JUVENILE BLUE CRAB, *CALLINECTES SAPIDUS*, SURVIVAL: AN EVALUATION OF EELGRASS, *ZOSTERA MARINA*, AS REFUGE

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ABSTRACT

Field experiments were conducted to examine rates of predation on juvenile blue crabs in different densities of eelgrass near Manahawkin, New Jersey. Tethering experiments from July to October 1985 showed that crabs in eelgrass were preyed on at lower rates than those in adjacent bare sand patches. In addition, intermediate densities of eelgrass provided the best refuge for blue crabs while crabs in low- and high-density eelgrass suffered higher rates of predation. We suggest that the root mats of high-density eelgrass may reduce the ability of blue crabs to hide and bury in the substratum. There was no effect of prey size (11-100 mm carapace width) on risk to predation. Predation on sand substrate declined during the observation period and rates dropped to zero in vegetation in October.

The blue crab, *Callinectes sapidus*, is one of the most important commercial species in mid-Atlantic coastal waters of the United States (Van Engel 1958; Williams 1984). Blue crabs are caught in abundance from Florida into New Jersey waters, and are taken in lesser numbers as far north as Nova Scotia (Williams 1984). Although the Chesapeake Bay system produces the greatest catches of blue crabs, commercial and recreational fishing is significant in many other Atlantic bays and estuaries.

Despite the economic importance of blue crabs and the large amount of prior research done on this species, there are many unanswered questions about the factors that influence blue crab abundance and distribution (Williams 1984), and our ability to predict annual harvests is extremely limited. The stages of the life cycle that are least understood are the larval and juvenile stages, and it is these which suffer most nonfishing mortality.

Studies of blue crab larval transport have shown that wind-driven circulation patterns influence the abundance of larvae that enter mid-Atlantic coast estuaries (Sulkin et al. 1980; Epifanio and Dittel 1982; McConnaugha et al. 1983; Provenzano et al. 1983; Epifanio et al. 1984; Johnson et al. 1984; Sulkin 1984). In addition, we know that juvenile blue crabs in most estuaries are found in much greater abundance in stands of submerged vegetation than on unvegetated substrate (Tagatz 1968; Diaz and Fredette 1982; Kennish et al. 1982; Penry 1982; Zimmerman and Minello 1984), and it is believed that submerged vegetation provides protection from predators for small blue crabs and for crabs undergoing ecdysis (Lippson 1973; Heck and Orth 1980; Heck and Thoman 1984; Orth et al. 1984). To date no studies have demonstrated that submerged vegetation actually provides protection for juvenile blue crabs under field conditions nor do we have data on the influence of vegetation density on survival of blue crabs. Below we describe the results of a series of field experiments designed to evaluate the protective properties of varying densities of eelgrass, *Zostera marina*, for different size classes of blue crabs. We also report on the identity of potential predators and estimate the role of submerged vegetation as it influences blue crab populations in New Jersey bays.

METHODS

Tethering experiments were conducted from July to October 1985 in shallow-water seagrass meadows near Manahawkin, NJ (lat. 39°N; long. 74°W). In this area, sand patches are interspersed among extensive seagrass beds dominated by *Zostera marina* (Macomber and Allen 1979). Large numbers of blue crabs inhabit these grass beds (cf. Kennish et al. 1984), just as they do in eelgrass beds of Chesapeake Bay (Heck and Orth 1980; Heck and Thoman 1984).

Blue crabs were collected by seine or dip net from *Zostera marina* and adjacent sand patches and prepared for tethering in the laboratory. No soft crabs

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Manuscript accepted September 1986.
FISHERY BULLETIN: VOL. 85, NO. 1, 1987.

(recently molted) were used in the experiments. Tethering of crabs was accomplished by tieing one end of a 1 m long piece of monofilament fishing line around the width of the body and securing the loop with "Super" glue (cyanoacrylate) to the top of the carapace. The other end of the line was tied to a J-shaped, heavy piece of wire (or stake) which was pushed into the sediment in the chosen seagrass or sand location. The super glue ensures that crabs do not escape and that a piece of the carapace is left on the line as evidence if predation does occur. The carapace width (CW) of all crabs was measured before placement in the field. For blue crabs larger than 40 mm CW, a 20-lb test steel leader was attached to the monofilament loop around the crab to prevent the cutting of the tether by the crabs' claws. Tethering techniques measure relative rates of predation and are used for comparison of mortality among sites. It is not intended to measure absolute rates of predation in any single habitat. Heck and Thoman (1981) provided an additional description of the tethering procedure.

A single blue crab was tethered to an individual stake, and three to four stakes were placed in each plant density and in unvegetated sand patches for each 24-h trial. The tethered crabs were left at the site for 24 h (+/−1 h), recovered, and predation losses scored. Twenty trials, utilizing a total of 218 crabs, were conducted from 15 July through 7 October.

The density of the seagrass was determined frequently during the study period by measuring dry weight biomass of the grass removed from 0.062 m^2 plots. Four samples with three replicates for each sample at each density were taken, and dry weights measured after drying at 100°C.

RESULTS

Vegetation clearly provides cover from predators for blue crabs (Fig. 1) as predation was always more intense in unvegetated sand patches than in seagrass. Relative rates of predation on tethered crabs on sand ranged from 24% to a high of 74% eaten per day. A 3-way contingency table analysis (survival × density × date) found significant interactions ($P < 0.01$) between crab survival and density of vegetation. Differences in predation rates among time periods were not statistically significant, although predation rates dropped steadily on sand after the middle of August and no predation was recorded in vegetation in October (Fig. 1). The influence of body size (CW) of crabs (Fig. 2) on risk to predation was also tested in a Kolmogorov-

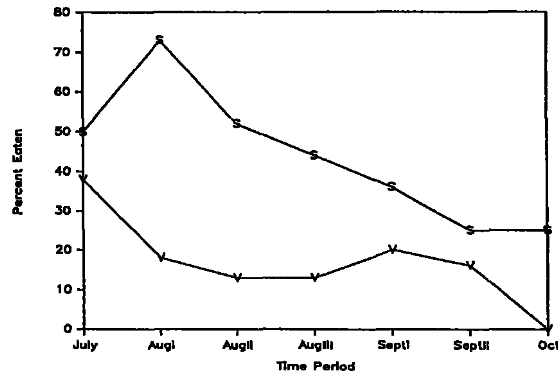

FIGURE 1.—Percent juvenile blue crabs eaten in sand (S) or vegetation (V), July to October 1985. Time period is broken into 2-3 wk periods.

Smirnov test and found not significant ($P > 0.05$).

Predation rate varied among densities of eelgrass (Fig. 3). Medium density seagrass provided the best refuge from predation with only 9% eaten per day ($N = 45$). A mean of over 19% per day was eaten in low-density ($N = 47$) and high-density ($N = 44$) grass sites. A Dunn's Multiple Comparison test (Hollander and Wolfe 1973) was used to analyze the predation-vegetation density data from July through September, excluding October because no predation occurred in eelgrass during that month. Predation rates in low and high densities were found to be significantly greater ($P < 0.05$) than in medium-density eelgrass.

Eelgrass biomass in low, medium, and high density 0.062 m^2 plots (Table 1) was found to be significantly different in a one-way analysis of variance ($P < 0.001$). Scheffé contrasts found that the mean dry weight of medium-density plots was significantly higher than low-density and significantly lower than high-density eelgrass plots.

TABLE 1.—Mean dry weights (g/0.062 m^2) of vegetation from experimental plots. **Significantly different at the $P < 0.01$ level.

Density	Mean	SD	P
Low	12.19	5.24	**
Medium	43.24	17.07	**
High	79.04	11.47	**

DISCUSSION

These data confirm results from other experimental studies of predation on decapod crustaceans (Heck and Thoman 1981; Orth and van Montfrans

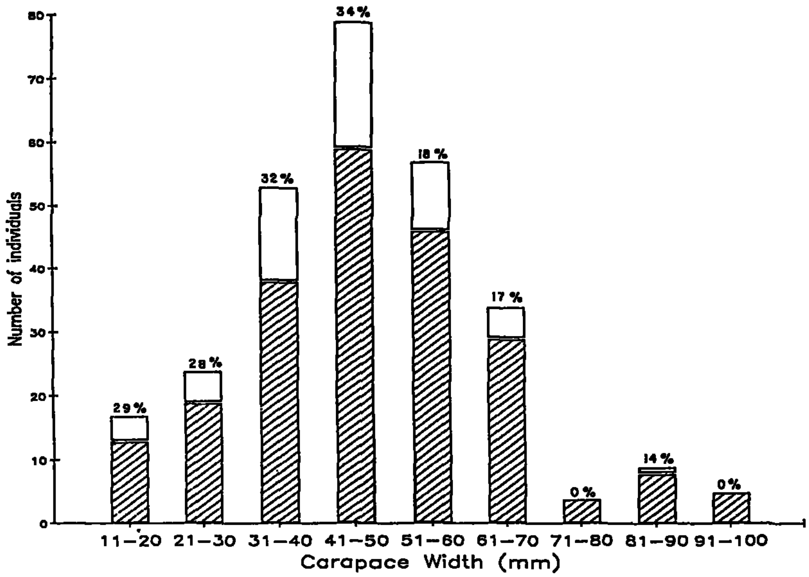

FIGURE 2.—Blue crab body size (carapace width (CW)) and risk of predation. Hatched bars indicate number of individuals tethered at that size and open bars indicate number of tethered crabs eaten.

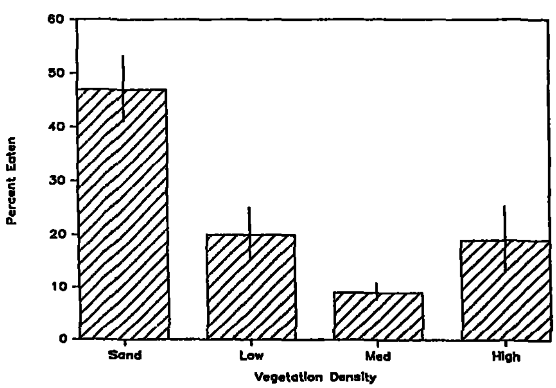

FIGURE 3.—The effect of eelgrass density on predation rates. Histograms are mean rates of predation from July through October on sand and at each eelgrass density. Vertical bars are +/– one standard error.

1982) and amphipods (Stoner 1982) that describe the importance of seagrasses as protective cover for prey. They clearly show that eelgrass provides refuge from predation and increased survival for juvenile blue crabs compared to that on adjacent unvegetated sand substrates.

Rates of predation on blue crabs within the three densities of vegetation, however, did not conform to patterns previously established, where predation on crustacean epifauna is inversely proportional to vegetation biomass (Stoner 1982; Leber 1985). In this study, risk of predation was lowest in intermediate densities rather than in high-density eelgrass.

Savino and Stein (1982) found that attack rates by largemouth bass on bluegills dramatically declined with increasing density of artificial vegetation, and capture rates by the predators were lower in vegetation than on bare substratum. Epifaunal amphipods and caridean shrimp also suffer lower rates of predation at high densities of vegetation (Nelson 1979; Stoner 1980; Coen et al. 1981; Leber 1985). These studies and others (Vince et al. 1976; Crowder and Cooper 1982; Minello and Zimmerman 1983) indicate that above-ground vegetation biomass reduces a visual predator's search and capture efficiencies and that vegetation may also provide a matching background in which epifaunal prey may hide (Endler 1978; Orth et al. 1984).

The root and rhizome mat of seagrasses may also lower search and capture efficiency of predators (Orth 1977; Blundon and Kennedy 1982b; Peterson 1982), but in addition a high-density root mat may reduce the ability of hard-bodied prey to bury and hide in the substratum. For example, Brenchley (1982) found that the burrowing ability of decapods in dense eelgrass root mats was reduced or prevented, and Bertness and Miller (1984) found that fiddler crabs, *Uca pugnax*, preferred to construct burrows in intermediate densities of salt marsh roots.

Juvenile blue crabs, unlike epifaunal caridean shrimp or amphipods, utilize below-ground refuges in seagrass beds. Our field and laboratory observations suggest that their primary mode of predator avoidance is to bury in the substratum. Orth and van Montfrans (1982) also noted burying behavior of juvenile blue crabs in laboratory experiments that examined predation by adult blue crabs in three densities of artificial seagrass and root mat. Their data also suggested mortality of juveniles is lowest in intermediate densities of seagrass.

We infer that at low seagrass densities the blue crabs are able to bury in the substratum, but the leaves and root mat of the grass do not reduce detection and capture efficiency of the predators as do intermediate seagrass densities. Furthermore, we suggest that the dense root mat and shoots of high-density seagrass may reduce the ability of blue crabs to bury themselves and that high blade density may reduce the crabs' visual ability to detect predators.

Based on our observations the dominant predators on blue crabs appear to be toadfish, *Opsanus tau*, the American eel, *Anguilla rostrata*, and other blue crabs. Toadfish are extremely common in the Manahawkin grass beds in the summer (June-September) and are known to readily consume brachyuran crabs, including blue crabs (Schwartz and Dutcher 1963; McDermott 1965; Wilson et al. 1982; Gibbons and Castagna 1985). In this study, there were instances where, upon recovery of tethers after a predation trial, toadfish had swallowed both the crab and tether and remained on the line, providing confirmation that toadfish are blue crab predators under field experimental conditions. Gut contents of American eels from the study area contained blue crabs (K. Able, pers. obs.) and Wenner and Musick (1975) found blue crabs to be a major part of the eel's diet.

Predation intensity appears to be distributed evenly over the size classes tested, although there is a trend of lower predation rates on the largest blue crabs (>71 mm CW). However, the sample size is small for these size classes ($N = 17$) so the estimate of predation on larger crabs may be inadequate. Escape in size has been observed in other invertebrate prey (Blundon and Kennedy 1982a; Peterson 1982; Wilson 1985) and a similar pattern was expected in this study because large adult blue crabs are found frequently on unvegetated substratum where risk of predation is highest (Heck and Thoman 1984). An additional large predator, the smooth dogfish, *Mustelus canis*, occurs in Barnegat Bay (Tatham et al. 1983) and we suspect it may feed on blue crabs in seagrass meadows at night (Casterlin and Reynolds 1979). *Mustelus* can grow to 1.5 m (Hildebrand and Schroeder 1928) and preys on blue crabs in eelgrass beds (Bigelow and Schroeder 1953). Hence, predation by smooth dogfish may account for loss of larger crabs and also suggests that there may be a temporal as well as spatial pattern of predation.

Researchers have suggested that the value of refuges for juvenile blue crabs and other invertebrate macrofauna is dependent on the interaction of several factors including species of vegetation, vegetation density, water quality, and type of predator (Heck and Thoman 1984; Orth et al. 1984). The data from these tethering experiments clearly indicate that eelgrass serves as protective cover and that eelgrass density is indeed an important factor in determining predation rates on juvenile blue crabs. The unexpected result that crabs in intermediate densities of eelgrass suffered lower predation rates than those in high densities underscores the complexity of the interactions that determine survival of juvenile blue crabs.

ACKNOWLEDGMENTS

Support for this study was provided by the New Jersey Department of Environmental Protection, Marine Fisheries Administration, and the Academy of Natural Sciences of Philadelphia.

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