# CHAPTER 1 TITLE HERE

## Introduction

The blue crab (Callinectes sapidus) is a highly ranked commercial and recreational fishery in South Carolina with 3.9 million lbs. landed, and a value of $5.1 million in 2018 (ACCSP Non-confidential Landings by Species (Blue Crab) 2020.).

To support management, it is important to understand recruitment dynamics of juvenile blue crab into the adult stage – the stage that is available to commercial and recreational fishers.

Models can be developed to assess recruitment dynamics, including testing of crab abundance in any given year and its relationship to crab abundance in preceding years.

If adult abundance in a year is predicted by juvenile abundance in the prior year (e.g., 1-yr lag), this may provide a more predictive understanding of the blue crab fishery.

The South Carolina Department of Natural Resources (SCDNR) monitors the status of juvenile and adult blue crab across a range of habitat types using multiple fisheries independent surveys. Past research has characterized blue crab life history in South Carolina using both fisheries independent and dependent data in various watershed systems. Fisheries independent data are collected by SCDNR through a suite of monitoring surveys which employ both passive and active fishing methods to collect blue crab at specific life stages. Fisheries independent data can also be used to determine an index of abundance in catch per unit effort.

## Methods

### Census Surveys

A suite of fisheries independent monitoring surveys employed by the South Carolina Department of Natural Resources (SCDNR) encounter the blue crab using methods that vary by survey (Table 1). Surveys vary in their gear types, sampling regimes and microhabitats within the estuary. Data from all surveys were subset from statewide to Charleston Harbor watershed (Ashley River, Cooper River, Wando River and Charleston Harbor) sites (Figure ).

#### CRMS Harbor Trawl

Monitoring has been conducted monthly (1980-2018) at fixed stations in the Ashley River (2 stations) and the Charleston Harbor (2 stations). Sites are located along the river continuum at a distance of approximately 20 river km (Fig ). Beginning in 2002, gear type and sample times were standardized to one 6m (headrope length) otter trawl net with 2.54cm stretch mesh and tickler chain towed parallel to the shoreline near low tide for 15 minutes. Trawls prior to 1986 were typically pulled for 30 minutes, with more tow time variation than in later years. All abundances were standardized to 15-minutes using the equation:

Before 2002, 6m (head rope length) otter trawls with 4.76cm stretch mesh nets were towed from July through December. Abundances taken from samples with a 2-net gear designation were standardized to a 1-net configuration using a regression calculation (r2 = 0.59) from an internal SCDNR publication (Wenner et al. 2002):

Crabs were often subsampled prior to 2002, with total abundance numbers for these samples calculated using:

CPUEs from the Harbor Trawl survey could have any of four standardization equations: 1) no standardization (observed abundance), 2) time-standardization to 15-minute tows, 3) weight standardization for sub-samples, or 4) gear standardization to a 2-net to 1-net gear type.

#### CRMS Creek Trawl

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#### Fisheries Dependent (NMFS and SCDNR)

Fisheries dependent data prior to 2003 are from the National Marine Fisheries Service (NMFS). Beginning in 2003, fisheries dependent data were collected by the SCDNR Fisheries Statistics Section through implementation of a daily or weekly trip tickets system. Data are reported to SCDNR by licensed wholesale vendors as part of the licensing agreement. These fisheries dependent data consist of general abundance information by reporting area, typically eight to ten-digit watersheds (USGS hydrologic units), with binned size data. Although these data can be used for temporally based, abundance information, they only reflect abundance of blue crab above the legal-size limit (>127 mm carapace width).

### CPUE Calculations

Raw fisheries independent data from the Harbor Trawl, Creek Trawl, and Ashley Potting surveys were exported from Microsoft Access databases, maintained by Crustacean Research and Monitoring Section (CRMS) of the South Carolina Department of Natural Resources’ Marine Resources Division. These raw data were standardized to gear and sampling time (Table ) and expressed in survey-specific catch per unit of effort (CPUE). The unit of effort for trawl surveys is one trawl; the unit of effort for the potting survey is one sampling event including 3 blocks of 5 pots.

Mean annual abundance numbers for the CRMS Harbor Trawl and Creek Trawl surveys were calculated as an arithmetic mean of all monthly CPUE values. Mean monthly CPUEs are an arithmetic mean of all abundances across all sampling sites in a month by survey. This was to prevent abundance values weighted by site, in case of uneven catches by site over time.

The Ashley Potting survey uses a randomized bloc w/in a fixed station sampling regime to randomly sample the area, but abundance of pots within a bloc and abundance by bloc are not significantly related. Cumulative sum abundance numbers by date were used as sampling event abundance. Mean annual CPUE was created by standardizing the arithmetic mean abundance of all sampling events (1=October, 1=November) by 240 minutes of soak time, using the equation:

Pre-processed fisheries independent data were received from the Environmental Research Section (SCECAP Open Water and SCECAP Tidal Creek surveys). SCECAP survey CPUE are corrected for the sample area of one downstream pass and one upstream pass of the sample site (VanDolah et al. 2004), based-on a formula of abundance by area sampled (Krebs 1972, VanDolah et al. 2004):

with 10,000 representing 1 hectare in meters, and 2.76 representing the width of the otter trawl net opening in meters(VanDolah et al. 2004). Tow distance is standardized to 250 meters (Tidal Creek survey) and 500 meters (Open Water survey).

Pre-processed fisheries independent data were received from the Inshore Fisheries Research Section (Trammel Net survey). The CPUE from the Trammel Net survey represents total abundance for each set of the trammel net not standardized for soak time or other variables. The Trammel Net survey employs a passive type of sampling that is designed to capture all fish within the sampling area regardless of net soak time.

***Size and Sexual Maturity Explanatory Variables***

A range of biotic data (size, sex, maturity) are recorded as part of several surveys (Table 1). The CRMS harbor and creek trawl surveys have data on size, sex and maturity. The CRMS Potting survey has data on size and not sexual maturity, as these data are recorded in terms of legal (>127 mm) and sublegal (<127 mm) categories. Gear employed as part of the potting survey (38mm mesh) is size selective, targeting legal-sized crab, and allows easy escape of juveniles who have a length to width ratio of about 1:2 (Tagatz 1968). Size data are recoded as part of the SCECAP suite of surveys, but this survey’s data are rounded to the nearest centimeter in contrast to all other survey size data which are expressed in millimeters. Sexual maturity data are not recorded as part of the SCECAP suite of surveys, although sex data for individuals is recoded. The trammel net survey has no size, sex or maturity data - only total abundance data per net deployment.

Individual crabs were assigned to the following size and sexual maturity categories (Table 1): Size Classes - juvenile (<60mm), subadult (61mm - 126mm), sublegal (<127mm) and adult (>126mm); Sexual maturity classes - mature female, immature female, mature male, and immature male. Sex and maturity were determined by presence of morphological characteristics of the abdomen as observed in situ. Size was determined by measurement of the carapace width in situ, from tip to tip. The juvenile size class of crab (<60mm carapace width) is based-on a trophic level shift in diet occurring in crab >60 mm carapace width (Laughlin 1982, Pattillo et al. 1997). The adult size class used (>127 mm carapace width) represents the legal-size limit for entry into the fishery in South Carolina. All crab with carapace widths between juvenile and adult sizes were considered subadult. Sublegal, when used, includes all crab <127mm.

CPUEs for size and sexual maturity variables were calculated by creating a percentage of total catch of each sexual maturity class for each sampling event (e.g., trawl, trammel set, or pot set). These percentages were then applied to the standardized total CPUE for the sampling event. Sexual maturity CPUE variables are conservative estimates because some individuals were categorized as unidentifiable.

### Analytical Methods

Adult CPUEs were compared to juvenile CPUEs 1 and 2 years prior to test the applicability of a juvenile index. Ordinary Least Squares regression models usi

Additional indices of adult CPUE and total CPUE were developed using single regression models (n=) for each life-stage specific category at 1-yr and 2-yr lags.

Significant (α = 0.05) models were ranked by explanatory power (i.e., r2)

## Results

### Long-term Trends of Abundance

Time series of annual commercial landings (Fig. 1) and adult (legal-sized) CPUEs from SCDNR fisheries independent surveys (fig. 2) show the high inter-annual variability of blue crab abundance. Standard error bars for annual samples on most surveys are outside the population mean, suggesting annual blue crab data with moving averages. A non-parametric LOESS (locally estimated scatterplot smoothing) smoothing function using local regression was applied to better represent these data for visual analyses.

The total pounds landed in the combined Charleston Harbor watersheds shows a trending decline from 2003 – 2010 after a 14-yr period of above long-term mean landings. There is a marked break in the trend of values beginning in 2003. No landings data for the Ashley River and Cooper River exist prior to 2003, which may account for the fluctuation reflected in the data (Fig. ). Long-term total pounds landed data could suggest a long-term cyclical seasonality, but the impact of these two missing reporting areas from 1980-2003 is unknown. When corrected for effort the same visual trend appears as total landings, but with less outliers.

There seems to be a seasonality in the CRMS Harbor Trawl mean annual adult abundance (Figure 2A), where every several years (3-6 years) a spike in adult abundance with high variability is observed. Years representing above average abundances in the CRMS Harbor Trawl have far more variability than years with below mean abundances. This could be due to acute occurrence of large catches rather than sustained large catches throughout the year.

Seasonality may also be present in the CRMS Creek Trawl, but closer to a decadal cyclical scale. Several ontogenetic stages of blue crab have seasonal and annual abundance patterns (Orth & van Montfrans 1987), but these data could show long-term trends beyond the life-cycle of the crab and outside the influence of cohorts. Seasonal variability of adult abundance in the CRMS Tidal Creek survey is lower than most surveys.

A long-term downward trend can be observed in the Ashely Potting survey, but possibly another 3-yr. seasonality of decline followed by a spike in abundance. The Ashely Potting survey’s sampling area is 762 linear meters along the channel of the Ashley River sampled in October and November. This survey provides a snapshot of the population in the time of year when large males egress from the fresher waters of the upper estuary. The negative trend in abundance over time from this small sampling window could suggest a shift in migration patterns.

No trends seem to exist for the SCECAP Open Water and Tidal Creek surveys. The SCECAP survey employs a random stratified by creek size on a statewide survey level. These survey’s data time series (Figures 2D and 2E) include several years that were not sampled and may be affected by uneven sampling events through years. The Trammel Net survey has no adult size information, but no trends seem present when considering total CPUE.

### Juvenile Index of Adult Abundance

Mean annual juvenile CPUE is not significantly related to mean annual adult CPUE in subsequent years for any survey (Table 3). These analyses were not performed on surveys without juvenile data (Trammel Net and Ashley Potting).

### Indices of Adult and Total Abundance

*\*Explore other indices of abundance for size class and sexual maturity categories as they relate to total or adult blue crab abundance in subsequent years (e.g. 1-yr and 2-yr lag)\**

The CRMS Creek Trawl is the only survey (see notes for Tables 5 & 6) with predictive relationships where size class and sexual maturity categories relate to total or adult abundance in successive years (Table 4). Fifteen size class and sexual maturity variables with 1- and 2-yr lag explain total CPUE and adult CPUE. The highest ranked model total Creek Trawl CPUE explained by subadult CPUE with a 2-yr lag (*p*-value = <0.01, r2 = 0.24; Fig. 3).

### Commercial Landings Predictions

\*Explore predictive relationships between fisheries-independent size class and sexual maturity abundance categories and commercial landings\*

Nine total predictive models using several size class and sexual maturity categories with 1-yr lag to explain effort corrected landings were developed. No 2-yr lagged size class and sexual maturity categories predict effort corrected landings. Predictive relationships were only found using the CRMS Harbor Trawl (N = 3) and Creek Trawl (N = 6) surveys. The strongest relationships ranked by explanatory power (r2) use the Harbor Trawl subadults with a 1-yr lag (*p* = <0.01, r2 = 0.43) and the Creek Trawl immature males with a 1-yr lag (*p* = <0.01, r2 = 0.41, Table 7).

Total landings (not effort corrected) have only two predictive relationships were size classs and sexual maturity variables from any survey predict total annual lbs landed (Table 8). These two poorly correlated relationships use mature males with a 1-yr lag from the Harbor Trawl (*p* = <0.05, r2 = 0.10) and adults with a 2-yr lag from the Ashley Potting Survey (*p* = <0.05, r2 = 0.15) to predict total annual pounds landed. Total landings data are missing for the Ashley and Cooper Rivers prior to 2004.

\*\*Table 7:\*\* Objective 3 - All significant relationships of effort corrected Charleston Harbor watershed (Ashley, Cooper and Wando Rivers and Charleston Harbor) commercial Landings by size classs and sexual maturity variables from all surveys using OLS regression.

ACCSP Non-confidential Landings by Species (Blue Crab) generated by SC (2020) Atlantic Coastal Cooperative Statistics Program. https//www.accsp.org; Data Wareh

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