29 Impacts of Piers on Juvenile Fishes in the Lower Hudson River

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ABSTRACT We examined the impacts of man-made structures, especially large piers, on fishes in the lower Hudson River, USA over a number of years. We used a multifaceted approach, and evaluated: 1) the distribution and abundance of fishes under piers, at pier edges, in pile fields, and in open water areas, 2) feeding and growth of young-of-the-year fishes (winter flounder, tautog, and Atlantic tomcod) under and around piers, and 3) availability of benthic prey for fishes under and adjacent to large piers. A review of our studies suggests that species diversity and species abundance were depressed under piers relative to nearby habitats. The only species that were routinely collected from under piers were those that do not appear to solely rely on the use of vision to forage (American eel, naked goby, Atlantic tomcod). Results from studies of the distribution of benthic invertebrate prey for fishes around piers suggest that prey abundances under piers are more than sufficient to support fish growth, however, results of directed growth studies indicate that feeding and growth rates of visually-feeding fish species (winter flounder, tautog) are negative under piers (that is, fish lose weight). It is not likely that factors associated with pier pilings, such as reduced flow or sedimentation, affect feeding, since studies of fish growth in pile fields (piers without the decking) indicate that fish grow well in that habitat. Rather, it appears that the decking associated with piers creates conditions of intense shading that impede foraging activities. We propose that under-pier areas, and potentially any areas that significantly reduce light penetration to depth in near shore areas, are poor habitats for fishes, and we urge careful consideration of shading effects prior to the construction, restoration, or renovation of overwater structures.

Introduction

The reshaping of New York Harbor by European settlers first occurred in the mid 1600s with the construction of two small, wooden piers along the East River to accommodate shipping and trade (Buttenwieser, 1987). From this modest start, the East River became an active seaport by the 1700s and efforts then were already underway to reshape its shoreline and construct larger piers in its waters. In contrast, waterfront development in the lower Hudson River lagged behind because the hard, rocky bottom of the Battery Park area tended to make pier building difficult (Buttenwieser, 1987). Eventually, the development of powerful pile-driving machinery overcame this obstacle and by the late 1800s the Hudson River supported hundreds of piers and docks.

Many eighteenth and nineteenth century piers were built upon filled, closed bases and were often situated in parallel and in close proximity to one another. These designs made piers more stable and capable of servicing larger ships, but they also obstructed water flow (Bone, 1997). Other early piers were made of wood and floated on the surface of the water in closed squares or rectangles, also restricting flow and allowing the buildup of stagnant water and refuse. In 1870, health concerns prompted open hearings held by the Department of Docks (1870–1942) where the construction of open-piling finger piers was suggested (Buttenwieser, 1987). This form, piers built on open piling bases and at right angles to the shoreline, is now common in New York Harbor.

The goal of the Department of Docks was to modernize the harbor for commercial shipping and they oversaw the construction of stone, iron, and concrete finger piers on a massive scale. Environmental impacts were largely ignored in favor of expanding trade capacity (Bone, 1997). During this era, Chelsea Piers were created as were numerous ferry terminals, warehouses, and immense stone and iron piers. In addition, the Department radically transformed the geography of Manhattan's waterfront, straightening the natural contours, dredging, and constructing an extensive system of riverwalls and bulkheads (Betts, 1997). Yet in spite of these efforts, the decline of New York Harbor as a commercial port was evident by the 1920s. Noncommercial

interests along the Upper West Side had already defeated measures to commercialize the principally residential neighborhoods and pushed instead to develop open, recreational spaces. The creation of Riverside Park and the later construction of recreational piers and athletic facilities effectively halted maritime commercial activity on the West Side. The continued decline of major shipping in New York Harbor came in the 1960s when commerce relocated to New Jersey's Elizabeth Seaport (Buttenwieser, 1987).

Today much of the New York Harbor waterfront stands in disuse and disrepair. There is a strong interest in revitalizing the city's waterfront including construction of the Hudson River Park (www.hudsonriverpark.org). When completed, this park will be a five-mile-long public walkway along the Hudson River stretching from Battery Place to 59th Street, and its development includes the restoration of thirteen preexisting piers (Wise, Woods, and Bone, 1997). Other plans for the waterfront include Trump Place on the Hudson River front between 59th and 72nd streets. Though the city is in need of more open space, there are apprehensions about the impacts of pier restoration and construction activity on the surprisingly resilient biological resources of the Hudson River Estuary (Able and Duffy-Anderson, 2005).

The concern for the Hudson River Estuary ecosystem is not misplaced. The progressive transformation of the Hudson River has taken its toll on near-shore habitats. Over the years, the practices of dredging, filling, and bulkheading have eliminated the naturally sloping land-sea interfaces of tidal marshes and beaches (Squires, 1992). Nearly 50,000 acres of tidal wetlands have been lost in New York Harbor, and over 20 percent of that loss has occurred recently, between 1950 and 1970 (Bone, 1997). Landfill and piers have been pushed out farther and farther into the Hudson River channel and have gradually created a passageway that is considerably more narrow than its pre-European state. These changes have likely affected local circulation patterns, water velocity, and bottom topography.

In spite of these perturbations, the Hudson River and its estuary are functional ecosystems that support a complex mosaic of animal life in their waters. Biological productivity is high and a variety of species of zooplankton (Stepien, Malone, and Chervin, 1981; Pace, Findlay, and Lints, 1992), deposit feeders (Rice et al., 1995), and suspension feeders (Strayer et al., 1994) are supported. An array of larger invertebrate organisms such as sevenspine bay shrimp (*Crangon septemspinosa*), daggerblade grass shrimp (*Palaemonetes pugio*), blue crabs (*Callinectes sapidus*), and a variety of molluscs are also common (Stanne, Panetta, and Forist, 1996), and many of these serve as prey for economically valuable species including Atlantic sturgeon (*Acipenser oxyrinchus*) (Dovel and Berggren, 1983; Van Eenennaam et al., 1996), shortnose sturgeon (*Acipenser brevirostrum*) (Hoff, Klauda, and Young, 1988), American shad (*Alosa sapidissima*) (Smith, 1985), striped bass (*Morone saxatilis*) (Waldman et al., 1990), and blue crabs (Wilson and Able, 1992). The estuary also provides critical spawning and juvenile habitat for a variety of ecologically important fish species such as Atlantic tomcod (*Microgadus tomcod*) (Dew and Hecht, 1994a; 1994b), winter flounder (*Pseudopleuronectes americanus*) (Able, Manderson, and Studholme, 1998), bluefish (*Pomatomus saltatrix*) (Chiarella and Conover, 1990), alewife (*Alosa pseudoharengus*) (Dovel, 1981), and bay anchovy (*Anchoa mitchilli*) (Dovel, 1981), among a variety of others (Able and Fahay, 1998). Finally, the Hudson River Estuary is an important migratory pathway for striped bass (Secor and Piccoli, 1996) and shad (Limburg, 1996), and provides important overwintering grounds for striped bass as well (Hurst and Conover, 1998).

The Hudson River Estuary is resilient but its aquatic species assemblage continues to be vulnerable to anthropogenic stress. Factors that degrade water quality such as chemical pollution, industrial discharge, municipal runoff, and sewage effluents compete with biological uses of the estuary. Efforts have been made to improve water and sediment quality in the lower Hudson River (Brosnan and O'Shea, 1996; O'Connor, Ranasinghe, and Adams, 1998), but there has been little effort to remedy the effects of centuries of shorezone modifications.

There have only been a few studies that examined the impact of man-made structures on estuarine fauna (Cantelmo and Wahtola, 1992; Stoecker, Collura, and Fallon, 1992) and as a result, we were interested in determining the impacts of man-made structures, especially large piers, on

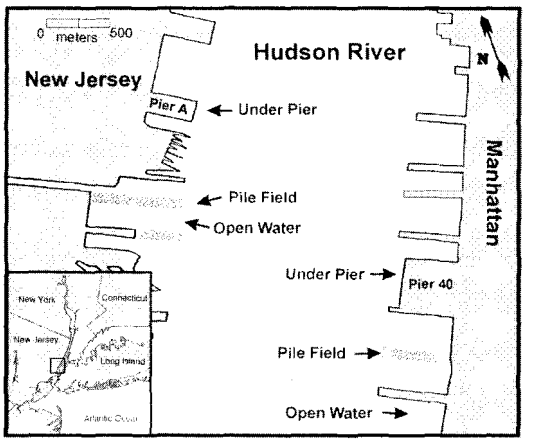

Figure 29.1. Location of the study areas in the lower Hudson River. Adapted from Able et al. (1998).

fishes in the lower Hudson River. In this chapter, we focus on the lower Hudson River and synthesize the results of our efforts from 1993 to 1999 to assess the effects of large municipal piers on juvenile fishes and selected invertebrates. Results of these studies may be representative of the effects of piers in general and could be of considerable interest to managers, developers, and conservationists working in the Hudson River Estuary and in other urban estuaries.

Studying the Effects of Piers

STUDY AREA

The study area was located in the lower Hudson River (New York Harbor), 3 km north of the Battery and 14 km south of the George Washington Bridge. Two concrete municipal piers, Port Authority Pier A (213 × 100 m), located in New Jersey, and Marine and Aviation Pier 40 (351 × 255 m), located in Manhattan, were selected as the target study sites (Fig. 29.1). We used a comparative approach and established four representative habitats associated with piers, including underneath piers, pier edges, pile fields, and open water. Under-pier sites were established under the platform decks of piers, edge sites were established at the light-shade interface between the edge of the pier and the water beyond, open water areas were located immediately adjacent to the piers (20–40 m beyond the pier edges), and pile field sites were established in areas consisting of pilings (after the deck tops of the piers had been removed). Pile fields were situated approximately 300 m south of Pier 40 in New York and approximately 450 m south of Pier A in New Jersey.

The study area has been highly modified from its original, pre-European contours and as a result virtually no natural, shallow-water habitat remains. Concrete bulkheads predominate on both sides of the Hudson River and make the transition from the street to the water level abrupt; depths at the water line average 3–5 m (Duffy-Anderson, personal observation). In addition, much of the Harbor bottom is dredged so there is a marked vertical drop off toward the channel (from 3 m to 16 m). The lower Harbor is tidally flushed so that, like other estuaries with extensive freshwater input, the zone undergoes dramatic changes in salinity over a single tidal cycle, as much as 7–21‰ (Duffy-Anderson, personal observation), though average ranges over one tidal cycle are approximately 5–10‰. In mid August, salinities can be as high as 28‰. Temperatures during the spring, summer, and fall sampling periods (May/June–September/October, 1993–99) generally ranged from 14–26 °C and levels of dissolved oxygen during the same period generally ranged from 3–8 mg l^{-1}. Photic depths in the summer range from 3–6 m depending on sediment loading and phytoplankton growth (Stross and Sokol, 1989). Average light intensities in open water areas are considerably higher (10–50 μE^{-2} s^{-1}, depths 2–5 m) than light levels underneath large piers with solid concrete tops (0–0.02 μE^{-2} s^{-1}, depths 2–3 m) (Able et al., 1998; Duffy-Anderson and Able, 1999).

HABITAT QUALITY ASSESSMENT TECHNIQUES

Our assessment strategy was consistent with the guidelines established by the National Marine Fisheries Service for fish habitat evaluation on Essential Fish Habitat (EFH) (Schreiber and Gill, 1995; Minello, 1999). EFH defines four levels of evaluation, ranging from the most basic, initial fish presence-absence characterization (Level 1) to the most sophisticated, estimates of fish production (Level 4) (Able, 1999). We used this multilevel approach to assess the impacts of piers on fishes in the Hudson River. First, we employed Level 1 and 2 approaches, and estimated distribution (Level 1) and abundance (Level 2) of fishes around piers and in

other adjacent habitats to rank their habitat value relative to one another. Next we used estimates of feeding and growth (Level 3) to quantify the habitat value of each of those areas. We have not attempted to employ a Level 4 approach, estimating fish production, as this method requires additional estimates of population size, rates of natural mortality, and fish immigration and emigration that are currently unavailable. Nonetheless, by using the first three levels of assessment we have provided a layered, multidimensional, and independent assessment of the habitat value of piers for fishes.

Responses of Fishes to Piers

DISTRIBUTION AND ABUNDANCE

We examined the spatial distribution (Level 1) and abundance (Level 2) of fishes under piers, at pier edges, in pile fields, and in open water in 1993, 1994, and 1996 (see Able et al., 1998 for a more complete description) to assess their value as habitat. Unbaited traps were deployed on the bottom at each of the study sites where they remained submerged for 24 h and were recovered on the following day. All captured fishes were measured and catch data were standardized to catch per unit effort (CPUE, expressed as individuals trap^{-1} day^{-1}).

As a result of the above efforts, we collected 1,756 individual fish of thirty different species in three years of sampling across all habitat types. Most of the fishes were young-of-the-year (YOY) individuals (see Able et al., 1998; Duffy-Anderson, Manderson, and Able, 2003), though large American eels (*Anguilla rostrata*) were common. The most abundant fish species was the striped bass, which made up 23 percent of the total catch. Atlantic tomcod, American eel, black sea bass (*Centropristis striata*), and cunner (*Tautogolabrus adspersus*) also constituted large portions of the fish catch, comprising 17 percent, 12 percent, 10 percent, and 7 percent, respectively. There were variations in abundance of individual species among years, with large numbers of certain species occurring in some years and not in others. For example, black sea bass were collected in high numbers in 1994 but in 1993 and 1996 they were very rare. Similarly, spotted hake (*Urophycis regia*) were collected in abundance in 1996 but were infrequent in 1993 and 1994. Finally,

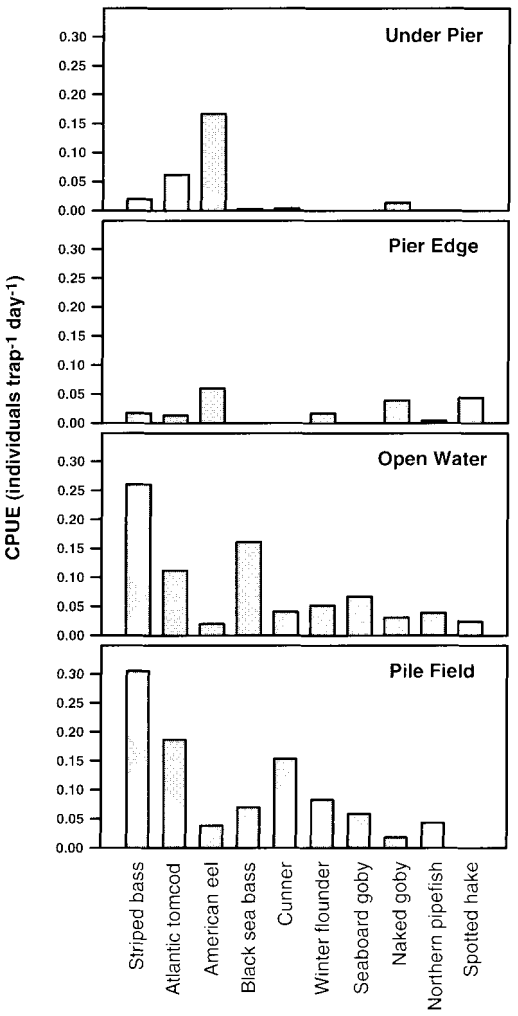

Figure 29.2. Mean abundance (CPUE) of the 10 most abundant fish species under piers, at pier edges, in open water, and in pile fields based on data collected in 1993, 1994, and 1996.

cunner were very abundant in 1993 and 1994, but were completely absent from collections in 1996.

There were marked dissimilarities in fish distribution in different habitats. Mean fish abundance (CPUE) was consistently lower under piers (though variability was high) compared to open water, pile field, or edge habitats. Only one species, the American eel, was ever collected from under-pier areas more frequently than in any other habitat (Fig. 29.2). Atlantic tomcod and naked goby (*Gobiosoma bosc*) were not uncommon in under-pier traps but they were collected in higher numbers at other sites. In addition, the total number

of species collected from under piers was lower (n = 16 species) than the total number collected in pile fields (n = 21 species) or in open water (n = 27 species). Many of the species collected from under-pier habitats were only collected once and were never observed under piers again during the three year sampling survey. In contrast, many of the species found in the other habitat types were observed there on more than just one occasion and some, such as spotted hake, tautog (*Tautoga onitis*), and northern pipefish (*Syngnathus fuscus*), were collected repeatedly (Able et al., 1998). It should be noted that the traps used in this study were designed specifically to sample small, young-of-the-year, benthic fishes. As such, other fish species that are common to the Hudson River may not have been effectively sampled, especially pelagic fishes that occur higher in the water column. Still, our data suggest that fish abundance is consistently depressed under piers over multiple years, indicating that piers are lower-quality habitats for fishes relative to edges, pile fields, or open water (Able et al., 1998; Duffy-Anderson and Able, 1999; Able, Manderson, and Studholme, 1999; Duffy-Anderson et al., 2003).

Interestingly, the three fish species collected under piers (American eels, Atlantic tomcod, and naked goby) and the decapod species (Able and Duffy-Anderson, 2005) collected share a common characteristic; they do not rely strictly on the use of vision to forage; rather, they demonstrate various abilities to utilize alternative sensory systems to locate and capture prey. For example, American eels and Atlantic tomcod can detect chemicals in solution (Herrick, 1904; Teichmann, 1954; Silver, 1979). Some gobies have been shown to have a similar ability to detect chemicals (Utne and Bacchi, 1997), though it has also been demonstrated that their reactive distance to predators declines with decreasing light intensity (Aksnes and Utne, 1997), suggesting that vision is still an important component of the overall sensory behavior of the animals. Intense shading from the solid decks of the piers examined in our study drastically reduced light penetration to the waters below. Light levels under piers were approximately 4–5 orders of magnitude lower than outside of piers (0.001–0.02 μE^{-2} s^{-1} under piers versus 20–60 μE^{-1} s^{-1} outside of piers, Duffy-Anderson and Able, 1999). Occasionally the levels were so low that they were below the detection of our light meters. Light is a limiting factor that affects the ability of visually-foraging fish to search for prey (Boeuf and Le Bail, 1999). At low light intensities, important factors associated with prey recognition, such as prey contrast and hue, are reduced (Gerking, 1994) limiting the ability of fish to identify prey items. Similarly, reactive distance, the maximum distance at which visual predators can detect their prey (Vinyard and O'Brien, 1976) declines with declining light intensities (O'Brien, 1979), reducing the search volume of visually feeding fish. Thus, visually foraging fishes may not occur under piers because conditions of intense shading interfere with one or more of the steps in the predation cycle. We therefore speculate that under-pier areas may only serve as functional habitat for a few select species, perhaps only those with supplementary sensory systems that allow them to forage more effectively in darkness, while simultaneously being inhospitable to a variety of other estuarine species.

GROWTH OF SELECTED FISHES

If certain species are better able to forage under piers than others, that ability should be reflected as a difference in growth rate. Therefore, we designed a series of experiments to determine differences in growth rates between fishes more frequently collected under piers and those that were infrequently found in under-pier habitats. We hypothesized that species collected under piers would have higher growth rates in under-pier habitats than species that occurred there less often. These studies would not only reveal more about differences in pier habitat use among fishes, but they would also provide a more quantitative measure of pier habitat quality (Level 3) that could augment our initial observations.

Based on abundances estimated from the trapping experiments, we chose two fish species that were uncommon in our under-pier collections, winter flounder and tautog, and one species that was collected from beneath piers more regularly, the Atlantic tomcod, as our target species for growth experiments. Young-of-the-year fish of a single species were confined to benthic cages deployed to open water, pile fields, under piers, and at pier edges for ten day periods and changes in fish

weight (that is, growth rate in weight) were determined. Randomly chosen specimens also served as controls, which were kept in the laboratory for ten days without food. Growth experiments occurred in 1994, 1996, 1997, and 1998 (see Duffy-Anderson and Able, 1999; Able et al., 1999; and Metzger, Duffy-Anderson, and Able, 2001 for more complete descriptions).

As a result of these experiments over four years, we observed variations in growth rate among habitat types and between the three test species. Young-of-the-year winter flounder had negative growth rates (that is, they experienced weight loss) when they were caged under piers, indicating that the fish had fed poorly (Fig. 29.3). In fact, weight loss under piers was strikingly similar to weight loss among control individuals, the fish that were intentionally starved in the laboratory for ten day periods. In contrast, winter flounder grew well in open water habitats adjacent to piers and in pile fields. Individuals also grew at pier edges but rates in that habitat were generally lower than in pile fields or open water (approximately 40 percent less).

Growth rates among caged YOY tautog followed similar patterns, though variability was somewhat higher (Fig. 29.3). Tautog caged under piers also lost weight at rates comparable to laboratory-starved control fish. In contrast, tautog caged at pier edges, in pile fields, and in open water grew rapidly with several individuals actually doubling their body weight over the course of the ten day experiments.

Results with Atlantic tomcod yielded somewhat different results. In contrast to the YOY winter flounder and tautog, two species that lost weight under piers, YOY Atlantic tomcod gained weight when caged in under-pier habitats, though weight gain under piers was not as rapid as weight gain at edges or in open water (Fig. 29.3). In fact, though growth under the pier was positive, it occurred at nearly half the rate as growth at pier edges or outside of the pier, a substantial discrepancy that could have important impacts on the overall recruitment success of juveniles to the adult population (Sogard, 1997; Beck et al., 2001).

The general outcome of the growth experiments followed hypothesized patterns. Fishes that were more frequently collected from under piers should be better able to utilize those habitats than fishes

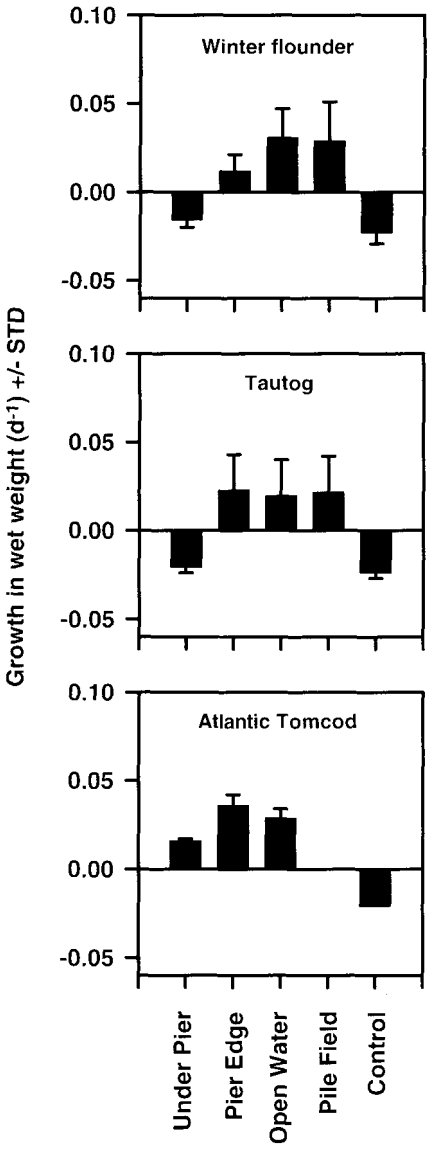

Figure 29.3. Mean growth rate in weight (G_W)$^{\pm}$ STD of young-of-the-year winter flounder, tautog, and Atlantic tomcod caged under piers and in adjacent habitats in the lower Hudson River based on data collected in 1994, 1996, 1997, and 1998.

that occur there less frequently, and indeed, growth observations supported that theory. However, the data also suggested that while YOY Atlantic tomcod could grow in under-pier habitats, growth was lower than at edges or in open water. Therefore, we concluded that under-pier areas were unsuitable habitats for YOY winter flounder and tautog, and low-quality habitats for Atlantic tomcod relative to edges or open water. It was still not clear

why piers had these negative effects, but it seemed unlikely that factors associated with pilings themselves were responsible because growth rates in pile fields (pilings without decking) were similar to growth rates in open water.

Why could Atlantic tomcod grow better under piers than winter flounder or tautog? We formulated two hypotheses to address this question: 1) Atlantic tomcod were better able to forage in low light and therefore could locate more food than winter flounder or tautog, or, 2) Atlantic tomcod consumed a different food source than the other two species. Winter flounder and tautog consume primarily benthic organisms as prey (Pearcy, 1962; Grover, 1982) but previous work on juvenile Atlantic tomcod suggested that individuals <90 mm TL consumed primarily planktonic prey types (Grabe, 1978). The Atlantic tomcod used in these experiments were in this size range (44–91 mm TL), therefore, the hypothesis that they utilized a different food source seemed likely. We examined the stomach contents of the caged fish to determine whether the diets among the three test species were dissimilar. We also used the data to compare the feeding habits of each species under, at the edge, and outside of the pier.

FEEDING

The stomachs from YOY winter flounder, tautog, and Atlantic tomcod used in several of the caging growth experiments (1996, 1997, 1998) were removed and the contents were identified. Afterwards, the contents were dried and weighed to examine stomach fullness. This procedure only revealed the diet of fishes at the end of the experiment but it probably represented the diet of the fishes during the entire ten day feeding experiments.

The types of prey consumed by winter flounder caged under piers, at pier edges, and in open water were similar and benthic organisms comprised the majority of the stomach contents. Interestingly, winter flounder caged under piers had some food in their stomachs but growth under piers was negative. Thus, it seemed that their restricted energy intake was not sufficient to meet their metabolic expenditures. Principal prey items of winter flounder caged at all locations were harpacticoid copepods and gammarid amphipods. Polychaetes, isopods, barnacles, ostracods, and brachiopods were also found in the stomachs of some fish caged at edges and in open water, but were absent from the stomachs of under-pier fish. Mean stomach content dry weights were generally lower under piers ($\bar{x} = 0.07$ mg $\pm$ 0.13) than in open water ($\bar{x} = 0.34$ mg $\pm$ 0.46), which is consistent with lower growth under piers compared to edges or outside.

Results were similar among caged tautog. Tautog also consumed primarily benthic organisms, though identification of stomach contents in this species was more difficult due to the grinding of food items with the pharyngeal teeth (Olla et al., 1974). Most of the contents appeared to be harpacticoid copepods and mysids, though amphipods were occasionally found in the stomachs of fishes caged outside of the pier. Tautog caged outside of the pier generally had higher stomach content dry weights ($\bar{x} = 0.24$ mg $\pm$ 0.54) than of those caged under the pier ($\bar{x} = 0.06$ mg $\pm$ 0.12) and lower stomach weights were probably directly related to poor growth of tautog under piers.

The diets of caged Atlantic tomcod were very similar to those of caged winter flounder and tautog; Atlantic tomcod consumed benthic prey organisms (see Metzger et al., 2001 for a more complete description). In fact, we did not find a single planktonic prey item in the stomachs of the dissected fish even though this has been reported in other studies (Grabe, 1978). Principal prey items for caged tomcod were harpacticoid copepods and amphipods, though we also found isopods, nematodes, invertebrate eggs, saltwater mites, and a polychaete. Like winter flounder and tautog, Atlantic tomcod caged under the pier had a lower mean stomach content dry weight ($\bar{x} = 0.34$ mg $\pm$ 0.77) than fish caged at the edge ($\bar{x} = 0.99$ mg $\pm$ 1.3) or outside of the pier ($\bar{x} = 1.01$ mg $\pm$ 1.13), again probably contributing to observed lower growth rates. It appeared that growth of Atlantic tomcod under piers was not explained by differences in diet. It seemed more likely that our first hypothesis, that Atlantic tomcod could forage more efficiently in low light than winter flounder or tautog, was correct.

Recall that at the conclusion of the growth experiments we determined that the growth rates of

all three test species, winter flounder, tautog, and Atlantic tomcod were depressed under piers relative to edges or open water. Since the above experiments revealed that all three of these species exploited the same food source, it could be that the general depression in growth rates under piers was due to lower abundances of benthic prey under piers compared to edges or outside. Since this hypothesis remained untested, we attempted to quantify the benthic prey organisms in the sediments around a pier to determine whether prey levels under piers were depressed.

PREY AVAILABILITY

We examined the availability of benthic prey for YOY fishes caged around a municipal pier by coring the sediments around Pier 40 during the summers of 1998 and 1999 (June–July). Four replicate samples (3.0 cm diameter, 2.0 cm depth) were collected under, at the edge, and outside of the pier. Samples were returned to the laboratory where the contents were sorted, identified, and enumerated (see Duffy-Anderson and Able, 2001 for a complete description).

The benthos was dominated by nematodes and foraminifera (98 percent), though invertebrate eggs, polychaetes (capitellids and nereids), and copepods also made up a portion of the assemblage. Previous work indicated that nematoda and foraminifera did not make up a significant portion of the diet of YOY winter flounder, tautog, or Atlantic tomcod (Grabe, 1978; Klein-MacPhee, 1978; Sogard, 1992; Stehlik and Meise, 2000; Vivian et al., 2000; Metzger et al., 2001). As such, more appropriate estimates of prey availability for these fishes excluded nematodes and foraminifera from the analyses. Interestingly, when these two taxa were eliminated, significantly higher fish prey abundances were noted under the pier compared to outside in both years, though there were no significant differences in prey dry weight across the transect (Duffy-Anderson and Able, 2001). Previous findings at a nearby pier (Pier 76) in the lower Hudson River (Stoecker et al., 1992) found overall invertebrate abundances were higher under the pier than outside. It is currently not known if the apparent lower prey availability in open water is a function of grazing by perhaps, more abundant fishes, and higher availability under the pier is due to reduced grazing under piers caused by a depression in fish abundance. It is important to note that benthic prey appeared to be available in sufficient quantities for feeding of fish caged underneath municipal piers. Therefore, the hypothesis of limited prey availability under piers seemed an unlikely explanation for lower growth rates under piers as determined in the caging experiments. With this hypothesis eliminated, the issue of low light availability under piers seemed to take on even more significance.

Discussion

The potential value of man-made structures as habitats for fishes is of considerable interest and may be especially relevant in urban estuaries like New York Harbor where little natural habitat remains in shallow, nearshore waters. We have shown that at least one type of man-made structure, large piers, do not afford suitable habitat to a number of fish species in the lower Hudson River. This conclusion is based on three of the four levels of habitat evaluation, distribution (Level 1), abundance (Level 2), and feeding and growth (Level 3), as previously outlined (Schreiber and Gill, 1995; Able, 1999; Minello, 1999). We conclude that under-pier areas are poor-quality habitats because they support low fish abundances, inhibit feeding, and suppress growth. We believe that low light levels under piers (as measured over several years of study) are directly related to their lower habitat value relative to other areas (Table 29.1) and several lines of evidence support this view. First, the few species that are more commonly collected from beneath piers (American eels, Atlantic tomcod, naked goby, decapod crustaceans) share an ability to capitalize on sensory systems other than vision (chemoreception, mechanoreception) to locate prey in conditions of near-darkness. Visually feeding fishes generally do not occur under piers, probably because the low-light conditions there interfere with their ability to feed. Second, two fish species that use visual foraging mechanisms, winter flounder and tautog, show reductions in food intake and poor growth under piers, in spite of having more than sufficient numbers of prey available for consumption. Third, these same two species of fish grow

Table 29.1. Habitat values of pier-related habitats in the lower Hudson River based on estimates of distribution, abundance, feeding, and growth of young-of-the-year fishes in New York Harbor

Habitat	Level 1 (Distribution)	Level 2 (Abundance)	Level 3 (Feeding and Growth)	Level 4 (Fish Production)
Under pier	–	–	–	N/A
Pier edge	++	++	++	N/A
Pile field	+++	+++	+++	N/A
Open water	+++	+++	+++	N/A

N/A indicates data not available.

well in pile fields, which are areas that are virtually identical in structure to piers themselves but lack the decking that reduce light levels in the water below. Finally, a species of fish that can utilize alternative prey detection mechanisms, the Atlantic tomcod, can grow under piers, albeit at reduced rates compared to other habitats. Considered collectively, these findings indicate that under-pier habitats are not utilized by many fish species because foraging is impeded by conditions of intense shading. The consequences of shading may not be solely restricted to piers, as other large objects casting substantial shadows may have similar effects. Such items could include, but are not limited to, permanently moored vessels, floating platforms, and large docks.

Management Considerations

An important consideration for proposed developments in New York Harbor is whether the effects of piers can be mitigated through structural modifications. We did not attempt to compare various pier characteristics in our studies, however, others have identified several key features of man-made structures that affect growth of adjacent vegetation and it may be that some of those factors are important for fishes and invertebrates as well. For example, dock height (distance from the water's surface) has been shown to be an important factor affecting growth of vegetation (Kearney, Segal, and Lefor, 1983; Burdick and Short, 1999). It follows that structures that float directly on the water's surface would allow the least amount of light penetration below and may, in fact, be a worst-case scenario for visual feeders. Similarly, pier width could have an affect on light penetration. The piers examined in our studies were extremely wide and covered in asphalt, allowing no light penetration immediately beneath their surfaces. Future pier construction efforts could consider a light-penetrable design. Artificial lighting beneath piers is probably not as efficient as allowing incident sunlight to pass through because fishes are sensitive to the characteristics of the light spectrum as well as to its absolute light intensity (Fernald, 1993). Finally, piers that are built in a north-south direction tend to support greater densities of eelgrass than piers that run east-west (Burdick and Short, 1998) because an east-west configuration follows the daily path of the sun and results in continuous shading beneath the pier.

It is currently not known whether the effects of piers can be reduced with nominal structural revisions or whether more drastic remedies are required. Studies that more closely examine the effects of edges may provide some answers. Fish abundances are higher at edges than under piers (Duffy-Anderson et al., 2003) and growth can occur at edges even among fish species that show negative growth under piers (Duffy-Anderson and Able, 1999). Pier edges have the potential to modify the intensity of shading by diffusing the pier shadow (Burdick and Short, 1998) and the duration of shading by refracting incident light. Our results suggest that some easing of shade effects occurs around edges so pier designs that allow greater edge-to-surface ratios may be preferable.

Future work should be conducted to determine how broadly applicable our observations of pier impacts are. The studies discussed in this chapter were conducted underneath very large piers but marinas, fishing piers, and individual boat docks

all have the capacity to shade potential fish habitat. Shade-related impacts in these systems may be of even greater concern as many of these smaller piers are often constructed in natural, shallow-water areas that provide important habitat for young-of-the-year fishes (Able and Fahay, 1998; Minello, 1999). The effects of piers in oceanic environments has not been well studied. Oceanic piers exist in many coastal communities but their effects on fishes are still unknown. Examples of ocean-side structures that could have shade-related impacts include beach-side homes, condominiums and hotels, and large, public piers. Studies that examine the impacts of piers in these environments are much needed and could provide important information on habitat use, growth, survival, and recruitment.

Conclusions

New York Harbor is home to a variety of marine and estuarine species that depend on informed and responsible management practices. Recognition of the important ecological role this system plays is critical to the overall health of the estuary. Development projects that would reduce species abundance, limit diversity, inhibit feeding, and lower growth should be avoided. We have demonstrated that municipal piers in the lower Hudson River have these consequences, and our studies suggest that shading is responsible. We support efforts to reduce the duration, intensity, and area of shading in existing and future pier development projects. The lower Hudson River continues to be important spawning and juvenile fish habitat for a host of commercially and recreationally important species so new development projects that have the potential to shade open, shallow-water (<5 m) areas in this system should be carefully evaluated prior to approval.

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