Using long-term survey data to predict blue crab (*Callinectes sapidus*) abundance and commercial landings in Charleston Harbor, South Carolina

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Abstract

Marked high fluctuations in blue crab (*Callinectes sapidus*) seasonal and annual abundance, and commercial landings are typical, but data from both fisheries independent and dependent surveys have shown declines in populations in recent years in South Carolina. Despite several long-term fisheries independent surveys encountering blue crab, predictive models have not recently been developed in South Carolina to quantify variation in abundance and commercial landings. The goal of this study is to assess the current status of blue crab in SC and explore the potential for developing a more predictive understanding of commercial landings. This goal is met through the following objectives: 1) assess long-term trends in blue crab landings and fisheries-independent abundance, 2) test the applicability of a juvenile index, where juvenile abundance in one year predicts adult abundance in a subsequent years (e.g. 1-yr and 2-yr lag), 3) 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), and 4) explore predictive relationships between fisheries-independent size class and sexual maturity abundance categories and commercial landings. Data from several long-term South Carolina Department of Natural Resources (SCDNR) fisheries independent blue crab surveys were standardized for each of six surveys and commercial landings data were compiled. Analyses testing the application of a juvenile index of abundance show that no juveniles collected in surveys explain variation in annual survey abundances. The Creek Trawl survey was the only survey with significant, but weak, correlative relationships between multiple lagged population structure variables and its own annual adult or total abundance. Significant relationships were found with effort-corrected commercial landings predicted by the previous year's abundance of male crabs. This relationship was most correlated for immature crabs collected in the Harbor Trawl survey, and for mature crabs collected in the Creek Trawl survey. These results suggest a larger influence on abundance of blue crab from fishing effort than population dynamics, and a potential influence from other external factors such as habitat or environmental variables.

Background

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. 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 fisheriesindependent surveys.

Methods

Survey Methods

A suite of fisheries independent monitoring surveys employed by the South Carolina Department of Natural Resources (SCDNR) encounter the blue crab using varying gear types in varying habitats with varying sampling regimes (Table 1).

Biotic data recorded as part of both surveys (size, sex, maturity). Size is determined by measurement of the carapace width. Sex and maturity are determined by presence of morphological characteristics of the abdomen.

Analytical Mehods

Data were put through a rigorous data wrangling process to standardize each survey relative to its own methods. Fisheries dependent commercial landings and fisheries independent survey abundances were truncated from statewide data to Charleston Harbor watershed data. Individual crabs were assigned to the following size and sexual maturity categories (Table 2): Size Classes - juvenile (>59mm), subadult (61mm - 126mm), sublegal (<127mm) and adult (>126mm); Sexual maturity classes: mature female, immature female, mature male, and immature male. Monthly means across all stations were used to calculate mean annual abundances as catch-per-unit-effort (CPUE). Adult CPUEs were compared to juvenile CPUEs 1 and 2 years prior to test the applicability of a juvenile index. 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 ($\alpha = 0.05$) models were ranked by explanatory power (i.e., r^2)

Table 1: SCDNR fisheries independent survey methodology.

Survey	Gear		Sample			Data	
	Gear Method	Gear Type	Sample Area	Sample Interval	Sample Method	N(events)	CPUE Standardization
CRMS							
Creek Trawl	Active	6m Trawl, 2.54cm stretch mesh	Ashley River, Wando River	Monthly, May-Sep	Fixed Stations	1827	Time
Harbor Trawl	Active	4.6m Trawl, 0.6cm D mesh	Ashley River, Charleston Harbor	Monthly	Fixed Stations	2956	Time, Gear
Ashley Fall Potting	Passive	0.6 x 0.6 x 0.46m Pot, 3.8 cm mesh	Ashley River	Monthly, Oct-Nov	Randomized Block w/in a Fixed Station	128	Time
ERS							
SCECAP Tidal Creeks	Active	5m trawl, 1.9cm bar mesh	Charleston Harbor Systemwide	Jun - Aug	Random Stratified	62	Volumetric
SCECAP Open Water	Active	5m trawl, 1.9cm bar mesh	Charleston Harbor Systemwide	Jun - Aug	Random Stratified	92	Volumetric
IFRS							
Trammel Net	Passive	183 x 2.1m trammel net	Charleston Harbor Systemwide	Monthly	Random Stratified	4736	None (Total)

Table 2: Blue crab size class and sexual maturity data found in SCDNR fisheries independent surveys

Survey	Total CPUE	Size				Class (Sex/Maturity)			
		Juvenile	Subadult	Sublegal	Adult	Immature Female	Mature Female	Immature Male	Mature Male
CRMS									
Creek Trawl	X	X	X	X	X	X	X	X	X
Harbor Trawl	X	X	X	X	X	X	X	X	X
Ashley Fall Potting	X			X	X				
ERS									
SCECAP Tidal Creeks	X	X	X	X	X				
SCECAP Open Water	X	X	X	X	X				
IFRS									
Trammel Net	X								

Restults

Objective 1

Assess long-term trends in blue crab landings and fisheries-independent abundance

Time series of mean annual commercial landings (Fig. 1) and adult abundances from SCDNR fisheries independent surveys (fig. 2) show the high inter-annual variablility of legal-sized “adult” blue crab (>126mm). These figures both show crab >126mm, which is the minimum legal limit of blue crab in South Carolina.

The total pounds landed in the combined Charleston Harbor watersheds shows a trending decline from 2003 - 2010, but when these same landings data are corrected for effort in terms of number of pots pulled that trend is not observed. The year 2003 marks the first year of “trip ticket” reporting, in which all commercial blue crab license holders are required to report their catch. This is the same time (>2003) landings data have incorporated data from the Ashley River and Cooper River reporting areas. This could be due to not being actively fished for blue crab, underreported for these reporting areas or included in another reporting area (e.g. a line of crab pots beginning in the Ashley River and continuing into Charleston Harbor where landings are eventually reported). Adult abundances from some surveys (B-Creek Trawl, C-Ashley Potting and D-SCECAP Open-Water) show a slight decline in adult abundance shortly after 2000.

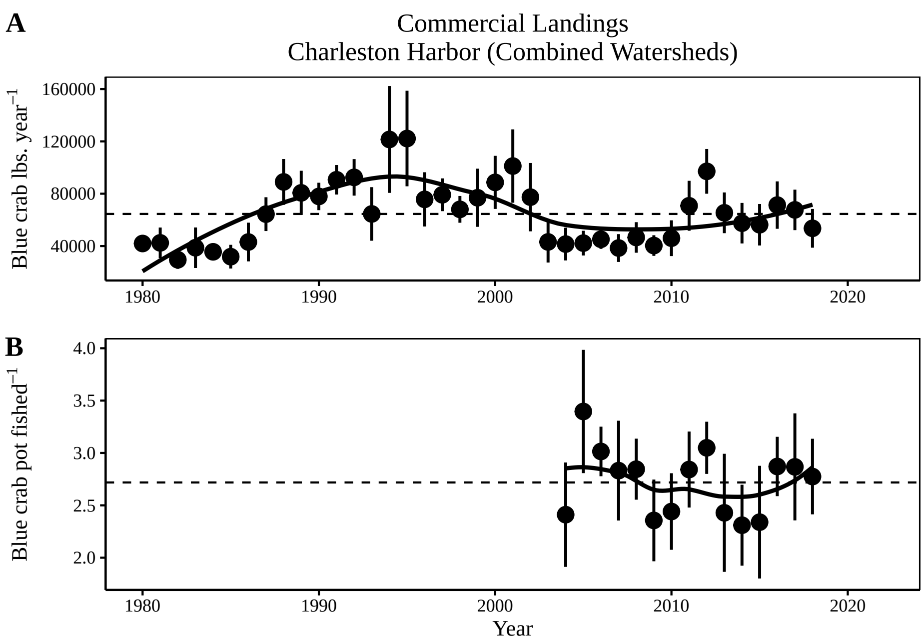

Figure 1: Plot represents mean annual time series of (A) total landings in total lbs./yr and (B) mean annual effort-corrected landings (total lbs./pot pulled/yr) for the combined reporting areas of the Charleston Harbor watershed

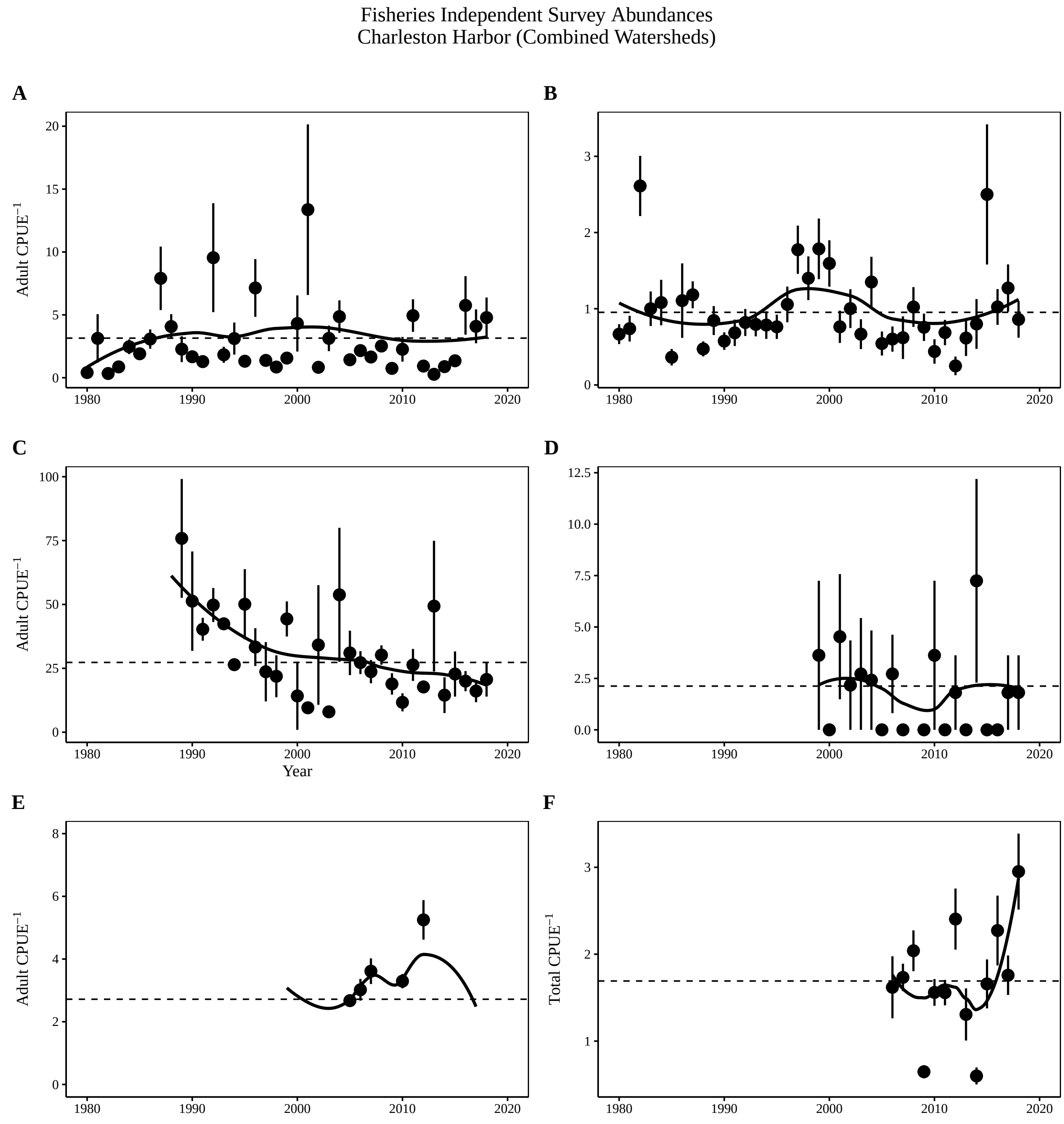

Figure 2: Plot represents mean annual adult survey abundances of the (A) Harbor Trawl, (B) Creek Trawl, (C) Ashley Potting Survey, (D) SCECAP Open-Water and (E) SCECAP Tidal-Creek surveys, with standard error, long-term mean (dashed) and a LOESS smoothing line (solid). The Tammel Net survey does not have size or sexual maturity data and is represented by total CPUE in this plot.

Objective 2

Test the applicability of a juvenile index, where juvenile abundance in one year predicts adult abundance in a subsequent years (e.g. 1-yr and 2-yr lag)

Mean annual juvenile CPUE is not significantly related to mean annual adult CPUE in subsequent years for any survey (Table 3).

Table 3: Insignificant and poorly correlated relationships of adult CPUEs by juvenile CPUEs

		Summary Statistics		
Dpendent Variable	Explanatory Variable	p-value	r2	Degrees of Freedom
Harbor Trawl				
Adult	Juvenile (1-yr. lag)	0.15	0.06	36
Adult	Juvenile (2-yr. lag)	0.86	<0.01	35
Creek Trawl				
Adult	Juvenile (1-yr. lag)	0.43	0.02	36
Adult	Juvenile (2-yr. lag)	0.35	0.02	35
SCECAP Open Water				
Adult	Juvenile (1-yr. lag)	0.19	0.11	36
Adult	Juvenile (2-yr. lag)	0.15	0.14	35
SCECAP Tidal Creek				
Adult	Juvenile (1-yr. lag)	0.77	<0.01	36
Adult	Juvenile (2-yr. lag)	0.24	0.14	35
Ashley Potting				
Legal (adult)	Sublegal (1-yr. lag)	0.34	0.03	36
Legal (adult)	Sublegal (2-yr. lag)	0.56	0.01	35

Objective 3

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 succesive years (Table 4). Fifteen size class and sexual maturity variables with 1- and 2-yr lag explain total CPUE and explain adult CPUE. The highest ranked model total Creek Trawl CPUE explained by subadult CPUE with a 2-yr lag (p-value = <0.01, r^2 = 0.24; Fig. 3).

Table 4: These are all relevant explanatory variables predicting CRMS Creek Trawl Survey total and adult CPUEs

		Summary Statistics		
Dependent Variable	Explanatory Variable	p-value	r2	Degrees of Freedom
Total CPUE	Subadult (2-yr. lag)	<0.01	0.24	35
Total CPUE	Mature Male (1-yr. lag)	<0.01	0.23	36
Total CPUE	Immature Male (2-yr. lag)	<0.01	0.21	35
Total CPUE	Sublegal (1-yr. lag)	<0.01	0.21	35
Total CPUE	Total CPUE (2-yr lag)	<0.01	0.21	35
Total CPUE	Subadult (1-yr. lag)	<0.01	0.18	36
Total CPUE	Immature Female (2-yr. lag)	<0.01	0.17	35
Total CPUE	Mature Female (2-yr lag)	<0.05	0.15	35
Total CPUE	Total CPUE (1-yr lag)	<0.05	0.14	36
Total CPUE	Sublegal (1-yr. lag)	<0.05	0.13	36
Total CPUE	Mature Male (2-yr. lag)	<0.05	0.13	35
Total CPUE	Adult (1-yr. lag)	<0.05	0.12	36
Total CPUE	Legal (1-yr. lag)	<0.05	0.12	36
Total CPUE	Immature Male (1-yr. lag)	<0.05	0.10	36
Total CPUE	Immature Female (1-yr. lag)	<0.05	0.10	36
Adult CPUE	Mature Male (1-yr. lag)	<0.01	0.16	36
Adult CPUE	Mature Female (2-yr lag)	<0.05	0.12	35

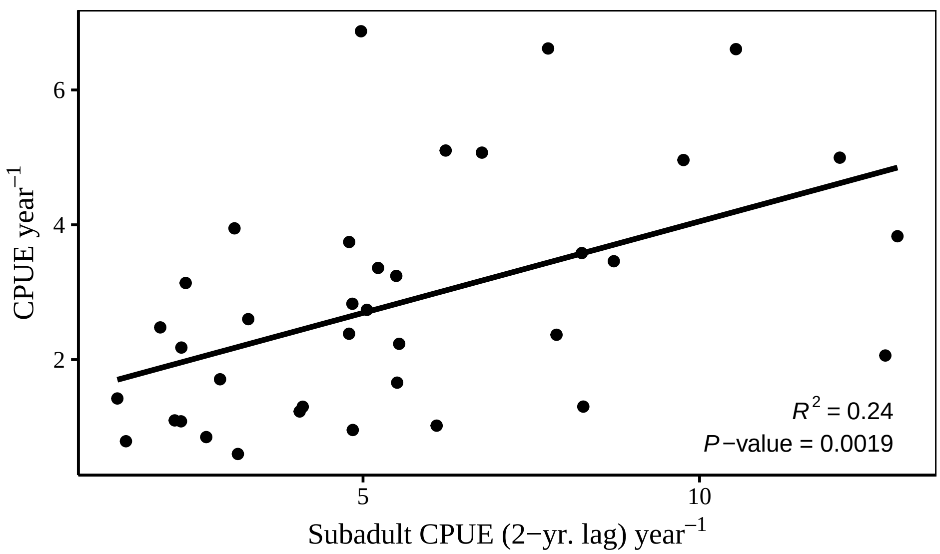

Figure 3: Plot showing the regression relationship of total Creek Trawl CPUE by Creek Trawl subadult CPUE from 2 years prior. This the highest correlated relationship of total or adult CPUE by lagged lifestage variable.

Tables 5 & 6

The SCECAP Tidal Creek survey has multiple very significant and highly correlative relationships with size and sexual maturity categories predicting total and adult CPUEs, but I would like it removed from the analyses. Constructing regression models using the same methodology as the other surveys makes SCECAP Tidal Creeks trawl look like a super star at first glance, with ridiculously high r^2's (Table 5). But there are a max of 6 sampling events/year (mean sampling events = 3.1) and never greater than 4 events after 2005 (Table 6). SCECAP Tidal Creek survey only has a total of 192 crab caught (135 in 2012) over the life of the survey with an inflated CPUEs based-on volumetric standardization of SCECAP's catch.

Tables 5: OLS regression results of SCECAP total and adult CPUE by all lifestages from SCECAP Tidal Creek survey

		Summary Statistics		
Dependent Variable	Explanatory Variable	p-value	r2	Degrees of Freedom
SCECAP Tidal Creek				
Total CPUE	Subadult (2-yr. lag)	<0.001	0.93	10
Total CPUE	Sublegal (2-yr. lag)	<0.001	0.92	10
Total CPUE	Total CPUE (2-yr lag)	<0.001	0.88	10
Total CPUE	Adult (2-yr. lag)	<0.01	0.54	10
Adult CPUE	Subadult (2-yr. lag)	<0.001	0.91	10
Adult CPUE	Sublegal (2-yr. lag)	<0.001	0.90	10
Adult CPUE	Total CPUE (2-yr lag)	<0.001	0.85	10
Adult CPUE	Adult (2-yr. lag)	<0.01	0.51	10
SCECAP Open Water				
Adult CPUE	Adult (1-yr lag)	<0.05	0.24	10

Tables 6: SCECAP Tidal Creek survey data table showing a small annual sample size with small raw abundance numbers, inflated CPUEs and several years with no sampling events

Year	Sampling Events	Raw Abundance	Total CPUE	Juvenile CPUE	Subadult CPUE	Adult CPUE
1999	6	4	9.7	0.0	7.2	2.4
2000	6	3	7.2	0.0	0.0	4.8
2001	4	1	3.6	0.0	0.0	3.6
2002	6	0	0.0	0.0	0.0	0.0
2003	6	2	4.8	0.0	4.8	0.0
2004	4	2	7.2	0.0	3.6	3.6
2005	8	7	12.7	1.8	0.0	10.9
2006	2	3	21.7	0.0	0.0	21.7
2007	4	12	48.1	0.0	15.0	33.2
2008	2	0	0.0	0.0	0.0	0.0
2009	0					
2010	4	18	65.2	3.6	32.6	29.0
2011	0					
2012	2	135	1291.1	0.0	1061.6	229.5
2013	0					
2014	0					
2015	2	1	7.2	7.2	0.0	0.0
2016	2	1	7.2	0.0	0.0	7.2
2017	2	2	14.5	0.0	7.2	7.2
2018	2	1	7.2	0.0	7.2	0.0

Objective 4

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 (r^2) use the Harbor Trawl subadults with a 1-yr lag (p = <0.01, r^2 = 0.43) and the Creek Trawl immature males with a 1-yr lag (p = <0.01, r^2 = 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, r^2 = 0.10) and adults with a 2-yr lag from the Ashley Potting Survey (p = <0.05, r^2 = 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 relatioships of effort corrected Charleston Harbor watershed (Ashley, Cooper and Wando Rivers and Charlesotn Harbor) commercial Landings by size classs and sexual maturity variables from all surveys using OLS regression.

		Summary Statistics		
Dependent Variable	Explanatory Variable	p-value	r2	Degrees of Freedom
Harbor Trawl (explanatory variable)				
Mean Landings (effort corrected)	Mature Male (1-yr. lag)	<0.01	0.43	13
Mean Landings (effort corrected)	Subadult (1-yr. lag)	<0.05	0.37	13
Mean Landings (effort corrected)	Total CPUE (1-yr. lag)	<0.05	0.32	13
Creek Trawl (explanatory variable)				
Mean Landings (effort corrected)	Immature Male (1-yr. lag)	<0.01	0.41	13
Mean Landings (effort corrected)	Sublegal (1-yr. lag)	<0.05	0.38	13
Mean Landings (effort corrected)	Subadult (1-yr. lag)	<0.05	0.35	13
Mean Landings (effort corrected)	Total CPUE (1-yr. lag)	<0.05	0.33	13
Mean Landings (effort corrected)	Juvenile (1-yr. lag)	<0.05	0.31	13
Mean Landings (effort corrected)	Immature Female (1-yr. lag)	<0.05	0.30	13

Table 8: All significant relatioships of total Charleston Harbor watershed (Ashley, Cooper and Wando Rivers and Charlesotn Harbor) commercial lbs landings by size classs and sexual maturity variables from all surveys using OLS regression.

		Summary Statistics		
Dependent Variable	Explanatory Variable	p-value	r2	Degrees of Freedom
Harbor Trawl (explanatory variable)				
Total lbs landed	Mature Male (1-yr. lag)	<0.05	0.10	36
Ashley Potting (explanatory variable)				
Total lbs landed	Adult (2-yr. lag)	<0.05	0.15	27

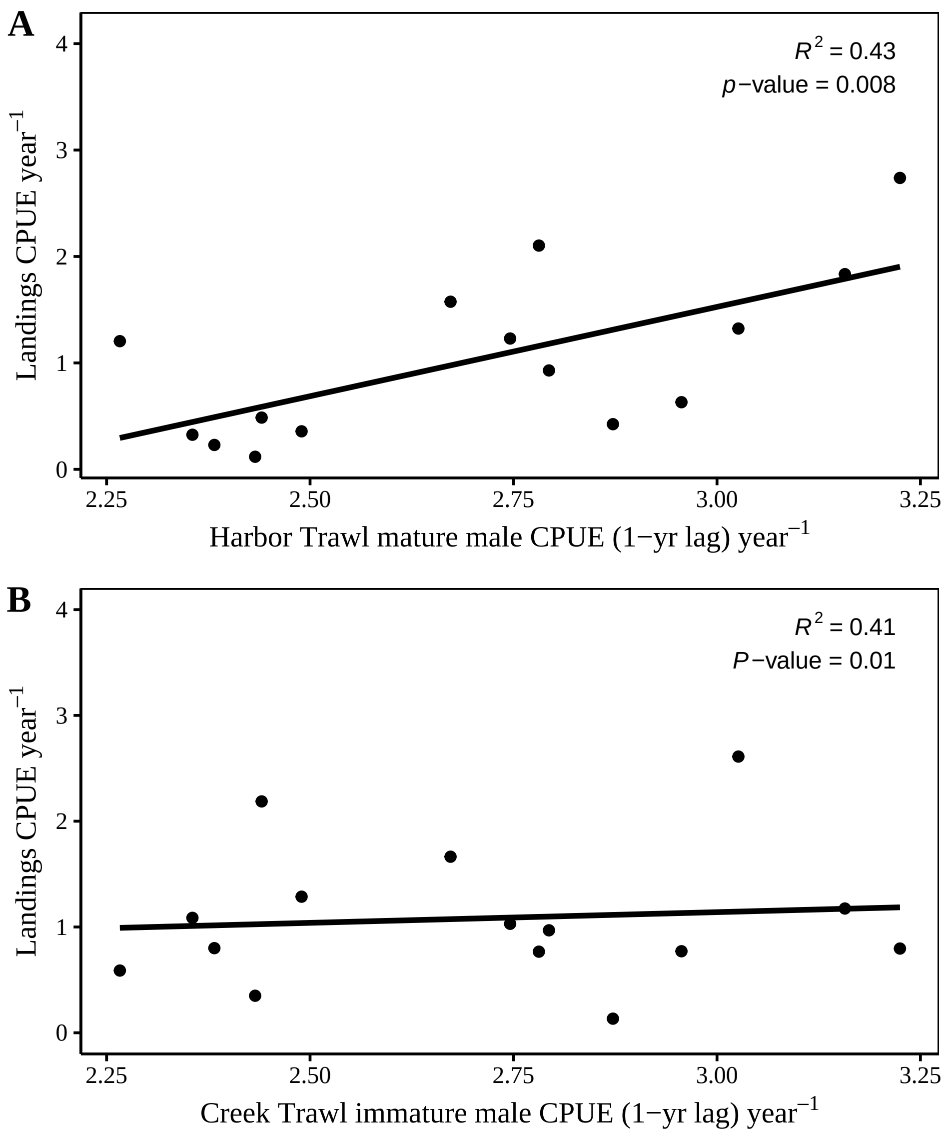

Figure 4: Ordinary Least Squares regression plots of select significant explanatory relatioships using lagged variables to Charleston Harbor watershed Landings CPUEs. Mean annual effort corrected landings by (A) Harbor Trawl mature males with a 1-yr lag, and (B) mean annual landings CPUE by Creek Trawl immature males CPUE with a 1-yr. lag.