MODELING THE IMPACT OF DROUGHT ON SOUTH CAROLINA BLUE CRABS USING A SPATIALLY-EXPLICIT INDIVIDUAL-BASED POPULATION MODEL

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Abstract. Blue crabs, *Callinectes sapidus*, have been experiencing severe declines across their entire geographic range. In South Carolina, annual commercial landings show significant correlations with rainfall, Palmer Drought Index, river discharge, and salinity. During drought years, when freshwater flow is lowest, and saltwater intrusion is highest, crab landings decrease.

Two possible hypotheses can be posed to explain this relationship between increased salinity and decreased crab landings. In the first hypothesis, crabs follow the optimal salinity upriver beyond the legal fishing limit. This hypothesis predicts that landings decrease due to lost fishing opportunity but crab abundance remains constant or may even increase. In the second hypothesis, crabs experience lower survival with increased salinity due to disease, starvation and/or cannibalism. This hypothesis predicts that landings decrease because crab abundance decreases.

To test the predictions of these two hypotheses, I constructed a spatially-explicit, individual-based population model called the South Carolina Blue Crab Regional Abundance Biotic Simulation (SCBCRABS). The SCBCRABS model follows individual crabs from settlement until death as they interact over a grid of habitat cells representing inland freshwater creeks, brackish marshlands, and the open ocean.

In the simulations, I modeled the effect of drought by changing the average salinity (0, +5, +10 ppt) and the effect of crab refuge size by moving the legal fishing limit (0, 5.3, 18.4% of total habitat as refuge) in the model.

As salinity increased, both adult density and annual landings decreased significantly. However, a decrease in refuge size had no significant effect on either adult density or annual landings. These results suggest that the negative correlation between crab landings and salinity is more likely due to decreased survival rather than lost fishing opportunity. Preserving historical levels of freshwater discharge may be essential to the sustainability of saltmarsh commercial species.

INTRODUCTION

Many saltmarshes have experienced large-scale diebacks linked to increasing drought conditions as a result of water management practices and global climate change. Since saltmarsh habitats are important nurseries for many commercial species including finfishes, shrimps, and blue crabs, understanding the influence of drought on marsh and fisheries health should be a top research priority (Alber et al. 2008).

The American blue crab, *Callinectes sapidus*, has been one of the most important commercial fisheries on the Atlantic coast for decades but over the last 20 years, populations of blue crabs from Chesapeake Bay to the Texas gulf coast have been declining at an alarming rate (ASMFC 2004). The causes of this dramatic decline are not well understood and vary with region. For example, in the Chesapeake Bay population, overfishing of the spawning stock appears to be a major factor, however, overfishing may not necessarily explain the declines in the Gulf of Mexico and the southeastern Atlantic coast where fishing efforts have remained relatively constant (Eggleston et al. 2004).

There are numerous additional environmental factors that may be contributing to the decline of blue crabs throughout their range including altered freshwater flow and coastal development leading to hypoxia, cannibalism, habitat loss, disease, and loss of prey species. All of these mechanisms are further exacerbated by prolonged periods of drought that dramatically alter the suitability of nursery habitats available for settlement by crab post-larvae and increase *Hematodinium* sp. infection rates (Lee & Frischer 2004).

BACKGROUND

In South Carolina, the blue crab fishery generates annually 5-7 million dollars (Whitaker et al. 1998). However, SC blue crabs have also experienced declines over the last 10 years. Annual landings have decreased dramatically from a high of 7.5 million pounds landed in

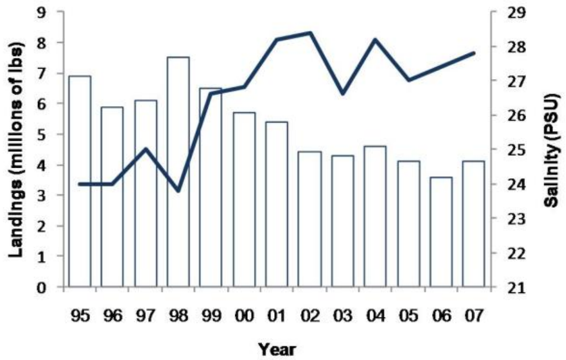

Figure 1. Annual landings of SC blue crabs (bars) and average salinity (line) by year. Salinity is significantly, negatively correlated with crab landings ($r^2 = 0.539$, df = 12, p = 0.003). Data provided by SCDNR.

1998 to 3.6 million pounds landed in 2006. The reason for this decline is unclear but does not appear to be due to changes in fishing effort or price. Changes in salinity, however, are negatively correlated with crab density (Figure 1), most likely due to decreased freshwater flow during prolonged periods of drought.

Several hypotheses have been proposed to explain this negative relationship between salinity and blue crab landings. (H_1) During periods of low river flow, the saltwater boundary pushes further upriver allowing crabs access to a refuge from commercial fishing pressure. This can lead to decreased commercial landings during drought years and increased landings during years of increased river flow (Wilber 1994). (H_2) Juvenile crab settlement, growth, or post-settlement mortality may change as juveniles and adults are pushed further upriver into a smaller nursery habitat (Posey et al. 2005). This can result in lower juvenile growth or survival, increased mortality from diseases, and decreased future landings.

EXPERIMENTAL DESIGN

In order to evaluate the impact of increased salinity and altered fishing boundaries, I conducted a simulation experiment using the SCBCRABS model (Childress 2007), a spatially-explicit, individual-based population model that follows the fate of individual crabs from settlement to death. Growth, movement, disease, reproduction, natural mortality and fishing mortality are size-specific and sensitive to the local environmental conditions of the patch where an individual is currently found. The patch water quality conditions (temperature, salinity, dissolved oxygen) change according to season and position along the river and mimic the rapidly changing conditions that real crabs experience.

In this study, baseline model conditions for all simulations were set as follows: initial-number-crabs 3000; births 10 / female / brood; immigration 10 larvae / week; number-traps 25; trapping-probability 0.25; predation-risk 0.25; carrying capacity 30000; temperature-change 0; dissolved-oxygen-change 0.

METHODS

Two conditions were varied in the model: salinity-change and legal-limit. The salinity-change parameters modeled were 0, +5, +10 average ppt. These represent the expected change in salinity for a normal year, a moderate drought, and a severe drought, respectively. The legal-limit parameters modeled were “decreased refuge” 0% of the total available habitat; “current refuge” 5.3% of the total available habitat, and “increased refuge” 18.4% of the total available habitat.

Conditions were varied according to a fully crossed ANOVA design with three levels of salinity and three levels of refuge size for a total of nine treatment combinations. Each combination was replicated by 5 runs of the model with a different initial random seed. Each run was allowed 10 years to reach stable population equilibrium.

The dependent variables from the model were the density of adult crabs at the end of the 10-year simulation and the annual landings of adult crabs for the final year. These data were analyzed using a two-way analysis of variance with a Tukey-Kramer post-hoc comparison. All statistical analyses were performed using JMP 8.0 (SAS Institute, Cary, NC).

RESULTS

In the past 10 years the annual landings of blue crabs in South Carolina have decreased by 1.8 million pounds or about 30% below the 20 year average (Figure 1). During that same time the average salinity recorded along several saltmarsh monitoring stations has increased 2.5-3.8 psu or about 8-10% above the long term average. As a result, there is a significant negative correlation between annual landings and average salinity ($r^2 = 0.539$, df = 12, p = 0.003).

I also found that salinity increases simulated in the SCBCRABS model caused a significant reduction in both adult crab density (Figure 2A) and commercial landings (Figure 2B). These declines were significant with an increased salinity of as little as 5 ppt. When the legal fishing boundaries were altered to increase fishing further upriver, there was no significant decrease in crab density (Figure 3A) or increase in annual landings over the current level of refuge size (Figure 3B). The only

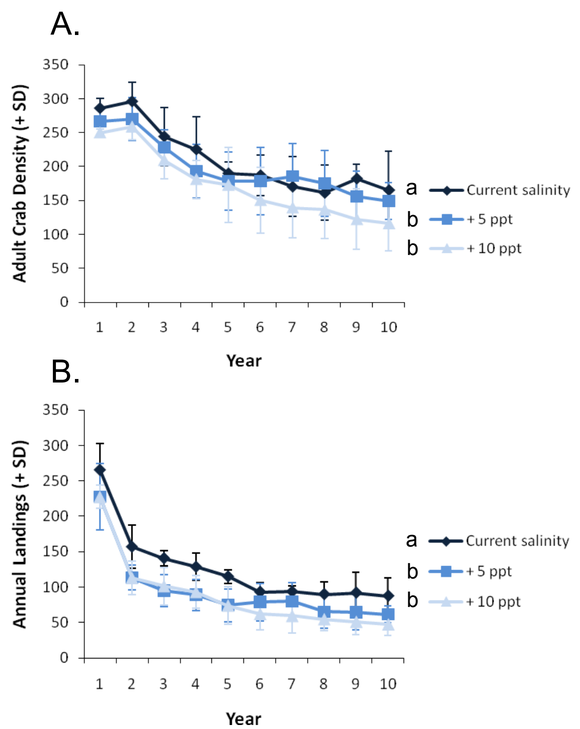

Figure 2. Adult crab density (A) and annual landings (B) for 10-year simulation varying average salinity at current refuge size. Lower case letters indicate statistical differences for the Tukey-Kramer post-hoc comparisons.

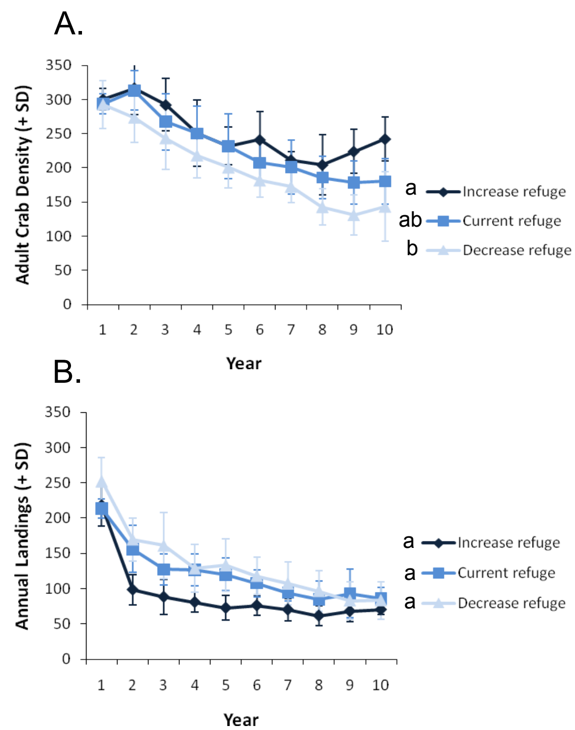

Figure 3. Adult crab density (A) and annual landings (B) for 10-year simulation varying fishing refuge size at current salinity levels. Lower case letters indicate statistical differences for the Tukey-Kramer post-hoc comparisons.

significant effect of changing refuge size was a difference in crab density between the decreased refuge and increased refuge sizes (Figure 3A). The influences of salinity and refuge size appeared to be independent of one another, as there was no significant interaction for either crab density or annual landings (Table 1)

Table 1. Two-way ANOVAs of Crab Density and Annual Landings with Simulated Changes in Salinity and Refuge Size

Variable	Simulation	df	F	P
Density	Salinity	2, 36	5.63	0.007
	Refuge size	2, 36	4.39	0.020
	Interaction	4, 36	0.45	0.776
Landings	Salinity	2, 36	11.7	0.001
	Refuge size	2, 36	1.49	0.239
	Interaction	4, 36	1.15	0.350

DISCUSSION

Blue crabs are declining in South Carolina with annual landings down 30% below the 20 year average catch. While many potential factors have contributed to this decline including intense fishing pressure, coastal development, and increased pollution, there is also a significant impact from annual freshwater discharge rates. As surface flow decreases in the coming years due to increased demand upstream or increased frequency of droughts, the danger to coastal wetlands is very clear (Erwin 2009). My study suggests that even a species with a wide salinity tolerance may be negatively impacted by this change.

Results from my individual-based, spatially-explicit model found that adult crab density decreased in higher salinities due to a combination of decreased growth and higher mortality in the upper river regions of the model. These habitat patches have lower food availability and higher densities of crabs, which led to increased mortality due to increased cannibalism.

Why are blue crabs negatively impacted by increases in salinity? Several possible reasons must be tested in future field research. Blue crabs clearly use salinity cues to select appropriate habitat for settlement, mating, and larval release. First, higher salinity at the mouths of rivers means that crab postlarvae may not perceive freshwater cues that would normally signal the saltmarsh nursery, thus, delaying settlement and increasing mortality. Second, males migrate upriver until they reach an optimal salinity of approximately 15 ppt. During drought years, these males must travel further upriver to reach their preferred salinity into areas with few saltmarsh prey species. Third, immature females must travel upriver until they reach males during the mating season. This extra distance travelled, coupled with lower food resources is likely to reduce the energy stores available for egg production. Finally, mated females must return to high salinity waters in order to release their larvae. If mature females reach the high salinity cue while still in the river they will potentially release their larvae too soon, leading to a reduced probability the larvae will reach the open ocean to complete the life cycle.

RECOMMENDATIONS

It seems apparent that freshwater discharge will continue to decrease through a combination of climate-driven drought and increasing demand for water upstream. As a result, coastal wetlands will continue to shift toward a saltmarsh community of species. What is unclear is whether the productivity of these new inland saltmarshes will be able to sustain species such as blue crabs that have already begun to decline. Changing the commercial fishing boundaries during periods of drought is unlikely to increase landings and may potentially decrease crab density. Outside of restoring rivers to historical levels of freshwater discharge, there may be few recommendations that can reverse the decline in blue crab landings that results from the effects of increased salinity.

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