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Fauna of Polyhaline Subtidal Marsh Creeks in Southern New Jersey: Composition, Abundance and Biomass[1]

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ABSTRACT: Three polyhaline subtidal marsh creeks in southern New Jersey were sampled with weirs and seines to determine seasonal patterns of utilization by fishes and macroinvertebrates. Sixty-four species of fish, 13 invertebrates, and the diamondback terrapin were collected in 69 weir and 57 seine samples from April to November 1988 and April to October 1989. Average abundance, biomass, and faunal composition were strongly seasonal with greatest abundances during spring and summer, and peaks in May and August. Sixteen species were represented by all life-history stages, including the five most important species by combined ranks of percent frequency, mean abundance, and mean biomass. These five species were important during spring, summer, and fall and included the fishes *Menidia menidia* and *Fundulus heteroclitus*, the shrimps *Palaemonetes vulgaris* and *Crangon septemspinosa*, and the crab *Callinectes sapidus*. In addition, there were distinct seasonal assemblages of other species which utilized the creeks primarily as young-of-the-year. Important species in spring collections included the fishes *Clupea harengus*, *Alosa aestivalis*, *Alosa pseudoharengus*, *Pollachius virens*, and *Urophycis regia*, while *Leiostomus xanthurus*, *Pomatomus saltatrix*, *Paralichthys dentatus*, *Mugil curema*, and *Strongylura marina* were important in the summer. Fall samples were best characterized by declining abundances of summer species. Thus, subtidal marsh creeks in southern New Jersey appear to be valuable nurseries for a variety of species which spawn over the continental shelf, as well as one of the most important habitats for estuarine residents.

Introduction

Numerous investigators have suggested that salt marshes are critically important nurseries for marine fishes and invertebrates (Gunter 1956, 1961; Nixon and Oviatt 1973; Subrahmanyam and Drake 1975; Daiber 1977; Weinstein 1979; Boesch and Turner 1984; Currin et al. 1984). However, most salt marsh studies have concentrated on a single species, or species group, and few have documented the overall faunal composition. Hence, only limited data to evaluate the nursery function of salt marshes are available. Studies of salt marsh communities in the northeastern United States are particularly lacking, although research activity has increased in the last decade (Nixon and Oviatt 1973; Daiber 1977; Werme 1981; Nixon 1982; Talbot and Able 1984; Talbot et al. 1986; Teal 1986; Sogard and Able 1991).

The salt marsh may be divided into several important contiguous subhabitats: 1) irregularly flooded marsh surface, including marsh pools, 2) regularly flooded intertidal marsh surface, 3) intertidal marsh creek, 4) subtidal marsh creek (*sensu* Hackney et al. 1976; Hackney 1977), and 5) bay-marsh fringe (i.e., shallow bay areas directly bordering the salt marsh).

Because tidal marsh creeks are a primary interface between the salt marsh and open estuarine waters, and they provide fish access to the marsh, numerous researchers have pointed out the need for research into the role of marsh creeks as fish habitat and in energy export from the marsh (Nixon and Oviatt 1973; Subrahmanyam and Drake 1975; Bozeman and Dean 1980; Weinstein et al. 1980; Currin et al. 1984; Weinstein 1984; Weinstein et al. 1984). Consequently, subtidal creek communities have been the most extensively examined among salt marsh habitats. These studies have been conducted in several types of marshes in several geographic regions: 1) Mangrove marshes in Australia (Blaber et al. 1985; Blaber 1986); 2) *Juncus* marshes in Florida (Subrahmanyam and Drake 1975; Subrahmanyam and Coultas 1980) and Mississippi (Hackney 1977; Hackney and de la Cruz 1981); 3) *Spartina* marshes in Georgia (Hackney and Burbanck 1976; Hackney et al. 1976), Virginia (Richards and Castagna 1970; Smith et al.

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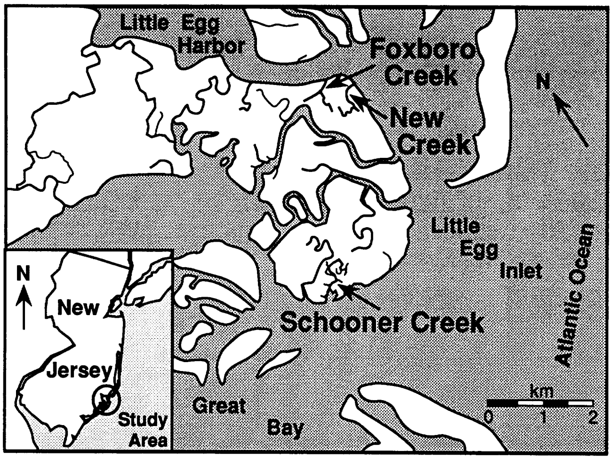

Fig. 1. Great Bay–Little Egg Harbor estuarine complex and study creeks in southern New Jersey.

1984; Cowan and Birdsong 1985), New Jersey (Sogard and Able 1991), and Massachusetts (Werme 1981; Teal 1985); and 4) mixed *Juncus* and *Spartina* marshes in Georgia (Dahlberg and Odum 1970; Dahlberg 1972) and North Carolina (Keup and Bayless 1964; Weinstein 1979; Weinstein et al. 1980). Most of these subtidal marsh creek studies were concentrated in the southeastern United States, while studies in the northeast have been limited (Werme 1981; Teal 1985; Sogard and Able 1991).

This study is part of a larger effort to describe the community structure and nursery function of the marsh surface, intertidal creek, and subtidal creek subhabitats within a representative salt marsh system in the northeastern United States. The specific goal was to describe the faunal composition and seasonal abundance patterns of polyhaline marsh creeks in a southern New Jersey salt marsh.

Materials and Methods

Study Sites

The study was conducted within the Great Bay-Little Egg Harbor estuarine complex in southern New Jersey (Fig. 1). The unaltered marsh in the study area is dominated by the grasses *Spartina alterniflora* (short form) and *Spartina patens* and is characteristic of salt marshes in the northeastern United States (Chapman 1960). Tidal creeks are abundant within the study area (Fig. 1), with at least 34 primary creeks (opening directly into the bay) and an additional 95 subtidal and intertidal tributaries. The three study creeks were of similar depths (0.5–1.0 m mean low tide depth at the mouth), lengths (approximately 1.0 km), and extent (23–26 ha subtidal areas), and were closed systems that received fresh water only through local runoff after rainfall.

Sampling Gear and Techniques

Sampling was conducted within three subtidal marsh creeks (Schooner, Foxboro, and New creeks) over a 3- to 5-d period (sample week) approximately fortnightly from April to November 1988 and April to October 1989 (Fig. 1, Table 1). During 1988 consecutive day and night tides were sampled from Schooner and Foxboro creeks, while night tides were sampled from all three creeks during 1989 (Table 1). Day and night tides were those in which at least the last two hours of flood occurred after sunrise and sunset, respectively.

Fishes, macroinvertebrates, and turtles were collected from the subtidal creeks using a weir system developed specifically for use in tidal marsh creeks (Fig. 2). The weir was set to block off the mouth of a creek at high tide to capture fishes leaving the creek with the ebb tide. Two wing nets (15.2 m long by 3.0 m high) were used to block off the

TABLE 1. Sampling effort by year, gear, and month. Numbers in parentheses indicate additional samples where the abundances of some species were not quantified.

Month	1988						1989		
	Day			Night			Night		
	Weir	Seine	Number of Creeks Sampled	Weir	Seine	Number of Creeks Sampled	Weir	Seine	Number of Creeks Sampled
April	—	—	0	(2)	—	1	3	1	2
May	1 (1)	—	1	1	—	1	3	3	2
June	1 (1)	(1)	2	(2)	(1)	1	3	3	2
July	5 (1)	2 (2)	2	6 (1)	5 (1)	2	6	6	3
August	3 (1)	4	2	2 (2)	2	2	5 (1)	6	3
September	3	4	2	2 (2)	4	2	5	5	3
October	2	2	1	2	2	1	1	1	1
November	(1)	1	1	—	1	1	—	—	0
Totals	15 (5)	13 (3)	2	13 (9)	14 (2)	2	26 (1)	25	3

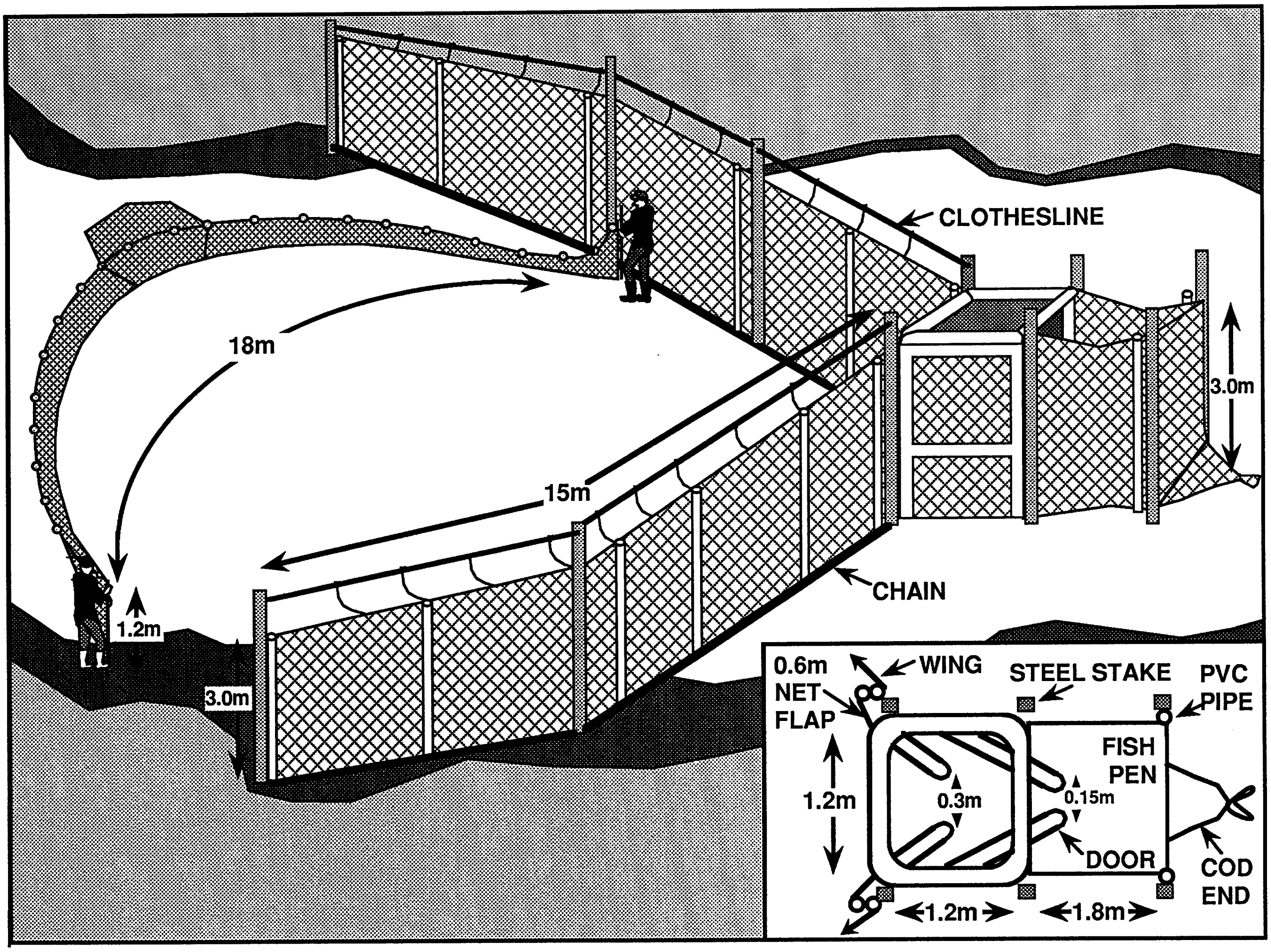

Fig. 2. Diagram of the fish weir and seine methodology (not to scale). Inset: schematic illustration of the weir from an overhead view.

creek and to lead fish into the rectangular weir (Fig. 2). The front of the weir consisted of a polyvinyl chloride (PVC) pipe frame (38 mm diameter) supporting two sets of doors leading into a large fish pen. All netting was 6.4 mm square-mesh nylon. Ropes on the steel support poles, and a 6.4 mm chain lining the wings along their entire length, held the weir and wings down to the substrate. Deployment of the weir was begun about 30 min before slack high tide and was completed within one hour.

Once set, the weir was allowed to fish over the entire ebb tide. At low tide a removable sliding panel was used to close off the front of the weir to prevent fish from entering the weir as a result of seining operations. The weir was hauled by raising it on ropes above the water line and removing the fish through the cod-end (Fig. 2 inset). The weir and wings were removed after each collection so that the steel supporting poles were the only permanent structures remaining in the creeks.

Because the weir is a passive gear which primarily captures animals moving with the tide, seine sampling (Fig. 2) was also conducted within the creeks to capture less mobile forms and species/individuals which actively avoid the weir and remain within the creeks. Seine samples were collected in the creek above the weir after the weir was closed off at low tide. During 1988 a block net was stretched across the creek at the head of the wings to contain fishes within the wing area. Then one haul with a bag seine (6.1 m long by 1.2 m high with 3.2 mm mesh) was made inside the wing area. Additional seine hauls were made on an irregular basis to collect length-frequency data on species of special interest. During 1989, seining operations were standardized to a single haul of a larger bag seine without the use of a block net. The seine was large enough (18.3 m long by 1.2 m high with 6.4 mm mesh) to allow the entire area (approximately 100 m^2) enclosed by the wings to be swept with a single "purse" of the seine.

Sample Analysis

A total of 69 weir and 57 seine samples was collected during the study; some species were not quantified in 15 weir and 5 seine samples (Table 1). Catches from weir and seine samples were put on ice and transported back to the laboratory for sorting and identification. However, turtles (*Malaclemys terrapin*) and horseshoe crabs (*Limulus polyphemus*) were immediately culled from the samples and released. For small samples, all species of fishes and invertebrates were sorted and enumerated. For large samples, the entire sample was sorted once to enumerate economically important species, species of special interest (e.g., *Sardinella aurita, Chaetodon ocellatus*), and generally any species present in low abundance which might be missed in subsampling. After the initial sort, all species were enumerated in a subsample (10–50% by wet weight of the sample). Infrequently much smaller subsamples by percent weight were taken. Total biomass for each species was recorded, except for turtles and horseshoe crabs, which were estimated by multiplying the number collected by the average weight of individuals from a subsample of 16 turtles and 116 horseshoe crabs. Nomenclature and taxonomy follow standard references for fishes (Robins et al. 1980) and invertebrates (Gosner 1979; Williams 1984) of the eastern United States.

Standard lengths (SL) measured to the nearest millimeter (or in some cases total lengths (TL), or disc width (DW)) of a subsample of up to 100 individuals of each fish species were measured. The carapace length (CL) of *M. terrapin* was measured in the field. Lengths of invertebrates were not taken, so average wet weight (g) was used as a measure of invertebrate size. Average invertebrate weights (sizes) were obtained by dividing the total wet weight of a subsample by the number of individuals in the subsample for each collection and then calculating a mean for all collections.

Water depth, air and water temperature, and salinity were recorded at high tide after the weir had been set and at low tide just prior to hauling the gear. Since high and low tide water temperatures were highly correlated (Rountree and Able personal observation), the mean of the high and low tide water temperature for each sample was examined for temporal trends.

Mean abundance for each species was calculated for weir and seine samples separately, while fish length and invertebrate size data were pooled from both gears. Abundance and size data were used to classify the life-history stages of each species. Because many of the collections made in 1988 did not quantify the abundance of all species, collections from 1989 were emphasized in the description of faunal composition and seasonality. To identify the dominant species utilizing the subtidal creeks, the paired weir and seine samples from 1989 were pooled into combined gear collections (n = 24) and the percent frequency, mean abundance, mean biomass, and rank of these variables were determined for all species. All species occurring in at least 50% of the samples plus any additional species which were ranked within the top ten by abundance or biomass were considered dominant. An index of overall species importance was calculated for each of the 20 species selected by the above criterion, by summing the three rank scores for each species and then ranking the sum over all species.

Dominant species within spring (April–June), summer (July–September), and fall (October–December) seasons were determined for each gear with data combined from night samples from 1988 and 1989 (n = 39 weir and 39 seine samples). Samples which were not fully quantified were excluded from this analysis. Because of sampling bias between weir and seine, and differences in seine methods between years, the data were standardized to mean percent relative abundance per sample.

Annual variation in the ten most abundant species collected in night weir samples during the summers of 1988 and 1989 was tested with an Analysis of Variance (ANOVA) with year, month, and creek class variables based on log-transformed (x + 0.5) abundances. Annual variation of the abundances of seine-collected fauna could not be tested because of differences in seine gear and techniques between years.

Results

Physical Characteristics

Creek water temperature averaged 19°C (±0.7 SE) and ranged from 8°C to 28°C (Table 2). Night water temperature was lowest in the spring and peaked in August (Fig. 3A). Salinity ranged from 23‰ to 33‰ and averaged 29‰ (±0.3 SE) (Table 2). No seasonal salinity trends were apparent, but salinity was slightly lower during 1989 than 1988, with means of 28‰ (±0.3 SE; range = 23–30) and 31‰ (±0.2 SE; range = 30–33), respectively. Mean tidal depth range was 0.8 m (±0.04 SE, Table 2).

Total Abundance and Biomass

An average of 15,388 (±6,733 SE) animals was collected per combined gear sample during night tides in 1988 and 1989 (n = 39). Overall abundance of the subtidal creek fauna was strongly seasonal (Fig. 3). Trends for both years and gears were similar, with major peaks occurring in late July and

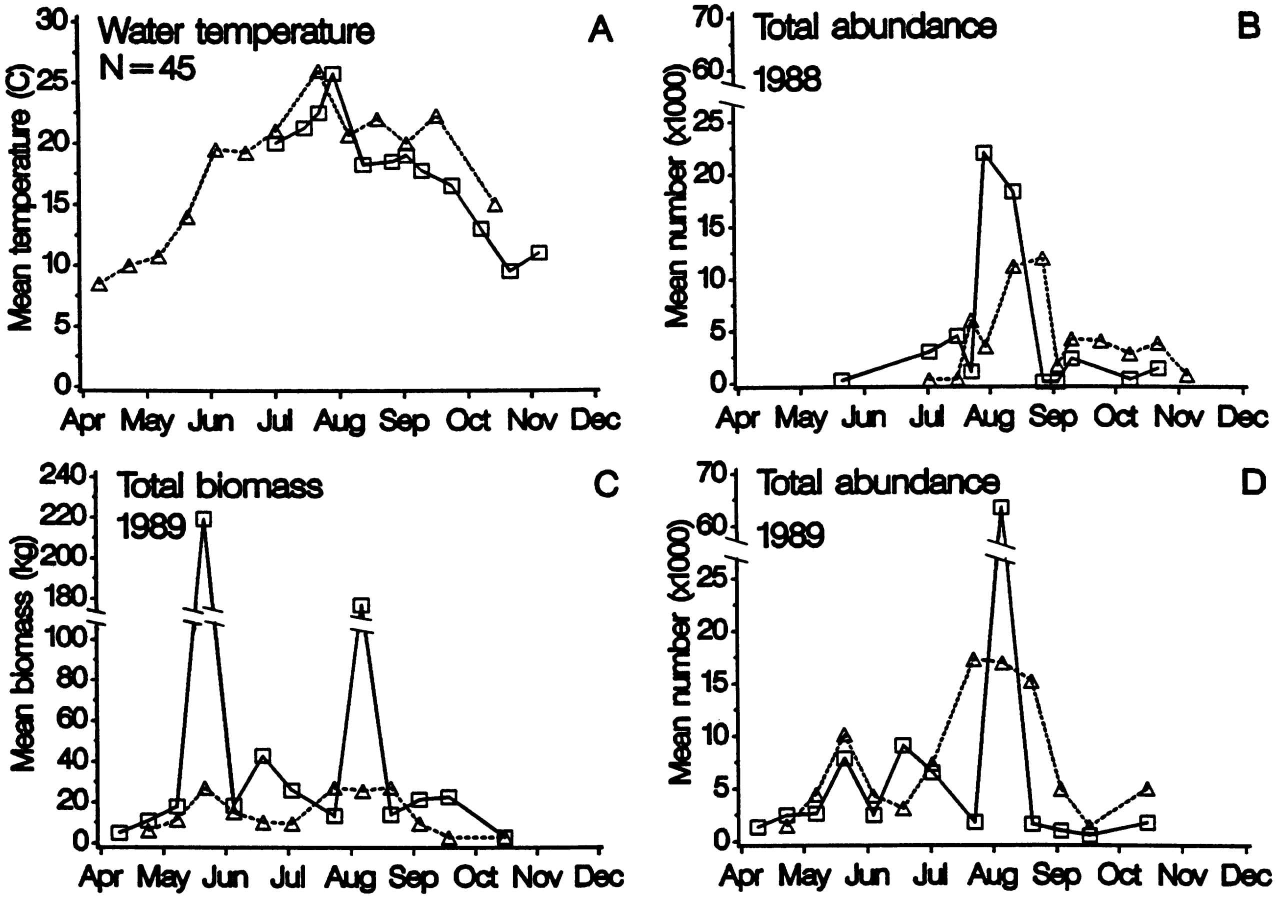

Fig. 3. Average weekly temperature, faunal abundance, and biomass in the study creeks for night samples: A) Water temperature by year (1988 = squares, n = 18), (1989 = triangles, n = 27); B) Total abundance by gear in 1988 (weir = squares, n = 13, and seine = triangles, n = 14); C) Total biomass by gear in 1989 (n = 26, 25, respectively); D) Total abundance by gear in 1989 (n = 26, 25, respectively). Note scale breaks in B–D.

August when water temperatures were greatest. Smaller peaks occurred for both gears in late May, and again for weir samples in late June and early July during 1989, the only year with adequate sampling prior to July. Abundances in seine samples exhibited some tendency to rise again in the fall after the sharp decline in early September (Fig. 3).

Total biomass averaged 62 (±22 SE) kg per sample for combined gear collections during 1989 night tides (n = 24). Total biomass exhibited a strikingly similar seasonal pattern to total abundance during 1989 (Fig. 3) except for the extremely high mean in late May weir samples. The May peak was due to collections of large numbers of mated pairs of adult horseshoe crab, *Limulus polyphemus,* while the August peak was due to large catches of the fish *Menidia menidia.*

Faunal Composition

Approximately 600,000 fishes of 64 species representing 36 families were collected within the sub-

TABLE 2. Mean temperature, salinity, and water depth at the mouth of the subtidal creeks for 64 weir samples taken July–November 1988 and April–October 1989 (tidal range = high tide–low tide).

Factor	Seasonal Range	Mean	SE	n
High tide				
Air temperature	3.0–32.0	18.6	0.9	61
Water temperature	8.0–28.0	18.3	0.6	62
Salinity	24–32	30.0	0.2	61
Depth	0.8–2.0	1.4	0.05	60
Low tide				
Air temperature	3.0–31.0	17.6	0.8	61
Water temperature	8.0–28.0	18.8	0.7	64
Salinity	23–33	29.2	0.3	61
Depth	0.2–1.2	0.7	0.03	57
Tidal range				
Air temperature	−13–+8	0.6	0.5	59
Water temperature	−8–+6	−1.1	0.4	60
Salinity	−2–+7	+0.8	0.2	59
Depth	0.3–1.4	0.8	0.03	57

TABLE 3. Abundance and size (length for fishes and turtles, weight for invertebrates) summary statistics of macrofauna collected within three subtidal marsh creeks during 1988 (day and night) and 1989 (night). Mean abundance (SE) and total number (sum) for each species were determined for each gear, while mean sizes (SE) were determined from pooled data. The fifth and ninety-fifth percentiles (P5–P95) for size were determined and used to classify the dominant life history stages for each species (yoy = young-of-year, juv = subadult, adu = adult, all = all stages).

Group	Abundance				Size			
	Weir		Seine					
Species	Mean (SE)	Sum	Mean (SE)	Sum	Mean (SE)	P5–P95	n	Life Stages
Invertebrates								
Illex illecebrosus	0.1 (0.1)	8	0.3 (0.3)	15	103 (33) g	3–140	4	yoy, adu
Limulus polyphemus	3.2 (1.9)	206	0	0	1,624 (82) g	1,261–1,982	18	adu
Palaemonetes vulgaris	414 (194)	24,849	790 (107)	41,888	0.4 (0.04) g	0.2–0.6	82	all
Crangon septemspinosa	183 (86)	11,180	145 (28)	7,850	0.3 (0.02) g	0.1–0.5	66	all
Penaeus aztecus	0.01 (0.01)	1	0.02 (0.02)	1	4.2 (2.4) g	2–7	2	yoy
Pagurus longicarpus	1.9 (0.9)	118	1.3 (0.5)	69	0.3 (0.03) g	0.2–0.7	22	all
Callinectes sapidus	20 (4)	1,201	24 (5)	1,304	35 (5) g	0.1–141	102	all
Callinectes similis	0.1 (0.1)	6	0.04 (0.04)	2	3 (0.9) g	0.3–71	5	yoy
Carcinus maenus	0.4 (0.2)	25	0.5 (0.2)	26	39 (10) g	15–71	5	juv, adu
Ovalipes ocellatus	4 (2)	246	0.1 (0.1)	6	5 (2.6) g	0.1–32	12	yoy, adu
Cancer irroratus	0.2 (0.1)	11	0	0	26 (13) g	13–39	2	yoy
Libinia dubia	0.1 (0.1)	4	0	0	95 (26) g	68–121	2	adu
Libinia emarginata	0.1 (0.04)	4	0	0	114 (44) g	70–201	3	adu
Fishes								
Mustelus canis	1.6 (0.7)	110	0.3 (0.2)	17	410 (5) TL	320–493	113	yoy
Raja eglanteria	0.01 (0.01)	1	0	0	695 DW	—	1	adu
Anguilla rostrata	1.0 (0.3)	66	0.6 (0.2)	32	417 (14) TL	199–618	103	juv, adu
Conger oceanicus	0.01 (0.01)	1	0.02 (0.02)	1	295 (36) TL	223–331	3	juv
Alosa aestivalis	2.2 (1.8)	149	0.5 (0.3)	26	91 (0.6) SL	80–101	162	yoy
Alosa mediocris	0	0	0.02 (0.02)	1	290 SL	—	1	adu
Alosa pseudoharengus	0.7 (0.3)	48	0.2 (0.1)	11	87 (2) SL	59–111	64	yoy
Alosa sapidissima	0.04 (0.04)	3	0.2 (0.2)	10	115 (13) SL	95–154	4	yoy
Brevoortia tyrannus	2.2 (0.8)	150	0.9 (0.5)	51	54 (2) SL	33–101	167	yoy
Clupea harengus	26 (25)	1,813	113 (112)	6,444	62 (0.4) SL	51–75	329	yoy
Sardinella aurita	1.0 (0.4)	70	0.2 (0.1)	9	45 (0.8) SL	35–56	62	yoy
Anchoa hepsetus	12 (11)	784	0.02 (0.02)	1	77 (0.9) TL	67–84	50	adu
Anchoa mitchilli	161 (55)	9,824	23 (9)	1,243	65 (0.3) TL	40–82	1,441	all
Synodus foetens	0	0	0.02 (0.02)	1	89 SL	—	1	yoy
Opsanus tau	0.2 (0.1)	15	0.5 (0.2)	30	89 (6) SL	36–165	50	all
Pollachius virens	2.8 (1.5)	192	0.02 (0.02)	1	63 (2) SL	42–92	122	yoy
Merluccius bilinearis	0.01 (0.01)	1	0	0	72 SL	—	1	yoy
Urophycis sp.	0	0	0.02 (0.02)	1	49 SL	—	1	yoy
Urophycis regia	0.6 (0.3)	39	0	0	144 (4) SL	96–193	39	yoy
Strongylura marina	5 (1)	347	3 (2)	180	140 (2) BL	76–218	545	all
Cyprinodon variegatus	1.5 (0.6)	97	21 (14)	1,110	35 (0.4) TL	28–43	212	all
Fundulus heteroclitus	211 (82)	12,432	546 (220)	28,935	56 (0.3) TL	34–84	2,788	all
Fundulus majalis	6 (2)	372	31 (11)	1,669	72 (1.2) TL	36–129	634	all
Lucania parva	0.05 (0.03)	3	1.1 (0.9)	106	30 (0.6)TL	25–36	44	adu
Membras martinica	0.02 (0.02)	1	0	0	98 TL	—	1	adu
Menidia beryllina	0.4 (0.3)	23	0.2 (0.2)	11	52 (4) TL	33–61	23	all
Menidia menidia	5,080 (3,336)	289,568	4,198 (1,171)	222,489	68 (0.2) TL	29–103	9,620	all
Apeltes quadracus	0.2 (0.1)	15	0	0	42 (1.5) SL	35–55	15	adu
Gasterosteus aculeatus	2.4 (1.6)	168	0.02 (0.02)	1	52 (0.7) SL	22–60	170	yoy, adu
Hippocampus erectus	0.3 (0.2)	21	0	0	1.4 (0.1) g	1–1.9	9	adu
Syngnathus fuscus	0.1 (0.04)	10	5.5 (1.4)	302	109 (2) SL	70–163	208	all
Morone americanus	0.03 (0.02)	2	0	0	273 (3) SL	270–276	2	adu
Centropristis striata	0.06 (0.03)	4	0.02 (0.02)	1	67 (13) SL	42–115	5	yoy, juv
Pomatomus saltatrix	21 (4)	1,441	2.8 (0.7)	158	97 (1) SL	48–168	1,699	yoy
Rachycentron canadum	0.01 (0.01)	1	0.02 (0.02)	1	63 (8) SL	55–71	2	yoy
Caranx hippos	0.9 (0.4)	61	0.3 (0.2)	19	86 (4) SL	30–129	80	yoy
Selene vomer	0.06 (0.04)	4	0	0	33 (5) SL	28–47	4	yoy
Trachinotus falcatus	0.03 (0.03)	2	0	0	20 (1) SL	19–21	2	yoy
Lutjanus griseus	0	0	0.1 (0.1)	6	31 (1) SL	26–35	6	yoy
Unknown gerreid	0	0	0.1 (0.04)	4	35 (4) SL	23–50	7	yoy
Stenotomus chrysops	0.04 (0.03)	3	0	0	99 (4) SL	89–113	6	yoy
Bairdiella chrysoura	0.1 (0.1)	8	0.1 (0.1)	6	84 (4) SL	55–102	14	yoy
Cynoscion regalis	0.6 (0.2)	43	0	0	389 (18) SL	139–521	41	yoy, adu

TABLE 3. Continued.

Group Species	Abundance				Size			Life Stages
	Weir		Seine					
	Mean (SE)	Sum	Mean (SE)	Sum	Mean (SE)	P5–P95	n	
Leiostomus xanthurus	169 (46)	11,654	18 (6)	1,006	68 (0.5) SL	40–98	2,889	yoy
Menticirrhus saxatilis	0.04 (0.03)	3	0	0	273 (10) SL	257–290	3	adu
Chaetodon ocellatus	0.01 (0.01)	1	0	0	15 SL	—	1	yoy
Tautoga onitis	0.1 (0.05)	10	0.5 (0.2)	30	58 (3) SL	31–90	45	yoy
Mugil cephalus	0.03 (0.02)	2	0.2 (0.2)	12	113 (7) SL	68–174	15	yoy
Mugil curema	7.8 (3.5)	538	29 (19)	1,580	72 (1) SL	27–109	1,007	yoy
Sphyraena borealis	2.6 (1.6)	180	6.6 (5.2)	378	103 (1) SL	69–142	291	yoy
Ammodytes americanus	0.01 (0.01)	1	0	0	95 SL	—	1	adu
Gobionellus boleosoma	0	0	0.1 (0.1)	6	29 (3) SL	14–35	6	all
Gobiosoma bosci	0.1 (0.04)	6	21 (5)	1,180	21 (0.3) SL	12–33	553	all
Scomberomorus sp.	0.03 (0.02)	2	0	0	48 (5) SL	43–53	2	yoy
Prinotus evolans	0.1 (0.1)	10	0.1 (0.04)	4	132 (19) SL	16–245	17	all
Paralichthys dentatus	5.2 (1.5)	359	0.04 (0.02)	2	206 (3) SL	165–250	289	yoy
Scophthalmus aquosus	0.01 (0.01)	1	0	0	23 SL	—	1	yoy
Pseudopleuronectes americanus	1.5 (0.3)	104	2 (0.5)	112	78 (2) SL	56–98	305	yoy
Trinectes maculatus	0.04 (0.3)	3	0	0	127 (10) SL	117–136	2	adu
Aluterus spp.	0.1 (0.1)	7	0	0	53 (6) SL	38–77	7	yoy
Monacanthus hispidus	0.1 (0.1)	7	0.02 (0.02)	1	28 (5) SL	15–53	8	yoy
Sphoeroides maculatus	0.1 (0.05)	5	0.02 (0.02)	1	81 (7) SL	55–110	8	yoy
Chilomycterus schoepfi	0.03 (0.02)	2	0	0	35 SL	—	1	yoy
Turtles								
Malaclemys terrapin	3.3 (0.5)	228	0.1 (0.1)	7	159 (2) CL	115–203	226	juv, adu
Total invertebrates	663 (286)	27,786	965 (123)	51,161				
Total fishes	5,767 (3,333)	328,711	5,041 (1,182)	267,175				
Total animals	6,654 (3,470)	365,961	6,006 (1,160)	318,343				

tidal creeks during the study (Table 3). Nearly 80,000 invertebrates comprising 13 species were dominated by decapod crustaceans. Two hundred and twenty-six turtles, *Malaclemys terrapin,* were also collected. The total number of species per combined gear sample ranged from 14 to 27 and averaged 19.6 (±0.5 SE) during night tides (n = 39).

Twenty of the 70 species collected during 1989 were considered most representative of the subtidal marsh creek fauna based on combined estimates of percent frequency, mean abundance, and mean biomass for combined gear samples (Table 4). *Menidia menidia* was the top ranked species by all three measures and was ranked first in overall importance. Another fish *Fundulus heteroclitus* was the second most important species, followed by the shrimp *Palaemonetes vulgaris* and the crab *Callinectes sapidus.* The fish *Clupea harengus* was highly ranked by abundance and biomass, but occurred infrequently, while the horseshoe crab *Limulus polyphemus* and fish *Cynoscion regalis* were highly ranked only for biomass. The turtle, *M. terrapin,* occurred frequently and was the third ranked species by biomass.

Most of the sixteen species represented by all life-history stages from early young-of-the-year to adults were commonly collected (Table 3), among those were the five most important species during 1989 (Table 4). An even greater component of the fauna (38 species) occurred primarily or exclusively as young-of-the-year (YOY), twelve of which were common and apparently use the creeks as nurseries (common >1.0 sample^{-1}, Table 3). Six of these were the fishes *Pomatomus saltatrix, Mugil curema, Paralichthys dentatus, Pseudopleuronectes americanus,* and *Mustelus canis,* which were among the 20 most representative species for 1989 (Table 4). Other notable fishes occurring primarily as YOY included *Pollachius virens, Alosa aestivalis, Brevoortia tyrannus, Sardinella aurita, Leiostomus xanthurus,* and *Sphyraena borealis.* A smaller component of the fauna (14 species) occurred exclusively as adults, three of which were common (*Limulus polyphemus,* and the fishes *Anchoa hepsetus* and *Lucania parva*). Additionally, the fishes *Anchoa mitchilli, Gasterosteus aculeatus,* and *Cynoscion regalis,* and turtle *Malaclemys terrapin* occurred primarily as adults (Table 3).

Seasonality

Although many species occurred throughout the spring, summer, and fall study period, distinct seasonal faunal assemblages in the creeks were identified. The fishes *Menidia menidia* and *Fundulus heteroclitus* and the shrimp *Palaemonetes vulgaris* were among the dominant species for all seasons and both gears, while the shrimp *Crangon septemspinosa*

TABLE 4. Summary statistics and overall rank for all species occurring in at least 50% of the samples and any additional species ranked within the top ten by abundance or biomass (g) for combined gear collections made during 1989 (n = 24). Overall rank was obtained by ranking the sum of the ranks of percent frequency, mean number, and mean biomass for each species.

Species	Percent Frequency	Rank	Mean Number (SE)	Rank	Mean Biomass (SE)	Rank	Overall Rank
Palaemonetes vulgaris	100	1	1,256 (456)	3	548 (244)	10	3
Crangon septemspinosa	100	1	562 (215)	4	251 (113)	16	5
Fundulus heteroclitus	100	1	1,418 (561)	2	2,971 (937)	4	2
Menidia menidia	100	1	15,266 (9,576)	1	33,018 (20,870)	1	1
Callinectes sapidus	96	5	61 (10)	9	1,763 (392)	6	4
Pomatomus saltatrix	83	6	28 (9)	11	1,254 (554)	8	6
Mugil curema	79	7	79 (51)	7	448 (161)	12	7
Anchoa mitchilli	75	8	164 (77)	6	299 (116)	15	9
Fundulus majalis	75	8	67 (23)	8	381 (130)	13	9
Malaclemys terrapin	75	8	5 (1)	17	4,354 (13)	3	8
Ovalipes ocellatus	67	11	9 (4)	14	72 (22)	20	15
Strongylura marina	67	11	14 (5)	12	300 (119)	14	12
Pseudopleuronectes americanus	63	13	3 (1)	20	29 (12)	27	19
Paralichthys dentatus	54	14	12 (4)	13	1,918 (588)	5	11
Mustelus canis	50	15	2 (1)	23	470 (184)	11	16
Cyprinodon variegatus	50	15	46 (33)	10	31 (22)	26	17
Syngnathus fuscus	50	15	1 (0)	29	2 (0)	43	20
Limulus polyphemus	29	23	7 (5)	16	11,252 (7,834)	2	14
Cynoscion regalis	33	21	1 (0)	28	1,462 (509)	7	18
Clupea harengus	25	24	340 (336)	5	882 (876)	9	13

was dominant during all seasons except for weir samples in the fall (Fig. 4). The fish *Anchoa mitchilli* was important in all seasons in weir samples, but was not important in any season for seine samples. Except for these dominant species, the spring fauna was otherwise strikingly different from summer and fall faunas (Fig. 4). Fishes such as *Alosa aestivalis, Alosa pseudoharengus,* and *Clupea harengus* were prevalent in the spring, as were *Gasterosteus aculeatus, Pollachius virens,* and *Urophycis regia* (all YOY except *G. aculeatus,* Table 3). Summer collections contained a diverse assemblage of quite different species, including YOY *Pomatomus saltatrix, Paralichthys dentatus, Strongylura marina,* and *Mugil curema,* while fall samples were best characterized by declining abundances of summer species (Figs. 4 and 5). A few faunal differences did appear in the fall when YOY crabs *Ovalipes ocellatus,* shrimp *Palaemonetes vulgaris,* and fishes *Fundulus heteroclitus, Fundulus majalis, Anchoa mitchilli,* and *Menidia beryllina* became briefly more abundant.

While many species contributed to the spring and summer peaks in total abundance, a few were clearly responsible for the magnitude of the peaks. The major summer peak was due to a large influx of YOY of the fish *Menidia menidia* in July (seine) and to their subsequent migration out of the creeks when they reached a size of 60–80 mm TL in early

TABLE 5. Annual variation in the mean (SE) abundances of the ten most abundant species collected in night weir samples during the summers (July–September) of 1988 (n = 11–15) and 1989 (n = 11–12).

Species	Mean (SE) 1988	Mean (SE) 1989	ANOVA
Menidia menidia	5,126 (3,062)	17,718 (17,079)	ns
Palaemonetes vulgaris	544 (376)	597 (526)	ns
Leiostomus xanthurus[a]	433 (223)	8 (4)	***[b]
Anchoa mitchilli	420 (223)	51 (29)	ns
Fundulus heteroclitus	291 (204)	145 (112)	ns
Pomatomus saltatrix	17 (4)	51 (15)	*[c]
Crangon septemspinosa	17 (14)	221 (216)	ns
Mugil curema	11 (7)	29 (7)	ns
Callinectes sapidus	6 (3)	46 (12)	***[b]
Strongylura marina	5 (2)	17 (7)	ns
Paralichthys dentatus[a]	0.6 (0.3)	26 (6)	***[b]

[a] Not in the top ten for both years.
[b] $p < 0.001$.
[c] $p < 0.05$.

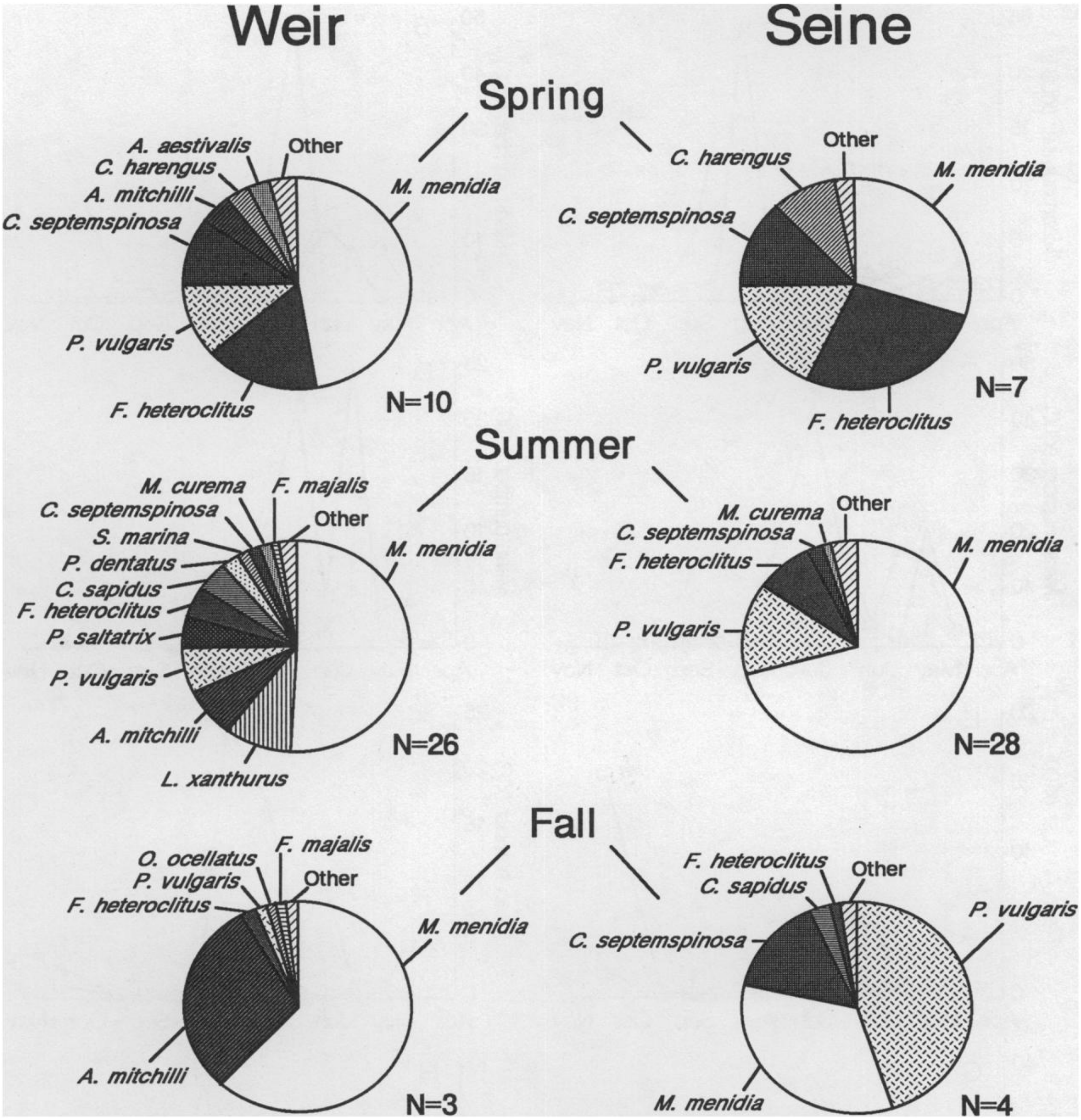

Fig. 4. Mean percent relative abundance of all species >1% by season and gear. Spring = April–June, summer = July–September, fall = October–December.

August (weir, Figs. 3 and 5). The fishes *Clupea harengus* and *Fundulus heteroclitus* made up the largest contribution to the May peak in abundance from seine samples, while the shrimp *Crangon septemspinosa* and fishes *Fundulus heteroclitus* and *Clupea harengus* were most responsible for the May peak in abundance from weir samples (Fig. 5). The June–July peak in weir abundance was due mainly to large catches of adult shrimps *Palaemonetes vulgaris* and *Crangon septemspinosa*. Extremely large unquantified catches of these two species were also recorded during the same period in 1988 (a crude number volume^{-1} estimate indicates numbers of >100,000 individuals per sample). The small increase in fall seine samples was primarily due to increased abundances of YOY fish *Anchoa mitchilli*, shrimps *Palaemonetes vulgaris* and *Crangon septemspinosa*, and the crab *Callinectes sapidus* (Figs. 4 and 5).

Seven of the ten most abundant species under-

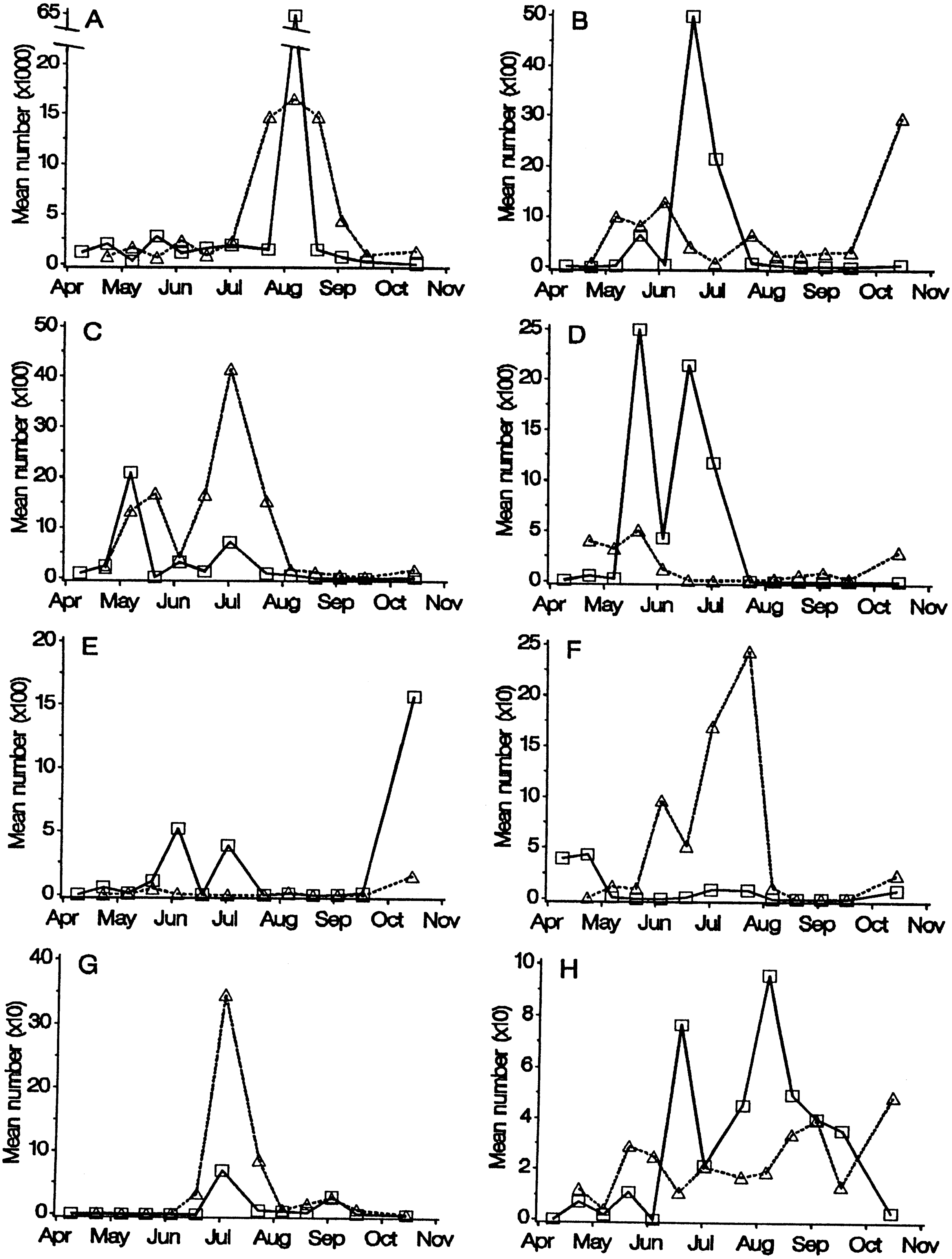

Fig. 5. Weekly mean abundances by gear of eight of the most abundant species collected during 1989 (weir = squares, n = 26; seine = triangles, n = 25): A) *Menidia menidia*, B) *Palaemonetes vulgaris*, C) *Fundulus heteroclitus*, D) *Crangon septemspinosa*, E) *Anchoa mitchilli*, F) *Fundulus majalis*, G) *Mugil curema*, H) *Callinectes sapidus*.

went sharp declines just prior to the August peak of *Menidia menidia* (Fig. 5). Only *Callinectes sapidus* exhibited peak abundance simultaneously with *Menidia menidia.* However, the abundances of several seasonally transient predators, *Paralichthys dentatus, Strongylura marina,* and *Pomatomus saltatrix,* peaked during the period of peak *Menidia menidia* catches. The less abundant predators *Sphyraena borealis* and *Cynoscion regalis* also first appeared during this period.

Annual Variation

Although the summer fauna of the marsh creeks was very similar between years, the abundances of four species varied significantly between years (Table 5). Based on weir samples, *Leiostomus xanthurus* and *Paralichthys dentatus* were the only species not among the top ten by abundance for both years. Of the nine species among the top ten for both years, only *Pomatomus saltatrix* and *Callinectes sapidus* were significantly more abundant in 1989. In general, total fauna abundance and the abundances of most individual species tended to be greater in 1989 (Figs. 3 and 5; Table 5). Although abundances could not be directly compared for seine samples between years, the overall faunal composition was very similar.

Discussion

Seasonal Abundance and Biomass

Although a comparison of absolute abundance and biomass data reported by other researchers was not possible because of differences in sampling techniques and methods, it is clear that the study creeks support a very high abundance of fishes and invertebrates. In fact, recent quantitative comparisons of several estuarine habitats in New Jersey, including eelgrass and subtidal creeks, found the highest fish densities in marsh creeks (Sogard and Able 1991; Wilson, Able, and Heck personal observation). It should be noted, however, that although studies in salt marsh habitats from Florida to Massachusetts generally report a strong seasonality of fauna, few studies provide data on seasonal patterns in total faunal abundance or biomass in marsh creeks (Subrahmanyam and Coultas 1980; Smith et al. 1984).

Seasonal patterns in faunal abundance in New Jersey marsh creeks were similar to those reported for polyhaline marshes in other regions. Spring (March–April), summer (August–September), and fall (November) peaks in total abundance were reported in a New England tidal embayment (Nixon and Oviatt 1973), in a pattern similar to our samples (Fig. 3). In Virginia, a major peak in fish abundance occurred in May followed by a smaller peak in July in one creek and in August for a second creek (Smith et al. 1984). In Florida, seasonal peaks in abundance occurred in March and July–August, but were highly variable between years (Subrahmanyam and Coultas 1980). Thus, although the timing of peak abundance can exhibit spatial and annual variation in a particular study, strong seasonal peaks are typical. Such seasonal patterns in abundance within estuaries have been attributed to seasonal shifts in faunal composition, immigration-emigration from estuaries, and predator-prey interactions (Nixon and Oviatt 1973; Subrahmanyam and Coultas 1980; Haedrich 1983).

Faunal Composition

Patterns of Utilization

The high diversity and abundance of YOY and juvenile fishes in the study creeks (Tables 3 and 4) strongly suggests this habitat is an important nursery ground for a large number of marine species. Further, marsh creeks also appear to be equally important habitats within the estuary for estuarine residents. Estuarine residents numerically dominated the fauna, based on these sampling techniques, and polyhaline subtidal marsh creeks are undoubtedly critically important habitats for the fishes *Menidia menidia* and *Fundulus heteroclitus,* the shrimp *Palaemonetes vulgaris,* and the crab *Callinectes sapidus* (Tables 3 and 4). Several other estuarine residents utilized marsh creeks extensively for restricted seasonal periods, including the fishes *Cyprinodon variegatus* (July) and *Gobiosoma bosci* (July–November). Other studies have also found marsh creeks to be dominated by estuarine residents (Richards and Castagna 1970; Nixon and Oviatt 1973; Subrahmanyam and Coultas 1980; Weinstein et al. 1980; Smith et al. 1984).

As is the case for most estuaries (Haedrich 1983), seasonal transients made up mostly of YOY and juveniles of marine species were the most diverse component of the fauna collected (Table 3). Notable among these were the crab *Ovalipes ocellatus* and the fishes *Pomatomus saltatrix, Mugil curema, Strongylura marina, Paralichthys dentatus, Mustelus canis,* and *Clupea harengus* (Table 3). However, several seasonal transients occurred in the creeks primarily as adults, including the horseshoe crab, *Limulus polyphemus,* and the fishes *Gasterosteus aculeatus, Anchoa mitchilli,* and *Cynoscion regalis.*

A significant component of the fauna were visitors from continental shelf and southern waters, as has been previously reported for New Jersey estuaries (Milstein and Thomas 1976). At least 15 less abundant species from the subtidal creeks fall into this category (including the crab *Callinectes similis* and the fishes *Selene vomer, Lutjanus griseus,* *Chaetodon ocellatus, Gobionellus boleosoma, Aluterus* spp., and *Monacanthus hispidus*). Finally, several oligohaline estuarine fishes (*Menidia beryllina, Morone americanus,* and *Trinectes maculatus*) were collected in small numbers (Table 3).

Seasonality

The seasonal pattern in total abundance resulted from the superimposed individual abundance patterns of the dominant species, although it mainly reflected the seasonal abundance pattern of *Menidia menidia* (Figs. 3 and 5). With *M. menidia* excluded, the major peak in total abundance would have been during June–July.

A comparison between gears of the temporal abundance patterns of dominant species suggests seasonal movement patterns. Since the weir is a passive gear, it primarily captures species which are moving out of the creeks with the tides (passively or actively), while the seine captures species which remain in the creeks to avoid the weir, as well as those which do not move with the tides. Therefore, while a species is resident within the creek it will be primarily collected by the seine. However, during periods of seasonal movements a species is more susceptible to the weir. A transition from residency to seasonal migration, then, may be suggested by a temporal shift in peak catches between gears. For example, peak weir catches which follow a sharp decline in seine catches suggest seasonal emigration from the creek. Contrastingly, peak catches in seine samples following a decline in weir catches suggest immigration into the creeks.

A pattern indicating emigration from the creeks is exhibited by the shrimps *Palaemonetes vulgaris* and *Crangon septemspinosa* during the late spring–early summer, and by the fish *Menidia menidia* during summer (Fig. 5). Other studies have shown that adult *Crangon septemspinosa* migrate from shallow estuarine to deeper estuarine and offshore waters with the onset of high water temperatures in July (Price 1961; Haefner 1979; Modlin 1980). Similarly a strong decline in the abundance of *Palaemonetes pugio* and *Palaemonetes* spp. in July has been reported in other marshes, but has been attributed to predation by fishes (Nixon and Oviatt 1973; Subrahmanyam and Drake 1975; Welsh 1975; Sikora 1977; Subrahmanyam and Coultas 1980). Large catches of resident YOY *Palaemonetes vulgaris* and *Crangon septemspinosa* in fall seine catches are the result of increased susceptibility to the seine as the shrimp grow. The sudden, dramatic increase and decline in *Menidia menidia* abundance in weir samples appears to have been due to mass migrations of YOY out of the creeks, and may be a prelude to the late fall estuarine-offshore migration described by others for northeastern estuaries (Conover and Ross 1982; Bengston 1984). A pattern of high weir catches followed by high seine catches, indicating immigration into the creeks, was exhibited by the fishes *Fundulus heteroclitus* and *Fundulus majalis* during the spring. Spring immigration of *Fundulus heteroclitus* into a shallow tidal embayment was similarly reported in a New England marsh (Nixon and Oviatt 1973).

The blue crab, *Callinectes sapidus,* exhibited both types of patterns. We observed initially high seine catches of juveniles in the early spring followed by a peak in weir catches in June, indicating movement out of the creeks. However, weir catches of YOY (and of adults) peaked in August and then declined throughout the fall, while catches of YOY in seine samples continued to rise throughout the summer and fall (Fig. 5), indicating seasonal movement of YOY into the creeks. Thus YOY appear to move into the creeks during late summer through fall where they remain resident until they migrate out of the creeks as juveniles in the spring. Other marsh creek studies have reported this seasonal migration pattern for *Callinectes sapidus* (Hines et al. 1987; Mense and Wenner 1989).

A comparison of abundance patterns among species reveals two trends suggesting strong interspecific interactions. First, seven of the ten most abundant species underwent dramatic declines in July (Fig. 5). Second, a number of seasonally transient predators first appeared, or exhibited maximum abundances, during the August peak in *Menidia menidia* abundance (including adult *Callinectes sapidus* and *Cynoscion regalis,* and YOY *Pomatomus saltatrix, Paralichthys dentatus, Strongylura marina,* and *Sphyraena borealis*). Many of the dominant marsh residents, such as *Fundulus heteroclitus* and *Palaemonetes vulgaris,* may have declined as a result of predation by seasonal transients like *Pomatomus saltatrix* and *Strongylura marina,* or as a result of migration into other areas to escape predation (upper creek or deeper bay regions not sampled by our gear). However, marsh residents may have migrated into other areas to avoid competition with the extremely high summer abundances of *Menidia menidia.* Alternatively, the disappearance of many of the marsh residents in August may simply have been due to a response to high water temperatures (Fig. 3A).

Differences between summer catches between 1988 and 1989 may have been partly due to differences in water temperatures between the years (Fig. 3). In fact, 50-year record low inshore water temperatures were recorded for 1988 (J. Eberwine, National Weather Service, personal communication) and we measured temperatures as low as 9°C within the study area in August 1988 when temperatures are normally above 20°C, suggesting that the lower abundances of typical summer fauna during 1988 may have been due to depressed water temperatures (Table 5, Fig. 3A).

Geographical Comparison

The fauna of the polyhaline subtidal marsh creeks studied in New Jersey is broadly similar to that of subtidal creeks in other regions of the eastern United States, although there is a pronounced decrease in shared fauna with more southern regions. Unfortunately, many of the published studies of marsh creeks do not report the overall faunal composition of the subtidal creeks separately from other habitats examined, and only rarely report a complete list of fauna.

To our knowledge only one study of marsh creek communities has been conducted north of New Jersey (Werme 1981; Teal 1985). All eleven species recorded in Werme's snorkeling survey, including the three most abundant species, *Menidia menidia, Fundulus heteroclitus* and *Fundulus majalis*, are common to New Jersey.

Previous subtidal creek studies in New Jersey used throw trap or drop cylinder/suction sampling techniques which are highly biased toward small epibenthic forms (Sogard and Able 1991; Wilson, Able, and Heck personal observation) and, hence, collected far fewer species than our study. We collected all 16 species taken by Sogard and Able (1991) and 17 of 21 species taken by Wilson, Able, and Heck (unpublished data). *Menidia menidia, Fundulus heteroclitus, Gobiosoma bosci, Anchoa mitchilli,* and *Fundulus majalis* were among the dominant fishes and *Palaemonetes vulgaris, Crangon septemspinosa, Pagurus longicarpus,* and *Callinectes sapidus* were among the dominant decapods (Sogard and Able 1991; Wilson, Able, and Heck personal observations). The dominant fauna collected in these previous studies, then, was most similar to that collected in our seine samples, and dissimilar to the weir samples (Fig. 4).

The faunal composition of subtidal creeks in North Carolina and Virginia is strikingly similar to that for New Jersey. We collected 79% (11 of 14) of the species reported from one Virginia trawl survey (Smith et al. 1984) and 17 of the 19 dominant species collected in a second Virginia seine and trawl study (Richards and Castagna 1970). We collected 54% (30 of 56) of the fishes and invertebrates reported in a more comprehensive seine study in North Carolina marsh creeks (Weinstein 1979; Weinstein et al. 1980). They report a similarly high diversity of 58 species (compared to 78 species herein), while most other studies report from 10 to 40 species. More importantly, the five most abundant species, *Anchoa mitchilli, Leiostomus xanthurus, Mugil curema, Menidia menidia,* and *Fundulus heteroclitus,* collected in a polyhaline creek by Weinstein (1979) were among the most abundant species in New Jersey.

Many species collected in New Jersey marsh creeks are also common to western Florida and Mississippi marsh creeks (Subrahmanyam and Drake 1975; Hackney 1977; Subrahmanyam and Coultas 1980; Hackney and de la Cruz 1981). However, many of the dominant species in our collections are replaced by closely related sibling species in the south (e.g., *Fundulus similis* replaces *F. majalis* and *F. grandis* replaces *F. heteroclitus*). At least 32% of the fishes collected in Florida (15 of 47) were collected in New Jersey (Subrahmanyam and Coultas 1980). In fact, their five most abundant species or their sibling counterparts (*Anchoa mitchilli, Leiostomus xanthurus, Fundulus similis, Fundulus grandis,* and *Cyprinodon variegatus*) were among the most abundant species collected in this study.

It seems clear from this comparison that many of the dominant marsh creek species have a very wide geographic distribution (particularly estuarine resident species such as *Fundulus heteroclitus, Fundulus majalis, Menidia menidia, Palaemonetes vulgaris, Gobiosoma bosci, Cyprinodon variegatus,* etc.). Many of the transient nursery species also have wide distributions (*Mugil curema, Leiostomus xanthurus, Strongylura marina,* etc.) or are replaced by closely related species in adjacent regions (e.g., *Brevoortia tyrannus* vs. *B. patronus*).

Conclusion

Marsh creek faunal composition, abundance, and biomass are strongly seasonal in southern New Jersey, with peaks of abundance and biomass occurring in May and August. These marsh creeks support a very diverse fauna, made up both of typical estuarine residents and of YOY of a variety of species which spawn over the continental shelf. Further, many of the dominant species collected in New Jersey marsh creeks are YOY and juveniles of economically important species in the Mid-Atlantic Bight. The abundance of YOY and juveniles in the creeks and the prevalence of the habitat in southern New Jersey strongly suggest that marsh creeks are a significant nursery habitat for many marine species in the adjacent Mid-Atlantic Bight. It is noteworthy that many of the dominant marsh creek species have wide geographic distributions despite important differences in dominant marsh vegetation (*Juncus, Spartina,* mixed), tidal flood regimes (diurnal, semidiurnal, high marsh, low marsh), and other factors.

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