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The Seasonality and Spatial Patterns of Juvenile Surf Zone Fishes of the Florida East Coast

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THE SEASONALITY AND SPATIAL PATTERNS OF JUVENILE SURF ZONE FISHES OF THE FLORIDA EAST COAST

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ABSTRACT: *Spatial and temporal patterns of variability were examined (April 1982 - June 1983) for 61 species of surf zone fishes (6,611) at beaches in Melbourne and Sebastian, Florida. The three numerically dominant species, Harengula jaguana, Anchoa lyolepis, and Trachinotus carolinus, comprised over 70% of all individuals. Temporal and spatial variability at several scales were important aspects of the structure of this fish assemblage. Fishes were most abundant seasonally during spring, summer, and fall (2,659) and least abundant during winter (6). Small scale spatial variability was found on beaches adjacent to the jetties at Sebastian Inlet. Both total number of individuals and species significantly decreased ($p<0.05$) with increasing distance from the jetty structures. Differences in subtidal habitat heterogeneity between Melbourne Beach and the beaches immediately south of Sebastian Inlet may account for the fact that twenty species were collected at the Sebastian sites which were not found at the Melbourne site.*

THE SAND beach surf zone habitat of Melbourne and Sebastian, Florida is one of the higher wave-energy environments along either the south Atlantic or Gulf coasts of the state (Galvin and Seelig, 1969). Turbulent wave conditions would appear to result in a harsh environment, yet it has been suggested that the surf zone provides a vital habitat for the development of juvenile fishes (Daly, 1970); and indeed most fishes of the surf zones are juveniles (Modde and Ross, 1981). Although the subtidal area of the sand beach generally affords little habitat heterogeneity (Springer and Woodburn 1960), the ichthyofaunal diversity of exposed beaches has been found to be relatively high (Cupka, 1972; Anderson et al., 1977; Modde and Ross, 1981; Gilmore et al., 1981; Applied Biology, 1981).

The majority of surf zone fishes demonstrate strong variability in their spatial and temporal association with a particular beach habitat (Tagatz and Dudley, 1961; Modde, 1980; Modde and Ross, 1981). The present survey was conducted to document the ichthyofauna of this high energy surf zone to examine the various levels of spatio-temporal variation in species composition and abundance of the primarily juvenile fishes from several exposed beach habitats.

Prior to this study the only systematic survey of the surf zones fishes from the Florida east coast was documented in an unpublished technical report by Applied Biology Inc. (1981). The main temporal factor examined

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was season, although tidal cycle and time of day were examined to a lesser extent. Spatial variability was assessed by long term sampling at two locations differing in their bottom topography and composition. Short term sampling was carried out to investigate whether the presence of jetty structures alters community composition of surf zone fishes.

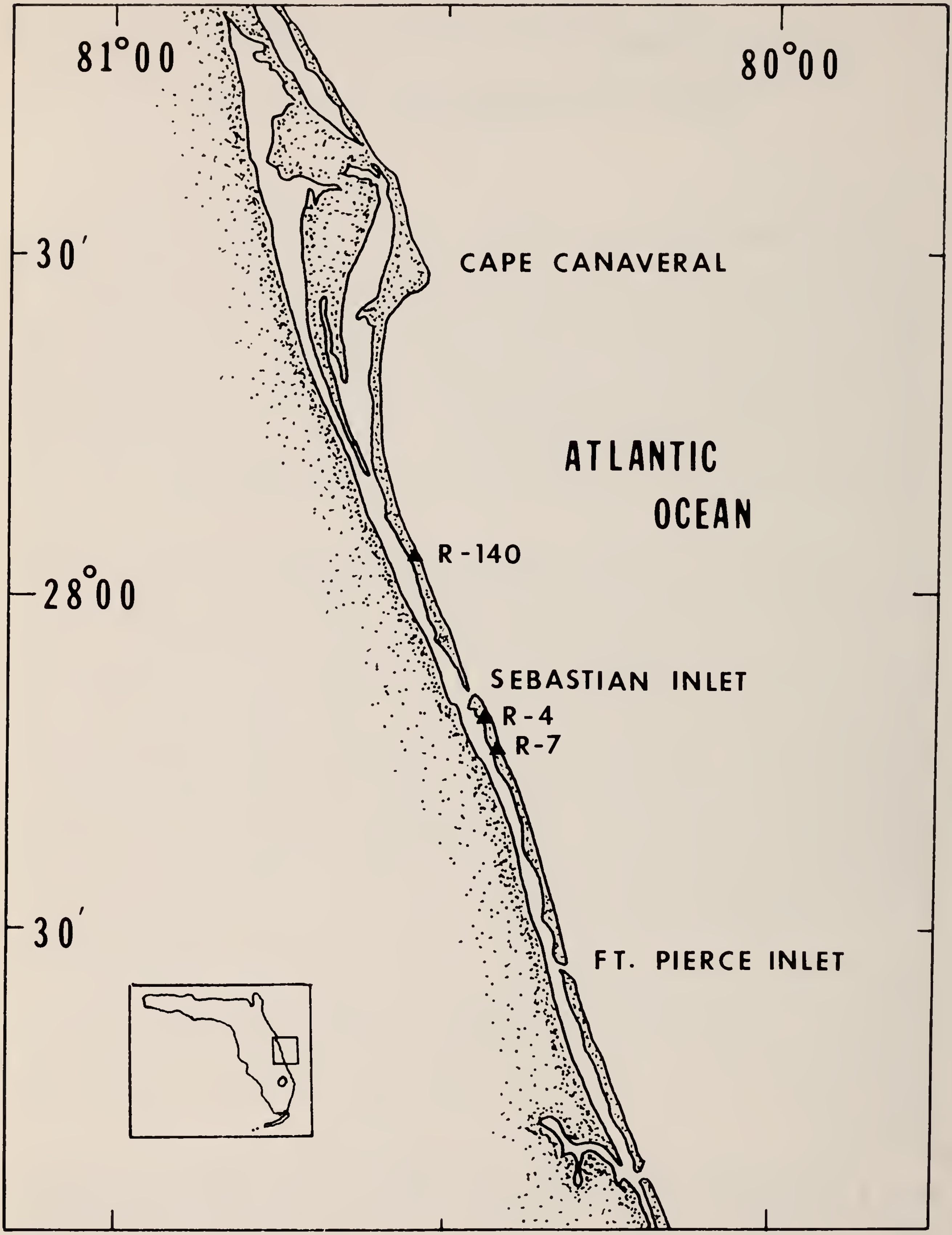

FIG. 1. Sampling locations at Melbourne (R-140) and Sebastian (R-4 and R-7) Beaches, Florida.

METHODS—The surf zone habitats of three sandy beach locations on the east central coast of Florida were selected as sampling sites. The primary site for monitoring the seasonal variations of surf zone fishes was located at marker R-140 (Florida Dept. of Natural Resources, coastal construction control line marker) just south of Melbourne Beach (Fig. 1). The subtidal habitat consisted of a uniform sand bottom. Water temperature and salinity ranged from 14.5 to 29.5°C and 34.5 to 35.5 ppt, respectively. Two sites were chosen at Sebastian Beach, approximately 1219 m (marker R-4) and 2133 m (marker R-7) south of Sebastian Inlet (Fig. 1). These two sites share similar habitat characteristics but are very different from the Melbourne (R-140) site. Both sites are influenced by water from the Indian River Lagoon while the rock jetties on either side of the inlet add structural diversity to the adjacent beaches. Furthermore, a series of outcropping coquina reef and sabellariid worm rock structures add structural heterogeneity to the benthic topography throughout the Sebastian Beach area. The Sebastian sites are similar to the Melbourne sites in water temperature and salinity, ranging from 17.5 to 30.0°C and 32.5 to 35.0 ppt, respectively.

Collections were made approximately monthly for 15 months (April 1982 to June 1983) at Melbourne and 14 months (May 1982 to June 1983) at Sebastian site (Peters, 1984). Samples consisted of three hauls using a 4.75 m x 1.22 m seine and three hauls using a 9.14 x 1.22 m seine, both with 6.35 mm Ace mesh. Each haul was pulled approximately 15 m offshore straight into the beach. Due to statistically significant differences ($p<0.05$, one-way analysis of variance) in the mean number of individuals and species collected with each of the two seines used, results will be reported separately.

All fishes captured were initially placed in a 10% buffered formalin solution for preservation. An abdominal incision was made on all fishes greater than 50 mm to allow the formalin to penetrate the gut cavity. Approximately 24 hours later, the fishes were rinsed in tap water and placed in 70% ethanol for storage. All fishes collected were identified to species (Hoese and Moore, 1977; Fischer, 1978; Jones et al., 1978; Dahlberg, 1980), weighed on an electronic balance to the nearest 0.01 g (wet weight) and measured to the nearest 1.0 mm (standard length).

The high wave energy and steep beach slope of the Melbourne Beach site made sampling at high tide impossible and this site was therefore sampled at low tide. Seining at the two Sebastian sites (R-4 & R-7) was not effective during low tide due to exposed coquina rock structures in the shallow subtidal region of these sites. Therefore all Sebastian samples were collected at high tide. Offshore reefs at the Sebastian sites diminished surf action sufficiently to allow sampling at high tide.

To evaluate the importance of sampling on different tides, a 24 hour sampling survey was conducted at both Melbourne (R-140) and Sebastian (R-4) to determine whether significant differences in fish species composition and abundance might result from the differences in tidal level sampled (Peters, 1984). Sampling of the 24 hour surveys were conducted during mild weather conditions to allow for effective seining at all tides. Six hauls using the 9.14 m x 1.22 m seine were done at each of the high, low, and mid-tides for a 24-hour period (48 total hauls). Preliminary results from the Melbourne site showed a significantly greater ($p>0.05$) number of individuals (421 vs. 189) but not species were collected in the high tide samples as compared with the low tide samples. No significant differences in either number of individuals or number of species were seen at the Sebastian site. The increased abundance in the high tide samples at Melbourne was due almost entirely to a single species, *Harengula jaguana*. We therefore believe the difference in tidal level sampled is of minor importance in a general comparison of data from Melbourne and Sebastian. Due to obvious habitat differences (specifically bottom structural heterogeneity) between the Melbourne and Sebastian sites, no statistical comparisons were made.

Three equi-distant (50 m) transects immediately north and south of the Sebastian Inlet jetties were sampled to determine if composition and abundance of surf zone fishes were influenced by the structural habitat diversity of the inlet and jetties. The subtidal area adjacent to the north jetty has a uniform sand bottom, whereas immediately south of the inlet subtidal rock outcroppings exist. Three hauls using the 9.14 m x 1.22 m seine were undertaken in June of 1983 at each of the six additional transect sites.

One-way analysis of variance (ANOVA), the Wilcoxon two-sample test, and the T′-method of paired comparisons (Sokal and Rohlf, 1981) were used to analyze the data. Pearson product-moment correlation coefficients were calculated to determine the degree of association between both water temperature and salinity and the mean number of species and individuals collected over the durations of the study at both the Melbourne and Sebastian sites.

RESULTS—Species Comparison—During the seasonality study, a total of 41 species and 2,665 individuals were collected (Table 1). The surf zones of all three sites were dominated by four families in terms of total abundance: Carangidae, Clupeidae, Engraulidae, and Sciaenidae. These groups comprised over 90% of all fishes captured. Sebastian (R-4) had the greatest number of species (32), whereas Melbourne had the greatest total abundance (1082) (May 1982 through June 1983, inclusive). The most abundant species from the Melbourne site was *Anchoa lyolepis* (dusky anchovy, Engraulidae) which totaled less than 11% at either of the two Sebastian sites. *Harengula jaguana* (scaled sardine, Clupeidae) was the most abundant species from both the Sebastian sites (Table 1). The most frequently occurring species from all three sites was *Trachinotus carolinus* (Florida pompano, Carangidae). The three additional species of carangids collected never exceeded 2% of the total abundance of any site, and their occurrence was sporadic. *Menticirrhus littoralis* (gulf kingfish, Sciaenidae) had the highest frequency of occurrence among sciaenids at both Sebastian sites.

Seasonality—Variations in abundance of regularly occurring species and in the total number of all fishes provided evidence for district seasonal trends at all three sites. The mean number of fish per seine haul generally peaked during the warmer months. Fish abundance was significantly higher ($p<0.05$) from April-October than from November-March at all three sites. Peaks in abundance of fish occurred in June-August, 1982 and April-June, 1983 (Fig. 2). Nearly 90% of all fishes captured were collected during April-July at all three sites. A slight rise in abundance occurred during September and October at the Melbourne and Sebastian (R-7) sites. No fish were captured in the November and January samples at any of the three sites.

Maxima for mean number of species per seine haul were less pronounced (Fig. 3). The greatest number of species were found at the Sebastian sites (particularly site R-4) during June and July, 1982. As with the number of individuals, a significantly greater number of species ($P<0.05$) were found in the surf zone during April-October than in November-March at all three sites; however, species numbers (unlike abundance) remained relatively high into the September-October period.

Temperature and total number of individuals were significantly correlated at R-4 and R-7 (R-4, $r=0.695$ and R-7, $r=0.739$; $P<0.05$). Water temperature and total number of species were also significantly correlated (R-140, $r=0.543$; R-4, $r=0.594$; R-7, $r=0.575$; $p<0.05$) in all cases. No significant correlations were found among salinity and the abundance of individuals and species.

Local Spatial Variability—A total of 1064 individuals of 21 species was collected from the north and south beaches in the area adjacent to the jetties at Sebastian Inlet (Table 2). A significantly greater ($p<0.05$, Wilcoxon two-

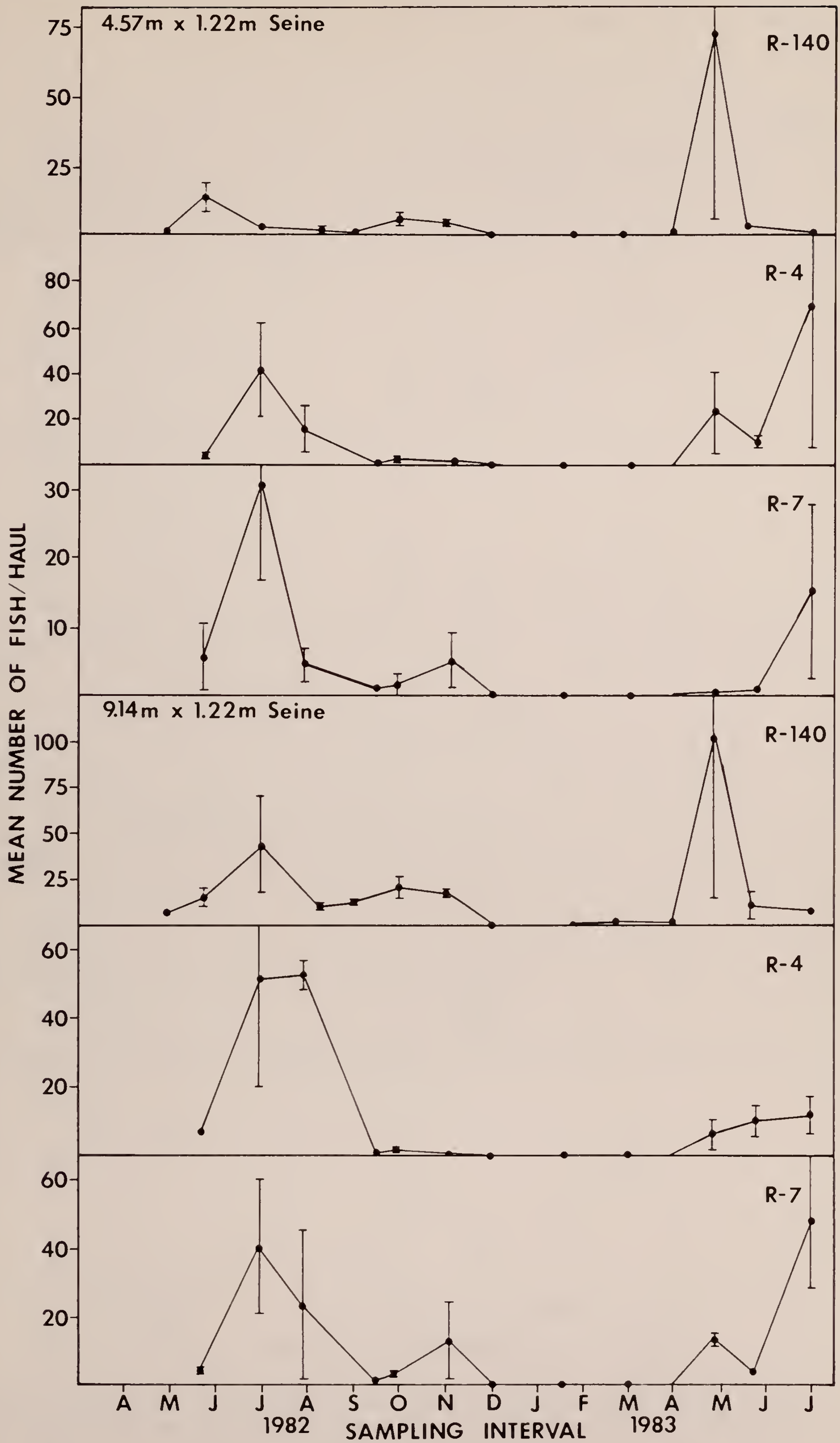

FIG. 2. Mean number of fish/haul (4.57 m x 1.22 m and 9.14 m x 1.22 m seines) collected each month from April, 1982 through June, 1983 from Melbourne (R-140) and Sebastian (R-4 and R-7) Beaches. Vertical bars are standard errors.

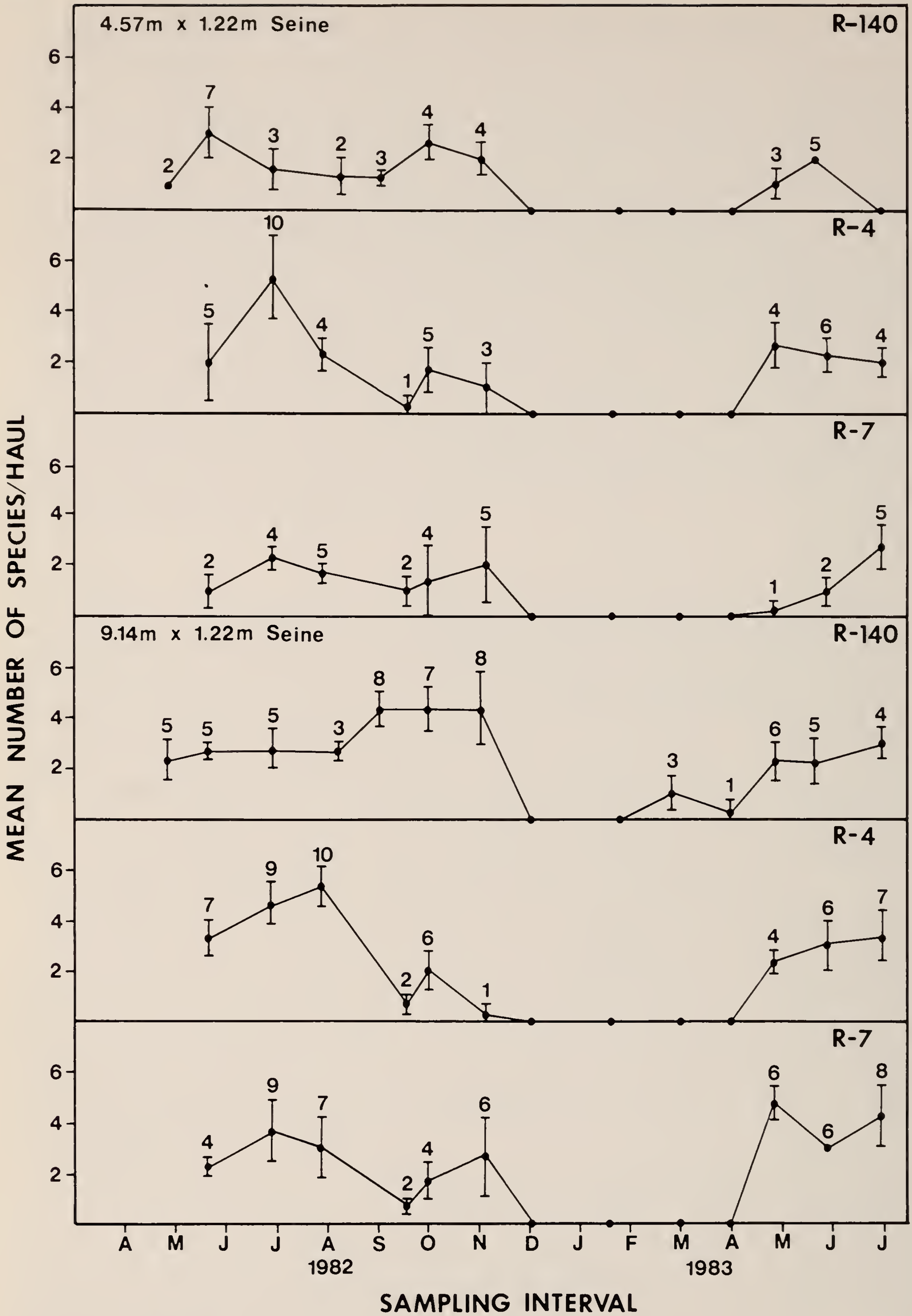

FIG. 3. Mean number of species/haul (4.57 m x 1.22 m and 9.14 m x 1.22 m seines) collected each month from April, 1982 through June, 1983 from Melbourne (R-140) and Sebastian (R-4 and R-7) Beaches. Vertical bars are standard errors. Numbers above error bars indicate total number of species collected.

TABLE 1. Total abundances and species composition of fishes collected from the surf zones of A) Melbourne Beach: R-140, B) Sebastian Beach: R-4, and C) Sebastian Beach: R-7, Florida between April 1982 and June 1983.

A) Melbourne Beach: R-140

SPECIES	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	JAN	FEB	MAR	APR	MAY	JUN	Total
Abudefduf saxatilis						3	1								4
Aluterus heudeloti					1										1
Anchoa hepsetus			3		1		1					1	1		7
Anchoa lyolepis												526	26		552
Anchoa mitchilli		10													10
Clupeidae larvae													8		8
Epinephelus sp.						1									1
Harengula jaguana			120										1		121
Hyporhamphus unifasciatus				7											7
Lobotes surinamensis					1										1
Lutjanus sp.							1								1
Menticirrhus littoralis	2	3	2	17	25	5	8			3		1	2	5	73
Menticirrhus saxatilis		2												4	6
Monacanthus hispidus	1				1	14	1								17
Mugil cephalus										1					1
Mugil curema		1				13	23						1		38
Pomatomus saltatrix	2	2	3			1								1	9
Syngnathus louisianae					3		1								4
Trachinotus carolinus	15	70	14	16	7	37	30			1		7	2	11	210
Trachinotus falcatus					1	1									2
Trachinotus goodei	2				1		1					2			6
Umbrina coroides		1									1	1			3
														Total	1082

TABLE 1. Continued

B) Sebastian Beach: R-4

SPECIES	APR*	MAY	JUN	JUL	AUG	SEP	OCT	NOV	JAN	FEB	MAR	APR	MAY	JUN	Total
Abudefduf saxatilis				1											1
Albula vulpes												4			4
Anchoa hepsetus		2	31										23	15	71
Anchoa lyolepis												3			3
Anchoa mitchilli			1				1							2	4
Anisotremus surinamensis						1									1
Bairdiella chrysura		1													1
Caranx hippos		2		5		1									8
Clupeidae larvae												78	10		88
Cynoscion nothus							1								1
Dasyatis sabina				4											4
Diplodus holbrooki		1													1
Epinephelus sp.					1										1
Eucinostomus gula			1												1
Eucinostomus jonesi			1												1
Harengula jaguana		1	152	180										194	527
Hyporhamphus unifasciatus			4												4
Lutjanus sp.						1									1
Menticirrhus americanus													1		1
Menticirrhus littoralis		8	7	1		3	1						1		21
Monacanthus erectus						1									1
Mugil cephalus												1			1
Mugil curema					1							4	6		11
Polydactylus octonemus			1	1		1							1		4
Pomatomus saltatrix			3										1	3	7
Sphyraena borealis			1												1
Syngnathus louisianae		1	1	1										1	4
Trachinotus carolinus		14	8	2	1	1	1					1	2	16	46
Trachinotus falcatus				1	2	2									5
Trachinotus goodei				1											1
Trichiurus lepturus		1													1
Umbrina coroides			70	9	1								14	11	105
														Total	931

TABLE 1. Continued

C) Sebastian Beach: R-7

SPECIES	APR*	MAY	JUN	JUL	AUG	SEP	OCT	NOV	JAN	FEB	MAR	APR	MAY	JUN	Total
Acanthocybium solanderi			1												1
Albula vulpes												8			8
Anchoa hepsetus		17	6	1			16					6		1	47
Anchoa lyolepis				68			1								69
Anchoa mitchilli						1	27								28
Caranx hippos			1												1
Clupeidae larvae												26			26
Eucinostomus argenteus			1												1
Harengula jaguana			162	6			2						2	92	264
Hyporhamphus unifasciatus				3										1	4
Lagodon rhomboides														1	1
Lutjanus sp.							1								1
Menticirrhus littoralis		1	1										2	5	9
Monacanthus hispidus			1												1
Mugil curema				1		4						2	4	1	12
Polydactylus octonemus														1	1
Pomatomus saltatrix		1										1	1	2	5
Selene vomer							1								1
Sphoeroides nephelus						3									3
Syngnathus louisianae							3								3
Trachinotus carolinus		9	32	1	4	3	3					7	5	13	77
Trachinotus falcatus			1	2	2	1									6
Trachinotus goodei				2											2
Umbrina coroides			8	3	1								1	69	81
														Total	652

*Sebastian R-4 and R-7 were not sampled on this date.

TABLE 2. Total abundances and species composition of fishes collected from the surf zones adjacent to the Sebastian Inlet jetties, Sebastian, Florida on 9 June, 1983.

Species	Distance from North Jetty			Inlet	Distance from South Jetty		
	100m	50m	0m		0m	50m	100m
Anchoa hepsetus	4	118	200		20		32
Anchoa mitchcilli			1		1		
Brevoortia tyrannus		1					
Caranx hippos			4		17	1	3
Cynoscion nebulosus						1	
Cyprinodon variegatus					1		
Harengula jaguana	17	15	22		38		110
Hyporhamphus unifasciatus					3		
Membras martinica		1					
Menticirrhus littoralus		1			36	6	37
Menticirrhus saxatilis					2		
Mugil curema	1	3	16		15	17	5
Pomatomus saltatrix			17		2		2
Scomberomorus maculatus			1				1
Selene vomer					1		
Sphoeroides nephelus					2	2	7
Strongylura marina					4	2	
Syngnathus louisianae							1
Trachinotus carolinus	1	3	2		138	5	65
Trachinotus falcatus					44	2	5
Umbrina coroides			3		1	5	2
Total number of species	4	7	9		16	9	11
Mean number of species/haul	2.00	3.00	5.00		10.33	5.33	7.00
Total number of fishes	23	142	263		325	41	270
Mean number of fish/haul	7.67	47.33	87.67		108.33	13.67	90.00

sample test) number of species were collected at the south beach (19) than at the north beach (12). Single specimens of *Brevoortia tyrannus* and *Membras martinica* were the only species from the north beach samples not found in the south beach samples. Nine species collected at the south beach were not present in the north beach samples. Mean number of individuals from the north and south beaches were not found to be significantly different ($p<0.05$, Wilcoxon two-sample test). However, there was a significant decrease ($p<0.05$) in the total number of individuals and species between the transect immediately adjacent to the jetty and the transect 100 m from the jetty both north and south of the jetties (Table 2).

Discussion—*Harengula jaguana* and *Anchoa lyolepis* were the two most abundant species in the present study. Other studies from the same general area (Gilmore et al., 1981; Applied Biology, Inc., 1981) also found these to be among the dominant species.

Overall species composition of the surf zone of the Melbourne-Sebastian area included many species in common with other exposed sandy beaches of the Atlantic coast, although the numerically dominant species differed. Studies from Connecticut and New York have reported *Menidia menidia* and *Fundulus majalis* (Hillman et al., 1977) or *Sphoeroides maculatus* and *Alosa aestivalis* (Schafer, 1967) as dominant species. Tagatz and Dudley (1961) found *Brevoortia tyrannus* and *Anchoa hepsetus* as the dominant species from the sandy beach habitat of Beaufort, North Carolina, while *Menidia menidia* and *Anchoa mitchilli* were the numerically dominant species from South Carolina shores (Anderson et al., 1977). Dahlberg (1972) found *Menidia menidia* and *Fundulus majalis* to be the two most abundant species from Sapelo Island, Georgia. Although *Menidia menidia* was collected from many Atlantic coast studies, it was not collected during this study. Gilmore and coworkers (1981) reported *Menidia menidia* as rare from the surf zone in the Indian River region and Melbourne-Sebastian should be near the southern terminus of its range (Johnson, 1975).

Dominant species from the beaches of the northeastern Gulf of Mexico were relatively more similar to those of the present study. Naughton and Saloman (1978) reported *Harengula jaguana* and *Menidia beryllina* as the two most abundant species at Panama City, FL, whereas *Harengula jaguana* and *Anchoa lyolepis* were the two most dominant species from the surf zone of a Mississippi site (Modde and Ross, 1981).

Species richness differs markedly among surf zone fish studies, possibly due to differences in methodology, geographic location and habitat complexity. In the present study, we recorded 61 species of fishes from the Melbourne-Sebastian region, which approximates (60) those collections made by Applied Biology (1981) in St. Lucie County, Florida. Studies to the north yielded 39 to 41 species from the Carolinas (Tagatz and Dudley, 1961; Cupka, 1972; Anderson et al., 1977) and 114 species from Georgia (Dahberg, 1972). Ichtyofaunal surveys of the gulf coast have yielded from 45 to 76 species (Naughton and Saloman, 1978; Modde and Ross, 1981).

Twenty species were collected at the Sebastian sites which were not found at the Melbourne site, whereas Melbourne only accounted for two species which were not present at the Sebastian beaches. The difference in species richness between Melbourne and Sebastian sites may have several causes. A major factor is that Sebastian Inlet provides access to the numerous estuarine habitats of the Indian River Lagoon such as seagrass beds, mud bottoms, brackish water environments and mangrove marshes. Several of the species only captured at Sebastian are species which are commonly associated with inland waters and bays such as *Eucinostomus argenteus* and *E. gula* (Gilmore et al., 1981). *Bairdiella chrysura* and *Lagodon rhomboides* are often found near shallow seagrass beds and other vegetated areas (Gilmore et al., 1981) but are seldom collected in the surf zone. *Sphyraena borealis* is often found in grassflats and mangrove areas, and *Dasyatis sabina* is frequently captured near fresh water canals and tributaries. Other examples are the syngnathids, *Syngnathus louisianae* and *Hippocampus erectus*, which are reported as being more common within the Indian River Lagoon (Gilmore et al., 1981).

An additional factor affecting species richness among sites is the difference in the subtidal habitat heterogeneity which exists between Melbourne Beach and the beaches immediately south of the Sebastian Inlet. The presence at Sebastian of rock jetties and offshore coquina rock and worm reef structures provides greater nearshore habitat diversity than at Melbourne Beach, which consists of a uniform sand bottom. An indicator of this difference is the occasional capture at Sebastian of *Anisotremus surinamensis* which is common near patch reefs and *Diplodus holbrooki* which is associated with vegetated rock bottoms (Gilmore et al., 1981). Bass (1979) has found increased diversities and abundances of fishes in the presence of oyster reef structures as compared with barren sand bottoms and attributes this to the additional sources of food and cover provided by the oyster reefs.

Additional evidence for the importance of increased habitat complexity to increased numbers of species in the surf zone is provided by the comparison of beaches north and south of the Sebastian Inlet immediately adjacent to the rock jetties. Eight species were collected from the north and south inlet beaches near the jetties which were not collected only 1 km away at the Sebastian R-4 site. Although rocky habitat (jetties) is common to both the north and south beaches, the significantly greater number of species collected from the south beach may be attributed to the immediate presence of beach rock outcroppings just offshore and adjacent to the south jetty. Hastings (1979) also concluded that additional bottom structures such as reefs and jetties provided supplemental sources of food and shelter which increase the habitat diversity above that of typical sand beach areas. Collections from the Melbourne-Sebastian area indicate distinct seasonal changes in fish abundance and diversity. High abundances in fish occurred during the spring and early summer months (90% of the total catch), decreasing to extremely low values from November through March [a pattern also reported from a study of the surf zone fishes of nearby Hutchinson Island (Applied Biology, Inc.

1981)]. Similar seasonal patterns in the abundance of surf zone fishes have been reported by Gunter (1958), Springer and Woodburn (1960), McFarland (1963), Schaefer (1967), Anderson and co-workers (1977), and Modde and Ross (1981). Gunter (1945) suggested that as temperature and salinity ranges deviate (usually decrease) from the normal average values for a habitat, fish abundances decrease. Both Anderson and co-workers (1977) and Modde and Ross (1981) found temperature to be a dominant factor correlated with fish abundance. In the present study temperature was positively correlated with total fish abundance and the number of species at all sites (except R-140, where abundance was nonsignificantly correlated with temperature). However, temperature also correlates with prey population abundance in the surf zone (Nelson, unpublished data), and thus fish populations may not be responding to temperature directly. In the present study, no correlation was found between abundance or the number of species and salinity since annual salinity variations were minor.

Several authors have provided schemes for categorizing the residency status of surf zones fishes (Greely, 1939; Warfel and Merriman, 1944; McFarland 1963; Cupka, 1972; Modde, 1980). Three groups of fishes (residents, seasonal migrants, and strays) were recognized for the Melbourne-Sebastian surf zones, based on the criteria of Cupka (1972) and Modde (1980). Total abundance, frequency of occurrence and variations in seasonal length frequency data were utilized in categorizing the species. Species classified as residents were *Trachinotus carolinus, Umbrina coroides, Mentichirrus littoralis, Anchoa hepsetus,* and *Mugil curema.* Modde (1980) also classified *Trachinotus carolinus* and *Mentichirrus littoralis* as residents of the surf zone of the coast of Mississippi but classified the remaining species as seasonal migrants. Conversely, the most abundant seasonal migrant in this study, *Harengula jaguana,* was considered a resident by Modde (1980). These differences may be more a result of sampling efforts than a reflection of true differences in residency status.

Many of the species classified as seasonal migrants in the present study are more commonly associated with habitats other than the surf zone and were normally caught during the warmer spring and summer months. For example, during periods of high offshore winds, *Moncanthus hispidus* was collected in association with the numerous mats of *Sargassum* blown onshore. Similarly, most species classified as strays (56%) were single specimens probably associated with a different habitat: e.g., *Aluterus heudeloti* and *Lobotes surinamensis* which were also found associated with *Sargassum* mats. Robertson and Lenanton (1984) have demonstrated that accumulations of macrophyte and detritus can significantly influence the abundance and species composition of surf zone fishes of sandy beaches in Western Australia.

Short term stochastic variability such as onshore movement of *Sargassum* probably plays a minor role in determining the species composition of the Melbourne-Sebastian surf zone community. However, differences in bottom composition and heterogenity are more important.

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Environmental Chemistry

THE GEOCHEMISTRY OF INTERSTITIAL WATER FOR A SEDIMENT CORE FROM THE INDIAN RIVER LAGOON, FLORIDA

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Abstract: *Chemical results for interstitial water from organic-rich sediments in the Indian River Lagoon, Florida, show a classic picture of biogeochemical reactions in anoxic environments. Interstitial nitrate was depleted throughout the sediment column and complete sulfate reduction was observed at a depth of <9 cm below the seawater-sediment interface. Interstitial water chlorinity decreased sharply with depth suggesting subsurface occurrence or intrusion of groundwater. Ammonia, phosphate and silica concentrations were high showing significant nutrient regeneration. Dissolved sulfide levels were also high and play a primary role in controlling interstitial water metal concentrations.*

Estuarine Sediments typically contain >50% water by weight or >70% water by volume. This interstitial water (or pore water) plays an important role as a medium for chemical exchange between sediments and the overlying water. Study of estuarine interstitial water can help assess a number of important environmental concerns including:

1. The redox state (oxic-suboxic-anoxic) in estuarine sediments.
2. Storage of nutrients and potentially toxic species and their release to the overlying water.

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