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Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a study across a pier edge

Received: 12 March 1998 / Accepted: 9 November 1998

Abstract The growth rates of two fish species, the winter flounder *Pseudopleuronectes americanus* (Walbaum) (19.3 to 42.6 mm total length, TL) and the tautog *Tautoga onitis* (Linnaeus) (23.9 to 55.9 mm TL), were used to evaluate habitat quality under and around municipal piers in the Hudson River estuary, USA. Growth rates were measured in a series of 10 d field caging-experiments conducted at two large piers in the summers of 1996 and 1997. Cages (0.64 m²) were deployed along transects that stretched from underneath the piers to beyond them, encompassing the pier edge (the transitional zone between the pier interior and the outside). Growth in weight (G_w) was determined at five locations along the transect, 40 m beneath the pier, 20 m beneath the pier, at the pier edge, 20 m beyond the pier edge, and 40 m beyond. Under piers, mean growth rates of winter flounder and tautogs were negative ($\bar{x} G_w = -0.02 \text{ d}^{-1}$), and rates were comparable to laboratory-starved control fishes ($\bar{x} G_w = -0.02 \text{ d}^{-1}$). In contrast, mean growth rates at pier edges and in open waters beyond piers were generally positive ($\bar{x} G_w$ ranged from -0.001 to $+0.05 \text{ d}^{-1}$), with growth at pier edges often being more variable and less rapid than at open-water sites. Analyses of stomach contents upon retrieval of caged fishes revealed that dry weights of food were generally higher among fishes caged at open-water stations (\bar{x} range = 0.02 to 0.72 mg dry wt) than at pier-edge (\bar{x} range = 0.01 to 0.54 mg) or under-pier (\bar{x} range = 0.03 to 0.11 mg) stations, although it was apparent that

benthic prey were available at all stations on the transect. Our results indicate poor feeding conditions among fishes caged under piers, and suboptimal foraging among fishes caged at pier edges. Inadequate growth rates can lead to higher rates of mortality, and, based on these and other earlier experiments, we conclude that under-pier environments are poor-quality habitats for some species of juvenile fishes.

Introduction

Urban estuaries are focal points for human activities, and they serve as nursery areas for a variety of juvenile fishes. These two potentially conflicting roles exist in an increasing number of estuarine systems; however, it is still unclear how they interact. The Hudson River estuary, USA, has long been the focus of intense human development (Pearce 1979), and it has been estimated that as little as 20% of the original (pre-European) wetlands area remain (Squires 1992). The continued loss of the natural, shallow-water habitat in the region has spurred an interest in the effects of man-made structures on fish habitat-use. The Hudson River estuary is representative of many other urban areas that experience anthropogenic influences, and studies in this region may be applicable to other urban estuaries.

Previously, we demonstrated that juvenile fish abundance was reduced under piers compared to adjacent open-water and pile-field areas (areas with pilings but lacking the over-structure of a pier) (Able et al. 1998). Additional data suggests that the growth rates of demersal juvenile fishes caged under the centers of municipal piers are depressed relative to open-water and pile-field areas (Able unpublished data). As a result, we proposed that under-pier areas were unsuitable habitats for some juvenile fishes (Able et al. 1998). However, it has yet to be determined where, relative to piers, these depressions in growth rate occur, or if the pattern is consistent over multiple years. If there is a gradient in

Communicated by N.H. Marcus, Tallahassee

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habitat quality correlated with distance from the pier, it may be reflected as a gradient in growth rates because growth is a good indicator of habitat-quality (Able 1999). Alternatively, the pier edge, the transitional zone between the pier interior and the outside, may be an important ecological zone, providing an abundance of prey items while at the same time offering increased refuge from predation. Areas with greater complexity tend to support more diverse assemblages of juvenile fishes (Sogard and Able 1991) and offer refuge from predation (Sogard and Olla 1993; Jordan et al. 1996), and it may be that the edges of piers offer similar benefits. In this case, growth might be most rapid in this zone. Accordingly, we offer the results of a 2 yr field study designed to examine changes in growth rates of juvenile fishes across a transect that stretched from below a municipal pier to beyond it, with particular emphasis on effects at the interface between highly structured, darkened, under-pier habitats and unstructured, lighted, open waters beyond piers.

Materials and methods

Species

We chose two species of fishes, the winter flounder *Pseudopleuronectes americanus* (Walbaum), and the tautog *Tautoga onitis* (Linnaeus), as the target species for our studies because: (1) they are important resource-fishes common to the New York–New Jersey Harbor Estuary (MacKenzie 1990); (2) they utilize this and other estuaries as nursery areas during the early life stages (Able and Fahay 1998); (3) they have been previously demonstrated to exhibit measurable habitat-specific growth in cages (Sogard 1992).

Study sites

Two concrete municipal piers, Port Authority Pier A (213 m × 100 m) and Marine and Aviation Pier 40 (351 × 255 m), were selected as study sites in the Hudson River estuary (40° 44' N; 74° 01' W; Fig. 1). These piers are similar in construction, and are typical of the many large municipal piers present elsewhere in the New York–New Jersey Harbor. Additionally, these locations have served as sites for our previous investigations into the effects of piers on the distribution of benthic fauna (Able et al. 1998).

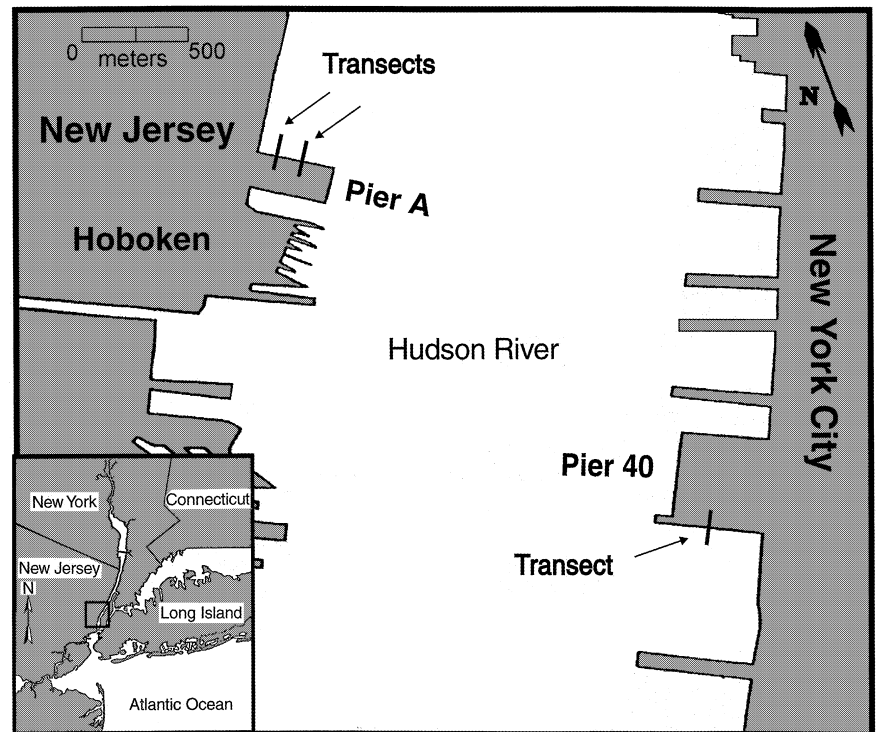
Physical parameters

Water temperature (°C), salinity (‰), and dissolved oxygen (mg l⁻¹) were recorded hourly at depth at one under-pier station (40 m beneath) and one open-water station (40 m beyond the pier edge) using continuously-recording dataloggers (Hydrolab Inc.). Water depths were recorded several times using a sounding lead ($n = 6$ in 1996, $n = 5$ in 1997), and light levels at the bottom were measured intermittently ($n = 10$ in 1996, $n = 5$ in 1997) at all stations using an underwater radiation sensor (LI-COR, Inc.). Bottom-substratum sampling was conducted in both years to determine differences in particle size among stations. Three replicate benthic samples were taken at each site, and a core sample (3 cm diam) was extracted from each. Samples were stored on dry ice in the field and returned to the laboratory, where the top 2 cm of each frozen core were extracted and wet-sieved through a 63 μm screen by a modification of the Folk (1980) method. Fine (< 63 μm; silt and clay) and coarse (> 63 μm; sand and larger particles) sediments were described as the percentage of the dry weight of the total sample.

Study design

Two transects stretching from under the pier to the open water beyond the pier were established in 1996 (Pier A). The first transect was located ≈75 m from the shoreline (hereafter referred to as the “Near” transect) and the second ≈125 m from the shoreline (referred to as the “Far” transect). Each transect was comprised of

Fig. 1 Location of study sites in New York–New Jersey (USA) Harbor estuary in 1996 and 1997



five stations: 40 m beneath the pier (-40 m), 20 m beneath (-20 m), at the pier edge (0 m), 20 m beyond the pier edge (+20 m), and 40 m beyond (+40 m). Only one transect (125 m from the shoreline) was used in 1997 (Marine and Aviation Pier 40), as in 1996 it was determined that transect distance from the shoreline had little effect on growth rates.

Juvenile winter flounder (19.3 to 42.6 mm TL) were captured by seine net in June and July in the shallow-water areas of adjacent Sandy Hook Bay, New Jersey (40° 25' N; 74° 01' W). Juvenile tautogs (23.9 to 55.9 mm TL) were captured in Clinton, Connecticut (41° 15' N; 72° 32' W) (1996) and in Sandy Hook Bay (1997) in August. Fishes were transported from the capture areas to the James J. Howard Marine Sciences Laboratory, Sandy Hook, New Jersey, where they were maintained in flow-through aquaria (640 liters) on a diet of live *Artemia* sp. (Utah Great Salt Lake) nauplii, frozen *Artemia* sp., and chopped clams for no more than 1 wk prior to each field experiment.

To evacuate the digestive tract, fishes were not fed for 2 d prior to an experiment. On the same day that the feeding regimen was stopped, fishes were marked with a subcutaneous injection of non-toxic acrylic dye and allowed a 24 h recovery. Twenty-four hours prior to field deployment, fishes were weighed (mg), and held in groups of three in flow-through containers pending transport to the field site.

Cages were constructed of a steel frame (0.85 m × 0.85 m × 0.45 m), from which a 3 mm mesh nylon bag (0.8 m × 0.8 m × 0.4 m) was suspended. This allowed passage of water, sediment, and prey into the interior but still retained the fishes. On the initiation of each experiment, fishes were transported to the field site, three fish were transferred to each cage, and the cage was lowered to the bottom. Three cages were deployed at each station on the transect in 1996, and in 1997, five cages were deployed at each station. After 10 d, all cages were retrieved, and the fishes were removed and transported back to the laboratory where they were re-weighed to determine changes in weight. We conducted two 10 d experiments with juvenile winter flounder in each year, one 10 d experiment using tautogs in 1996, and two 10 d experiments with tautogs in 1997.

Concurrent with each field experiment, 15 fish were randomly chosen to serve as controls. Control fish were held without food for 2 d, marked with dye, and weighed. These fish were retained in the laboratory for 10 d without food under parameters similar to field fish. At the conclusion of the field experiment, control fish were re-weighed to determine changes in weight. This provided the standard by which changes in growth among experimental fish were evaluated.

We investigated whether benthic prey were available for consumption at all transect stations by dissecting the stomachs of all fishes used in the experiments. Stomach contents were counted, identified, dried in a 60 °C drying oven for at least 24 h, and weighed on an analytical balance (mg). This revealed the diet of fishes on the last day of the investigation, and may reflect the feeding regime of fishes during the entire duration of the experiment.

Statistical analyses

Growth in weight was assumed to be exponential (Duffy and Epifanio 1996) and the rate coefficient (G_W) was calculated on a daily time step (d^{-1}) according to:

$$G_W = (\ln W_f - \ln W_i) / t,$$

where W_i = initial weight of a fish prior to deployment, W_f = final weight of the fish at conclusion of the study, and t = duration of experiment in days. The initial day of the experiment was the day on which the fishes were weighed in the laboratory, and the final day was the day on which they were retrieved from the field and re-measured, for a total of 11 d ($t = 11$). Differences in growth rates and stomach-content dry weights among the five transect stations and the laboratory controls were determined using separate ANOVA procedures. Tukey multiple-comparison tests were used to assess differences, and inference was made at $\alpha = 0.05$.

Results

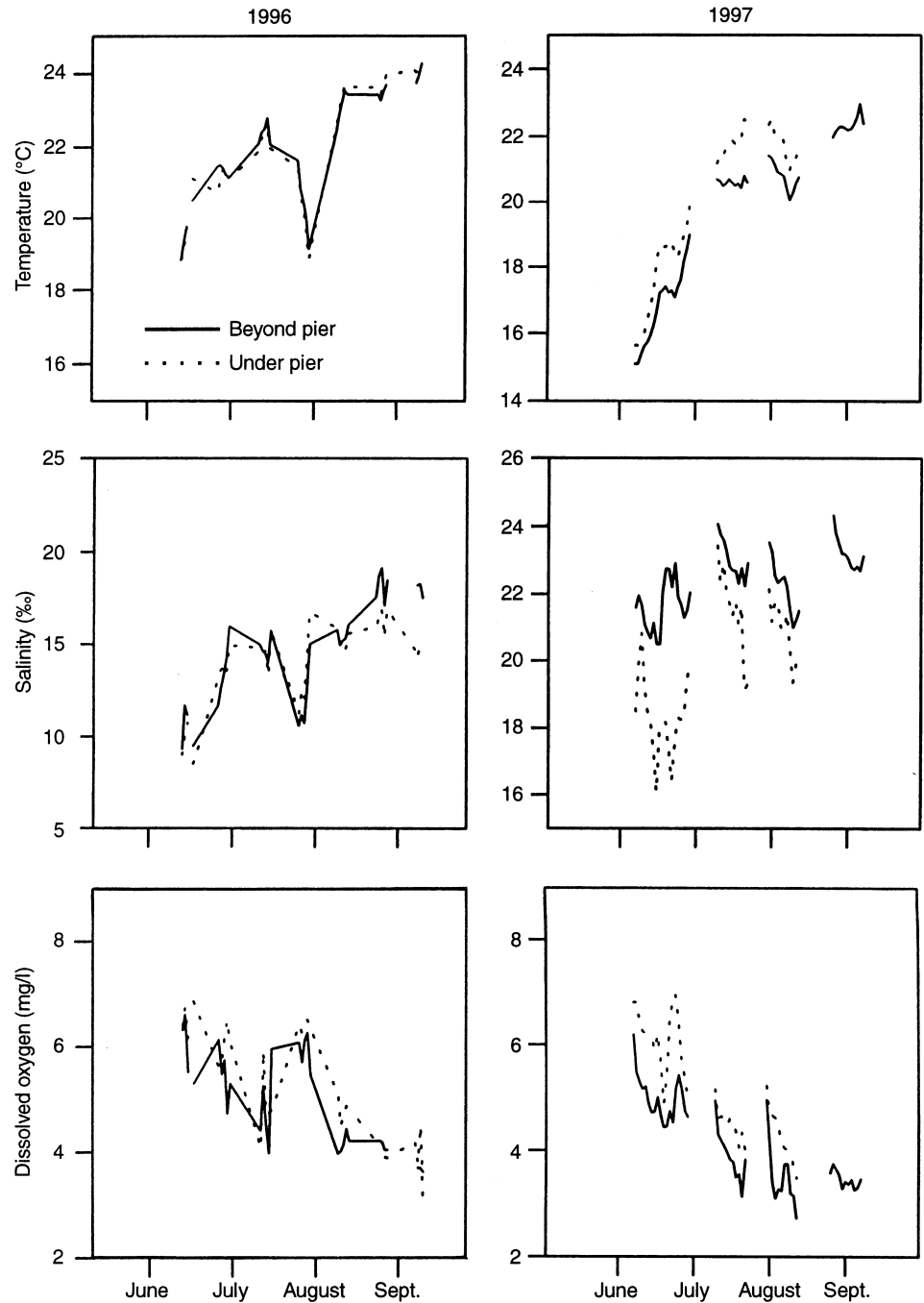
Physical parameters

Average daily temperatures during the study in 1996 ranged from 18 to 24 °C. Salinities were variable, ranging from 9 to 19‰, and average levels of dissolved O₂ ranged from 3 to 7 mg l⁻¹ (Fig. 2). Average temperatures in 1997 ranged from 15 to 23 °C. Average salinities varied between 16 and 24‰, and levels of dissolved oxygen between 3 and 7 mg l⁻¹ over the course of the study. Multiway ANOVA revealed no significant differences in any of these physical parameters among sites in 1996, although in 1997 water temperatures underneath the pier were significantly higher than those recorded beyond the pier ($p = 0.03$). Similarly, waters beyond the pier were significantly more saline in 1997 than the waters beneath. The datalogger deployment station beyond the pier was deeper than the deployment station beneath it, so slight differences in temperature and salinity may have been due to cooler, deeper, more saline waters outside the pier. The levels of dissolved oxygen in 1997 also differed somewhat between under the pier and beyond the pier, although not significantly so.

Analyses of sediment composition indicated that in both years the sediments were composed primarily of fine particles, although sediments at Pier A in 1996 were generally finer than sediments at Pier 40 in 1997 (Table 1). Sediments collected at Station -40 m at the Far transect were significantly coarser ($p = 0.002$) than those collected at all other stations in 1996. Similarly, samples collected at Station -20 m were composed of significantly coarser sediments ($p \leq 0.001$) than all other sites in 1997. In both cases, sediments contained a large number of concrete particles, and it may be that some of the concrete pile-supports under the municipal piers were deteriorating and that small fragments were present in our samples.

The average depth was 2.3 m beneath and beyond Pier A, and no significant differences among stations or between study transects were detected in 1996 (Table 1). The average depth was 3.1 m at Station -40 m, and 5.4 m at Station +40 m, with sites beyond the pier being significantly deeper than sites beneath the pier in 1997 ($p \leq 0.001$). In both years, light levels at under-pier sites (-20, -40 m) were very low, often below the detection of the light meter, while levels at stations at the pier edge (0 m) and in the open water beyond the pier (+20, +40 m) tended to be higher and more variable (Table 1). Specifically, light levels were significantly lower under the pier than beyond the pier in 1996 ($p \leq 0.001$). The trend toward higher light levels beyond the pier was retained in 1997, although only light levels at +20 m were significantly higher than at other stations on the transect ($p = 0.04$). Variations in light levels in 1997 among open-water stations were most probably related to the substantial differences in depth along the transect, as it was observed that light levels at the +40 m station

Fig. 2 Temperature, salinity, and dissolved oxygen levels under and beyond municipal piers in 1996 and 1997



(\bar{x} depth = 5.4 m) were always lower than light levels at the +20 m station (\bar{x} depth = 4.4 m).

Winter flounder, *Pseudopleuronectes americanus*

Seventy percent of the fish were recovered in the first experiment of 1996, 72% in the second. Recoveries for each experiment in 1997 were 82 and 93%, respectively. Differences in percent recovery among sites in the study transect were slight. Under-pier recovery was 61% for both the first and second experiments in 1996. Recovery at the edge was 61 and 94%, respectively, while

recovery among open-water cages was 78 and 67%. Control recoveries were 100% for both experiments. The results of 1997 were similar. In the first experiment recovery was 87%, under the pier, 80% at the edge, 73% in open water, 93% control; in the second experiment recoveries were 80, 100, 100, and 100%, respectively. No cages were found opened at the end of the study, and it was assumed that all cages had remained sealed for the entire duration of the experiment. Thus, escape from the enclosures is an unlikely explanation for the differences, and it is more likely that caged individuals died and decomposed during the 10 d of each experiment.

Table 1 Mean (\pm SE) sediment composition, station depth, and light intensity for experimental transects in Hudson River (Fig. 1) in 1996 (Pier A) and in 1997 (Pier 40). Stations are designated as distances beneath pier (–) or beyond (+) pier edge (0 m). In 1996, there were two transects: 75 m from shoreline (*Near*) and 125 m

from shoreline (*Far*); in 1997 there was only one transect 125 m from shoreline. Depth and light intensity on bottom measured at several times during study period are shown (% *fine* percentage of sediment particles $< 63 \mu\text{m}$, determined by dry weight; * significant difference as determined by Tukey multiple-comparison test)

Year, Transect, Station	Sediments (% fine)	Depth (m)	Light intensity ($\mu\text{E m}^{-2} \text{s}^{-1}$)
1996			
Near			
–40 m	93.1 (5.73)	2.1 (0.05)	0 (0.001)*
–20 m	93.5 (1.62)	2.3 (0.06)	0.02 (0.01)*
0 m	91.6 (1.57)	2.3 (0.07)	25.8 (5.41)
+20 m	99.5 (0.06)	2.4 (0.15)	53.5 (5.68)
+40 m	99.7 (0.06)	2.4 (0.14)	58.6 (7.81)
1996			
Far			
–40 m	60.6 (10.4)*	2.3 (0.14)	0 (0.001)*
–20 m	95.6 (1.26)	2.4 (0.06)	0.01 (0.003)*
0 m	91.6 (2.35)	2.4 (0.08)	32.9 (4.34)
+20 m	98.0 (0.22)	2.3 (0.02)	55.8 (7.10)
+40 m	97.6 (0.57)	2.2 (0.02)	49.5 (4.69)
1997			
–40 m	68.7 (4.78)	3.1 (0.03)	0 (0.0)
–20 m	31.3 (2.74)*	2.2 (0.14)	0.02 (0.009)
0 m	67.9 (2.38)	3.6 (0.14)*	6.1 (3.31)
+20 m	79.8 (3.75)	4.4 (0.24)*	18.1 (8.66)*
+40 m	72.4 (2.22)	5.4 (0.22)*	5.0 (1.83)

Growth rates varied with habitat type. Overall, winter flounder demonstrated negative growth rates when maintained in under-pier cages ($\bar{x} G_W = -0.016 \text{ d}^{-1}$), and these rates were comparable to controls ($\bar{x} G_W = -0.023 \text{ d}^{-1}$). Rapid, positive growth rates were observed among fish maintained in cages deployed in open water ($\bar{x} G_W = +0.02 \text{ d}^{-1}$), and several individuals in open-water cages doubled their body weight over the course of the 10 d study. Variability in growth rate was highest at the pier edge, with individual rates ranging from -0.04 to $+0.10 \text{ d}^{-1}$, although overall mean G_W was positive ($+0.012 \text{ d}^{-1}$).

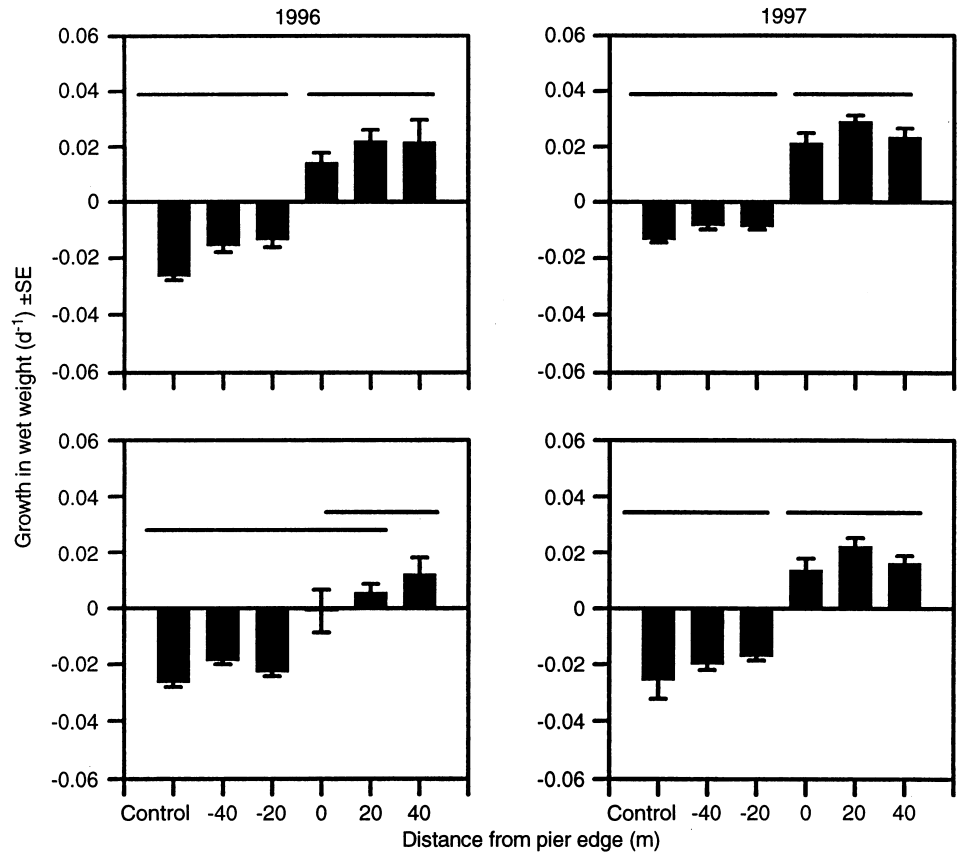
Mean G_W in each cage in 1996 was calculated to ensure statistical independence (Hurlbert 1984), and two-way ANOVAs were conducted on each experiment to examine the effects of transect (Near vs Far), station (–40, –20, 0, +20, +40 m), and their interaction. There were no significant differences in G_W between the two transects, there were significant differences among stations, and there were no significant interactions. Therefore, data were pooled across the two transects and re-analyzed using nested ANOVA designs. The analyses reiterated the significant differences in growth rates among stations, and Tukey multiple-comparison tests revealed that in the first experiment growth rates among fish caged at 0 m ($\bar{x} G_W = +0.014 \text{ d}^{-1}$), +20 m ($\bar{x} G_W = +0.022 \text{ d}^{-1}$), and +40 m ($\bar{x} G_W = +0.022 \text{ d}^{-1}$) were significantly different from those caged at –20 m ($\bar{x} G_W = -0.014 \text{ d}^{-1}$), –40 m ($\bar{x} G_W = -0.016 \text{ d}^{-1}$), and the laboratory control ($\bar{x} G_W = -0.026 \text{ d}^{-1}$) (Fig. 3). The results of the second experiment generally supported the previous observations. Fish caged at under-pier stations demonstrated negative growth rates ($\bar{x} G_W = -0.023$ and -0.019 d^{-1} for –20 and –40 m, respectively) that were

comparable to laboratory-starved rates ($\bar{x} G_W = -0.027 \text{ d}^{-1}$). Growth of fish at the pier edge ($\bar{x} G_W = -0.001 \text{ d}^{-1}$) and in open-water areas ($\bar{x} G_W = +0.006$ and $+0.012 \text{ d}^{-1}$ for +20 and +40 m) were not significantly different from each other, although growth at the edge was also not significantly different from under-pier rates.

The results of the 1997 experiments corroborated those of 1996. Fish caged under the pier (–20, –40 m) demonstrated negative growth rates ($\bar{x} G_W = -0.009$ and -0.008 d^{-1} respectively) that were significantly different from fish caged at the pier edge ($\bar{x} G_W = +0.021 \text{ d}^{-1}$) and in open water ($\bar{x} G_W = +0.029$ and $+0.024 \text{ d}^{-1}$) in the first experiment. Significant differences in growth rates were also noted between under-pier fish ($\bar{x} G_W = -0.017$ and -0.02 d^{-1}) and those at pier edges ($\bar{x} G_W = +0.014 \text{ d}^{-1}$) and in open-water areas ($\bar{x} G_W = +0.022$ and $+0.016 \text{ d}^{-1}$) in the second trial (Fig. 3). Under-pier rates were comparable to laboratory control rates in both 10 d experiments ($\bar{x} G_W = -0.013 \text{ d}^{-1}$ in the first experiment, $\bar{x} G_W = -0.026 \text{ d}^{-1}$ in the second).

Winter flounder are apparently capable of feeding under piers, at least to some degree. Stomach-content analyses revealed that they had food in the stomachs at the time of cage retrieval at all transect stations (Fig. 4). Regardless of station, the principal food items in the stomachs were harpacticoid copepods and gammarid amphipods. It was noted that polychaetes, isopods, barnacles, ostracods, and brachiopods formed a small portion of the diet of fishes caged at 0, +20 and +40 m, and were largely absent from the stomachs of under-pier fish. Due to logistical constraints, dry weight analyses could not be performed for the first experiment of 1996. However, dry weight analyses from the second experiment revealed that mean dry weights were lower at –40,

Fig. 3 *Pseudopleuronectes americanus*. Mean (\pm SE) growth rate in weight (G_W) at transect stations (-40, -20, 0, +20, +40 m) in 1996 and 1997 (Top, bottom histograms first and second 10 d experiment in each year; horizontal lines similar values, determined by Tukey multiple-comparison tests)



-20, and 0 m than at +20 and +40 m, although no significant differences were detected. Analysis of the first experiment of 1997 showed that mean dry weights were lower at the -40 and -20 m stations, while dry weights were considerably higher at 0, +20 and +40 m. The stomachs of all control fish were empty. Analysis of the second experiment in 1997 showed that stomach content dry weight at +40 m was significantly higher than at +20 m, 0, -20, -40 m, and the laboratory controls. Stomachs of some laboratory fish ($n = 4$) contained unidentified material that may have been introduced into the water column through the filtered seawater system at the laboratory.

Tautog, *Tautoga onitis*

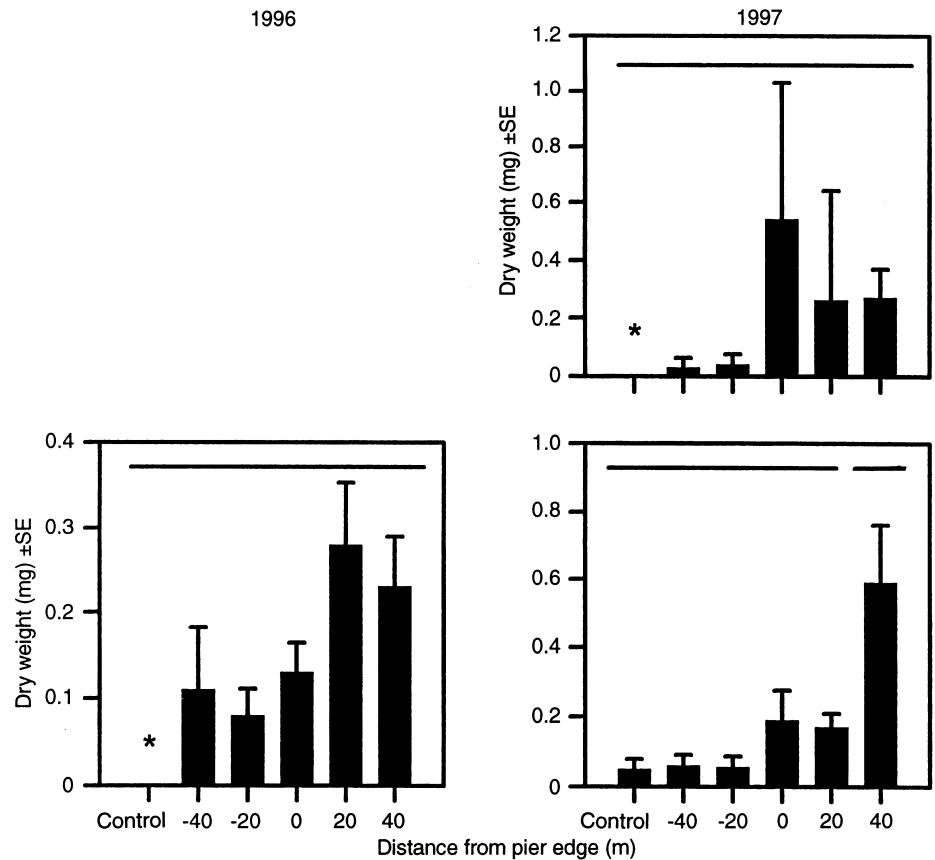
The total percent recovery of caged tautogs was better than the recovery of winter flounder, with 88% for the one experiment in 1996, and 97 and 98% for the two experiments in 1997. The tautog used in these studies were somewhat larger than winter flounder, and better recovery of fish during these experiments may have been a function of size and development. Differences in percent recovery among transect stations were slight. Average percent recovery under the pier in 1996 was 91%, recovery at the edge was 89%, and among open-water cages recovery 94%; recovery among controls was 92%. Recoveries in 1997 were 93 and 100% under the pier,

100 and 87% at the edge, 97 and 100% in open water, and 100 and 100% in the laboratory controls for the first and second experiments, respectively.

Juvenile tautog growth patterns were similar to those observed among juvenile winter flounder, with lowest growth rates amongst under-pier fish. Nested ANOVA and Tukey post-hoc tests revealed that G_W was significantly depressed among fish caged under the pier ($\bar{x} G_W = -0.023$ and $\bar{x} G_W = -0.024 d^{-1}$ for -20 and -40 m, respectively) compared to fish caged at the pier edge ($\bar{x} G_W = +0.014 d^{-1}$) and in open water ($\bar{x} G_W = +0.043 d^{-1}$ and $+0.048 d^{-1}$ for +20 and +40 m, respectively) in 1996 (Fig. 5). Variability in growth was highest among fish caged at the pier edge. Results from 1997 supported the general observed trends. Growth rates at -40 m ($\bar{x} G_W = -0.022 d^{-1}$), -20 m ($\bar{x} G_W = -0.015 d^{-1}$), and in the laboratory ($\bar{x} G_W = -0.022 d^{-1}$) were significantly lower than growth rates at the pier edge ($\bar{x} G_W = +0.053 d^{-1}$), +20 m ($\bar{x} G_W = +0.049 d^{-1}$), and +40 m ($\bar{x} G_W = +0.04 d^{-1}$) in the first experiment. Similarly, growth rates among fishes caged in open water ($\bar{x} G_W = +0.005$ and $+0.001 d^{-1}$) and at the pier edge ($\bar{x} G_W = +0.003 d^{-1}$) were greater than under the pier ($\bar{x} G_W = -0.019$ and $-0.026 d^{-1}$) or control ($\bar{x} G_W = -0.021 d^{-1}$) rates in the second experiment.

Analyses of tautog stomach contents revealed trends similar to those determined for winter flounder. Food was available for consumption at all transect stations, although tautogs beyond the pier or at the pier edge

Fig. 4 *Pseudopleuronectes americanus*. Mean (\pm SE) stomach-content dry weight at transect stations (-40, -20, 0, +20, +40 m) in 1996 and 1997 (Top, bottom histograms analyses of first and second 10 d experiment in each year; horizontal lines similar values, determined by Tukey multiple-comparison tests; * all fishes had empty stomachs) Dry weights were only available for second experiment in 1996



generally had higher stomach-content weights than fish at under-pier stations (Fig. 6). Contents were not readily identifiable, probably because tautogs use modified pharyngeal teeth to grind ingested foods (Olla et al. 1974). It appeared that most of the contents were small pieces of harpacticoid copepods, mysids, and amphipods. Mean stomach-content dry weights in 1996 were significantly higher at +40 m than at all other transect stations. Stomachs of control fish were all empty. Total dry weights were lowest at the edge and comparable between under-pier and open-water fish in the first experiment in 1997, and highest among fish caged at +20 m in the second. No significant differences were detected in either experiment. Control fish in the first trial of 1997 all had empty stomachs, while in the second trial the stomach of one individual contained some partially digested material.

Discussion

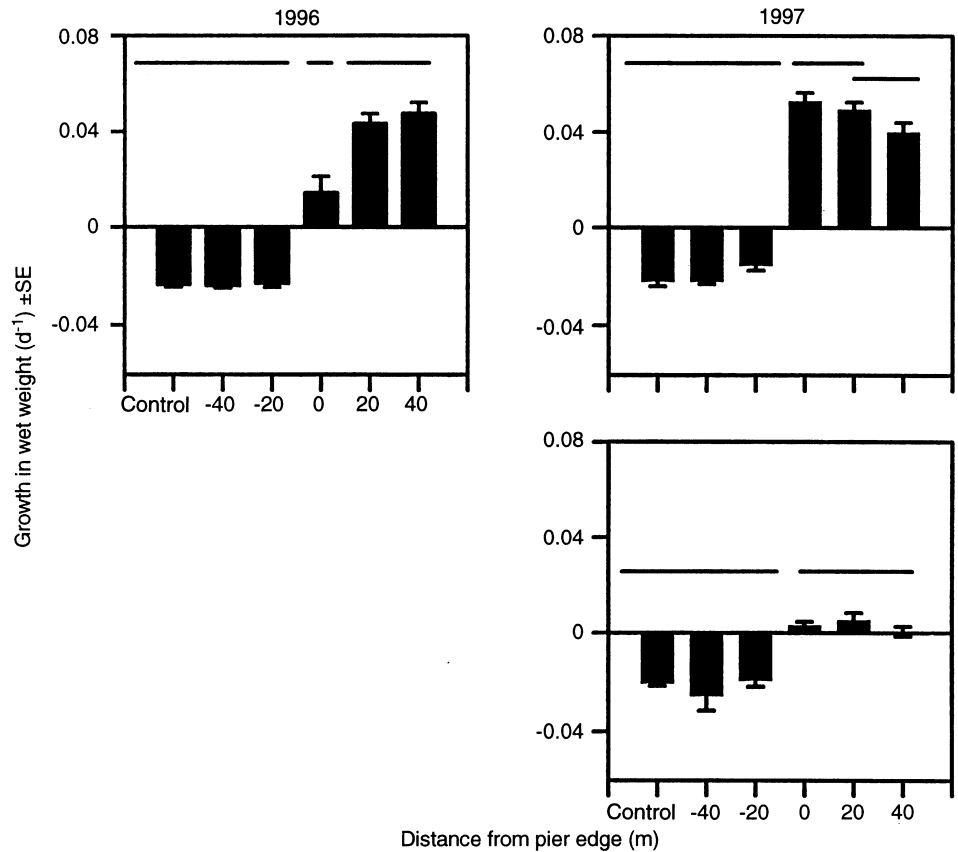
The results indicate that growth rates of juvenile winter flounder *Pseudopleuronectes americanus* and tautogs (*Tautoga onitis*) caged under municipal piers are less than those of fishes caged at pier edges or in open waters beyond piers. The similarities between negative growth rates observed among under-pier fishes and those characteristic of laboratory-starved control individuals imply that fishes caged under piers experienced poor feeding

conditions and perhaps even periods of starvation. Starvation of juveniles may weaken overall condition, potentially making these individuals more vulnerable to predation (Gibson 1994), physiological stress (Johnson and Evans 1996), and disease (Vethaak 1992).

Additionally, the results suggest that variability in growth rate was often very high at the pier edge. Reduced growth rates at pier edges suggest these fishes did not feed at optimal conditions. Smaller body size increases the risk of size-selective mortality (Sogard 1997), either by increasing the likelihood of losses to overwinter mortality (Johnson and Evans 1990, 1991; Smith and Griffith 1994) or capture by predators (Post and Evans 1989; Duffy et al. 1997). Similarly, foraging efficiency (Ghan and Sprules 1993) and prey-handling time (Bindoo 1992) may also be compromised, contributing to reduced feeding success. In turn, all these factors could act to remove individuals from the population and thereby reduce the number of survivors to the adult population.

In our experiments, fishes were caged under piers for the full duration of the 10 d experiments, yet fishes need not restrict themselves under piers. Rather, forays to open-water regions from under-pier areas (or vice versa) could occur. For example, fishes may use piers as a refuge from predators, similar to the way they may use complex structure as cover (Sogard and Able 1994; Persson and Eklov 1995). Fishes that use under-pier areas during non-feeding hours would be less likely to be

Fig. 5 *Tautoga onitis*. Mean (\pm SE) of growth rate in weight (G_W) at transect stations (-40, -20, 0, +20, +40 m) in 1996 and 1997. Only one 10 d experiment was conducted in 1996. Further details as in legend to Fig. 3



impacted by poor feeding conditions. However, even short periods under piers during normal feeding hours would impact the total amount of time available for foraging and therefore reduce the potential for growth. Alternatively, it is worth noting that the home ranges of small, recently settled fishes are probably small, based on data for overlapping sizes of winter flounder (Saucerman and Deegan 1991) and tautogs (Able and Fahay 1998).

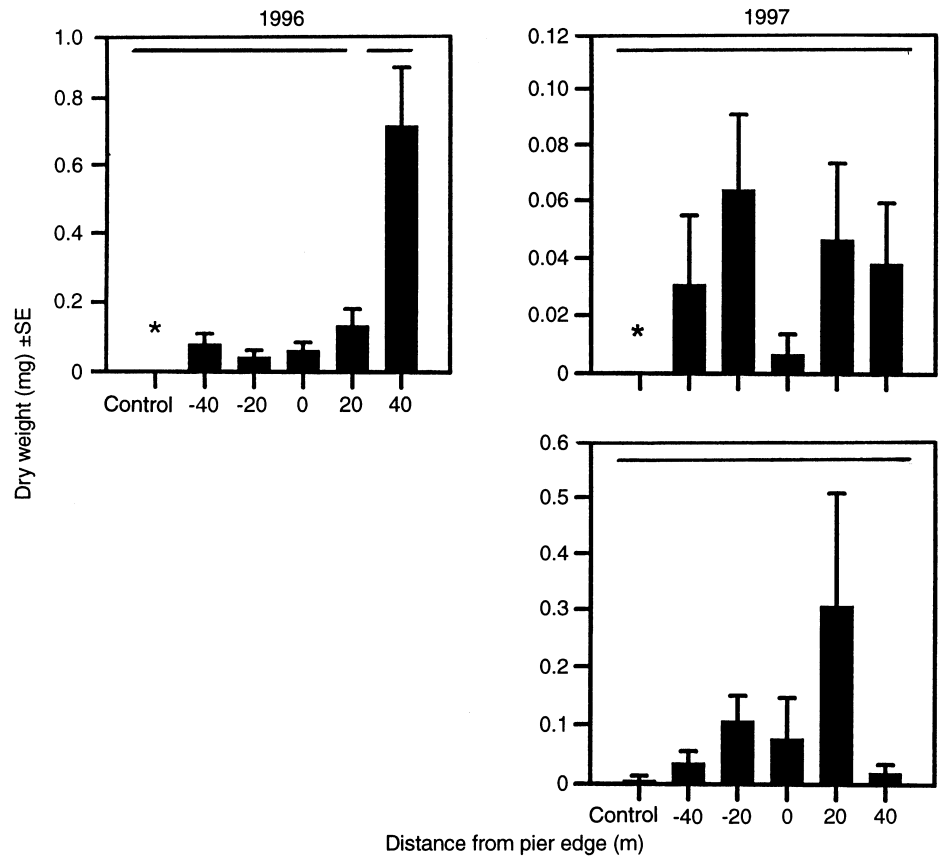
We were unable to pinpoint the minimum distance under piers where consistent negative growth rates appeared. At 20 m beneath the pier growth rates were negative, but it is likely that there are distances between the pier edge and -20 m where that change occurs. Growth experiments that focus on effects within this range (0 m to -20 m) might provide more conclusive data, although we speculate that light availability plays a role. We measured a variety of physical and chemical characteristics beneath and outside piers in both years, and determined that only variations in light availability were consistently different between areas beneath the pier and areas outside. Moreover, under-pier areas were never exposed to sunlight, whereas all cages deployed at pier-edge areas were, at least at certain times of day, exposed. It could be that exposure to sunlight, even intermittently, is sufficient to promote growth.

Light availability may be an important component of feeding success. Previous work on the effects of turbidity (with associated changes in light intensity) indicated that reductions in prey contrast (Chesney 1989; Miner and

Stein 1993), foraging efficiency (Greycay and Targett 1996), reactive distance (Barrett et al. 1992), and visual range (Vinyard and O'Brien 1976) reduce feeding success. Poor light conditions under piers may have similar effects, especially if fishes rely on vision to acquire food. The use of vision as the principal means of capturing prey is common, and available evidence suggests that winter flounder and tautogs are visual-feeders. Pearcy (1962) reported that juvenile winter flounder maintained in conditions of total darkness did not feed on live zooplankton, and Olla et al. (1969) only observed actively feeding, adult, winter flounder during daylight hours. Less is known about the feeding activity of juvenile tautog, although sonic tracking of adults indicated that they are inactive and have empty guts at night (Olla et al. 1974), suggesting that they also feed during daylight hours.

While it seems likely that visually feeding fishes would be unable to feed in darkened under-pier environments, we cannot exclude the possibility that there was less food available under piers for consumption. It may be that juvenile fishes are able to successfully consume prey in darkened habitats but that food availability is too low to support good growth rates. Indeed, we found that under-pier fishes had some food in their stomachs at the time of cage retrieval. However, previous analyses by Stoecker et al. (1992) of abundance of benthic invertebrates under and between municipal piers in the lower Hudson River determined that there were

Fig. 6 *Tautoga onitis*. Mean (\pm SE) stomach-content dry weight (mg) at transect stations (-40, -20, 0, +20, +40 m) in 1996 and 1997 [Top graphs first 10 d experiment in each year; bottom graph second 10 d experiment (only one 10 d experiment was conducted in 1996)]. Further details as in legend to Fig. 4



no differences in densities of invertebrate fauna between sites. Given that the study site (Pier 76) and depths (2 to 3 m) used in the Stoecker et al. (1992) investigation were similar to those in the current study, it is likely that the densities and assemblages of invertebrate fauna are similar as well.

There were significant differences in depth between under-pier and open-water regions at the study site in 1997. While water-column depth and light intensity are related, we argue that depth probably contributed little to the observed differences in growth. Growth rates determined in 1997 when depths were variable, compared well to rates determined in 1996 when water-column depths were similar across the study transect. This suggests that depth was not the parameter governing differences in growth, and provides additional evidence that factors associated with piers themselves are responsible.

Mortality of caged fishes during the experiments could have also affected growth rate by reducing the total fish biomass per cage. However, observed differences in growth rates were probably not significantly affected by variations in fish density. Using cages similar to those used in this study, Sogard (1992) demonstrated that growth rates of juvenile winter flounder, tautog, and naked goby (*Gobiosoma bosc*) were not significantly related to the density of fishes in a cage. Therefore, even though we observed slight differences in mortality (i.e. number recovered) between fishes caged under piers, at pier edges, and in open water, these variations probably

contributed little to the greater observed differences in growth rate.

While we attempted to account for a variety of physical and chemical characteristics between below the pier and the outside areas, we did not measure the current regime of the waters surrounding the pier sites. The presence of the pilings may have served to dampen the flow regime around the pier and thus reduce the availability of prey items to fishes caged in the interior. Prior work suggests that juvenile tautog are capable of feeding on items in the plankton (Grover 1982), although winter flounder feed almost exclusively on benthic prey (Klein-MacPhee 1978). We found very few planktonic prey items ($n = 3$) in the stomachs of any of the fishes used in this study, and it is unlikely that reduced availability of suspended prey greatly impacted the fishes' ability to feed. Moreover, Able (unpublished data) has found that both juvenile winter flounder and juvenile tautogs caged in pile-field areas grew well, indicating that: (1) both species were capable of finding and consuming sufficient quantities of food in spite of potential reductions in flow and turbulence, and (2) reduced light availabilities due to pier-roofing may be critical.

Urban estuaries will continue to be centers of human activities and fish production, and the impacts of development on fish populations will persist. Some man-made structures may have a role as habitat for fishes (Able et al. 1998), although areas beneath large piers do not appear to be suitable for the juveniles of at least two

species, and perhaps for juvenile fishes in general. Winter flounder and tautogs are rarely collected under municipal piers, and we have shown that under-pier areas, and to a lesser extent pier edges, provide sub-optimal feeding conditions for these species. We submit that while the pier edges act as transitional zones between open water and under-pier areas, they do not confer any additional benefits to the condition of these juvenile fishes. Since poor growth rates may decrease survival, we suggest that large pier structures may be detrimental to recruitment.

Acknowledgements We wish to thank N. Comanducci, T. Lynch, C. Metzger, J. Rosendale, and D. Vivian for their support in the field. D. Vivian provided much of the assistance with stomach-content analyses. We are grateful to A. Stoner and B. Phelan for their aid in the maintenance of the fishes. P. Bologna provided comments on an earlier version of this manuscript. Support for this project was provided by the Hudson River Foundation. This paper is Rutgers University Institute of Marine and Coastal Sciences Contribution No. 98-32.

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