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A CHARACTERIZATION OF JUVENILE FISH ASSEMBLAGES AROUND MAN-MADE STRUCTURES IN THE NEW YORK–NEW JERSEY HARBOR ESTUARY, U.S.A.

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ABSTRACT

We deployed benthic traps in the Arthur Kill (1995), Kill van Kull (1996), and Hudson River (1996), U.S.A, near wrecks, pile fields, piers, and in open water areas (no structure). Over 8300 fish of 31 different species of fish were collected, the majority of which were young-of-the-year individuals (98%). Many typical estuarine species were found in all three waterways and across several habitats, though species abundance and diversity was significantly depressed under piers (mean CPUE = 0.15 ind trap^{-1} d^{-1}). Since the majority of the fish were collected from the Arthur Kill (n = 7812), the assemblage structure in this system was evaluated more thoroughly. Assemblage structure was significantly different among habitat types (wreck, pile field, open water) with mean CPUE in open water areas (mean = 6.1 ind trap^{-1} d^{-1}) being lower than near wrecks (mean = 6.8 ind trap^{-1} d^{-1}) or pile fields (mean = 6.6 ind trap^{-1} d^{-1}). Results suggest that fish assemblage patterns may be a function of structural complexity, though other factors such as shading or water depth may also have measurable effects. Collectively, the data suggest that the New York–New Jersey Harbor estuary provides habitat for a number of economically and ecologically important species.

The New York–New Jersey Harbor estuary, U.S.A., is a large, urban estuary that serves as a nursery ground to a variety of juvenile fishes (Able et al., 1998). Many different types of man-made structures dominate the shoreline yet we are just beginning to understand how these objects impact young-of-the-year fishes (Able et al., 1999; Duffy-Anderson and Able, 1999). Continued evaluation of anthropogenic structures is critical to understanding their ecological role for fishes, yet assessment of this habitat is difficult. In the present study, we employed approaches established by the National Marine Fisheries Service (Schreiber and Gill, 1995; Minello, 1999) and estimated distribution and abundance of fishes around man-made structures to rank their fish habitat value relative to one another. Other investigators have used this approach successfully in estuarine habitats. For example, Heck et al. (1995) used faunal abundance and species richness to determine that eelgrass was important to macrofauna in a Massachusetts estuary. Likewise, Szedlmayer and Able (1996) determined that species abundance was positively correlated with habitat type, and Sogard and Able (1994) examined distribution of fishes and crustaceans by using artificial seagrass habitats. Thus, the characterization of faunal assemblages may offer a reliable method to evaluate the use of man-made structures in urban, shallow-water environments.

We undertook a 2-yr field study to characterize the fish assemblages near several representative man-made structures in three interconnected waterways within the New York–New Jersey Harbor estuary, the Arthur Kill, the Kill van Kull, and the Hudson River (Fig. 1). In the first year, we used field trapping techniques to examine the abundance and diversity of fish near partially submerged wrecks, in pile fields, and in open water areas in the Arthur Kill. In the second year, we conducted our trapping survey at similar habitats in the Kill van Kull, and we also examined the assemblage around a municipal pier in

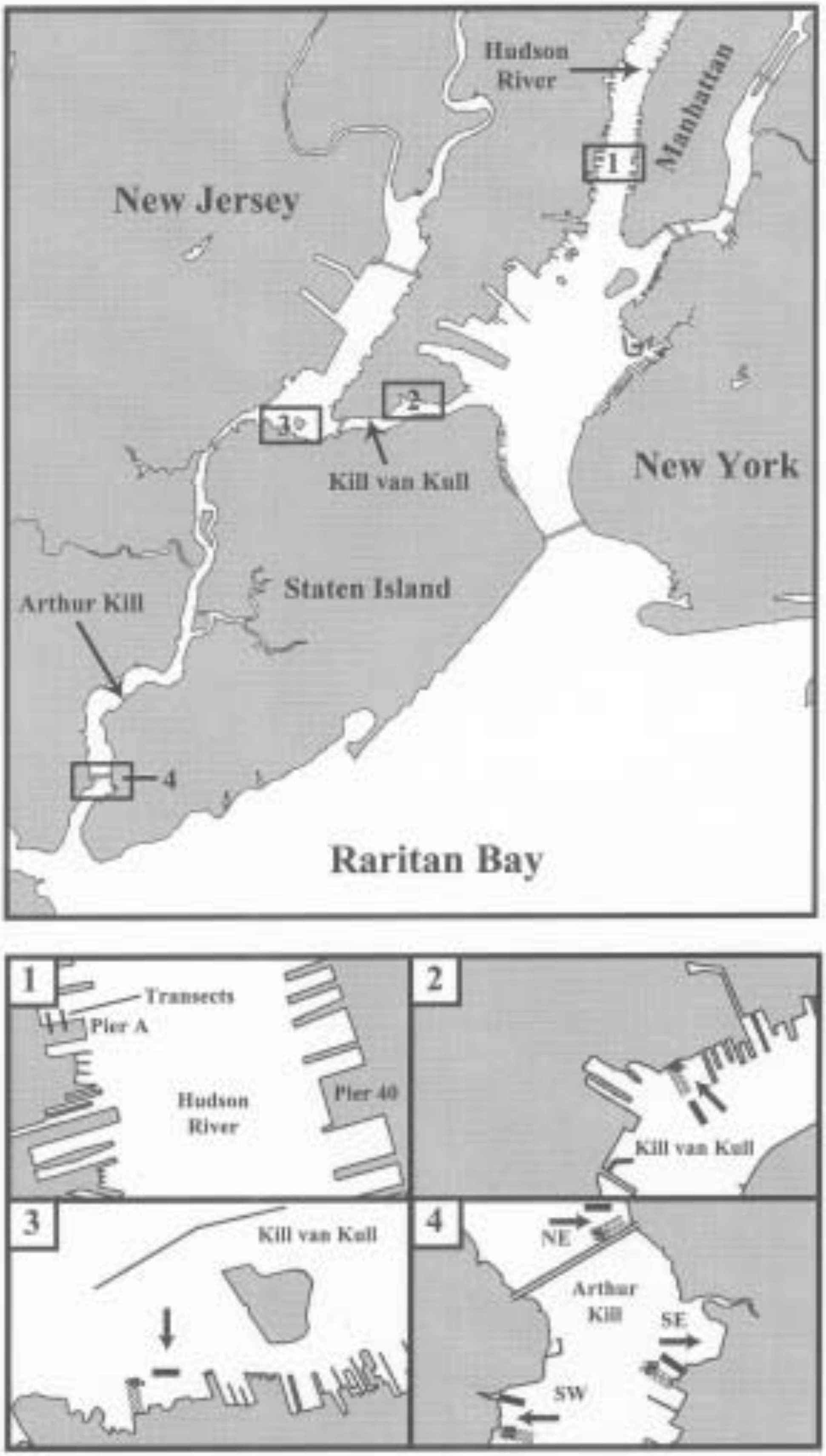

Figure 1. Top panel. Locations of the general study areas in the Hudson River (1), Kill van Kull (2, 3), and Arthur Kill (4) in the New York–New Jersey Harbor estuary, U.S.A. Bottom panels. Locations of the specific habitats in the Hudson River (Pier A), Kill van Kull, and Arthur Kill (wreck, pile field, open water). Wrecks are designated by black bars, pile fields are designated by circles, and open water areas are indicated by arrows.

the Hudson River. In our view, a characterization of the faunal assemblage associated with several types of man-made structures could be a useful approach for assessing their value as habitat and for monitoring changes in habitat quality in these waterways.

Materials and Methods

Study Sites.—Three replicate sampling areas were established in the Arthur Kill in 1995, northeast (NE), southeast (SE), and southwest (SW), with representative structures, wreck, pile field, and open water reference sites situated within each (Fig. 1). Five replicate traps were deployed in each of the study habitats. Traps deployed in the open water areas were located more than 10 m from adjacent pile fields and wrecks.

The study sites in 1996 were situated in the Kill van Kull and the Hudson River (Fig. 1). Two study areas were designated in the Kill van Kull, one on the north side of the Kill, near Bayonne, New Jersey, and one on the south side, on Staten Island, New York. Wreck, pile field, and open water sites were established within each area and three replicate traps were deployed to each type of habitat. In the Hudson River, a large, commercial pier on the New Jersey shoreline (Port Authority Pier A, 213 × 100 m) was selected as the study site and replicate traps (n = 3) were deployed around piers (at the edge, 20 m underneath, 40 m underneath) and in open water (20 m beyond and 40 m beyond) (Fig. 1).

Sampling Technique.—Sampling techniques have been described elsewhere (Able et al., 1998) but are briefly described here. The collecting traps were welded steel frames (0.9 m × 0.5 m × 0.3 m) covered with 2-mm plastic mesh. Each trap had a 3-mm nylon cod end and a V-shaped throat that allowed entrance to the trap. All traps were set on the bottom unbaited for 24 h and then recovered. All fish were counted and identified, and the traps were immediately redeployed. The procedure was repeated for four consecutive days. All captured fishes were measured (mm) and catch data were standardized to catch per unit effort (CPUE, expressed as ind trap^{-1} d^{-1}).

Sampling in the Arthur Kill was conducted on alternate weeks from August–November 1995 (Table 1). Sampling in the Kill van Kull and the Hudson River occurred on alternate weeks from June–October 1996. Trapping effort (trap days) was described as the sum total of the number of days fished by all replicate traps.

Physical Parameters.—Water temperature (ºC), salinity (‰), dissolved oxygen (mg L^{-1}) were measured at hourly intervals for a 24-h period using dataloggers (Hydrolab Datasonde). Measurements among stations within a given waterway were always collected simultaneously. Specifically, in 1995, measurements were simultaneously collected at the NE, SE, and SW sites for one 24-h period during each week of the trapping survey. In 1996, dataloggers were simultaneously deployed at the Hudson River site (under and outside of the pier) and in the Kill van Kull (at the wreck, pile field, and open water sites) once each week, though on two occasions equipment malfunctions resulted in incomplete collections. Station depths (m) were measured with a sounding lead several times (at least five times at each station) during the study. Light levels (μE m^{-2} s^{-1}) at depth were also recorded periodically (at least six separate times) using a LI-COR underwater radiation sensor.

Statistical Analyses.—Variations in species abundance were assessed using non-parametric multivariate analyses. These approaches were selected over parametric designs as the data were highly variable and did not meet the criteria for parametric measures. All analyses were conducted using the Primer statistical package (Plymouth Marine Laboratory, U.K.). The methods used included group-average cluster analyses (Bray-Curtis), non-metric multi-dimensional scaling (n-m MDS), and Analysis of Similarity (ANOSIM) randomization tests (analogous to MANOVA). In an ANOSIM analysis the test statistic is used to evaluate the degree of separation between samples, and is generally evaluated on whether or not it is significantly different from zero. Similarity percentages (SIMPER analyses) were calculated to determine the contribution of each species to the similarity of replicate samples and to the dissimilarity between samples. Stress values generated by nm-MDS analyses indicate the degree of distortion between similarity rankings. Stress <0.1 suggests a good to excellent ordination with little likelihood of misrepresentation, stress <0.2 provides a useful representation of the data though points at the edges of the range may be somewhat distorted. Analyses were performed using the calculated CPUE of all species of fish captured during the study. These values were fourth-root transformed prior to analysis to down weight the contribution of the dominant species while still allowing for the contribution of less abundant species.

RESULTS

PHYSICAL PARAMETERS.—There were significant differences in the average depth of stations in the Arthur Kill among locations (2-way ANOVA, $P < 0.001$) and habitat types ($P < 0.001$), though there were no significant interactions between the two factors. Stations were significantly deeper in the NE (mean = 1.8 m ± 0.4) than in SE (mean = 0.95 m ± 0.3) or SW areas (mean = 0.92 m ± 0.2), and wreck sites were generally more shallow than pile field and open water areas. Depths were also significantly different among stations in the Kill van Kull. All sites located along the north shore of the Kill van Kull were significantly more shallow (mean = 1.7 m ± 0.1) than sites along the south shore (mean = 2.3 m ± 0.2, $P < 0.05$), though there were no differences in depth among the three habitat types within each location. Average depths at the pier site in the Hudson River were not significantly different underneath and outside of the pier (2.2 m ± 0.7 and 2.2 m ± 0.6, respectively).

Temperatures, salinities, and levels of dissolved oxygen were seasonally variable but were similar among sites. Average temperatures ranged from 10–24^{o}C, salinities ranged from 9–26‰, and levels of dissolved oxygen were between 4–8 mg L^{-1}. Multiway ANOVA failed to detect significant differences in any of these variables and results were similar to previously published reports (Able et al., 1998).

Light levels on the bottom at sites in the Arthur Kill and in the Kill van Kull varied considerably, but statistical differences between locations or among habitats were not detected (mean = 146, $\mu E\ m^{-2}\ s^{-1} \pm 76$). However, light levels around the pier in the Hudson River did vary significantly ($P < 0.001$). Along both transects, levels under the pier were lower (mean = 0.01, $\mu E\ m^{-2}\ s^{-1} \pm 0.01$) than levels at the pier edge (mean = 25.9 $\mu E\ m^{-2}\ s^{-1} \pm 12.1$) or in the open water beyond the pier (mean = 54.4, $\mu E\ m^{-2}\ s^{-1} \pm 24.7$).

DISTRIBUTION AND ABUNDANCE BY WATERWAY.—The abundance of fishes collected from the Arthur Kill was high (n = 7812; mean CPUE = 6.5 ind $trap^{-1}\ d^{-1}$) compared to the Kill van Kull (n = 224; mean CPUE = 0.45 ind $trap^{-1}\ d^{-1}$) and the Hudson River (n = 270; mean CPUE = 0.22 ind $trap^{-1}\ d^{-1}$) (Table 1). In all three systems, fishes collected during the study were generally small in size (Fig. 2), and young-of-the-year individuals comprised the majority of the total catch (98%). Median fish size varied within the three waterways; the smallest median size occurred in the Arthur Kill (40 mm) and the largest in the Hudson River (173 mm). The large number of young-of-the-year silver perch (*Bairdiella chrysoura*) in the Arthur Kill probably served to lower the median value determined for that system, while adult American eels (*Anguilla rostrata*) probably accounted for most of the contribution toward the higher median value determined for the Hudson River.

As noted above, silver perch made up the majority of the catch from the Arthur Kill (66%) (Table 2). Naked goby (*Gobiosoma bosc*) was the second most abundant species (24% of the total). Interestingly, no silver perch were collected in the following year from

Table 1. Summary of trapping effort, number of fish collected, and total catch per unit effort (CPUE) in habitats in the Arthur Kill, Kill van Kull, and lower Hudson River. Samples from the Arthur Kill were collected on alternate weeks, August–November 1995. Samples collected from the Kill van Kull and the Hudson River were collected on alternate weeks, from June–October 1996. See Figure 1 for sampling locations.

Location Habitat	Trapping effort (trap days)	Number of fish	Total CPUE (ind trap^{-1} d^{-1})
Arthur Kill			
Wreck	405.5	2,752	6.80
Pile field	395.9	2,600	6.60
Open water	401.1	2,460	6.10
Kill van Kull			
Wreck	166.4	97	0.58
Pile field	166.5	59	0.35
Open water	166.5	68	0.41
Hudson River			
Under pier	725.5	132	0.18
Outside pier	482.5	139	0.29

either the Kill van Kull or the Hudson River. A similar pattern was observed for oyster toadfish (*Opsanus tau*) and bay anchovy (*Anchoa mitchilli*). Other species showed the reverse trend. For example, striped bass (*Morone saxatilis*), Atlantic tomcod (*Microgadus tomcod*), and spotted hake (*Urophycis regia*) were collected in comparatively high numbers from both the Kill van Kull and Hudson River and were rarely, if ever, collected in the Arthur Kill (Table 2).

DISTRIBUTION AND ABUNDANCE BY HABITAT TYPE.—The total number of fish trapped in the Kill van Kull and Hudson River was low, though several interesting trends were observed from these collections. There were no differences in fish abundance or distribution between the two study areas in the Kill van Kull (Bayonne, New Jersey and Staten Island, New York) but there were significant effects of habitat type (2-way ANOSIM, $P = 0.001$), though caution should be used in this interpretation due to the low fish sample size. Catch per unit effort was significantly higher in wreck areas (0.58 ind trap^{-1} d^{-1}) than in open water (0.41 ind trap^{-1} d^{-1}) or pile fields (0.35 ind trap^{-1} d^{-1}). Results are similar to those obtained in the Arthur Kill where CPUE was also higher in wreck sites (6.8 ind trap^{-1} d^{-1}) and sample size was considerably larger. In the Hudson River, CPUE was significantly higher in open water areas (0.29 ind trap^{-1} d^{-1}) compared to under the pier (0.18 ind trap^{-1} d^{-1}) (Two-way ANOSIM, $P < 0.05$). Species richness was depressed under the pier as well. In fact, only four species were ever collected under the pier, adult American eel, and juvenile Atlantic tomcod, conger eel (*Conger oceanicus*), and spotted hake, compared to 11 species collected at edges and 16 species collected in open water.

While data obtained from the Kill van Kull and the Hudson River suggest interesting trends, collections from these two systems resulted in so few individuals that further analyses were deemed inappropriate. Therefore, further analysis of fish distribution around man-made structures will be based on data collected from the Arthur Kill.

ASSEMBLAGE STRUCTURE IN THE ARTHUR KILL.—There were significant effects of sampling location (NE, SE, SW) and habitat type (wreck, pile field, open water) on fish assemblage structure in the Arthur Kill (2-way ANOSIM, $P < 0.001$). Non-metric MDS ordinations (Fig. 3) of the SE and the SW areas showed that open water stations were

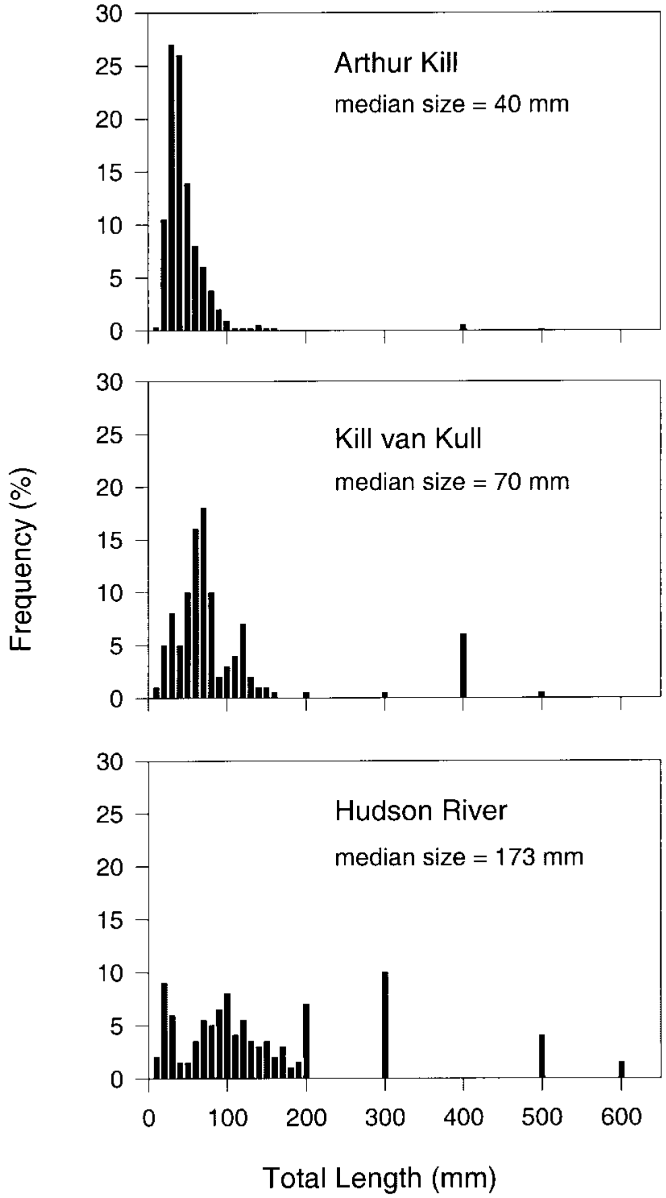

Figure 2. Length-frequency distributions of fishes collected in the Arthur Kill (top), Kill van Kull (middle) and Hudson River (bottom).

positioned to the left while stations in the structured habitats (pile field and wreck) were ordinated to the right.

Many of the dominant fishes were typically more abundant in the two structured habitats (wrecks or pile fields) than in the open water sites, and only silver perch was collected in greater numbers in open water. Among others, mummichog (*Fundulus heteroclitus*), bay anchovy, naked goby, American eel, and Northern pipefish (*Syngnathus fuscus*) were generally more abundant in wrecks and pile fields than in open water areas (Fig. 4). Several species, including mummichog, tautog (*Tautoga onitis*), silver perch, American eel, oyster toadfish, and Northern pipefish, contributed to the dissimilarity between unstructured open water areas and the structured habitats (Table 3).

Table 2. Fish species, size range and total number of individuals collected from benthic traps deployed in the Arthur Kill (1995), the Kill van Kull (1996) and the lower Hudson River (1996).

Scientific name	Common name	Size Range TL (mm)	Arthur Kill	Kill van Kull	Hudson River	Total
Bairdiella chrysoura	Silver perch	11–103	5,139	0	0	5,139
Gobiosoma bosc	Naked goby	13–65	1,782	48	43	1,873
Fundulus heteroclitus	Mummichog	21–125	454	3	0	457
Anchoa mitchilli	Bay anchovy	19–34	203	0	0	203
Menidia menidia	Atlantic silverside	24–168	63	50	1	114
Anguilla rostrata	American eel	75–660	24	3	70	97
Pseudopleuronectes americanus	Winter flounder	45–211	17	45	10	72
Microgadus tomcod	Atlantic tomcod	68–250	0	23	38	61
Syngnathus fuscus	Northern pipefish	67–204	34	18	9	61
Opsanus tau	Oyster toadfish	25–167	50	0	0	50
Urophycis regia	Spotted hake	41–204	1	0	40	41
Conger oceanicus	Conger eel	72–223	0	4	34	38
Morone saxatilis	Striped bass	47–185	0	22	14	36
Tautoga onitis	Tautog	62–182	21	1	1	23
Gobiosoma ginsburgi	Seaboard goby	30–50	3	3	0	6
Micropogonias undulatus	Atlantic croaker	25–157	4	0	1	5
Menticirrhus saxatilis	Northern kingfish	104–132	4	0	0	4
Chaetodon ocellatus	Spotfin butterflyfish	29–57	4	0	0	4
Fundulus majalis	Striped killifish	75–102	3	0	0	3
Etropus microstomus	Smallmouth flounder	16–35	0	1	2	3
Myoxocephalus aenaeus	Grubby	50–57	0	3	0	3
Centropristis striata	Black sea bass	124–127	2	0	0	2
Hypsoblennius hentz	Feather blenny	70–77	2	0	0	2
Paralichthys dentatus	Summer flounder	177–325	1	0	1	2
Tautogolabrus adspersus	Cunner	112	1	0	0	1
Trinectes maculatus	Hogchoker	100	0	0	1	1
Scophthalmus aquosus	Windowpane	62	0	0	1	1
Prionotus carolinus	Northern searobin	69	0	0	1	1
Morone americana	White perch	191	0	0	1	1
Cynoscion regalis	Weakfish	53	0	0	1	1
Caranx hippos	Crevalle jack	45	0	0	1	1

DISCUSSION

The extensive loading of pollutant materials, decades of dredging and bulkheading, and the construction of commercial, industrial, and residential areas have altered and degraded much of the natural fish habitat in the New York–New Jersey Harbor estuary. The results of this degradation have been documented in earlier investigations that have chronicled the decline of resource species present in the region (Carriker et al., 1982; Sindermann et al., 1982). However, our results demonstrate that in spite of potentially

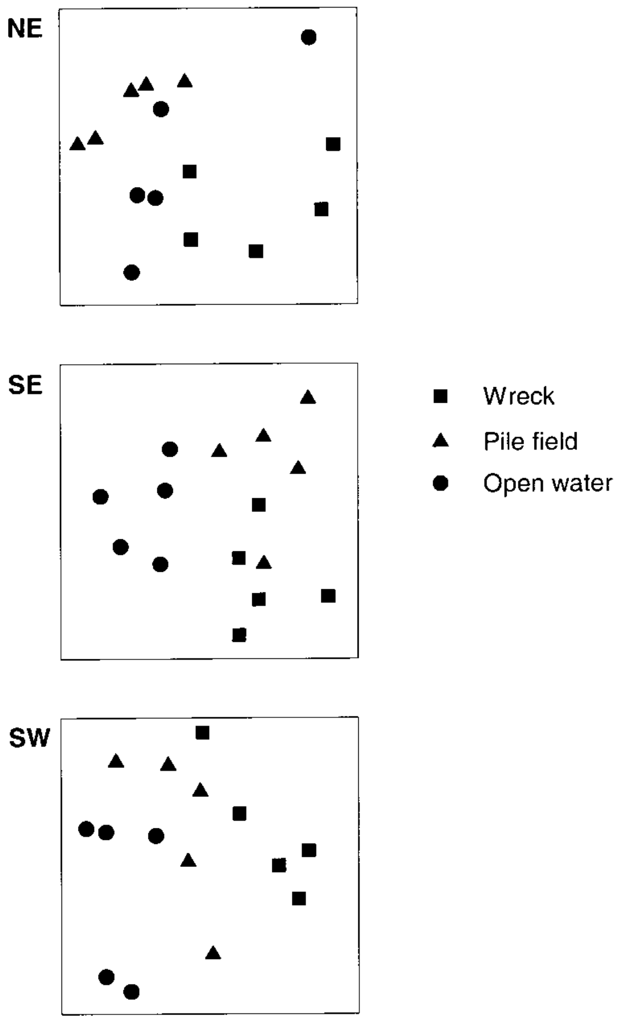

Figure 3. Non-metric multidimensional scaling analysis of habitat types in the Arthur Kill (wreck, pile field, open water) computed from 4th-root transformed abundances of principal fish collected. NE, stress = 0.17; SE, stress = 0.17; SW, stress = 0.17.

degrading land-use practices and variable water quality, a variety of juvenile fishes use the New York–New Jersey Harbor estuary as a nursery area. It is interesting to note that since the 1970s a great deal of effort has been made to upgrade water quality in this system, and a more recent investigation indicates that these efforts have met with some success (Brosnan and O'Shea, 1996). It may be that the improved water quality of the region has permitted the reinvasion of fish to the area. Regardless of the origin, our data indicate that the Arthur Kill, Kill van Kull and Hudson River are utilized by the juveniles of a variety of marine and estuarine fish, including a number of important resource species.

Distribution and Abundance by Waterway.—Fishes were most abundant in collections from the Arthur Kill with fewer fish collected from the Kill van Kull and the Hudson River. Though we cannot dismiss the possibility that the overall lower CPUE in the Hudson River and Kill van Kull reflects less optimal habitat for juvenile fishes in these areas compared to the Arthur Kill, it seems more likely that interannual variation in species abundance are responsible for the differences. A variety of species demonstrate interannual variations in recruitment, and lower abundances in the 1996 collections could also be related to lower recruitment levels in that year for some species. For example, over 5,000

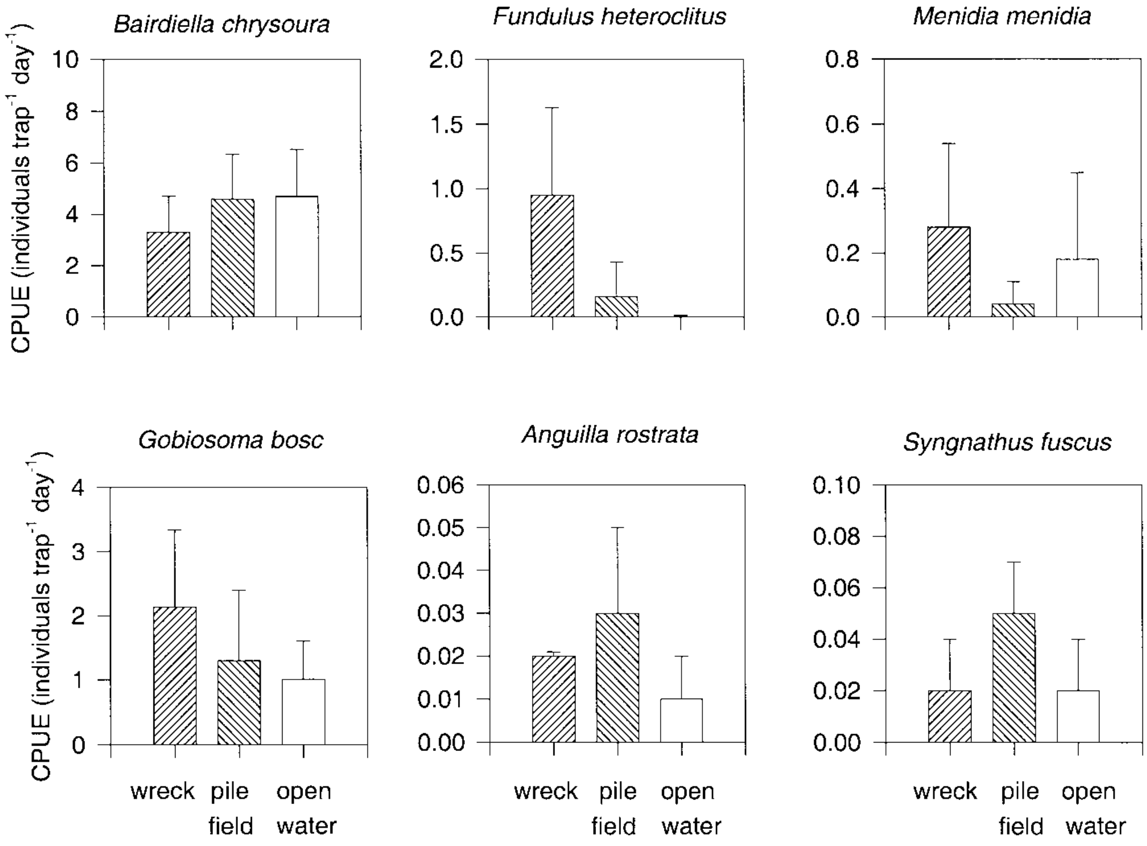

Figure 4. Mean abundance (CPUE) ± SE of the dominant fish species collected in traps deployed in wrecks, pile fields, and in open water in the Arthur Kill.

silver perch were collected from the Arthur Kill in 1995 yet the species was entirely absent from both the Kill van Kull and the Hudson River collections in 1996. While it could be construed that silver perch are simply absent from these two waterways, it should be noted that the Arthur Kill, Kill van Kull, and Hudson River are interconnected. Given the proximity of these systems to one another (Fig. 1) and the broad mobility of silver perch (Able and Fahay, 1998), young-of-the-year fish should be able to move readily among these sites. Therefore, it is likely that the absence of this species in collections in 1996 reflects a poor recruitment year rather than a genuine difference in habitat use.

In spite of oscillations in abundance, many of the species, both resident and transient (Able and Fahay, 1998), were found in all three waterways in both years. Naked goby (resident), winter flounder (*Pseudopleuronectes americanus*) (resident), and Northern pipefish (transient) were collected in comparatively high numbers from each of these systems, and a variety of other species (e.g., American eel, *Menidia menidia* (Atlantic silverside), and tautog; all transient) were collected from all three systems though in unequal numbers. This suggests that both resident and transient species are capable of utilizing a variety of different waterways within the New York–New Jersey Harbor estuary. Of course, some exceptions should be noted. For example, Atlantic tomcod and striped bass were entirely absent from collections in the Arthur Kill but were relatively abundant in traps deployed in the Hudson River and Kill van Kull. While it is impossible to entirely separate the contribution of interannual variation to these observations, certain aspects of the life histories of these fish could be cited to explain these differences. Atlantic tomcod have a resident population in the Hudson River (Dew and Hecht, 1994a,b), where they

Table 3. Fish species contributions to the average dissimilarity between the habitats (wreck, pile field, open water) in the Arthur Kill in 1995. Asterisks indicate important discriminating species.

NORTHEAST					
Wreck vs Pile field dissimilarity = 38.1%		Wreck vs Open water dissimilarity = 35.6%		Pile field vs Open water dissimilarity = 31.4%	
Species	Percent contribution	Species	Percent contribution	Species	Percent contribution
Fundulus heteroclitus	19.9*	*Fundulus heteroclitus*	21.7*	*Bairdiella chrysoura*	16.0*
Gobiosoma bosc	17.5*	*Bairdiella chrysoura*	13.7*	*Tautoga onitis*	15.4*
Bairdiella chrysoura	12.1*	*Anchoa mitchilli*	12.4*	*Syngnathus fuscus*	12.8*
Anchoa mitchilli	12.0*	*Gobiosoma bosc*	10.3*	*Opsanus tau*	12.0
Tautoga onitis	10.7*	*Opsanus tau*	9.6*	*Anchoa mitchilli*	11.7*
Syngnathus fuscus	8.0*	*Syngnathus fuscus*	8.7*	*Gobiosoma bosc*	10.4*
Anguilla rostrata	7.2*	*Tautoga onitis*	8.0*	*Anguilla rostrata*	9.9*
Opsanus tau	5.2	*Anguilla rostrata*	7.5*	*Menidia menidia*	8.4
Menidia menidia	4.9				
Pseudopleuronectes americanus	2.5				
SOUTHEAST					
Wreck vs Pile field dissimilarity = 28.1%		Wreck vs Open water dissimilarity = 31.8%		Pile field vs Open water dissimilarity = 32.0%	
Species	Percent contribution	Species	Percent contribution	Species	Percent contribution
Anchoa mitchilli	19.0*	*Fundulus heteroclitus*	28.6*	*Fundulus heteroclitus*	18.6*
Opsanus tau	14.0*	*Anchoa mitchilli*	20.5*	*Opsanus tau*	15.5*
Menidia menidia	13.8*	*Menidia menidia*	13.1*	*Anguilla rostrata*	11.4*
Pseudopleuronectes americanus	10.2*	*Bairdiella chrysoura*	11.0*	*Anchoa mitchilli*	10.6*
Anguilla rostrata	10.1*	*Syngnathus fuscus*	9.0*	*Pseudopleuronectes americanus*	10.4*
Fundulus heteroclitus	10.0*	*Anguilla rostrata*	6.7	*Bairdiella chrysoura*	10.1*
Syngnathus fuscus	8.1*	*Gobiosoma bosc*	4.8*	*Syngnathus fuscus*	9.0*
Tautoga onitis	6.1	*Opsanus tau*	3.4	*Tautoga onitis*	5.9
Gobiosoma bosc	4.7	*Pseudopleuronectes americanus*	2.9	*Gobiosoma bosc*	4.4
				Menidia menidia	4.1
SOUTHWEST					
Wreck vs Pile field dissimilarity = 31.8%		Wreck vs Open water dissimilarity = 38.9%		Pile field vs Open water dissimilarity = 31.9%	
Species	Percent contribution	Species	Percent contribution	Species	Percent contribution
Fundulus heteroclitus	23.9*	*Fundulus heteroclitus*	24.1*	*Syngnathus fuscus*	17.6*
Bairdiella chrysoura	12.8*	*Opsanus tau*	11.8*	*Anchoa mitchilli*	16.5*
Syngnathus fuscus	12.6*	*Anchoa mitchilli*	11.7*	*Bairdiella chrysoura*	11.5*
Opsanus tau	9.1*	*Gobiosoma bosc*	11.0*	*Menidia menidia*	11.1*
Pseudopleuronectes americanus	8.9*	*Anguilla rostrata*	8.9*	*Gobiosoma bosc*	10.2*
Menidia menidia	8.8*	*Pseudopleuronectes americanus*	8.6*	*Opsanus tau*	10.1*
Anguilla rostrata	8.7*	*Menidia menidia*	8.2*	*Fundulus heteroclitus*	8.4
Tautoga onitis	8.2*	*Tautoga onitis*	7.6	*Anguilla rostrata*	8.3
Gobiosoma bosc	3.7*	*Bairdiella chrysoura*	5.8	*Pseudopleuronectes americanus*	6.3
Anchoa mitchilli	3.3	*Syngnathus fuscus*	2.4		

spawn in low salinity waters in December and January. The larvae hatch and are transported downstream to the river mouth in February and March. The juveniles become demersal, and begin moving back upriver in July and August. As such, highest abundances would be expected in the Hudson River, with progressively lower abundances in waters farther away, a pattern consistent with the data presented here. Adult striped bass spawn in the upstream waters of the Hudson River and young-of-the-year are transported downstream to lower, tidal areas (Able and Fahay, 1998). Particular to the New York–New Jersey Harbor estuary, it has been shown that young-of-the-year striped bass utilize the Kill van Kull as a passageway between the Hudson River and Newark Bay in late summer and early fall (Dovel, 1992). Since the majority of the striped bass obtained in the present study were collected in the lower Hudson River and the Kill van Kull in September (n = 21) it is likely that we intercepted some individuals as they followed this migratory pattern.

Distribution and Abundance by Habitat Type.—There were differences in assemblage structure between wreck, pile field, and open water sites in the Arthur Kill. Data indicated that fish assemblages in open water habitats were significantly different from those in wreck or pile field areas, while assemblages in wrecks and pile fields were similar to one another. Further, abundance was lower in open water areas than in wrecks or pile fields.

Therefore, we concluded that assemblage composition may have been a function of structural complexity, an idea that has been supported by work conducted in a variety of other systems (Lewis and Stoner, 1983; Rountree, 1989; Sogard and Able, 1991; Blaber et al., 1992; Jenkins and Wheatley, 1998). It should be noted however, that the sampling gear itself may have served to enhance the structural complexity of the habitats, especially at the open water sites. Accordingly, abundance may have been artificially inflated due to the attraction of fish to the traps. Nonetheless, identical traps were fished in all sites and we did find that assemblage structure was similar in the more complex habitat types (wrecks and pile fields) compared to the less complex, open water areas.

The role of submerged, structured habitats has been well-studied, particularly artificial reefs. It has been suggested that fishes aggregate to complex reefs because they provide greater food resources (Hueckel and Buckley, 1987), heightened visual or olfactory cues (Gorham and Alevizon, 1989), or protection from predation (Hixon and Beets, 1989). The latter purpose may be particularly important for juvenile fishes. For example, Gorham and Alevizon (1989) demonstrated that artificial streamers provided effective shelter for juvenile fishes in Florida, and Coen et al. (1999) suggested that a well-developed matrix of shell crevices provides important refuge habitat for post-settlement toadfish, blennies, and gobies. Our results could indicate that the fish utilize man-made structures as predation refugia, though it should be noted that it is likely that juvenile fishes also aggregate around man-made structures due to the presence of food (fouling prey items). Additional work is required to determine the precise behavior of juvenile fishes around anthropogenic structures in the New York–New Jersey Harbor estuary.

Certainly larger-scale differences like structural complexity can affect faunal assemblages, but even more subtle habitat heterogeneities may also exert measurable effects. We observed that the impacts of heightened structural complexity were negated underneath large, pile-supported piers. The source of this influence remains unclear, though it has been speculated that poor feeding conditions stemming from low light penetration is a factor (Able et al., 1999; (Duffy-Anderson and Able, 1999; Duffy-Anderson and Able 2001).

Piers were not the only site where we observed the effects of compounding factors on assemblage structure over and above those of structural complexity. We determined that assemblage structure in the NE area of the Arthur Kill was different from that in the SE and SW study areas, in spite of sampling in habitats with similar structural composition. Temperatures, salinities and levels of dissolved oxygen were similar across study sites though all sites in the NE were significantly deeper than sites in the SE or SW areas. Interestingly, several species that typically inhabit shallow water were collected in the lowest numbers from the NE area (e.g., mummichog, striped killifish (*Fundulus majalis*), and bay anchovy) which suggests that differences in assemblage structure were due to an absence of shallow-water species. Notably, these same species did not occur at the Hudson River sites, areas that also lacked shallow water habitat due to the presence of bulkheads in this portion of the river. Perhaps the observed differences in depth had a concomitant, though not significant, affect on light level, and slightly lower light levels also contributed to differences in the faunal assemblage. In any case, it is apparent that even modest differences in habitat characteristics can have considerable effects on species composition.

In summary, the primary goal of these investigations was to characterize the fish assemblage around man-made structures in the Arthur Kill, Kill van Kull, and Hudson

River. Taken collectively, the data derived from this work suggest that: (1) the juveniles of a number of economically and ecologically important species are common to the New York–New Jersey Harbor estuary, (2) these juveniles are capable of utilizing a variety of different waterways within the system, (3) they can exploit a variety of habitat types within these waterways, and (4) their abundance and distribution is influenced by the structural complexity of man-made habitats though other factors (such as shading or water depth) may also contribute to overall assemblage structure.

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