



Fish Assemblage Structure of the Shallow Ocean Surf-Zone on the Eastern Shore of Virginia Barrier Islands

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This study provides an in-depth description of the fishes in the shallow surf-zone (<0.4 m), a little-studied micro-habitat of the ocean surf. Fish assemblages were examined with respect to three temporal cycles (seasonal, diel and tidal) and at both large and small spatial scales. Sampling was conducted at the Virginia barrier islands using an 8 m bag seine dragged parallel to the beach in water with an average depth of 0.2 m. The fish assemblage was relatively species poor, in fact, there were only two year-round residents, *Membras martinica* (rough silverside) and *Mugil curema* (white mullet). Three species, *M. martinica*, *Trachinotus carolinus* (Florida pompano) and *Menticirrhus littoralis* (gulf kingfish), comprised 94% of all species captured. Both fish species richness and total abundance peaked in the late summer and were lowest in the winter. Multidimensional scaling analysis failed to identify a distinct nighttime fish assemblage. However, univariate analyses found there was a significant increase in species richness at night, due to an influx of predatory adult fishes. Further, significantly more species were collected at high than low tide. Higher species richness and total fish abundance occurred in the shallow water (<0.4 m) of runnels, low wave energy habitats on the backside of small sand bars. The increased richness and abundance suggests a small-scale movement of fishes parallel to the beach face as fishes seek sheltered runnel habitats. This study quantifies the observation that many fishes do utilize the shallow surf-zone, perhaps to minimize predator encounters and/or take advantage of an under-utilized intertidal food source.

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Introduction

Many fishes and macro-crustaceans of the ocean surf-zone community are larval and juvenile individuals that use the shallow water as a nursery habitat (Lasiak, 1986; Robertson & Lenanton, 1984; Ruple, 1984; Ross *et al.*, 1987; Gibson *et al.*, 1993; Santos & Nash, 1995). Such near-shore shallow water habitats are beneficial to juvenile fishes as refugia from aquatic predators or they may provide potential foraging areas. For example, in east coast salt marshes, fishes (e.g. *Fundulus heteroclitus*, common mummichog and *Fundulus luciae*, spotfin killifish) and invertebrates (*Palaemonetes pugio*, grass shrimp) have been shown to utilize the shallow water on the marsh surface in order to minimize encounters with aquatic predators or to take advantage of an under-utilized food resource (Talbot & Able, 1984; Smith & Able, 1994;

Yozzo *et al.*, 1994; Kneib, 1997). If the distribution of fishes in the surf-zone likewise is determined by these factors, it is a logical hypothesis that these organisms should move into the shallowest water possible, given their species-specific size and/or morphological adaptations.

Despite the potential importance of the shallow surf-zone as a habitat for fishes, previous surf ichthyofaunal studies have usually examined fish assemblages in water 0.4 m and deeper; very few have focused on the fishes that utilize water less than 0.4 m. Harvey (1998) specifically examined the shallowest waters on a sandy beach of Sapelo Island, Georgia, and was able to demonstrate that *Fundulus majalis* (striped killifish) exhibits a clear preference for runnels, isolated troughs of water behind small sand bars. However, his sampling was both temporally (i.e. one week) and spatially (i.e. one site on one beach) constrained. Santos and Nash (1995), Abou-Seedo (1990) and Peters and Nelson (1987) included water less than 0.4 m deep in their analyses, but in each study the authors seined perpendicularly to the shoreline,

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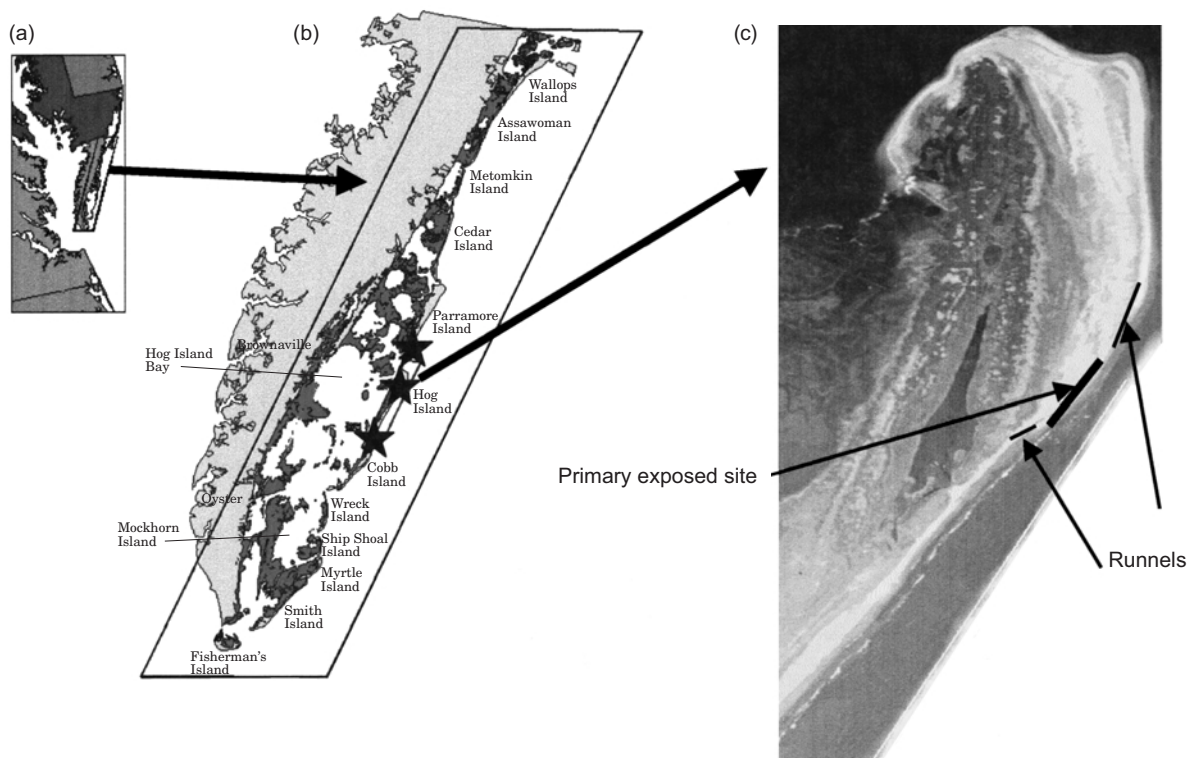


FIGURE 1. The (a) Delmarva Peninsula, (b) Virginia Coast Reserve Long-Term Ecological Research Site, and (c) the north end of Hog Island. The three sampling locations are designated by a star on map (b). At our main sampling site on the north end of Hog Island, the exposed sampling location and adjacent runnel sites are indicated. Primary exposed site: latitude 75°66'W; longitude 37°44'N.

thereby integrating fish collections over a broad range of depths.

Previous authors have extensively described the invertebrate assemblages of United States east coast beaches (Anderson *et al.*, 1977; Leber, 1982; McDermott, 1983), but similar comprehensive ichthyofaunal analyses have not been conducted. McDermott (1983), in New Jersey, and DeLancey (1989), in South Carolina, focused primarily on the food web relationships of shallow surf-zone fishes. The most common fish species were found to be either planktivores (*Menidia menidia*, Atlantic silverside, *Anchoa mitchilli*, bay anchovy, and *Anchoa hepsetus*, striped anchovy), benthic invertivores (*Menticirrhus littoralis*, gulf kingfish, and *Trachinotus carolinus*, Florida pompano) or benthic omnivores/detritivores (*Mugil curema*, white mullet). Peters and Nelson (1987) and Peters (1984) have reported that a similar low diversity fish assemblage is found in the surf-zone on the east coast of Florida.

The objective of this study was to conduct an in-depth analysis of the Virginia barrier island surf, focusing on the fish assemblage in water shallower than 0.4 m. The dynamics of the fish assemblages are described with respect to three temporal scales:

(1) seasonal, (2) diel, and (3) tidal. In addition, spatial assemblage structure variation was examined on two scales: (1) small scale spatial differences between exposed beach sites and adjacent runnel habitats, and (2) large scale variations among island sites.

Materials and methods

Study site

The study took place at the Virginia barrier islands, part of the Virginia Coast Reserve Long-Term Ecological Research Site (Figure 1). The primary North Hog sampling location was an exposed beach site with no offshore sandbars. This site was characterized by moderate to heavy wave action (waves typically exceed 1 m in height), no permanent macrofaunal burrows within the intertidal zone, a rather wide surf-zone, presence of relatively deep reduced sediment layers, and intermediate beach particle size. Based on the classification system of McLachlan (1980), the North Hog Island Site is rated 12 (assessed from data collected by Harris, 1988, and Layman, unpubl. data) and falls within the range of beaches described as 'moderately exposed'. Salinity in the Hog Island

TABLE 1. The average temperature of the shallow surf-zone taken coincident with the fish samples each month. All temperatures are reported in °C

1997					1998					1999				
Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Feb
29.3	27.2	23.0	9.8	7.8	6.2	11.5	14.1	16.0	19.1	25.8	27.1	26.5	21.5	6.1

surf-zone ranged from 32 to 36 (using the Practical Salinity Scale) during the study period.

General shallow surf-zone sampling protocol

The 'shallow surf-zone' was the area of the surf immediately adjacent to the beach that is less than 0.4 m deep. All collections were made with a seine 8 m long and 1.5 m deep, with a 1 m square bag and three-sixteenths of an inch (0.48 cm) square mesh throughout. A single seine haul was made by two persons through the shallow swash area parallel to the beach face. One person pulled the outer wing of the seine at a depth of ~0.4 m (estimated at the troughs of passing waves) and the other person pulled the opposite wing along the edge of the shoreline. This procedure sampled an average depth of 0.2 m. During each haul, the net was pulled 15 m along the beach into the prevailing longshore current. The next haul within each seine series was conducted 5 m further up the beach to sample a different section of the shallow surf. Each individual seine was estimated to have swept an approximate area of 120 m². Fishes were held in an aerated holding bucket until all seines at a sampling site or time were completed; this ensured that no individuals were captured more than once in a set of seine hauls. Adult fishes were identified based on the descriptions of Murdy *et al.* (1997) and juveniles using Development of Fishes of the Mid-Atlantic Bight (1978). Voucher specimens are held at the Virginia Coast Reserve Long-Term Ecological Research laboratory.

Temporal analyses

Sixteen seine hauls (8 at high and 8 at low tide) were made on each of two days within a month. Sampling began 30 min prior to high or low tide. Because surf-zone fishes school, and individual hauls are highly variable (Lasiak, 1982; Ross *et al.*, 1987; Gibson *et al.*, 1993; Clark *et al.*, 1996a), the 32 individual seines were pooled to represent a monthly sample. Samples were taken each month from August 1997 to October

1998 (except January 1998) and in February 1999, each on the same 150 m stretch of beach on Hog Island.

Depending on fish abundance, each series of eight seine hauls took 30 to 90 min. Since the sampling protocol was consistent (i.e. 32 seines of equal distance, at the same site and standardized by tide), no richness index was necessary to compare the number of species collected among months. Instead, collections conducted in an identical manner can most accurately be compared using direct species counts; this approach avoids problems inherent to richness indexes (Ludwig & Reynolds, 1988). Evenness was calculated using the following equation:

$$E = ((1/\lambda) - 1) / (e^H - 1)$$

where $\lambda = \Sigma(n_i/N)^2$ [Simpson's diversity index (Simpson, 1949)] and $H = -\Sigma p_i \ln(p_i)$ [Shannon's diversity index (Shannon, 1949)]. This evenness index is less biased than the more commonly used J' of Pielou (1975, 1977) because of its independence from sample richness (Ludwig & Reynolds, 1988). Clark *et al.* (1996a) suggested that seasonal fluctuations in the faunal abundance of the surf-zone are especially important on beaches in which temperature change exceeds 20 °C annually, a criterion that was met in our study. In order to elucidate the potential relationship between temperature and fish abundance in the shallow surf, species richness, total number of individuals, and evenness were correlated with the average monthly temperature (see Table 1). Temperature of the shallow surf was measured with a YSI model 30 SCT meter.

For day/night comparisons, sampling was conducted on three nights: 7/8 July, 30/31 July, and 12/13 August. Over the three nights, eight series of samples were collected. Each series of samples consisted of eight consecutive seine hauls, as is described in the monthly sampling protocol. Each series of seine hauls was compared to a set of daytime hauls conducted at the identical tide on the previous day. Comparisons between high and low tide fish collections were made

using the monthly data. Within a month, the 16 high and 16 low tide seines were pooled and compared on a pairwise fashion.

Spatial analyses

Small-scale spatial variations in fish assemblage structure were analysed by comparing collections at the north Hog Island site to those in shielded 'runnel' habitats (Komar, 1998). The width and depth of the runnels, as well as the height of the shielding sand bar, varied considerably due to tidal conditions, recent sediment transport, and various other factors. Unlike the study of Harvey (1998), runnels were sampled that were not completely isolated from wave exposure, for example at high tide when small waves moved across the bar and through the runnel. Even so, for every runnel sample there was a clear bar that dissipated wave energy, and the runnel itself was always a well-formed depression. Eight seine collections at the main North Hog site were compared with eight seine collections in one of two runnel habitats immediately adjacent to the exposed site (runnels were within 100 m of the exposed site). Each series of seines were taken at random times within the tidal cycle, but the eight paired runnel seines and exposed site seines were always taken consecutively. The seine was deployed in the same manner at the runnels and at the exposed site.

In order to evaluate fish assemblages at different locations on the Virginia barrier islands, two additional sites were sampled (the southern end of Hog Island and Parramore Island) in July and August, 1999 (See Figure 1). All three locations were exposed beach sites with similar wave energy, surf-zone width, beach slope and particle size. Thirty-two seines were taken each month at these sites, following the collection protocol used in the monthly sampling.

Sampling efficiency

Due to mesh size and net length, capture efficiency varies among species (Parsley *et al.*, 1989; Monteiro-Neto & Musick, 1994; Allen *et al.*, 1995). Thus our use of only a single sampling gear likely resulted in bias against certain fish species. For example, catch efficiency was probably rather low for larger species. Earlier studies have discussed the effect that net efficiency can have on beach seine collections (Gulland, 1983; Lasiak, 1984a; Lyons, 1986; Nash, 1986; Parsley *et al.*, 1989; Pierce *et al.*, 1990; Romer, 1990; Monteiro-Neto & Musick, 1994; Nash *et al.*, 1994; Lamberth *et al.*, 1995). In this

study, net collection efficiency may have been lower in the turbulent water of the exposed beach site than in the calm runnel water, despite a focused effort to minimize among site sampling variations. Conversely, fishes may be more likely to detect and avoid the net in the calm water. Similarly, earlier studies have debated the validity of making direct day and night collection comparisons (e.g. Horn, 1980; Nash, 1986; Wright, 1989; Gibson *et al.*, 1996). In an attempt to minimize these sampling problems, numerous individual samples were taken at a given site or sampling time; a minimum of 16 individual seines were conducted for any particular comparison.

Statistical analyses

All data sets used in univariate tests (comparing species richness, total number of individuals, or fish lengths among months, site, day/night or high/low tide samples) which met assumptions of normality and homogeneity of variance were compared using analysis of variance (ANOVA), or with paired *t*-tests when data were collected in paired fashion. Comparisons which did not meet variance or distributional assumptions were carried out with the Kruskal-Wallis (multiple comparisons) or Wilcoxon Signed Rank (paired comparisons) non-parametric tests. There is much concern over the 'experimentwise' error rate when multiple comparisons are made within a given study; however, the objective of this study was to make a series of individual comparisons. For example, day/night and runnel/exposed site analyses are considered separately. Therefore, significance of each experiment was evaluated at the 0.05 level following the precedent set by Carmen and Walker (1982) and Soto and Hurlbert (1991). All univariate statistical analyses were conducted with SigmaStat Statistical Software[®] (1997).

For analyses in which sufficient samples were available (seasonal, day/night and exposed/runnel comparisons), the multidimensional scaling (MDS) technique proposed by Field *et al.* (1982), Clark (1993), and Clark and Ainsworth (1993) was also used to compare fish assemblage structure. In all multivariate analyses, fish abundances were first root-root transformed in order to decrease the influence of the most abundant species (Clark & Green, 1988). Similarity matrices were calculated using the Bray-Curtis similarity index (Bray & Curtis, 1957). Ordination plots based on these pairwise similarities were constructed by the MDS technique using the SPSS statistical software package.

TABLE 2. The total number of individuals captured in 32 seines conducted each month at the main exposed beach site on Hog Island, Virginia from August 1997 to February 1999. Density is expressed as number of fish m^{-2} . Species abbreviations are as follows: *Membras martinica*=Mm; *Menticirrhus littoralis*=Ml; *Trachinotus carolinus*=Tc; *Fundulus majalis*=Fm; *Mugil curema*=Mc; *Menticirrhus saxatilis*=Ms; *Cyprinodon variegatus*=Cv; *Fundulus heteroclitus*=Fh; *Sphyræna* sp.=Ssp.; *Sciaenops ocellatus*=So; *Paralichthys dentatus*=Pd; *Syngnathus fuscus*=Sf

Month	Mm	Ml	Tc	Fm	Mc	Ms	Cv	Fh	Ssp.	So	Pd	Sf	Total	Average Density
Aug-97	419	372	31	34	—	9	3	—	—	—	—	1	869	0.226
Sep-97	14	528	2	6	4	16	—	—	—	—	—	—	570	0.148
Oct-97	145	260	4	7	—	7	—	—	—	—	—	—	424	0.110
Nov-97	40	15	—	4	2	2	20	—	—	2	—	—	83	0.022
Dec-97	12	—	—	—	—	—	—	—	—	—	—	—	12	0.003
Feb-98	18	—	—	—	—	—	—	—	—	—	—	—	18	0.005
Mar-98	104	—	—	—	3	—	—	—	—	2	—	—	107	0.028
Apr-98	141	—	—	—	17	—	—	—	—	—	—	—	158	0.041
May-98	46	—	—	—	2	—	—	—	—	—	—	—	48	0.013
Jun-98	17	—	5	1	12	—	2	—	—	—	—	—	37	0.010
Jul-98	340	17	249	1	30	2	1	3	1	—	1	3	643	0.167
Aug-98	1027	221	81	30	3	14	2	—	—	—	—	—	1378	0.359
Sep-98	2	118	14	3	—	2	—	—	—	—	—	—	139	0.036
Oct-98	10	84	5	1	—	—	—	—	—	—	—	—	100	0.026
Feb-99	19	—	—	—	2	—	—	—	—	—	—	—	21	0.006
Total	2354	1615	391	87	75	52	29	3	3	2	1	1	4607	
(%)	51	35	8	2	2	1	1	<1	<1	<1	<1	<1		

Results

Seasonal analysis

The fish assemblage of the shallow surf-zone on the Virginia barrier islands had low diversity and was dominated by three species, *M. martinica*, *M. littoralis*, and *T. carolinus*, which accounted for 94% of all fishes collected. The seven most common species accounted for 99.9% of the catch (Table 2) and *M. martinica* was the most abundant fish species (51% of all individuals). There was a distinct seasonal trend in species richness and abundance (Figure 2). Most fishes were collected June through October, with the largest collection in August 1998 (1378 total fish; estimated density=0.36 fish m^{-2}). Fish species richness was highest in the summer and early fall. The lowest species richness and overall fish abundance occurred during the winter and spring. Species evenness was also at a minimum during winter months. Seasonal abundance trends were further supported by distinct positive correlations of species richness, total number of individuals and evenness with temperature (Figure 3). Both richness ($R^2=0.54$; $P=0.002$) and total number of individuals ($R^2=0.51$; $P=0.003$) were found to be significantly correlated with temperature.

A MDS ordination plot (Figure 4) revealed distinct groupings of monthly fish samples. Winter and spring samples are in close proximity in ordination space because each of these months was characterized by

low species richness and low overall fish abundance. The second major grouping corresponds to the late summer and early fall samples (August through to October) in which species richness and abundance were high. The June sample is differentiated by low abundance despite a relatively high species richness. The July and November samples are differentiated in ordination space because of the presence of species that were not captured in other months.

Almost all fishes collected were less than 100 mm in total length. Table 3 gives the average monthly size of the three dominant members of the fish community during the summer months. There was a trend of increasing size from the early to late summer. This trend was most pronounced for *T. carolinus*, which had an average size of 22.7 mm in June and 90.1 mm in August. The average length of *M. littoralis* decreased slightly from July to August, but both months had a significantly higher mean length than June. For these three species there was a significant difference in mean length among months (*M. martinica*, ANOVA, $F_{2,134}=38.8$; *T. carolinus*, Kruskal-Wallis, $df=2$, $H=119.2$; *M. littoralis*, Kruskal-Wallis, $df=2$, $H=45.2$; $P<0.001$ for all cases).

Day/night analysis

Although significantly more fish species were collected at night (paired *t*-test, $df=7$, $t=4.2$, $P=0.004$), the

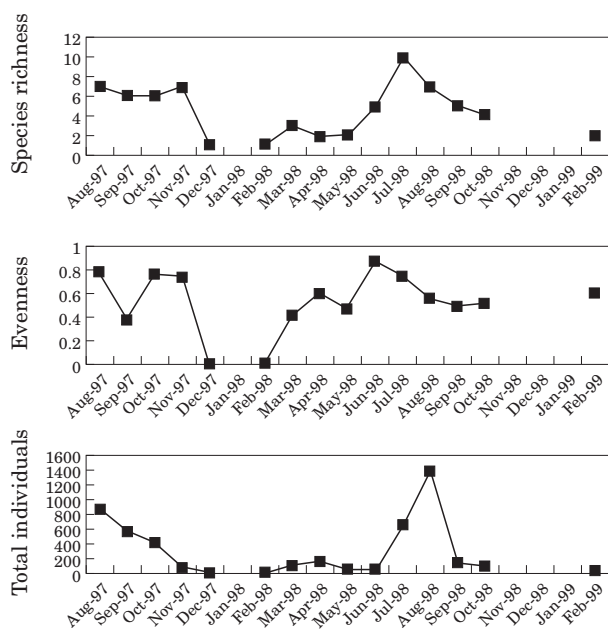


FIGURE 2. Fish species richness, evenness and total number of individuals at the main sampling site on the north end of Hog Island over the 15 month study period. Richness is expressed as total number of species and evenness calculated using the index given in the Methods section (Ludwig & Reynolds, 1988).

total numerical abundance did not differ (paired t -test, $df=7$, $t=0.35$, $P=0.74$). The significant increase in species richness was due primarily to three adult fish species, none of which was collected during the daylight hours (*Paralichthys dentatus*, summer flounder, *Leiostomus xanthurus*, spot, and *Astroscopus guttatus*, northern stargazer). The size of these fishes ranged from 15.1 to 37.1 cm. The three most commonly collected species at night were the same as during the day, *M. martinica*, *T. carolinus*, and *M. littoralis*. These three species made up 90% of the total number of fishes at night, compared to 98% in the paired daytime samples. A MDS ordination plot did not reveal distinct day/night groupings of fish samples (Figure 5); the sampling dates are clustered to a much greater extent than are the day or night samples.

Tidal analysis

For both high and low tide samples, richness peaked in the summer or early fall and declined to a single species in the winter (Table 4). Species richness was significantly greater at high tide (paired t -test, $df=14$, $t=3.86$, $P=0.002$), but numerical abundance did not differ (paired t -test, $df=14$, $t=1.24$, $P=0.23$). For individual species, only *T. carolinus* was more

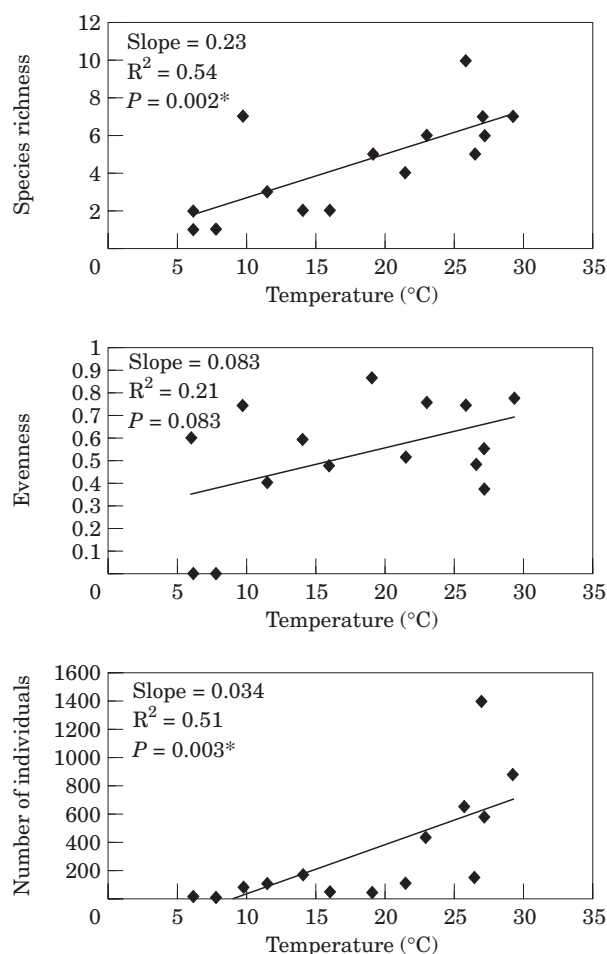


FIGURE 3. Fish species richness, evenness, and number of individuals correlated to temperature of the shallow surf-zone on the monthly sampling dates. Slopes of the lines, r -squared values and P -values are indicated on the plots. Significant regressions are indicated with a *.

commonly collected at high tide (Wilcoxon Signed Rank, $P=0.02$).

Runnel analysis

There were clear differences in species richness and total abundance between the main North Hog site and adjacent runnel habitats (Figure 6). On eight of the 10 days in which these comparisons were made, richness was greater in the runnel habitats; on nine of the sampling days, total fish abundance in the runnels was higher. Both species richness (paired t -test, $df=9$, $t=3.0$, $P=0.014$) and total abundance (paired t -test, $df=9$, $t=2.6$, $P=0.027$) were found to be significantly greater at the runnel site. The significant increase in species richness was due to the occurrence of rarely collected species including *Anchoa* sp. (anchovies),

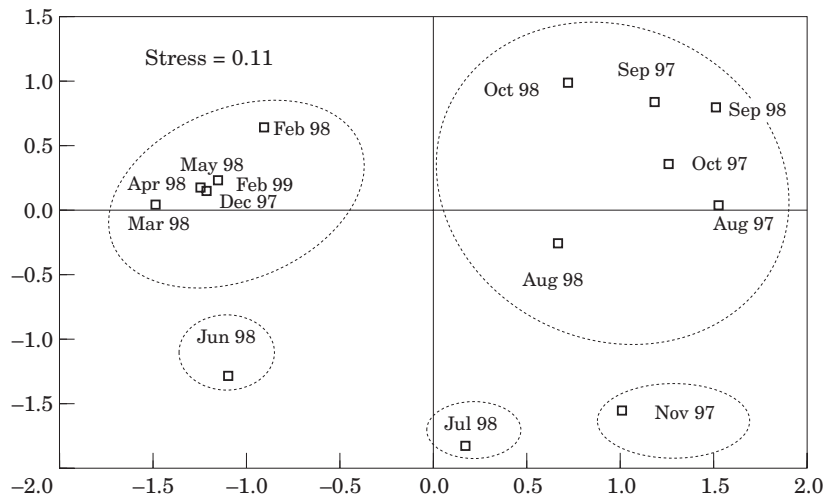


FIGURE 4. Multidimensional scaling ordination plot of the seining data at the main exposed Hog Island sampling location for the fifteen monthly collections. Groups of samples are delineated at the 60% level of similarity.

TABLE 3. The average monthly size of the three most common fish species during June, July and August 1998. Sizes are given in mm

	<i>Membras martinica</i>	<i>Trachinotus carolinus</i>	<i>Menticirrhus littoralis</i>
June	44.1	22.7	30.1
July	63.9	48.0	66.8
August	67.8	90.1	53.1

Fistularia tabacaria (bluespotted cornetfish), *Hyporhamphus unifasciatus* (halfbeak), *Spherooides maculatus* (northern puffer) and juvenile *Anguilla rostrata* (American eels), as well as resident marsh fish species, including the *Fundulus heteroclitus* (common mummichog) and *Cyprinodon variegatus* (sheepshead minnow). In contrast, the significant increase in total abundance of fishes was primarily due to large collections of the three most common shallow surf residents, *M. martinica*, *M. littoralis*, and *T. carolinus*. Despite the clear trends in univariate statistical analyses, there were no distinct groupings of the exposed

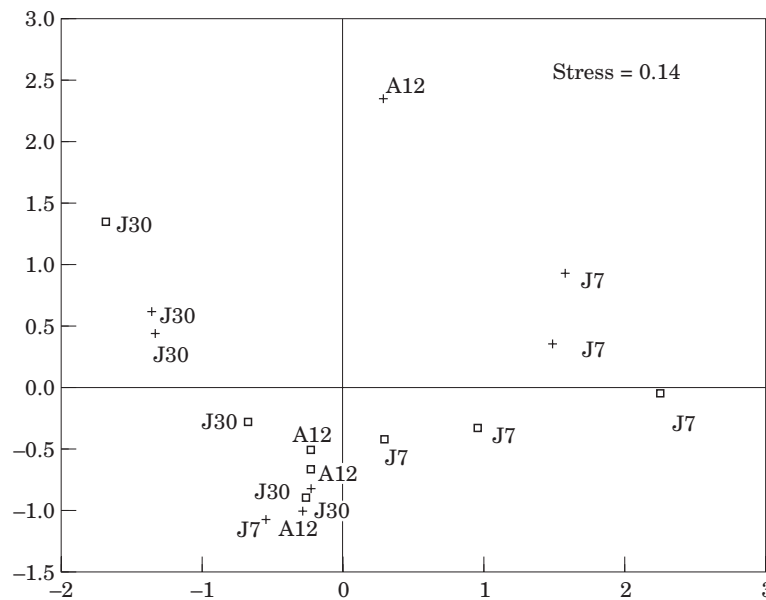


FIGURE 5. The multidimensional scaling ordination plot of the 16 day/night sampling data sets. The dates of sampling are abbreviated as follows: 7/8 July=J7, 30/31 July=J30, and 12/13 August=A12. Crosses: day samples; squares: night samples.

TABLE 4. The fish species richness, total number of individuals and number of the three most common species at high (H) and low (L) tide. These data are compiled from the monthly seining samples in which eight seines were conducted at high tide and eight at low tide on two days during the month of interest. The high and low tide data were compared with a paired *t*-test and resulting *P*-values are given at the bottom of the table. Significant results are designated with a *. Abbreviations are as follows: *Membras martinica*, Mm; *Menticirrhus littoralis*, Ml; *Trachinotus carolinus*, Tc

Month Tide	Richness		Total Individuals		Mm		Ml		Tc	
	H	L	H	L	H	L	H	L	H	L
Aug-97	7	3	351	518	39	380	238	134	31	0
Sep-97	6	3	262	308	14	0	229	299	2	0
Oct-97	6	4	247	177	23	122	121	48	4	0
Nov-97	7	5	34	51	7	33	2	13	0	0
Dec-97	0	1	0	12	0	12	0	0	0	0
Feb-98	1	1	6	12	6	12	0	0	0	0
Mar-98	3	1	67	42	62	42	0	0	0	0
Apr-98	2	2	49	109	41	100	0	0	0	0
May-98	2	1	26	22	24	22	0	0	0	0
Jun-98	5	3	13	0	6	11	0	0	2	3
Jul-98	8	6	320	325	30	310	8	9	248	1
Aug-98	7	4	452	926	185	842	161	60	64	17
Sep-98	4	4	114	25	0	2	98	20	12	2
Oct-98	4	3	23	77	7	3	12	72	3	2
Feb-99	2	2	10	11	9	10	0	0	0	0
<i>P</i> -values	0.0002*		0.67		0.06		0.25		0.03*	

and runnel sites in MDS space (Figure 7). This suggests that although the richness and abundance of fishes on any given day typically are higher in the runnel than at the adjacent exposed beach site, the fish assemblage is not predictable from day to day.

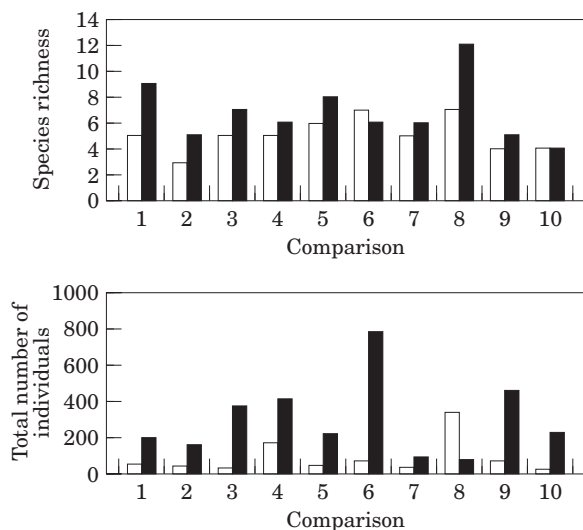


FIGURE 6. Fish species richness and number of individuals collected at the main exposed sampling site on the north end of Hog Island compared to adjacent runnel habitat collections taken immediately before or after. Open bars: exposed site; closed bars: runnel site.

Inter-island analysis

Membras martinica, *T. carolinus* and *M. littoralis* were the three most commonly collected fish species at the North Hog, South Hog, and Parramore sites during both July and August (Table 5). During each month the rank order (based on abundance of each of these species) was consistent across the three sites. The similarity among sites suggests that the fauna of Hog Island is representative of other Virginia barrier islands.

Discussion

The number of fish species collected in the shallow surf-zone on Hog Island (25) is below the range (26 to 71) reported in previous surf-zone ichthyofaunal studies (Brown & McLachlan, 1990). Importantly, only seven species accounted for 99% of all fishes collected. Although surf-zone habitats are typically dominated by relatively few species (Lasiak, 1984a; Ross *et al.*, 1987; Brown & McLachlan, 1990; Romer, 1990), the shallow surf-zone was even more species poor. Very few species are able to utilize the turbulent, shallow water. The species that were found in the shallow surf-zone can be classified into one of five life-history categories: seasonal nursery juveniles, adult transients, year-round residents, seasonal or nocturnal migrants, and marsh pond

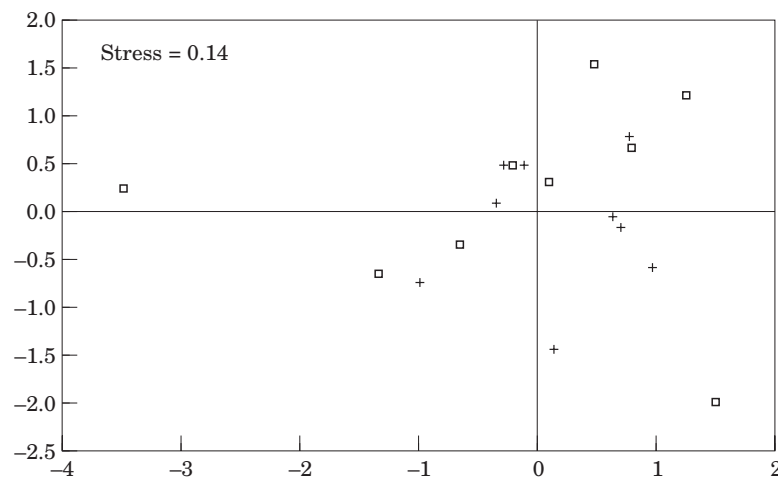


FIGURE 7. The multidimensional scaling ordination plot of samples taken at exposed sites and adjacent runnel habitats during July. Crosses: exposed samples; squares: runnel samples.

TABLE 5. The percent composition of fishes collected at the main site on the north end of Hog Island, the site at the south end of Hog Island, and on Parramore Island in July and August 1998

	July			August		
	Main	South	Parramore	Main	South	Parramore
<i>M. martinica</i>	51	46	80	75	51	51
<i>T. carolinus</i>	37	27	13	6	10	6
<i>M. littoralis</i>	6	24	6	15	36	42
<i>M. curema</i>	4	—	—	<1	—	—
<i>F. majalis</i>	<1	—	—	—	2	2
<i>C. variegatus</i>	<1	<1	—	<1	—	—
<i>M. saxatilis</i>	<1	<1	<1	<1	<1	<1
<i>Sphyaena sp.</i>	<1	—	—	—	—	—
<i>F. heteroclitus</i>	<1	<1	—	—	—	—
<i>P. dentatus</i>	<1	—	—	—	—	—

residents (Table 6). The majority of the species collected in this study were either seasonal juveniles that utilize the shallow waters as a nursery area or adult transient species that are much more common in other marine habitats. These fishes are typically invertivores or planktivores, and are common in the shallow surf-zone during the warmer months of the year. Only two species, *M. martinica* and *M. curema*, were year-round residents. Other adult marine species occasionally moved into the shallows either at night (e.g. *L. xanthurus*) or during a particular season (e.g. *S. ocellatus*). Finally, some of the fish species were residents of marsh ponds on the Virginia barrier islands. These fishes are swept into the ocean as the ponds periodically drain (Layman *et al.*, in press).

Most species utilize the shallow surf during the summer and early fall and then migrate to deeper waters or southward during cooler months, as

has been shown in other studies (Gunter, 1945; McFarland, 1963; Modde & Ross, 1981; Guillen & Landry, 1982; Leber, 1982; Lasiak, 1984b; Peters, 1984; Peters & Nelson, 1987; Ross *et al.*, 1987; Santos & Nash, 1995; Clark *et al.*, 1996a). This seasonal migration is supported by the significant relationship between species abundance and average monthly temperature. Although not directly demonstrated here, it seems likely that temperature either directly, or indirectly (i.e. by influencing the timing of spawning), is the underlying mechanism of seasonal shallow surf-zone dynamics.

MDS revealed no distinct grouping that would suggest distinct day and night fish assemblages. However, the univariate statistics clearly showed a significant increase in species richness at night. This agrees with other studies which have shown that the abundance of relatively rare species may increase at night,

TABLE 6. List of species captured in the shallow surf zone of Hog Island during sampling conducted from August 1997 until February 1999. Each species is classified according to site(s) of capture, time of capture, surf utilization, and trophic level. Trophic level classifications (for the age class of fish which we specifically collected) are based on the descriptions of Murdy *et al.* (1997). *Site*: E=exposed; R=runnel; B=Both. *Time*: D=Day; N=Night; B=Both. *Surf utilization*: Y=year-round resident; J=seasonal nursery juvenile; M=island marsh pond resident; T=adult transient common in other marine habitats. *Trophic level*: P=planktivore; W=water column macroinvertebrates; I=benthic invertivore; F=piscivore; A=algivore; D=detritivore

Scientific name	Common name	Site	Time	Surf utilization	Trophic level
Fish species					
<i>Anchoa</i> sp.	Anchovy	R	B	J	P
<i>Anguilla rostrata</i>	American eel	R	D	J	P/I
<i>Astroscopus guttatus</i>	Northern stargazer	E	N	T	F
<i>Brevoortia tyrannus</i>	Atlantic menhaden	R	D	J	P
<i>Caranx hippos</i>	Crevalle Jack	R	D	J	I/W
<i>Cyprinodon variegatus</i>	Sheepshead minnow	B	B	M	A
<i>Fistularia tabacaria</i>	Bluespotted cornetfish	R	D	T	W/F
<i>Fundulus heteroclitus</i>	Common mummichog	B	B	M	I/W/D
<i>Fundulus majalis</i>	Striped killifish	B	B	T	I/W
<i>Hyporhamphus unifasciatus</i>	Halfbeak	R	D	T	W/F
<i>Leiostomus xanthurus</i>	Spot	B	N	T	I/F
<i>Membras martinica</i>	Rough silverside	B	B	Y	P
<i>Menticirrhus saxatilis</i>	Northern kingfish	B	B	J	I
<i>Menticirrhus littoralis</i>	Gulf kingfish	B	B	J	I
<i>Mugil curema</i>	White mullet	B	B	Y	A/D
<i>Paralichthys dentatus</i>	Summer flounder	B	B	J/T	W/F
<i>Peprilus</i> sp.	Butterfish	B	B	J	P/W
<i>Psenes</i> sp.	Driftfish	B	D	J	P/W
<i>Sciaenops ocellatus</i>	Red drum	E	D	T	F/I
<i>Sphoeroides maculatus</i>	Northern puffer	R	D	T	I
<i>Sphyrna</i> sp.	Barracuda	B	B	J	W/F
<i>Strongylura marina</i>	Atlantic needlefish	B	D	T	W/F
<i>Sygnathus fuscus</i>	Northern pipefish	B	B	T	P/I
<i>Trachinotus carolinus</i>	Florida pompano	B	B	J	I/W

but the main changes in fish assemblage structure were due to variability of the most common fish species (Romer, 1990; Gibson *et al.*, 1996). Additionally, I was able to identify a significant trend of increased richness, as well as a significant trend in increased abundance of *T. carolinus*, in high tide samples. Gibson *et al.* (1998) identified three main reasons for such diel, tidal, or similar fish migrations: (1) foraging considerations, (2) predator avoidance, and (3) selection of suitable environmental conditions. The former two explanations are most likely in the shallow surf-zone.

Nocturnal increases in species richness are related to the shoreward movements of piscivorous fishes (e.g. *Leiostomus xanthurus*), forcing prey fishes into shallower water (Girsa & Zhuravel, 1983; Brown & McLachlan, 1990; Ansell & Gibson, 1990; Gibson *et al.*, 1996). In contrast, tidal migrations within the shallow surf are likely related to the availability of food (Brown & McLachlan, 1990; Gibson *et al.*, 1996). High tides allow some fishes to move into the

uppermost 'zones' of intertidal invertebrate distributions, an area inaccessible to other fishes (Brown & McLachlan, 1990). This foraging explanation may explain the increased abundance of *T. carolinus*, a benthic invertivore (Armitage & Alevizon, 1980), at high tide. In contrast, fishes that do not migrate with tidal cycles may be utilizing food items that are available at various intertidal depths (e.g. the zooplanktivorous *M. martinica*), and their presence in the shallow surf-zone is due primarily to predator avoidance. Movements based on the selection of optimal environmental conditions is unlikely, as the shallow surf-zone actually necessitates increased energy expense in order to maintain position and move freely in such a dynamic, turbulent area (Clark *et al.*, 1996a).

Previous studies have made surf-zone wave exposure comparisons among sites separated by many hundreds of metres (Hillman, 1977; Brown & McLachlan, 1990; Romer 1990; Pihl & van der Veer, 1992; Gibson, 1994; Clark *et al.*, 1996b; Clark, 1997).

One drawback of such large-scale comparisons is that many factors, including substrate type, sediment size, distance from potential sources of colonization, temperature, and presence of structure, are likely to vary among the sites. The present study minimized these spatial differences by examining the effects of wave exposure on a much smaller scale; fish assemblages were compared in runnel and exposed sites immediately adjacent to one another.

Due to variable collections of common species and the sporadic occurrence of relatively rare fish species, there was no distinct runnel fish assemblage identifiable in MDS space. However, the univariate statistical approaches reveal a very important trend in the data; both species richness and overall fish abundance were significantly higher in the runnels. This statistical result further substantiates the observations of Harvey (1998), who documented the preference of *F. majalis* for runnels. Overall the data suggest that even though there were not distinct runnel and non-runnel fish assemblages (i.e. assemblages varied more among days than between runnel and exposed sites on a single day), there were typically more species and a higher number of species in the runnels on any given day. This concentration of fishes in the runnels may be in direct response to the decreased physical wave energy (Romer, 1990; Clark *et al.*, 1996b), or an indirect effect resulting from turbidity preferences (Lasiak, 1984b; Clark *et al.*, 1996b), avoidance of predation (Robertson & Lenanton, 1984; Gibson *et al.*, 1998; Harvey, 1998), increased food availability (DeLancey, 1989; Gibson *et al.*, 1998; Harvey, 1998), or the benefits of macrophyte/debris accumulation (Lenanton, 1982; Robertson & Lenanton, 1984; Peters & Nelson, 1987; Lenanton & Caputi, 1989). A combination of all these factors likely contribute to the preference for runnel habitats.

A convergence of shallow surf-zone fishes into runnels emphasizes a much debated question in surf-zone ecology; what factors actually cause differences in fish assemblage structure among sites with varying levels of wave exposure? The shallow surf-zone may provide the ideal habitat in which this question can be evaluated. The abundance of runnel systems on many beaches (Komar, 1998) provides a natural experiment in which there is significant wave exposure variation among sites (i.e. runnel and exposed locations) in close proximity. Close sampling locations helps minimize the influence of confounding variables inherent to spatial comparisons. Furthermore, the shallow surf-zone is more easily sampled (i.e. it does not require the use of a boat or extensive trawl system) and multiple samples can be taken in a short time period.

Earlier studies have documented the movement of fishes in and out of the surf-zone on seasonal, diel, or tidal cycles (Lasiak, 1984a,b; Peters, 1984; Senta & Kinoshita, 1985; Ross *et al.*, 1987; Wright, 1988, 1989; Abou-Seedo, 1990; Brown & McLachlan, 1990; Gibson *et al.*, 1993; Lamberth *et al.*, 1995; Santos & Nash, 1995; Clark *et al.*, 1996a,b; Gibson *et al.*, 1996; Gibson *et al.*, 1988). These patterns may be defined as perpendicular movements, towards or away from the beach. The present study has provided evidence that the same perpendicular movements occur in the shallow surf-zone. For example, this study demonstrates the importance of seasonal movements in the shallow water, due primarily to the influx of juveniles during the summer months. Also important are perpendicular movements on diel and tidal cycles, as fish species richness increases at night and during high tide.

The results of this study also suggest that an additional movement might occur parallel to the beach face, as fishes move into or among preferred runnel habitats. The dynamic nature of the runnels themselves (due to tidal influences, shifting sediment, etc.) suggests that fishes may undertake frequent small-scale movements seeking runnels that provide maximum benefit. A related observation was made by McLachlan and Hesp (1984) who suggested that fishes prefer lower energy bay habitats over high energy horn areas on beaches with distinct cusp morphology. Fishes may migrate parallel to the beach seeking bay habitats, much as they move into runnels in the shallow surf-zone. The result is a convergence of surf-zone residents and a distinct concentration of food web interactions (McLachlan & Hesp, 1984).

In conclusion, the shallow surf-zone is characterized by low species diversity, and serves as a nursery area (or, in certain cases, a year-round habitat) for those species which are able to utilize the shallow water. Some characteristics of the shallow surf reflect those reported for the overall surf-zone, including seasonal, tidal, and diel trends in richness and abundance. Of these temporal scales, seasonal movements seem to be the most important component of the shallow surf-zone fish dynamics. Additionally, fishes of the shallow surf demonstrate a preference for low energy runnel habitats. The mechanism underlying this phenomena remains unclear, but it may be the end result of small-scale movements parallel to the beach face.

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