

An Assessment of the Feeding Success of Young-of-the-Year Winter Flounder (*Pseudopleuronectes americanus*) Near a Municipal Pier in the Hudson River Estuary, U.S.A.

J. T. DUFFY-ANDERSON* and K. W. ABLE

*Rutgers University, Institute of Marine and Coastal Sciences, Marine Field Station,
800 c/o 132 Great Bay Boulevard, Tuckerton, New Jersey 08087*

ABSTRACT: We examined feeding success of young-of-the-year winter flounder (*Pseudopleuronectes americanus* Walbaum) (20–50 mm TL) around a large, municipal pier in the Hudson River estuary, USA. Replicate, 3-h feeding experiments were conducted using benthic cages (0.64 m²) deployed under, at the edge, and outside of the pier during late spring and early summer in 1998 and 1999. Significantly more winter flounder caged under piers had empty stomachs (\bar{x} = 71.9%) than at the edge or in open water (\bar{x} = 29.2% and 14.4%, respectively). Feeding intensity was significantly higher outside of the pier (\bar{x} = 0.40%) than the edge or under the pier (\bar{x} = 0.19% and 0.03%, respectively). Simultaneous with feeding experiments, benthic core samples were collected adjacent to cages. Variability was high, but abundances of prey were consistently higher under the pier (\bar{x} = 200.14 ± 113.3 SD in 1998; 335 ± 290.2 in 1999) than at the edge (\bar{x} = 126.6 ± 50.2 in 1998; 70.8 ± 68.5 in 1999) or in open water (\bar{x} = 53.4 ± 16.1 in 1998; 123.8 ± 193.9 in 1999). No significant differences in prey biomass were determined, suggesting that small, numerous prey were available under the pier and fewer, larger taxa were present at the edge and outside. Data indicate that feeding is suppressed among young-of-the-year winter flounder caged under piers in spite of sufficient prey available. Based on these and other experiments we submit that areas under piers are not suitable long-term habitats for juvenile fish because they interfere with normal feeding activities.

Introduction

The New York-New Jersey Harbor estuary is a highly modified ecosystem that serves as an important nursery ground for a variety of estuarine-dependent fishes (Able and Fahay 1998). Developments to this system have included such practices as dredging, landfills, bulkheading, and pier construction which, over the decades, have left few shallow water areas and little natural fish habitat. The Hudson River estuary is a particularly altered system, but many estuaries are increasingly exposed to these and other anthropogenic influences prompting a considerable interest in determining effects of man-made structures on fishes and fish habitat use.

Earlier investigations by our laboratory determined that growth rates of some juvenile fishes are depressed under large, municipal piers (Able et al. 1999; Duffy-Anderson and Able 1999) in the Hudson River estuary. These studies examined a variety of potential causes for poor growth under piers and tentatively concluded that low light levels

could play a role by affecting feeding success. There has been no study designed to quantify feeding success of juvenile fishes around municipal piers, nor have any attempts been made to examine prey distribution around these structures, a potentially important source of variation in growth rate. We now present the results of a two-year field investigation of the feeding success of winter flounder, *Pseudopleuronectes americanus* (Walbaum), on available prey around municipal piers in the Hudson River estuary.

Winter flounder are an important component of the demersal fish assemblage in the Hudson River estuary, and they use the estuary as a nursery area for their young (Able and Fahay 1998). Young-of-the-year (YOY) winter flounder feed on benthic invertebrates in this and other systems (Pearcy 1962; Klein-MacPhee 1978; Vivian et al. 2000), and in turn may serve as an important trophic link to higher ecosystem levels (Bowen and Harrison 1996; Manderson et al. 2000). Winter flounder populations are vulnerable to fluctuations in recruitment (Rose et al. 1996; Able and Fahay 1998; Sogard et al. in press), which may be driven, in part, by size-specific mortality during early life history stages (Sogard 1997; Van der Veer et al. 1997). As a result, factors that affect feeding and growth

*Corresponding author: current address: National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way, NE, Seattle, Washington 98115-0070; tele: 206/526-6465; fax: 206/526-6723; e-mail: Janet.Duffy-Anderson@noaa.gov.

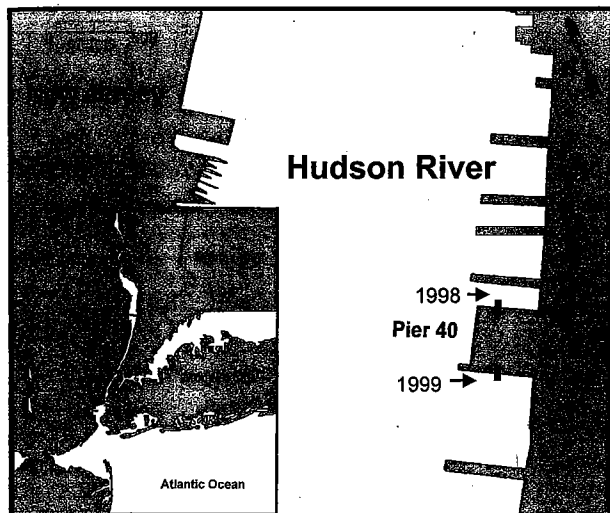


Fig. 1. Study area in the Hudson River estuary ($40^{\circ}44'N$, $74^{\circ}01'W$). Black bars indicate transects in 1998 and 1999.

of larvae and juveniles can play an important role in determining year-class success in this species.

Materials and Methods

Young-of-the-year winter flounder were collected from Sandy Hook Bay, New Jersey ($40^{\circ}25'N$, $74^{\circ}01'W$) during June and July 1998 and 1999. These winter flounder (20–50 mm TL) were maintained at the James J. Howard Marine Sciences Laboratory, Sandy Hook, New Jersey, until needed for an experiment, generally less than 5 d. Fish were held in the laboratory in flow-through fiberglass tanks (640 l) where they were maintained on a 14:10-h photoperiod and fed a diet of frozen *Artemia* sp. and chopped clams. Feeding was stopped two days prior to a field experiment to allow evacuation of the stomach. On the day of the experiment, winter flounder were transferred from holding tanks to a cooler filled with filtered seawater and transported to the field site by boat.

The study site was located at Marine and Aviation Pier 40, a large (351×255 m), concrete pier situated in the Hudson River estuary ($40^{\circ}44'N$, $74^{\circ}01'W$; Fig. 1). This pier has served as a study site in several of our earlier studies on effects of municipal piers on distribution (Able et al. 1998) and growth (Able et al. 1999; Duffy-Anderson and Able 1999) of YOY winter flounder in the Hudson River estuary. A transect comprising three stations was established: 40 m underneath the pier (-40 m), the pier edge (0 m), and 40 m outside of the pier edge in open water ($+40$ m). The transect was established on the north side of Pier 40 in 1998 and on the south side in 1999. Ferry activity on the north side of the pier prevented use of that tran-

sect in 1999. It should be noted that although we have also examined pier-related effects on growth rate at a similar, adjacent pier (Pier A), we were unable to conduct feeding experiments at this site due to intense construction activity.

Replicate, steel-frame benthic cages ($0.85 \times 0.85 \times 0.45$ m) fitted with a 3-mm nylon bag ($0.8 \times 0.8 \times 0.4$ m) were deployed at each transect station ($n = 4$). At the start of each feeding experiment, 3 winter flounder were haphazardly selected from the cooler, transferred into each cage, and the cage was lowered to the bottom. After 3 h, all cages were retrieved, fish were removed, chilled (to prevent regurgitation), and transferred to vials of 10% buffered formalin. Three hours was deemed an appropriate duration for feeding as preliminary experiments showed that this interval allowed YOY winter flounder an opportunity to feed but was not so long that ingested material was passed out of the stomach and into the intestine (Duffy-Anderson unpublished data).

Twelve YOY winter flounder served as controls during each experiment. Control fish were treated in an identical manner to experimental fish, though rather than being added to cages they were held in a filtered seawater-filled cooler on board the boat for the 3-h experimental duration. At the conclusion of the field experiment, control fishes were chilled and transferred to formalin as described above.

In total, we conducted two 3-h feeding experiments in 1998 and three experiments in 1999. Recovery of live winter flounder in 1998 was 100% for both experiments. Recovery of live fish in 1999 was 93% for the first experiment, 100% in the second, and 100% in the third. Dead fish from 1999 were eliminated from further analyses.

STOMACH CONTENTS

In the laboratory, fish were re-measured (mm SL), the stomachs were excised, and the contents were removed. Contents were placed in a solution of 70% ethanol and Rose Bengal to aid in identification. After at least 24 h, stained stomach contents were passed through a $63\text{-}\mu\text{m}$ sieve to remove the staining fluid and to concentrate the sample. Stomach contents were then identified (to family in most cases) and enumerated using a dissecting microscope. Only whole organisms were counted, fragments were not enumerated but were included in the weight of stomach contents. Contents were then dried for at least 24 h in a 60°C drying oven and weighed (mg) on a microbalance (Cahn C-35). Each individual winter flounder (minus the excised stomachs) was dried in a 60°C drying oven for 72 h and weighed (g).

Ontogenetic diet shifts have been reported in

YOY winter flounder (Pearcy 1962; Stehlik and Meise 2000; Vivian et al. 2000), which could lead to variability in diet regardless of pier habitat. We used ANOVA ($\alpha = 0.05$) to determine whether there were significant differences in initial fish size among transect stations. If fish sizes were determined to be similar, any differences in feeding intensity or diet were assumed to be unrelated to fish size. Percent body weight (BW) was used as an index of feeding intensity (Brodeur et al. 2000) to correct for any potential differences in feeding with respect to fish size, calculated as:

$$\%BW = (\text{stomach content weight/whole body weight}) \times 100$$

BW was compared among transect stations according to a nested ANOVA design on arcsin transformed values. In this design, cages are used as the experimental units, nesting fish within cages. Tukey multiple comparison tests were used in post-hoc analyses (SYSTAT 8.0).

PREY AVAILABILITY

We determined whether there were differences in benthic prey availability for YOY winter flounder by collecting benthic samples at each station using a dredge (Wildco) deployed immediately adjacent to the cages. Circular cores of sediment (3.0 cm diameter, 2.0 cm depth) were collected from each replicate sample ($n = 4$) and immediately preserved in 10% buffered formalin. Core samples were returned to the laboratory where contents were stained with Rose Bengal, transferred to 70% ethanol, sorted, identified, and enumerated. Only the uppermost portion of the sediments were sampled as it has been previously determined that winter flounder generally feed on epibenthic prey items (Pearcy 1962; Carlson et al. 1997; Vivian et al. 2000) which are located within the top few centimeters of sediment. All organisms from cores (excluding foraminifera, nematodes, and diatoms) were enumerated, dried in a 60°C drying oven, and weighed (mg).

DATA ANALYSES

Prey organisms identified in stomachs and in benthic cores were pooled into broader taxonomic categories for data analyses due to the presence of several rare organisms. This was deemed an appropriate method as the focus of the study was not to fully characterize the invertebrate assemblage around piers, rather it was to determine availability of prey for YOY winter flounder. Taxa included Polychaeta (included capitellidae, orbiniidae, phyllodoceidae, spionidae, glyceridae, nereidae, pectinariidae), Oligochaeta, Turbellaria, Maxillopoda (primarily harpacticoida but also includes calan-

oida, cyclopoida, copepodites, copepod eggs), Malacostraca (primarily amphipoda but also includes isopoda, decapoda, ostracoda, cumacea), Chelicerata (halacaridae), Insecta (collembola), Bivalvia (clams), Mollusca, (primarily gastropods and gastropod eggs), and Other, which included rare items including other invertebrate eggs (non-gastropod and copepod), fish eggs, worm tubes, tunicates, and hydroids. The phylum Annelida was added to incorporate fewer than 10 worms that were missing key body parts and could not be identified further. It should be noted that although nematodes, diatoms, and foraminifera were also occasionally found in stomachs of caged fish they were not enumerated because they have not been previously identified as prey for YOY winter flounder (Pearcy 1962; Klein-MacPhee 1978). These taxa are abundant in the sediments of the Hudson River estuary (Duffy-Anderson personal observation) and were probably ingested by winter flounder incidentally. It should be noted however, that nematodes may sometimes be consumed by other types of fishes (Hofsten et al. 1983).

Differences in percentages of fish with empty stomachs among transect locations were determined using a one-way ANOVA on arcsin transformed values. Variations in feeding intensity (%BW) were determined as described above. Differences in core sample dry weights were determined using one-way ANOVA. In all cases, inference was determined at $\alpha = 0.05$.

Non-parametric multivariate approaches were selected to determine whether there were differences in composition of stomach contents and prey availability with respect to location relative to the pier. These approaches were chosen due to the proliferation of zero counts and unequal variances of the mean. All non-parametric analyses were conducted using the Primer statistical package (Plymouth Marine Laboratory, United Kingdom) and were performed on ranks of the mean number of prey in each taxa identified from stomachs of the three fish in each cage, and on ranks of the absolute numbers of prey in each taxa identified from cores. Cluster analyses (Bray-Curtis similarity), non-metric multi-dimensional scaling (n-m MDS), ANOSIM randomization tests with 20,000 simulations (analogous to MANOVA), and SIMPER analyses (which describe the contribution of each taxa to the overall dissimilarity of the sample) were used to determine differences in prey assemblage structure in the stomachs and in core samples. In an ANOSIM analysis the test statistic (R) is used to evaluate the degree of separation between samples; $R = 1$ if all replicate samples within a group are more similar to one another than to any replicates in other groups, $R = 0$ if similarities within sites

TABLE 1. Standard lengths (mm) of winter flounder used in field experiments conducted in the Hudson River estuary in 1998 and 1999. Values are means \pm one standard deviation.

| Year | Under Pier | Pier Edge | Outside Pier |
|------|------------|------------|--------------|
| 1998 | 44.0 (4.2) | 41.3 (5.4) | 40.5 (5.1) |
| 1999 | 26.6 (4.6) | 26.0 (5.1) | 26.0 (4.9) |

and between sites are equal. R is generally evaluated on whether or not it is significantly different from zero. Stress values generated by nm-MDS analyses indicate whether 2-dimensional ordinations are useful depictions of the relationships between the samples. Stress < 0.1 suggests a good to excellent ordination with little likelihood of misrepresentation, stress < 0.2 provides a useful description of the data though points at the edges of the range may be misrepresented.

Results

Field experiments were conducted on July 7 and 9, 1998 and June 1, 9, and 28, 1999. Two-way ANOVA showed that sizes of winter flounder were significantly different between years ($p < 0.001$) but not among transect stations within years ($p = 0.10$), with no significant interaction between the two factors. Winter flounder used in experiments in 1998 were larger ($\bar{x} = 42.7$ mm SL \pm 5.3 SD) than winter flounder used in 1999 ($\bar{x} = 26.1$ SL \pm 4.9 SD), because experiments in 1998 were conducted later in the season when only larger-sized fish were available (Table 1). Since body sizes were relatively similar among transect stations within each year, it is unlikely that differences in feeding along the transect in any given year could have been influenced by differences in body size. It is more likely that differences were the result of caging location.

STOMACH CONTENTS

The percentage of winter flounder with empty stomachs varied significantly across the study transect ($p < 0.001$; Table 2). More winter flounder with empty stomachs were noted in under-pier and control environments ($\bar{x} = 71.9\%$ and 91.7% , respectively) than in edge or open water habitats ($\bar{x} = 29.2\%$ and 14.4% , respectively), indicating that many winter flounder caged under the pier were not feeding for the entire duration of the experiment. A few winter flounder held under control conditions had some food in the stomachs, but the material was usually highly digested, indicating that fish had not fed recently. Fish caged along the pier transect had relatively undigested and identifiable prey matter in the stomachs, suggesting that feeding had been more recent. Variations in feeding intensity, as determined by percent body weight,

TABLE 2. Percentage of winter flounder with empty stomachs in the Hudson River estuary arranged by date and sampling location relative to a pier, i.e., under (-40 m), at the edge (0 m), outside of the pier ($+40$ m), and a filtered seawater control.

| Location | July 7, 1998 | July 9, 1998 | June 1, 1999 | June 9, 1999 | June 28, 1999 |
|----------|--------------|--------------|--------------|--------------|---------------|
| Under | 58.3% | 83.3% | 40% | 100% | 77.8% |
| Edge | 41.6% | 16.7% | 12.5% | 41.7% | 33.3% |
| Outside | 16.7% | 8.3% | 8.3% | 16.7% | 22.2% |
| Control | 91.2% | 83.3% | 83.3% | 91.7% | 100% |

were observed across transect stations in both years (Fig. 2) and significant differences were noted in several of the experiments. In all five experiments, feeding intensity of winter flounder caged underneath the pier was consistently less than at edges or outside of the pier and generally more comparable to controls. No significant differences were noted among fish caged at different locations in the first experiment of 1998 (July 7), though the second study of that year (July 9) determined that feeding intensity was significantly higher among fish caged outside of the pier than among fish under it or at the edge ($p = 0.01$). A similar pattern was noted in all three experiments of 1999; winter flounder caged outside of the pier fed with greater intensity than fish caged in other habitats or in controls.

In 1998, winter flounder caged under the pier and at the pier edge consumed primarily Maxillopoda (among fish caged under the pier this category was solely comprised of harpacticoid copepods and copepod eggs; Table 3). Fish caged outside of the pier consumed a more diverse diet composed of gastropods, Maxillopoda (which among open water fish was comprised solely of calanoid copepods and copepod eggs), amphipods, worms, and other items (Table 3). Significant differences in stomach content composition across the transect were detected (Global R = 0.262, $p = 0.006$), and similarity analyses suggested that stomach contents of winter flounder caged under the pier were more homogeneous (both in terms of numbers and types of prey consumed; \bar{x} similarity = 79.1%) than stomach contents of fish caged at edges or in open water (\bar{x} similarity = 30.1% and 43%, respectively).

In 1999, winter flounder caged under the pier ate mostly Maxillopoda, which again was comprised only of harpacticoid copepods, though some clams were also found in the stomachs. Fish caged at the pier edge and outside of the pier also ate primarily Maxillopoda (98% and 99% harpacticoids, respectively) though other taxa were also consumed and the diet was more diverse than under piers. There were significant differences in stomach content compositions with pier location

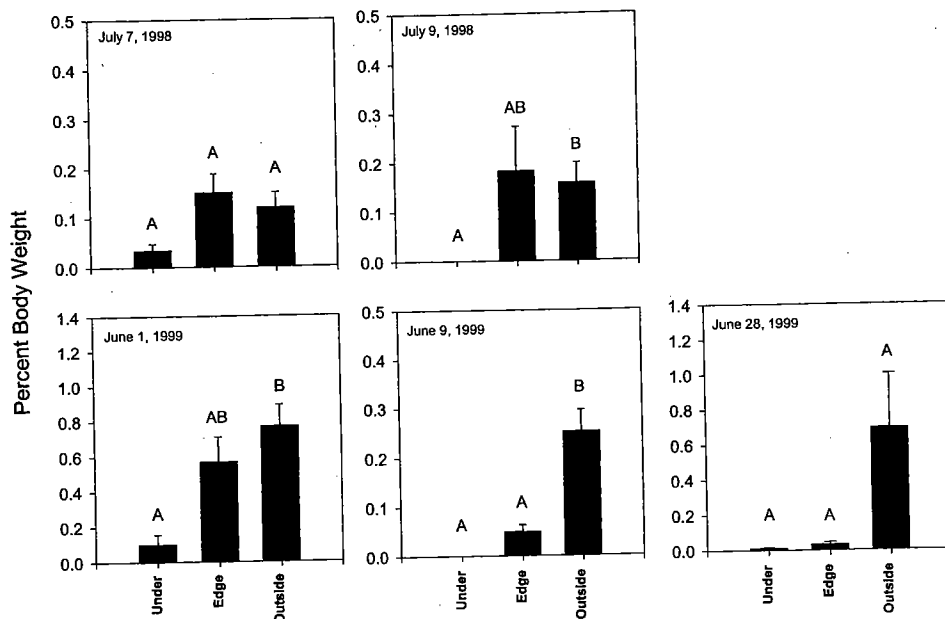


Fig. 2. Mean feeding intensity, expressed as stomach contents as a percentage of body weight, of *Pseudopleuronectes americanus* (\pm SE) under, at the edge, and outside of a municipal pier and in filtered seawater (control). Letters above bar graphs indicate significant differences as delineated by Tukey multiple comparison test ($\alpha = 0.05$).

(Global $R = 0.238$, $p = 0.01$) and it was noted that stomach compositions of fish under the pier were again more homogeneous (\bar{x} similarity = 74.1%) than at edges or in open water (\bar{x} similarity = 54.5% and 48.6%, respectively).

PREY AVAILABILITY

There were significant differences in distribution and abundance of prey organisms across the transects (ANOSIM, $p < 0.001$, Global $R = 0.360$ in 1998; Global $R = 0.230$ in 1999; Table 4). Abundances of prey under the pier were consistently higher ($\bar{x} = 200.14 \pm 113.3$ SD in 1998; 335 ± 290.2 in 1999) than at the edge ($\bar{x} = 126.6 \pm 50.2$ in 1998; 70.8 ± 68.5 in 1999) or in open water ($\bar{x} = 53.4 \pm 16.1$ in 1998; 123.8 ± 193.9 in 1999; Fig.

3). No significant differences in total prey dry weight with transect station were detected in any of the experiments. In several instances, prey dry weights were greater outside of the pier or at the edge than underneath. This suggests that smaller, more abundant prey types occurred under the pier whereas larger, less abundant prey were more common at the edge and in open water.

Samples collected under the pier were primarily composed of copepods (55% in 1998; 80% in 1999), the majority of which were harpacticoids (Table 4). Samples from pier edges and outside of the pier also contained a number of copepods, though they were not as common at the edge or outside of the pier (especially in 1999) as they were underneath. Oligochaetes and polychaetes were

TABLE 3. Mean (standard deviation) of the percent composition (by number) of the stomach contents of winter flounder caged in three habitats around a municipal pier in the Hudson River estuary.

| Taxa | 1998 | | | 1999 | | |
|--------------|---------|-------------|-------------|-----------|------------|-------------|
| | Under | Edge | Outside | Under | Edge | Outside |
| Polychaeta | 0 (0) | 15.6 (35) | 6.6 (12.2) | 0 (0) | 15 (19) | 18.5 (28.6) |
| Oligochaeta | 0 (0) | 0 (0) | 2.5 (7.1) | 0 (0) | 0 (0) | 1.1 (3.3) |
| Turbellaria | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Maxillopoda | 100 (0) | 30.8 (43.5) | 15 (17.2) | 79.2 (25) | 67 (33.9) | 55.4 (33.6) |
| Malacostraca | 0 (0) | 10.4 (19.8) | 26.2 (33.3) | 0 (0) | 8.7 (12) | 22.6 (30.0) |
| Chelicerata | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0.5 (1) |
| Insecta | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Bivalvia | 0 (0) | 0 (0) | 0 (0) | 20.8 (25) | 0 (0) | 0 (0) |
| Gastropoda | 0 (0) | 20.8 (29.2) | 42.3 (38.7) | 0 (0) | 0 (0) | 0 (0) |
| Other | 0 (0) | 22.3 (21.2) | 7.3 (13.9) | 0 (0) | 9.4 (18.6) | 1.8 (4.2) |

TABLE 4. Mean (standard deviation) of the percent composition (by number) of the prey collected from benthic cores taken in three habitats around a municipal pier in the Hudson River estuary.

| Taxa | 1998 | | | 1999 | | |
|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | Under | Edge | Outside | Under | Edge | Outside |
| Annelida | 0 (0) | 0 (0) | 0 (0) | 0.28 (0.3) | 0.13 (0.23) | 0.06 (0.11) |
| Polychaeta | 12.3 (0.34) | 13.1 (4.2) | 10.5 (0.69) | 9.3 (2.6) | 14.5 (4.9) | 19.4 (16.7) |
| Oligochaeta | 30.6 (3.3) | 48.7 (2.5) | 32.5 (8.4) | 6.5 (4.5) | 36.9 (26.2) | 15.9 (11.4) |
| Turbellaria | 0.26 (0.37) | 0.27 (0.38) | 1.3 (1.2) | 0.24 (0.24) | 0 (0) | 0.26 (0.3) |
| Maxillopoda | 54.6 (3.9) | 38.0 (4.9) | 53.7 (8.2) | 80.0 (5.3) | 33.0 (28.6) | 46.3 (32.3) |
| Malacostraca | 0.22 (0.13) | 0 (0) | 0.53 (0.74) | 0.25 (0.25) | 0.07 (0.11) | 0.23 (0.31) |
| Chelicerata | 1.4 (1.1) | 0.98 (0.14) | 1.1 (1.5) | 0.44 (0.37) | 7.4 (6.7) | 9.3 (12.3) |
| Insecta | 0.16 (0.22) | 0.33 (0.47) | 0 (0) | 0.02 (0.04) | 0 (0) | 0.03 (0.05) |
| Bivalvia | 0.42 (0.15) | 0 (0) | 0 (0) | 0.42 (0.09) | 0.07 (0.11) | 0.06 (0.11) |
| Gastropoda | 0 (0) | 1.5 (2.2) | 0 (0) | 2.5 (1.9) | 7.4 (7.4) | 7.1 (3.0) |
| Other | 0 (0) | 0 (0) | 0.26 (0.37) | 0 (0) | 0.53 (0.92) | 1.3 (2.3) |

also present in relatively high numbers at all transect stations but were slightly more abundant at edges in both years. Specifically, in 1998, prey compositions under the pier were more dissimilar to those outside of the pier than they were to edges (Table 5). This observation can also be viewed in the nm-MDS analysis (Fig. 4a) where samples from edges generally ordinated with samples from outside the pier rather than with those from underneath. In 1999, similarity analyses indicated that assemblages under the pier were dissimilar to outside and edge and that edge and outside assemblages were more similar to one another (Table 6). The nm-MDS analysis showed that samples collected from under the pier ordinated slightly to the right of samples from edges and outside, whereas edge and outside tended to cluster together and intersperse (Fig. 4b).

Discussion

Our study showed that feeding among YOY winter flounder is significantly depressed underneath a large, municipal pier in the Hudson River estuary. A greater percentage of winter flounder with empty stomachs were observed under the pier compared to outside or at the edge, and feeding intensity (as measured by %BW) was always less than at the other two sites. These studies support the findings of earlier investigations (Able et al. 1999; Duffy-Anderson and Able 1999) that indicated that growth of juvenile fish (winter flounder and tautog, *Tautoga onitis*) was depressed underneath large pier structures, and suggest that the poor growth rates determined in those studies were a result of inadequate feeding under piers.

Our analyses of potential prey availability for

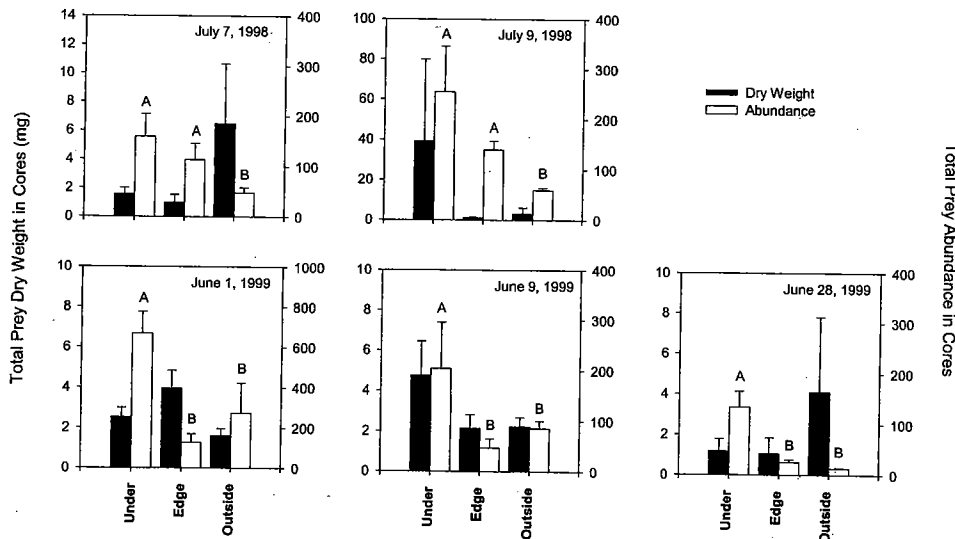


Fig. 3. Mean abundance (white bars) and dry weight (black bars) of total prey enumerated from benthic cores (\pm SE) collected under, at the edge, and outside of a municipal pier in the Hudson River estuary. Letters above bar graphs indicate significant differences as delineated by Tukey multiple comparison test ($\alpha = 0.05$).

TABLE 5. Percent contribution (%Cont) of invertebrate taxa to the mean dissimilarity of the prey composition under, at the edge, and outside of a municipal pier in the Hudson River estuary in 1998.

| Under vs. Edge Mean Dissimilarity = 22.1% | | Under vs. Outside Mean Dissimilarity = 29.7% | | Outside vs. Edge Mean Dissimilarity = 25.1% | |
|--|-------|---|-------|--|-------|
| Taxa | %Cont | Taxa | %Cont | Taxa | %Cont |
| Maxillopoda | 21.4 | Chelicerata | 17.4 | Oligochaeta | 21.5 |
| Chelicerata | 15.2 | Maxillopoda | 17.2 | Chelicerata | 17.5 |
| Bivalvia | 14.4 | Oligochaeta | 15.0 | Maxillopoda | 15.4 |
| Turbellaria | 10.6 | Polychaeta | 13.7 | Polychaeta | 13.0 |
| Insecta | 9.7 | Bivalvia | 11.9 | Turbellaria | 12.4 |
| Polychaeta | 9.4 | Turbellaria | 10.1 | Insecta | 7.1 |
| Oligochaeta | 7.2 | Malacostraca | 6.9 | Bivalvia | 6.1 |
| Malacostraca | 6.6 | Insecta | 5.2 | Gastropoda | 3.6 |
| Gastropoda | 5.6 | Other | 2.7 | Malacostraca | 3.5 |

winter flounder indicated that invertebrate prey were numerically more abundant under piers than at the edge or outside. This was unexpected because previous work on invertebrate prey assemblages under piers in the Hudson River estuary indicated that densities and compositions were similar under and outside of piers (Stoecker et al. 1992). Our data indicate that the numbers of prey available under the pier were more than sufficient for fish feeding and, presumably, growth. The invertebrate assemblage under the pier was dominated by harpacticoid copepods, but harpacticoids also comprised a significant portion of the edge and open water prey. Harpacticoids are an essential food source for a variety of fishes (Alheit and Scheibel 1982; Gee 1989; Coull et al. 1995; Gregg and Fleeger 1997) and are the principal prey of metamorphosing and small juvenile winter flounder (Pearcy 1962; Vivian et al. 2000). YOY winter flounder caged under the pier had ample access to an important food source, but fed poorly or not at all.

Diet diversity is an important component of overall feeding and growth, and it was noted that the stomach contents of feeding winter flounder were more homogeneous under the pier (primarily consisted of harpacticoid copepods and copepod eggs), than stomach contents of winter flounder caged at the edge or in open water beyond the pier. Both polychaetes and amphipods, two known preferred prey items for juvenile winter flounder (Pearcy 1962; Franz and Tanacredi 1992; Vivian et al. 2000), were present under the pier and presumably could have been ingested by winter flounder caged in that location. Polychaetes made up a greater percentage of prey under the pier than outside of the pier in 1998, and malacostracans were present in higher percentages under the pier than at the edge in both 1998 and 1999. In spite of these observations, winter flounder under the pier never had either prey taxa in their stomachs. It is unknown why winter flounder did not feed on

these prey items under the pier, but difficulty localizing (infaunal polychaetes) and capturing (highly mobile amphipods) these taxa in comparatively dark habitats seems likely.

Oligochaetes made up a large portion of the prey assemblage yet they were rarely found in the stomachs of fish caged in any of the habitats. The absence of oligochaetes from winter flounder diets is not unusual. Vivian et al. (2000) found few oligochaetes in the stomachs of caged or wild-caught winter flounder in New York Harbor, and Stehlik and Meise (2000) noticed few oligochaetes in the stomachs of winter flounder caught in adjacent Sandy Hook Bay, New Jersey. A literature review by Stehlik and Meise (2000) indicated that studies of winter flounder diets conducted from the 1960s through the 1990s revealed few instances where oligochaetes were an important component of the diet. While it appears that oligochaetes are occasionally consumed by juvenile winter flounder, they are probably not an important prey source for this species regardless of their abundance.

It is important to note that a variety of factors can contribute to variations in short-term feeding. General characteristics of the environment such as tidal stage, weather condition, and time of day can all exert influence over fish feeding behavior. Broad-scale differences in environment may be of consequence in determining variations in feeding intensity between individual experiments, however they are less likely to affect feeding within a single experiment since all fishes along the transect would be exposed to the same general effects. More relevant to our focus perhaps are differences among local physical parameters, those which may vary between transect locations within a given experiment. Previous studies in our laboratory of this and other piers in the Hudson River estuary have determined that water temperatures, salinities, depths, levels of dissolved oxygen, and sediment grain size are all relatively similar under and outside of piers, though we have found that light levels

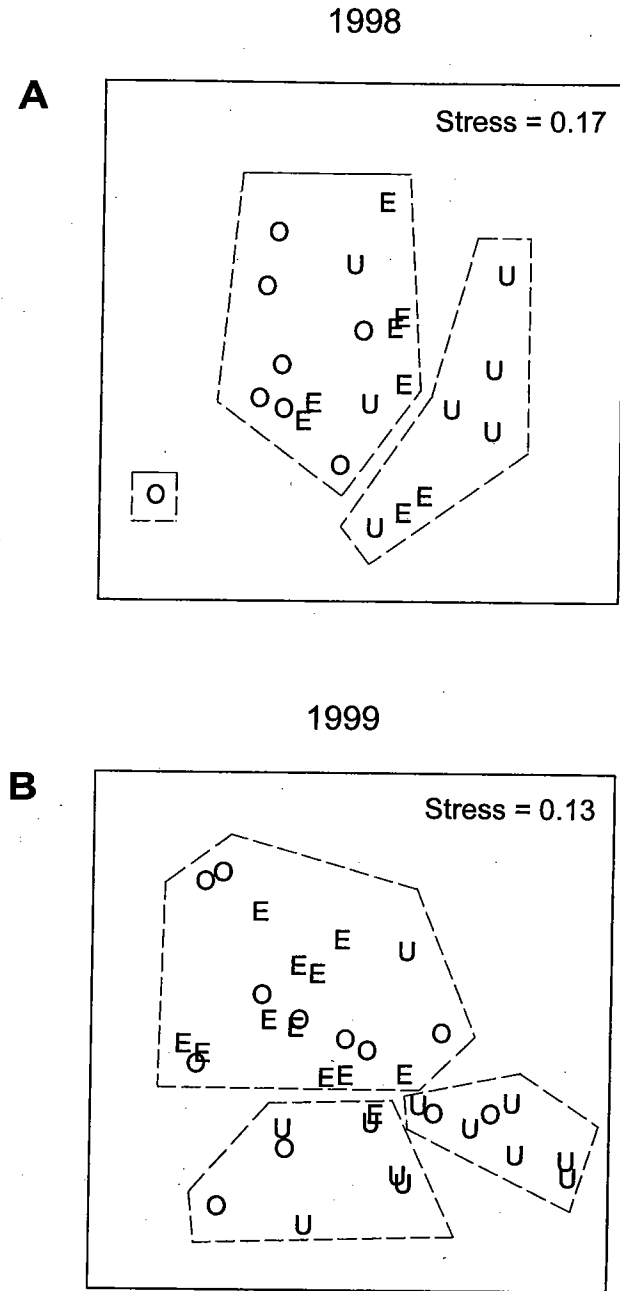


Fig. 4. Non-metric multi-dimensional scaling analysis of core samples collected for examination of prey availability for winter flounder under (U), at the edge (E), and outside (O) of a municipal pier in 1998 (A) and 1999 (B). Dashed lines indicate clusters formed by group cluster analyses.

between the interior and outside are strikingly different (Able et al. 1998, 1999; Duffy-Anderson and Able 1999). Light levels in waters beneath piers are extremely low, often four orders of magnitude below levels in adjacent open water ($< 0.002 \mu\text{E m}^{-2} \text{s}^{-1}$, $> 50 \mu\text{E m}^{-2} \text{s}^{-1}$ under and outside of piers,

respectively), effects which are probably related to intense shading by the concrete-covered pier. It is well established that winter flounder are visual feeders (Pearcy 1962; Olla et al. 1969; Klein-MacPhee 1978; McDonald 1983) and low light environments under piers may interfere with their ability to localize, capture, and ingest prey. Most fishes do have minimal light intensity thresholds for feeding and growth (Boeuf and LeBail 1999), though threshold intensity varies with species. Certainly, low light intensities reduce prey contrast (Chesney 1989) and decrease reactive distance (Vogel and Beauchamp 1999), potentially interrupting a successful predatory bout. Previous studies using other visually-feeding fishes have shown that low light levels limit feeding success (Connaughton et al. 1994; McMahon and Holanov 1995; Ryer and Olla 1999). It seems likely that low light levels would have detrimental effects on the feeding success of visually-feeding fishes, making not only piers, but any darkened habitat a poor foraging location.

It should be cautioned that although low light levels under piers seem likely to disrupt visual foraging tactics, we do not know whether winter flounder could not feed or merely did not feed under piers. Winter flounder may have simply become inactive under piers, adopting an energy-conserving, low activity strategy. Many fishes become less active at night (Olla et al. 1969, 1974; Gomelyuk et al. 1989; Burrows 1994), and low light levels under piers may be sufficient to elicit such a response. Regardless of whether they do not or cannot feed under piers, if winter flounder spend any time under piers during normal diurnal foraging hours they ultimately decrease their total feeding and growth potential. Fish could simply move away from piers to feed and a variety of species are more abundant outside of piers than underneath (Able et al. 1998). This response is another clear indication that under pier areas are suboptimal habitat for YOY fishes. Since poor growth rates among larval and juvenile fishes have been correlated with increased vulnerability to predation (Duffy et al. 1997), higher rates of over-winter mortality (Sogard 1997), and lower recruitment (Houde 1987), piers could have significant detrimental effects.

The greater numerical abundance of prey under piers is an intriguing observation. The overall lower densities of epibenthic invertebrates at edges and outside of the pier could be a function of grazing by epibenthic predators. As we have pointed out, abundances of potential predators such as juvenile fishes are depressed under large piers (Able et al. 1998). Harpacticoid copepods made up a large percentage of the prey at all caging locations

TABLE 6. Percent contribution (%Cont) of invertebrate taxa to the mean dissimilarity of the prey field under, at the edge, and outside of a municipal pier in the Hudson River estuary in 1999.

| Under vs. Edge Mean Dissimilarity = 35.6% | | Under vs. Outside Mean Dissimilarity = 35.9% | | Outside vs. Edge Mean Dissimilarity = 27.4% | |
|--|-------|---|-------|--|-------|
| Taxa | %Cont | Taxa | %Cont | Taxa | %Cont |
| Maxillopoda | 26.5 | Maxillopoda | 23.4 | Maxillopoda | 21.2 |
| Gastropoda | 11.6 | Polychaeta | 12.3 | Polychaeta | 19.7 |
| Chelicerata | 11.3 | Gastropoda | 12.3 | Gastropoda | 16.4 |
| Bivalvia | 10.7 | Chelicerata | 11.0 | Oligochaeta | 12.2 |
| Polychaeta | 10.5 | Bivalvia | 10.0 | Annelida (unidentified) | 5.9 |
| Malacostraca | 6.9 | Malacostraca | 7.0 | Malacostraca | 5.8 |
| Annelida (unidentified) | 6.8 | Oligochaeta | 6.7 | Other | 5.7 |
| Turbellaria | 6.0 | Annelida (unidentified) | 6.7 | Chelicerata | 4.1 |
| Oligochaeta | 5.5 | Turbellaria | 6.5 | Bivalvia | 3.9 |
| Other | 2.5 | Insecta | 2.6 | Turbellaria | 3.3 |
| Insecta | 1.8 | Other | 1.6 | Insecta | 1.9 |

and several studies suggest that juvenile fishes have little impact on local harpacticoid population dynamics (Alheit and Scheibel 1982; Cordell 1986; Webb 1991a,b). These studies suggest that grazing by predators was not the source of the variations in copepod (again, primarily harpacticoid) distribution observed in 1999. Further study of copepod dynamics in the Hudson River estuary is required before a final assessment can be made.

As we have noted elsewhere (Duffy-Anderson and Able 1999), juvenile fishes such as winter flounder may use areas underneath piers intermittently, minimizing the effects of poor feeding conditions. Dark habitats under piers may serve as a predator refuge, obscuring the outline of prey fish and temporarily confusing the pursuing attacker. Once the threat has passed, the prey fish can move out into lighted waters and resume feeding activity. Other studies have shown that fishes utilize darkened or murky habitats to evade predators. For example, Valdimarsson and Metcalfe (1997) showed that during winter, juvenile Atlantic salmon (*Salmo salar*) become nocturnal to hide from diurnal predators, sacrificing optimal diurnal feeding conditions. Maes et al. (1998) suggested that fishes and crustaceans preferentially utilize a highly turbid portion of a Belgian estuary as a predation refuge, and Abrahams and Kattenfeld (1997) hypothesized that juvenile fish prefer predator-free, low-food areas to prey-rich, predation-heavy environments. With particular reference to piers, fishes that swim rapidly through the water column, such as juvenile striped bass (*Morone saxatilis*), could move into and out of areas under the pier relatively quickly, so this trade off of lower food for lower risk would likely be minimal. Some juvenile flatfishes have smaller home ranges (Able and Fahay 1998) and may not venture out from beneath piers as quickly, making their trade-off potentially more costly. Additional studies that monitor movements of YOY fishes around piers could provide valuable

information on behavior of fishes around man-made structures and could help to resolve outstanding questions of how and when fishes utilize areas under piers.

YOY winter flounder fed poorly or not at all in waters beneath a pier in the Hudson River estuary, in spite of prey abundances that appear to have been sufficient for feeding to occur. Differences in prey availability across the pier transect do not appear to be the source of variations in feeding or growth (Duffy-Anderson and Able 1999) of juvenile winter flounder. The impacts of low light availability appear to take on an even greater significance. Based on these and other observations on effects of this pier and other piers on abundance (Able et al. 1998) and growth (Able et al. 1999) of juvenile fishes, we propose the areas underneath piers are poor quality long-term fish habitat because they interfere with normal feeding activities. These results may be indicative of the effects of large piers in general in this and a variety of other urban estuaries.

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**Habitat Quality in the New York/New Jersey Harbor Estuary:
An Evaluation of Pier Effects on Fishes**

Final Report to the Hudson River Foundation

J. T. Duffy-Anderson

K. W. Able

May 1999

Introduction:

Urban estuaries are focal points for human activities and they serve as nursery areas for a variety of juvenile fishes and crustaceans. These two potentially conflicting uses exist in an increasing number of systems, yet it is still unclear how these two factors interact. One question is whether man-made structures degrade natural environments or whether they act to supplement existing habitats. We investigated the roles of a variety of artificial structures, particularly piers, in the lower Hudson River to determine what effects, if any, piers and pier edges have on recently settled fishes. We evaluated these potential habitats using distribution, abundance and growth rate as measures of habitat quality.

Methods and Results:

Trapping

In 1995, the assemblage of fishes relative to municipal piers was examined using two approaches. First, we conducted a field trapping study to examine the abundance and diversity of organisms in each of three habitats, under a large pier, in a pile field area, and at an open water site. Second, we used a field caging technique to examine the effect of piers on growth rates of the juveniles of two target species, the winter flounder, *Pseudopleuronectes americanus*, and the tautog, *Tautoga onitis*, across the same three habitats. Data collected from this investigation indicated that diversity and abundance of fishes were depressed under piers (see Able et al. 1998), and that growth rates among juveniles of the target species were habitat-specific, with greater growth rates occurring among fishes caged in open water and pile field habitats than among fishes caged in under-pier areas (see Able et al. in press).

In 1996, our efforts were focused on the patterns of species abundance and distribution

relative to one municipal pier with a concentration on the pier edge. The trapping survey for 1996 was honed to an under-pier, pier-edge, beyond-pier (open-water) ecotone. We also examined growth rates of juvenile winter flounder and juvenile tautog in caging studies (1996 and 1997) conducted along the same ecotone. Results from the growth studies indicate that growth rates of both winter flounder and tautog are negative under piers and are comparable to lab-starved controls. In contrast, mean growth rates at pier edges and in open water beyond piers were generally positive, with growth at pier edges often being more variable and less rapid than at open water sites (see Duffy-Anderson and Able 1999).

Trapping Results Across the Pier Edge (1996)

The number of species collected in the Hudson River during the study period was low compared to the number captured in 1995 (see Able et al. 1998). From June through October, only 20 different species of fish were captured, for a total of 270 individuals (Table 1). The most abundant fish species in the system was the American eel, *Anguilla rostrata*, of which 70 individuals, or 25.9% of the total fish catch, were obtained (Figure 1). Naked goby, *Gobiosoma bosc*, spotted hake, *Urophycis regia*, and Atlantic tomcod, *Microgadus tomcod*, also constituted a significant portion of the fish catch, comprising 15.9%, 14.8%, and 14.1% respectively.

Abundances of decapod crustaceans in the Hudson River were also low compared to abundances derived in 1995. Only three species of decapods were captured throughout the entire study, the grass shrimp, *Palaeomonetes pugio*, the sand shrimp, *Crangon septemspinosa*, and the blue crab, *Callinectes sapidus*. All three of these species were captured in greater numbers than fishes at all sites, and the total number of decapods caught reached 8405 individuals for the season. Grass shrimp were the single most abundant animal caught in the Hudson River, comprising 61.7% of the total animal catch.

Size and seasonal patterns of fishes

With the exception of the American eel, fishes collected during the study were generally small (Figure 2). Young-of-the-year individuals comprised a large portion (58%) of the total number of fishes captured confirming that the traps used in the study were well suited to the capture of juvenile forms. Juvenile conger eels were only captured during the month of June (Figure 3), and juvenile spotted hake were captured primarily in June (Figure 4). Juvenile Atlantic tomcod were found in high numbers from June through August (Figure 5), and juvenile striped bass were captured in greatest numbers in September (Figure 6).

Fish abundance and distribution

CPUE among fishes across the pier ecotone varied with species. For example, among American eel and Atlantic tomcod, CPUE tended to be higher in the under pier habitat than edge or open water areas (Figure 7). Spotted hake were occasionally found under Pier A, though mean CPUE was higher in edge and open water areas. No other fish species were found under Pier A, therefore CPUE among all other fish species was higher at either pier edge or open water habitats compared to under pier sites.

Distribution of decapod crustaceans

Blue crab adults and juveniles were collected during the study, with adults being present in the collections throughout the study and a cohort of juvenile blue crabs appearing in September (Figure 8). *P. pugio* and *C. septemspinosa* were collected throughout the duration of the study. All three species of decapods were captured at all sites along the pier transects however, mean decapod CPUE was higher at pier edge and open water sites compared to under pier areas (Figure 9).

Statistical Analyses - Trapping Study

