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[Article]

Postcapture Survival and Future Reproductive Potential of Ovigerous Blue Crabs *Callinectes sapidus* Caught in the Central North Carolina Pot Fishery

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Abstract.—Harvest restrictions by sex or reproductive status are used to protect many spawning stocks. In most U.S. states, fishery regulations for blue crabs *Callinectes sapidus* require release of ovigerous crabs. Ovigerous crabs caught in pots become stressed by capture and physically damage the egg mass and remove eggs. We conducted a survey to assess the extent of egg mass damage in pot-caught crabs as well as crabs caught by hand and not subjected to pot stress. Egg mass damage was more prevalent in pot-caught crabs (>45% during all months) than in crabs caught by hand (<6% during all months). We investigated the postcapture survival, reproductive output, and larval viability of crabs with varying amounts of egg mass damage by collecting ovigerous crabs from the pot fishery and confining them in the field for the duration of their lifetimes. Over 80% of the crabs survived to release the clutch present at capture, and crabs produced up to six clutches of eggs. Of 156 clutches produced in confinement, only 1 was damaged. Crabs confined individually and fed do not experience the stress that causes egg mass damage in pots. The lipid content of early-stage eggs (77.0 ± 1.3% [mean ± SE]), larval carapace width (269.0 ± 3.34 μm), and larval survival time without food (3.0 ± 0.11 d) were similar for all clutches and levels of egg mass damage. Clutch volume decreased by approximately 20% with each subsequent clutch, and the percentage of embryos developing normally decreased from 97 ± 0.6% for clutch 1 to 79 ± 10.8% for clutch 5. Immediate release of ovigerous crabs could be a viable management strategy, but it would have severe economic consequences for fishermen in high-salinity areas. Area closures, combined with subsidies for crabbers during critical times, may be the most viable management strategy until crab populations recover from current diminished levels.

Protection of the spawning stock is a central management strategy for many commercially harvested species (e.g., Lipcius et al. 2003; Nemeth 2005; Eggleston et al. 2009; Ishida et al. 2009; Ye and Dennis 2009). Because measures taken to protect the spawning stock are based on the ecology, life history, and behavior of the species, these measures are variable among species. Harvest restrictions based on size, sex, or reproductive status are sometimes employed. When making decisions regarding harvest restrictions, managers must consider the fate of nontarget individuals caught as bycatch. Handling may cause physical damage or physiological stress to the animals as well as death (Zhou and Shirley 1995; Davis 2002; Stoner et al. 2008). Even if the nontarget individuals survive, their future reproductive output may be decreased. Knowledge of the impacts of capture and release on the survival and future reproductive output of nontarget individuals is essential for successful spawning stock protection.

Blue crabs *Callinectes sapidus* are heavily fished along the Atlantic and Gulf coasts of the United States (NMFS 2008a). Major fisheries exist from New Jersey to Texas, with each state harvesting over 1 million pounds (450,000 kg) in 2008 (NMFS 2008b). The blue crab fishery is managed on a state-by-state basis, and protection of egg-bearing (ovigerous) females is a common management strategy. Of the 12 major blue crab harvesting states, 9 prohibit the harvest of ovigerous crabs. Virginia allows the harvest of crabs with early-stage (orange) egg masses but limits the harvest of mid- (brown) and late-stage (black) egg masses to 10 per bushel from mid-March to mid-July (VMRC 2007a). Two states (North Carolina and Alabama) place no restrictions on the harvest of ovigerous crabs.

Female blue crabs mate following their terminal molt, store sperm, and produce multiple clutches of eggs over their lifetime (Hines et al. 2003; Dickinson et al. 2006; Darnell et al. 2009). Thus, all mature females should be treated as spawning stock, regardless of whether or not they are carrying an egg mass. Restrictions on harvesting ovigerous crabs protect only

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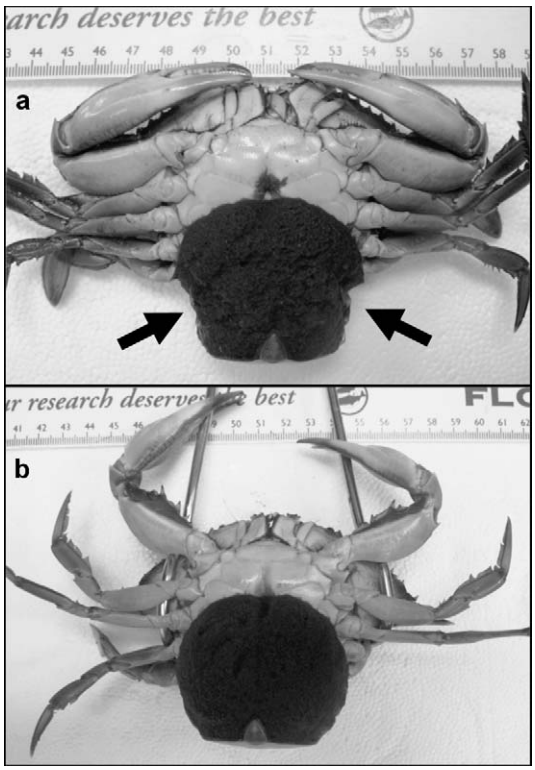

FIGURE 1.—Ovigerous blue crabs with **(a)** egg mass damage and **(b)** an intact egg mass. The locations of egg mass damage are indicated by arrows in (a). The crab in (a) would have been assigned to the low-damage group, while the crab in (b) would have been assigned to the no-damage group.

the proportion of the spawning stock that is ovigerous, however.

Ovigerous crabs are active foragers and are regularly caught in crab pots (Ballance and Ballance 2004; Rudershausen and Turano 2006). Because spawning crabs migrate to high-salinity water, they make up a large proportion of the catch in high-salinity pot fisheries (Rittschof et al., in press). In North Carolina, Ballance and Ballance (2004) observed that 27% of the total catch over 2 years in the vicinities of the Ocracoke and Hatteras Inlet spawning sanctuaries was composed of ovigerous crabs. This percentage does not include crabs between clutches of eggs. Ramach et al. (2009) examined population dynamics in a high-salinity embayment and found that during peak spawning times ovigerous females comprised 23% of the total population. If nonovigerous, mature females are included, females comprised 76% of the adult crab population (Ramach et al. 2009). In high-salinity dredge fisheries, such as the recently closed Virginia winter dredge fishery, the catch is more than 90% females (Burreson et al. 2000). A moratorium was recently placed on this fishery as an emergency measure to protect the blue crab spawning stock (VMRC 2007b).

The effects of capture on ovigerous blue crab survival and reproduction are unknown. Ovigerous crabs caught in the pot fishery often mutilate their egg masses (Dickinson et al. 2006; Figure 1). While the exact cause of egg mass mutilation is unknown, it is probably a response to the stress of confinement. Ovigerous blue crabs held individually in the laboratory have been observed to mutilate their egg masses, picking off eggs with their chelae and walking legs (R. B. Forward, Jr., Duke University; A. H. Hines, Smithsonian Environmental Research Center; and T. A. Ziegler, Everglades National Park, personal communications), especially when stressed by low oxygen levels (Rittschof, personal observation). Similar phenomena have been observed in other crab species, including the rock crab *Cancer irroratus* (S. Rebach, North Carolina Sea Grant, personal communication) and the fiddler crab *Uca subcylindrica* (Rabalais and Cameron 1983). It is also likely that at least some of the damage observed for pot-caught crabs is the result of aggressive interactions with other crabs within the pot. Dickinson et al. (2006) observed that the majority of ovigerous crabs caught in pots in July and August in Newport and North rivers of North Carolina showed signs of egg mass damage. Egg mass mutilation by crabs caught by hand was virtually nonexistent, as only 3% of hand-caught ovigerous crabs showed evidence of egg mass damage (Dickinson et al. 2006).

Even if crabs are returned to the water alive, the reproductive output from the current egg mass might be severely diminished if capture affects the eggs not killed by removal. The status of the embryos in the remaining egg mass is unknown, however. There are no data on the survival of ovigerous blue crabs caught in the pot fishery and returned to the water.

If the female crab survives, reproductive output from future clutches may be reduced due to physiological stress. Ovigerous crabs caught in pots and released experience stress in two discrete stages: while confined in the crab pots (pot stress) and after being removed from the pot but before culling and release (handling stress). The purpose of this study was to examine the effects of pot stress on egg mass damage, postcapture survival, and reproductive output among ovigerous female blue crabs. We conducted a survey in four areas to compare the extent of egg mass damage in crabs caught in the pot fishery with that in crabs caught by hand. To compare postcapture survival, reproductive output, and larval viability of pot-caught females with varying amounts of egg mass damage, ovigerous crabs

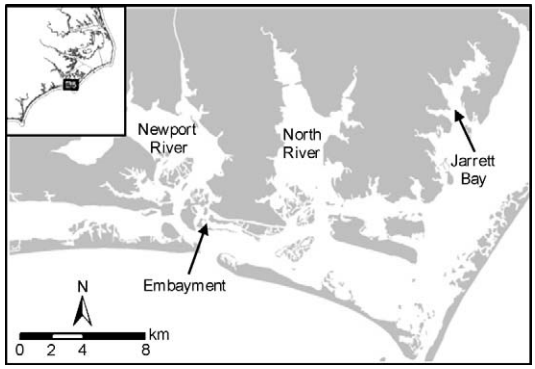

FIGURE 2.—Locations of the sampling sites for the survey of egg mass damage among blue crabs.

were collected from the pot fishery and confined individually in the field for the remainder of their lifetime.

Methods

Survey of egg mass damage.—To assess the frequency and extent of egg mass damage, we conducted surveys of ovigerous crabs in four areas in North Carolina from May to September 2002: (1) a high-salinity embayment within the Rachel Carson National Estuarine Research Reserve at Beaufort (34°42.64′N, 76°40.37′W), (2) Jarrett Bay (34°46.84′N, 76°29.79′W), (3) the Newport River (34°45.56′N, 76°41.50′W), and (4) the North River (34°45.55′N, 76°36.26′W) (Figure 2). The Rachel Carson embayment served as the control site; here ovigerous crabs were collected individually by hand at night using dip nets. At the three remaining sites, ovigerous crabs were collected from commercial crab pots with the assistance of local commercial crabbers. Upon capture, each female's egg mass was visually examined and classified into one of four categories of damage based on the percentage of the egg mass remaining: no damage (100% remaining), low damage (75–99%), moderate damage (50–74%), or high damage (<50%). Deviation from the characteristic smooth, rounded shape of an intact, undamaged egg mass was used to estimate the amount of damage to the egg mass. Damaged masses are ragged or pitted where the female has pinched and pulled off parts of the egg mass with her chelae (Figure 1).

Data were grouped by site and month. Sampling of all four areas did not occur each month. Only during July were all four sites sampled (Figure 3); thus, only data from July were used in comparisons of sites. A chi-square test (Sokal and Rohlf 1995) was used to test the null hypothesis that the proportion of crabs with visible egg mass damage was similar among the four sites, followed by pairwise chi-square tests using the Dunn–Sidak correction (Sokal and Rohlf 1995).

Field confinement study.—The second objective of this study was to assess the survival and future reproductive potential of ovigerous crabs caught in the pot fishery. During the summers of 2007 and 2008, 79 ovigerous blue crabs were sampled from the North River pot fishery with the assistance of Ray Golden, a local commercial crabber. In 2007 sampling occurred from July to September, while in 2008 sampling occurred from April to July. After each crab pot was hauled and emptied, ovigerous crabs were culled from the catch and measured for carapace width. Each female was assigned an egg damage category and tagged with an individually numbered plastic tag attached with 18-gauge plastic-coated copper wire wrapped around the large lateral spines. Crabs were placed into 18-cm × 13-cm × 9-cm plastic containers containing approximately 3 cm of ambient estuarine water from the collection site and transported in a cooler to the Duke University Marine Laboratory. Crabs remained in the cooler for 1–3 h, depending on when they were captured during the collecting trip.

On arrival at the laboratory, crabs were confined individually in a high-subtidal area in plastic minnow traps buried halfway into the sediment on their long axis (adapted from the method used by Dickinson et al. 2006). Crabs were fed frozen seasonal fish and shrimp daily when water temperatures were above 14°C and monitored twice weekly for the presence of eggs until their death.

Each clutch was measured and its volume was calculated as the product of the length (anterior–posterior), width (left–right), and depth (dorsal–ventral) of the egg mass. Clutch viability and larval fitness were assessed using five measurements: (1) the lipid content of early-stage eggs, (2) the percentage of embryos developing normally, (3) egg size, (4) larval size, and (5) larval survival time without food. Lipid content was determined using the colorimetric sulfo-phosphovanillin method for extracting and quantifying total lipids (Barnes and Blackstock 1973). Preweighed samples of early-stage eggs (>50% yolk; stages 1–4 of DeVries et al. 1983) from each clutch were lyophilized, lipids were extracted and quantified, and the percentage of lipids by weight was determined based on the dry mass of the egg sample.

The percentage of embryos developing normally (percentage normal development) and egg size were assessed for late-stage eggs (stages 8–9 of DeVries et al. 1983). Four samples of 20 eggs each, one from each quadrant of the egg mass (based on anterior–posterior and left–right division of the egg mass), were assessed

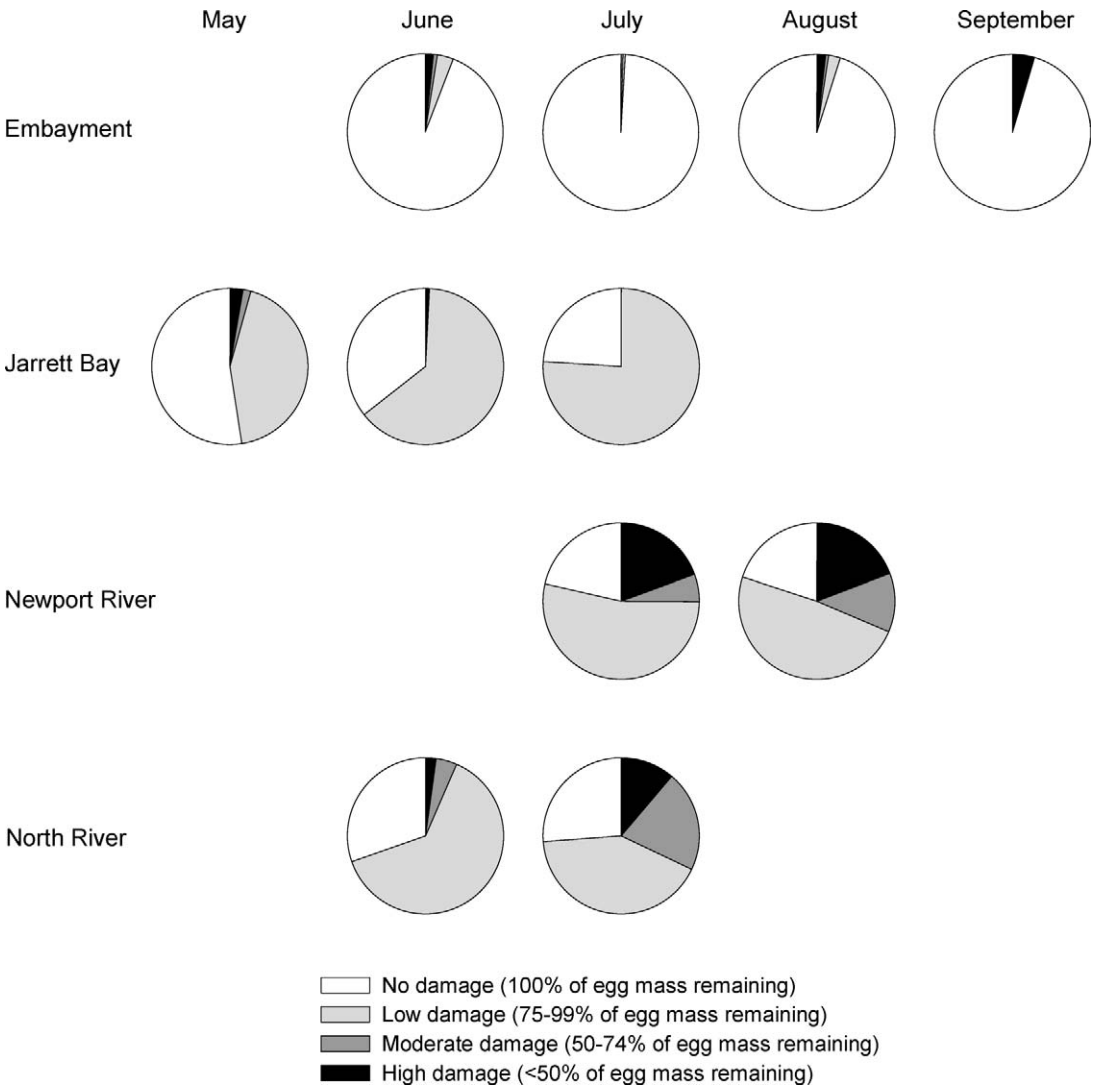

FIGURE 3.—Relative amounts of egg mass damage at capture at the four sampling sites during the 2002 survey, by site and sampling month.

for normal development using an inverted light microscope. Eggs were examined and the percentage of each sample developing normally was determined. Embryos were classified as normal if they were in the appropriate stage of development based on the classification of DeVries et al. (1983). Eggs and embryos that were not classified as normal included eggs that did not begin development and embryos that began development but ceased it at an earlier time. Egg diameter was measured using an inverted light microscope fitted with an ocular micrometer and was assessed for four samples of 20 eggs per clutch, one sample from each quadrant of the egg mass. Only eggs containing normally developing embryos were measured. All measurements were taken 48–8 h before hatching.

Larval size and the duration of larval survival without food were measured to assess larval viability. Approximately 1–2 d prior to hatching, crabs were removed from the field cages and placed individually into buckets containing approximately 6 L of aerated ambient seawater until larval release occurred. For crabs held in buckets for more than 24 h, water was changed daily. Within 6 h of larval release, 30 stage-1 zoeae from each clutch were collected. Carapace width, (measured between the tips of the lateral spines) was

determined for 20 stage-1 zoeae from each clutch. Additionally, 10 stage-1 zoeae were placed individually in test tubes containing 20 mL of aged seawater filtered to remove particles greater than 1 μm. The tubes were stored in metal racks, loosely covered with plastic wrap, and maintained at 25°C with a 12 h light : 12 h dark cycle. Larvae were not fed and were observed every 12 h for swimming ability by capping and inverting tubes to elicit swimming. Preliminary experiments indicated that once the zoeae ceased swimming under these conditions death typically followed within 12 h. Time until swimming ceased was used for all analyses.

Adult postcapture survival time was calculated as the time from capture until death. We compared survival times among egg mass damage categories using a nonparametric Kruskal–Wallis analysis of variance (ANOVA), as the data were not normally distributed. Adult survival was also examined for three time periods: until release of the first clutch, to oviposition of a second clutch, and to oviposition of a third clutch. The proportions of crabs in each damage category were compared within each time period using a chi-square test (Sokal and Rohlf 1995) to determine whether the level of egg mass damage present at capture affected survival. Survival was also examined within egg mass damage categories, comparing the three time periods using a chi-square test. Clutch viability and larval fitness were analyzed using ANOVA and generalized linear mixed models (GLMMs; Schall 1991; Breslow and Clayton 1993). The effects of level of egg mass damage on each measurement were assessed using ANOVA. If the assumptions of normality and homogeneity of variance were not met, the nonparamatric Kruskal–Wallis ANOVA was used. A separate ANOVA was fit for each measurement, followed by Holm–Sidak multiple comparison tests when statistical significance was indicated. Each measurement was assessed for the first clutch to determine the direct effects of pot stress on the clutch present at capture. Subsequent clutches were analyzed separately to assess the indirect effects of pot stress on future clutch production. For all analyses, the level of egg mass damage represents the level recorded at capture. Analyses of variance and multiple comparison tests were conducted in SigmaPlot 11 (Systat Software, San Jose, California).

Separate GLMMs were fit for each measurement to assess the effects of clutch number and crab size. For each GLMM, the measurement was used as the response variable, clutch number and adult female carapace width were set as fixed effects, and crab number was set as the random effect to account for the repeated measurement on each crab with each successive clutch. Models were simplified to the most parsimonious model possible without significant loss of explanatory power. The GLMM analyses were conducted in R version 2.8.1 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Survey of Egg Mass Damage

A total of 3,805 ovigerous crabs were surveyed for egg mass damage during the summer of 2002. Egg mass damage was observed during each sampling month at all sites and generally occurred more frequently during the warmer months (Figure 3). The percentage of crabs showing some level of egg mass damage ranged from 0.3% in the Rachel Carson embayment during July to 80% in the Newport River in August (Figure 3). During the month of July, the proportion of crabs with damaged egg masses varied significantly among sites (χ^2 test; $P < 0.001$). The proportion of crabs with damaged egg masses was significantly greater at the three pot-fishery sites (Jarrett Bay, the Newport River, and the North River) than in the Rachel Carson embayment, where crabs were caught by hand (χ^2 tests; $P < 0.001$). The proportion of crabs with damaged egg masses was similar among the three pot-fishery sites (χ^2 tests; $P > 0.05$).

Field Confinement Study

A total of 79 ovigerous females were collected from the pot fishery in 2007 and 2008. Of these 79 crabs, 21 (26.6%) had intact egg masses, 22 (27.8%) had 75–99% of the egg mass remaining and were placed in the low-damage category, 15 (19.0%) had 50–74% of the egg mass remaining and were placed in the moderate-damage category, and 21 (26.6%) had less than 50% of the egg mass remaining and were placed in the high-damage category. Crabs were selected to provide relatively equal sample sizes in each category. Thus, while 73.4% of the crabs used in this study showed some signs of damage upon capture, there is no relation to the proportion of damage in the population at that time.

Females collected from the pot fishery survived up to 321 d after capture. Survival time averaged 99.6 d (SE, 14.3 d) and did not vary with level of egg mass damage (Kruskal–Wallis ANOVA; $P = 0.784$). Crabs survived to produce up to six clutches after capture. Of the 156 total clutches produced in confinement, only 1 clutch (0.6%) showed any evidence of egg mass damage. Most crabs (81%) survived until hatching of their first clutch (Figure 4). The proportion of crabs surviving to release their first clutch was not significantly related to egg mass damage category (χ^2

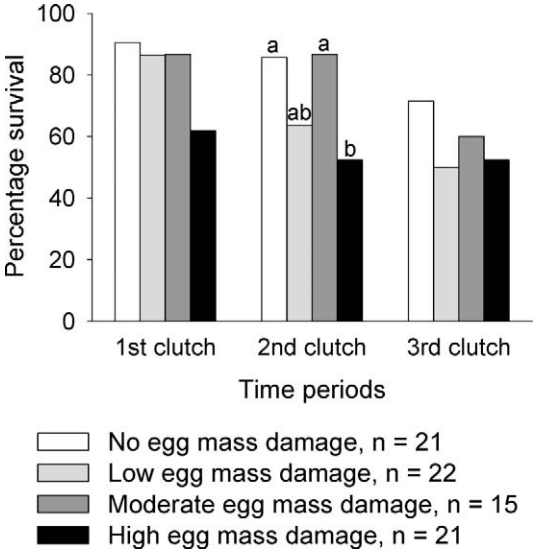

FIGURE 4.—Percentages of blue crabs surviving to release the clutch present at capture, to produce a second clutch, and to produce a third clutch, by extent of egg mass damage at capture. Different letters above the bars indicate statistically significant differences ($P < 0.05$).

test; $P = 0.074$). A total of 71% of all crabs collected survived to produce a second clutch of eggs; the proportion of crabs surviving to produce a second clutch was significantly related to egg mass damage category (χ^2 test; $P = 0.044$), with fewer of the high-damage crabs surviving to produce a second clutch than crabs with either no damage or moderate levels of damage at capture. A total of 58% of all crabs, including 52% of the crabs with highly damaged egg masses, survived to produce a third clutch of eggs. The proportion of crabs surviving to produce a third clutch was not significantly related to damage category at capture (χ^2 test; $P = 0.448$). Survival only varied among the three time periods examined for crabs collected with low egg mass damage (χ^2 test; $P = 0.035$); the relationship between time period and the proportion of crabs surviving was not significant for crabs with no, moderate, or high egg mass damage (χ^2 test; $P > 0.05$).

Lipid content was not analyzed in relation to the level of damage for clutch 1, as lipid data were not available for crabs captured with mid- or late-stage egg masses. The lipid content of early-stage eggs from subsequent clutches averaged 77.0% (SE, 1.3%) of dry egg weight (Figure 5a). Lipid content was independent of clutch number (GLMM; $P = 0.675$), carapace width

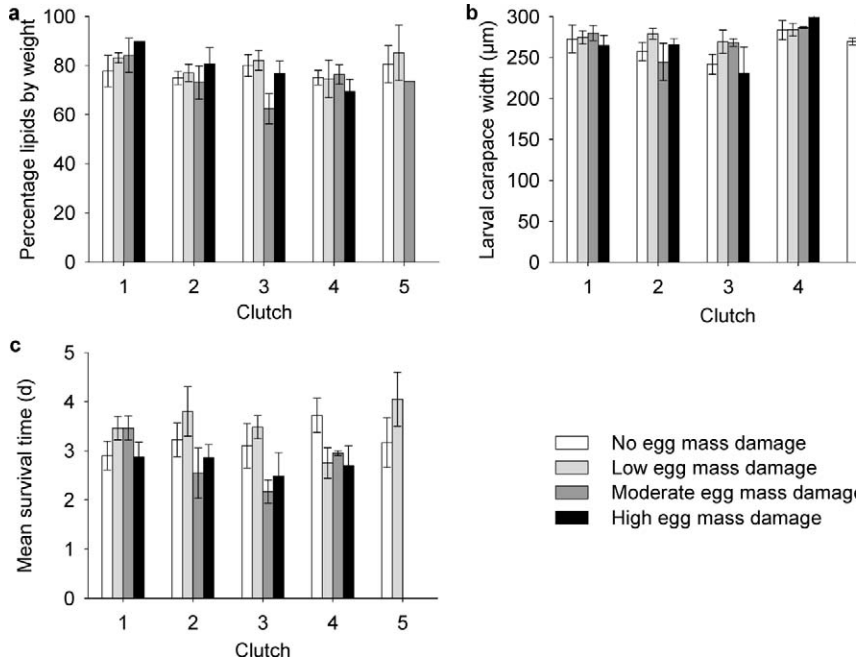

FIGURE 5.—Three predictors of clutch viability and larval fitness—**(a)** percentage lipids by weight, **(b)** larval carapace width, and **(c)** mean larval survival time without food—by clutch and extent of egg mass damage at capture. Error bars indicate SEs.

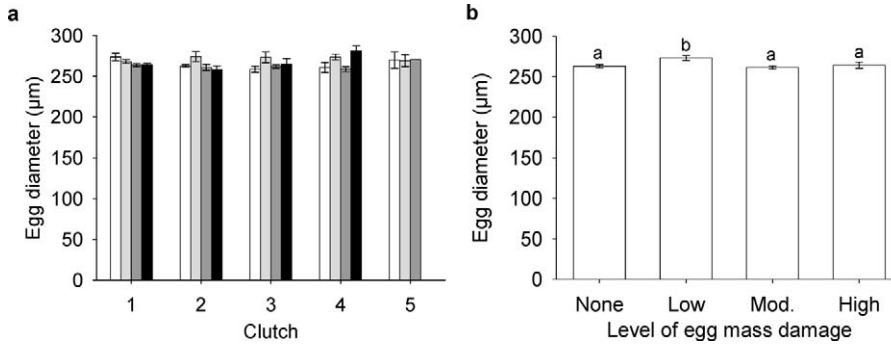

FIGURE 6.—Mean egg diameter **(a)** for clutches 1–5 by the extent of egg mass damage at capture and **(b)** by damage category averaged over all clutches. Error bars indicate SEs; different letters indicate statistically significant differences ($P < 0.05$).

(GLMM; $P > 0.657$), and the level of egg mass damage (ANOVA; $P = 0.157$).

Larval carapace width averaged 269.0 μm (SE, 3.34 μm; Figure 5b). Larval carapace width was independent of clutch number (GLMM; $P = 0.299$), carapace width (GLMM; $P = 0.109$), and the level of egg mass damage for all clutches (Kruskal–Wallis ANOVA; $P = 0.307$ for clutch 1, $P = 0.434$ for subsequent clutches).

Duration of larval survival without food averaged 3.0 d (SE, 0.11 d; Figure 5c). Duration of larval survival was independent of clutch number (GLMM; $P = 0.498$), carapace width (GLMM; $P = 0.700$), and the level of damage for all clutches (Kruskal–Wallis ANOVA; $P = 0.379$ for clutch 1, $P = 0.430$ for subsequent clutches).

Egg diameter averaged 266.4 μm (SE, 1.0 μm) and was independent of both carapace width (GLMM; $P = 0.142$) and clutch number (GLMM; $P = 0.705$) (Figure 6a). For clutch 1, egg diameter was independent of the level of egg mass damage present at capture (Kruskal–Wallis ANOVA; $P = 0.306$) but varied significantly among damage categories for subsequent clutches (ANOVA; $P = 0.007$). Crabs with low levels of damage produced significantly larger eggs after the initial clutch than did crabs with no damage, moderate damage, or high damage (Holm–Sidak multiple comparison test; $P < 0.05$; Figure 6b).

The percentage of embryos developing normally averaged 89.3% (SE, 1.9%; Figure 7a) and was independent of female carapace width (GLMM; $P = 0.3845$). Clutch number was a significant predictor of the percentage developing normally (GLMM; $P < 0.001$), with earlier clutches having a greater percentage of normally developing eggs than later clutches (Figure 7b). The percentage of embryos developing normally was independent of the level of damage for both clutch 1 (Kruskal–Wallis ANOVA; $P = 0.379$) and subsequent clutches (Kruskal–Wallis ANOVA; $P = 0.430$).

Because the volume of clutch 1 was related to the level of damage, which reduced the volume of the egg mass, clutch volume data from this clutch were not analyzed. Clutch volume for subsequent clutches averaged 19.3 cm^3 (SE, 0.9 cm^3). Clutch number was

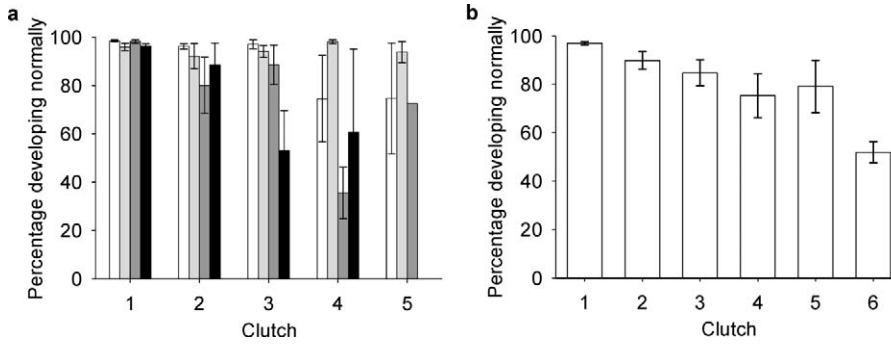

FIGURE 7.—Percentage of embryos developing normally **(a)** for clutches 1–5 by the extent of egg mass damage at capture and **(b)** for clutches 1–5 averaged over all damage categories. Error bars indicate SEs.

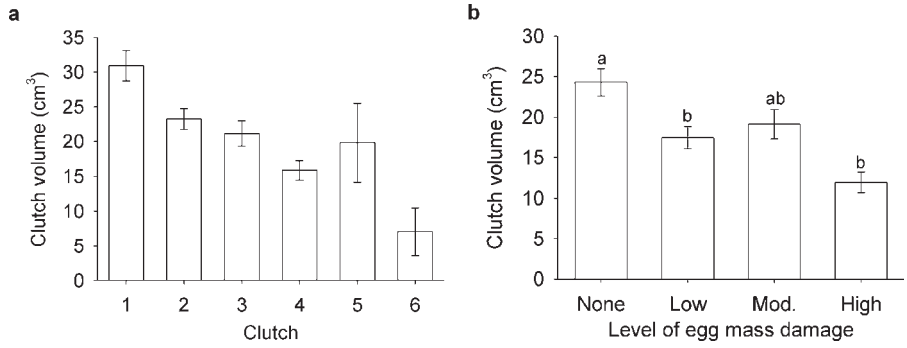

FIGURE 8.—Mean clutch volume **(a)** for clutches 1–6, averaged over all egg mass damage categories and **(b)** by damage category averaged over all clutches. Error bars indicate SEs; different letters indicate statistically significant differences ($P < 0.05$).

a significant predictor of clutch volume (GLMM: $P < 0.001$), clutch volume decreasing with successive clutches (Figure 8a). Female carapace width was also a significant predictor of clutch volume (GLMM; $P < 0.001$), with larger females producing larger clutches. Finally, the clutch volume of later clutches was related to the level of egg mass damage present at capture (Kruskal–Wallis ANOVA; $P < 0.001$); clutch volume generally decreased with increasing amount of egg mass damage present at capture (Figure 8b). Crabs with low or high damage produced significantly smaller clutches than did crabs with no damage (Holm–Sidak test; $P < 0.05$), while the clutch volume of crabs with moderate damage was statistically similar to that of all other damage categories (Holm-Sidak test; $P > 0.05$).

Discussion

We examined the effects of pot stress on the survival and future reproductive potential of ovigerous blue crabs from the pot fishery. Ovigerous crabs caught in pots frequently damaged their egg masses, though we rarely observed this behavior in crabs caught by hand (Figure 2). We hypothesize that ovigerous females damage their egg masses as a stress response when caught in crab pots. Thus, levels of egg mass damage at capture were used as a proxy for levels of pot stress, assuming crabs with the highest levels of damage were the most stressed. We acknowledge that the cause of egg mass mutilation is unknown and that it is possible that some of the egg mass damage we observed was due to mutilation by other crabs in the pot. However, either mechanism of egg mass damage should serve as a reliable indicator of stress level while in the pot.

Ovigerous crabs caught in the pot fishery showed high levels of survival, and survival was only reduced for the most highly damaged (and presumably highly stressed) individuals (Figure 4). Following capture, females survived to produce multiple clutches of eggs, and over 50% of the crabs collected survived to produce at least 3 clutches. The ovigerous crabs from the pot fishery used in this study showed better survival than those captured by hand and monitored by Dickinson et al. (2006), though this is likely due to refinements in confinement techniques over time. Less than 1% of the egg masses produced in confinement were damaged, indicating that crabs confined individually and fed are not subject to the same stress experienced when captured in crab pots.

Lipid content, larval size, larval survival time, and the percentage of embryos developing normally all showed no relationship with the level of egg mass damage for either the clutch present at capture or later clutches (Figures 5, 7). Egg diameter varied significantly with the level of egg mass damage for later clutches, but no clear trend was evident; low-damage crabs produced the largest eggs, which were significantly larger than those of crabs in all other damage categories (Figure 6). These data suggest that pot stress does not reduce the viability of future clutches. Thus, if a crab survives the capture and handling process, it will continue to spawn, and the level of damage to the egg mass does not affect the quality or fitness of future clutches.

Of the measurements assessed for clutch viability and larval fitness, all remained relatively constant over all successive clutches, with the exception of the percentage of embryos developing normally, which decreased with increasing clutch number (Figure 7). While some of the undeveloped embryos never began to develop, others began development but stopped developing at an early stage. This result supports previous results showing that the percentage of embryos developing normally decreased with successive clutch number in blue crabs captured by hand and

confined from terminal molt to death (Darnell et al. 2009). This decrease may be due to decreasing viability or number of stored sperm over time (e.g., Paul 1984; Siva-Jothy 2000; Wolcott et al. 2005; Reinhardt 2007) or decreasing viability of eggs with female age (e.g., Fasenko et al. 1992; Kern et al. 2001). The decrease seen here was modest, however, as the percentage developing normally decreased less than 20% from clutch 1 to clutch 5 compared with the 40% decrease from clutch 1 to clutch 4 seen by Darnell et al. (2009).

The well-established relationships of increasing clutch volume with increasing body size (Hines 1982; Dickinson et al. 2006; Darnell et al. 2009) and decreasing clutch volume with increasing clutch number (Dickinson et al. 2006; Darnell et al. 2009) (Figure 8a) were observed for crabs collected from the pot fishery. Additionally, clutch volume was significantly related to the level of egg mass damage, as crabs with more heavily damaged egg masses produced smaller clutches than crabs with undamaged egg masses (Figure 8b). For clutch 1 this is to be expected, as damage directly reduces the size of the egg mass. This relationship, however, was observed for later clutches. There are two possible explanations for this. First, pot stress could be negatively impacting future clutch volumes owing to lasting damage to the pleopods. Second, it is possible that crabs with more heavily damaged eggs masses were carrying a later clutch than crabs with less heavily damaged egg masses. In other words, crabs with heavily damaged egg masses may have produced smaller clutches because they were carrying their second or third clutch when caught, rather than their first. Spawning females rapidly migrate seaward (e.g., Carr et al. 2004; Rittschof et al., in press). In a small, tidal estuary such as the Beaufort Inlet drainage, a female can migrate from the upper estuary to the high-salinity sounds or coastal ocean before release of the first clutch. Because of the small size of the estuary and the concentration of the fishery in the upper estuary, ovigerous crabs caught by the fishery during a year with normal rainfall would be expected to be on their first clutch. This study was conducted during two drought years, however, which increased salinity in North River to 30–35‰. Thus, spawning crabs likely remained in the North River even after release of their first clutch. If this hypothesis is correct and crabs with more heavily damaged egg masses are producing smaller clutches because they are on a later clutch, it is possible that vulnerability to pot stress increases with age. Further investigation is needed to elucidate the cause-and-effect relationship between egg mass damage, clutch volume, and crab age.

Given the life history and spatial ecology of blue crabs, protection of the spawning stock is a complex issue. Blue crabs have a migratory life cycle (e.g., Blackmon and Eggleston 2001; Carr et al. 2004; Reyns and Eggleston 2004; Aguilar et al. 2005), they produce multiple clutches of eggs (Hines et al. 2003; Dickinson et al. 2006; Darnell et al. 2009), and peak spawning corresponds to what is traditionally the peak harvest in the pot fishery. The results of this study suggest that pot stress has minimal effects on the survival and future reproductive output of spawning female crabs. Crabs caught in the fishery survived well, continued to spawn, and with the exception of a slight increase in the number of undeveloped eggs in later clutches, clutch viability and larval fitness were constant over all clutches. Indeed, the patterns of clutch viability and larval fitness were similar to those seen in crabs captured by hand and not subjected to pot stress (Darnell et al. 2009).

We emphasize that we minimized handling stress in this study. Ovigerous crabs were removed from the catch immediately after being emptied from the pot, approximating the handling techniques of a crabber who culls crabs after each pot. Most crabbers cannot afford to cull by this method, as it requires either an additional person or a longer time per pot. Depending on when the catch is culled, there could be a significant effect of handling stress on female survival and future spawning. Crabs are usually held dry after capture, often packed tightly into hundred-pound boxes. Thus, crabs that are not culled immediately face heat and desiccation stress and the possibility of physical damage from other crabs, and their egg masses can become anoxic and unable to dissipate wastes.

The survival and future reproduction of caught-and-released ovigerous crabs depends on the handling of the crabs after they are removed from the pot, and effective regulations would therefore need to require immediate culling and release of ovigerous crabs. Based on the way commercial crabbers must operate to make a profit, this is not a feasible option, as it would greatly increase culling time and decrease the already small profit margin. A more suitable option would be to subsidize crabbers in high-salinity (thus mainly female) areas during some portion of the year, while at the same time closing the fishery in those areas. The timing of such a subsidy and closure should be decided on a state-by-state basis, based on when spawning stock biomass can be maximized. This, combined with spatial closures in peak spawning areas (spawning sanctuaries), may be the best management option for protecting the blue crab spawning stock, and it deserves further investigation.

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