

Distribution of Winter Flounder, *Pseudopleuronectes americanus*, in the Hampton–Seabrook Estuary, New Hampshire: Observations from a Field Study

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Abstract From July to October 2004, five sites in the Hampton–Seabrook Estuary in New Hampshire were sampled with beam and otter trawls. The goals were to describe winter flounder (1) abundance in the estuary, (2) size class distributions, (3) spatial distribution by different size classes, and (4) distribution patterns. Of the 19 species caught, winter flounder was the most abundant and was dominated by young-of-the-year (YOY) fish. The five sites were fairly homogenous in depth, bottom type, salinity, and temperature. However, YOY abundance ranged from 2.1 to 32.1 fish 1,000 m⁻² depending on the site. Benthic community was the best indicator of juvenile winter flounder abundance. Catch data of other organisms fluctuated, but no one species was a strong predictor of winter flounder abundance and distribution. During late summer and early fall, the estuary is used primarily by YOY winter flounder, indicating that this estuary functions as a nursery ground.

Keywords Winter flounder · Juveniles ·
Essential fish habitat · Benthic community · Habitat ·
Feeding ecology

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Introduction

Winter flounder, *Pseudopleuronectes americanus*, is a commercially and recreationally important demersal flatfish found along the northwestern Atlantic coast from Georgia, USA to Labrador, Canada (Scott and Scott 1988). It is most common from Nova Scotia to New Jersey (Perlmutter 1947). As with most groundfish species, catches have declined precipitously in recent years. Total commercial landings of all three winter flounder stocks in 1981 were about 17,575 mt. Since then, catches have declined dramatically to 3,600 mt in 2005 (NEFSC 2006). Habitat characteristics of winter flounder vary among life stages and affect their distributions. Winter flounder reside in depths from the shallow subtidal to 37 m (McCracken 1963). Reproductively isolated adult populations typically undergo onshore migrations in early spring into specific estuaries or coastal embayments where spawning occurs (Lobell 1939; Perlmutter 1947; Sails 1961b) and the young-of-the-year (YOY) remain for their first 2 years before moving offshore (Pereira et al. 1999). These estuaries serve as critical nursery grounds for winter flounder. In order to sustain this species, it is important to protect winter flounder essential fish habitat.

Many winter flounder populations have been well studied, especially those south of Cape Cod (DNC 2008; Manderson et al. 2003; Meng et al. 2005; Pearcy 1962). Several estuarine systems north of Cape Cod have been characterized with respect to winter flounder also (Hanson and Courtenay 1996; Lazzari 2008; van Guelpen and Davis 1979); however, these studies occurred in Maine or further down east. Only scant information is available in New Hampshire, with most studies occurring in the Great Bay Estuary (Armstrong 1995; Fairchild et al. 2005; Wanat 2002).

Study Location

The Hampton–Seabrook Estuary (HSE) is located in the southeastern corner of New Hampshire. It is a small (approximately 192 ha at mean high water), tidally dominated estuary (Fig. 1) comprising several rivers and numerous creeks; all tidal waters enter and exit through the sole harbor entrance. Water depth is relatively shallow, ranging from <1 m in the tidal creeks to >6 m at the harbor entrance at mean low water, with 1–3 m of water in most channels at mean low tide (Jones 2000). More than 88% of the water in the estuary is replaced on each tide, with the average tidal flow equaling $623,000 \text{ l s}^{-1}$ (PSNH 1973). Due to this strong tidal flushing, low dissolved oxygen is not a limiting factor in the estuary (Jones 1997).

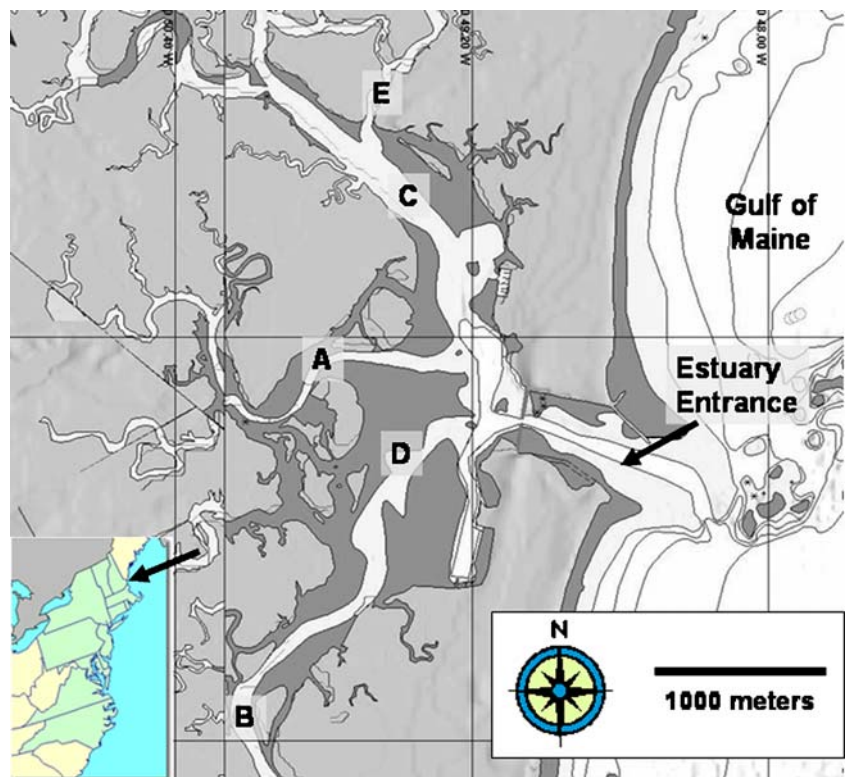
Like most coastal areas, human impact has increased around the HSE as adjacent municipalities have grown. Both of the largest towns in the estuary watershed, Hampton and Seabrook, have had a 22% population increase in the last decade (NHOEP 2006). Fishing activities within the HSE waters are mostly recreational; anglers primarily target striped bass (*Morone saxatilis*), summer flounder (*Paralichthys dentatus*), and winter flounder, while seasonal softshell clamming for *Mya arenaria* occurs on several flats. Also, Hampton Harbor is the homeport for a small commercial fishing fleet. To

maintain navigable channels, periodic dredging occurs during months when winter flounder spawn.

Despite the increased anthropogenic effects in the HSE and their probable linkages to the declining Gulf of Maine fish stocks, only a limited interpretation of the biological sampling conducted in the HSE has been made. Estuarine fish have been sampled monthly (beach seine, April to November) as part of the environmental monitoring of the nearby Seabrook Power Station (NAI 2007) and by New Hampshire Fish and Game (NHFG 2005). Both sampling programs have shown that YOY winter flounder abundance has declined since 1980 (NAI 2007). To our knowledge, sampling has not been conducted in the deeper waters of the estuary where larger winter flounder, and other species not caught by beach seine, may reside.

Because relatively little is known about the fish assemblages within the deeper channels of the HSE, we set out to characterize the estuary by reporting on the species composition of deeper water trawl catches. Since the estuary is dominated by winter flounder, we described (1) the abundance of winter flounder in the estuary, (2) the size class distribution of winter flounder, and (3) the spatial use of the estuary by different size classes of flounder. We also investigated factors that could explain winter flounder distribution patterns.

Fig. 1 The Hampton–Seabrook Estuary in New Hampshire with the five sampling stations denoted (*A* Brown River, *B* Blackwater River, *C* Hampton River, *D* Middle Ground, and *E* Tide Mill Creek), and an inset map showing the position of the estuary (denoted by *black arrow*) relative to the US eastern seaboard



Materials and Methods

Five sampling stations were selected based on preliminary trawling done in spring 2004 (Fig. 1). Sites were chosen in the Hampton River (HR; 42°54.5'N, 70°49.5'W), Tide Mill Creek (TMC; 42°54.7'N, 70°49.6'W), Brown River (BR; 42°53.9'N, 70°49.3'W), Middle Ground (MG; 42°53.8'N, 70°49.3'W), and Blackwater River (BWR; 42°53.0'N, 70°50.0'W). At each station, a fixed submersible data logger (Star-Oddi™ DST CTD) recorded temperature and salinity hourly. During the study, the data logger at MG was lost, so temperature and salinity at this site were estimated by averaging BR and HR data since these sites were physically closest to MG.

Fish and macroinvertebrates were collected weekly at each site with a 1-m beam trawl (4-mm mesh liner) and a 4.8-m otter trawl (25-mm mesh body, 6-mm mesh cod end) from 13 July through 18 October 2004, with some missed sampling due to weather conditions and tides. Three replicate tows were taken with each gear within similar depth intervals, each parallel to the shore and each approximately 100 m long. Mean depth and tow speed were recorded for each trawl. All macroinvertebrates and fish were enumerated and measured, with the exception of sevenspine bay shrimp, *Crangon septemspinosa*, and hermit crabs, *Pagurus* sp., which were scored as present or absent in the catch.

To characterize the benthic community in the estuary, and therefore prey availability to benthic feeders, a series of six 10-cm replicate benthic cores (0.0079 m²) was taken at each station biweekly during the period of trawling. Cores were stored in Zip-Lock™ bags, placed on ice, and returned to the laboratory where they were sieved through a 1-mm mesh sieve. All organisms were stained with Rose Bengal and preserved in 10% buffered formalin until analyses. Prey taxa were identified to the lowest possible taxonomic level and counted.

Statistical Analysis

Due to autocorrelation and non-normality of salinity and temperature time series data, daily average water temperature and salinity were compared among sites using non-parametric Kolmogorov–Smirnov two-sample distribution tests with a Bonferroni corrected critical p value of 0.005 ($=\alpha/10$) to reduce type I error from making multiple pairwise comparisons.

Numerical relative abundance of fish and macroinvertebrates caught in the trawls was estimated as catch-per-unit-effort (CPUE), expressed as number caught 1,000 m⁻². Differences in $\log_{10}(x+1)$ -transformed CPUE among sites and weeks were determined by analysis of variance (ANOVA, $\alpha=0.05$). Correlations between relative abun-

dance of YOY winter flounder and relative abundance of co-occurring species or abiotic factors (bottom temperature, bottom salinity, depth) were determined using the non-parametric Spearman rank correlation coefficient. Mean percent composition of benthic taxa was calculated by averaging the six replicate cores for each week and site.

Temporal and spatial differences in the community structure of the demersal fish and macroinvertebrate assemblages in HSE were evaluated by hierarchical cluster analysis and non-metric multi-dimensional scaling (MDS) based on Bray–Curtis similarity indices, which range from 0 for absolute dissimilarity to 1 for absolute similarity (Clarke 1993; Clarke and Green 1988; Clarke and Warwick 1994). The Bray–Curtis similarity was calculated using weekly mean $\log_{10}(x+1)$ -transformed CPUE or biweekly percent composition for each species found in trawls or benthic cores, respectively, at each site. Cluster analysis results were presented as dendrograms, and the MDS plot presented the relation among weekly site assemblages as a schematic of relative distances. Average dissimilarity (δ) percentages were calculated to quantify species contributions to the dissimilarity between any two assemblages. Hierarchical cluster analysis, MDS plots, and dissimilarity calculations were performed using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 5.0 software (Plymouth Marine Laboratory), and all other statistical analyses were performed using SAS version 9.3 software (SAS, Cary, NC, USA).

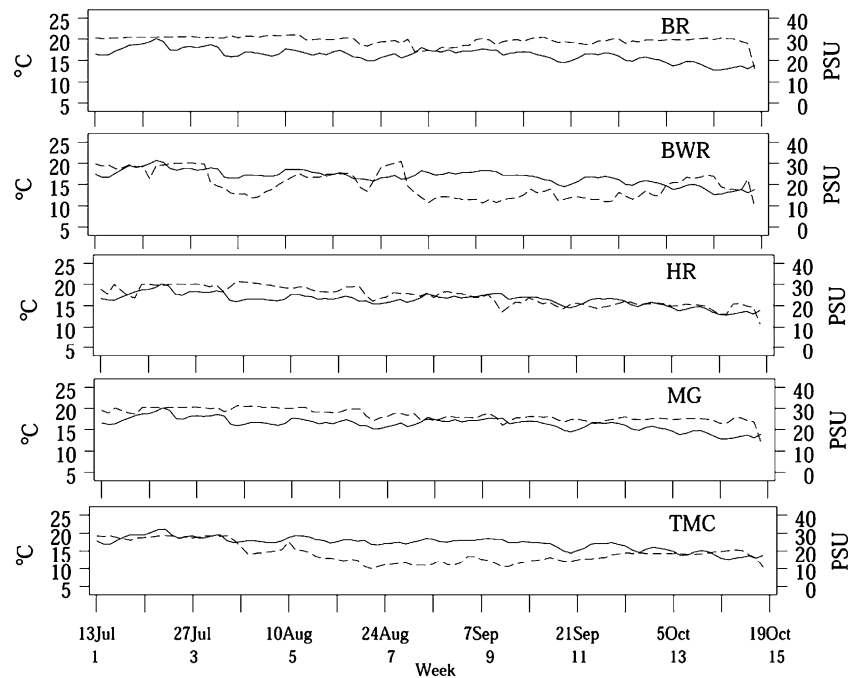
Results

Mean daily bottom water temperature significantly differed among stations from 13 July to 18 October 2004 in the HSE (Fig. 2). Tide Mill Creek was the warmest site (mean=17.3°C), followed by BWR (mean=16.9°C). No temperature differences existed among HR, BR, or MG (mean=16.4°C).

Mean daily bottom salinity significantly differed among all stations (Fig. 2), except between BWR and TMC which had the lowest salinity (20 and 19 psu, respectively). Highest salinity (29 psu) was at BR followed by MG (27 psu) and HR (25 psu).

Depth and tow speed significantly differed during sampling among sites and gears. Depth of tows varied depending on gear type and site (two-way ANOVA, $df=313$, site \times gear, $p<0.022$). Otter trawl tows at TMC (mean=3.7 m) were deeper than all other tows except otter trawl tows at BR (mean=3.0 m), which in turn were deeper than all trawls at BWR and HR. There were no significant differences among all other tows among sites and gears, which ranged from 2.3 to 2.9 m in average depth among sites

Fig. 2 Daily average bottom water temperature ($^{\circ}\text{C}$; solid line) and bottom salinity (psu; dotted line) from 9 July through 19 October 2004 at Brown River (BR), Blackwater River (BWR), Hampton River (HR), Middle Ground (MG), and Tide Mill Creek (TMC) in the Hampton–Seabrook Estuary



($p > 0.05$). Tows at BR (mean=1.3 kt) were significantly slower than all other tows (mean range=1.4–1.5 kt; two-way ANOVA, $p < 0.05$), and otter trawls (mean=1.3 kt) were significantly slower than beam trawls (mean=1.5 kt; $p < 0.05$).

Catch Analyses

Excluding sevenspine bay shrimp and hermit crabs, a total of 14 species were caught in 159 beam trawl tows and in 156 otter trawl tows from 13 July to 18 October 2004 in the HSE (Table 1). Green crabs, *Carcinus maenas*, dominated the average weekly catch at all sites regardless of gear type. Winter flounder was the second most abundant species caught at all sites except BWR when the beam trawl was used; there, they ranked third, behind sand lance, *Ammodytes americanus*. The only other ubiquitous species was windowpane flounder (*Scophthalmus aquosus*), but abundance was much lower than other species.

Winter flounder were divided into two age groups (age 0 and \geq age 1 fish) on the basis of length. Age 0 winter flounder were determined from weekly length–frequency distribution (Figs. 3 and 4) which corresponded to length at age for inshore winter flounder populations north of Cape Cod (P. Nitschke, personal communication; Sherman et al. 2005; Witherell and Burnett 1993). Age 0 winter flounder were classified as < 6 cm for weeks 1–4; < 8 cm for weeks 5–6; < 10 cm for weeks 7–10; < 12 cm for weeks 11–14; and < 13 cm for week 15, as seen in Fig. 3. This growth rate was similar to cultured fish growth rates for the same

time period (mid July to late October; E. A. Fairchild, unpublished data).

The densest concentrations of winter flounder caught by beam trawl were found in HR (Table 1), and these were predominantly age 0 fish (Table 2; Fig. 5). Both BWR and TMC were the sites with the lowest abundance of winter flounder regardless of gear type or season. Abundance of age 0 winter flounder ranged from a low of 2.1 fish/1,000 m^2 in BWR to a high of 32.1 fish/1,000 m^2 in HR in the early season. A shift in winter flounder distribution was seen in the later season in the otter trawl when more fish were caught in MG than in HR; again, these flounder were predominantly age 0 fish (Table 2; Figs. 5 and 6). Abundance ranged from 3.7 to 17.6 fish/1,000 m^2 in the late season.

The size distribution for winter flounder collected in the HSE was similar across sites (Fig. 7). Due to differences in mesh sizes, tow speed, and depth of tows, there was a gear selectivity effect between the beam and otter trawls; beam trawl collected primarily small age 0 fish, and otter trawl caught larger age 0 fish and some subadults (130–270 mm TL) and adults (> 230 mm TL). This gear selectivity effect was apparent in weeks 13–15 when mean beam trawl CPUE of YOY winter flounder declined at most sites, and mean otter trawl CPUE increased as the fish grew and became more vulnerable to the larger gear (Fig. 5). Because of this discrepancy, benthic and fish community analyses were divided into an early beam trawl season (27 July to 17 September; Fig. 3) and a late otter trawl season (20 September to 18 October; Fig. 4).

Table 1 Mean catch per unit effort (number $1,000 \text{ m}^{-2}$) of the weekly mean catch of fishes and macroinvertebrates caught by 1-m beam trawl and 4.8-m otter trawl in Hampton–Seabrook Estuary, New Hampshire from 13 Jul to 18 Oct 2004

Species	1-m Beam trawl						4.8-m Otter trawl					
	Blackwater River (N=11)	Brown River (N=11)	Hampton River (N=10)	Middle Ground (N=11)	Tide Mill Creek (N=10)		Blackwater River (N=11)	Brown River (N=11)	Hampton River (N=10)	Middle Ground (N=11)	Tide Mill Creek (N=9)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
<i>Ammodytes americanus</i>	9.39	7.16	0.61	0.41	0.30	0.30	0.33	0.33	0.44	0.44		
<i>Cancer irroratus</i>			0.61	0.41	1.87	3.64	2.08				1.18	0.39
<i>Carcinus maenas</i>	35.76	7.68	111.5	29.31	32.33	6.03	12.73	2.15	52.67	14.26	55.14	10.10
<i>Cyclopterus lumpus</i>			0.33	0.33	0.33	0.30	0.30				0.07	0.07
<i>Homarus americanus</i>			1.33	0.54	0.30	0.30	0.30				0.83	0.27
<i>Leucoraja erinacea</i>											0.49	0.21
<i>Meridia menidia</i>												
<i>Myoxocephalus octodecemspinosus</i>	0.30	0.30			0.30	0.30	0.30	0.45	0.45			
<i>Ovalipes ocellatus</i>											0.06	0.06
<i>Paralichthys dentatus</i>	0.30	0.30									0.06	0.06
<i>Photis gummellus</i>					0.33	0.33						
<i>Prionotus carolinus</i>												
<i>Pseudopleuronectes americanus</i>	2.73	1.17	12.73	2.05	28.67	7.95	11.82	3.09	6.00	2.15	8.54	1.34
<i>Scophthalmus aquosus</i>	1.21	0.81	0.61	0.41	2.00	0.74	3.03	1.59	0.33	0.33	2.78	0.43
<i>Syngnathus fuscus</i>			0.91	0.47	0.33	0.33	0.61	0.61	0.33	0.33		
<i>Tautoglabrus adspersus</i>	0.30	0.30									0.07	0.07
<i>Urophycis chuss</i>			0.61	0.41	1.00	0.71	0.61	0.41			0.56	0.36
											1.00	1.00
											0.76	0.43
											0.54	0.25
											0.08	0.08

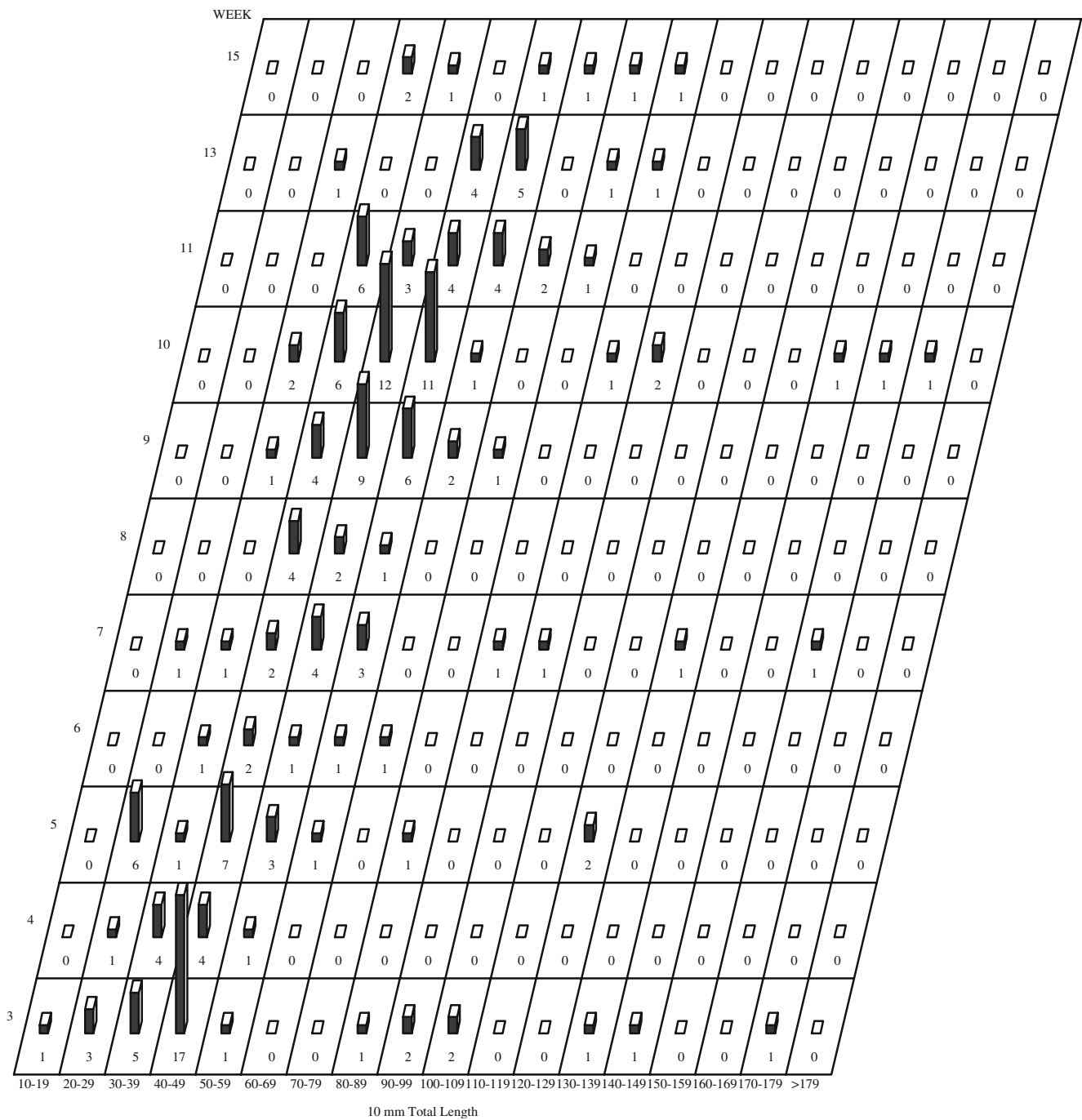


Fig. 3 Length–frequency distribution of winter flounder collected by beam trawl from sampling weeks 3 through 15 (27 July through 18 October) pooled across all sites in the Hampton–Seabrook Estuary

Using Spearman rank correlation, there were several variables that were weakly ($r < 0.35$) correlated with YOY winter flounder abundance, and these differed between gear types (Table 3). All were positive correlations except for temperature and YOY winter flounder caught in the otter trawl. Relative abundance of macroinvertebrates and fish, salinity, temperature, and depth cannot alone explain YOY winter flounder abundance during this period in the HSE.

Benthos

Seventeen taxa from 234 cores were identified to characterize the epifaunal and infaunal benthic community in the estuary (Table 4). Paraonidae was the most abundant benthic taxon among all sites, except at BR where it was the second most abundant taxon. Overall, Paraonidae was found in 62.8% of the core samples and represented 40.3%

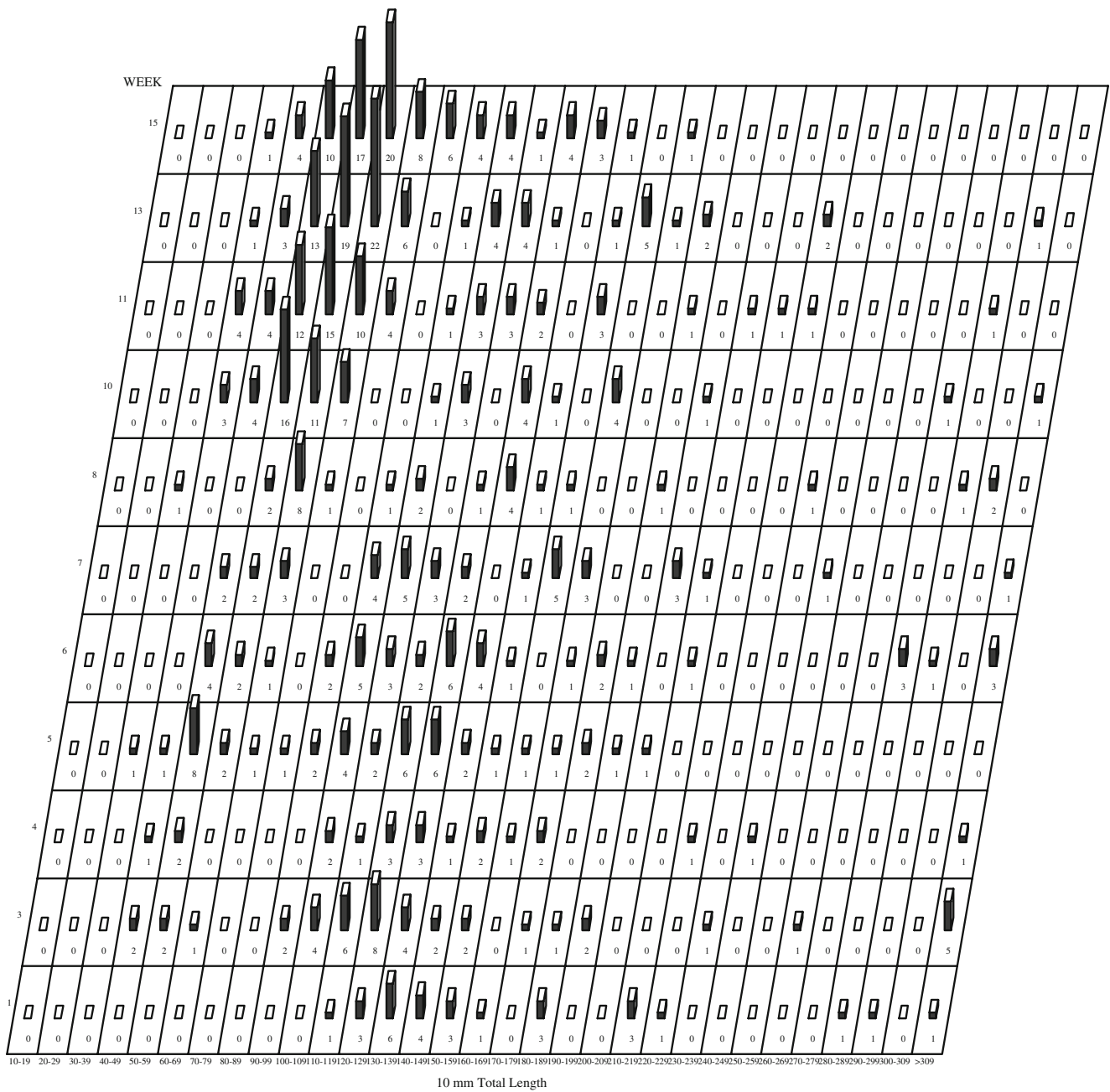


Fig. 4 Length–frequency distribution of winter flounder collected by otter trawl from sampling weeks 1 through 15 (13 July through 18 October) pooled across all sites in the Hampton–Seabrook Estuary

of taxa. Frequencies of occurrence of other abundant benthic invertebrates found in cores were 37.6% for Oligochaeta, 19.7% for Spionidae, 18.4% for Nereidae, and 9.8% for Amphipoda.

Early Season Community Analyses

The dendrogram from the cluster analysis separated the benthic assemblage sampled during week 7 (24 August) at TMC (group 1) from all other assemblages at 23.8%

similarity (Fig. 8). This benthic community was represented by Nereidae (48.5%), Paraonidae (6.8%), Oligochaeta (6.6%), Capitellidae (2.4%), and Terebellidae (2.4%). The remaining communities were separated into two major groups (groups 2 and 3) by those clads with less than 58.3% similarity with all remaining clads (Fig. 8). Group 2 consisted primarily of HR and BR weekly core averages. In this group, the abundance of Paraonidae contributed 73.3%, followed by Oligochaeta (15.3%), Nereidae (3.8%), and Spionidae (3.4%) to the average similarity of 49.1% of

Table 2 Arithmetic and geometric mean CPUE (number 1,000 m⁻²) of YOY winter flounder caught by 1-m beam trawl during the early season (27 Jul–17 Sep 2004) and 4.8-m otter trawl during the late season (20 Sep–18 Oct 2004) in Hampton–Seabrook Estuary, New Hampshire

Site	Early (beam trawl)					Late (otter trawl)				
	Number	Arithmetic mean CPUE	95% C.I.	Geometric mean CPUE	95% C.I.	Number	Arithmetic mean CPUE	95% C.I.	Geometric mean CPUE	95% C.I.
Hampton River	24	32.1	±13.3	17.5	±14.1	6	12.5	±3.7	12.2	±3.9
Brown River	24	11.3	±5	5.3	±5	9	10.4	±4.3	9.0	±5.6
Middle Ground	24	9.2	±4.3	4.2	±4	9	17.6	±6	16.1	±7.2
Tide Mill Creek	21	7.6	±4.8	2.7	±3.3	6	8.0	±5.1	6.8	±7
Blackwater River	24	2.1	±1.8	0.6	±0.9	9	3.7	±3.7	2.0	±3.5

N number of tows

Fig. 5 Weekly mean CPUE (number per 1,000 m²) of young-of-the-year winter flounder, *P. americanus*, collected by 1-m beam trawl and 4.8-m otter trawl at five sites in the Hampton–Seabrook Estuary from 13 July through 18 October 2004

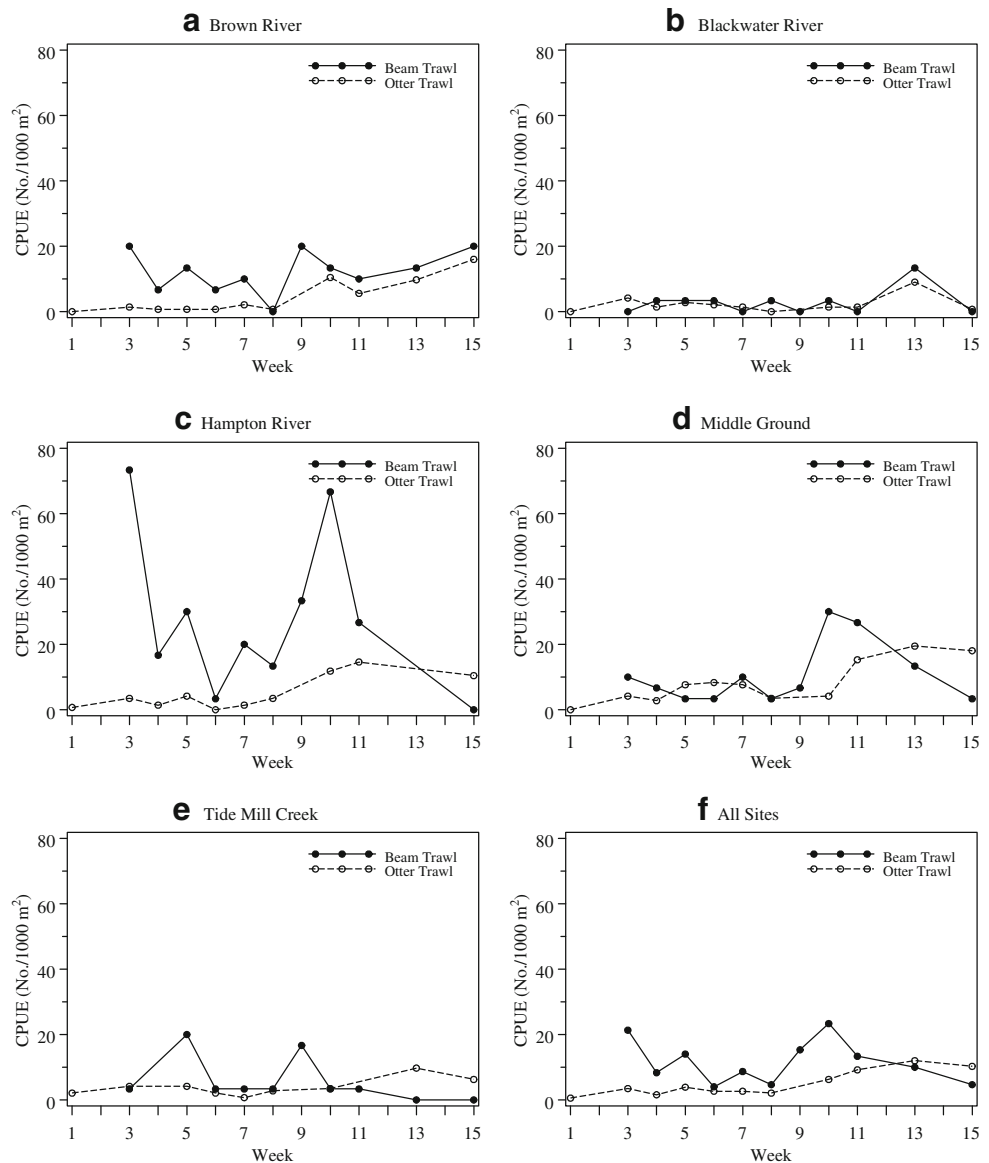
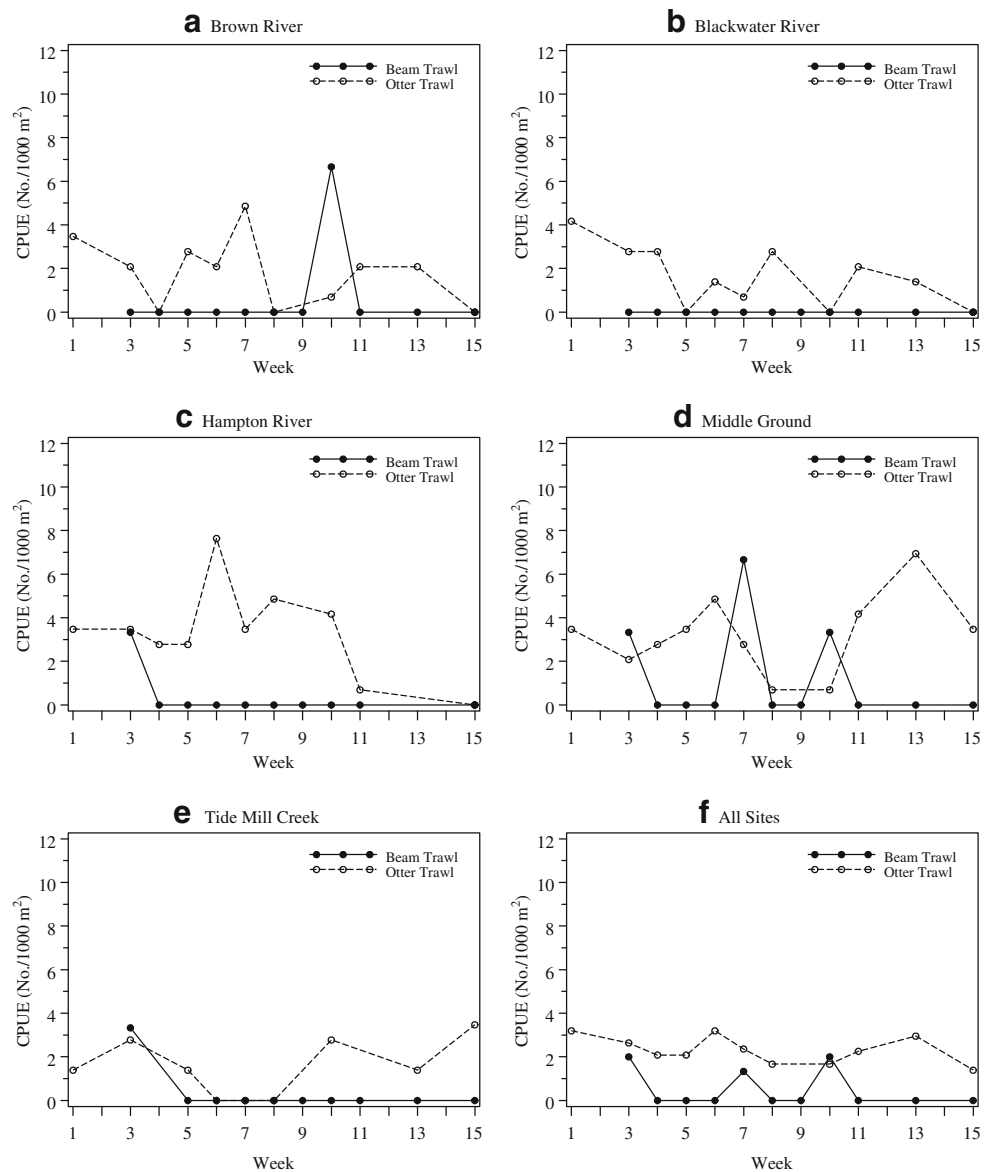


Fig. 6 Weekly mean CPUE (number per 1,000 m²) of age 1 or older winter flounder, *P. americanus*, collected by 1-m beam trawl and 4.8-m otter trawl at five sites in the Hampton–Seabrook Estuary from 13 July through 18 October 2004



weekly core averages. Group 3 contained all BWR weekly cores, as well as two TMC and two MG weekly cores. Taxa that contributed to the 60.5% similarity among communities within group 3 were Paraonidae (74.9%), Oligochaeta (14.1%), and Amphipoda (6.0%).

Multidimensional scaling shows a non-metric two-dimensional representation of the degree of separation of weekly core averages among sites (Fig. 9). When CPUE of YOY winter flounder is superimposed on the MDS plot, the benthic communities of group 2 show higher abundance of YOY winter flounder than groups 1 and 3 (ANOVA, $df=2$, $p<0.01$; Fig. 9). Higher abundance of Nereidae and lower abundance of Paraonidae in group 1 contributed 38.2% and 28.8%, respectively, to the average dissimilarity of 76.5% between benthic assemblages of group 1 and group 2. Taxa

contributing to the 45.0% average dissimilarity between group 2 and 3 were Paraonidae (22.4%), Oligochaeta (19.2%), Amphipoda (14.4%), and Spionidae (13.3%). All four of these taxa except Amphipoda were more abundant in benthic assemblages of group 2 compared to group 3.

Multidimensional scaling also defines the community structure of the five sites using the relative abundance of all fish and macroinvertebrates caught with beam trawl during weeks sampled by benthic cores (Fig. 10). Trawl catches at BWR and HR separated out from the other sites, whereas there was clustering among the remaining sites indicating higher similarity. When the benthic communities identified by cluster analysis (Fig. 8) are superimposed on the MDS plot (Fig. 10), it is evident that the benthic community group 2 is correlated to the greatest abundance of YOY winter

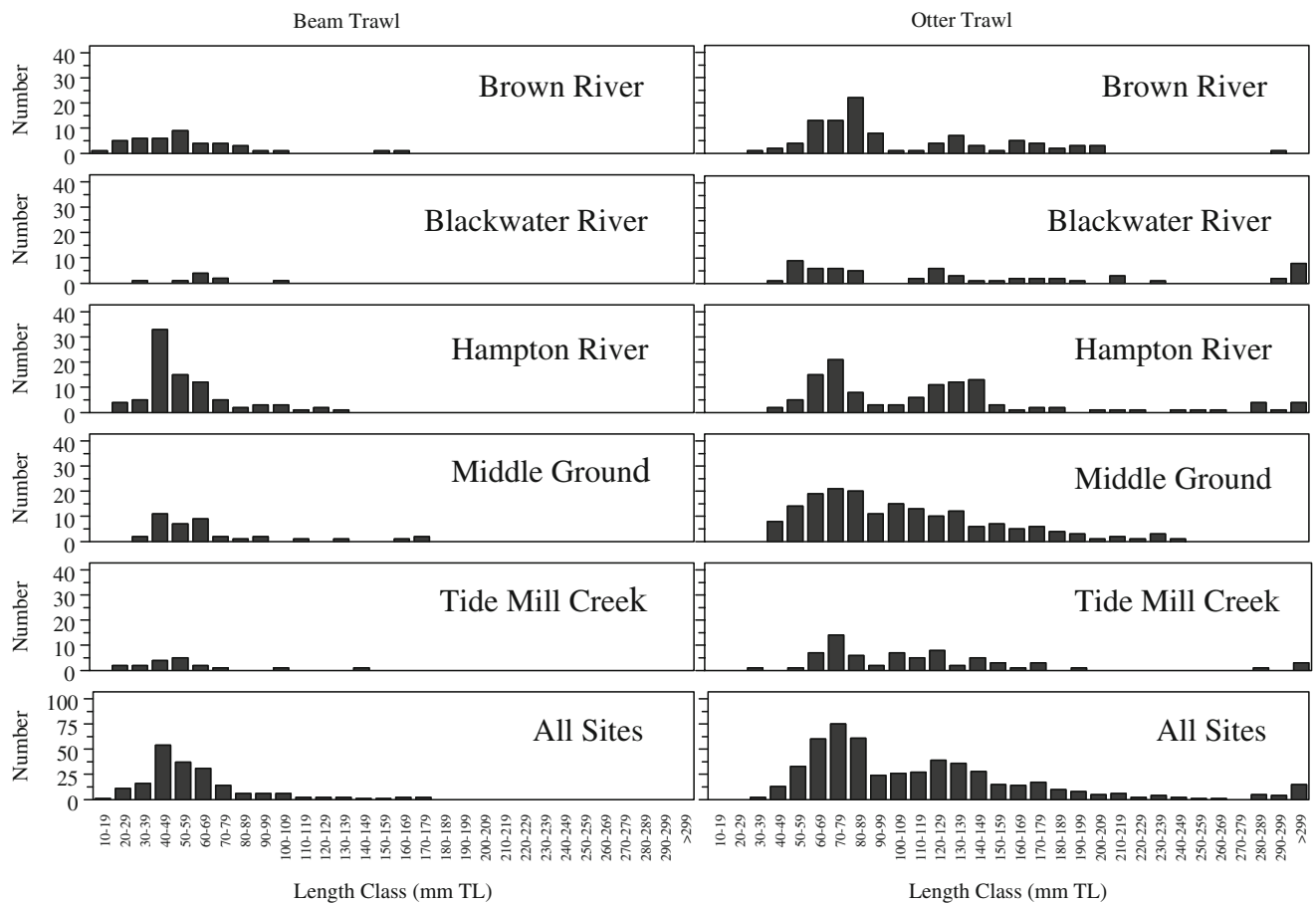


Fig. 7 Length–frequency distribution of 10 mm total length classes of winter flounder collected by a 1-m beam trawl (*left*) and a 4.8-m otter trawl (*right*) at five sites from 8 July through 18 October 2004 in the Hampton–Seabrook Estuary

flounder and all other fish assemblages caught by beam trawl in the early season. Typically, those sites with low fish abundance are linked to benthic community groups 1 and 3.

Late Season Community Analyses

The dendrogram from the cluster analysis separated the benthic assemblage sampled into three groups (Fig. 11). Group 1 consisted of both TMC samples and separated from all other assemblages at 24.9% similarity. The abundance of Spionidae contributed 64.1% followed by Oligochaeta (18.1%) and Nereidae (12.9%) to the average similarity of 74.6% of weekly core averages. The remaining communities were separated into two major groups (groups 2 and 3) by those clads with less than 50.24% similarity with all remaining clads (Fig. 10). Group 2 consisted entirely of core averages from weeks 11 and 15. In this group, the abundance of Paraonidae (87.8%) and Oligochaeta (8.0%) contributed to the average similarity of 70.9% of weekly core averages. Group 3 contained mostly week 13 cores samples. Taxa that contributed to the 65.1% similarity among communities within group 3 were Para-

onidae (51.1%), Oligochaeta (35.5%), and Capitellidae (7.0%).

Multidimensional scaling shows a non-metric two-dimensional representation of the degree of separation of weekly core averages among sites with CPUE of YOY

Table 3 Significant Spearman rank correlation coefficients (r_s) for fish and macroinvertebrate catch in relation to YOY winter flounder catch

Variable	r_s
Beam trawl	
Green crab	0.229 ($p=0.004$)
Lobster	0.268 ($p=0.0007$)
Red hake	0.026 ($p=0.0009$)
Salinity	0.307 ($p<0.001$)
Lumpfish	0.164 ($p=0.039$)
Rock crab	0.224 ($p=0.005$)
Otter trawl	
Temperature	-0.284 ($p=0.0003$)
Lobster	0.185 ($p=0.020$)
Red hake	0.349 ($p<0.0001$)
Rock crab	0.307 ($p<0.0001$)

Table 4 Mean ($\pm 95\%$ confidence interval) percent composition and mean density (N/m^2) of taxa observed in benthic cores taken in Hampton–Seabrook Estuary, New Hampshire from 13 July to 18 October 2004

Taxon	Brown River ($n=42$)			Blackwater River ($n=48$)			Hampton River ($n=48$)			Middle Ground ($n=48$)			Tide Mill Creek ($n=48$)			All sites ($n=234$)		
	Percentage	C.I.	N/m^2	Percentage	C.I.	N/m^2	Percentage	C.I.	N/m^2	Percentage	C.I.	N/m^2	Percentage	C.I.	N/m^2	Percentage	C.I.	N/m^2
Oligochaeta	26.8	± 9.88	211.0	6.6	± 5.06	60.7	8.8	± 4.68	100.2	14.1	± 7.60	150.3	10.4	± 4.92	200.4	13.0	± 2.98	142.8
Paraonidae	26.6	± 8.07	295.4	41.5	± 11.41	440.4	58.4	± 11.54	564.3	45.2	± 11.66	690.9	28.1	± 10.90	237.3	40.3	± 4.98	449.5
Spionidae	12.0	± 7.28	108.5	0.6	± 1.02	21.1	7.2	± 5.61	97.6	2.5	± 4.26	5.3	21.0	± 9.01	390.3	8.6	± 2.78	125.0
Nereidae	9.7	± 6.66	51.2	0.0		0.0	3.7	± 4.45	21.1	3.5	± 3.22	23.7	14.6	± 7.97	113.4	6.2	± 2.35	41.7
Amphipoda	5.7	± 5.78	60.3	8.2	± 6.79	42.2	1.4	± 1.95	7.9	3.6	± 4.54	15.8	1.8	± 2.17	13.2	4.1	± 2.02	27.0
Mysidacea	5.3	± 6.73	12.1	0.0		0.0	0.0		0.0	0.5	± 1.05	2.6	0.0		0.0	1.1	± 1.21	2.7
Capitellidae	3.9	± 3.96	69.3	5.5	± 5.98	31.6	0.9	± 1.30	7.9	1.0	± 1.21	18.5	0.3	± 0.60	2.6	2.3	± 1.45	24.9
Nephytidae	2.6	± 2.99	15.1	0.9	± 0.90	13.2	3.1	± 4.27	13.2	2.8	± 4.30	13.2	1.5	± 2.21	10.5	2.2	± 1.40	13.0
Nematode	1.8	± 2.57	30.1	4.4	± 4.86	23.7	0.5	± 1.05	2.6	1.3	± 2.04	36.9	1.7	± 2.24	15.8	2.0	± 1.25	21.6
<i>Crangon septemspinosa</i>	0.6	± 1.2	3.0	0.0		0.0	0.5	± 1.05	2.6	0.0		0.0	0.0		0.0	0.2	± 0.30	1.1
Phyllocladiae	0.2	± 0.44	3.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	± 0.08	0.5
<i>Carcinus maenas</i>	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.3	± 0.70	2.6	0.1	± 0.14	0.5
Nudibranchia	0.0		0.0	0.0		0.0	1.4	± 2.79	5.3	0.0		0.0	0.0		0.0	0.3	± 0.56	1.1
Orbiniidae	0.0		0.0	6.4	± 5.65	39.6	1.5	± 1.79	7.9	1.7	± 2.49	5.3	1.0	± 1.43	13.2	2.2	± 1.34	13.5
Polychaete Unid	0.0		0.0	0.8	± 1.19	10.5	3.9	± 4.61	23.7	0.0		0.0	0.0		0.0	1.0	± 0.97	7.0
Tellinidae	0.0		0.0	0.0		0.0	0.3	± 0.70	2.6	3.0	± 4.40	7.9	0.0		0.0	0.7	± 0.90	2.2
Terebellidae	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.3	± 0.6	2.6	0.1	± 0.12	0.5

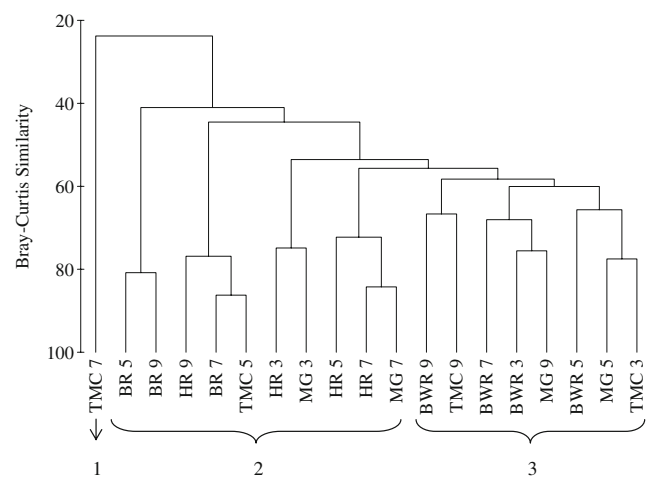


Fig. 8 Dendrogram from hierarchical cluster analysis using Bray–Curtis similarities based on mean composition of taxa from six benthic cores at five sites (*BR* Brown River, *BWR* Blackwater River, *HR* Hampton River, *MG* Middle Ground, *TMC* Tide Mill Creek) in the Hampton–Seabrook Estuary during weeks 1, 3, 5, 7, and 9 during 13 July–17 September 2004

winter flounder superimposed (Fig. 12). YOY winter flounder abundance was not correlated to the benthic communities (ANOVA, $df=2$, $p=0.1416$). Higher abundance of Spionidae and lower abundance of Paraonidae in group 1 contributed 29.6% and 38.1%, respectively, to the average dissimilarity of 81.6% between benthic assemblages of group 1 and group 2. Groups 1 and 3 differed (63.8% average dissimilarity) mainly due to higher abundance of Spionidae (34.2%) and lower abundance of Paraonidae (23.9%) and Capitellidae (12.7%) in group 1. Groups 2 and 3 were least dissimilar (49.8% average dissimilarity); higher abundance of Paraonidae (33.3%) and lower abundance of Oligochaeta (21.4%) and Capitellidae (17.2%) in group 2 accounted for the main differences between benthic communities.

Discussion

Winter flounder is the most abundant finfish in the HSE during summer and fall (Table 1). Although all age classes are found, YOY and age 1 winter flounder are the most prevalent (Figs. 3, 4, 5, 6, and 7), indicating that this estuary functions as a nursery ground for this species. The abundance and distribution of YOY winter flounder are only poorly correlated to the abundance of other species and abiotic factors in the HSE (Table 3). Because estuarine systems are so dynamic, it can be difficult to isolate single variables.

Young winter flounder are strongly associated with specific habitats (Goldberg et al. 2002; Lazzari 2008; Meng et al. 2002; Meng et al. 2005). In Narragansett Bay, Rhode

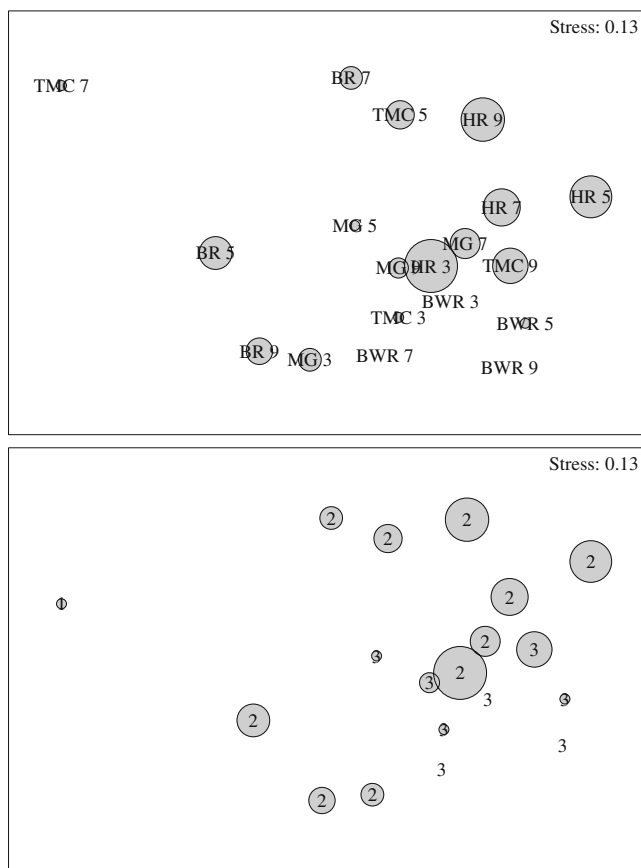


Fig. 9 Two-dimensional MDS ordination of Bray–Curtis similarities based on mean composition of taxa from benthic cores at five sites (*BR* Brown River, *BWR* Blackwater River, *HR* Hampton River, *MG* Middle Ground, *TMC* Tide Mill Creek) in the Hampton–Seabrook Estuary during weeks 1, 3, 5, 7, and 9 sampled by 1-m beam trawl during 13 July–17 September 2004 with superimposed circles of increasing size with increasing relative abundance of YOY winter flounder (*top*) and with benthic community groups identified from the cluster analysis (*bottom*)

Island, winter flounder abundance was higher in coves, all sites with marsh or beach edges, and where human disturbances occurred (Meng et al. 2005). In addition, densities increased with algal cover and decreased with dissolved oxygen, though the correlation was weak ($r^2 = 0.16$). In a comparison of 28 Maine estuaries and four habitat types, age 0 winter flounder typically were most abundant in eelgrass habitats (Lazzari 2008). Although winter flounder abundance and distribution can be linked to several variables, these variables can change even within a single year class. For example, in the Navesink River, Sandy Hook Bay estuarine system (NSHES), New Jersey, age 0 winter flounder density was correlated to water depth. More newly settled fish were found in 2–6 m waters (Manderson et al. 2003); depth decreased as fish length increased so that fish >35 mm SL were found in 1-m-deep water (Manderson et al. 2004). Likewise, Stoner et al. (2001) found that YOY could be subdivided into three size

classes (<25, 25–55, >55 mm TL); for each size class, different parameters (temperature, prey availability, substrate type, depth, presence of macroalgae) affected fish location.

In this study, the five stations sampled were spatially separate (Fig. 1) but fairly homogenous, lacking distinct habitat differences. The majority of the HSE bottom is featureless, characterized by fine- to medium-grained sand (roughly >90%), with the remainder described as mud (E. A. Fairchild, unpublished data; L. Ward, unpublished data). Though macroalgae and rocks are largely absent from the HSE, there are extensive blue mussel *Mytilus edulis* and softshell clam beds in some areas. Though there were differences in temperature, salinity, and depth between some stations (Fig. 2), all parameters were well within the normal tolerances for all age classes of winter flounder (Able and Fahay 1998; Bigelow and

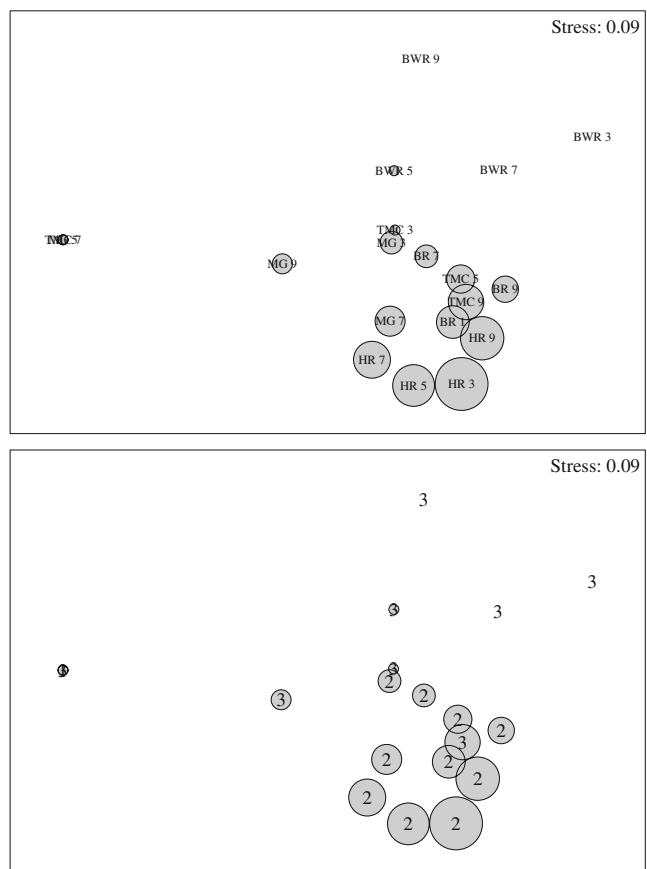


Fig. 10 Two-dimensional MDS ordination of Bray–Curtis similarities based on average log ($x+1$)-transformed relative abundance of fish and macroinvertebrate assemblages taxa at five sites (*BR* Brown River, *BWR* Blackwater River, *HR* Hampton River, *MG* Middle Ground, *TMC* Tide Mill Creek) in the Hampton–Seabrook Estuary during weeks 1, 3, 5, 7, and 9 sampled by 1-m beam trawl during 13 July–17 September 2004 with superimposed circles of increasing size with increasing relative abundance of YOY winter flounder (*top*) and with benthic assemblage groups identified from the cluster analysis (*bottom*)

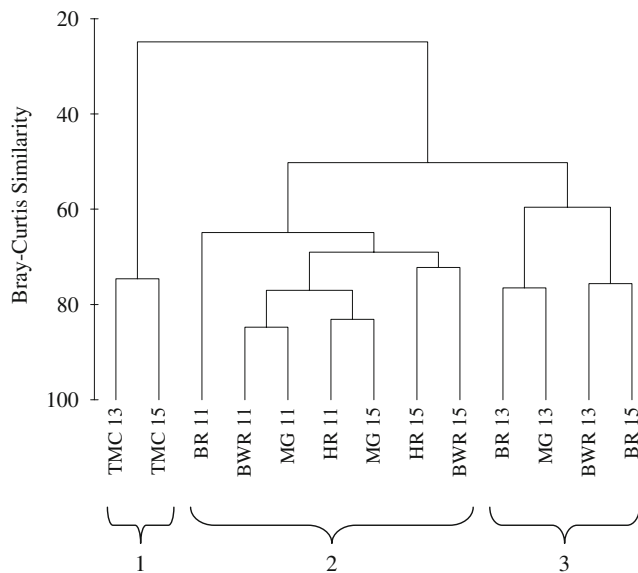


Fig. 11 Cluster analysis dendrogram of Bray–Curtis similarities based on mean composition of taxa from 6 benthic cores at five sites (*BR* Brown River, *BWR* Blackwater River, *HR* Hampton River, *MG* Middle Ground, *TMC* Tide Mill Creek) in the Hampton–Seabrook Estuary during weeks 11, 13, and 15 during 20 September–18 October 2004

Schroeder 1953; Casterlin and Reynolds 1982; Pereira et al. 1999). In summer and early fall, HR appears to be the most productive nursery area for small YOY winter flounder (Table 2; Figs. 5 and 7). Upper estuarine areas are favorable sites for newly settled winter flounder too in Rhode Island (Meng et al. 2002) and New Jersey (Manderson et al. 2003). However, apart from location, little similarity exists between these sites and the HR. Howell et al. (1999) noticed that fish density was lower in sandy sites compared to muddy sites in Connecticut, but the HR is entirely sandy. In the HSE, as these flounder grow, there is an ontogenetic shift down-estuary from HR to MG (Table 2; Figs. 5 and 7). We suspect that in the HSE, prey distribution plays a greater role in defining YOY winter flounder distribution and abundance than habitat does.

In the early season analyses, when fish were smaller, the benthic community was highly linked to YOY winter flounder distribution and abundance. Significant differences in Paraonidae, Oligochaeta, and the Nereidae polychaete abundances were found between benthic groups, and winter flounder were more prevalent in areas with higher concentrations of these taxa (Fig. 9). Generally, HR, where the most YOY winter flounder were found, supported the most biomass (other catch) too (Fig. 10). BWR, which had the lowest winter flounder abundance (Table 2), had the least biomass (Fig. 10). The sites where few or no YOY winter flounder are present may be poor areas for other fishes too. In these inferior areas, the benthic community may not support suitable feeding grounds for other bottom feeders,

which describes the majority of the HSE fish assemblage (Table 1). In summer, YOY winter flounder distribution and abundance, as well as all other fish and macroinvertebrates in the HSE, were linked to the benthic community.

Small winter flounder are opportunistic feeders and prey on small epibenthic and benthic organisms such as amphipods, nematodes, and small polychaetes. As the fish grow >50 mm TL, there is a diet shift to larger organisms like larger polychaetes and softshell clam siphons (Linton 1922; Mulkana 1966; Percy 1962; Richards 1963; Stehlik and Meise 2000). The benthic community in the HSE is similar (Table 4) and primarily characterized by the Paraonidae polychaetes and oligochaetes as found in the core samples. Winter flounder rarely consume oligochaetes (Armstrong 1995; Fairchild 1998; Stehlik and Meise 2000), so these are not a primary factor in prey availability.

Late season community analyses were not so distinct. Though there were differences in the benthic communities as a result of varying percentages of Paraonidae, oligochaetes, Spionidae polychaetes, and other polychaetes (Fig. 11), and there were differences in abundance of YOY winter flounder between sites (Table 2), there was no correlation between the two. Likewise, there was no apparent trend between YOY flounder abundance, the macroinvertebrate and other fish catch, and the benthic community during September and October (Fig. 12). This may be due to smaller sample sizes in the late season analyses and complications of using core samples to characterize benthic communities.

When using core samples to identify potential prey, some bias can occur. Epibenthic organisms, particularly crustaceans like mysids and amphipods, can be poorly

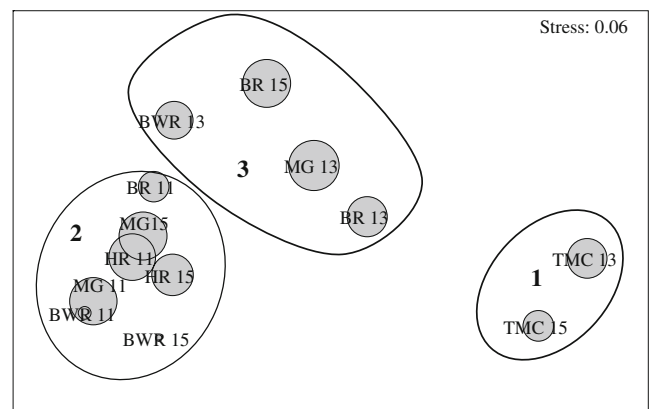


Fig. 12 Two-dimensional MDS ordination of Bray–Curtis similarities based on average $\log(x+1)$ -transformed relative abundance of fish and macroinvertebrate assemblages taxa at five sites (*BR* Brown River, *BWR* Blackwater River, *HR* Hampton River, *MG* Middle Ground, *TMC* Tide Mill Creek) in the Hampton–Seabrook Estuary during weeks 11, 13, and 15 sampled by 4.8-m otter trawl during 20 September–18 October 2004 with superimposed circles of increasing size with increasing relative abundance of YOY winter flounder

represented in the samples, yet are very important prey items for juvenile flatfish. In addition, bivalves such as softshell clams, usually occur deeper than the core sample, yet are an important prey item as juvenile flatfishes nip on exposed siphons (Peterson and Quammen 1982). To compound matters, core samples sometimes are not representative of actual prey abundances due to patchy distribution of benthic organisms (Ivlev 1961). To account for this non-uniform distribution, a series of six replicate cores was taken at each station every time the benthic community was sampled in this study. We arrived at this quantity by examining how few cores could be analyzed and still yield the same results as larger samples. However, we were not able to accurately quantify deeper organisms like softshell clams. For instance, softshell clam beds are present in MG, yet they were not represented in the core samples. It is likely that larger YOY winter flounder move into MG because of this food source; as the fish grow, they consume larger amounts of clam siphons (Stehlik and Meise 2000). Like our study, Stoner et al. (2001) found that in the NSHES, the density of 25 to 55 mm TL winter flounder was highly correlated to abundance of prey, while larger YOY were not.

However, other studies have not found such strong connections between food availability and juvenile winter flounder distribution. For instance, in Rhode Island estuaries, winter flounder density did not reflect prey availability (Meng et al. 2004). Winter flounder were caught at all sites but were most abundant in macroalgae sites, and larger fish were associated with eelgrass. Amphipods were underrepresented in the cores compared to gut content analyses, suggesting that food availability should not be used as a sole indicator of habitat quality. In Great Bay Estuary, New Hampshire, amphipods and juvenile winter flounder abundance were not correlated (Wanat 2002); *in situ* caging studies indicated that high growth was not dependent on high prey availability, but more impacted by substrate composition (Fairchild et al. 2005). In the HSE where habitat differences are minimal, hydrodynamic processes may help explain, in part, juvenile winter flounder distribution.

Winter flounder are eurythermal (Casterlin and Reynolds 1982), euryhaline (Bigelow and Schroeder 1953), and found over a wide range of depths and substrate types (Able and Fahay 1998). Despite this plasticity, in Great Bay, New Jersey, the highest abundances of YOY fish have been found in small coves just inside of estuarine inlets (Able and Fahay 1998). Such areas may serve as critical habitats because of their low current speeds, the deposition of fine-grain sediments that often occur in such locations, and their close proximity to spawning adult areas near the mouth of the estuary. In the HSE, the tidal amplitude is greater than south of Cape Cod, and therefore, tidal

flushing is stronger. MG, the closest site to the mouth of the estuary, had the highest abundance of YOY winter flounder during the fall, not during the late spring/early summer when larvae have recently settled. It is likely that the tidal currents transported the larvae into the estuary. Due to a combination of parameters (hydrodynamic conditions, prey, predators, habitat, temperature, salinity), more larvae survived and settled out in the HR than the other four sites sampled. Similar settlement patterns have been reported for winter flounder in the Mystic River Estuary, CT (Pearcy 1962), Narragansett Bay, RI (Meng et al. 2005), NSHES, NJ (Manderson et al. 2003), and Niantic River Estuary, CT (DNC 2008).

As winter flounder grow, they move into deeper waters, eventually leave their natal waters, and move offshore (Howe and Coates 1975; Saila 1961a). In the HSE, as these larger fish move down estuary towards the mouth, they collect in and around MG where more favorable feeding grounds and habitat exist. As winter flounder continue to grow, another ontogenetic shift occurs around age 2 when fish presumably move out of the estuaries. This has been confirmed with acoustically tagged fish in the HSE (E. A. Fairchild, unpublished data).

The HSE is different from the well-studied winter flounder estuarine nurseries south of Cape Cod (DNC 2008; Manderson et al. 2003; Meng et al. 2004; Richards 1963). It is a homogenous area with low species diversity (Table 1), especially compared to more southern estuaries. Green crabs and winter flounder are the most abundant species and are ubiquitous within the estuary (Table 1). Green crabs are a documented predator of juvenile winter flounder (Fairchild and Howell 2000; Taylor 2004) and negatively affect flounder abundance. In a modeling exercise, Taylor (2005) calculated that green crabs may account for as much as 8% of the daily mortality rate and consume 32% of the flounder year class in the Niantic River, CT. Because of the low species diversity in the HSE compared to the Niantic River (DNC 2008), green crabs may have a greater predatory impact on newly settled juvenile flounders in NH. However, despite this relationship, no strong correlation was found in the current study (Table 3).

Estuaries are dynamic ecosystems; their residents typically can tolerate a wide range of environmental variables. Winter flounder in general exhibits this high plasticity. However, within specific nursery areas, there appears to be a particular habitat in which juvenile distribution and abundance are highest. Although all size classes of winter flounder utilize the HSE, it is primarily occupied by YOY in the summer and fall, indicating that the estuary functions as a nursery ground. It is imperative for the sustainability of this important demersal food fish that these essential fish habitats are recognized and protected.

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