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Blue crab (Callinectes sapidus) habitat utilization and survival in the Hudson River

Kim A. Wilson
Department of Biological Sciences
Central Connecticut State University
New Britain, Connecticut 06050

Kenneth W. Able
Marine Field Station
Institute of Marine and Coastal Sciences
Rutgers University
800 Great Bay Boulevard
Tuckerton, NJ 08087

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ABSTRACT

This project examined the life history distribution and abundance of blue crabs (Callinectes sapidus) in the lower Hudson River during the period from May 1989 to June 1992. Sampling was conducted at 10 sites (Denning Point, Moodna Creek, Constitution Island, Iona Marsh, Peekskill, Haverstraw Bay, Croton Bay, Nyack, Piermont Marsh and Liberty State Park) from the Beacon-Newburg area (97 RKM) to New York Harbor (RKM 0). A variety of vegetated and unvegetated habitats were sampled monthly, May to October, for blue crabs and co-occurring decapod crustaceans and fishes using a 4.9-m otter trawl in water 2-5 m deep and a 1 m^2 aluminum throw trap in water 0.5-2 m deep. Relative risk to predation for juvenile blue crabs in three habitat types (Vallisneria, Myriophyllum, unvegetated sediment) was tested using tethering techniques in September 1990 and 1991. Food habits of potential fish predators of blue crabs were investigated by gut content analysis at three sites (Constitution Island, Iona Marsh, Croton Bay) in August 1991 when small juvenile crabs were abundant.

Blue crab abundance showed interannual and seasonal variability. Crab density at some sites ranged from $0/m^2$ in the spring to as high as $100/m^2$ in August 1991. Usually, the greatest number of crabs in trawls were caught in sites heavily vegetated with Vallisneria and Potamogeton. The numbers of crabs caught (trawl) and crab density (throw trap) were lowest in 1990 and in the spring and early summer of 1991. In August 1989 and 1990, small numbers of juvenile crabs (<10 mm CW) appeared in the samples, but in August 1991, large numbers of small, early stage juvenile crabs (3-10 mm CW) entered the river and were collected at most sites in average densities up to $38/m^2$. Tethering experiments showed that vegetation provides cover from predation relative to

unvegetated habitat. Crabs tethered in Vallisneria had the lowest mortality rates. Mortality rates in all habitats varied between years. Examination of fish stomachs in August 1991 found five species of fishes had consumed blue crabs: Morone saxatilis, M. americana, Fundulus diaphanus, Cynoscion regalis, and Trinectes maculatus. These results demonstrate that the Hudson River provides a nursery area for blue crabs but ingress into the system has huge annual variability.

INTRODUCTION

Blue crabs are caught in abundance along the Atlantic coast from Florida to New Jersey, and are taken in lesser numbers as far north as Nova Scotia (Williams 1984). Despite the interest in blue crabs and their fishery value, very little has been published on blue crab biology in the Hudson River; there is virtually no information on the life history or habitat utilization. In other localities, the biology of adult crabs is fairly well-known, particularly in Chesapeake Bay, but less is known about juvenile blue crab ecology in any area.

In areas where post-larval recruitment to the estuary has been studied (eg. Delaware Bay, Chesapeake Bay), investigators have found that blue crab larvae develop offshore for approximately 31-35 days during the summer and then are carried into the estuary as megalopae (Epifanio et al. 1984, Goodrich et al. 1990). After settling in shallow water habitats, they molt into first crab stage at 2-3 mm in carapace width (CW) (Orth et al. 1987, Olmi et al. 1990). In Chesapeake Bay, early stage crabs are much more abundant in the shallow eelgrass meadows than in unvegetated sediment or marsh creeks (Orth et al. 1987).

Recently, researchers in other localities have found blue crab life history patterns that are different, in some aspects, from the population studied in Chesapeake Bay. For example, on Florida's Gulf of Mexico coast, females travel long distances along the coast and exhibit extensive migratory patterns (Hunt and Marx 1987). The ecology of the juvenile blue crabs also show some important differences between localities. For example, juveniles in Chesapeake Bay utilize eelgrass habitats in large numbers compared with low densities in marsh creeks (Orth and van Montfrans 1987). In southern New Jersey, however, juvenile crabs are distributed evenly among several shallow water habitats, including eelgrass, marsh creeks, macroalgae and unvegetated substrates (Wilson et al. 1990a).

These differences among localities suggest that we should be cautious in generalizing about blue crab natural history from one system to the next. Certainly, the structure of estuaries, as determined by salinity, tidal and current flow, etc. from Chesapeake Bay to the Hudson River is very different, as are habitat characteristics such as types of submerged vegetation, and salinity and temperature regimes. Thus, the importance of determining the life history and habitat utilization of the blue crab in the Hudson River is apparent, not just because we lack descriptions of blue crab ecology in the river, but also because the blue crab population in the Hudson is exposed to and lives in a unique estuarine system where differences in life history from the classic Chesapeake Bay blue crab may exist. An understanding of all these factors may be critical to the continued development of the fishery in the Hudson River.

The best available information to date indicates that blue crabs in the Hudson River occur from New York Harbor to the Troy Dam. An impingement study conducted at Indian Point Power Plant found that there were changes in sex ratio and size class of blue crabs over a one-year period (Normandeau 1986). Although blue crabs are occasionally listed as a component species of the benthos (Ristich et al. 1977, Hirschfield et al. 1966), no information is available on habitat utilization or characteristics of the habitat. As a further indicator of our level of knowledge, a recent summary of estuarine research in the Hudson River (Smith 1992) does not contain a single article on blue crabs.

In this project we examined the life history patterns, habitat use, abundance, and seasonal distribution of the blue crab in the Hudson River. We investigated predation rates on blue crabs in different habitats and characterized blue crab refuges and habitats. We also considered the seasonal distribution of co-occurring decapod crustaceans and fishes, especially as potential predators of juvenile blue crabs.

MATERIALS AND METHODS

STUDY SITES

Blue crabs were sampled using an otter trawl and throw trap at 10 sites (Fig. 1) from the Beacon-Newburg area (RKM 97) to New York Harbor (RKM O). Nine sites were sampled monthly with the trawl, eight sites with the throw trap from May-November 1989, May-October 1990, June-October 1991, and June 1992 (Table 1). Some sites were not sampled in some months due to bad weather, dense vegetation (Trapa natans) or other problems.

The northernmost site, Denning Point, is an area off Fishkill Creek. Trawls were run parallel to shore, approximately 100 m offshore, south of Denning Point through Vallisneria americana. The water chestnut (Trapa natans) was present but was usually too dense for passage of the boat or trawl. The next site, across the river, was south of the mouth of Moodna Creek (RKM 90). Trawls were towed approximately 100 m off and parallel to shore; throw trapping was conducted south of the creek delta, 100 - 200 m offshore. The next site (RKM 83) was in a very small embayment on the south side of Constitution Island. This site was interesting because it was such a small area of shallow water and within 200 m of shore the water depth increased precipitously to over 30 m. The Iona Marsh site (RKM 72) was sampled with the throw trap in a tidal creek on the west side of the railroad tracks, south of Round Island. The trawl site was a small embayment south of Round Island, and east of the railroad tracks. The Peekskill site, across the river from the Iona Marsh trawl site, was a trawl site only. Trawling was conducted east of the channel through the bay. The Haverstraw Bay site (RKM 57) is in the largest bay in the Hudson River. We trawled on the southeast side where the bay varies little in depth. The throw trap site was on the north side of the Croton Point Park off a small sandy beach and a bulkhead. Croton Bay, south of the Croton Point peninsula, is a large shallow (2 m) area. Trawling was conducted approximately 200 m from shore. The throw trap site was near the northern shore of the marsh on Croton Point. The Nyack (RKM 45) trawl site (no throw traps) was approximately 1/2 km offshore and 1 km north of the Tappan Zee bridge. The Piermont Marsh site (RKM 38) was in a very broad, shallow area south of the Piermont pier. The trawls were run 100-200 m offshore; throw trapping was conducted within 30 m of the marsh edge. The

Liberty State Park site (RKM 0) was a throw trap site only, on the west side of New York Harbor off a small Spartina salt marsh immediately north of the tourist building complex.

SAMPLING METHODS

A 4.9-m otter trawl with a 0.64-mm mesh liner was used to sample for crabs in shallow water between 2 and 5 m deep and to estimate seasonal distribution along sites. The trawls also let us identify other species (fishes and decapod crustaceans) that co-occur with blue crabs in different habitats. Four two-minute tows were conducted at each site. The towing direction was 180° relative to the previous trawl. All fish and decapods were immediately identified, counted, measured, and returned to the water. Size of decapod crustaceans was determined to the nearest millimeter carapace width (CW) (crabs) or total length (shrimp). Fish were measured to the nearest millimeter total length (TL). Specimens that required further identification were frozen and later identified in the laboratory. Most trawls were taken within two hours of daytime high tide at each site.

A 1 m^2 aluminum throw trap (0.75 m deep with 0.64 mm mesh that floats above the trap) was used to quantitatively sample for small juvenile crabs and associated decapods and fishes in shallow areas of less than 1.5 m at low tide. The throw trap quantitatively estimates epibenthic macrofauna densities in shallow water (Kushlan 1981). The trap was thrown into place, trapping epibenthic and pelagic decapods and fishes. A bar seine was pushed through the trap until three consecutive passes produced no decapods or fishes. Four replicate samples in vegetation and four replicates in unvegetated areas were attempted at the eight throw trap sites every sampling period.

Data on habitat quality, including water temperature, salinity, dissolved oxygen, and vegetation type were taken at all sampling sites. Salinity was measured using either a refractometer or a YSI conductivity meter; physical data were taken on bottom water after the water was collected in a Niskin bottle. Dissolved oxygen was measured with a YSI dissolved oxygen meter.

PREDATION STUDIES

Predation studies using tethering techniques (Heck and Thoman 1981, Wilson et al. 1990b) were conducted to estimate relative rates of predation on juvenile blue crabs among three habitat types. Estimates of predation rates in different habitats provides some measurement of the refuge value of certain types of vegetated and unvegetated habitats and help define and explain habitat quality.

Juvenile blue crabs (9-45 mm CW) were tethered in three types of habitats: Myriophyllum (water milfoil), Vallisneria americana (water celery), and unvegetated sediment as controls at the Haverstraw Bay and Croton Bay sampling sites in September 1990 and 1991 (Fig. 1, Table 2). Crabs were tethered using 6-lb. test monofilament fishing line tied around the lateral spines and across the body (Wilson et al. 1987). A drop of super glue (cyanoacrylate) ensured that the tether remained attached to the crab. The other end of the line was tied to a wire stake. At the start of each experimental trial the stake was pushed into the desired test substrate. Each stake held only a single crab. The tethered crabs are able to walk, swim and feed, and bury into the substrate (Wilson et al. 1987, 1990b). Crabs were measured prior to tethering and then placed in the habitats for 24 hours (±1 hour). After the test period, they were recovered, measured, and scored for survival in each habitat. A small piece of the carapace remained attached to the tether in cases where the crab had been eaten.

In September 1990, a total of 55 crabs were tethered in two trials in Vallisneria, Myriophyllum and unvegetated habitats at the Haverstraw Bay site. Thirty-three crabs were tethered in Vallisneria and unvegetated habitat in the Croton Bay site. In September 1991, a total of 52 crabs were tethered in the same three habitats at Haverstraw Bay in three trials; 118 crabs were tethered in Vallisneria and unvegetated sediment at the Croton Bay site in four trials.

Food habits of fishes that co-occur in shallow (<4 m) habitats with juvenile blue crabs were analyzed by examination of gut contents to determine frequency of predation. This analysis was conducted in August 1991 when there were large numbers of small juvenile blue crabs present in the sampling sites. Fishes collected in trawls and throw traps in August 1991 at Constitution Island, Iona Marsh, and Croton Bay were examined for presence of blue crabs in their stomachs (Table 6). The fishes were collected, frozen, and then identified, measured, and dissected in the laboratory under a microscope. Whole blue crabs found in the stomachs were measured (CW); blue crab parts were noted.

RESULTS

PHYSICAL CHARACTERISTICS OF SITES

All trawl and throw trap sites were in shallow water (<4 m) on a variety of vegetated and unvegetated sandy and mud bottoms (Table 3). The most common vegetation types in which we sampled with trawl and throw trap were Myriophyllum, Vallisneria americana, and Potamogeton spp. (Table 2). Trapa natans did not occur downriver of Constitution Island.

Temperature, salinity, and dissolved oxygen varied little among sites, but there were distinct seasonal patterns in all sites in salinity and temperature (Figs. 2 and 3). No difference between bottom and surface salinity was observed. All of the sites except Liberty State Park showed salinities ranging from 0 to 11 ppt (Fig. 2). Only Liberty State Park, 38 km downriver from Piermont Marsh, had salinities up to 26 ppt in the summer. The salinity at Denning Point (RKM 92) never rose higher than 5 ppt (Fig. 2). In the spring, the salinity at the sites from Denning Point (RKM 92) to Croton Bay (RKM 55) were usually 0-1 ppt. Generally in August and September the salinity rose at all sites. For example, salinity at Piermont in August 1989 was 11 ppt, while at Denning Point in the same period the salinity rose to 5 ppt. At Haverstraw and Croton bays, the salinity varied from 0 ppt in the spring to 9 ppt in the fall.

Water temperature ranged from 12°C in the spring to 29°C in the summer at most sites (Fig. 3). All sites were within 2°C of each other during each sampling period. For example, Denning Point in August 1989 was 25°C, Piermont Marsh was 25°C, and Liberty State Park was 26°C. The water cooled in October 1989 and 1991 by 8-10°C to 13-15°C at all sites. Dissolved oxygen measurements varied little among sites or seasonally. Only once at Liberty State Park did dissolved oxygen levels fall below 4.5 ppm (August 1991). All other sites varied between 8.0 and 12 ppm (Table 4).

ABUNDANCE AND DISTRIBUTION

The otter trawl and throw trap are distinctly different types of sampling gear. The trawl can be inefficient, especially in structured habitats. We found that it catches larger crabs (>30 mm CW) more readily, along with other animals that are not buried in the sediment. The throw trap, on the other hand, is highly efficient (Kushlan 1981), catches animals shallowly buried in sediment, provides quantitative density estimates from shallow water, and usually captures smaller crabs (<40 mm CW).

Over the three-year period, the greatest total number of crabs (n = 369, 30% frequency of occurrence) in trawls was caught at Iona Marsh (Fig. 4). In contrast, a total of 48 crabs (4% of all trawls) were caught by trawl at the Moodna Creek site and a total of 139 crabs (11% of all trawls) were caught in Croton Bay. Denning Point had a total of 102 crabs.

There is some distinctive interannual variation in numbers of crabs collected (Fig. 5 and 6). In 1990, virtually no crabs were caught in May, June, and July in either throw traps or trawls. This is in contrast to 1989, when crabs were caught consistently throughout the sampling season in trawls and in the fall in throw traps. Crabs were more abundant in late summer 1991 as well and showed large peaks in abundance in trawls at Iona Marsh (over 185 crabs) and Constitution Island (over 40 crabs) in the fall. Very high densities (up to $120/m^2$ at Haverstraw Bay) of small juveniles occurred in late summer 1991 in throw traps; in 1989 and 1990 densities in throw traps never exceeded $5/m^2$. Seasonal variation in abundance is evident as well, although it is less pronounced than the variation between years (Fig. 5 and 6). In general, crabs were less abundant in upriver sites in the spring, demonstrated by density of $0/m^2$ in throw traps and only 0-2 crabs caught by trawls at any site upriver of Croton Bay. At Piermont Marsh, the southernmost trawl site, crabs appear earlier in the season.

The most outstanding seasonal pattern in abundance is the appearance of small juvenile crabs in August and September, especially in 1991 (Figs. 7a, 7b, 7c, 7d, 7e). In that year, large numbers of early stage juvenile crabs (3-5 mm CW) were sampled in most of the throw trap sites in August except Iona Marsh and Moodna Creek. Denning Point was not sampled with the throw trap in 1991. Liberty State Park, Piermont Marsh, Croton Bay, Haverstraw Bay, and Constitution Island showed very high average densities of crabs ranging from $6/m^2$ at Liberty State Park to $38/m^2$ at Haverstraw Bay (Fig. 6). At Haverstraw Bay, some throw trap samples had as many as $100/m^2$. By September and October, crab density in throw traps dropped for all years. For example, density in throw traps at Haverstraw Bay in September was $16/m^2$ and $2.3/m^2$ at Liberty State Park. Very small crabs (<15 mm CW) did not appear in throw traps at Moodna Creek in 1991 until September ($9.7/m^2$) (Fig. 6 and 7). In 1989 and 1990, the influx of small juveniles was not as great, but was observed in changes in throw trap densities in August, and in differences in mean size (CW) in July, August, and September (Table 5).

The trawl samples confirm this seasonal increase in abundance in the late summer and fall. Trawls (four each period) at Iona Marsh caught over 185 crabs in September and 125 crabs in October 1991, most of which were small juveniles (15-40 mm CW). Numbers of crabs dropped, in general, in the late fall, although crabs were still abundant in November 1989 at Iona Marsh, and relatively abundant at most sites in October 1991. This greater abundance of crabs in the fall of 1991 was reflected later in abundances at most sites in June 1992 where numbers were significantly higher than in either June 1990 and June 1991.

There was not an outstanding difference in abundance or distribution of males and females among the sampling sites (Fig. 9). The sex ratio of crabs from the combined trawl and throw trap collections at each site fluctuated close to 1:1, although usually slightly more male crabs were caught. There was a slight trend for a greater proportion of the individuals to be female (0.53) in the downriver sites (Fig. 10).

HABITAT UTILIZATION

Vegetation was present seasonally at most of the trawl and throw trap sites (Table 2). Vallisneria americana was the most common, occurring at most sites from Piermont Marsh to Denning Point. Trapa natans occurred from Constitution Island to Denning Point, although it was not often sampled because access to these sites was difficult. Myriophyllum occurred from Croton Bay to Denning Point. Vallisneria occurs as meadows or large patches of dense shoots. Myriophyllum, on the other hand, grows in slightly deeper (2-4 m) water, and is patchily distributed, and arises from a single stem.

Crabs occurred at similar abundance levels in vegetated and unvegetated habitats in most years. In 1989 and 1990 when crab abundance was relatively low, there were no clear differences in densities in vegetated and unvegetated throw trap samples. In 1991, however, differences became apparent and in most sites there were greater densities of crabs inside vegetated compared with unvegetated areas (Fig. 8). Outstanding differences were apparent at Constitution Island in August 1991 where average density of crabs was $22/m^2$ in Vallisneria and $2/m^2$ in unvegetated adjacent mud areas. At Liberty

State Park, the dominant vegetation available for throw trapping was Ulva lactuca. When it was possible to sample in the Ulva, the densities of crabs were no greater than in surrounding unvegetated sediment. At Haverstraw Bay, the dominant vegetation sampled by throw trap for crabs was Myriophyllum. In September 1991, Myriophyllum had lower average densities ($10/m^2$) of crabs than adjacent sand ($22.3/m^2$), but in August 1991, the situation was reversed and Myriophyllum throw traps had much higher densities of crabs than unvegetated sediment. At Croton Bay in 1991, throw traps in Vallisneria always contained more crabs than unvegetated habitat.

The trawl samples suggest that more crabs reside in vegetated areas and that larger crabs occur more frequently in unvegetated areas. Quantitative comparisons with the trawl are impossible, in part because of low efficiency of the trawl, but also because it is impossible to know the exact character of the habitats in the path of the trawl. We do know, however, that trawl sites such as Nyack and Haverstraw Bay are unvegetated, and that sites such as Croton Bay, Iona Marsh, and Constitution Island are heavily vegetated. With that in mind, there was a general pattern of smaller crabs (<50 mm CW) that occurred in the heavily vegetated trawl sites and large crabs (>100 mm CW) most often occurred in unvegetated trawl sites. The largest numbers of crabs caught in trawls also occurred in heavily vegetated sites (eg. Iona Marsh, Croton Bay, Constitution Island) (Fig. 4). No trawls were taken at Liberty State Park, so we do not know the abundance pattern of large crabs at that site.

PREDATION ON JUVENILES

Tethering experiments in both 1990 and 1991 found higher rates of predation in unvegetated sediment compared with areas vegetated with either Myriophyllum or Vallisneria (Fig. 11). Quite surprising were the differences between years (1990 and 1991) in predation rates in all of the habitats. At the Croton Bay site mortality nearly doubled in the unvegetated areas, and tripled in the Vallisneria from 1990 to 1991. Predation rates were higher in Myriophyllum (17.1%) compared with Vallisneria (9.4%) in the Haverstraw Bay site in 1990. There were no significant differences in the size distribution of crabs tethered and those that were eaten, although a slightly greater proportion of smaller crabs (<15 mm CW) were eaten than large (Fig. 12).

Gut content analysis of fishes caught in trawls in August 1991 at Croton Bay, Iona Marsh, and Constitution Island found that Morone americana, M. saxatilis, Fundulus diaphanus, Cynoscion regalis, and Trinectes maculatus consumed juvenile blue crabs (Table 6). These collections were made in the sites in which we found the highest densities of small juvenile blue crabs. Seven M. saxatilis individuals (5.5%) were found to have consumed blue crabs, and four M. americana individuals (2.9%) had blue crabs in their guts. Morone spp. occur in most of the sites sampled, and are quite abundant in some sites (Fig. 13). They consumed crabs in each of the sites where gut contents were analyzed (Table 7). The average size of the crabs in the guts of all fishes was 5 mm CW. All of the other fish species that were collected at these sites (see Appendix Tables) did not contain blue crabs.

DISCUSSION

The abundance of blue crabs in the lower Hudson River is quite variable annually, and shows seasonal variation in distribution and abundance. But in general, the density of crabs in shallow water in the Hudson is comparable with shallow water densities measured in southern New Jersey eelgrass meadows (Wilson et al. 1990a). However, crab density in the Hudson is much lower than in Chesapeake Bay, where, although variable, the density of crabs in eelgrass meadows ranges from 3 to 90/m^2. The pattern of appearance of very small (<5 mm) juveniles in the lower Hudson is very similar to that observed in other systems, including southern New Jersey, Delaware Bay, South Carolina, and Chesapeake Bay (Orth and van Montfrans 1987, Epifanio et al. 1984, Mense and Wenner 1989, Wilson et al. 1990a). In this study, we did not examine larval transport or megalopal recruitment to high salinity portions of the estuary, but the pattern of appearance of juveniles is consistent with reports from the Chesapeake Bay, Charleston Harbor, and southern New Jersey. Thus, mechanisms similar to those that operate elsewhere on the east coast probably affect recruitment of post-larvae to the Hudson estuary. Water temperature, wind direction, waves, and storm events have all been proposed as important factors in the return of blue crab post-larvae to an estuary (Epifanio et al. 1984, Johnson et al. 1984, Johnson 1985, Goodrich et al. 1990). For the Hudson estuary, factors that affect post-settlement (ie. after megalopae and juveniles have come into the estuary and become benthic) survival such as physical characteristics of the estuary, predation, and habitat availability may be the most important considerations for explanation of variation in abundance and distribution.

One of the important factors may be the availability and amount of shallow water (<5 m) habitats in the system. The Hudson River is a narrow, deep drowned valley with little shallow water (Limburg et al. 1986). Other ares that exhibit high abundance of blue crabs have large expanses of shallow water, often vegetated, and relatively undisturbed shoreline with marshes and tidal creeks (Orth and van Montfrans 1990). Blue crab abundance in the Hudson may be partially dependent on the lack of large areas of shallow water habitat that act as nursery and feeding grounds, and molting habitat (Hines et al. 1987).

The physical characteristics of the water and the seasonal and annual variation in those characteristics are also important influences on crab distribution and abundance. The physical factors we measured (salinity, temperature, and dissolved oxygen) varied seasonally and generally confirm reports by other Hudson River investigators on range and location (Mancroni et al. 1992, Limburg et al. 1986). The salinities in the Hudson (RKM 0-97) are, on average, much lower than those reported from other blue crab studies. For example, in southern New Jersey, the salinity in Little Egg Harbor and Great Bay fluctuated around 25 ppt (Wilson et al. 1990a).

Within the range of salinities in the 97 kilometers of the river that we sampled there was no distinct pattern of crab abundance associated with salinity. There was a slightly greater proportion of females at downriver (seasonally higher salinity) sites, but we suspect we would have found even more adult females in areas with higher salinity, such as lower New York Harbor and Raritan Bay, as seen for other populations on the east coast (Van Engel 1958, Tagatz 1968, Archambault et al. 1990). An interesting trend we observed in 1991 was that of small juveniles moving upriver into very low salinities (0-2 ppt) during the fall. Archambault et al. (1990) reported from a trawl study in and near Charleston Harbor, South Carolina that small crabs moved into lower salinity (0-10 ppt) habitats, while large (>125 mm CW) were more abundant at high salinity (26-30 ppt). There is some evidence that juvenile crabs grow more per molt when in warm, low salinity water (23°C, 3 ppt) (Cadman 1990). It is not known if juvenile blue crabs actually seek out and migrate to low salinity water.

Seasonal variation in water temperature may explain some of the observed distribution patterns in the Hudson, and it may also contribute to interannual variation in abundance of both juveniles and adults. The blue crab in the Hudson River is in the northern portion of its range (Williams 1984) where the average water temperature is 0-3°C in January and February (Wells and Young 1992, Mancroni et al. 1992). Thus, overwintering mortality may be an important factor affecting variation in crab abundance. Crab density and numbers of crabs in trawls were always lower in spring samples relative to the previous fall collections. A similar pattern was observed in southern New Jersey, where spring crab density was 0-0.9/m^2, and in the previous fall densities ranged from 0.9 to 1.5/m^2. In extreme winters, blue crabs may suffer higher mortality, and reduce abundance of crabs for the following year. We also observed that fewer crabs were collected in upriver sites in the spring, while they were collected at downriver sites such as Piermont Marsh. In Chesapeake Bay, large adults overwinter in high salinity areas near the mouth of the estuary (Schaffner and Diaz 1988), but there is no information available on overwinter survival rates in cold temperature/low salinity conditions. We do not know if crabs migrate downriver in the late fall, or if the reduced numbers of crabs upriver in the spring is due to winter mortality.

Predation on small juveniles may be an equally important source of mortality to the Hudson River blue crab population. Predation rates in the Hudson were within the range (21% mortality in eelgrass; 45% in unvegetated sediment) found in eelgrass meadows and unvegetated sediment in southern New Jersey (Wilson et al. 1990b). The lower rates of predation in the vegetation relative to the unvegetated habitat adds more support to the growing body of evidence that vegetation provides a predator refuge for epibenthic animals (Heck and Wilson 1987, Wilson et al. 1987, Barshaw and Lavalli 1988, Wilson et al. 1990b) and that vegetated habitats perform important nursery functions (Heck and Thoman 1984, Orth et al. 1984).

Many other factors may enter into predation rates and variation in predation. We found that predation rates varied between the two types of vegetation, Myriophyllum and Vallisneria. Myriophyllum was not as effective a refuge as Vallisneria for juvenile blue crabs. This may be due to the differences in the growth form of the two species. At the sediment surface where blue crabs bury (Barshaw and Able 1990), Myriophyllum does not form dense aggregations, but instead grows from a single stem, and these stems may be 6 cm or greater apart. Vallisneria, on the other hand, often grows in the form of a meadow, with shoots growing very close together, forming dense patches. Vallisneria may be a better refuge because of this dense aggregation, providing more places to hide. Its structural complexity may also decreases predator encounter rates and capture efficiency (Main 1987).

Predation rates in all of the habitats tested may be prey-density dependent. We found that predation rates in the three habitat types showed remarkable increases from 1990 to 1991. Crab density in September 1991 at Croton Bay and Haverstraw Bay (tethering sites) was 25 times higher than in 1990 at the same time. Fish predators (eg. Morone americana, M. saxatilis) may form behavioral search images for small juvenile blue crabs when they become more common, and through a predator functional response more crabs are consumed. Cannibalism may also play a role. The greater density of blue crabs, including many that had grown to over 20 mm CW, may have contributed to increased predation rates on the smaller individuals. Thus, predation rates may be density dependent, so that in periods of high recruitment of crabs to the estuary, proportionately greater numbers of crabs are preyed on, reducing the contribution of the new recruits to the population.

The incidence of blue crabs in fish guts was not very high, and this may indicate that fish predators are not important to the crab population. On the other hand, both Morone americana and M. saxatilis are extremely common (Fig. 13, Appendix Tables 1-10; Wells et al. 1992, McKown and Young 1992) and, when young, utilize shallow vegetated areas in the river and tributaries (Dovel 1992, Wells et al. 1992). At such high numbers they may have an impact on juvenile blue crab density. M. saxatilis may be the more important predator because the young of the year are abundant in the lower parts of the river close to the salt wedge (Dovel 1992), and would thus overlap with the smallest recruiting juvenile crabs in shallow downriver sites.

The patterns of crab distribution and abundance that emerge from this study seem to be most associated with habitat type and distance upriver. In general, more crabs were found in shallow water vegetated habitats than unvegetated sites. For example, Croton Bay, Iona Marsh, and Denning Point had some of the greatest abundances of blue crabs (and fishes). All three of these areas were heavily vegetated where we trawled, especially with Vallisneria americana, Myriophyllum sp., and in the spring Potamogeton spp. Juvenile crabs in some sites occurred in greater densities in vegetation, although this was not always true. Orth and van Montfrans (1987), working in Chesapeake Bay, found much higher densities of juvenile crabs in eelgrass habitat than in unvegetated sediment, but Wilson et al. (1990a) found juveniles (at very low density) to be more evenly distributed among habitats in southern New Jersey estuaries. In the Hudson, crabs may enter the estuary and settle and utilize the first available, and limited, shallow water habitats.

The occurrence of the smallest and earliest stage crabs downriver and larger crabs upriver suggests that influx of post-larvae is from the New York Bight or Raritan River estuary, with subsequent settlement in the lower river. The juveniles then move steadily upriver as they grow. Our data show that the earliest crab stages (<5 mm CW) appear only as far as Constitution Island. In August 1991, we found no very small juveniles in samples at Moodna Creek, but in September, larger juveniles (10-25 mm CW) were collected there. Recruiting juveniles may also stop at some downriver vegetated shallow water sites such as Croton Bay, feed, molt, and then move further upriver. Thus, we observe the pattern of larger juveniles appearing at upriver sites in September and October. Crabs may also use vegetated tributaries (eg. Croton River) as nursery habitats, although we have no data to support this idea.

In conclusion, this study demonstrates the importance of shallow, vegetated habitats for the survival of blue crabs. These habitats provide settling ares for recruiting juveniles and refuge from predation. Habitat type and distance upriver seem to be the best predictors of distribution and seasonal abundance. Salinity and distance upriver are, of course, correlated. However, between Piermont Marsh and Denning Point the salinity changes very little (0-6 ppt) and yet we found some distinctive upriver patterns in seasonal abundance and distribution. Biological factors such as predators and vegetation type, which are also heavily influenced by salinity gradients, may be of more importance to the blue crab population than salinity. There is tenuous evidence from Chesapeake Bay that larval recruitment level influences adult stock in later years (Lipcius and van Engel 1990). However, in the Hudson River it may be that within a certain range of recruitment levels, other factors such as habitat availability and quality, predation, and overwintering may most strongly influence success and growth of the blue crab population.

Compared with Chesapeake Bay, the Hudson River has very few shallow, vegetated habitats so there may always be high post-settlement mortality of blue crabs because of limitations in appropriate habitats. There is no way to restore the bulkheaded and dredged regions of the lower Hudson, but other shallow water areas like Croton Bay, Iona Marsh, Constitution Island and Denning Point appear to be critical nursery habitats for blue crabs (as well as many fish species), much like the Chesapeake Bay eelgrass meadows, and need to be preserved for that function (see Buckley 1992).

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