Technical Report

A SYNTHESIS OF IMPACTS OF PIERS ON JUVENILE FISHES AND SELECTED INVERTEBRATES IN THE LOWER HUDSON RIVER

Kenneth W. Able and Janet T. Duffy-Anderson

August 2005

Institute of Marine and Coastal Sciences
Rutgers, The State University of New Jersey
71 Dudley Road
New Brunswick, NJ 08901-8521

This is IMCS Contribution #2005-13

A SYNTHESIS OF IMPACTS OF PIERS ON JUVENILE FISHES AND SELECTED INVERTEBRATES IN THE LOWER HUDSON RIVER

Kenneth W. Able and Janet T. Duffy-Anderson*

August 2005

Marine Field Station, Institute of Marine and Coastal Sciences
Rutgers, The State University of New Jersey
Tuckerton NJ 08087-2004

* Current address: NOAA/National Marine Fisheries Service, Seattle, WA

This is IMCS Contribution Number #2005-13

TABLE OF CONTENTS

ABSTRACT

We examined the impacts of man-made structures, especially large piers, on fishes and selected invertebrates in the lower Hudson River, USA over a number of years. Using a multi-faceted approach, we evaluated: 1) the distribution and abundance of fishes and invertebrates 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 the results from our studies on distribution of fishes and invertebrates suggests that species diversity and species abundance were depressed under piers relative to other areas. 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, and selected decapod crustaceans). 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 (i.e., fish lose weight). Growth studies on a species of fish (Atlantic tomcod) that can utilize alternative prey detection mechanisms show that this species can grow under piers, though at reduced rates compared to other habitats. 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 which 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 over-water structures.

INTRODUCTION

Pier Development: A Historical Perspective

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 stronger 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 made 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 of Docks 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, and construction of the Hudson River Park has begun. When completed, this park will be a 8-km long public walkway along the Hudson River stretching from Battery Park City to 59th Street, and it's development includes the restoration of 13 pre-existing piers (Wise et al. 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.

Biological Importance of the Hudson River Estuary

The concern for the Hudson River estuarine 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 20,000 ha of tidal wetlands have been lost in New York Harbor, and over 20% 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 et al. 1981; Pace et al. 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*), ~~and~~ daggerblade grass shrimp (*Palaemonetes pugio*), blue crabs (*Callinectes sapidus*), and a variety of molluscs are also common (Stanne et al. 1996), and many of these serve as prey for economically valuable species including Atlantic sturgeon (*Acipenser oxyrhynchus*) (Dovel and Berggren 1983; Van Eenennaam et al. 1996), shortnose sturgeon (*Acipenser brevirostrum*) (Hoff et al. 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 et al. 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 et al. 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 et al. 1992), and as a result, we were interested in determining the impacts of man-made structures, especially large piers, on fishes in the lower Hudson River. In this paper, 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.

MATERIALS AND METHODS

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 x 100 m), located in New Jersey, and Marine and Aviation Pier 40 (351 x 255 m), located in Manhattan, were selected as the target study sites (Fig. 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.

Physical Characteristics

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; therefore, 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 discussed in this chapter (May/June - September/October, 1993-1999) 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 $\mu E\ m^{-2}\ s^{-1}$, depths 2 - 5 m) than light levels underneath large piers with solid concrete tops (0 - 0.02 $\mu E\ m^{-2}\ s^{-1}$, 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 multi-level 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 and crustaceans 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 which are currently unavailable. Nonetheless, by using the first three levels of assessment, we have provided a layered, multi-dimensional, and independent assessment of the habitat value of piers for fishes and selected crustaceans.

RESULTS

Distribution and Abundance

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

As a result of the above efforts, we collected 1756 individual fish of 30 different species in three years of sampling across all habitat types (Table 1). Most of the fishes were young-of-the-year (YOY) individuals (see Able et al. 1998; Duffy-Anderson et al. 2003), though large American eels (*Anguilla rostrata*) were common. The most abundant fish species was the striped bass, which made up 23% 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%, 12%, 10%, and 7% respectively. There were variations in abundance of individual species between 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 (Table 1). Similarly, spotted hake (*Urophycis regia*) were collected in abundance in 1996 but were infrequent in 1993 and 1994. Finally, cunner were very abundant in 1993 and 1994, but were completely absent from collections in 1996. It should be noted, however, that the majority of the individuals were collected in 1993 and 1994, whereas the catch in 1996 was considerably lower. More of the trapping effort in 1996 was focused under the piers compared to 1993 or 1994, which may have reduced the total catch (Table 2), though these differences could also be due to an overall depression of fish abundance in 1996.

In spite of some variation in fish abundance among years, 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 (Fig. 2). Only one species, the American eel, was ever collected from under-pier areas more frequently than in any other habitat, though a number of eels were collected in all the other habitats as well (Fig. 3). Atlantic tomcod and naked goby (*Gobiosoma bosc*) were not uncommon in under-pier traps, but they were collected in higher numbers at other sites (Fig. 3). 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. Nonetheless, we believe that fishes found under the piers, excluding Atlantic tomcod, American eel, and naked goby, are only transitory or accidental visitors to under-pier areas. If fishes were utilizing under-pier habitats for any significant length of time, for foraging or as a refuge for example, they probably would have appeared in the traps in higher numbers during at least some portion of the study, especially given the day and night sampling. In fact, it is likely that water under large piers may be actively avoided by fishes on large time scales (days, weeks). This is not to say that under-pier areas cannot be utilized by fish on smaller time scales (minutes, hours). It may be that short forays to under-pier sites are not adequately sampled using benthic traps. 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 et al. 1999; Duffy-Anderson et al. 2003).

The abundance of decapod crustaceans across all habitat types during the trapping study was high, with nearly 17,000 individuals collected. However, the total number of species collected was considerably lower than for fish; only six species were cataloged (Table 3) (Note: mud crab (Xanthidae) abundance was not quantified, though the crabs were occasionally found in some of the samples). The three most abundant decapods in the system were the daggerblade grass shrimp, which constituted 64% of the total decapod catch, the sevenspine bay shrimp, which made up 32% of the catch, and the blue crab, which constituted approximately 3.5% of the total. Since these three species were much more abundant than the other species that were occasionally collected in the lower Hudson River, the survey in 1996 only focused on these species and the remainder of the discussion will be restricted to these three as well.

Both adult and large juvenile blue crabs were present in the collections throughout the studies and a cohort of YOY blue crabs appeared each fall. Daggerblade grass shrimp and sevenspine bay shrimp were collected throughout the seasonal duration of the studies. All three decapods were captured repeatedly at all habitat sites (Fig. 4), though mean abundance (CPUE) varied widely, and no clear trends in habitat use were apparent except that values were lower in pile fields. Perhaps the potentially greater abundance of fish predators in this habitat caused a reduction in numbers of these common prey (Fig. 2). This pattern for decapods is in contrast to results for fishes (see above) where under-pier abundances were clearly depressed. We concluded that decapods were capable of utilizing all the habitats, including under-pier areas, and can probably move readily among habitat sites.

Interestingly, the three fish species collected under piers (American eels, Atlantic tomcod, and naked goby) and the decapod species 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) as can some (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). This suggests that vision is still an important component of the overall sensory behavior of the animals. The use of chemoreception in decapod foraging is well established and has been studied in shrimp (Carr 1978; Carr et al. 1984; Carr and Derby 1986) and crabs (Pearson and Olla 1977) among others (Ache 1982). Decapods possess olfactory receptors on the first antennae and chemoreceptors on the legs and mouthparts (Zimmer-Faust 1989), providing the animals with a sense of both smell and taste and potentially allowing them to feed in low light areas. 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 m^{-2} s^{-1} under piers vs. 20 - 60 μE m^{-2} 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 Lebail 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 interferes 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, *Tautog onitis*, 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 10-d periods, and changes in fish weight (i.e. growth rate in weight) were determined. Randomly chosen specimens also served as controls which were kept in the laboratory for 10 d without food. Growth experiments were conducted in 1994, 1996, 1997, and 1998 (see Duffy-Anderson and Able 1999; Able et al. 1999; and Metzger et al. 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 (i.e., they experienced weight loss) when they were caged under piers, indicating that the fish had fed poorly (Fig. 5). 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 10-d periods. In contrast, winter flounder grew well in cages 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% less).

Growth rates among caged YOY tautog followed similar patterns, though variability was somewhat higher (Fig. 5). 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 10-d 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. 5). 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 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 10 d 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. This observation deviated from our expectation that these winter flounder would have no food at all in the stomachs; after all, the fish had lost weight at nearly the same rate as fish that had been intentionally starved in the laboratory. Clearly, however, winter flounder caged under piers were capable of limited feeding, but since growth under piers was negative, 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 ± 0.13) than in open water ($\bar{x}$ = 0.34 mg ± 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). However, 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 ± 0.54) than those caged under the pier ($\bar{x}$ = 0.06 mg ± 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). This observation may have been a consequence of the cage mesh (3 mm), but since tomcod were caged identically in all habitats (under pier, pier edge, open water), the effect was consistent across habitats. Principal prey items for caged tomcod were harpacticoid copepods and amphipods, though we also found isopods, nematodes, invertebrate eggs, salt water mites, and a single 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 ± 0.77) than fish caged at the edge ($\bar{x}$ = 0.99 mg ± 1.3) or outside of the pier ($\bar{x}$ = 1.01 mg ± 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.

As noted previously, 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%), though invertebrate eggs, polychaetes (capitellids and nereids), and copepods also comprised a portion of the assemblage. Previous work indicated that nematoda and foraminifera did not constitute 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, and 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 (Fig. 6). Previous findings at a nearby pier (Pier 76) in the lower Hudson River (Stoecker et al. 1992) found that 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 4), 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 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, 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.

Ecological Considerations

The sampling methods used in our studies undoubtedly influenced the observed species assemblage in all habitats. We were particularly interested in young-of-the-year, benthic fishes and we designed our traps to specifically target those individuals. However, other types of species can probably be collected from all habitats, including under-pier areas. For example, Stoecker et al. (1992) noted that two pelagic fishes, the striped bass and the white perch (*Morone americana*), were collected in gill nets deployed under a pier (Pier 76) in the lower Hudson River. It is unknown whether alternate collection mechanisms would have revealed additional patterns in under-pier habitat use, but it seems likely that pelagic fishes occurring under piers, especially visually-feeding pelagic species, would be subjected to many of the same pier-related impacts that affect benthic fish, including reduced visibility and poor foraging. Since pelagic species presumably travel through under-pier areas more quickly than benthic fishes, the magnitude of pier-related influences is probably diminished. However, any amount of time spent under piers during daylight hours would reduce the cumulative opportunity for diurnal foraging, lowering the overall growth potential (Houde 1987; Sogard 1997; Duffy-Anderson and Epifanio 1999).

Piers and shading can exert effects over multiple life history stages. Factors that appear to have little influence on feeding among larvae, such as turbidity (Breitburg 1988) or light intensity (Connaughton et al. 1994), may have dramatic effects on the feeding of juveniles and adults. Chesney (1989) noted that, if the prey field of a predator was made progressively narrow by conditions of increasing turbidity, the effects on foraging would be more pronounced among juveniles and adults than among larvae. Perhaps the consequences are similar in conditions of declining subsurface illuminations. If so, under-pier areas may be adequate during certain life history stages but inadequate during others. Species that are able to utilize additional sensory systems for feeding may be able to exploit under-pier habitats for greater portions of their life cycles than those that do not. However, even larvae require threshold light intensities for feeding (Connaughton et al. 1994), and they need adequate photoperiods for normal development and pigmentation (Boeuf and Le Bail 1999). Therefore, although prey consumption among larvae may be less affected by shading than juveniles or adults, prolonged near-darkness conditions may still have consequences.

Pier effects may vary seasonally. For example, adult American eels, which demonstrate negative phototaxis, are often found in shallow, under-pier habitats in the Hudson River during the spring and summer months when waters there are warm. However, when temperatures cool in the fall, eels probably migrate away from under-pier, shallow-water areas into deep bays to overwinter (Able and Fahay 1998). Thus, under-pier habitats may be utilized less frequently in winter months than during summer. Also, many YOY fishes migrate into deeper channel waters or offshore in winter; thus negative impacts are probably limited to summer months. Unfortunately that is the time of year during which most growth occurs for estuarine fishes (Able and Fahay 1998). Pier effects are likely to vary annually as well as seasonally. Interannual fluctuations in larval supply affect the delivery of juveniles such as in the lower Hudson River which can in turn, influence the number of fish that utilize under-pier habitats. Variations in the supply of Atlantic tomcod larvae and juveniles to the lower Hudson River are driven in large part by hydrodynamic processes (Dew 1995), temperature (Dew and Hecht 1994b), and salinity (Dew and Hecht 1994a). If conditions fluctuate in any given year, the number of Atlantic tomcod juveniles delivered to New York Harbor will vary, affecting the number of fish utilizing under-pier areas.

Additional work is needed to determine how piers affect fish behavior. Movements of YOY fishes are probably influenced by pier structures, particularly if those structures are located in shallow-water areas which are typically utilized by age-0 fish (Able and Fahay 1998). As noted earlier, most fishes probably do not utilize under-pier areas for long durations of time but shorter duration movements may occur. Piers may support growth of encrusting organisms (Glasby 1999) potentially offering a food source for fishes, or they may serve as refugia from predation, either by providing structured habitat in the form of pilings, or by providing a darkened habitat which would obscure the outline of a prey fish. However, forays to under-pier areas are probably limited (seconds, minutes, hours). In situ video observation, and mark-recapture studies such as coded wire tagging or ultrasonic tracking all provide promising avenues for future research to examine fish movements around piers and other man-made structures.

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 eelgrass (Kearney et al. 1983; Burdick and Short 1998a). Piers and docks that are built higher off of the water's surface allow greater penetration of incident sunlight, allowing growth of eelgrass and potentially providing more light for visually-foraging fishes. 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 affects eelgrass density, with wider piers and tighter plank spacing supporting lower eelgrass densities than narrow piers with planks that are separated to allow light penetration (Kearney et al. 1983). 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. Periodic gaps in the asphalt covering or steel grates on the deck may be appropriate mechanisms to allow the passage of light to the waters below. 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 1998b). An east-west configuration follows the daily path of the sun and results in continuous shading beneath the pier. Piers that have a north-south construction are perpendicular to the path of the sun, making it possible to illuminate the interior for at least some portion of each day. Piers that have a north-south orientation may be able to support greater numbers of fishes.

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 1998b) 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:surface ratios may be preferable.

The effects of piers may be influenced by the surrounding landscape. Piers constructed in relatively unaltered, natural habitats are likely to have far greater impacts than structures that are built in areas that have already been extensively modified. Thus, pier construction in highly modified, urbanized areas may be less serious, but they are not without consequence. Large municipal piers, or numerous small piers built in sequence, limit the amount of illuminated water available and reduce the total forage area. Continued reductions in open, shallow-water habitat in urbanized estuaries like New York Harbor could have repercussions on growth and survival of YOY fish. Careful consideration should be given to the surrounding terrain prior to pier construction or renovation.

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 situated in an estuarine, tidally-flushed locale. The impacts of piers in fresh water systems have not been examined to the best of our knowledge. Lakes and tidal fresh water rivers are home to large numbers of fish and they often have a myriad of smaller-sized piers. 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) and decapods (Bishop and Khan 1991). Additionally, 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 such as the Steel Pier in Atlantic City, New Jersey. 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 acute 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; therefore, 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.

ACKNOWLEDGMENTS

We gratefully acknowledge the support of the Hudson River Foundation, whose continued interest in our ideas have made the work presented in this chapter possible. Funding was provided under grants 001/96A and 001/98A and through the HRF Tibor Polgar Fellowship program. Special thanks are due to J. Manderson, D. Vivian, C. Metzger, J. Finley, R. Deacon, K. Lesser, N. Comanducci, J. Rosendale, T. Lynch, and J. Liming who logged many long hours on the Hudson River collecting data in the heat of summer. The National Marine Fisheries Service at Sandy Hook, the U.S. Army Corps of Engineers at Caven Point, The River Project, the Borough of Rumson, and Liberty State Park all generously provided access to their facilities. M. Ludwig (NMFS) and M. Kennish (Rutgers University) provided comments on an earlier version of this manuscript. This report is Rutgers University, Institute of Marine and Coastal Sciences Contribution 2005-13. This is FOCI Contribution Number 0440.

LITERATURE CITED

Able K. W. 1999. Measures of juvenile fish habitat quality: examples from a National Estuarine Research Reserve, p. 134-147. In: Benaka, L. R. (ed.), Fish Habitat: Essential Fish Habitat and Rehabilitation. Amer. Fish. Soc., Special Symp. 22, Bethesda, MD.

Able K. W. and M. P. Fahay. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, NJ.

Able K. W., J. P. Manderson, and A. L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: the effects of man-made structures in the lower Hudson River. *Estuaries* 21(4b):731-744.

Able, K.W., J.P. Manderson and A.L. Studholme. 1999. Habitat quality for shallow water fishes in an urban estuary: The effects of manmade structures on growth. Mar. Ecol. Prog. Ser. 187: 227-235.

Ache, B. W. 1982. Chemoreception and thermoreception, p. 369-398. In: Atwood, H. L. and D. C. Sandeman (eds.), The Biology of Crustacea Vol. 3. Academic Press, New York.

Aksnes, D. L. and A. C. W. Utne. 1997. A revised model of visual range in fish. *Sarsia* 82: 137-147.

Beck, M.W., K.L. Heck Jr., K.W. Able, D. Childers, D. Eggleston, B.M. Gillanders, B. Halpern, C. Hays, K. Hoshino, T. Minello, R. Orth, P. Sheridan and M. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51(8): 633-641.

Betts, M. B. 1997. Masterplanning: municipal support of maritime transport and commerce 1870-1930s, p. 39-83. In: Bone, K. (ed.), The New York Waterfront: Evolution and Building Culture of the Port and Harbor. Monacelli Press Inc., New York.

Bishop, J. M. and M. H. Khan. 1991. Depth as a factor in abundance and size of juvenile penaeid shrimps in the absence of estuaries and marshes. *Mar. Biol.* 109:103-114.

Boeuf, G. and P. Y. Le Bail. 1999. Does light have an influence on fish growth? *Aquaculture* 177(1-4):129-152.

Bone, K. 1997. Horizontal city: architecture and construction in the port of New York, p. 87-151. In: Bone, K. (ed.), The New York Waterfront: Evolution and Building Culture of the Port and Harbor. Monacelli Press Inc., New York.

Breitburg, D. L. 1988. Effects of turbidity on prey consumption by striped bass larvae. *Trans.*

Am. Fish. Soc. 117:72-77.

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

Burdick, D. M. and F. T. Short. 1998a. The effects of boat docks on eelgrass in coastal waters of Massachusetts. *Environ. Manage.* 23(2):231-240.

Burdick, D. M. and F. T. Short. 1998b. Dock design with the environment in mind: minimizing dock impacts to eelgrass habitats. An interactive CD-ROM; University of New Hampshire, Durham, NH.

Buttenwieser, A. L. 1987. Manhattan Water-Bound: Planning and Developing Manhattan's Waterfront from the Seventeenth Century to the Present. New York University Press, New York.

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

Carr, W. E. S. 1978. Chemoreception in the shrimp *Palaemonetes pugio*: The role of amino acids and betaine in elicitation of a feeding response by extracts. *Comp. Biochem. Physiol.* 61A:127-131.

Carr, W. E. S. and C. D. Derby. 1986. Behavioral chemoattractants for the shrimp *Palaemonetes pugio*: identification of active components in food extracts and evidence of synergistic mixture interactions. *Chem. Senses* 11:49-64.

Carr, W. E. S., J. C. Netherton III, and M. L. Milstead. 1984. Chemoreception in the shrimp *Palaemonetes pugio*: variability in responsiveness and the stimulatory capacity of mixtures containing amino acids, quaternary ammonium compounds, purines, and other substances. *Comp. Biochem. Physiol.* 77A:469-474.

Chesney, E. J. 1989. Estimating the food requirements of striped bass larvae *Morone saxatilis*: effects of light, turbidity, and turbulence. *Mar. Ecol. Prog. Ser.* 53:191-200.

Chiarella, L. A. and D. O. Conover. 1990. Spawning season and first-year growth of adult bluefish from the New York Bight. *Trans. Amer. Fish. Soc.* 119:455-462.

Connaughton, V. P., C. E. Epifanio, and R. Thomas. 1994. Effects of varying irradiance and feeding in larval weakfish (*Cynoscion regalis*). *J. Exp. Mar. Biol. Ecol.* 180:151-163.

Dew, C. B. 1995. The nonrandom size distribution and size-selective transport of age-0 Atlantic tomcod (*Microgadus tomcod*) in the lower Hudson River Estuary. *Can. J. Fish. Aquat. Sci.* 52:2353-2366.

Dew, C. B. and J. H. Hecht. 1994a. Hatching, estuarine transport, and distribution of larval and early juvenile Atlantic tomcod, *Microgadus tomcod*, in the Hudson River. *Estuaries* 17: 472-488.

Dew, C. B. and J. H. Hecht. 1994b. Recruitment, growth, mortality, and biomass production of larval and early juvenile Atlantic tomcod in the Hudson River Estuary. *Trans. Amer. Fish. Soc.* 123:681-702.

Dovel, W. L. 1981. Ichthyoplankton of the lower Hudson Estuary, New York. *NY Fish Game J.* 28:21-39.

Dovel, W. L. and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson estuary. *NY Fish Game J.* 30:140-172.

Duffy-Anderson, J. T. and K. W. Able. 1999. Effects of municipal piers on the growth of juvenile fish in the Hudson River Estuary: a study across a pier edge. *Mar. Biol.* 133: 409-418.

Duffy-Anderson, J.T. and K.W. Able. 2001 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. *Estuaries* 24:430-440.

Duffy-Anderson, J. T. and C. E. Epifanio. 1999. A model of the effects of limited prey availability on the survival of weakfish (*Cynoscion regalis*) larvae. *Bull. N J Acad. Sci.* 44:13-17.

Duffy-Anderson, J.T., J. P. Manderson and K.W. Able. 2003. A characterization of juvenile fish assemblages around man-made structure in the New York-New Jersey Harbor Estuary, U.S.A. Bulletin of Marine Science 72(3): 877-889.

Fernald, R. D. 1993. Vision. p. 161-189, In: Evans, D. H. (ed.), The Physiology of Fishes. CRC Press, Boca Raton.

Gerking, S. D. 1994. Feeding Ecology of Fish. Academic Press. New York, NY.

Glasby, T.M. 1999. Differences between subtidal epibiota on pier pilings and rocky reefs at marinas in Sydney, Australia. *Est. Coast. Shelf Sci.* 48: 281-290.

Grabe, S. A. 1978. Food and feeding habits of juvenile Atlantic tomcod, *Microgadus tomcod*, from Haverstraw Bay, Hudson River. *Fish. Bull. U. S.* 76: 89-94.

Grover, J. J. 1982. The comparative feeding ecology of five inshore, marine fishes off Long Island, New York. Ph.D. Dissertation, Rutgers University.

Herrick, C. J. 1904. The organ and sense of taste in fishes. *Bull. U. S. Fish Comm*. 22: 239-272.

Hoff, T. B., R. J. Klauda, and J. R. Young. 1988. Contribution to the biology of shortnose sturgeon in the Hudson River Estuary. p. 171-189, In: Smith, C. L. (ed.), Fisheries Research in the Hudson River. State University of New York Press, Albany, NY.

Houde, E. D. 1987. Fish early life dynamics and recruitment variability. *Amer. Fish. Soc. Symp*. 2: 17-19.

Hurst, T. P. and D. O. Conover. 1998. Winter mortality of young-of-the-year Hudson River striped bass (*Morone saxatilis*): size dependent patterns and effects on recruitment. *Can. J. Fish. Aquat. Sci.* 55:1122-1130.

Kearney, V., Y. Segal, and M. Lefor. 1983. The effects of docks on salt marsh vegetation. Connecticut State Department of Environmental Protection, Hartford, CT.

Klein-MacPhee, G. 1978. Synopsis of biological data for the winter flounder, *Pseudopleuronectes americanus* (Walbaum). FAO Fish. Synopsis 117:1-43.

Limburg, K. E. 1996. Growth and migration of 0-year American shad (*Alosa sapidissima*) in the Hudson River Estuary: otolith microstructural analysis. *Can J. Fish. Aquat. Sci.* 53:220-238.

Metzger, C.V., J.T. Duffy-Anderson, and K.W. Able. 2001. Effects of a municipal pier on growth of young-of-the year Atlantic tomcod (Microgadus tomcod): A study in the Hudson River Estuary. Bull. NJ Acad. Sci. 46(1):5-10.

Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of Essential Fish Habitat. p. 43-75, In: Benaka, L. R. (ed.), Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fisheries Society, Special Symposium 22, Bethesda, MD.

O'Brien, W. J. 1979. The predator-prey interaction of planktivorous fish and zooplankton. *Am. Sci.* 67:572-581.

O'Connor, J. S., J. A. Ranasinghe, and D. A. Adams. 1998. Temporal change in sediment quality of the New York Harbor area. *Bull. N J Acad. Sci.* 432:1-6.

Olla B. L., A. L. Bejda, and A. D. Martin. 1974. Daily activity, movements, feeding, and seasonal occurrence in the tautog, *Tautoga onitis*. *Fish. Bull.* 72:27-35

Pace, M. L., S. E. Findlay, and D. Lints. 1992. Zooplankton in advective environments: the Hudson River community and a comparative analysis. *Can. J. Fish. Aquat. Sci.* 49:1060-1069.

Pearcy, W. G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). *Bull. Bingham Oceanogr. Coll.*, Yale Univ. 18:1-78.

Pearson, W. H. and B. L. Olla. 1977. Chemoreception in the blue crab (*Callinectes sapidus*). *Biol. Bull.* 153:46-54.

Rice, C. A., P. D. Plesha, E. Casillas, D. A. Misitano, and J. P. Meador. 1995. Growth and survival of three marine invertebrate species in sediments from the Hudson-Raritan Estuary, New York. *Environ. Toxic. Chem.* 14:1931-1940.

Schreiber, R. A. and T. A. Gill. 1995. Identification and mapping of essential fish habitat: an approach to assessment and protection. Habitat Policy and Management Division, NMFS and Strategic Environmental Assessments Division, NOS, NOAA.

Secor, D. H. and P. M. Piccoli. 1996. Age- and sex-dependent migrations of striped bass in the Hudson River as determined by chemical microanalysis of otoliths. *Estuaries* 19:778-793.

Silver, W. L. 1979. Electrophysiological responses from the olfactory system of the American eel. Ph.D. Dissertation. Florida State University.

Smith, C. L. 1985. The Inland Fishes of New York State. NY State Department of Environmental Conservation, Albany.

Sogard, S. M. 1992. Variability in growth rates of juvenile fishes in different estuarine habitats. *Mar. Ecol. Prog. Ser.* 85:35-53

Sogard, S. M. 1997. Size-selective mortality in the juvenile stage of teleost fishes: a review. *Bull. Mar. Sci.* 60:1129-1157.

Squires, D. F. 1992. Quantifying anthropogenic shoreline modification of the Hudson River and Estuary from European contact to modern time. *Coast. Manage.* 20:343-354

Stanne, S. P., R. G. Panetta, and B. E. Forist. 1996. The Hudson: An Illustrated Guide to the Living River. Rutgers University Press, New Brunswick, NJ.

Stehlik, L. L. and C. J. Meise. 2000. Diet of winter flounder in a New Jersey estuary: ontogenetic change and spatial variation. *Estuaries*. 23(3): 381-391.

Stepien, J. C., T. C. Malone, and M. B. Chervin. 1981. Copepod communities in the estuary and coastal plume of the Hudson River. *Est. Coast. Shelf Sci.* 13:185-195.

Stoecker R. R., J. Collura, and P. J. Fallon Jr. 1992. Aquatic studies at the Hudson River Center Site. p. 407-427, In: Smith, C.L. (ed.), Estuarine Research in the 1980s. The Hudson River Environmental Society Seventh Symposium on Hudson River Ecology. State University of New York Press, Albany, NY.

Strayer, D. L., C. C. Hunter, C. L. Smith, and C. K. Borg. 1994. Distribution, abundance, and roles of freshwater clams (Bivalvia: Unionidae) in the freshwater tidal Hudson River. *Freshw. Biol.* 31:239-248.

Stross, R. G. and R. C. Sokol. 1989. Runoff and flocculation modify underwater light environment of the Hudson River Estuary. *Est. Coast. Shelf Sci.* 29:305-316.

Teichmann, H. 1954. Vergleichende Untersuchugen an der Nase der Fische. *Z. Morphol. Oekol. Tiere.* 43:171-212.

Utne, A .C. W. and B. Bacchi. 1997. The influence of visual and chemical stimuli from cod (*Gadus morhua*) on the distribution of two-spotted goby *Gobiusculus flavescens* (Fabricius). *Sarsia* 82:129-135.

Van Eenennaam, J. P., S. I. Dorashov, G. P. Moberg, J. G. Watson, D. S. Moore, and J. Linares. 1996. Reproductive conditions of the Atlantic sturgeon (*Acipenser oxyrinchus*) in the Hudson River. *Estuaries* 19:769-777.

Vinyard, G. L. and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *J. Fish. Res. Bd. Can.* 29: 1193-1201.

Vivian, D.N., J.T. Duffy-Anderson, R.G. Arndt, and K.W. Able. 2000. Feeding habits of young-of-the-year winter flounder, *Pseudopleuronectes americanus*, in the Hudson River Estuary, U.S.A. *Bull. NJ Acad. Sci.* 45:1-6.

Waldman, J. R., D. J. Dunning, Q. E. Ross, and M. T. Mattson. 1990. Range dynamics of Hudson River striped bass along the Atlantic coast. *Trans. Amer. Fish. Soc.* 119:910-191.

Wilson, K. A. and K. W. Able. 1992. Blue crab (*Callinectes sapidus*) habitat utilization and survival in the Hudson River. Rutgers University, Institute of Marine and Coastal Sciences, Tech. Rept. 92 - 49.

Wise, M. Z., W. Woods, and E. Bone. 1997. Evolving purposes: The case of the Hudson River waterfront. p. 193-233, In: Bone, K. (ed.), The New York Waterfront: Evolution and Building Culture of the Port and Harbor. Monacelli Press Inc., New York, NY.

Zimmer-Faust, R. K. 1989. The relationship between chemoreception and foraging behavior in crustaceans. *Limnol. Oceanogr.* 34:1367-1374.

LIST OF TABLES

Table 1. Species names and absolute abundance of fishes collected in benthic traps deployed in the lower Hudson River in 1993, 1994, and 1996. Size ranges presented are total lengths (TL) expressed in mm. Adapted from Able et al. (1998).

Species	1993	1994	1996	Size Range
Morone saxatilis	207	188	14	17-185
Microgadus tomcod	103	160	38	23-250
Anguilla rostrata	94	55	70	130-650
Centropristis striata	4	177	0	17-81
Tautogolabrus adspersus	84	42	0	14-190
Pseudopleuronectes americanus	15	80	10	12-280
Gobiosoma ginsburgi (seaboard goby)	92	0	0	16-42
Gobiosoma bosc	19	9	43	15-49
Syngnathus fuscus (northern pipefish)	25	31	9	25-229
Urophycis regia (spotted hake)	2	2	40	41-204
Conger oceanicus (conger eel)	5	4	34	36-300
Menidia menidia (Atlantic silverside)	6	6	1	22-85
Prionotus evolans (striped searobin)	0	12	1	19-67
Tautoga onitis	10	1	1	54-125
Bairdiella chrysoura (silver perch)	1	9	0	40-76
Etropus microstomus (smallmouth flounder)	4	5	1	22-49
Morone americana	0	8	1	73-205
Anchoa mitchilli	0	8	0	29-84
Myoxocephalus aenaeus (grubby)	6	2	0	16-94
Hypsoblennius hentz (feather blenny)	5	0	0	18-31
Paralichthys dentatus (summer flounder)	2	0	1	177-310
Peprilus triacanthus (butterfish)	0	1	0	16
Chaetodon ocellatus (spotfin butterflyfish)	1	0	0	48
Opsanus tau (oyster toadfish)	1	0	0	22
Trinectes americanus (hogchoker)	0	0	1	100
Micropogonias undulatus (Atlantic croaker)	0	0	1	157

Species	1993	1994	1996	Size Range
Scophthalmus aquosus (windowpane)	0	0	1	62
Cynoscion regalis (weakfish)	0	0	1	53
Caranx hippo (crevalle jack)	0	0	1	45
unidentified *sample lost	0	0	1	22

Table 2. Trapping effort (expressed as trap days) at each study site in the lower Hudson River in 1993, 1994, and 1996.

Year (sampling period)	**Under Pier**	**Pier Edge**	**Pile Field**	**Open Water**
1993 (June 21 - October 8)	324	0	325	314
1994 (May 16 - September 16)	311	0	285	306
1996 (June 10 - October 25)	484	242	0	483
Total	**1119**	**242**	**610**	**1103**

Table 3. Absolute abundances of decapod crustaceans collected in benthic traps deployed in the lower Hudson River in 1993, 1994, and 1996. N/A indicates data not available.

Species	**1993**	**1994**	**1996**
Palaemonetes pugio	1588	3826	5356
Crangon septemspinosa	540	2058	2786
Callinectes sapidus	118	209	263
Carcinus maenas (green crab)	10	22	N/A
*Cancer irroratus (*Atlantic rock crab)	4	0	N/A
Libinia emarginata (portly spider crab)	2	0	N/A

Table 4. 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. N/A indicates data not available.

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

LIST OF FIGURES

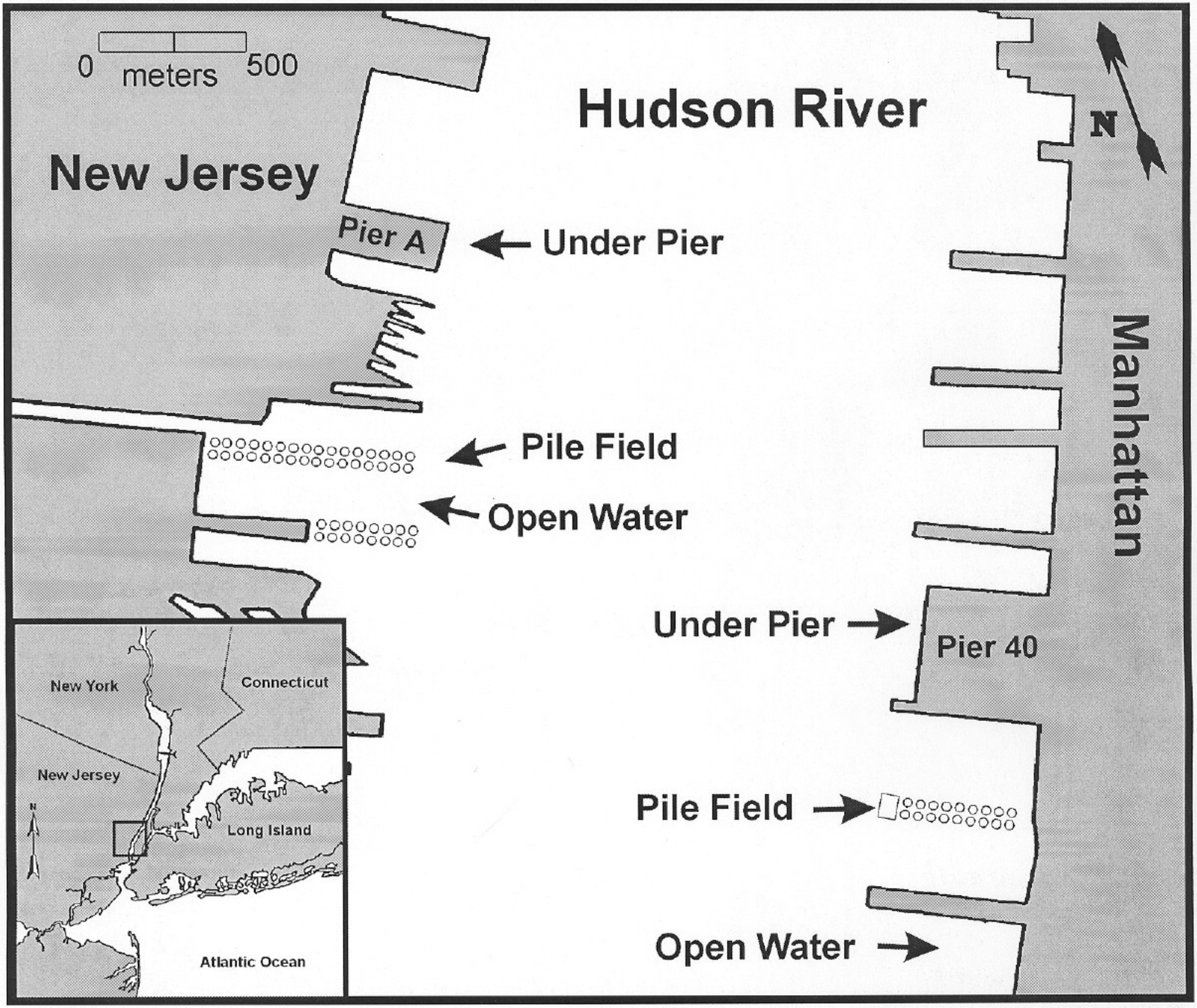
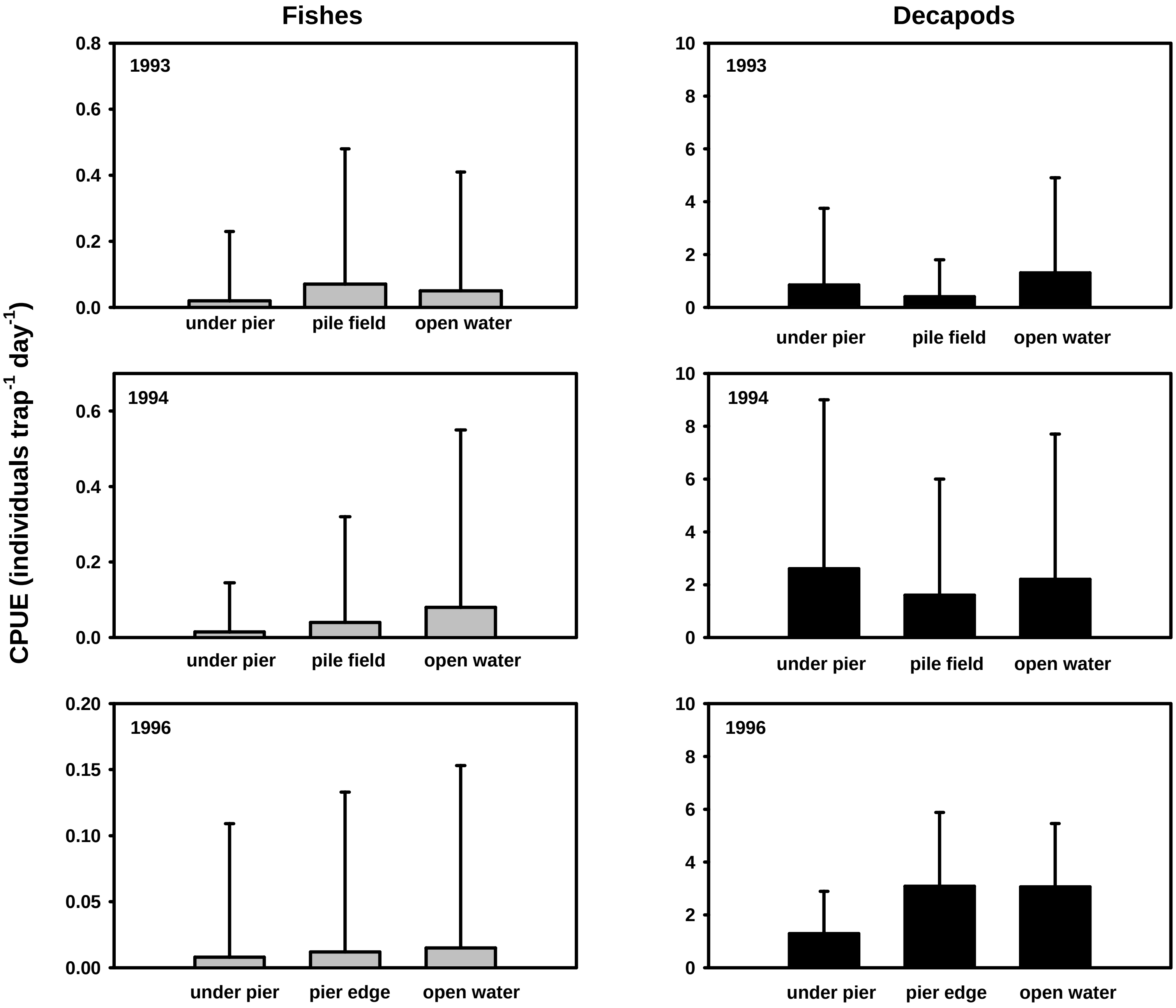
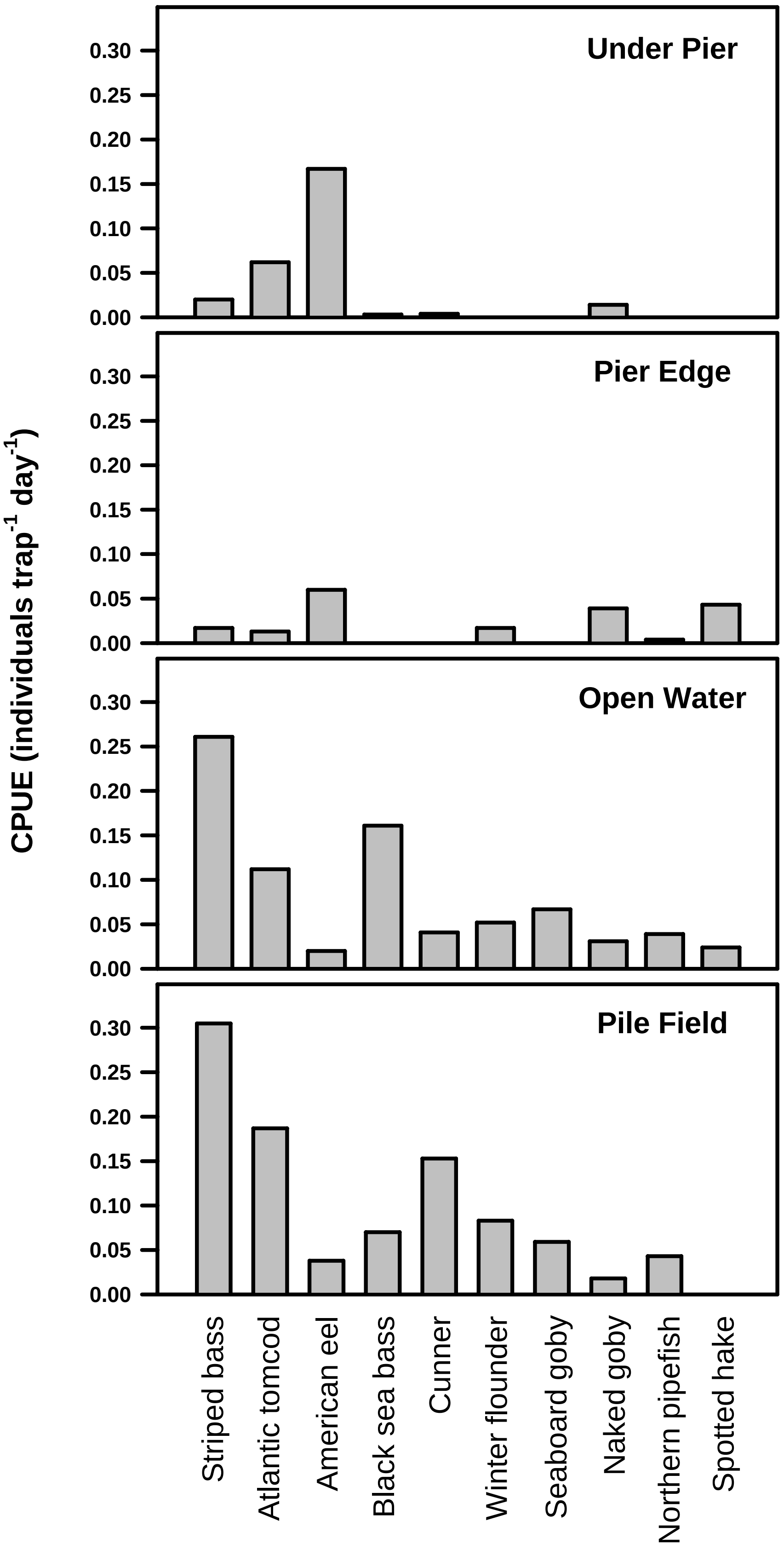
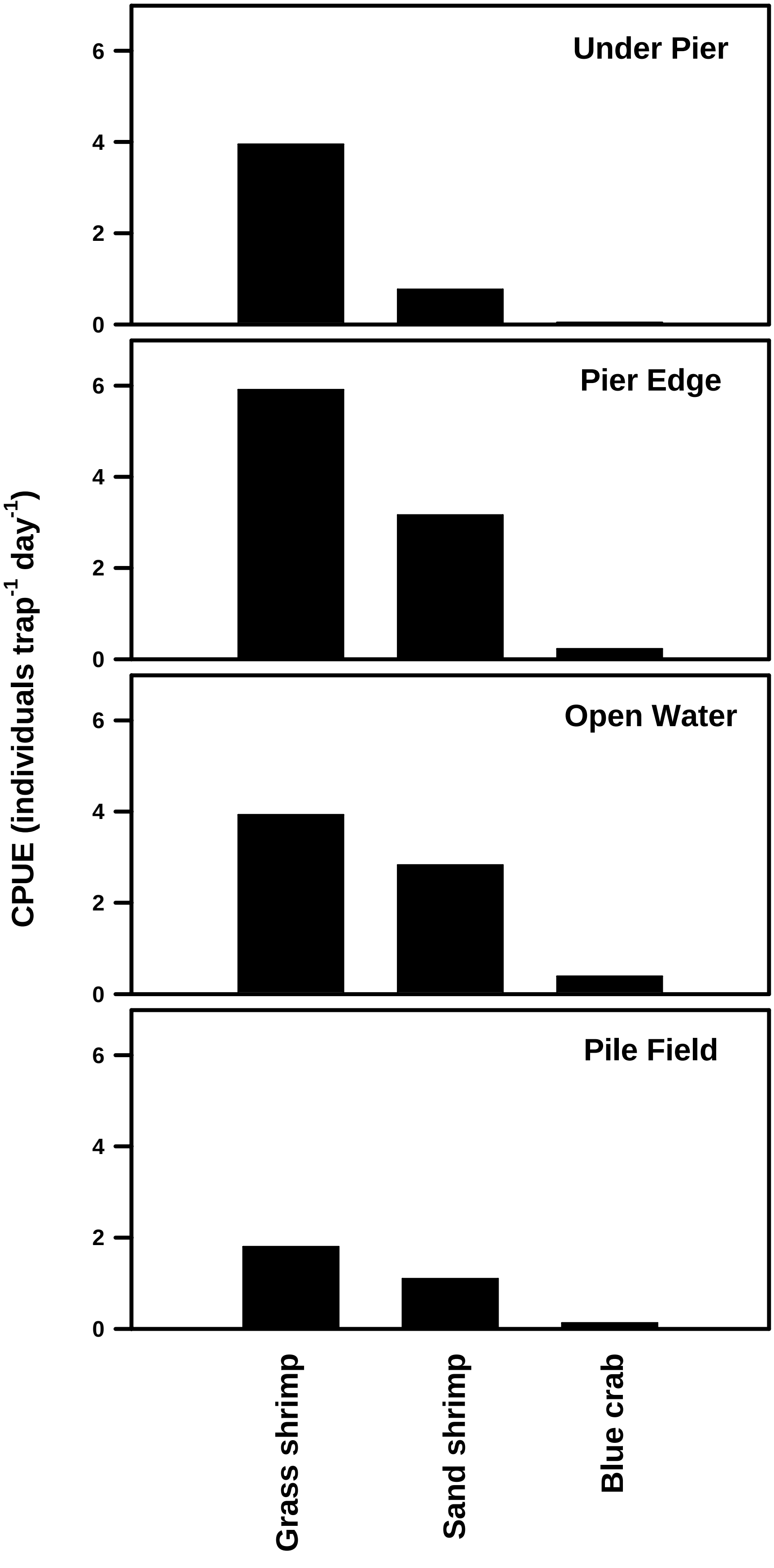


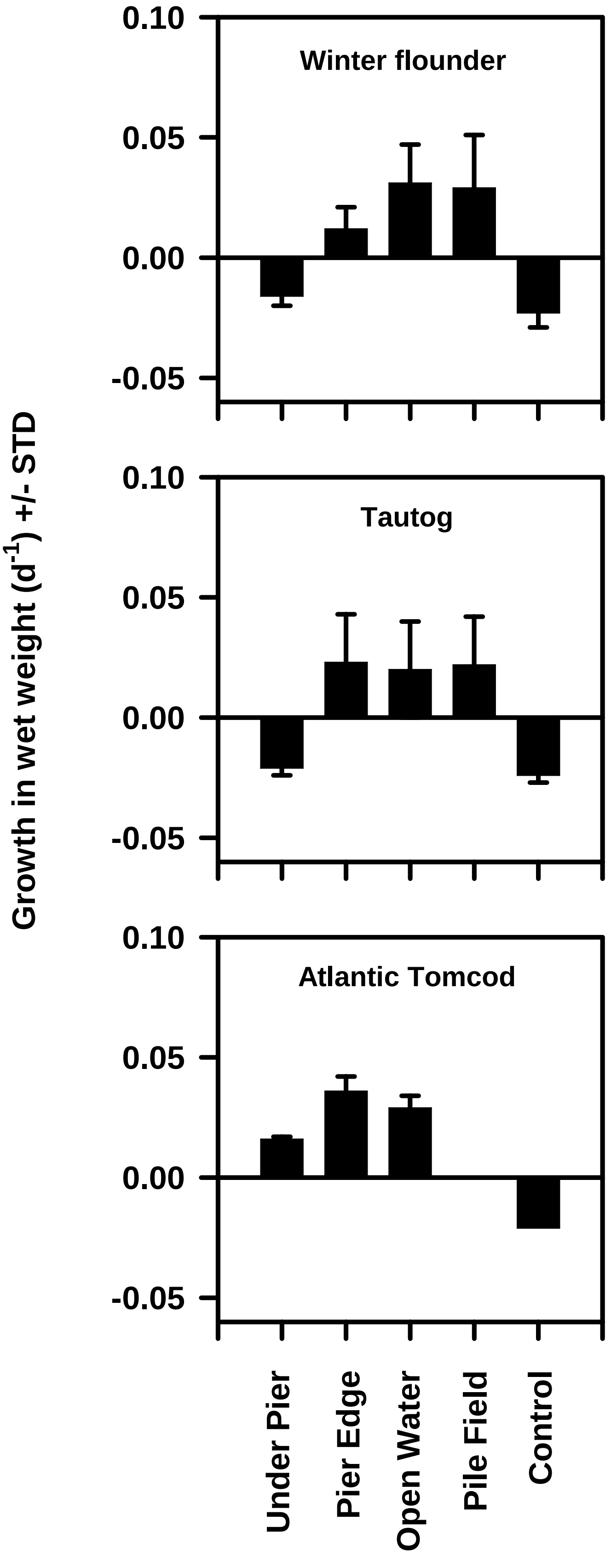
FIG. 1 Location of the study areas in the lower Hudson River. Adapted from Able et al. 1998


Fishes
Decapods
CPUE (individuals trap^{-1} day^{-1})
1993
0.8
0.6
0.4
0.2
0.0
under pier
pile field
open water
1993
10
8
6
4
2
0
under pier
pile field
open water
1994
0.6
0.4
0.2
0.0
under pier
pile field
open water
1994
10
8
6
4
2
0
under pier
pile field
open water
1996
0.20
0.15
0.10
0.05
0.00
under pier
pier edge
open water
1996
10
8
6
4
2
0
under pier
pier edge
open water

Under Pier
Pier Edge
Open Water
Pile Field
CPUE (individuals trap^{-1} day^{-1})
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Striped bass
Atlantic tomcod
American eel
Black sea bass
Cunner
Winter flounder
Seaboard goby
Naked goby
Northern pipefish
Spotted hake



Under Pier
Pier Edge
Open Water
Pile Field
0
2
4
6
CPUE (individuals trap^{-1} day^{-1})
Grass shrimp
Sand shrimp
Blue crab


Winter flounder
Tautog
Atlantic Tomcod
0.10
0.05
0.00
-0.05
Growth in wet weight (d^{-1}) +/- STD
Under Pier
Pier Edge
Open Water
Pile Field
Control

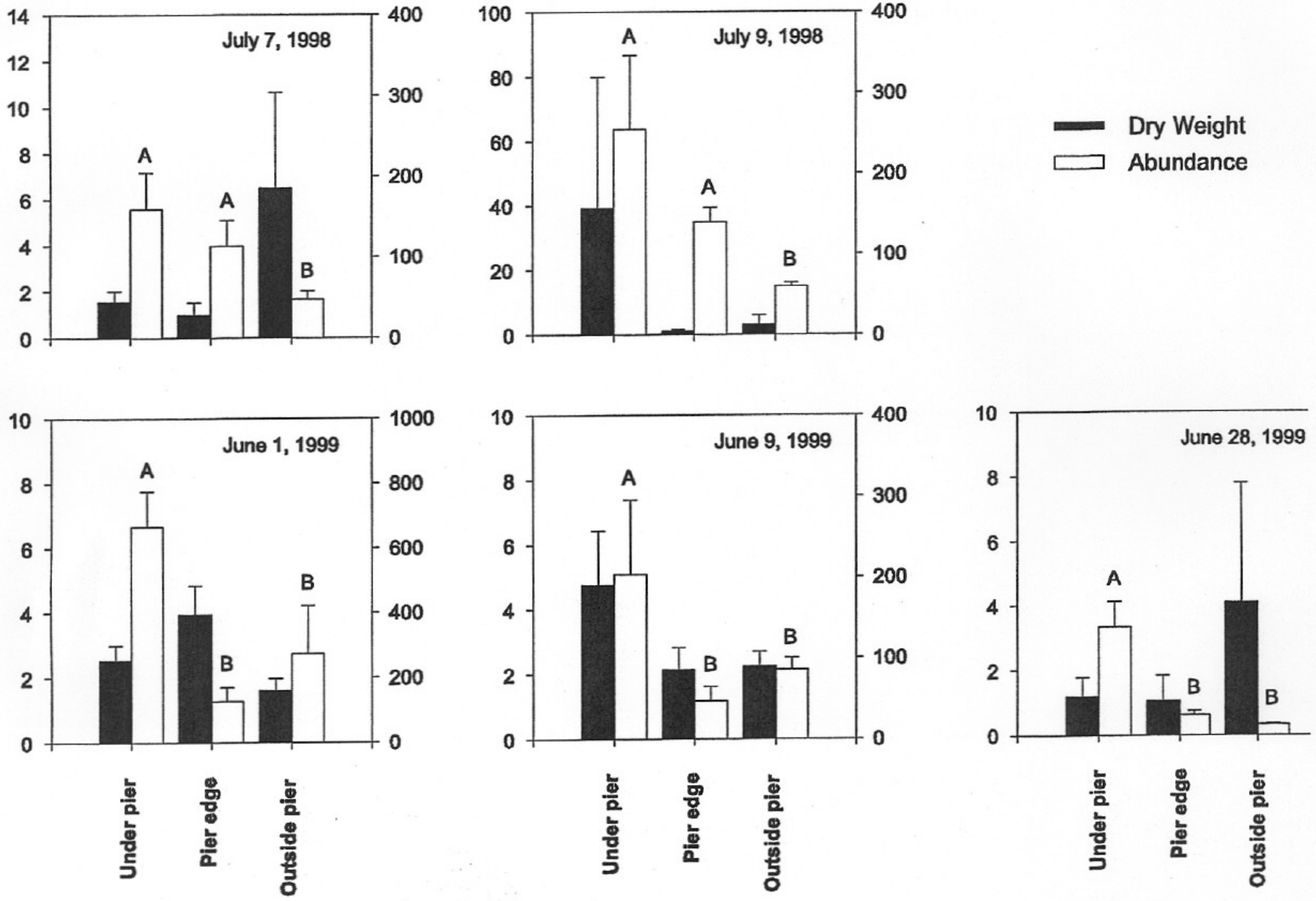


Fig. 6 Mean abundance (white bars) and dry weight (black bars) of total fish prey enumerated from benthic cores (+/- SE) collected under, at the edge, and outside of a municipal pier in the Hudson River estuary. Letters above bar graphs indicate significant differences in abundances as delineated by Tukey multiple comparison test. Adapted from Duffy-Anderson and Able (2001)