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The Summer Zooplankton of the Surf Zone at Folly Beach, South Carolina[1]

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ABSTRACT

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The zooplankton of the surf zone at a beach site in South Carolina was numerically dominated during the summer by larval decapods, mysids, and copepods. Taxa that were abundant in the surf zone have also been commonly collected in estuarine and nearshore waters in this biogeographic region, and are not restricted to the beach environment. Time of day apparently influenced the relative abundance of macroinvertebrates such as brachyuran megalopae and mysids, caught with a 505-*mm* net, whereas tidal stage had a greater influence on smaller zooplankters such as calanoid copepods and meroplanktonic larvae, captured with a 100-*mm* net.

ADDITIONAL INDEX WORDS: *Beach survey, relative abundance, taxonomic composition, tidal and diel effects, surf zone, zooplankton*

INTRODUCTION

The oceanic surf zone and sandy beach ecosystem of the southeastern United States encompass an extensive area. Despite the importance of this dynamic, harsh environment as a habitat and nursery area for numerous marine organisms, it remains one of the least studied of common marine ecosystems. PEARSE *et al.* (1942) provided a broad ecological assessment of sandy beaches near Beaufort, North Carolina. Groups such as the ichthyofauna (MODDE and ROSS, 1981) and the infaunal macroinvertebrates (LEBER, 1982) have been studied at numerous sites in the Southeast, whereas little attention has been given to the taxonomic composition and relative abundance of planktonic organisms in the surf zone. Examples of prior studies are MCFARLAND (1963), who sampled the plankton at a beach in Texas, and RUPLE (1984), who studied the ichthyoplankton in the surf zone of a barrier island in Mississippi. The objectives of the present study were to characterize the zooplankton of the surf zone during the summer, a period when planktivorous fishes are numerous within this habitat (ANDERSON *et al.*, 1977; MODDE and ROSS, 1981, 1983), and to measure some of the physical parameters that may influence the occurrence of zooplankton in the surf zone.

MATERIALS AND METHODS

As part of an ecological study that included collection of fishes and macroinvertebrates and trophic analysis, plankton samples were collected from 10 July through 26 November 1980, at a site on Folly Beach, South Carolina (32° 42.0'N, 79° 53.8'W), which is a barrier island (DELANCEY, 1984). The gently sloping beach (1-2% slope) is composed chiefly of fine sand and broken shell. The study site was a section of beach approximately 100 m in length, bounded on the northeast by a large rocky groin and on the southwest by a wooden groin. It was situated near the northeastern end of the island, near the mouths of several rivers and Charleston Harbor. Tides ranged from −0.2 to 2.0 m from mean low water, and wave heights varied from about 0.1 to 1.0 m during the study period.

Samples were collected on 12 dates during the 4.5 month study period, with one to four weeks elapsing between sampling periods. Each sampling period consisted of four consecutive collections

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made at roughly six-hour intervals, coinciding with slack tide, near high and low tide. This scheme ensured that both high and low tidal stages, and day and night periods were sampled. Two 30-cm nylon plankton nets of 505-μm and 100-μm mesh sizes were used to sample in the surf. The 505-μm net was towed by hand approximately 100 m, and the 100-μm net for approximately 10 m, parallel to the beach in 1 m water depth. All tows were made with the current. No attempt was made to meter water flow through the nets, since varying effects of current and wave action would have made such measurements inaccurate. Samples were rinsed with seawater and preserved in 10% seawater-formalin. Following each collection, water and air temperature ($\pm$0.5 °C) and salinity ($\pm$1°/$_{oo}$) were recorded.

In the laboratory, organisms were stained with rose bengal to facilitate their removal from detritus and other extraneous material. Samples collected with the 505-μm net were analyzed in their entirety, with the exception of a single very high density sample, which was subsampled with a plankton splitter (BURRELL *et al*, 1974). Samples collected with the 100-μm net were subsampled with a Hensen-Stempel 1 ml pipette after dilution to a known volume. Several aliquots from each sample were analyzed on a Sedgewick-Rafter counting slide, until at least 1% of the total volume of the sample was examined. For samples that contained large amounts of sand, the liquid portion was repeatedly decanted until nearly all of the organisms were removed (determined by volumetrically subsampling the remaining sand fraction) and the liquid fraction was analyzed as above. Organisms were identified to the lowest feasible taxon and counted.

Counts of abundant taxa were subjected to the Mann-Whitney U test and the Kruskal-Wallis test to examine the effects of time of day and tidal stage as single factors and in combination, respectively, on the abundance of important taxa in the surf (SIEGEL, 1956). An index of relative abundance was also calculated for each sampling period for various taxonomic groups in order to examine temporal patterns in their abundance (ELLIOT, 1977).

RESULTS

505-μm net

An estimated total of 14,025 organisms was collected by use of this plankton net in 47 collections. A total of eight phyla were collected, with arthropods dominating in terms of numbers of individuals and taxa. Sixty-nine species of macroinvertebrates and 15 species of larval fishes were identified in these samples. Numbers of organisms varied greatly among samples, ranging from none to 6,592 individuals. The largest collection (estimated by subsample) represented 47.0% of the total catch.

Decapod larvae dominated the samples numerically, comprising 78.5% of the total catch (74.1% of the total were brachyuran larvae). Mysids ranked second in abundance, comprising 8.6% of the total, while amphipods (2.9%), isopods (2.5%), and hydromedusae (1.8%), followed in abundance. Amphipods were the most diverse taxonomic group collected, with 22 species identified.

The eleven most abundant and/or frequently collected (at least 50% occurrence in samples) macroinvertebrates comprised 85.6% of the total catch (Table 1). Megalopae of the fiddler crab genus *Uca* were an order of magnitude more numerous than any other macroinvertebrate collected. These megalopae were also the most frequently collected macroinvertebrate. Results of the Mann-Whitney U test indicate that significantly greater numbers of *Uca* were collected at night than during the day, although they were frequently taken during both day and night and high and low tides (Table 2).

Megalopae of the wharf crab, *Sesarma cinereum*, were the second most abundant macroinvertebrate collected. Like *Uca* megalopae, they were also collected in significantly greater abundance at night.

The mysid genus *Bowmaniella*, the third most abundant taxon, was represented chiefly by juveniles, although immature and mature individuals of both sexes (including brooding females) were also collected. Two species (*Bowmaniella brasiliensis*

Table 1. *Estimated number, percent of the total catch, and percent frequency of occurrence (F) of the most important macroinvertebrates collected in 47 samples with the 505-μm mesh plankton net at Folly Beach.*

Taxon or Stage	Est. no.	% of Total	F
Uca spp. megalopae (B)	8,399	59.9	79
Sesarma cinereum megalopae (B)	748	5.3	49
Bowmaniella spp. (M)	734	5.2	55
Portunid megalopae (B)	648	4.6	55
Metamysidopsis sp. (M)	428	3.1	55
Sphaeroma quadridentatum (I)	263	1.9	45
Palaemonetes spp. larvae (C)	224	1.6	68
Xanthid zoeae (B)	173	1.2	26
Labidocera aestiva (Ca)	142	1.0	55
Xanthid megalopae (B)	136	1.0	36
Phialidium spp. (Hy)	115	0.8	51

B = Brachyuran crab, M = Mysid, I = Isopod, C = Caridean shrimp, Ca = Calanoid copepod, Hy = Hydromedusa.

and *B. floridana*) were identified by examination of mature males, since females and immature males of these species are not readily separable at the species level (STUCK *et al.*, 1979). Significantly greater numbers of *Bowmaniella* spp. (93.1% of the total) were collected at night (Table 2).

In addition to *Uca* and *Sesarma*, other relatively abundant decapods included portunid megalopae, many of which were *Arenaeus cribrarius* (unpublished data), larvae and postlarvae of the caridean shrimp *Palaemonetes*, and zoeae and megalopae of xanthid crabs. Many larval decapods were represented by either early (I and II) or late stages (V-VII), with few intermediate stages being observed.

The mysid genus *Metamysidopsis*, the isopod *Sphaeroma quadridentatum*, the calanoid copepod *Labidocera aestiva*, and hydromedusae of the genus *Phialidium* were also numerous in these samples.

Organisms that are characteristic of sandy beaches, such as the mole crab, *Emerita talpoida*, and haustoriid amphipods were common in these samples but were not taken in great quantity. All such organisms combined comprised less than 5% of the total catch.

Eight of the eleven most important groups were apparently collected in significantly greater abundance at night than during the day (Table 2), whereas tidal stage had an apparently significant influence on only three groups. Results of the Kruskal-Wallis test reveal that time of day and tidal stage in combination influenced six groups. *Sphaeroma quadridentatum*, for example, was collected in significantlygreater abundance during high tide at night (79.1% of the total).

Examination of trends in abundance of larval decapods over the study period revealed that some peaks of abundance occurred near full or new moon phases, but these patterns were inconsistent. Abundance of larval decapods and mysids declined in the late fall, coinciding with falling water temperatures.

100-μm net

An estimated total of 242,335 organisms were found in 44 samples taken by this gear. Thirty-three taxa were identified, with copepods comprising over 86% of the total number. Seven species of copepods were identified, with undetermined species in three other genera and four other families also being noted. Meroplanktonic larvae of invertebrates were also numerous in these samples. Of the twelve most abundant and/or frequently occurring identification categories (taxa or developmental stages) collected in these samples, two species of calanoid copepods, *Acartia tonsa* and *Paracalanus crassirostris*, comprised over 56% of the total catch (Table 3).

Acartia tonsa ranked first in abundance, being 2.5X times more abundant than the next most abundant taxon. It was the second most frequently collected taxon, occurring in 42 of 44 collections. Like most taxa collected with the fine net, juvenile forms dominated the population of *Acartia tonsa* during the study period. Copepodid stages com-

Table 2. *Estimated number (N), percent frequency of occurrence (F), and results of statistical analyses of the most important macroinvertebrates collected by the 505-μm mesh plankton net, according to time of day and tidal stage.*

	Collection groups								Statistical results		
	High tide Day		High tide Night		Low tide Day		Low tide Night		Kruskal-Wallis	Mann-Whitney	
Number of Collections	13		11		12		11				
Taxon or Stage	N	F	N	F	N	F	N	F		D vs Nt	H vs L
Uca spp. megalopae (B)	64	77	1,018	82	64	75	7,253	82	NS	*	NS
Sesarma cinereum megalopae (B)	11	39	86	73	26	42	625	46	NS	*	NS
Bowmaniella spp. (M)	2	15	301	64	49	58	382	82	*	*	NS
Portunid megalopae (B)	8	31	189	73	21	33	430	91	*	*	NS
Metamysidopsis sp. (M)	58	46	188	82	34	33	148	64	NS	*	NS
Sphaeroma quadridentatum (I)	35	31	208	100	6	33	14	18	*	*	*
Palaemonetes spp. larvae (C)	21	46	18	64	114	83	71	82	*	NS	*
Xanthid zoeae (B)	0	0	18	9	119	50	36	46	*	NS	*
Labidocera aestiva (Ca)	17	46	38	64	13	42	74	73	NS	*	NS
Xanthid megalopae (B)	0	0	57	82	0	0	79	73	*	*	NS
Phialidium spp. (Hy)	25	39	38	46	25	67	27	55	NS	NS	NS

Kruskal-Wallis test detected differences among median numbers of collection groups. Mann-Whitney U test detected differences between median numbers collected during day (D) versus night (Nt) and high tide (H) versus low tide (L). B = Brachyuran crab, M = Mysid, I = Isopod, C = Caridean shrimp, CA = Calanoid copepod, Hy = Hydromedusa, NS = not significant, * = significant ($P \leq 0.05$).

Table 3. *Estimated number, percent of the total catch, and percent frequency of occurrence (F) of the most important zooplankters collected in 44 samples with the 100-μm mesh plankton net at Folly Beach.*

Taxon or Stage	Est. no.	% of Total	F
Acartia tonsa (Ca)	100,989	41.7	96
Paracalanus crassirostris (Ca)	36,774	15.2	98
Copepod nauplii	35,115	14.5	98
Lichomolgidae (Cy)	14,361	5.9	33
Brachyuran zoeae	7,088	2.9	27
Polychaete larvae	6,989	2.9	73
Calanoid copepodids	6,041	2.5	84
Oithona colcarva (Cy)	6,022	2.5	84
Cirriped nauplii	5,668	2.3	75
Pseudodiaptomus coronatus (Ca)	5,030	2.1	50
Nematoda	3,348	1.4	48
Cirriped cyprids	1,654	0.7	50

Ca = Calanoid copepod, Cy = Cyclopoid copepod.

prised 76.6%, adult males 12.6%, and adult females 10.8% of the total. Significantly greater numbers of *Acartia tonsa* were collected on low tide than on high tide, whereas time of day did not appear to greatly influence abundance (Table 4).

Paracalanus crassirostris ranked second in abundance and together with copepod nauplii, was the most frequently collected zooplankter. Significantly greater numbers (over 60% of the total) of *Paracalanus crassirostris* were collected during low tide than during high tide. Copepod nauplii constituted the third most abundant group. No significant effect of time of day or tidal stage could be detected on numbers of copepod nauplii collected.

Other abundant groups collected with the 100-μm net included undetermined species of the cyclopoid copepod family Lichomolgidae, which are generally symbiotic on sessile invertebrates (HUMES and STOCK, 1973), brachyuran crab zoeae (of which over 79% were identified as *Uca*), larval polychaetes, the cyclopoid copepod *Oithona colcarva*, naupliar and cyprid stages of barnacles, calanoid copepodids, the calanoid copepod *Pseudodiaptomus coronatus*, and nematodes. Unlike the dominant taxa collected with the 505-μm net, these organisms seemed to be more strongly influenced by tidal stage than time of day, since seven of the twelve most abundant groups were significantly more abundant at low tide, while none were significantly more abundant at high tide. Only *Pseudodiaptomus coronatus* was collected in significantly greater abundance at night, whereas time of day and tidal stage in combination significantly affected only one species, *Oithona colcarva*.

No clear trends in abundance with respect to other factors were observed for zooplankton collected with the 100-μm net, although abundance did decline in the late fall.

DISCUSSION

Plankton collections made in the surf zone were dominated numerically by larval decapods, mysids, and calanoid copepods. MCFARLAND (1963) found the plankton collected over a beach in Texas to be composed primarily of copepods, mysids, chaetog-

Table 4. *Estimated number (N), percent frequency of occurrence (F), and results of statistical analyses of the most important zooplankters collected by the 100-μm mesh plankton net, according to time of day and tidal stage.*

	Collection groups								Statistical results		
	High tide Day		High tide Night		Low tide Day		Low tide Night		Kruskal-Wallis	Mann-Whitney	
Number of Collections	12		9		12		11				
Taxon or Stage	N	F	N	F	N	F	N	F		D vs Nt	H vs L
Acartia tonsa (Ca)	12,960	83	13,950	100	36,651	100	37,428	100	NS	NS	*
Paracalanus crassirostris (Ca)	9,280	92	4,590	100	14,088	100	8,786	100	NS	NS	*
Copepod nauplii	7,980	92	5,160	100	8,777	100	13,198	100	NS	NS	NS
Lichomolgidae (Cy)	2,660	33	3,760	33	1,134	33	6,807	27	NS	NS	NS
Brachyuran zoeae	40	8	200	22	1,020	33	5,828	46	NS	NS	*
Polychaete larvae	1,480	58	580	78	1,480	75	3,449	82	NS	NS	NS
Calanoid copepodids	300	42	500	67	1,747	50	3,494	73	NS	NS	*
Oithona colcarva (Cy)	1,000	67	520	67	2,881	100	1,621	100	*	NS	*
Cirriped nauplii	820	58	980	78	2,087	92	1,781	73	NS	NS	*
Pseudodiaptomus coronatus (Ca)	220	25	1,270	44	1,020	58	2,520	73	NS	*	*
Nematoda	720	58	580	33	1,094	58	954	36	NS	NS	NS
Cirriped cyprids	260	42	380	78	820	50	194	36	NS	NS	NS

Kruskal-Wallis test detected differences among median numbers of collection groups. Mann-Whitney U test detected differences between median numbers collected during day (D) versus night (Nt) and high tide (H) versus low tide (L). Ca = Calanoid copepod, Cy = Cyclopoid copepod, NS = not significant, * = significant ($P \leq 0.05$).

naths, and larval decapods during the warmer months. Of the most abundant taxa collected at Folly Beach, few can be considered restricted to or originating from the sandy beach, but rather to be common components of estuarine or neritic oceanic waters of the Atlantic and Gulf coasts. Larval *Uca* spp., for example, have been shown to be extremely abundant in many estuaries and nearshore waters in this region during the summer (NICHOLS and KENEY, 1963; TAGATZ, 1968; WILLIAMS, 1971; SANDIFER, 1973; CHRISTY, 1982). Larvae of other decapods such as *Sesarma cinereum*, portunids, and *Palaemonetes* have also been collected in abundance in the region (TAGATZ, 1968; WILLIAMS and DUEBLER, 1968; DUDLEY and JUDY, 1971; STUCK and PERRY, 1981). The adults of many of these species reside in saltmarshes, and it appears that after spawning early larvae are carried out of estuaries (some passing through the surf zone) into nearshore oceanic waters to complete development and return to estuaries as late larvae or postlarvae (NICHOLS and KENEY, 1963; SANDIFER, 1975; CHRISTY, 1982; EPIFANIO *et al.*, 1984). Many species such as *Uca* may congregate in the surf zone and ride flooding tides into nearby inlets.

With the exception of lichomolgid copepods that were abundant at Folly Beach, the copepods observed in this study have been shown to be abundant in numerous estuaries on the Atlantic and Gulf coasts (DARNELL, 1958; WOODMANSEE, 1958; GRICE, 1960; LONSDALE and COULL, 1977; THAYER *et al.*, 1978; KNOTT, 1980; FULTON, 1984). To some extent, the meroplanktonic larvae (such as polychaetes) collected in this study may have originated from adult populations that reside in the beach sand, but species identification was not attempted for these groups.

The abundant mysids, *Bowmaniella* and *Metamysidopsis*, are commonly collected over sandy beaches, yet also occur in estuaries (WILLIAMS, 1972; STUCK *et al.*, 1979; MODLIN, 1982). Based on the presence of mature individuals, brooding females, and small juveniles it appears that some species of mysids maintain breeding populations in the surf zone during the warmer months.

At least one species, the isopod *Sphaeroma quadridentatum*, is a representative of the fouling community that is present on the rocky and wooden groins in the area; they may have been swept off the groins or may have actively moved into the surf zone, particularly during high tide at night (SCHULTZ, 1975).

Among factors examined in this study, both time of day and tidal stage appear to influence, at least indirectly, the abundance of many taxa in the surf zone, although these results were probably biased to some extent by use of small plankton nets. Larger macroinvertebrates were generally collected in greater abundance at night, whereas smaller zooplankters, such as calanoid copepods, were more abundant during low tide. This differential effect of time of day and tidal stage was also observed by SAMEOTO (1975, 1978) in Canada, who found mysids to be more abundant at night, whereas calanoid copepods were more influenced by tidal movements. This may be a reflection of the ability of larger macroinvertebrates to avoid sampling gear during daylight, or represent diurnal changes in activity (HOPKINS, 1965; CHRISTY, 1982). Planktivorous fishes collected concurrently with this study consumed more macroinvertebrates and fewer copepods at night than during the day, suggesting that brachyuran megalopae and mysids were more active in the water column at night (DELANCEY, 1984). The increased abundance of smaller zooplankton in the surf zone during low tide may be due to the action of ebbing tides concentrating these organisms in the surf, in addition to flushing them from nearby rivers.

Brachyuran zoeae collected at Folly Beach seemed to be more influenced by tidal movements, whereas catches of megalopae were more affected by time of day. This apparent shift in behavioral response to different stimuli (such as light level) with advancing age has been documented for the larvae of several brachyuran species in the laboratory (SULKIN, 1984). Such behavior may enable early zoeae to be rapidly transported out of estuaries in surface waters (presumably minimizing predation by planktivorous fishes), whereas megalopae may avoid some predation by being more active at night when reentering estuaries (CHRISTY, 1982; EPIFANIO *et al.*, 1984).

Other factors that may have had some influence on plankton catches at Folly Beach include lunar phase, as peaks of abundance of early decapod larvae may have been indicative of increased levels of spawning by adults in estuaries near new or full moon phases (DECOURSEY, 1981; CHRISTY, 1982), and water temperature, as catches of all groups declined in the fall. This seasonal decline in abundance may also be attributed to decreased availability of detritus and phytoplankton as food sources for zooplankton in the fall months (WOODMANSEE, 1958; MCFARLAND, 1963; KNOTT, 1980).

CONCLUSIONS

In conclusion, the surf zone at Folly Beach was shown to contain a variety of planktonic organisms and macroinvertebrates during the summer and fall of 1980. Many larvae collected in the surf apparently originated in nearby saltmarshes and estuaries, whereas the copepods and mysids are common components of estuarine and nearshore waters. Few taxa could be considered "true" beach fauna. In terms of faunal composition the beach sampled in this study does not represent a closed system, but appears to be strongly influenced by nearby habitats, such as rivers. This concurs with McLACHLAN *et al.* (1981) and LEBER (1982) who demonstrated that beach ecosystems can be influenced trophically by nearshore waters, subtidal areas, and terrestrial systems.

The abundance of many taxa in the surf is apparently influenced to some degree by the tidal stage and time of day. The findings contained in this study may be applicable to other beaches that are similarly situated near rivers, and are of similar physical characteristics.

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□ RESUMEN □

El zooplancton de la zona de rompientes de una playa en Carolina del Sur estuvo dominado durante el verano por decápodos larvales, mysidos y copépodos. Se recogieron asi mismo taxas en aguas del estuario y litorales, si bien también aparecieron abundantemente en la zona de rotura. La hora del dia aparentemente influye en la relativa abundancia de macroinvertebrados tales como brachyuran megalopae y miridos, recogidos con una red de 505 μm, mientras que el estado de la marea tiene una mayor influencia en pequeño zooplancton como los copépodos calanoides y larvas meroplanctónicas recogidos con una red de 100 μm.--*Miguel A. Losada, Universidad de Santander, Santander, Spain*

□ ZUSAMMENFASSUNG □

Während des Sommer bestehen die Zooplankton der Brandungzone eines Strandgebietes im Staat Süd-Karolina am meistens aus Dekapode, Myside und Kopepode. Die Taxa, die in der Brandungzone zahlreich sind, wurden auch in der Meeresbucht und dem Gewässer in der Nähe des Strands dieses biogeographischen Gebiets gewöhnlich gesammelt; sie werden ausserhalb der Strandumgebung auch zu finden. Die Tageszeit schien eine Einwirkung über die relative Nummer solcher wirbelosen Tiere wie brachiuranische Megalopae und Myside (die mit einem 505-μm Netz gefangen wurden) zu haben; andererseits haben die Ebbe und Flut eine grössere Einwirkung über kleinere Zooplankton wie kalanoide Kopepode und meroplanktonische Larven (die mit einem 100-μm Netz gefangen wurden).--*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*