectively, were typically higher during the fall. There was no consistent pattern in seasonal diversity (H′) estimates from seine collections; however, H′ from the lagoon basin collections were higher during fall seasons (paired t-test, $t = 5.703$, df = 4, $P < 0.005$). No consistent patterns of D or H′ were apparent from collections of larger size-



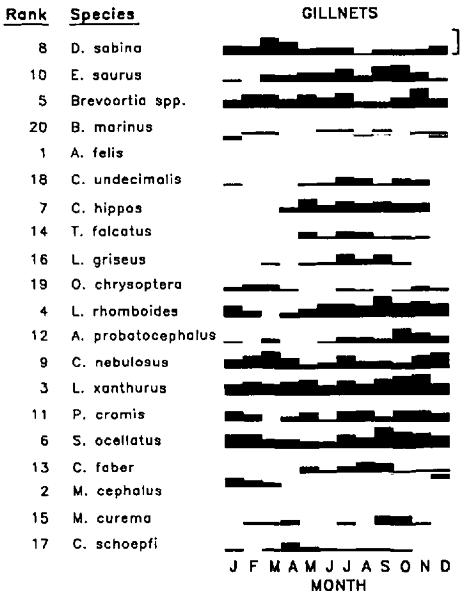


Figure 8 (left). Variations in the relative occurrence of the most abundant (total CPUE) species captured in fixed-station trawls in the northern Indian River Lagoon. Results were pooled by month from January 1991 to December 1993. The height of the bars represents the percentage of monthly samples in which the species was present. *The height of the bracket is equal to 100% occurrence.

Figure 9 (right). Variations in the relative occurrence of the most abundant (total CPUE) species captured in fixed-station gillnets in the northern Indian River Lagoon. Results were pooled by month from January 1991 to December 1993. The height of the bars represents the percentage of monthly samples in which the species was present. *The height of the bracket is equal to 100% occurrence.

class fish captured in gillnets. Highest dominance index values (D_1 and D_2) were associated with lower diversity estimates for both shallow-water and basin collections which illustrated the effects of numerically dominant species on diversity estimates. This pattern was less evident for gillnet collections of larger size-class fish, in part due to the lower total numbers of species (S) and lower species richness (D) estimates.

Estimates of similarity (PSI) between fish communities in successive spring and fall seasons ranged from 57–74% in shallow-water habitats (including seine and gillnet collections) and from 54–76% in deeper basin habitats (Table 4). These values indicated there were substantial seasonal differences in the composition or relative abundances of species in these habitats. There were statistically significant differences in the species composition of lagoon-basin collections between several seasons based on species abundance rankings (Table 4).

Discussion

The IRL is recognized as one of the most diverse estuaries in North America. This diversity is reflected in the lagoonal fish fauna that contains members of both tropical Caribbean and warm-temperate Carolinian fish faunas (Briggs, 1974; Gilmore, 1977). However, inventories of the fish species from the southern (Gilmore et al., 1981) and northern (Snelson, 1983) portions of the lagoon suggest that the northern IRL contains a relatively impoverished fish fauna that is most similar to that of warm-temperate fish communities (Snelson, 1983), and our

Table 4. Measures of community structure for seasonal fish collections from the northern Indian River Lagoon (fall 1990–spring 1993), including total CPUE's (N), number of species (S), relative dominance (D_1 and D_2), Margalef's richness (D), Shannon-Wiener diversity (H'), and percent similarity (PSI). PSI values represent similarity between indicated season and previous season; * Wilcoxon's signed-rank test, significant at $P < 0.05$.

	Season					
Index	Fall 1990	Spring 1991	Fall 1991	Spring 1992	Fall 1992	Spring 1993
Beach seines						
N	1,025.6	1,514.2	956.4	1,445.7	1,258.0	1,394.8
S	54	56	50	53	50	48
D_1	0.12	0.17	0.13	0.19	0.14	0.22
D_2	0.24	0.29	0.24	0.31	0.27	0.39
D	7.64	7.51	7.14	7.15	6.86	6.49
H'	1.208	1.301	1.279	1.238	1.249	1.173
PSI		74.15	72.91	66.36	70.20	57.55
Offshore seines						
N	981.3	1,043.0	1,375.9	1,624.5	1,401.1	1,297.2
S	45	41	50	48	50	46
D_1	0.20	0.24	0.22	0.20	0.19	0.16
D_2	0.40	0.44	0.33	0.33	0.36	0.29
D	6.39	5.76	6.78	6.36	6.76	6.28
H'	1.163	1.139	1.203	1.246	1.166	1.188
PSI		66.89	72.88	70.02	71.91	67.02
Trawls						
N	321.5	369.5	245.8	320.5	288.5	279.3
S	51	45	53	42	43	39
D_1	0.27	0.26	0.17	0.18	0.18	0.24
D_2	0.37	0.45	0.31	0.36	0.32	0.44
D	8.66	7.44	9.45	7.11	7.41	6.75
H'	1.164	1.104	1.165	1.104	1.197	1.077
PSI		76.11	58.56	54.05*	64.27*	58.77*
Gillnets						
N	182.2	162.7	262.3	193.7	259.6	188.7
S	25	34	28	30	31	28
D_1	0.24	0.32	0.31	0.26	0.30	0.26
D_2	0.44	0.41	0.44	0.47	0.46	0.41
D	4.61	6.48	4.85	5.51	5.40	5.15
H'	1.03	1.128	1.043	1.064	1.072	1.075
PSI		65.02	63.04	65.73	73.33	70.81

species composition data supports this characterization. For example, with the exception of *Strongylura notata, Diapterus auratus,* and *Chasmodes saburrae,* species of tropical origin (e.g., *Albula vulpes, Hyporhamphus unifasciatus, Lutjanus griseus,* and *Centropomus undecimalis*) are poorly represented in our collections, and members of tropical fish families such as the Apogonidae, Chaetodontidae, Pomacentridae, Labridae, and Scaridae, which are well represented in the southern portion of the IRL (Gilmore et al., 1981), were not collected from our study area. Still, the total number of fish species collected in our study (S = 108) was higher than the total number of species collected in other warm-temperate systems in Florida (S = 76; Livingston, 1976), Georgia (S = 70; Dahlberg and Odum, 1970), South Carolina (S = 51; Cain and Dean, 1976) and Texas (S = 90; Hook, 1991), as well as from earlier investigations of the northern IRL (S = 47, Schooley, 1977; S = 57, Mulligan and Snelson, 1983). Regardless, our collections were dominated numerically by less than ten species. These abundant species were mostly small members of neritic, epibenthic, or demersal forage groups and had the greatest influence on measures of community structure. This pattern of numerical dominance by relatively few species is typical of estuarine systems (Bozeman and Dean, 1980; Horn, 1980; Cowan and Birdsong, 1985; Warlen and Burke, 1990; Yoklavich et al., 1991) and was demonstrated in earlier investigations of the IRL fish fauna (Schooley, 1977; Mulligan and Snelson, 1983; Gilmore, 1988).

Our sampling efforts included two complimentary strategies—monthly fixed-station (FS) and seasonal stratified-random (SR) sampling. Comparisons of data from both FS and SR sampling strategies indicated that species composition between the two datasets were very similar. Eighty four species were common to both FS and SR collections, and 22 of the 24 species that were unique to either FS (S = 5) or SR (S = 19) were represented by three individuals or less (Table 1). Species observed in our FS collections during the summer or winter were also typically captured in SR collections during the following fall or spring season, respectively. Although spring and fall seasons are the most similar in terms of environmental conditions, seasonal percent similarity measures for FS data indicated that spring and fall were the least similar in terms of the species composition and relative abundances of species. Therefore, we believe that the more intensive, concentrated sampling effort during spring and fall SR sampling resulted in greater resolution and provided a more comprehensive and accurate assessment of differences in seasonal measures of the northern IRL fish community (e.g., species diversity, H′; species richness, D; number of species, S; and relative dominance, D_1 and D_2). Monthly fixed-station (FS) sampling served a complimentary purpose and provided a means to quantify seasonal variations in measures of the northern IRL fish community including estimates of species richness, composition, abundance, and diversity.

Our data revealed consistent seasonal patterns of species richness and abundance among fish communities in our study area. Seasonal changes in environmental factors were, in some cases, strongly associated with species richness and abundance measurements which typically increased during summer or fall and decreased during winter. Although species richness and abundance estimates were closely associated with changes in water temperature, the separate or combined effects of temperature and other biotic or abiotic factors which also reflect seasonal cycles (i.e., salinity, turbidity, dissolved oxygen, macrophyte growth, etc.) can influence patterns of species use within the lagoon (Blaber and Blaber, 1980; Moser and Gerry, 1989; Peterson and Ross, 1991). Estimates of species diversity (H′) also exhibited consistent variations related to seasonal cycles in the lagoon, reaching maxima during warmer seasons and minima during colder seasons. Other studies from the northern IRL (Schooley, 1977) and southern IRL (Gilmore, 1988) have reported similar seasonal patterns of H′ based on seine collections from these areas. The observed increases in species richness and diversity during warmer months is typical of many tropical, warm-temperate, and temperate estuaries (Subrahmanyam and Drake, 1975; Warburton, 1978; Heck et al., 1989; Tito De Morais and Tito De Morais, 1994 and others). In general, our seasonal diversity (H′) estimates from the northern IRL (H′ = 0.9–1.4) were similar to other estimates reported from shallow grassbeds and basin habitats in the southern IRL and northern IRL, respectively (mean H′ = 0.4–1.5, Gilmore, 1988; seasonal H′ = 1.2–1.6, Mulligan and Snelson, 1983). However, our estimates were somewhat lower than earlier estimates from northern IRL seine collections (H′ = 0.8–2.6, Schooley, 1977) as well as from other warm-temperate estuaries (Bechtel and Copeland, 1970; Dahlberg and Odum, 1970; Livingston, 1976; Hook, 1991). The observed differences, particularly those from similar northern IRL sampling locations, are difficult to interpret due to differences in collection techniques and data analyses.

Our data characterized seasonal differences in species composition and abundances for shallow-water and deeper basin habitats in the lagoon. The seine, trawl, and gillnet sampling gears used in this study were effective at capturing small juveniles, small species, and sub-adults or adults of larger species common in our study area (Snelson, 1983), and our analyses identified major periods of recruitment and patterns of seasonal estuarine use for many of the abundant species collected. Juvenile recruitment periods for different species were observed during all four seasons in both shallow-water and basin collections. In contrast, seasonal catch rate patterns for larger sub-adult and adult stages captured in gillnets were less defined since many of these species were collected in the study area throughout the year. An exception included species with tropical affinities such as *Centropomus undecimalis, Trachinotus falcatus,* and *Lutjanus griseus* which were rarely collected during the colder months of the year. Predictable seasonal patterns of estuarine fish recruitment and estuarine utilization by fish have been demonstrated by Gilmore (1988), Warlen and Burke (1990), Rulifson (1991) and others from the east coast of the United States; Livingston et al. (1976), Ogren and Brusher (1977), and Hook (1991) from the Gulf of Mexico; and Horn (1980), De Ben et al. (1990), and Yoklavich et al. (1991) from the west coast of the United States. Haedrich (1975) and Livingston (1976) suggested that temporal segregation by species that share the same resource allows more species to utilize the system throughout the year. Analyses of similarity data from our collections indicated that the northern IRL fish community does not experience large replacements of dominant fish species on a seasonal basis. Instead, most species were collected in the lagoon throughout the year, although often at different life-history stages or in increased abundances. Such temporal peaks in recruitment or estuarine use by juvenile fishes of both transient and resident species can have an influence on estimates of lagoon biodiversity. Sampling designs that do not effectively monitor the various life-history stages or which miss overdominant juvenile phases and forage fishes may result in an inaccurate estimation of the overall diversity in the system, or may be inadequate to detect changes in the diversity or abundances of fish communities. Our data demonstrated how the use of different sampling gear affect descriptions of the lagoon fish community. For example, the presence of abundant species such as *Leiostomus xanthurus* or *Brevoortia* spp. in the lagoon during fall seasons would have been largely overlooked by using only seine and trawl gear types (Figs. 6–9). Therefore, multi-gear collection methods, which sample multiple life-history stages over a wide array of habitat types, are the most effective means of monitoring ontogenetic progressions in resource use by fishes in the lagoon, and are critical in effectively defining the biodiversity of fishes in the IRL system.

Measures of fish community structure have been used to examine long-term changes in faunal composition and also to assess impacts of disturbances on estuarine systems. Bechtel and Copeland (1970) first promoted the use of fishes as indicators of environmental degradation in estuaries by relating species diversity (H′) to pollution levels in Galveston Bay, Texas. Haedrich (1975) related measures of annual diversity (H′) and seasonal similarity (PSI) in estuarine fish populations to environmental quality in nine temperate Massachusetts estuaries and embayments. With an understanding of the inherent variances associated with descriptive indices of northern IRL fish communities, our estimates of species abundance, richness, diversity, and similarity may be useful in efforts to quantify the current and future status of IRL ichthyofauna. However, many of the most abundant species or resident species (e.g., *Anchoa mitchilli, Lucania parva, Brevoortia* spp.) have contagious distribution patterns that directly affect diversity measures. If not accounted for, these effects can strongly influence estimates of overall community structure.

The IRL is unique among estuaries on the Atlantic coast of the U.S. because it has a fauna that is influenced by the Florida Current, moderate inshore salinities, and zoogeographical boundaries (Gilmore et al., 1981). Therefore, it is expected that the influences of such physical mechanisms on recruitment, distribution, or seasonality of fish populations in the IRL will likely be different from the mechanisms found in other systems, making direct comparisons of diversity measures with other systems unwarranted for purposes of assessing the relative condition of the lagoon. From a management perspective, the question of how the IRL compares with other estuarine systems is less important than how it compares with itself over a given period of time. Previous assessments of community structure in the lagoon contain inherent limitations that reduce their usefulness in making long-term comparisons of the overall fish fauna. The FDEP's Marine Fisheries-Independent Monitoring Program collections represent the most comprehensive, quantitative dataset on northern IRL fish communities at this time. Effective assessments of ecosystem changes, including loss or recovery of biodiversity, require ecologically sound endpoints against which changes can be evaluated. The results presented in this study quantify seasonal variations in typical measures of the lagoon fish community based on several years of data from the FDEP's Fisheries-Independent Monitoring Program in the northern IRL, and can provide a readily comparable baseline for future investigations of fish communities in the system.

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