Going with the flow:
Forecasting the impact of climate change on blue crabs

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ABSTRACT. Blue crabs are one of the most important commercial fisheries in South Carolina, but landings have declined during recent droughts. Climate forecast models suggest that in the Southeastern US, we can expect our future climate to be wetter, hotter and more variable than in the past, with a net decrease in freshwater surface flow. To better understand the complex interaction of climate change on river flow and blue crab abundance, we used a spatially-explicit, individual-based population model (ACE-SCBCRABS) parameterized from field observations of water quality, crab abundance, predation, disease, and fishing effort collected in the ACE Basin National Estuarine Research Reserve. In this study, we explored how changes in river flow under future scenarios of climate change might impact blue crabs landings over the next 75 years. We examined how the rate of freshwater flow decrease and the degree of inter-annual flow variability might interact to influence crab abundance, commercial landings, and disease. Models were run for 150 years beginning with flow rates observed in 1940 and projecting forward in time to the year 2090. Decreasing freshwater flow and increasing inter-annual variability both caused a significant decrease in crab landings. Models run under 1940 conditions of flow decline and variability show crab landings at our current harvest level. Models run under 1975 conditions of flow decline and variability show a reduction in crab landings of 30%. Models run under 2010 conditions of flow decline and variability show a reduction in crab landings of 76%. These results suggest that current levels of freshwater decline and inter-annual variability there is a 29% risk of collapse for the South Carolina blue crab fishery by the year 2090.

INTRODUCTION

Blue crabs (*Callinectes sapidus*) are one of the most important commercial fisheries in the state of South Carolina with annual landings averaging 5.5 million lbs. Inter-annual variation in SC crab landings is significantly correlated with annual levels of freshwater discharge explaining > 20% of its variation (Childress 2010).

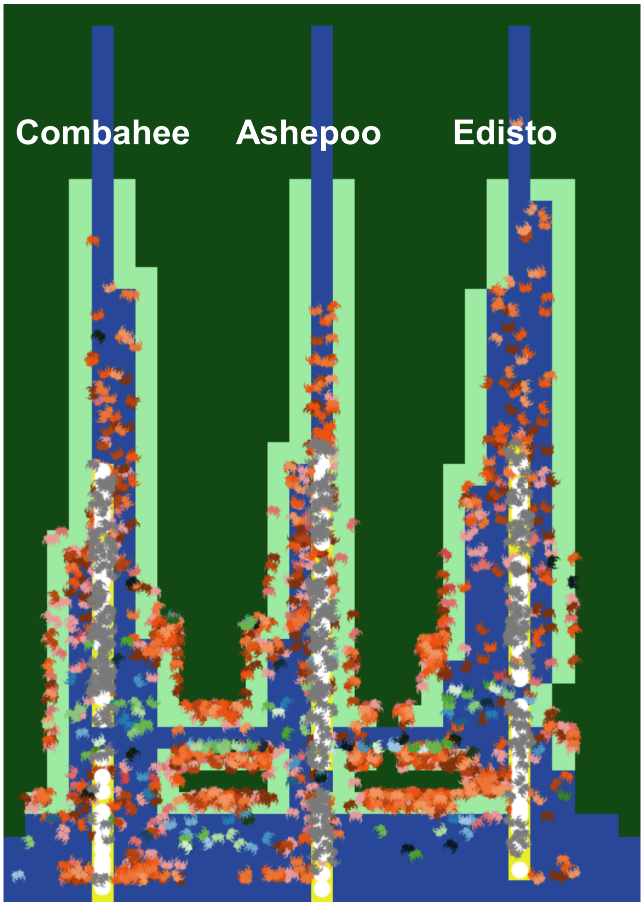

Figure 1. Visual representation of the ACE-SCBCRABS individual-based population model (IBM). Each habitat cell of the model (blue = water, light green = shallow marsh, dark green = land, white = crab trap) is parameterized for temperature, salinity, and dissolved oxygen which vary with season and freshwater flow specific to each of the three rivers, Ashepoo (middle), Combahee (left), and Edisto (right). Crabs (red = juvenile, blue = males, green = females, gray = trapped) are removed from the model by mortality from temperature, salinity, dissolved oxygen, disease, predation, cannibalism, and fishing. Crabs are added to the model by reproduction from mature females. Freshwater flow input to the model was varied to represent historical and projected changes in surface run-off.

During droughts, freshwater input to the marsh decreases and salinity increases. As salinity increases, crab abundance decreases due to increasing infection by a lethal parasite, *Hematodinium* sp. (Lee and Frisher 2004; Parmenter et al. 2013). However, the degree to which crab decline is linked to decreasing freshwater depends on the level of freshwater flow into the marsh. A four-year study of the blue crabs in the ACE Basin National Estuarine Research Reserve (NERR) during the 2010 drought found that crabs decreased in the low flow Combahee River due to increased disease but increased in the high flow Edisto River due to decreased predation by freshwater predators (Parmenter 2012).

To better understand the net impact of freshwater flow on crab population dynamics and fisheries landings, we constructed a spatially-explicit individual-based population model (IBM) for the crabs of the ACE Basin NERR (Childress and Parmenter 2012). Using this model (Figure 1), we evaluated the impact of historical, current and projected decreases in freshwater on future blue crab landings.

PROJECT DESCRIPTION

In this experiment, we asked the ACE-SCBCRABS model to project future blue crab population density and commercial landings for different scenarios of freshwater decline. Our hypothesis was that both the rate of freshwater decline and the amplitude of flow variability would negatively impact future crab abundance.

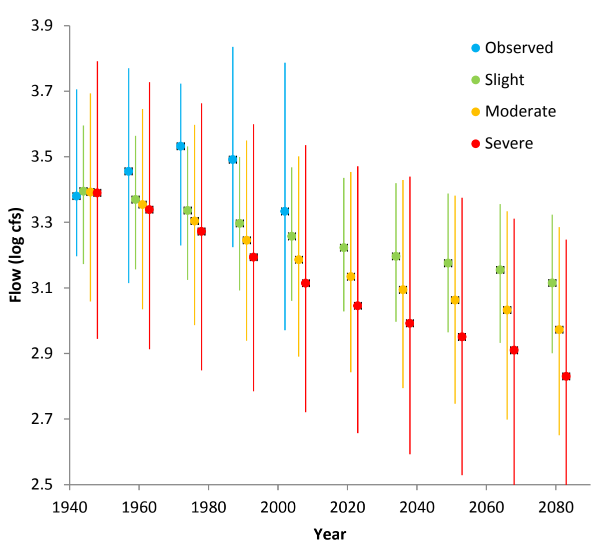

Figure 2. Freshwater flow (average, minimum and maximum) for 15 year periods from 1940 to 2090 based on the historical record of Edisto River discharge (observed). We simulated the rate of flow decline and amplitude of inter-annual variation from 1940 (slight), 1975 (moderate) and 2010 (severe) as input for 500 replicate runs of the ACE-SCBCRABS model.

METHODS

First, we modified the ACE-SCBCRABS IBM to include an annual decline in freshwater flow and increase in inter-annual variability estimated from the historical record of flow from the Edisto River (USGS gaging station 02175000). We set these levels to approximate the rate of flow decline and variability in 1940 (slight, slope = 0.002, amplitude = 0.2), 1975 (moderate, slope = 0.003, amplitude = 0.3), and 2010 (severe, slope = 0.004, amplitude = 0.4) (Figure 2). Inter-annual variability was modeled as a best fit sine curve with a period of 8 years.

Then, we ran the model 500 times with starting values of flow at 3.4 (approximately 2500 cfs) and 2000 crabs (approximately 6.6 million lbs.). We measured crab abundance and % diseased crabs annually for 150 years (1940-2090). From the model output, we projected annual SC landings (in millions lbs.) by multiplying by a scaling factor of (0.00333).

Sensitivity analysis of flow decline (slope) and inter-annual variability (amplitude) was conducted using a fully-factorial RMANOVA. Analysis of crab abundance at the simulation endpoint was conducted using a one-way ANOVA with four levels of conditions (observed, slight, moderate and severe) with Tukey's HSD post-hoc comparisons.

RESULTS

Blue crab abundance, and hence, commercial landings were sensitive to both the rate of freshwater decline (RMANOVA, $F = 3.548$, $df = 4,49$, $P = 0.0128$) and the inter-annual variation (RMANOVA, $F = 91.23$, $df = 4,49$, $P < 0.0001$). The relative importance of each changed with time with amplitude variation explaining the majority of crab abundance variation in the early years and slope variation explaining the majority of variation in the later years. Under conditions of slight flow decline and variability, crab abundance remained relatively stable for the entire simulation period (Figure 3A). With moderate flow decline and variability, crab abundance initially decreases (1940-1970) due to increased predation followed by an increase when flows are optimal (1970-2000) to a slight decline thereafter as rising salinity increases disease (Figure 3B). With severe flow decline and variability, crab abundance decreases almost the entire period with one brief period of positive growth (1990-2000). This steady decline is due to both increased predation when flows are high and increased disease when flows are low (Figure 3C).

To estimate the probable outcome of future scenarios for the SC blue crab fishery, we plotted the frequency of final crab abundance (scaled to annual landings) of 500 model runs for the endpoint year 2090.

Historical records of SC blue crab annual landings from 1979-2013 have a mean (+/- SD) of 5.50 +/- 1.14 million lbs. (Figure 4A). Simulated annual landings for 2090 assuming a slight flow decline and variability are statistically similar (5.41 +/- 1.04) (Figure 4B). However, simulated annual landings for 2090 for a moderate (Figure 4C) and severe (Figure 4D) flow decline and variability are significantly lower with means of 3.87 +/- 0.88 and 1.34 +/- 0.60 million lbs. respectively (Tukey's HSD post-hoc comparisons).

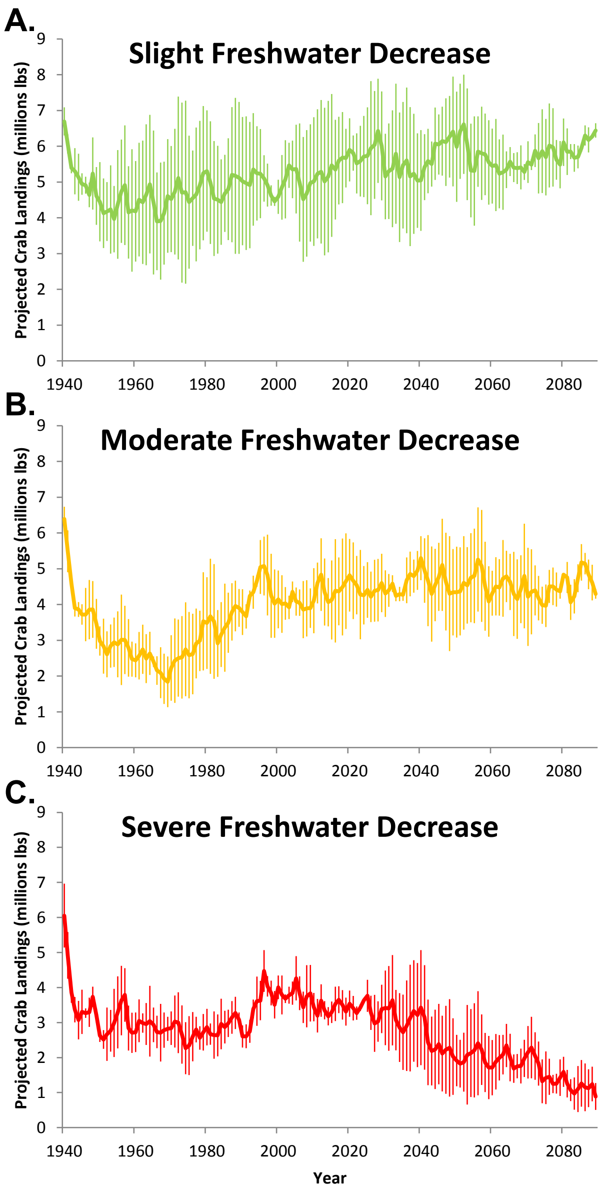

Figure 3. Projected annual landings of blue crabs (mean +/- SD) for 150 year from 1940 to 2090. We simulated the rate of flow decline and amplitude of inter-annual variation using rates from (A) 1940 (slight decrease), (B) 1975 (moderate decrease) and (C) 2010 (severe decrease) as input for 500 replicate runs of the ACE-SCBCRABS model.

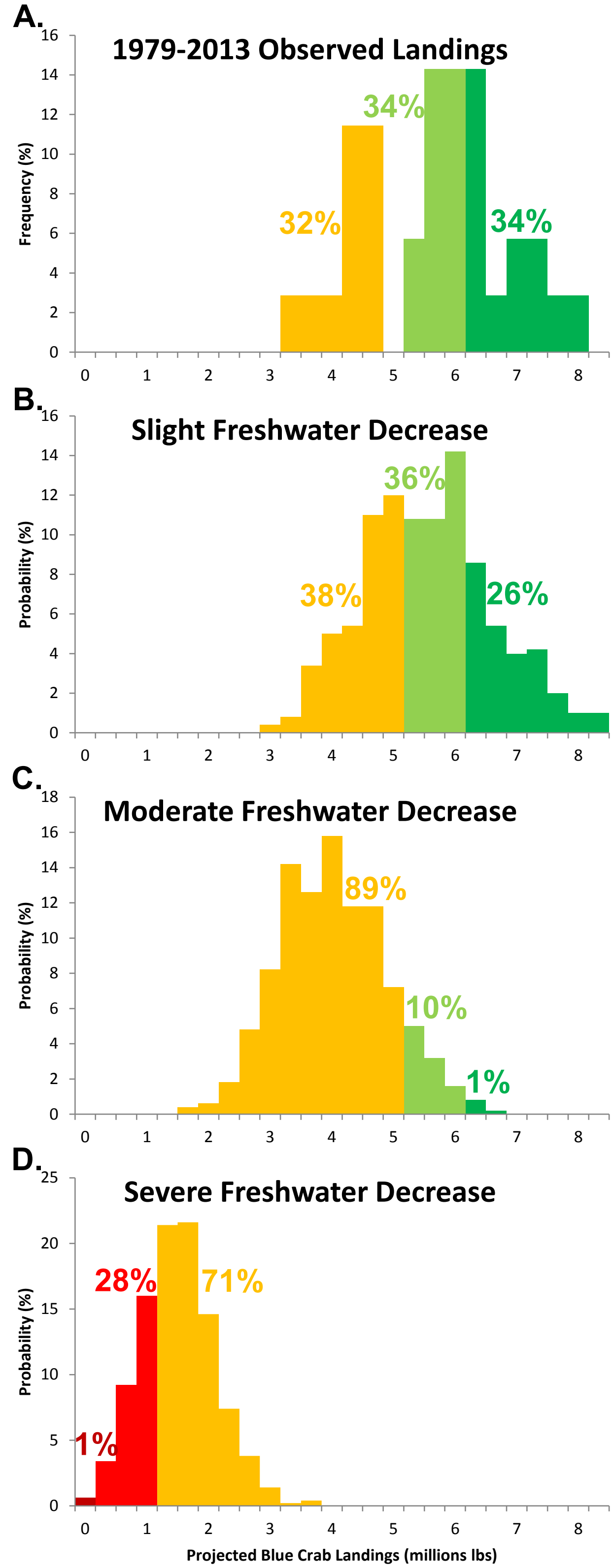

Figure 4. Frequency histogram of SC blue landings (A) observed from 1979 to 2013, (B) projected using slight flow decline and variability, (C) projected using moderate flow decline and variability, and (D) projected using severe flow decline and variability.

DISCUSSION

Blue crabs are one of the most important commercial fisheries in South Carolina, but landings have declined during recent droughts (Childress 2010). This relationship between freshwater discharge and blue crab landings has been observed for other populations of blue crabs including those in Florida (Wilber 1994), Georgia (Lee and Frischer 2004) and Louisana (Sanchez-Rubio et al. 2011). Our previous research has found that during droughts the salinity profiles in the estuary shift upriver increasing exposure to higher salinity water. Droughts cause blue crabs in high salinity rivers to decline due to increased disease while blue crabs in low salinity rivers increase due to reduced predation (Parmenter 2012; Parmenter et al. 2013).

Our modeling effort revealed that both freshwater flow decline and freshwater flow inter-annual variability significantly influenced crab abundance. When the model was run with a slight flow decline and variability, the number of crabs forecasted for 2090 was statistically similar to observed annual landings. However, when the model was run with either moderate or severe flow decline and variability, the number of crabs forecasted for 2090 significantly decreased 30% and 76% respectively.

In all scenarios, crabs initially increase as predation declines with increasing salinity, but eventually crabs decrease due to increasing disease. A similar pattern of initial increase for several decades followed by steady decline in recent years is corroborated by a recent review of blue crab population connectivity along the Atlantic coast (Colton et al. 2013). These populations also show a cyclic inter-annual variation in crab abundance similar to the patterns observed in our model populations.

How much will river flows in the Southeastern US change in the future? Climate forecast models suggest that we can expect our future climate to be wetter, hotter and more variable than in the past, with a net decrease in freshwater surface flow (Seager et al. 2009). This will have broad and significant effects throughout coastal ecosystems (Gilbert et al. 2012). Our research suggests that commercial blue crab landings will significantly decrease (landings below 5 million lbs.) with an 89% probability under a moderate flow decline and variability; and will potentially collapse (landings below 1 million lbs.) with a 29% probability under a severe flow decline and variability.

The risk of blue crab fishery collapse by the end of this century is non-trivial, but is reversible if river discharge levels can be restored to historical levels. This will require a coordinated effort of all stakeholders if we are meet our increasing demand for freshwater while allowing our estuaries to remain productive nurseries for blue crabs.

LITERATURE CITED

Childress, M.J. 2010. Modeling the impact of drought on South Caroline blue crabs using a spatially-explicit individual-based population model. *Proceedings of the 2010 South Carolina Water Resources Conference*, Columbia, SC.

Childress, M.J. and Parmenter, K.J. 2012. Dying of thirst: Impact of reduced freshwater inflow on South Carolina blue crabs. *Proceedings of the 2012 South Carolina Water Resources Conference*, Columbia, SC.

Colton, A.R., M.J. Wilberg, V.J. Coles and T.J. Miller. 2013. An evaluation of the synchronization in the dynamics of blue crab (*Callinectes sapidus*) populations in the western Atlantic. *Fisheries and Oceanography* doi:10.1111/fog.12048

Gilbert, S., K. Lackstrom and D. Tufford. 2012. The impact of drought on coastal ecosystems in the Carolinas: *CISA-2012-01* Columbia, SC: Carolinas Integrated Sciences and Assessments.

Lee, R.F. and M.E. Frischer. 2004. The decline of the blue crab: changing weather patterns and a suffocating parasite may have reduced the numbers of this species along the Eastern seaboard. *American Scientist* 92: 548-553.

Parmenter, K.J. 2012. The effects of drought on the abundance of the blue crab, *Callinectes sapidus*, in the ACE Basin NERR in South Carolina. PhD dissertation, Clemson University, pp 179.

Parmenter, K.J., P.A. Vigueira, C.K. Morlok, J.A. Micklewright, K.M. Smith, K.S. Paul and M.J. Childress. 2013. Seasonal prevalence of *Hematodinium* sp. infections of blue crabs in three South Carolina (USA) rivers. *Estuaries and Coasts* 36:174-191.

Sanchez-Rubio, G., H.P. Perry, P.M. Bieslot, D.R. Johnson and R.N. Lipcius. 2011. Climate-related hydrological regimes and their effects on abundance of juvenile blue crabs (*Callinectes sapidus*) in the northcentral Gulf of Mexico. *Fisheries Bulletin* 109:139-146.

Seager, R., A. Tzanova, and J. Nakamura. 2009. Drought in the southeastern United States: causes, variability over the last millennium, and the potential for future hydrodynamic change. *Journal of Climate* 22:5021-5045.

Wilber, D.H. 1994. The influence of Apalachicola River flows on blue crab, *Callinectus sapidus*, in north Florida. *Fishery Bulletin* 92: 180-188.