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The Distribution of Shallow Water Juvenile Fishes in an Urban Estuary: The Effects of Manmade Structures in the Lower Hudson River

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ABSTRACT: The objective of this study was to determine what effect, if any, large pile-supported platforms (piers) have on the habitat distribution and abundance of juvenile fishes. Trapping techniques were used in 1993 and 1994 under piers, in pile fields, and in open-water habitat types in shallow areas (<5 m) in the lower Hudson River estuary (40°44'N, 70°01'W). Nearly 1500 fishes, mostly juveniles, representing 24 species were collected in 1865 trap-days from May through October in the 2-yr study. The presence of relatively large numbers of young-of-the-year (YOY) fish during both years lends support to the idea that shallow areas in the lower Hudson River estuary currently function as nursery habitats for a variety of fishes. Two seasonal assemblages were apparent, but their composition varied somewhat between years. *Microgadus tomcod* and *Pseudopleuronectes americanus* YOY dominated an early summer assemblage (May–July) while large numbers of YOY *Morone saxatilis* were collected as part of a late summer assemblage (August–September). The effects of habitat type on fish assemblage structure were significant during both years. Fish abundance and species richness were typically low under piers; YOY fishes were rare and *Anguilla rostrata* accounted for a large proportion of the total catch. In contrast, YOY fishes dominated collections at pile field and open-water stations, where abundance and species richness were high. These results indicate that habitat quality under the platforms of large piers (>20,000 m^2) is probably poor for YOY fishes when compared with nearby pile field and open-water habitat types.

Introduction

Within many urban estuaries along the northeastern region of the United States, water and habitat quality have been so degraded (O'Connor and Huggett 1988) that many fish species effectively had been excluded (but see Haedrich and Haedrich 1974). This is particularly true in the New York-New Jersey Harbor Estuary, including the lower Hudson River estuary, where the general consensus was that this was one of the most intensively developed and heavily industrialized systems on the East Coast (Pearce 1979, 1993; Gottholm et al. 1993). In recent years, however, levels of sediment contamination from heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and DDT and its byproducts have declined from the peak levels reached in the 1960s and 1970s (Valette-Silver 1993) and water quality levels have improved (Brosnan and O'Shea 1996). Perhaps in response to this improvement in water quality, there is accumulating evidence that fish populations may be increasing in abundance and diversity. This would be particularly important for those species that utilize habitats in the harbor-estuary as nurseries.

There are, however, other anthropogenic activities, such as dredging and construction, that continue in the harbor-estuary and can affect fish habitat quality. Prompted in part by these concerns, and in response to such controversial proposals as the construction of the Westside Highway in the

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mid 1980s (Moran and Kiefer 1986), water and habitat quality issues in the harbor-estuary continue to receive increased attention. Although nearly three quarters of the shoreline has been already altered, additional modifications and development continue to be proposed, including the construction of large pile-supported platform structures (piers). However, there is considerable controversy as to whether these structures, and the pile fields that remain when the pier surfaces are removed, degrade the quality of fish habitat or in fact, actually enhance its use, primarily by attracting migratory or resident fishes (Waldman 1992).

While there have been a number of reports on the fishes of the harbor-estuary (see among others Esser 1982; Wilk 1984; Beebe and Savidge 1988; Studholme 1988; MacKenzie 1990), studies of the effects of platform structures are very limited. With the exception of the largely unpublished Westway report (United States Army Corps of Engineers 1984; Cantelmo and Wahtola 1992) and a survey of a single pier site along the Manhattan (New York) shoreline (Energy and Environmental Analysts, Inc. 1988; Stoecker et al. 1992), there have been few studies to determine the effects of man-made platforms on fishes in this system or others.

The purpose of this study, therefore, was to begin to evaluate the role of platform structures, particularly piers and pile fields, as habitats for shallow-water fishes. Since there is increasing evidence that survival of juvenile fishes has important implications for recruitment success and the subsequent size of adult populations (Cushing 1974, 1996; Sissenwine 1984; Sissenwine et al. 1984; Houde 1987; Bailey and Houde 1989; Cushing 1996), we focused on the juvenile stages. This would allow an evaluation of the quality of these habitats as nursery areas.

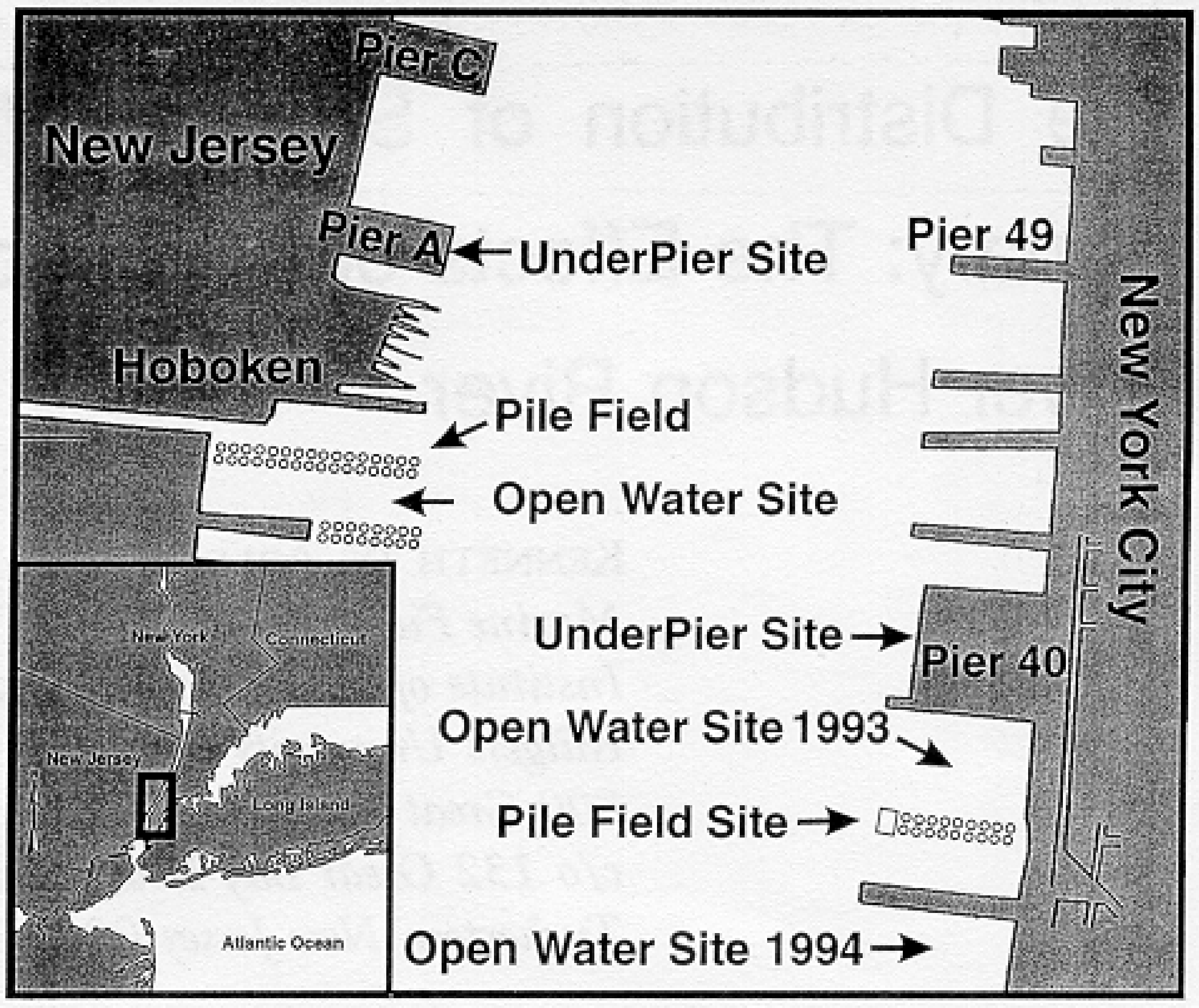

Fig. 1. Location of the study area and study sites in the lower Hudson River estuary in 1993 and 1994.

Materials and Methods

STUDY AREA

The study area was located in the lower Hudson River estuary, south of the George Washington Bridge and approximately 3 km north of the Battery (40°44′N; 74°01′W) (Fig. 1). Along the New York and New Jersey shorelines three types of subtidal habitats were selected: an underpier area located beneath a pile-supported platform; a pile field consisting of an array of wooden pier supports where the deck or platform had been removed; and an open-water area that lacked the structural complexity of the pile field and underpiers. The study sites, all <1.3 km apart, were located in the vicinity of the Holland Tunnel ventilator shaft on the Manhattan (New York) side of the river and near the Weehawken Ferry terminal on the Hoboken (New Jersey) side (Fig. 1). The sites were the same for both 1993 and 1994 with the exceptions noted below.

Both underpier habitats were situated beneath large concrete pile-supported platform structures (Fig. 1 and Table 1). In New York, the site was beneath the Marine and Aviation Pier 40, currently operated as a parking garage. In New Jersey, the site was under Port Authority Pier A, which was no longer used commercially. Both structures were >20,000 m^2; however, the New York site was about four times larger than its New Jersey counterpart (Table 1). The sampling stations were established as close to the middle of the underpier area as possible: at Pier 40 (New York), approximately 90 m north of the southern edge of the platform and 130 m west of the shoreline; at Pier A (New Jersey), about 55 m north of the southern edge of the pier and 165 m east of the shoreline.

Pile field habitats were located in arrays of pilings (>6000 m^2); in New York, approximately 300 m south of Pier 40 and in New Jersey, about 450 m south of Pier A (Fig. 1 and Table 1). In 1993, stations in both locations were established on the outer set of pilings, adjacent to open-water areas to the north and >100 m from the shoreline. In 1994, due to construction, stations at the New York site were relocated to the center of the pile field, approximately 12 m from the 1993 location.

Open-water habitats were situated south of the underpier sites in large (>13,500 m^2), open areas adjacent to pile fields and/or large platforms or piers (Fig. 1 and Table 1). In 1994, due to the same construction activities that affected station locations in the New York pile field, the New York open-water site had to be relocated about 430 m

TABLE 1. Characteristics of the study sites in the lower Hudson River estuary in 1993 and 1994. See Fig. 1 for study site locations.

Location/Habitat-Year	Area m^2 × 10^3	Depth $\bar{x}$ (Range) m	Temperature Range °C	Salinity Range ‰	Dissolved Oxygen Range mg l^{-1}	Sediment Grain Size $\bar{x}$ (Range) % Fine (<63μm)
New York—1993						
Underpier	89.5	1.4 (1.2–1.7)	19.3–25.8	14.9–25.0	3.4–6.3	—
Open water	57	4.4 (3.8–5.0)	—	—	—	—
Pile field	13.5	3.6 (2.8–4.5)	16.3–25.2	16.0–28.1	2.6–9.0	—
New Jersey—1993						
Underpier	21.3	1.1 (1.0–1.1)	18.3–25.3	13.5–25.1	3.6–9.0	—
Open water	13.6	1.6 (1.5–1.8)	—	—	—	—
Pile field	6.1	1.6 (1.4–1.9)	19.1–25.2	16.8–25.5	1.7–6.2	—
New York—1994						
Underpier	89.5	1.7 (1.4–2.1)	12.2–26.2	7.0–23.8	2.9–9.1	95.5 (95.1–95.9)
Open water	41.1	3.9 (2.8–4.5)	10.7–26.3	13.6–25.6	0.2–7.1	98.4 (97.8–98.9)
Pile field	13.5	1.1 (0.7–1.6)	—	—	—	67.7 (51.7–93.8)
New Jersey—1994						
Underpier	21.3	1.3 (1.0–1.5)	12.4–26.4	6.3–23.7	3.6–10.9	92.8 (90.2–94.8)
Open water	13.6	1.4 (1.1–1.7)	—	—	—	93.0 (91.1–94.2)
Pile field	6.1	1.7 (1.4–2.1)	11.9–26.4	6.7–25.3	0.6–9.0	84.6 (74.7–92.6)

south, adjacent to Pier 32 (Fig. 1). In both New York and New Jersey, stations were located at least 25 m from adjacent pile fields or piers and 75 m from the shoreline.

PHYSICAL CHARACTERISTICS

Temperature (°C), salinity (‰), and dissolved oxygen (mg l^{-1}) were recorded using Hydrolab Datasonde 1 ($n = 2$) and Datasonde 3 Multiprobe ($n = 2$) dataloggers (Hydrolab Corporation). The probes were attached to concrete blocks (lowered to the bottom) such that the recordings were made about 25 cm above the substrate. In 1993 and 1994, the Hydrolabs were deployed in the New York and New Jersey underpier habitats and the New Jersey pile field habitat. In 1993, one was deployed in the New York pile field and in 1994, in the New York open-water site. In addition, surface temperature (°C) and salinity (‰) were measured with a standard mercury thermometer and refractometer at each site during each trap-day.

Light levels were recorded with a LiCor spherical quanta sensor (LiCor Corporation) in both 1993 (1000 EST, July 29; 1300, September 4; 1100, September 29) and 1994 (0900 EST, June 1; 1100, June 20; 1400 August 10). Measurements were made at depths of 0.5 m, 1.0 m, 2.0 m and where feasible, 3.0 m below the water surface at each site. Depths (±0.5 m) were measured ($n = 5$ times yr^{-1}) at each station and standardized to meters below mean low water (bmlw) by applying corrections for tidal heights at the Battery, New York (United States Department of Commerce 1992, 1993). Sediment grain-size was determined using one 3-cm diameter core from each of three box core samples collected at each habitat site during August 1994 ($n = 18$ cores). Particle size distribution of the sediment mineral fraction was measured by modifying the standard sieving procedure of Folk (1980) and determining the percentages by weight of fines (silt and clay grain size <63 μ) to coarse sediment (sand-sized and larger particles) (see Able et al. 1995 for details).

STUDY DESIGN

Trapping studies were conducted to determine relative distribution and abundance of juvenile fishes from late spring and early summer to fall in 1993 and 1994. Using techniques that have proven effective for collecting young-of-the-year (YOY) fishes (Able et al. 1995; Able and Hales 1997), single traps were deployed at each station ($n = 5$) in each habitat type ($n = 3$) at each location ($n = 2$) for a total of 30 traps per trial.

In 1993, hourglass-shaped traps, constructed of 2-mm mesh attached to welded steel frames (90 × 90 × 30 cm) were used. A 2.5-cm opening extended around the midsection of the trap, providing fish access to the traps from any direction in a horizontal plane. In 1994, the trap design was modified to enhance catch efficiency for recently settled fishes. These rectangular traps, also constructed of 2-mm mesh stretched over a welded steel frame (91 × 46 × 30 cm), had a 3-mm nylon mesh codend and a single opening (2.5 × 46 cm) at the end of a V-shaped throat. Traps were fished for 4- or 5-d trials, every 2 wk for 4 mo each year ($n = 8$ trials yr^{-1}; Table 2). At the start of each trial, unbaited traps were secured to pilings, pier supports, or floats in the open-water habitats and lowered to the bottom at each station. After approximately 24 h, each trap was retrieved, emptied of all fish, and redeployed. All fish were identified to species, counted, and standard (SL) and total (TL) lengths measured to the nearest mm. Nomenclature for *Pseudopleuronectes americanus* follows Cooper

TABLE 2. Summary of trapping effort (expressed as total number of trap days) at the study sites in the lower Hudson River estuary in 1993 and 1994.

	New Jersey			New York			
Trapping Period	Underpier	Pile Field	Open Water	Underpier	Pile Field	Open Water	Total
1993 June 21–October 8	162	163	153	162	162	161	963
1994 May 16–September 16	156	155	157	155	130	149	902
Total	318	318	310	317	292	310	1865

(1996). Catch data was standardized to catch per unit effort (CPUE), expressed as number of individuals captured per trap per day. To evaluate the relative catch efficiencies of the two trap designs, catches were compared by deploying three traps of each type during a 4-d trapping trial in August and September 1994. Traps were fished in the New York open-water and New Jersey pile field sites using methods described above.

STATISTICAL ANALYSIS

Assemblage structure was analyzed with a nonparametric multivariate approach that has been used to examine the impacts of environmental factors, including anthropogenic disturbance, on the structure of marine communities (Grey et al. 1990; Dawson-Shepherd et al. 1992; Clarke and Warwick 1994). This approach was selected, in part, because the proliferation of zero counts in the dataset prevented conformity with parametric assumptions. The method allows for the identification of differences in assemblage structure in groups of samples by applying group-average cluster analysis, nonmetric multidimensional scaling (n-m MDS), randomization tests analogous to multivariate analysis (MANOVA), as well as the calculation of similarity percentages (SIMPER analysis), which describe the contribution of each species to the average dissimilarity between groups of samples. All analyses were performed using the PRIMER program (version 4.01b) and Systat (version 5.0). The CPUE of each fish species composing greater than 1% of the total abundance in any sample was 4th-root transformed to down-weight numerically dominant species. The transformed mean CPUE was used to construct Bray-Curtis similarity matrices (Bray and Curtis 1957).

Seasonal changes in assemblage structure within years were identified by performing group-average cluster analysis and n-m MDS on Julian day by species matrices constructed from the transformed mean CPUE of the species on each trap day within each year. Stress coefficients and Shepard diagrams were examined to identify degenerate solutions in all n-m MDS ordinations. Distinct sample groups indicated by the cluster analysis and n-m MDS ordination were identified as seasonal periods with different assemblage structures. Species contributions to the average dissimilarity of sample groups ($\bar{x}\ \delta_i$) as well as $\bar{x}\ \delta_i$/standard deviation (SD) δ_i ratios were calculated (SIMPER analysis) to identify important discriminating species, that is, species with high $\bar{x}\ \delta_i$, high $\bar{x}\ \delta_i/\mathrm{SD}(\delta_i)$ (see Clarke 1993).

Habitat-specific differences in assemblage structure were identified by constructing station by species similarity matrices from the transformed mean CPUE of the species at each of the 30 stations within each seasonal period. Cluster analysis and n-m MDS were performed on the matrices to construct graphical representations of station groups. Two-way analysis of similarity (ANOSIM) tests, with location and habitat type as factors, were applied to the matrices to test for significant differences ($p < 0.05$) in assemblage structure within each seasonal period. All ANOSIM tests were performed with 20,000 simulations (see Clarke 1993). The species responsible for differences in assemblage structure were determined by performing SIMPER analysis.

Results

PHYSICAL CHARACTERISTICS

Station depths were subtidal, generally <2.2 m below mean low water (bmlw) (Table 1). The only sites that were somewhat deeper (>2.8 m bmlw) were the New York open-water sites (1993 and 1994) and the New York pile field (1993) (Table 1). Temperatures exhibited broad seasonal fluctuations typical of Middle Atlantic Bight estuaries but varied little between habitats (Table 1). Average temperatures were lowest during the first sampling period in each year (16°C, late June 1993; 11°C, mid May 1994) peaking at 26°C in late August 1993 and late July 1994 before declining in the fall (Fig. 2a). Salinities were also typical of Middle Atlantic estuaries with significant tidal and riverine influences, ranging from 13‰ to 28‰ from late June through September, with somewhat lower values (7–24‰) recorded in late May and early June 1994 (Table 1). Although generally consistent throughout the study area, salinities were somewhat higher at the deeper sites, for example, 1994 New York open-water site averaged 21‰ as compared with 16–17‰ at the shallower sites (Able et al. 1995). Both temperature and salinity exhibited

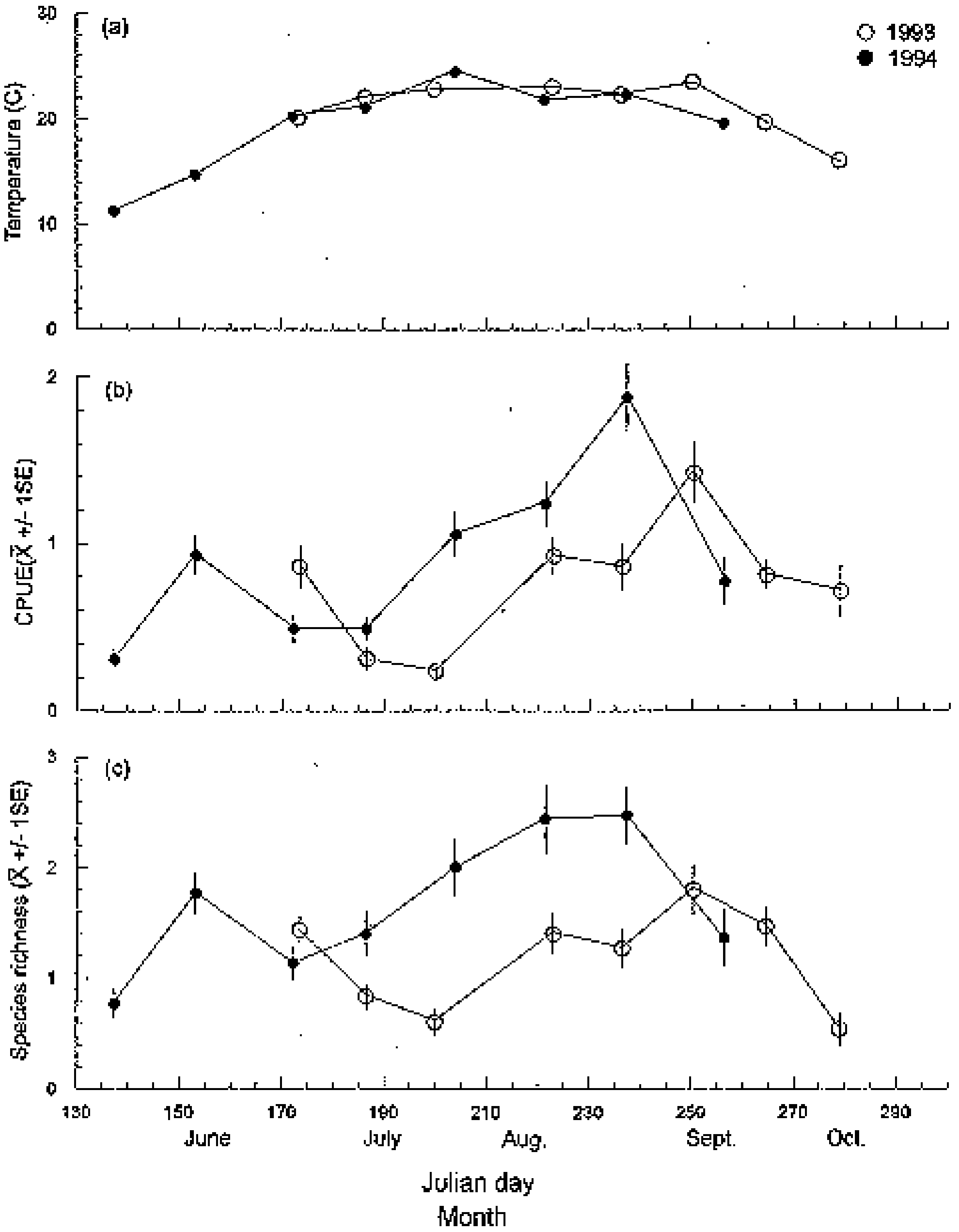

Fig. 2. Seasonal patterns of (a) temperature, (b) fish abundance (expressed as mean catch per unit effort [CPUE]), and (c) species richness at the stations in the lower Hudson River estuary in 1993 and 1994.

diel variations (mean change 1.4°C and 5‰ respectively) as a result of tidal fluctuations that averaged 1.4 m d^{-1}.

Other physical parameters, including underwater light levels, dissolved oxygen concentrations and sediment grain size varied by habitat type. In the open-water and pile field habitats, average light intensity was relatively high, ranging from >566 μE m^{-2} s^{-1} at depths of 0.5 m to >9 μ E m^{-2} s^{-1} on the bottom. In contrast, light levels in the underpier habitats were <0.12 μ E m^{-2} s^{-1} throughout the water column. In both 1993 and 1994, dissolved oxygen minima were generally higher in underpier habitats than in the pile field or open-water sites (Table 1). This pattern was particularly evident during 1994 when dissolved oxygen concentrations always exceeded 2.8 mg l^{-1} in the underpier habitats but fell to hypoxic levels <1 mg l^{-1} in the New York open-water and New Jersey pile field sites (Table 1). Fine sediments (<63 μ, silt and clay) were characteristic of both underpier and open water habitats ($>90\%$ fine fraction) while sediment samples collected in the pile fields were composed of a significantly lower proportion of fine sediments (51–92.6% fine fraction: $p < 0.05$, Kruskal-Wallis test, $w = 13.5$, $df = 5$) and often contained fragments of concrete and wood (Table 1).

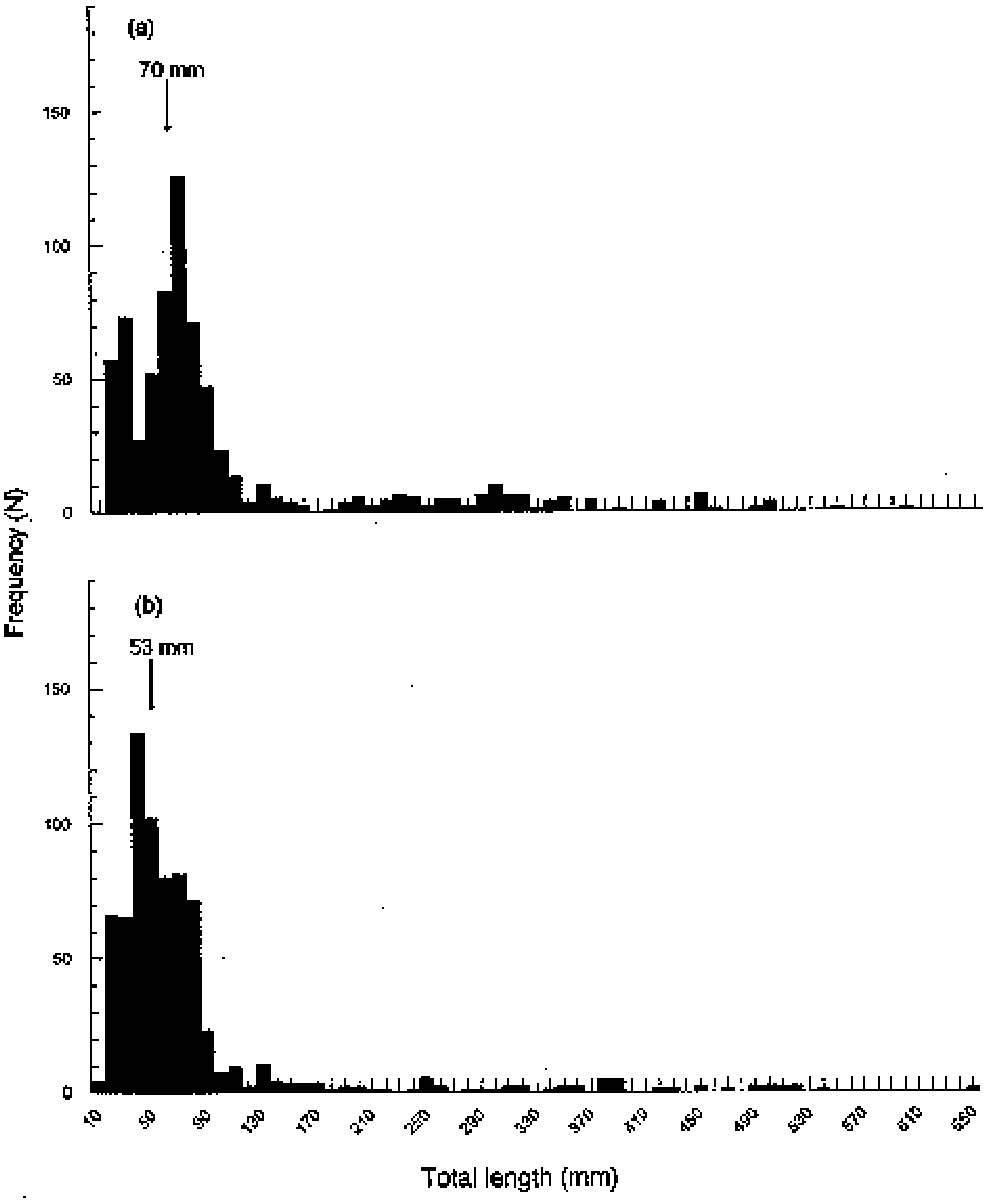

Fig. 3. Composite length frequency for fishes collected in traps in the lower Hudson River estuary in (a) 1993 and (b) 1994. Arrows and associated values indicate median.

PATTERNS OF FISH SIZE, ABUNDANCE, AND SPECIES COMPOSITION

During the 2 yr of the study, nearly 1500 fishes were collected, most of which were small juveniles (<100 mm total length, TL), many being recently settled individuals <50 mm TL (24%, 1993; 45%, 1994) (Fig 3). Although comparison of the two trap types indicated there were some differences in catch efficiencies (the 1993 type caught more individuals than the 1994 type, $p < 0.01$), with the exception of *Morone saxatilis* at one site, there were no significant differences in abundance of the dominant fish species ($p > 0.05$, ANOVA). Additionally, the fish assemblages sampled by the two trap types were not significantly different ($p > 0.05$, one-way ANOSIM) and the length frequencies were similar. As a result, we feel that comparisons of size and assemblage structure between the 2 yr are appropriate. The number and catch rates (mean CPUE) of fishes varied annually (Table 3; Fig. 2c), perhaps due in part to the differences in sampling periods, trap type, attraction to structure

TABLE 3. Rank abundance and lengths of fishes collected in traps in the lower Hudson River estuary in 1993 and 1994. (Rank abundance based on mean catch per unit effort [x̄ CPUE]).

Species	Rank Abundance (x̄ CPUE)		Number Collected		Median Total Length (Range) mm	
	1993	1994	1993	1994	1993	1994
Morone saxatilis	1 (0.24)	1 (0.22)	207	188	67 (44–134)	71 (17–165)
Microgadus tomcod	4 (0.10)	3 (0.17)	103	160	70 (23–236)	49 (31–225)
Anguilla rostrata	3 (0.11)	5 (0.07)	94	55	300 (150–600)	358 (130–650)
Tautogolabrus adspersus	5 (0.10)	6 (0.05)	84	42	84 (21–190)	18 (14–127)
Pseudopleuronectes americanus	8 (0.02)	4 (0.09)	15	80	64 (40–280)	50 (12–141)
Syngnathus fuscus	6 (0.03)	7 (0.04)	25	31	128 (73–229)	110 (58–190)
Centropristis striata	13 (0.01)	2 (0.21)	4	177	42 (31–51)	41 (17–81)
Gobiosoma bosc	7 (0.02)	10 (0.01)	19	9	26 (16–48)	32 (17–49)
Gobiosoma ginsburgi	2 (0.11)	— (0.00)	92	0	30 (16–42)	—
Menidia menidia	10 (0.01)	12 (0.01)	6	6	77 (66–85)	72 (65-80)
Tautoga onitis	9 (0.01)	16.5 (0.00)	10	1	108 (54–160)	61 —
Bairdiella chrysoura	17 (0.00)	9 (0.01)	1	9	34 —	47 (40–76)
Conger oceanicus	13 (0.01)	14 (0.00)	5	4	94 (72–300)	95 (36–102)
Etropus microstomus	14 (0.00)	13 (0.01)	4	5	39 (36–49)	34 (22–47)
Prionotus evolans	— (0.00)	8 (0.01)	0	12	—	29 (19–67)
Myoxocephalus aenaeus	13 (0.01)	15.5 (0.00)	6	2	32 (26–94)	28 (16, 40)
Hypsoblennius hentz	11 (0.01)	— (0.00)	5	0	21 (18–31)	—
Anchoa mitchilli	— (0.00)	11.5 (0.01)	0	8	—	60 (29–84)
Morone americana	— (0.00)	11.5 (0.01)	0	8	—	147 (73–205)
Urophycis regia	15.5 (0.00)	15.5 (0.00)	2	2	176 (139, 212)	60 (59, 60)
Paralichthys dentatus	15.5 (0.00)	— (0.00)	2	0	301 (292, 310)	—
Peprilus triacanthus	— (0.00)	16.5 (0.00)	0	1	—	— 16
Chaetodon ocellatus	17 (0.00)	— (0.00)	1	0	— 48	—
Opsanus tau	17 (0.00)	— (0.00)	1	0	—	—
Total fish	(0.79)	(0.91)	686	800	70 (18–600)	53 (12–650)

provided by traps, or larval supply. In 1993, from late June to early October, 686 fishes were collected with CPUE averaging 0.79 ± 0.05 individuals trap^{-1} d^{-1} (Table 3). In 1994, when trapping began in mid May and ended in September, catches were higher (n = 800; x̄ CPUE = 0.91 ± 0.05 individuals trap^{-1} d^{-1}; Table 3). Seasonal patterns of fish abundance were relatively similar in both years: high catches in early (1994) and mid (1993) June before peaking in mid to late August (Fig. 2b).

Faunal diversity was fairly broad with 24 species of fishes, representing 19 families, collected during the 2 yr of the study (Table 3). In each year, however, a small number of species dominated the collections, with the five most abundant accounting for over 80% and the 10 most abundant, 95% of the total catch. Several species were consistent faunal components during both years (Table 3). Young-of-the-year *Morone saxatilis* were the most abundant, accounting for 30% and 24% of the total catch in 1993 and 1994 respectively. Young-of-the-year *Microgadus tomcod* were also collected in large numbers, representing 15% (1993) and 20% (1994) of the catch. Juvenile *Anguilla rostrata* also contributed substantially to the catch (14%, 1993; 7%, 1994). Although not quite as abundant, *Syngnathus fuscus* occurred in relatively large numbers during both years (Table 3).

Some species exhibited striking annual differences in abundance (Table 3). *Gobiosoma ginsburgi,* which ranked second in average abundance in 1993 was absent in 1994. In 1994, only half as many *Tautogolabrus adspersus* were collected as compared with 1993 and while age 1+ fish (median TL = 84 mm) dominated the 1993 catch, nearly all fish collected during the following year were recently settled individuals (median TL = 18 mm). Young-of-the-year *Centropristis striata,* which were rare in 1993 (n = 4) were collected in large numbers in 1994 (n = 177) and ranked second in abundance. *Pseudopleuronectes americanus* were five times as abundant in 1994 as in 1993.

FISH ASSEMBLAGE STRUCTURE

Seasonal Patterns

Two seasonal assemblages of fishes were identified in the study area based on analysis of assemblage structure (Fig. 4a, b). Although more gradual in 1993 than in 1994, the transition from species assemblages characteristic of the earlier part of the summer to those characteristic of the later part of the season was supported by cluster analysis. In 1994, two distinct groups were identified (Fig. 4b). The first group included samples collected from May through early July (designated early summer, Julian days 136–188), and the second included samples from late July through September (designated late summer, Julian days 200–258). In 1993, two groups were also identified (Fig. 4a), with a period of overlap in July (Julian days 185–201). Examination of the data showed that although the abundances of all species were low during July, the samples were dominated by species characteristic of the early summer period. Consequently, in 1993, samples from June through July (Julian days 172–201) were included in the early summer group, while those collected from August through the beginning of October (Julian days 221–280) constituted the late summer group (Fig. 4a). *Microgadus tomcod* and *P. americanus* dominated the early summer collections in both years and were also the only species abundant during that period that were also important discriminating species (high x̄ δ_i, high x̄ $\delta_i/\mathrm{SD}[\delta_i]$, Table 4). Although more abundant during late summer, *T. adspersus* and *A. rostrata* were also typical (high x̄ S_i, high x̄ $S_i/\mathrm{SD}[S_i]$) of samples collected in the early summer in 1993 and 1994 respectively (Table 4).

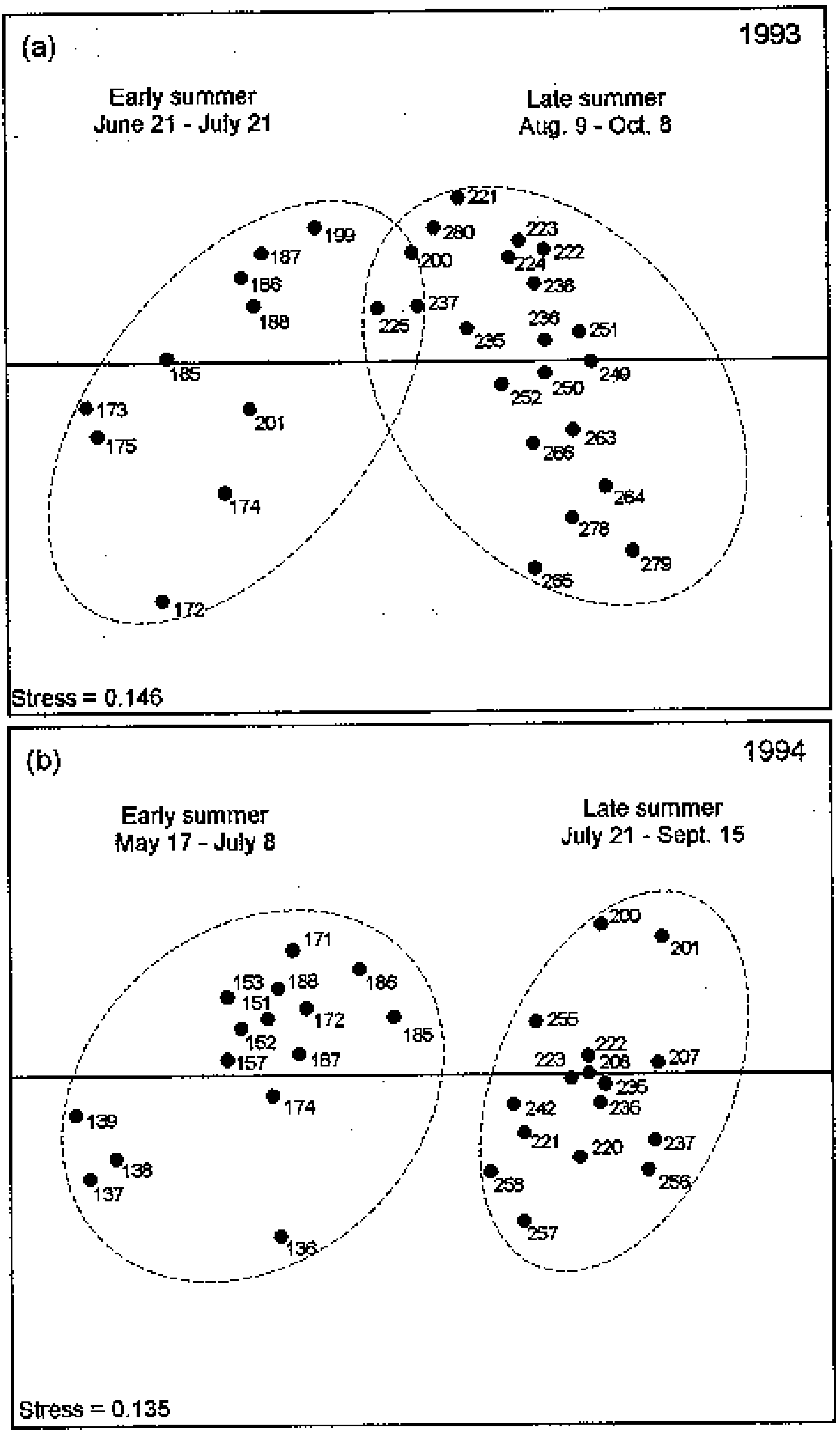

Fig. 4. Seasonal patterns of fish assemblage structure in the lower Hudson River estuary in (a) 1993 and (b) 1994 based on n-m MDS ordination of Bray-Curtis similarities computed from 4th-root-transformed abundances of fish species collected in traps. Dashed lines indicate samples that formed groups in group-average cluster analysis.

Species richness (mean number of fish species collected per station per trial) was higher during late summer, particularly in 1994 (Fig. 2c). During this period, the species assemblage was dominated by *M. saxatilis,* which ranked first in 1993 and second in 1994 in its contribution to the dissimilarity of the seasonal sample groups (Table 4). Also consistently more abundant were *S. fuscus* and, as in-

TABLE 4. Average abundance (expressed as mean catch per unit effort [$\bar{x}$ CPUE]) and percent contribution of fishes to the average dissimilarity of early and late summer sample groups indicated by cluster analysis and ordination of trap collections in the lower Hudson River estuary in 1993 and 1994. (See Fig. 4 for seasonal ordination; 1993, early summer: June 21–July 21, late summer: August 9–October 8; 1994, early summer: May 17–July 8, late summer: July 21–September 15.)

1993 Average Dissimilarity = 69.81				1994 Average Dissimilarity = 69.96			
	Abundance ($\bar{x}$ CPUE)				Abundance ($\bar{x}$ CPUE)		
Species	Early Summer	Late Summer	Percent Contribution	Species	Early Summer	Late Summer	Percent Contribution
Morone saxatilis	0.000	0.322[a]	17.64[b]	*Centopristis striata*	0.000	0.411[a]	18.14[b]
Microgadus tomcod	0.332[a]	0.010	13.58[b]	*Morone saxatilis*	0.016	0.424[a]	13.71[b]
Gobiosoma ginsburgi	0.011	0.145	9.25[b]	*Microgadus tomcod*	0.318[a]	0.015	13.17[b]
Anguilla rostrata	0.046	0.128[a]	8.34[b]	*Pseudopleuronectes americanus*	0.102[a]	0.071	7.24[b]
Pseudopleuronectes americanus	0.034[a]	0.007	8.14[b]	*Tautogolabrus adspersus*	0.002	0.096	7.11
Syngnathus fuscus	0.004	0.036	6.46[b]	*Syngnathus fuscus*	0.015	0.056	7.02[b]
Myoxocephalus aenaeus	0.019	0.000	6.36[b]	*Anguilla rostrata*	0.051[a]	0.078[a]	5.50
Gobiosoma bosc	0.000	0.030	5.62	*Gobiosoma bosc*	0.012	0.009	4.32
Tautogolabrus adspersus	0.065[a]	0.122[a]	5.51	*Prionotus evolans*	0.000	0.028	4.14
Tautoga onitis	0.006	0.014	4.57	*Morone americana*	0.011	0.007	3.74
Conger oceanicus	0.019	0.000	3.83	*Bairdiella chrysoura*	0.000	0.022	3.34
Menidia menidia	0.000	0.010	2.43	*Anchoa mitchilli*	0.007	0.011	3.20
Fish	0.548	0.888		Fish	0.566	1.254	

[a] Species indicated as typical ($\bar{S}_i$ and $\bar{S}_i/SD(S_i \geq 1)$ of samples within the seasonal period by the SIMPER analysis.

[b] Species important in the discrimination of the seasonal sample groups (i.e., discriminating species; $\bar{\delta}_i$ and $\bar{\delta}_i/SD(\delta_i) \geq 1$).

dicated previously, *T. adspersus* and *A. rostrata*. Of these, only *A. rostrata* was typical of the late summer collections, while along with *M. saxatilis*, only *S. fuscus* was an important discriminating species during both 1993 and 1994 (Table 4). Species dominance in late summer assemblages was influenced by annual variability. In 1993 *G. ginsburgi*, and in 1994 *C. striata* were important discriminating species (Table 4). *Centropristis striata* made the largest contribution (>18%) to the dissimilarity of the seasonal sample groups in 1994 (Table 4).

Location and Habitat Patterns

Location and habitat type affected fish assemblage structure during both seasonal periods in 1993 and 1994 (Table 5). Of these two factors, however, habitat type accounted for the largest proportion of the variation in assemblage structure during three of the four seasonal periods: early summer 1994 and late summer in both 1993 and 1994 ($R > 0.493$; Table 5). In those three seasons, underpier stations were clearly differentiated from those in the pile field and open-water habitats in the ordination and cluster analyses (Fig. 5b, c, d). During the early summer period in 1993, habitat-specific station groups were not clearly delineated in the analysis (Fig. 5a) and the effect of location on assemblage structure was greater than that of habitat type (Table 5).

Average species richness and fish abundance were consistently higher and the seasonally dominant species typically were more abundant in New York than in New Jersey during both years (Table 6). Species characteristic of early summer assemblages that were more abundant in New York included *Anguilla rostrata, Microgadus tomcod* (1993 and 1994), and age 1+ *Tautogolabrus adspersus* (1993). Most of the species dominant during the late summer, for example, *A. rostrata* in 1993 and 1994; *Gobiosoma ginsburgi*, age 1+ *T. adspersus*, and *G. bosc* in 1993; and *Centropristis striata* in 1994, were also more abundant in New York. In contrast, age-0 *T. adspersus*, which were important components of the late summer assemblage in 1994, were collected in greater numbers in New Jersey. Abundances of young-of-the-year *Pseudopleuronectes americanus* and *Morone saxatilis* in New York and New Jersey varied between seasons and between years (Table 6). Recently settled *P. americanus* were more abundant at the New Jersey sites during early summer 1994 while more were collected in New York sites during the late summer of that year. Larger

TABLE 5. Results of two-way ANOSIM for the effects of location and habitat type on fish assemblage structure in the lower Hudson River estuary during the early and late summer periods in 1993 and 1994.

Season	Year	Factor	R
Early summer	1993	location	0.556***
		habitat type	0.183**
	1994	location	0.384***
		habitat type	0.493***
Late summer	1993	location	0.167*
		habitat type	0.717***
	1994	location	0.328**
		habitat type	0.600***

* $p \leq 0.05$.

** $p \leq 0.01$.

*** $p \leq 0.001$.

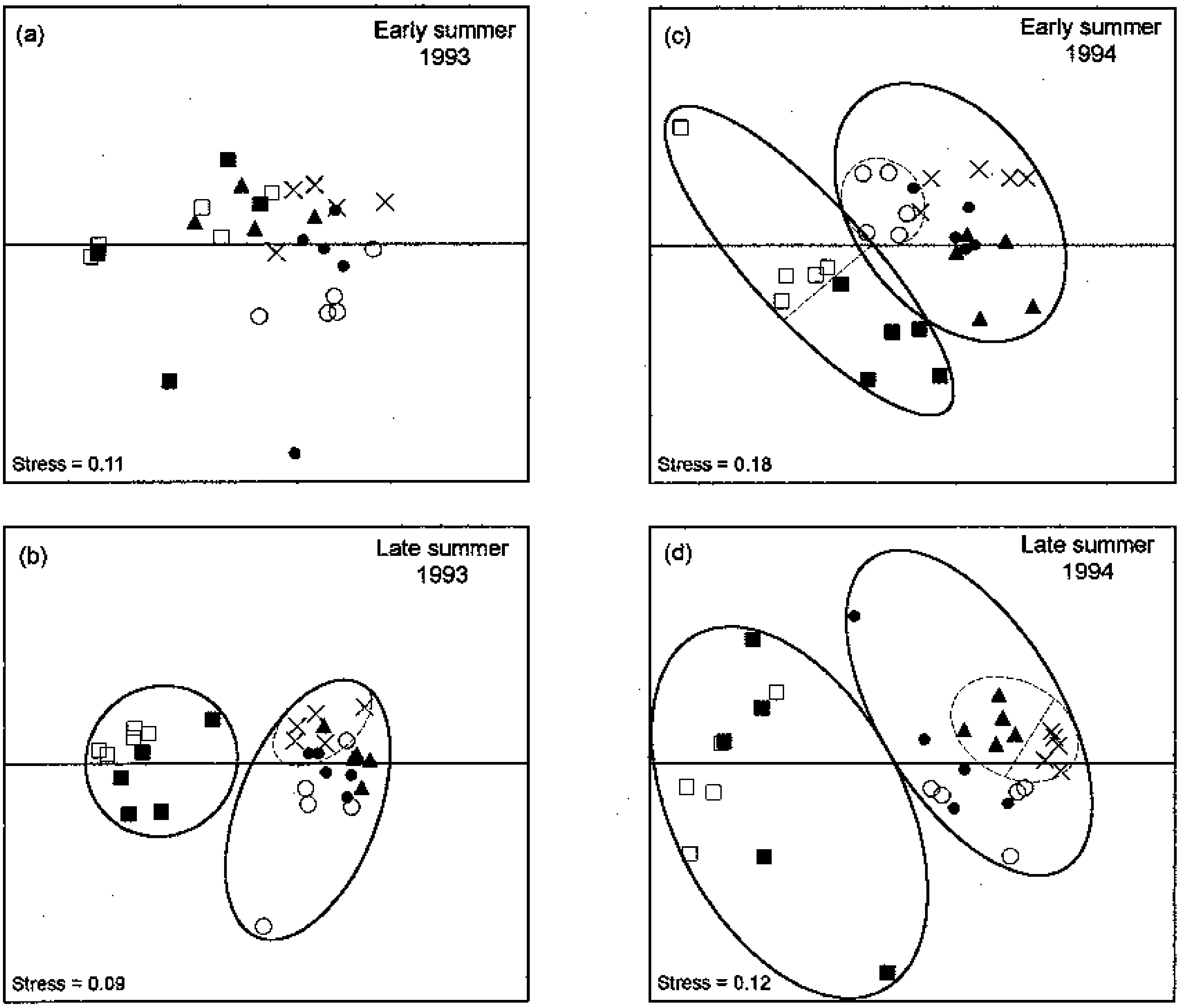

Fig. 5. Habitat station groups during the early and late summer periods in 1993 and 1994 based on n-m MDS ordination of Bray-Curtis similarities computed from 4th-root transformed abundances of principle fish species collected in traps at the 30 stations. (■ New Jersey underpier, □ New York underpier, ● New Jersey pile field, ○ New York pile field, ▲ New Jersey open water, X New York open water. Solid lines = major cluster groups; dashed lines = cluster subgroups.

numbers of *M. saxatilis* were collected in New Jersey than New York during the late summer in 1994 in contrast with the pattern of distribution evident in 1993.

Habitat effects, which were particularly evident during early summer 1994 and late summer periods in both years (Table 5 and Fig. 5b, c, d) were related primarily to differences in assemblage structure between the underpiers and the other two habitat types: pile fields and open water. The average dissimilarity between assemblages characteristic of the underpier station groups and the other two habitat types ranged from 52.5 to 93.8 ($\bar{x}$ = 75.8%). In contrast, dissimilarities between pile field and open-water station groups ranged from 40.6 to 53.3% ($\bar{x}$ = 46.3%).

The habitat effects were primarily related to low fish abundance and low species richness under piers as compared with the open-water and pile field habitats (Table 6). Only *A. rostrata* was consistently collected under the large platforms, accounting for 28–84% of the total catch in the underpier habitats, while contributing <8% to the total numbers of fishes in the open-water and pile fields. With the exception of *M. tomcod* and *G. bosc*, YOY individuals of the dominant species (e.g., *M. saxatilis*, *G. ginsburgi*, *C. striata*, and *P. americanus*) were rarely collected at the underpier sites although they were abundant in the open water and pile field habitats (Table 7). Young-of-the-year *M. tomcod* was commonly collected under piers during early summer but were less abundant there than in the pile fields and open water.

Site-specific differences in assemblage structure were also evident, and with the exception of early summer 1994, were primarily confined to the open-water and pile field sites (Fig. 5b, c, d). However, few species appeared to show consistent pat-

TABLE 6. Average abundance of important discriminating species and their percent contribution to the average dissimilarity of New York and New Jersey fish assemblages collected in traps in the lower Hudson River estuary during early and late summer periods in 1993 and 1994.

Early Summer 1993 Average Dissimilarity = 65.9				Early Summer 1994 Average Dissimilarity = 55.1			
	Abundance ($\bar{x}$ CPUE)				Abundance ($\bar{x}$ CPUE)		
Species	New Jersey	New York	Percent Contribution	Species	New Jersey	New York	Percent Contribution
Microgadus tomcod	0.199	0.343	29.3	*Microgadus tomcod*	0.285	0.360	21.8
Anguilla rostrata	0.027	0.057	17.4	*Anguilla rostrata*	0.009	0.093	21.9
Tautogolabrus adspersus	0.003	0.120	11.6	*Pseudopleuronectes americanus*	0.107	0.098	17.7
Fish	0.297	0.655		Fish	0.459	0.668	

Late Summer 1993 Average Dissimilarity = 66.7				Late Summer 1994 Average Dissimilarity = 64.0			
	Abundance ($\bar{x}$ CPUE)				Abundance ($\bar{x}$ CPUE)		
Species	New Jersey	New York	Percent Contribution	Species	New Jersey	New York	Percent Contribution
Morone saxatilis	0.521	0.201	17.6	*Morone saxatilis*	0.308	0.551	18.7
Anguilla rostrata	0.046	0.230	16.0	*Centropristis striata*	0.177	0.638	17.8
Gobiosoma ginsburgi	0.154	0.168	14.2	*Tautogolabrus adspersus*	0.144	0.037	10.6
Tautogolabrus adspersus	0.029	0.206	10.3	*Anguilla rostrata*	0.056	0.099	10.5
Gobiosoma bosc	0.019	0.048	10.0	*Pseudopleuronectes americanus*	0.050	0.101	8.4
Fish	0.877	1.043		Fish	0.850	1.670	

tens in relative abundance between the pile field and open-water sites. During early summer 1994, assemblages characteristic of the underpier sites were different due to the high relative abundances of *A. rostrata* and *M. tomcod* at the New York and New Jersey sites respectively (Fig. 5c and Table 7). Also during this period, the largest numbers of *A. rostrata* and *G. bosc* were collected at the New York pile field stations, which formed a distinct group in the analysis (Fig. 5c).

During the late summer period, the New York open-water areas were the only sites to have unique assemblage structures in both 1993 and 1994 (Fig. 5b, d). Species richness was consistently high (Table 7) and the number of dominant species was very abundant at each of the two sites (in 1993, *G. ginsburgi, G. bosc,* and *S. fuscus*; in 1994, *C. striata, P. americanus,* and *S. fuscus*). Although the New Jersey open-water site also formed a distinct station group in late summer 1994 (Fig. 5d), recently settled *T. adspersus* were the only constituents of the assemblage that were most abundant at the New Jersey site.

Discussion

SPECIES COMPOSITION

The fish fauna collected by trapping in the lower Hudson River estuary during 1993 and 1994 were relatively diverse and generally consistent with the species composition expected in this section of the harbor-estuary (see for example Beebe and Savidge 1988). The pelagic component of the fauna (e.g., *Anchoa mitchilli* and *Menidia menidia*) were not well represented because these forms are not collected effectively by traps. On the other hand, several species that are attracted to structure (e.g., *Centropristis striata* and *Tautogolabrus adspersus*) and thus possibly attracted to traps may have higher relative abundance. Regardless, the predominance of young-of-the-year demersal fishes, many of them newly settled individuals, provides strong evidence that despite extensive anthropogenic disturbance in the system, this portion of the estuary is a nursery area for a number of species.

Patterns of use in the lower Hudson River estuary as nursery habitat are varied. Several species that spawn in brackish or freshwater areas move into the lower estuary as they grow. Young-of-the-year *Microgadus tomcod,* for example, composed a significant portion of our trap collections in late spring and early summer, which is consistent with results of other surveys (McLaren et al. 1988; Dew and Hecht 1994). This species spawns upriver in midwinter and, depending on freshwater flow regimes, can be transported into the estuary during the spring (Dew and Hecht 1994). The disappearance of YOY *M. tomcod* from our study sites in July probably reflects the upriver migration that occurs in the summer, possibly in response to increasing water temperatures as well as freshwater flow (Klauda et al. 1988; Dew and Hecht 1994).

The timing of the appearance of YOY *Morone saxatilis* at the study sites in mid-summer is in agreement with the pattern described by Dovel (1992)

TABLE 7. Abundance of important discriminating fish species in lower Hudson River estuary station groups during the early and late summer periods in 1993 and 1994. (See Fig. 5 for station groups.)

Late Summer 1993	Abundance ($\bar{x}$ CPUE)		
Species	Underpier	Pile Field and New Jersey Open Water	New York Open Water
Morone saxatilis	0.000	0.648	0.219
Anguilla rostrata	0.402	0.004	0.011
Gobiosoma ginsburgi	0.005	0.165	0.462
Tautogolabrus adspersus	0.005	0.231	0.000
Gobiosoma bosc	0.048	0.020	0.043
Syngnathus fuscus	0.000	0.037	0.128
Fish	0.490	1.232	1.082
Species richness	2.000	4.267	5.600

Early Summer 1994	Abundance ($\bar{x}$ CPUE)			
Species	New Jersey Underpier	New York Underpier	New York Pile Field	Open Water and New Jersey Pile Field
Anguilla rostrata	0.014	0.122	0.130	0.014
Microgadus tomcod	0.198	0.089	0.322	0.439
Pseudopleuronectes americanus	0.000	0.000	0.131	0.161
Gobiosoma bosc	0.000	0.000	0.061	0.005
Fish	0.271	0.236	0.709	0.721
Species richness	2.200	2.200	4.200	3.733

Late Summer 1994	Abundance ($\bar{x}$ CPUE)			
Species	Underpier	Pile Field	New Jersey Open Water	New York Open Water
Morone saxatilis	0.012	0.322	0.727	1.183
Centropristis striata	0.025	0.276	0.215	1.627
Tautogolabrus adspersus	0.019	0.038	0.341	0.091
Anguilla rostrata	0.167	0.059	0.012	0.000
Pseudopleuronectes americanus	0.006	0.090	0.102	0.160
Syngnathus fuscus	0.000	0.102	0.000	0.154
Fish	0.317	1.007	1.482	3.430
Species richness	3.000	5.200	5.200	7.400

in which downstream migration into the estuary occurs following spring spawning upriver (Able and Fahay 1998). The movement of young fish into shallower nearshore habitats is also consistent with findings from other estuaries such as the Potomac River where these movements may be related to greater prey abundance or increased feeding success (Boynton et al. 1981).

Other species that utilize New York Harbor or the lower Hudson River as a nursery area are derived from spawning populations in the adjacent ocean. *Centropristis striata,* for example, spawns in the Middle Atlantic Bight from April through November with a portion of the young-of-the-year remaining offshore while another portion moves into estuaries, including the Hudson River (Able et al. 1995). Another study has suggested they probably remain in specific areas (Able and Hales 1997) until they leave in the fall. Settlement occurs at sizes ranging from 10 mm TL to 16 mm TL (Able et al. 1995), which is close to the smallest size (17 mm TL) collected at our sites in mid July. *Anguilla rostrata,* which spawn in the Sargasso Sea, are carried into estuaries along the entire northeast coast (Able and Fahay 1998) and was one of the few species collected that was composed primarily of large juveniles and adults. The adaptability of this species in surviving in widely diverse habitats (Helfman et al. 1987) is consistent with their occurrence in each of the three habitat types in the lower estuary.

Finally, the occurrence of other species is the result of recruitment from local populations. *Pseudopleuronectes americanus,* for example, migrate from offshore to spawn in late winter in areas of the New York-New Jersey Harbor Estuary (Phelan 1992), with young-of-the-year utilizing a variety of areas in this system as nursery habitats (Goldberg et al. unpublished data). *Gobiosoma ginsburgi* is found in estuaries but also in nearshore coastal habitats with newly settled individuals collected in both areas from mid-summer through fall (Duval and Able 1998). In contrast *G. bosc* is strictly estuarine dependent, with spawning in New Jersey estuaries beginning in June and settlement occurring at about 8–13 mm TL (Able and Fahay 1998), close to the size of the smallest individuals (16 mm TL) collected at our study sites in 1993.

Temporal differences in occurrence and abundance were characteristic of many of the species in the lower Hudson River estuary. The most striking example of interannual variability was for *C. striata,* which while rarely collected in 1993, was a dominant species in 1994, perhaps due to differences in larval supply. The pattern was reversed, however, for *G. ginsburgi,* which ranked fourth in overall abundance in 1993 but was absent from the collections in 1994. Young-of-the-year *P. americanus* ranked only eighth in 1993 but were fourth in 1994, perhaps due to the earlier initiation of trapping. Although interannual variability in catch rates of certain species like *C. striata* and *P. americanus* may be related, in part, to the changes in trap design between years, the experiments conducted to compare these traps indicated that this was not a significant factor.

Seasonal changes in species composition were also evident, particularly in 1994 when two separate assemblages were identified, one in late spring and early summer and a second one in late summer and early fall. This pattern was less distinct in 1993, when perhaps, due to the later start of sampling, some of the YOY spring fauna (e.g., *P. americanus*) were less well represented in the collections. During late summer, as the number of fishes and species increased, the assemblage was based on YOY that consistently move into the lower estuary at that time (e.g., *M. saxatilis* [Dovel 1992]), as well as others that occurred less consistently and resulted from spawning in the estuary during the summer (e.g., *G. bosc* [Able and Fahay 1998]; *S. fuscus* [Campbell and Able 1998]), or were transported into the system from offshore (e.g., *C. striata* [Able et al. 1995]). In 1994, the coincident appearance of recently settled *C. striata, T. adspersus,* and *P. evolans* during mid-July in the lower estuary contributed to the significant distinction between early and late summer assemblages.

HABITAT USE

While the structure of fish assemblages was affected by location, perhaps due to differences in depth at some sites, the most significant influence was related to habitat type, specifically the habitats under piers. In both 1993 and 1994, in three of the four seasonal assemblages, the underpier fauna were distinct regardless of location. This distinction reflects, in part, the decreased species diversity and lower abundance of fishes as compared with the pile fields and open-water habitats. Of the 25 species collected during the 2 yr, only 14 occurred under the piers. With the exception of *A. rostrata,* which accounted for 60% of the total number of fish collected under the piers, and *M. tomcod,* which accounted for 19%, other species occurred only incidentally.

In other surveys of the open-water and underpier areas of the lower Hudson River estuary, a small number of species were the principle constituents of seasonal collections. For example, *M. saxatilis, P. americanus, M. americanus,* and *M. tomcod* composed about 88% of the fish collected from December to March in 1982–1983 as part of the Westway survey (United States Army Corps of Engineers 1984) and about 90% of the collection during the same months in 1986–1987 at Pier 76 (Stoecker et al. 1992). As part of the Westway survey, Cantelmo et al. (1985) found no significant differences in abundance of *M. saxatilis* between interpier (open-water) and underpier habitats; however, in the Pier 76 study, distribution was relatively habitat specific with more fish, primarily *A. rostrata, M. americanus,* and *P. americanus* collected in the underpier area than in the interpier habitat where *M. saxatilis* was more abundant (Stoecker et al. 1992). From mid-June through August, comparable to our sampling period, very few fish were collected in either habitat at Pier 76 (Energy and Environmental Analysts 1988). Since little length frequency data are presented for either study, comparisons with our findings on habitat use by newly settled and YOY fishes is difficult.

In the current study, the consistently depauperate nature of the fish fauna under piers of different sizes in both years indicates that these habitats are less frequently used as nurseries than the adjacent pile fields and open water areas. While this could be related to a variety of factors (i.e., an over abundance of predators), comparisons of growth rates across these three habitats suggests that the fish under the piers are not feeding (Able et al. 1995). The reasons for this are not completely clear but may be related to lack of suitable prey or little light penetration, which may, along with turbidity, affect the ability of fishes to feed and/or indirectly limit food availability (Benfield and Minello 1996). Our measurements indicate that light levels at the water surface in the open-water and pile field habitats were several orders of magnitude higher than at the water surface under the piers. Perhaps those species that rely primarily on vision and feed during the day, for example, *P. americanus* (Pearcy 1962; Olla et al. 1969), avoid these underpier habitats. This would account for the differences in relative abundance as compared with the open-water and pile field habitats. Although some fish species can feed under conditions equivalent to dusk, feeding activity decreases significantly at these levels for most visual feeders (Blaxter 1970). Juvenile *Cynoscion regalis,* for example, when held under dark conditions in the laboratory, reduced feeding on *Neomysis americana,* switching to less efficient nonvisual encounters to detect and ingest prey (Grecay and Targett 1996). In contrast, a nocturnal species such as *A. rostrata,* which relies on other senses such as olfaction (Miles 1968; for review on *Anguilla* spp. see Tesch 1975, 1977), was one of the dominant species under the piers. The same reliance on other sensory cues is also true for *M. tomcod* (Herrick 1904), which was the second of the two dominant underpier species. Other explanations for the low abundance of demersal fishes, that is, lower prey availability or higher predator abundance, have yet to be investigated.

In summary, it is apparent that at least from late spring through fall, young-of-the-year and newly settled juveniles of a range of fishes are relatively abundant in the open-water and pile field areas of the lower Hudson River estuary, indicating that these serve as good nursery habitats. This is not the case for the areas under piers on either the New York or New Jersey shorelines which, based on the sparse numbers of the early life-history stages, are poor nursery habitats.

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LITERATURE CITED

ABLE, K. W. AND M. P. FAHAY. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, New Jersey.

ABLE, K. W. AND L. S. HALES, JR. 1997. Habitat fidelity, movements and growth of juvenile black sea bass, *Centropristis striata,* in a southern New Jersey estuary. *Journal of Experimental Marine Biology and Ecology* 213:153–167.

ABLE, K. W., A. L. STUDHOLME, AND J. P. MANDERSON. 1995. Habitat Quality in the New York/New Jersey Harbor Estuary: An Evaluation of Pier Effects on Fishes. Final Report. Hudson River Foundation, New York.

BAILEY, K. M. AND E. D. HOUDE. 1989. Predation on eggs and larvae of marine fishes and the recruitment problem. *Advances in Marine Biology* 25:1–83.

BEEBE, C. A. AND I. R. SAVIDGE. 1988. Historical perspective of fish species composition and distribution in the Hudson River Estuary. *American Fisheries Society Monograph* 4:25–36.

BENFIELD, M. C. AND T. J. MINELLO. 1996. Reactive effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. *Environmental Biology of Fishes* 46:211–216.

BLAXTER, J. H. S. 1970. 2. Light 2.3 Animals 2.32 Fishes, p. 213–320. *In* O. Kinney (ed.), Marine Ecology, Volume 1, Environmental Factors. Part 1. John Wiley and Sons, London.

BOYNTON, W. R., T. T. POLGAR, AND H. H. ZION. 1981. Importance of juvenile striped bass food habits in the Potomac Estuary. *Transactions of the American Fisheries Society* 110:56–63.

BRAY, J. R. AND J. T. CURTIS. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* 27:325–349.

BROSNAN, T. M. AND M. L. O'SHEA. 1996. Long-term improvements in water quality due to sewage abatement in the lower Hudson River. *Estuaries* 19(4):890–900.

CAMPBELL, B. C. AND K. W. ABLE. 1998. Aspects of the life history of the northern pipefish, *Syngnathus fuscus. Estuaries.* 21:470–475.

CANTELMO, F. R., L. VALE, T. KELLY, AND B. STEWART. 1985. Importance of underpier areas in the lower Hudson River for striped bass. *Coastal Zone Management* 85:706–715.

CANTELMO, F. R. AND C. H. WAHTOLA, JR. 1992. Aquatic habitat impacts of pile-supported and other structures in the lower Hudson River, p. 59–75. *In* W. Wise, D. J. Suszkowski, and J. R. Waldman (eds.), Proceedings: Conference on the Impacts of New York Harbor Development on Aquatic Resources. Hudson River Foundation, New York.

CLARKE, K. R. 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18:117–143.

CLARKE, K. R. AND R. M. WARWICK. 1994. Change in marine communities: An approach to statistical analysis and interpretation. National Environmental Research Council, United Kingdom.

COOPER, J. A. 1996. Monophyly and intrarelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. Ph.D. dissertation, University of Ottawa, Ottawa, Canada.

CUSHING, D. H. 1974. The possible density-dependence of larval mortality and adult mortality in fishes, p. 103–112. *In* J. H. S. Blaxter (ed.), The Early Life History of Fish. Springer-Verlag, Berlin.

CUSHING, D. H. 1996. Towards a science of recruitment in fish populations. Ecology Institute, Oldendorf/Luhe, Germany.

DAWSON-SHEPARD, A. R., R. M. WARWICK, AND K. R. CLARKE. 1992. An analysis of fish community responses to coral mining in the Maldives. *Environmental Biology of Fishes* 33:367–380.

DEW, C. B. AND J. H. HECHT. 1994. Hatching, estuarine transport, and distribution of larval and early juvenile Atlantic tomcod, *Microgadus tomcod,* in the Hudson River. *Estuaries* 17:472–488.

DOVEL, W. L. 1992. Movements of immature striped bass in the Hudson Estuary, p. 279–302. *In* C. L. Smith (ed.), Estuarine Research in the 1980s. State University of New York Press, Albany, New York.

DUVAL, E. J. AND K. W. ABLE. 1998. Aspects of the life history of the seaboard goby, *Gobiosoma ginsburgi,* in estuarine and inner continental shelf waters. *Bulletin of the New Jersey Academy of Science* 43:5–10.

ENERGY AND ENVIRONMENTAL ANALYSTS, INCORPORATED. 1988. Hudson River Center Site Aquatic Environmental Study. Final Report. Prepared for New York City Public Development Corporation. Energy and Environmental Analysts, Incorporated. New York.

ESSER, S. C. 1982. Long-term changes in some finfishes of the Hudson-Raritan Estuary, p. 299–314. *In* G. F. Mayer (ed.)., Ecological Stress and the New York Bight: Science and Management. Estuarine Research Federation, Columbia, South Carolina.

FOLK, R. L. 1980. Petrology of Sedimentary Rocks. Hemphill Publishing Company, Austin, Texas.

GOTTHOLM, B. W., M. R. HARMON, AND D. D. TURGEON. 1993. Assessment of chemical contaminants in the Hudson-Raritan Estuary and coastal New Jersey. Marine Environmental Quality Report to the National Status and Trends Program, National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

GRECAY, P. A. AND T. E. TARGETT. 1996. Effects of turbidity, light level and prey concentration on feeding of juvenile weakfish, *Cynoscion regalis*. *Marine Ecology Progress Series* 131:11–16.

GREY, J. S., K. R. CLARKE, R. M. WARWICK, AND G. HOBBES. 1990. Detection of initial effects of pollution on marine benthos: An example from the Ekofisk and Eldfisk oil fields, North Sea. *Marine Ecology Progress Series* 66:285–299.

HAEDRICH, R. L. AND S. O. HAEDRICH. 1974. A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. *Estuarine and Coastal Marine Science* 2:59–73.

HELFMAN, G. S., D. E. FACEY. L. S. HALES, JR., AND E. L. BOZEMAN, JR. 1987. Reproductive ecology of the American eel. *American Fisheries Society Symposium* 1:42–56.

HERRICK, C. J. 1904. The organ and sense of taste in fishes. *Bulletin of the United States Fish Commission*. Vol. XXII for 1902: 239–272.

HOUDE, E. D. 1987. Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium* 2:17–29.

KLAUDA, R. J., R. E. MOOS, AND R. E. SCHMIDT. 1988. Life history of Atlantic tomcod, *Microgadus tomcod*, in the Hudson River Estuary, with emphasis on spatio-temporal distribution and movements, p. 219–251. *In* C. L. Smith (ed.), Fisheries Research in the Hudson River. State University of New York Press, Albany, New York.

MACKENZIE, C. L., JR. 1990. History of the fisheries of Raritan Bay, New York and New Jersey. *Marine Fisheries Review* 52:1–45.

MCLAREN, J. B., T. H. PECK, W. P. DEY, AND M. GARDINIER. 1988. Biology of Atlantic tomcod in the Hudson River Estuary. *American Fisheries Society Monograph* 4:102–112.

MILES, S. G. 1968. Rheotaxis of elvers of the American eel *Anguilla rostrata* in the laboratory to water from different streams in Nova Scotia. *Journal of the Fisheries Research Board of Canada* 25:1591–1602.

MORAN, M. A. AND D. S. KIEFER. 1986. The Westway, p. 131–154. *In* K. E. Limberg, M. A. Moran, and W. H. McDowell (eds.), The Hudson River Ecosystem. Springer-Verlag, New York.

O'CONNOR, J. M. AND R. J. HEADGATE. 1988. Aquatic pollution problems, North Atlantic coast, including Chesapeake Bay. *Aquatic Toxicology* 11:163–190.

OLLA, B. L., R. WICKLUND, AND S. WILK. 1969. Behavior of winter flounder in a natural habitat. *Transactions of the American Fisheries Society* 98:717–720.

PEARCE, J. B. 1979. Raritan Bay—a highly polluted estuarine system, p. 32–47. *In* J. B. Pearce (ed.), Reviews of Water Quality and Transport of Materials in Coastal and Estuarine Waters. Cooperative Research Report Number 118. International Council for the Exploration of the Sea, Copenhagen, Denmark.

PEARCE, J. B. 1993. Coastal development and cumulative effects, p. 1645–1659. *In* Coastal Zone 1993, Proceedings, Eighth Symposium on Coastal and Ocean Management. American Society of Civil Engineers, New Orleans, Louisiana.

PEARCY, W. G. 1962. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). *Bulletin of the Bingham Oceanographic Collection, Yale University* 18:1–78.

PHELAN, B. A. 1992. Winter flounder movements in the inner New York Bight. *Transactions of the American Fisheries Society* 121: 777–784.

SISSENWINE, M. P. 1984. Why do fish populations vary?, p. 59–94. *In* R. M. May (ed.), Exploitation of Marine Communities. Dahlem Konferenzen, Springer-Verlag, New York.

SISSENWINE, M. P., E. B. COHEN, AND M. D. GROSSLEIN. 1984. Structure of the Georges Bank ecosystem. *Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer* 183:243–254.

STOECKER, R. R., J. COLLURA, AND P. J. FALLON, JR. 1992. Aquatic studies at the Hudson River Center site, p. 407–427. *In* C. L. Smith (ed.), Estuarine Research in the 1980s: Hudson River Environmental Society, Seventh Symposium on Hudson River Ecology. State of New York Press, Albany, New York.

STUDHOLME, A. L. 1988. An overview of the biological resources of the Hudson-Raritan Estuary, p. 59–94. *In* Hudson/Raritan Estuary: Issues, Resources, Status and Management. National Oceanic and Atmospheric Administration, Estuarine Programs Office, NOAA Estuary-of-the-Month Seminar Series, Number 9. Washington, D.C.

TESCH, F.-W. 1975. 8. Orientation in space: Animals, 8.2 Fishes, p. 657–707. *In* O. Kinney (ed.), Marine Ecology, Volume II, Physiological Mechanisms, Part 2. John Wiley and Sons, London, England.

TESCH, F.-W. 1977. The Eel. Chapman and Hall, Limited. London, England.

UNITED STATES ARMY CORPS OF ENGINEERS—New York Division and United States Department of Transportation, Federal Highway Administration Region I. 1984. Final Supplemental Environmental Impact Statement, Westway Highway Project, Volume II, Fisheries Portion.

UNITED STATES DEPARTMENT OF COMMERCE. 1992. Tide Tables 1993.

UNITED STATES DEPARTMENT OF COMMERCE. 1993. Tide Tables 1994.

VALETTE-SILVER, N. J. 1993. The use of sediment cores to reconstruct historical trends in contamination of estuarine and coastal sediments. *Estuaries* 16:577–588.

WALDMAN, J. R. 1992. Determining the habitat value of piers and platforms: An empirical approach, p. 207–221. *In* W. Wise, D. J. Suszkowski, and J. R. Waldman (eds.), Proceedings: Conference on the Impacts of New York Harbor Development on Aquatic Resources. Hudson River Foundation, New York.

WILK, S. J. 1984. Finfish resources of the Sandy Hook Bay—Lower Bay complex—A review of research findings, p. 25–32. *In* A. L. Pacheco (ed.), Raritan Bay—Its Multiple Uses and Abuses. Workshop sponsored by American Littoral Society, New Jersey Marine Sciences Consortium, National Marine Fisheries Service, Sandy Hook Laboratory, Technical Series Report Number 30.

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