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Pilot Evaluation of Early Juvenile Blue Crab Stock Enhancement Using a Replicated BACI Design

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We quantified whether local populations of early juvenile blue crabs (J1–2) could be enhanced through the translocation of crabs to underutilized nursery habitats, and if enhancement success, survival, and potential impacts of stocked crabs on their benthic prey varied in a density-dependent manner. Using plankton nets, ∼143,000 blue crab megalopae were collected as they ingressed into Pamlico Sound, NC. Of these, ∼13,800 early juvenile blue crabs (J1–2 stages) were then stocked at potential nursery sites relatively far removed (32–70 km) from their initial settlement areas using a replicated before-after control impact (BACI) experimental design. On average, there was negative enhancement success (−34%) five weeks after local crab enhancement, and no evidence of density-dependent enhancement success, mortality, or impact on potential crab prey. Poor stocking success was likely due to pelagic emigration from enhancement sites relative to controls. Attempts to assess the feasibility of stocking blue crabs at local scales of small coves should (i) probably not consider J1–2 stages because of their apparent propensity to emigrate from these areas, or (ii) further assess the effects of geomorphology and wind fetch of release sites on density-dependent emigration.

Keywords BACI, blue crabs, density-dependence, stock enhancement, translocation

INTRODUCTION

The continuous global decline of major fishery species (Food and Agriculture Organization [FAO] Report, 2001; Worm et al., 2006) has stimulated increasing interest in the application of stock enhancement, the release of cultured juveniles into wild populations to augment the natural supply of juveniles and optimize harvests by overcoming recruitment limitation (Blankenship and Leber, 1995), as a means to rebuild or augment depleted fisheries (Munro and Bell, 1997; Travis et al., 1998; Cowx, 1999). Multiple stock enhancement programs and pilot releases of hatchery-reared individuals appear to be successful (e.g., McEachron et al., 1994; Leber and Arce, 1996; Fushimi, 1998; Agnalt et al., 1999; Lenanton et al., 1999; Davis et al., 2005), whereas others suggest stock enhancement efforts are not or may not be logistically or economically advisable (Hilborn, 1998; Ottera 1999; Kellison et al., 2003; Kellison and Eggleston 2004). Because of the extensive effort necessary to estimate the success and possible ecological ramifications of stock enhancement, it is advisable to first address the likelihood of actually enhancing wild stocks using pilot studies, because failure at this stage would render future investigations of ecological and economic potential of stocking unnecessary (Kellison et al., 2003). If release scenarios determine that post-release survival of hatchery-reared organisms will achieve biological and economic goals (e.g., Kellison and Eggleston, 2004), then managers can focus on potential ecological impacts of release (e.g., Leber, 1995; McMichael et al., 1999). Conversely, if survival of hatchery-reared individuals in the wild is not sufficient to achieve biological and economic goals, then managers can abandon a particular species from further consideration of stocking, or determine the mechanisms underlying enhanced mortality after its release into the wild and attempt to mitigate these mechanisms (e.g., Olla et al., 1994; Zaragoza et al., 1994; Kellison

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et al., 2000; Davis et al., 2004). The goal of this study was to assess the biological feasibility of stock enhancement of the blue crab in estuarine systems by conducting pilot releases of early juvenile blue crabs in relatively underutilized nursery habitats that varied in their background density of cannibalistic conspecifics, and measuring relative stocking success as a function of crab density over time, as well as the effects of stocking density on predation-induced mortality of stocked crabs and potential ecological effects of stocking on local crab prey populations.

The ecologically important blue crab represents the most valuable crab fishery in the world, as well as for many states along the U.S. east and gulf coasts (Eggleston, 2003). Of concern is the sharp population decline in blue crabs within some of their major population centers, including the Chesapeake Bay and the Albemarle-Pamlico Estuarine system (NCAPES) in North Carolina. These estuaries represent the two largest estuaries in the U.S. In Chesapeake Bay, the blue crab spawning stock declined by 81% in abundance and 84% in biomass from 1991 to 1999 (Lipcius and Stockhausen, 2002). Moreover, there has been a concurrent 8% decline in the size of harvested females in Chesapeake Bay. Similarly, blue crab abundance and spawning stock have declined since 1999 as a consequence of hurricane floodwaters and overfishing of highly aggregated crabs that migrated en masse from floodwaters (Eggleston et al., 2004). There has also been a 12% decline in mean size of mature females blue crabs in the Pamlico Sound, NC since 1987 (Eggleston et al., 2004). The larval and post-larval settlement data from Chesapeake Bay and the Pamlico Sound, NC indicate that blue crab populations are likely recruitment-limited as a consequence of historically low levels of spawning stocks (Lipcius and Stockhausen, 2002; Etherington and Eggleston, 2003; Eggleston et al., 2004).

Combining traditional fisheries management, spawning stock protection, and stock enhancement may be effective for rebuilding spawning stocks of the blue crab. Stock enhancement programs directed toward releasing hatchery-reared organisms in recruitment-limited populations attempt to release organisms at a size above which intense predation-induced mortality occurs, while balancing the hatchery costs of raising individuals to a relatively large size. This study provides a unique perspective on related blue crab studies in this volume, in which relatively large crabs (>24 mm carapace width, CW) were released, since the size-at-release in this study was relatively small (mean = 3.6 mm CW).

STUDY AREAS AND METHODS

The ecological feasibility of stock enhancement was assessed by capturing blue crab megalopae as they ingressed from the continental shelf through Oregon Inlet, NC, rearing these megalopae to the first benthic instar stage (i.e., J1) in the laboratory, then stocking J1–2 stage crabs into relatively underutilized nursery habitats containing varying background densities of early juvenile blue crabs, and measuring the relative success of stocking over time. Each stocking site was paired with a nearby control containing similar habitat characteristics. A replicated before-after control impact (BACI) experimental design was employed in this study rather than using a mark-recapture experimental design with stocked crabs via micro-wire tagging because the relatively small size of crabs used in this study were too small to tag with micro-wire techniques (Johnson and Eggleston, in press). In this study, the potential response of blue crab predators to stocking, as well as predation-induced mortality of stocked crabs, was also quantified in stocked vs control sites. Finally, we examined the potential impact of crab stocking on their prey. Hypotheses tested in this study, stated as alternative (expected) hypotheses, are described below.

Collection of Crabs

Blue crab megalopae were captured from nighttime flood tides just prior to the new moon at Oregon Inlet, North Carolina, USA, using passively fished plankton nets (1 m width × 0.5 m height × 500 *u*m) during September 2001–2003. Megalopae were transported to the North Carolina Aquarium on Roanoke Island, NC, and introduced into 500-l fiberglass tanks filled with artificial seawater at 24 ppt. Tanks were supplied with aeration; half the water volume was exchanged every other day. Artificial habitat in the form of window-screening material was added to the tanks to minimize cannibalism of settled juveniles, and seagrass and macroalgae obtained from field sampling were placed into mesh bags and introduced to holding tanks to mimic potential chemical cues that would induce metamorphoses to the first benthic instar (Forward et al., 2003). Megalopae metamorphosed ∼6 days after capture. The megalope were not fed because of the large amount of live and dead plankton present; however, first benthic stage crabs (i.e., J1) were fed Tetramin Beta fish food (high-protein diet). Three screen substrates were provided in each tank for cover. To acclimate crabs to a lower salinity before their introduction to field stocking sites (see below), the salinity in the holding tanks was lowered from the initial salinity of 24 ppt by 5-ppt increments every several days until it reached 5 ppt, which was the average salinity of the stocking sites (see below). Survival of megalopae during this period was relatively high (∼70%); however, post-settlement cannibalism could be high if densities of J1 crabs were not diluted every two days. The time from initial capture of megalopae to subsequent stocking in the field was 14 days (e.g., 6 days to molt from megalopae to J1 crabs, 5 days to lower salinity of J1 crabs from 24 to 5 ppt, and 1–2 days for stocking).

Study Sites

Wild-caught, early juvenile blue crabs were stocked into relatively shallow (<1 m deep) estuarine habitats containing varying background densities of blue crabs (see below) at 4 locations in

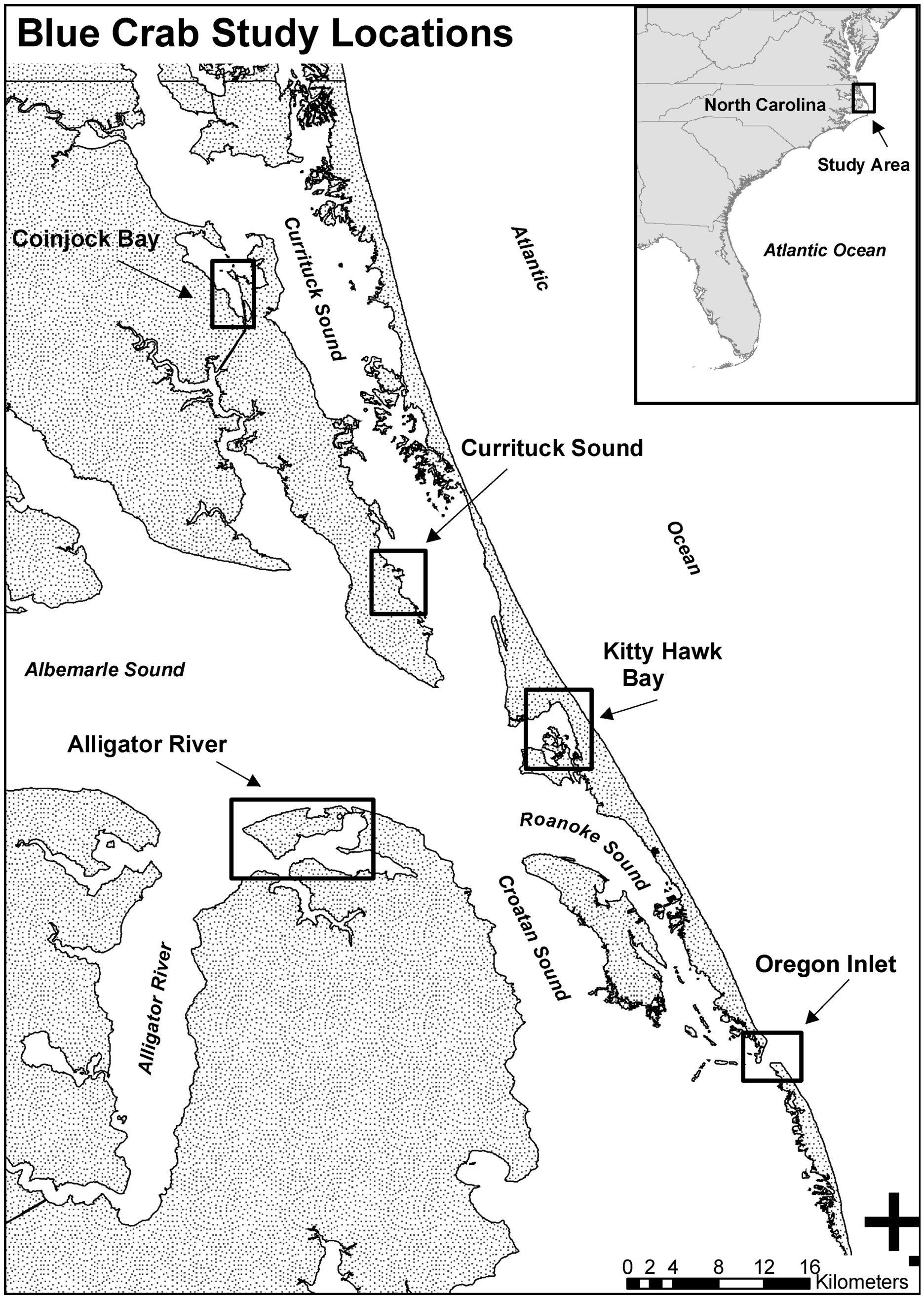

Figure 1 Four locations of blue crab stocking experiments in northeastern North Carolina, including (1) Alligator River, (2) Currituck Sound, (3) Coinjock Bay, and (4) Kitty Hawk Bay. Megalopal stage blue crabs were collected from Oregon Inlet during nocturnal flood tides.

northeastern North Carolina: (1) Alligator River, (2) Currituck Sound, (3) Coinjock Bay, and (4) Kitty Hawk Bay (Figure 1). All 4 stocking locations were surrounded by salt marsh (primarily *Juncus* sp., *Spartina* sp., *Phragmites* sp.), contained submerged rooted vascular (SRV) plants (primarily *Myriophyllum heterophyllum* and *Ruppia maritima*), and displayed relatively high DO levels (~8–9 mg DO/l). Moreover, all 4 locations were similar in terms of salinity (~6 ppt), water depth (~0.7 m), and temperature range (November =~10°C vs September =~22°C). Each location contained 1–2 stocking sites (herein referred to as "S" sites) and paired control sites (herein referred to as "C" sites). The study sites were relatively far removed (32–70 km) from the major source of blue crab megalopae in an attempt to locate potential nursery habitats with minimal background densities of early juvenile blue crabs which we could enhance. All sites were chosen based on (1) ease of accessibility, (2) lack of any human impacts such as docks, point sources for storm runoff, no trawling, etc., (3) presence of relatively dense SRV plants, and (4) varying background densities of early juvenile crabs. Each stocking site was matched with an adjacent

(∼0.5 km away) control site that had similar SRV plant and sediment characteristics.

Crab Stocking

Experimental releases of wild caught, early juvenile blue crabs (overall mean size = 3.6 mm CW) were conducted in eastern NC during late summer–early fall in 2001 (Alligator River and Currituck Sound), 2002 (Coinjock Bay), and 2003 (Kitty Hawk Bay). In all years, we used a BACI (Before-After-Control-Impact) design with sampling beginning two weeks prior to the introduction of wild-caught juvenile crabs to the stocking sites to determine background levels of crab density, continuing at 1-, 2-, and 5-week intervals until 5 weeks post-stocking. Crabs were stocked at a density of 10 crabs/m^2 above ambient crab densities, which ranged from 0–32 crabs/m^2, and stocked over habitat areas ranging in size from 80–150 m^2, which were delineated with PVC-pipe stakes. A stocking density of 10 crabs/m^2 was chosen because densities above this level can lead to rapid emigration via pelagic dispersal (Reyns and Eggleston, 2004). Prior to stocking, crabs were checked for injuries; crabs missing appendages were not introduced into the experimental sites. Crab density pre- and post-stocking was quantified by suction sampling in SRV plant habitats following protocols described in Orth and van Montfrans (1987) and Etherington and Eggleston (2000). Briefly, sampling was conducted using a suction-dredge apparatus with 790–μm mesh collection bags. Sampling rings, which enclosed 1.674 m^2 of the bottom, were haphazardly thrown into a continuous area of SRV plants. Each sample consisted of 6 minutes of suctioning, followed by dip-netting until 3 consecutive sweeps contained no decapod crustaceans or fish. A total of 4 suction samples were taken per site and sampling period. In addition to blue crab density, the density and diversity of macrofaunal prey were also quantified at all sites in 2001. The efficiency of suction sampling for early juvenile blue crabs is 88% in seagrass (Orth and van Montfrans, 1987), and all suction sampling data was adjusted accordingly and standardized to m^2.

Juvenile blue crabs reared from wild-caught megalopae were introduced to 2 randomly chosen release sites at each location (Alligator River, Currituck Sound, and Coinjock Bay), or one randomly chosen site at Kitty Hawk Bay, while the remaining 1–2 sites at each location served as controls. We continued to monitor densities of blue crabs for up to 5 weeks post-release until water temperatures cooled to the point that crabs were beginning to burrow into the sediment (∼10°C). To determine if stocked crabs appeared to overwinter in stocked sites, we quantified crab densities in early April 2003 following releases in Coinjock Bay in fall 2002. No crabs were present in stocked sites in April 2003 at S5 and S6 in Coinjock Bay.

We hypothesized that (**H1**) the success of crab stocking, as measured by the difference in mean density of early juvenile crabs (<10 mm carapace width, CW) between stocked and control sites, would increase at each stocked site after stocking, but (**H2**) would be an inverse function of crab density because of the increasing risk of cannibalism with increasing crab density and increasing probability of pelagic emigration with crab density (Reyns and Eggleston, 2004). We chose a crab size of <10 mm CW because the average size of early juvenile crabs in control and stocked sites 5 weeks after stocking was 9.3 mm CW. We tested **H1** qualitatively by plotting stocking success (i.e., difference in mean crab density = mean crab density at stocked sites minus mean density at control sites) over time (2 weeks before stocking, 1 week before stocking, 1 week after stocking, 2 weeks after stocking, 5 weeks after stocking) at each site. To test **H2**, we statistically examined the relationship between stocking success and the average pre-stocking density of early juvenile crabs over all sites using linear and non-linear regression models.

Potential Impacts of Crab Stocking on Predators and Prey

The suction samples in 2001 were sorted in the laboratory for potential macrofaunal prey (e.g., molluscs, polychaetes, tanaeids, isopods, and amphipods), as well as potential predators (predominantly blue crabs >10 mm CW and oyster toadfish, *Opsanus tau*). We hypothesized that (**H3**) the density of early juvenile blue crabs in our sites would be an inverse function of predator densities, and (**H4**) the density of prey would be an inverse function of early juvenile blue crab densities. The latter would allow us to begin to assess some of the ecological impacts of stock enhancement. Hypotheses 3 and 4 were statistically tested with linear and non-linear regression models.

Density-Dependent Mortality

Early juvenile blue crabs reared in the laboratory after being captured as megalopae were tethered in control (N = 10–15 crabs) and stocked (N = 10–15 crabs) sites to measure predation-induced mortality and to begin to assess the mechanisms underlying the poor stocking success observed at certain locations (see below). Tethering experiments were conducted in stocked and control sites in the Alligator River (S2 and C2; N = 15 crabs/site) and Currituck Sound (S3 and C4; N = 15 crabs/site) during 2001, and in Kitty Hawk Bay (S7 and C7; N = 10 crabs/site) during 2003. Tethering is useful for measuring relative rates of predation across experimental treatments as long as the treatment does not interact with the tethering technique (Peterson and Black, 1994). In these experiments, blue crabs (mean size = 5.4 mm CW) were each tethered to a 5-cm piece of monofilament line; one end of the line was attached to the carapace of a blue crab with super glue and the other end attached to a line running parallel to shore. Each tethered crab was located 1 m apart and relocated with floats anchored adjacent to ends of the transect line. The tethering experiment was conducted over a 2-day period following stocking of crabs in the various stocking sites. Although each tethered crab can probably be viewed as an independent replicate since they were located 1 m apart and could not interact, we took a statistically conservative approach and used the percent mortality of all 10–15 crabs at a given site as one replicate in statistical analyses (see below). Tethered crabs were checked after 24 hr and 48 hr and scored as either dead (piece of carapace remained glued to monofilament line), missing (no evidence of carapace on the monofilament line), or alive. Only dead crabs were used in statistical analyses. We hypothesized that (**H5**) predation-induced mortality would be higher on early juvenile blue crabs in stocked vs control sites because of the increased risk of cannibalism in the stocked site, and that (**H6**) predation-induced mortality of stocked crabs would generally increase with ambient densities of early juvenile blue crabs. Hypothesis 5 was tested with a t-test with mean percent mortality after 24 hr or 48 hr as separate response variables ($N = 3$), and site (treatment (stocked) or control)) as a factor. Hypothesis 6 was tested with linear and non-linear regression models with percent mortality from tethering experiments conducted in the Alligator River (S2, C2), Currituck Sound (S3, C3), and Kitty Hawk Bay (S7, C7) as the response variable, and the ambient, pre-stocking density of early juvenile crabs in a given site as the independent variable ($N = 6$).

RESULTS

During fall 2001–2003, using plankton nets we collected ~143,000 blue crab megalopae as they were ingressing during new moon, nocturnal flood tides into Pamlico Sound through Oregon Inlet. Of these, ~13,800 early juvenile blue crabs were then stocked at potential nursery sites. Thus, following the field and laboratory methods described above, we attained a ~10% survival rate for megalopae growing to the first and second benthic instar stages. A 10% survival rate in the laboratory for these stages of blue crabs was similar to results obtained by Zmora et al. (2005) in a hatchery environment, and are generally considered high from an aquaculture perspective.

Stocking experiments had mixed results in enhancing local populations depending upon location and the time since stocking. In the Alligator River during 2001, there were relatively large fluctuations in stocking success at the S1 site, ranging from a high of 45 crabs/m^2 after 1 week since stocking to a low of −8 crabs/m^2 after 2 weeks post-stocking, to a final increase of 10 crabs/m^2 5 weeks after stocking (Figure 2). Conversely, crab stocking success at the S2 site in the Alligator River displayed relatively low variation over time, with a general decline in stocking success from 1–5 weeks post-stocking, and no evidence of stocking success 5 weeks after stocking (Figure 2). In Currituck Sound during 2001, there was relatively little variation in stocking success over time at the S3 site, and no evidence of stocking success after 5 weeks post-release, similar to the pattern observed at S2 in the Alligator River (Figure 2). Although stocking early juvenile blue crabs at the S4 site in the Alligator River reversed a trend of declining crab density at the stocked site relative to the control site observed prior to stocking, it was not enough to enhance crab densities relative to the control site 5 weeks after stocking (Figure 2). During 2002 in Coinjock Bay, stocking appeared to be successful at both sites, and was approximately 2 times more successful at S5 than S6 (Figure 2). Coinjock Bay was the only location where there were no early juvenile crabs present prior to stocking. After 2 weeks, stocking increased crab density by 2 crabs/m^2 and 1 crab/m^2 at S5 and S6, respectively, relative to controls (Figure 2). Sampling was not conducted 5 weeks post-stocking at Coinjock Bay, as was done at all other locations, due to equipment failures and poor weather. Experimental and control sites were, however, sampled with suction sampling in April 2003 to determine the fate of stocked crabs—no crabs in the appropriate size range were collected. During 2003 in Kitty Hawk Bay, crab stocking was initially successful, reaching a peak enhancement of 21 crabs/m^2 2 weeks after stocking; however, mean crab densities in the stocked site were ~8-fold lower than the control site 5 weeks after stocking (Figure 2). Thus, in terms of testing H1, 3 of 7 experimental sites showed evidence of local stocking success 2–5 weeks after crab stocking.

Regarding H2, there was no statistically significant relationship between stocking success at 2 weeks or 5 weeks post-stocking, and pre-stocking crab densities (linear and non-linear regression models; all $p > 0.56$; Figures 3 and 4). Two weeks after stocking, 5 sites showed a positive response to stocking, with stocking success ranging from 1–19 crabs/m^2 (Figure 3). For sites that showed a positive response to stocking, stocking success increased with pre-stocking densities of early juvenile blue crabs (Figure 3). Five weeks after stocking, 1 of 5 sites showed a positive response to stocking, and 3 of 5 sites showed a relatively strong negative response to stocking (Figure 4). Thus, there was little evidence of local stocking success 5 weeks after local crab enhancement using J1–2 stages of blue crabs at a density of 10 crabs/m^2.

Contrary to our alternative hypotheses (H3 and H4), there was no statistically significant relationship between the density of early juvenile blue crab predators and early juvenile blue crabs, or the density of early juvenile blue crabs and the density of their potential prey (linear and non-linear regression; all $p > 0.66$; Figure 5). The percent mortality of early juvenile blue crabs, as measured with tethering experiments, did not vary significantly between control and stocked sites, irrespective of whether or not the experiment ran for 24 hr or 48 hr (H5) (t-test; $p = 0.33$ and $p = 0.26$, respectively; Figure 6). Moreover, the percent mortality of early juvenile crabs measured by tethering over 24 hr and 48 hr did not vary significantly with ambient densities of early blue crabs (H6) (linear and non-linear regression models; all $p > 0.18$). Thus, the combined evidence from correlative analyses from suction sampling data and from tethering experiments suggests that there were weak effects to no effects of crab stocking on local-scale predator-prey dynamics.

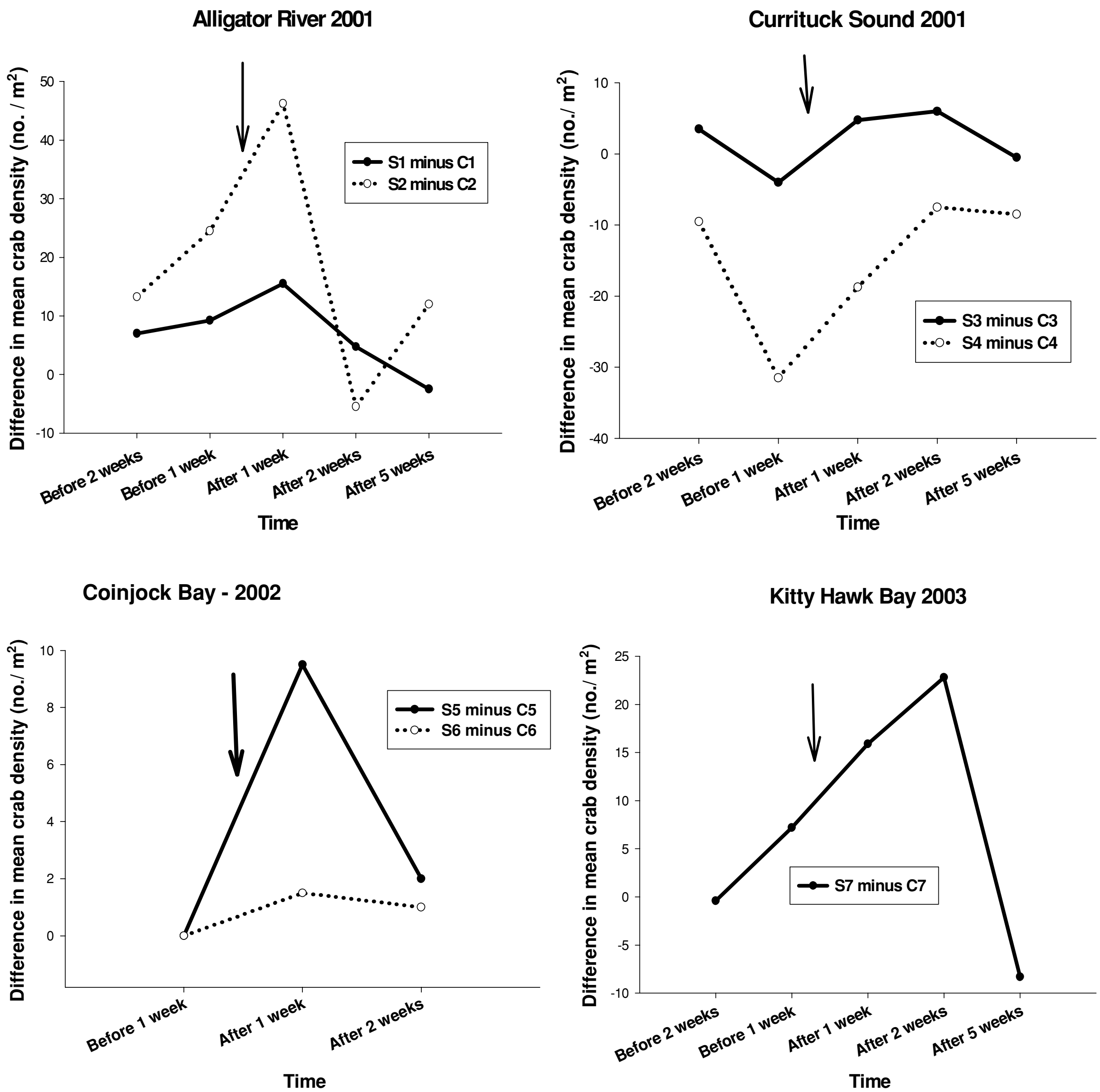

Figure 2 Effects of sampling site within the Alligator River, Currituck Sound, Coinjock Bay, and Kitty Hawk Bay, NC, USA, and time on the difference between mean crab densities in paired stocking vs control sites before vs after stocking early juvenile blue crabs (J1–2 stages) at a density of 10 crabs/m^2 on time indicated by the arrow. Each data point represents the mean density of crabs <10 mm carapace width (CW) in the stocked sites ($N = 4$ suctions samples) minus the mean density of <10 mm CW crabs in the control sites ($N = 4$ suction samples). Values above zero indicate a positive response to stocking relative to a paired control. Error bars were eliminated for clarity.

DISCUSSION

This study assessed the feasibility of stocking early juvenile blue crabs (J1 benthic instars) in seemingly underutilized nursery habitats located relatively far from their initial settlement sites, which are seagrass beds located near Oregon Inlet, NC (Etherington and Eggleston, 2000, 2003; Reyns and Eggleston, 2004). Translocating J1 crabs a distance of 32–70 km away from Oregon Inlet could enhance survival relative to their high probability of mortality (0.25–0.67/6 hr) and emigration (0.29–0.72/6 hr) as J1–3 stages in segrass beds near Oregon Inlet (Etherington et al., 2003; Reyns and Eggleston, 2004). Conversely, placing early juvenile crabs in a different nursery habitat in terms of benthic vegetation type (*Zostera marina* in natural settlement areas vs SRV in introduced sites), may have reduced post-stocking survival. The results from this study suggest that BACI experimental designs provide a reliable method for quantifying stocking success when mark-recapture and genetic tagging methods are unavailable.

We hypothesized highest stocking success at sites containing no ambient densities of crabs (e.g., Coinjock Bay), and that stocking success would decrease with increasing ambient crab densities. Lack of crabs at a site could, however, indicate that crabs are absent due to poor water quality or lack of food, as opposed to lack of immigration. Our results suggest that local populations of free-ranging early juvenile blue crabs can be

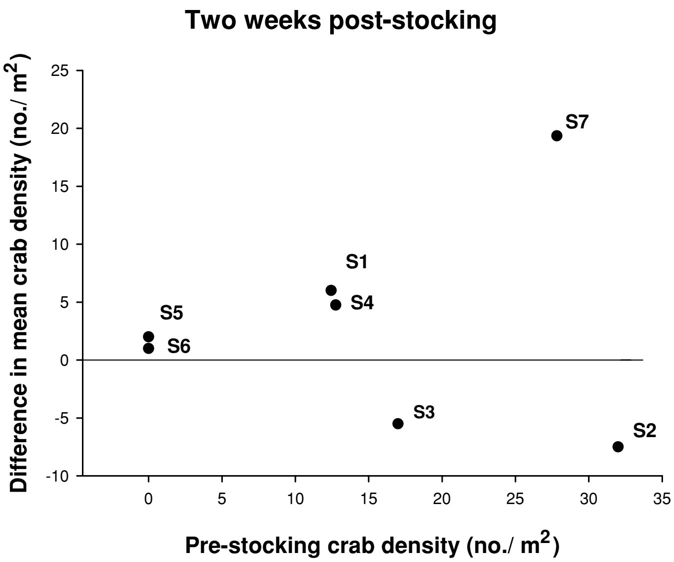

Figure 3 The relationship between stocking success (i.e., mean density of crabs <10 CW in stocked vs paired control sites) two weeks after stocking and pre-stocking crab density (crabs <10 mm CW). Mean values above zero indicate a positive response to stocking. Alphanumerics denote stocking sites (see Figure 2). There was no statistically significant relationship (linear and non-linear regression models) between stocking success (i.e., difference in mean crab density between stocked and control sites) and pre-stocking crab densities.

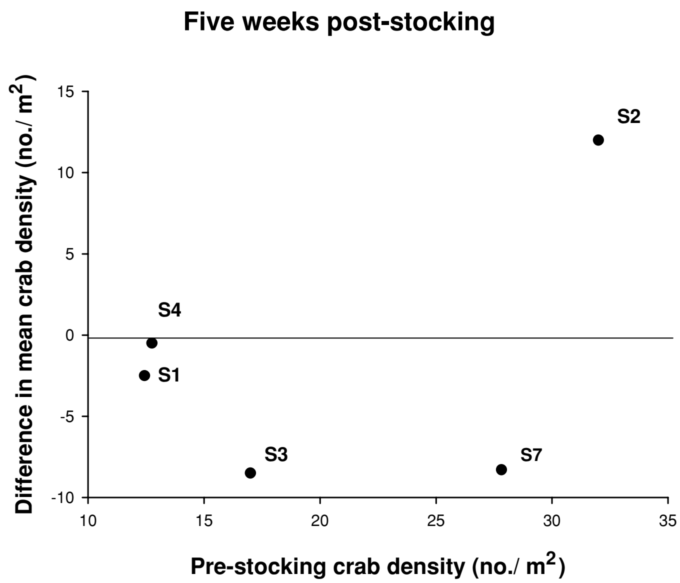

Figure 4 The relationship between stocking success (i.e., mean density of crabs <10 CW in stocked versus paired control sites) five weeks after stocking and pre-stocking crab density (crabs <10 mm CW). Mean values above zero indicate a positive response to stocking. Alphanumerics denote stocking sites (see Figures 2–5). The Coinjock Bay sites were excluded because they were not sampled five weeks after stocking. There was no statistically significant relationship (linear and non-linear regression models) between stocking success (i.e., difference in mean crab density between stocked and control sites) and pre-stocking crab densities.

successfully stocked at relatively short (2 weeks) time scales, and that, with the exception of 2 sites, stocking success after 2 weeks actually increased with the ambient crab density, opposite the pattern we expected. For example, stocking was successful in habitats with relatively high ambient densities of crabs (e.g., crab density at S7 2 weeks post-stocking was ∼27 crabs/m^2), or where the ambient density of crabs was zero (e.g., S5 and S6). Five weeks after stocking, there was only 1 of 5 sites that exhibited successful local enhancement, and this site had the highest ambient density of crabs of all sites sampled (i.e., S2 at 5 weeks post-stocking).

The potential of a given site to display high stocking success will likely depend on a suite of biological and environmental factors including (i) adequate water quality, (ii) the presence of sufficient prey types and abundances, (iii) low densities of natural predators, and (iv) habitats that are below carrying capacity to reduce competition with natural crabs. The propensity for relatively small early juvenile blue crabs to exhibit pelagic dispersal is the most likely explanation for why local stocking success was so low after 5 weeks in this study, and why some sites may exhibit better stocking success than others. For example, predation-induced mortality did not appear to explain the loss of crabs from stocked vs control sites because mortality rates did not vary between stocked and control sites, nor did crab mortality vary as a function of ambient densities of crabs. Moreover, there appeared to be adequate amounts of food since there was no apparent decline in the density of potential prey with increasing densities of early juvenile blue crabs. Conversely, early juvenile blue crabs are highly mobile in seagrass beds and can exhibit nearly complete exchange of individuals at scales of 1 m^2 in just 6 hr (Etherington et al., 2003). Pelagic dispersal is a common strategy for early juvenile blue crabs and increases sharply with increasing ambient densities above 10 crabs/m^2 (Blackmon and Eggleston, 2001; Reyns and Eggleston, 2004).

The degree to which a stocking site is exposed to open water or constricted likely also predisposes crabs to pelagic dispersal. For example, the one site in this study with consistently poor stocking success was S4, which was located at the tip of a small peninsula along the western shoreline of Currituck Sound and was exposed to the fetch of the entire width of Currituck Sound (Figure 1). Conversely, sites located in the relatively constricted Coinjock Bay (Figure 1), which also had no ambient densities of blue crabs, consistently showed a positive response to stocking. Similarly, the S2 site located in the relatively constricted East Lake region of the Alligator River (Figure 1) showed high stocking success after 5 weeks, even though it contained very high ambient densities of crabs. Relatively small blue crabs located in constricted salt marsh creeks typically show high site fidelity during the summer (van Montfrans et al., 1991; Johnson and Eggleston, in press). Thus, we hypothesize that sites with constricted openings and low to no densities of early juvenile blue crabs will show the best response to local stocking attempts.

The negative stocking success (mean = –34% enhancement) of early juvenile blue crabs ∼35 days after stocking in this study contrasts with the success (mean = +158% enhancement) ∼60 days after stocking hatchery-reared blue crabs in

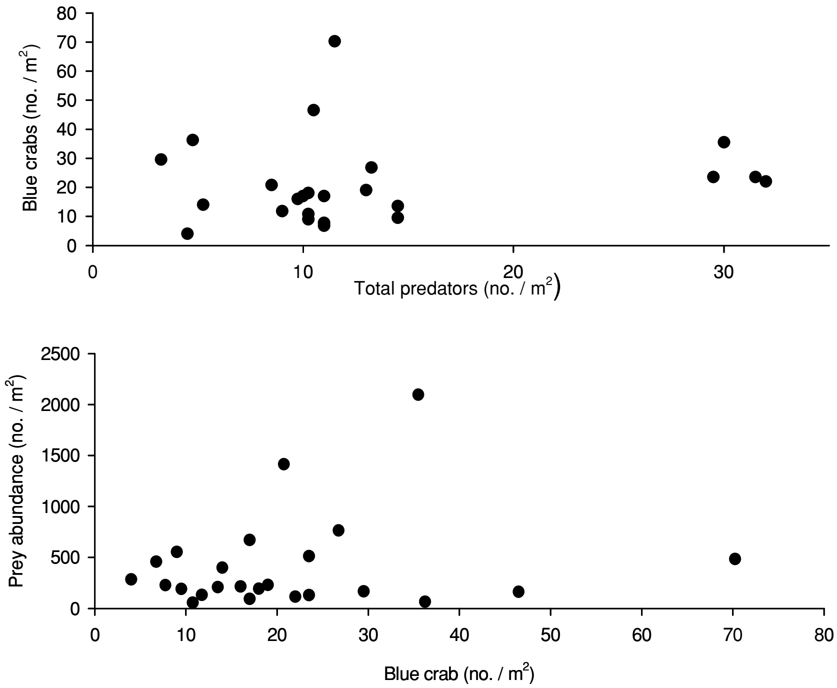

Figure 5 Relationships between the density of (a) early juvenile blue crabs (<10 mm CW) and their potential predators (primarily Oyster toadfish and blue crabs >10 mm CW), and between the density of (b) early juvenile blue crabs and their potential prey (molluscs, polychaetes, tanaeids, isopods, and amphipods) from Alligator River and Currituck Sound suction samples in 2001. See text for results of statistical analyses.

small coves located in the meso-haline zone of Chesapeake Bay (Davis et al., 2005; Hines et al., 2008). For example, Davis et al. (2005) released hatchery-reared crabs larger in size (6–30 mm CW) than those released in this study and found that 60 days after release, enhancement levels ranged from 28–366%, and

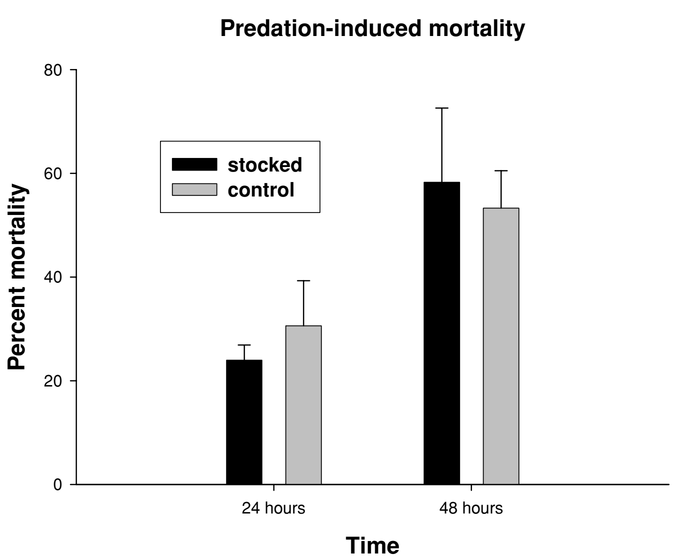

Figure 6 Mean percent predation-induced mortality (+SE) of early juvenile blue crabs from tethering experiments in stocked vs control sites at the Alligator River (S2, C2), Currituck Sound (S3, C3), and Kitty Hawk Bay (S7, C7) over a 24-hr and 48-hr period. Each mean percentage is based on percent mortality of 10–15 tethered crabs within a given site within a year ($N = 3$). See text for results of statistical tests.

that crabs released in early summer reached maturity. In addition to releasing larger crabs, Davis et al. (2005) released crabs at much lower densities (0.07–0.33 crabs/m^2) than in our study (10 crabs/m^2 above ambient densities of 0–34 crabs/m^2). Other differences between this and the Davis et al. (2005) study, which could help explain the low stocking success of crabs in this study, include: (i) sites in this study contained SRV within coves of varying fetch, whereas sites in Davis et al. (2005) contained coarse woody debris, no SRV, and had restricted openings; (ii) 7.3% of the estuarine bottom in stocked and control sites were sampled in this study, whereas 25–32% of release sites and 4–5% of control sites were sampled in the Davis et al. (2005) study; (iii) sampling of crabs was conducted by suction sampling in this study, whereas sampling of crabs was conducted with beach seining and a benthic sled in the Davis et al. (2005) study; and (iv) the experimental design in this study was a replicated and paired BACI design, whereas released individuals were tracked using micro-wire tagging techniques in the Davis et al. (2005) study. Given that equal areas of control and stocked sites were sampled in this study, and that the capture efficiency of early juvenile blue crabs using suction sampling is nearly 100% (Orth and von Montfrans, 1987; Etherington and Eggleston 2000), we suggest that the low stocking success observed in this study is most likely due to differences in emigration behavior (rather than mortality) between relatively small wild crabs stocked at high densities in this study vs relatively large hatchery-reared crabs stocked at low densities in Davis et al. (2005) and Hines et al. (2008). For example, in this study there was no difference in predation-induced mortality rates of crabs in stocked vs control sites, no evidence of density-dependent mortality, and no evidence of food limitation. Early juvenile blue crabs (J1–2) do, however, exhibit a circadian rhythm in which crabs swim vertically in the water column at night (Forward et al., 2005), and pelagic dispersal is primarily undertaken by the earliest stages (J1) (Reyns et al., 2006), with secondary pelagic dispersal increasing during flood tides at night and with wind speed, as well as with increasing densities of conspecifics (Blackmon and Eggleston, 2001; Reyns and Eggleston, 2004). Both wild and hatchery-reared stages of J1 crabs exhibit a circadian rhythm in swimming activity at night (R. Forward, Duke University, unpublished data), suggesting that it is the difference in crab size that is driving the likely high emigration of stocked crabs from stocking sites in this study. Thus, attempts to assess the feasibility of stocking blue crabs at local scales of small coves should (i) probably not consider J1–2 stages because of their apparent propensity to emigrate from these areas, or (ii) further assess the effects of geomorphology and wind fetch of a given release site on density-dependent emigration.

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