Dying of Thirst: Impact of Reduced Freshwater Inflow on South Carolina Blue Crabs

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ABSTRACT. Over the past decade the annual landings of South Carolina blue crabs have declined by 30% while marsh salinity has steadily increased due to persistent drought conditions. We hypothesized that the link between increasing salinity and declining crab landings was salinity induced changes in crab settlement, predation or disease. To test these alternatives, we conducted a four-year study of blue crabs in the three rivers of the ACE Basin National Estuarine Research Reserve (NERR). From 2009 to 2012, salinity increased in each river as annual freshwater discharge decreased. Larval settlement was not related to salinity, post-settlement predation was negatively related to salinity, and *Hematodinium* sp. infection was positively related to salinity. Crab abundance declined in the high salinity river (Combahee) due to increased disease in juveniles. Crab abundance increased in the low salinity river (S. Edisto) due to reduced predation on juveniles and adults. Crabs were most abundant and had lower predation and lowest disease at intermediate salinities such as those found in the Ashepoo River, where losses of juveniles were offset by increases in adults.

To forecast the long-term effects of drought on crab population structure, we created a spatially-explicit, individual-based model (IBM) of the ACE Basin NERR. We linked river discharge data with in-situ water quality estimates to predict the seasonal and annual variation in salinity for each of our rivers. Data from our crab field censuses and experiments were used to parameterize the relationships between salinity and settlement, movement, predation and disease. We then conducted an 80-year simulation using the forecasted river discharge. The model predicts initial decreases in river discharge to have a positive effect on crab population density as more of the marsh reaches optimal intermediate salinity. However, further decreases in river discharge beyond current discharge levels result in declining crab density. These results suggest that any further reduction of freshwater discharge below current average discharge levels could result in increased crab disease and decreased commercial landings.

INTRODUCTION

The blue crab, *Callinectes sapidus*, comprises one of the most important commercial fisheries in the state of South Carolina but has been declining over the last 15 years. The factors most correlated with this decline are decreasing freshwater discharge and increasing marsh salinity (Childress 2010). Previous studies have found that increases in salinity can decrease larval settlement (Bishop et al. 2007), decrease juvenile growth and survival (Posey et al. 2002), and increase crab disease (Lee and Frischer 2004).

In this paper, we summarize a four-year field study that examines the effect of salinity on crab settlement, movement, predation and disease in the ACE Basin NERR (Fig. 1 - Parmenter 2012; Parmenter et al. 2012). We then incorporate our findings into an individual-based population model in order to forecast the future of blue crabs in South Carolina based on projected decreases in freshwater discharge.

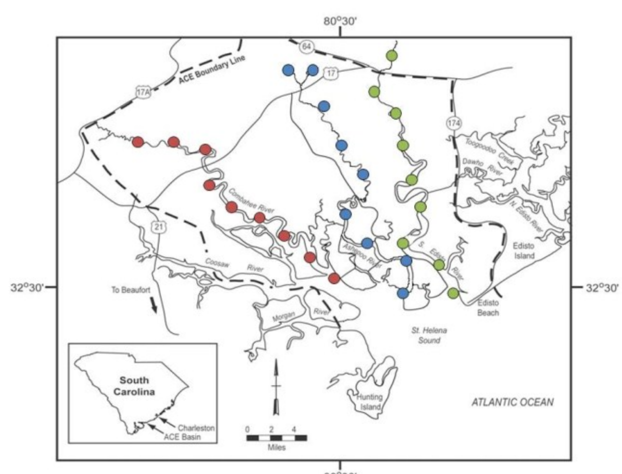

Figure 1. Nine crab sampling stations in each river of the ACE Basin NERR; the Ashepoo (blue), Combahee (red) and S. Edisto (green) rivers. Salinity decreases from station 1 (St Helena Sound) to station 9 (ACE NERR northern boundary line).

PROJECT OBJECTIVES

1. To characterize the seasonal, annual and spatial patterns of salinity in the ACE Basin NERR in relation to freshwater discharge.
2. To determine the influence of salinity on crab settlement, predation and disease.
3. To forecast the influence of future changes in freshwater discharge on the population structure of blue crabs in the ACE Basin NERR.

FIELD METHODS

We conducted quarterly sampling of juvenile and adult crabs using modified commercial crab pots. Water quality (temperature, pH, DO and salinity) was measured at each sampling station. Blood samples for each crab were screened for *Hematodinium* sp infection (Parmenter et al. 2012). Twenty crabs were tethered at stations 1, 3, 5 & 7 in each river and predation was estimated after 24 hours. Post-larval and juvenile settlement was measured by larval collectors at stations 1, 2, 3 & 4 in each river during the months of Aug, Sept and Oct. See Parmenter (2012) for more details on the field sampling methods.

FIELD RESULTS

Crab abundance was strongly correlated with river, station within river, and season (Fig. 2A). Total crab abundance was highest in the Ashepoo (intermediate salinity) and lowest in the S. Edisto (lowest salinity). Male crabs were most abundant in intermediate salinity stations (4-6) and females were most abundant in high salinity stations (1-3). Juvenile crabs were most abundant in March and adult crabs were most abundant in September.

Salinity was strongly correlated with river, station within river, season and year (Fig. 2B). The river with the highest freshwater discharge (S. Edisto) had the steepest salinity profile and the river with the lowest freshwater discharge (Combahee) had the shallowest salinity profile. Salinity is highest in September and lowest in March. Salinity increased from 2009 to 2012.

Settlement was correlated with river, but not with station within river or year (Fig. 2C). Higher salinity was not always correlated with higher settlement of megalopae and juvenile crabs.

Predation was correlated with river, station within river, crab size, and crab shape (Fig. 2D). Predation decreased significantly as salinity increased.

Disease was correlated with river, station within river, season and year (Fig. 2E). Disease was highest in the river with the highest salinity (Combahee) and was highest at stations with the highest salinity.

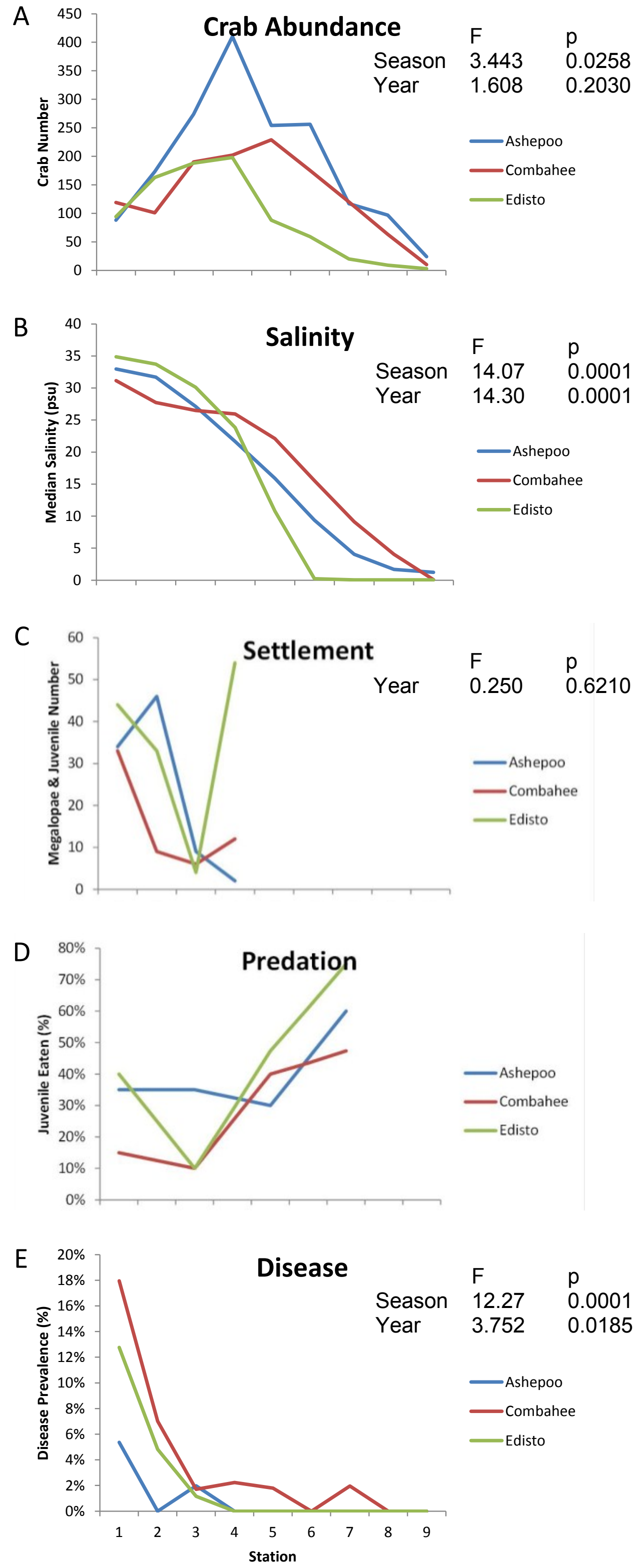

Figure 2. Variation in crab number (A), salinity (B), crab settlement (C), crab predation (D) and crab disease (E) in relation to river and station within river. Salinity is negatively correlated with predation and positively correlated with disease. Settlement is unrelated to salinity.

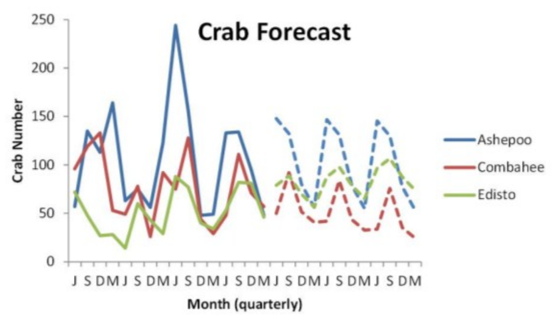

Figure 3. Observed (solid lines) and predicted (dotted lines) abundance of blue crabs in the three rivers of the ACE Basin NERR. Forecasts are based on an autoregressive integrated moving average (ARIMA) model with seasonal exponential smoothing.

A forecast of future crab abundances in the ACE Basin NERR was conducted using a seasonal ARIMA forecast model (Fig. 3). If freshwater discharge continues to decrease as it did from 2009 to 2012, the model predicts that crab abundances will decline in the highest salinity river (Combahee) due to increased disease, will rise in the lowest salinity river (S. Edisto) due to decreased predation, and will remain the same in the intermediate salinity river (Ashepoo) (Parmenter 2012).

MODELING METHODS

With support from SC Sea Grant and SC Department of Natural Resources, we developed an individual-based population model known as SCBCRABS for the ACE Basin NERR including the Ashepoo, Combahee and S. Edisto Rivers (Childress 2010). The spatial map has 1189 habitat cells of three different types: open water, shallow marsh, and land (Fig. 4A). Each habitat cell also has a depth category of 0.5-15 m. These three factors, the type of habitat cell, depth, and position in the map, influence the water quality parameters present at that spatial location.

Crabs enter the model as first stage juveniles. The number that settle during any week is determined by female size as well as immigration of settlers from a source outside of the model. Settlement is spatially constrained to the lower reaches of the shallow marsh habitat cells and is temporally constrained to occur from July until November. Crabs grow by changing to the next largest size class in the model. There a total of 20 size classes corresponding to a 1 cm increase in carapace width. Newly settled juveniles (J1) are assumed to be 1 cm CW while the largest adults (M20) are assumed to be 20 cm CW. Each individual crab has a sex (male or female), an age (number of days since previous molt), a disease status (no, yes), a reproductive status (no, yes), and a heading (degrees) (Fig. 4B).

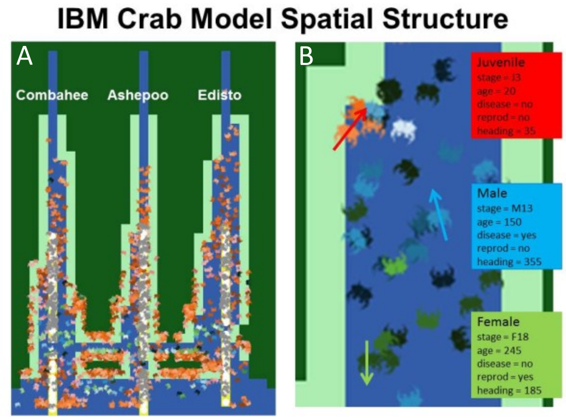

Figure 4. (A) The spatial structure of the SCBCRABS model showing the three habitat types and three rivers of the ACE Basin NERR. (B) Individual crabs are tracked from settlement to death in the model as they disperse, grow, reproduce and die according to routines that consider sex, stage, season, water quality and habitat.

Water quality parameters are determined for each habitat patch in the model based on a weekly time step (Fig. 5). Discharge (log cubic feet / sec) is determined by week of the year and follows a sine curve based on the monthly averages from the USGS station (02175000) at Givhans, SC. Temperature is determined by week of the year and follows a sine curve based on records from the St. Pierre Creek station in the ACE Basin NERR. Dissolved oxygen is based on a temperature-related sine curve. Salinity is based on discharge and an empirically determined salinity profile logistic curve (Fig. 2B).

Each individual is subjected to a series of subroutines weekly that determine its dispersal, survival, growth and reproduction. The model incorporates the influence of temperature, dissolved oxygen and salinity effects on crab settlement, dispersal, fishing, predation, disease, growth and reproduction as measured in our field experiments or from previously published studies.

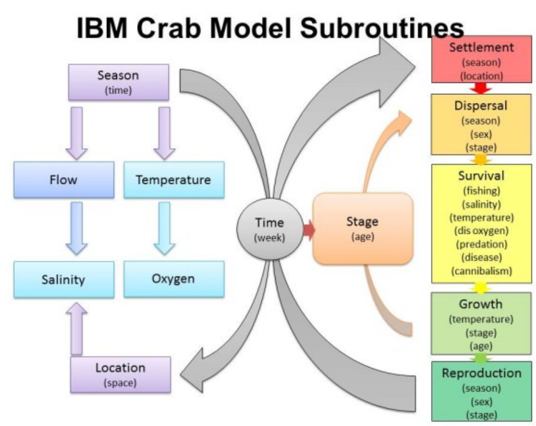

Figure 5. Flow diagram of the relationship between water quality variables and crab life history subroutines.

MODELING RESULTS

To model the impact of reduced freshwater discharge into the ACE Basin NERR, a linear regression was fitted to the USGS Edisto River historical discharge data (Fig. 6A). Initial discharge was set at 3.469 log cfs (2944 cfs) approximately equal to the annual discharge in 1975 and the mean annual discharge from the period 1939-2011. The model then decreased flow linearly by 0.0086 log cfs per year for 75 years. The end flow was 2.824 log cfs (666 cfs), above the observed minimum annual flow (645 cfs) during the drought of 2002.

Five replicate runs of the model were conducted and the mean (+/- standard deviation) number of crabs in the model and the % of crabs alive but infected with disease were recorded for each year (Fig. 6B).

During the hindcast portion of the model (1975 to 2011), decreasing discharge has a net positive effect on crab numbers in the ACE Basin NERR (Fig. 6B). Crabs increase due to reduced predation as low salinity regions decrease. A maximum crab density is reached about 2011 at discharge rate of 3.159 log cfs (1443 cfs), a little above the actual observed rate of 2.973 log cfs (940 cfs).

During the forecast portion of the model (2012 to 2050), further reductions in discharge below 3.159 log cfs (1443 cfs), predict fewer and fewer crabs due to increased disease as high salinity regions increase (Fig. 6B). Disease prevalence (% alive but infected) does not reach its maximum (1.85%) until 2030 at a discharge rate of 2.996 log cfs (990 cfs).

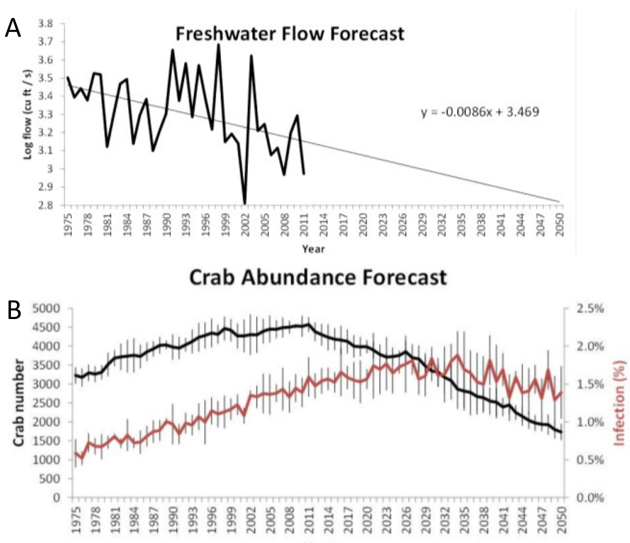

Figure 6. (A) Observed annual discharge of the Edisto River (black line) and projected future decline in discharge (gray straight line). (B) Output of the SCBCRABS model for crabs in the ACE Basin NERR showing crab number (black line) and disease prevalence (red line) by year.

DISCUSSION

Crab survival decreases at high salinity due to increased disease (Parmenter et al. 2012) and crab survival decreases at low salinity due to increased predation (Parmenter 2012). Therefore, it is expected that crabs will do best at intermediate salinity. This is exactly the pattern we observed in the ACE Basin NERR, with highest crab density at stations with intermediate salinities and with the highest density in the river with intermediate salinity (Ashepoo).

Furthermore, freshwater discharge is known to influence the salinity profile of each river. As freshwater discharge decreased over the past four years, crab abundance increased in the high discharge river (S. Edisto) while it decreased in the low discharge river (Combahee). This pattern is corroborated by the predictions of the SCBCRABS IBM. When the model begins with historical levels of freshwater discharge, crab abundance increases as discharge is reduced, eventually reaching maximum crab abundance at a level of approximately 80% of the average discharge rate. Any further reduction in freshwater discharge results in higher disease prevalence and decreasing crab abundance.

Although the IBM model suggests we are just now reaching the critical minimum discharge level in the ACE Basin NERR, evidence from across the entire state of South Carolina suggests that declining discharge is already causing a decline in crab landings (Childress 2010). In fact this pattern was first reported by Wilber (1994) for a single river in north Florida and has been reported more recently for juvenile crabs in the Gulf of Mexico (Sanchez-Rubio et al. 2011). Furthermore, a recent model examining the relationship between recruit-stock relationships for blue crabs in North Carolina was also sensitive to differences between wet and dry years (Ogburn et al. 2012). Therefore, future reductions in freshwater discharge due to drought or consumption are expected to have negative consequences for blue crab abundance and their commercial fishery, as hypothesized by Lee and Frischer (2004).

It is difficult to predict how drought will impact the southeastern US over the next 50 years (Gilbert et al. 2012), but a majority of climate models predict droughts of increasing duration and severity (Seager et al. 2009). Blue crabs may be an ideal indicator species of salt marsh condition due to their unique role as mid-level predator that helps to structure salt-marsh communities (Alber 2002). Previous studies have linked blue crab declines to cascading trophic effects on salt marsh die-back (Silliman et al. 2005, Altieri et al. 2012). The annual landings of blue crabs might be an appropriate indicator of the health of the salt marsh community as a whole.

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