Economic Valuation of Submerged Aquatic Vegetation in the Albemarle-Pamlico Estuary

Final Report

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Executive Summary

Submerged aquatic vegetation (SAV), also referred to as underwater grasses or seagrasses, grow in estuarine environments. Many aquatic species that are important to commercial and recreational fisheries use SAV for habitat, food, and nurseries. SAV also filters nutrients, prevents erosion, and sequesters carbon, all of which generate valuable ecosystem services. These services make SAV a vital contributor to the health of estuarine ecosystems and coastal communities.

The SAV located in the Albemarle-Pamlico (A-P) estuary provides significant market and nonmarket value to the state of North Carolina. Recent analysis by Field et al. (2020) suggests that SAV coverage in the A-P estuary has declined over the last 15 years. In this report, we quantify potential economic losses resulting from future declines in SAV coverage in the A-P estuary over the next decade. Our analysis is not comprehensive; it does not quantify all economic losses, nor does it consider all potential decadal declines in SAV coverage. Instead, we focus on four categories of ecosystem services and consider how their values change across four alternative SAV loss scenarios. The four categories we consider are:

- Commercial fisheries
- Recreational fishing
- Residential property values
- Carbon storage and sequestration

For each of these categories, we estimate changes in economic value resulting from SAV losses over the next decade that add up to 5, 15, 25 and 50 percent losses.

The key findings from our analysis are:

- Our estimate of economic losses increases proportionately with declines in SAV acreage and is roughly $1,290 per lost acre. There are relatively few reliable studies that quantify commercial fishing, recreational fishing, property value, or carbon storage and sequestration losses from SAV, and our estimate is the first to account for all four categories of losses over a decadal scale. For several reasons that we summarize below, we caution that our estimate should be interpreted as an incomplete and conservative estimate of the total benefits of SAV.
- Table 1 reports upper bound, lower bound and midpoint estimates of aggregate economic losses over the next decade across the four categories we considered from alternative SAV loss scenarios.

Table 1:
Aggregate Economic Losses from SAV Coverage Declines
(millions of 2019 dollars)

Scenario	Lower Bound Estimate	Upper Bound Estimate	Midpoint Estimate
5 Percent Decadal Loss	$6.07	$11.22	$8.64
15 Percent Decadal Loss	$16.22	$26.79	$21.50
25 Percent Decadal Loss	$31.99	$57.69	$44.84
50 Percent Decadal Loss	$63.02	$114.30	$88.66

- Our midpoint estimate of total economic losses associated with a 5 percent decadal loss in SAV is $8.7 million per year (2019 dollars), whereas our midpoint estimate of economic losses with a 50 percent decadal loss is $88.7 million per year.
- Over half of these economic losses are due to declines in sequestered carbon. Our midpoint carbon sequestration loss estimates range from $5.6 million per year (5 percent decadal loss) to $55.6 million per year (50 percent decadal loss).
- Declines in SAV result in reduced nursery habitat for blue crab and thus reduce the health of the commercial blue crab fishery. Midpoint profit loss estimates for the blue crab commercial fishery range from $0.7 million (5 percent decadal loss) to $6.6 million (50 percent decadal loss).
- The midpoint recreational fishing annual losses, which are limited to declines in catch for spotted seatrout and red drum, range from $0.5 million under the 5 percent decadal loss scenario to $4.2 million under the 50 percent decadal loss scenario.
- Annual losses associated with residential property values are substantial and range from $2.0 million under the 5 percent decadal scenario to $22.6 million under the 50 percent decadal loss scenario. These losses are more the one-quarter of total losses.

These losses are economically large and significant. They do not, however, capture the full market and nonmarket losses from declines in SAV coverage. For example, our loss estimates for commercial and recreational fisheries are limited to three species – blue crab, red drum, and spotted seatrout – although other species would be negatively affected by SAV declines. Moreover, we only quantify those nutrient filtration benefits that impact commercial fisheries, recreational fisheries, and property values even though SAV filters nutrients and improves water quality throughout the A-P estuary. An additional limitation is that we only monetize coastal erosion losses for SAV near residential properties although much SAV is located along undeveloped shorelines. We also do not quantify losses to waterfowl hunters and nature watchers. We hope the data and biological modeling gaps that limited us from quantifying these additional losses will be filled with future research.

Introduction

Submerged aquatic vegetation (SAV), or underwater grasses or seagrasses, provides many ecosystem services to estuaries and coastal areas throughout the world. As Blandon and zu Ermgassen (2014) and Waycott et al. (2009) have shown, these services are now under threat as SAV coverage has declined globally in recent decades. In North Carolina, the losses are less stark but still concerning – a recent report by Field et al. (2020) found that high salinity SAV coverage in the Albemarle-Pamlico (A-P) estuary declined by 5,686 acres (or 5.6 percent) between 2006 and 2013.

Because SAV restoration is costly and prone to fail unless vigorous monitoring efforts are employed after project completion (Fonseca et al., 2001; Bayraktarov et al., 2016),[1] ecosystem services losses from declines in SAV coverage may be substantial. Some of these losses can be measured through market outcomes such as declines in the profitability of commercial fishing. Other losses, however, cannot be measured through markets and thus are harder to measure. This report aims to quantify both market and nonmarket losses from potential declines in SAV coverage in the A-P estuary over the next ten years. Our analysis employs a decadal time frame because: 1) North Carolina coastal habitat policy development and implementation operates on a 5- to 10-year time frame; 2) projections more than a decade into the future would likely have greater uncertainty and thus be more speculative; and 3) newer and richer data as well as better understanding of biological and economic processes are likely to arise over the next decade, which will motivate an updated analysis.

We focus on four prominent categories of losses – commercial fishing, recreational fishing, residential property values, and carbon storage and sequestration – where data and biological models permit us to estimate losses for four different SAV loss scenarios. In reviewing the existing SAV valuation literature, Barbier et al. (2011) identify few reliable value estimates for SAV that are largely limited to commercial fishing. As noted by Dewsbury et al. (2016), investigations of other SAV benefits often rely on questionable economic assumptions[2] and report the total value of the coastal ecosystem where SAV resides instead of SAV's contribution to the ecosystem. In recent decades, economic studies of SAV's role in carbon sequestration and storage have become more common (Pendelton et al., 2012; Van Houtven et al., 2016), and our study here uses a similar framework tailored to the A-P estuary and leveraging more recent data.

Although our study is more comprehensive than previous economic studies of SAV, it is important to emphasize that by no means does it represent a full and complete accounting

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[1] Bayraktarov et al. (2016) report that the average SAV restoration project costs roughly $50,000 per acre (2019 dollars) and the median survival rate for restored SAV one to two years after project completion is only 38 percent. Fonseca et al. (2001) point out that the largest cost component for SAV restoration projections is post-completion monitoring.

[2] For example, restoration costs are often used in these studies to measure economic value, but as discussed by Bockstael et al. (2000), restoration costs are only valid measures of willingness to pay under a restrictive set of circumstances.

of SAV benefits. Section 9 of this report discusses limitations with our analysis, the data and models that underly it, and market and nonmarket SAV benefits that are not monitized. With better data and advances in our understanding of complex, interdependent biological and economic systems that impact SAV, future research will be able to improve on our current analysis. Nevertheless, the quantification of the four categories of economic losses reported in this report may help state and local resource managers and policy makers as they make decisions that will affect SAV coverage and condition in the future.

The A-P estuary contains the largest acreage of SAV along the Atlantic seaboard of the United States. Anthropogenic pressures from growing coastal populations and more intensive resource use and extraction have led to declines in SAV coverage in recent decades. If these trends continue or accelerate, the market and nonmarket benefits of SAV will decline. In this report, we consider four different SAV loss scenarios involving 5, 15, 25, and 50 percent decadal SAV losses where losses occur gradually across years. For each scenario, we quantify economic losses associated with commercial fishing, recreational fishing, residential property values, and carbon sequestration. Our estimates suggest that aggregate losses for these categories are large and economically significant. For example, for the 50 percent decadal SAV loss scenario, we find a midpoint estimate of total losses across the four categories equal to $88.7 million per year.

This report documents the data, biological modeling, and economics that went into constructing our loss estimates. We begin in Section 1 by providing a basic overview of the state of SAV in the A-P estuary including changes in SAV coverage over time as well as current threats to SAV. We then provide in Section 2 an explanation of our approach to measuring market and nonmarket losses from SAV losses within the willingness to pay framework. We also describe the four SAV losses scenarios that we consider.

In Section 3, we provide an overview of the biological modeling that links SAV coverage to fishery production for three species that are important to commercial and recreational fisheries in the A-P estuary – blue crab, spotted seatrout, and red drum. We then utilize the catch predictions presented in Section 3 to estimate changes in economic value to commercial and recreational fisheries under different SAV loss scenarios. In Section 4, we provide estimates for how changes in catch affect profits in the commercial blue crab fishery under different scenarios. In Section 5, we monetize how changes in catch rates from SAV loss translate into economic losses for recreational anglers.

We utilize the hedonic method in Section 6 to measure how changes in SAV coverage will be capitalized into residential properties near the A-P estuary's shoreline. We then consider in Section 7 how SAV coverage losses will lead to reduced carbon sequestration and storage. Section 8 then aggregates these losses across the four categories recognizing that there may be some double counting across the recreational fishing and property value categories. Section 9 discusses how the current analysis can be improved with future research that fills important data and modeling gaps and then discusses how future research might quantify some of the SAV value not accounted for in this report. We conclude in the final section by summarizing our key findings.

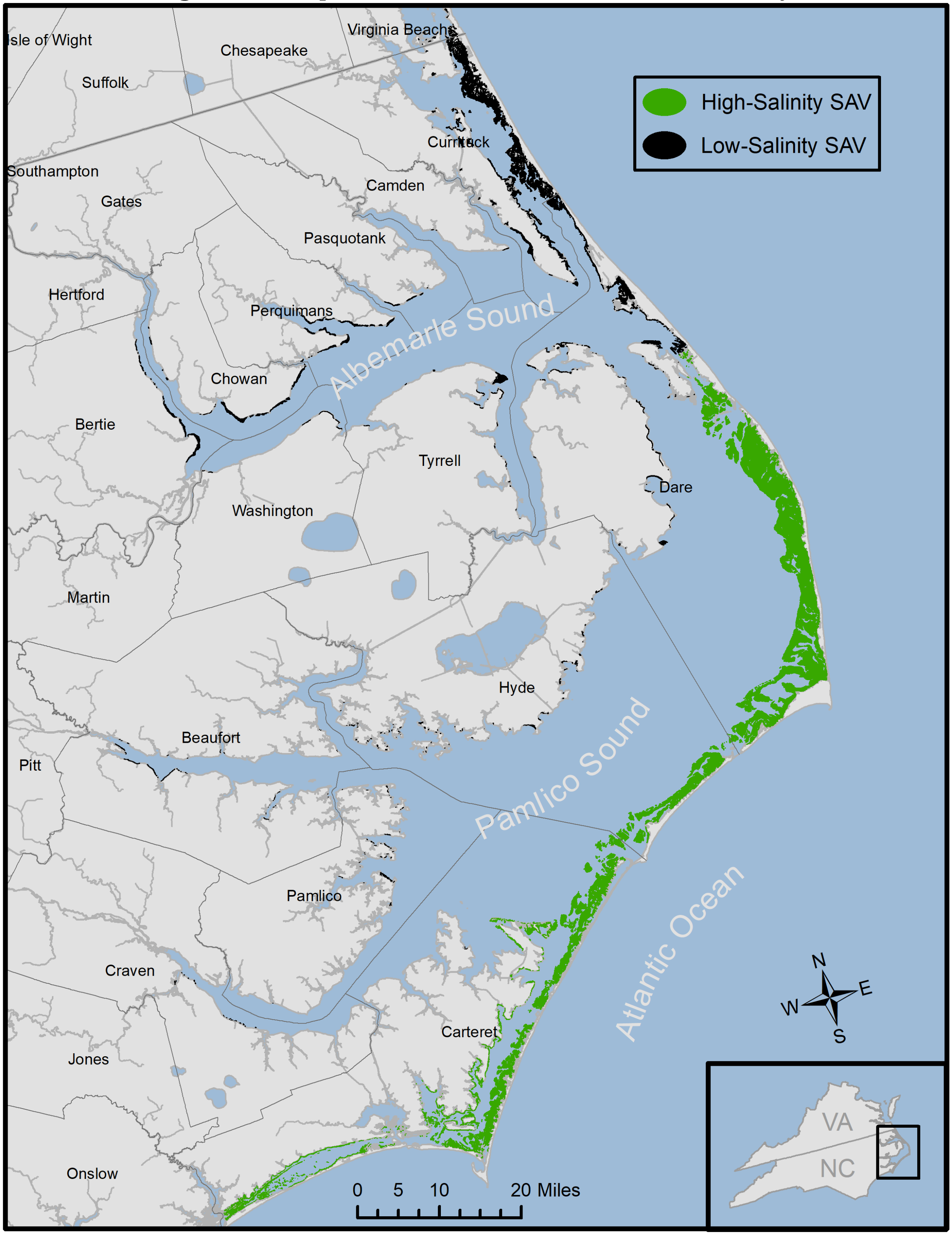
Section 1: Submerged Aquatic Vegetation in North Carolina

Seagrass, or submerged aquatic vegetation (SAV), are rooted plants that grow underwater in shallow aquatic environments around the world. SAV provides a variety of ecosystem services that enhance the quality of life in many coastal communities. Moreover, SAV sequesters and stores carbon and thus provides a global public good that generates benefits to society at large. Scientists have estimated that nearly one-third of SAV has been lost globally since 1980 and that this decline has accelerated in recent years (Blandon and zu Ermgassen, 2014; Waycott et al., 2009; Powell et al., 2017). Anthropogenic stressors such as increased human populations, economic development, and more intensive resource use and extraction in coastal regions have led to increased stormwater runoff and erosion. Shoreline modification through the construction of hard shorelines, piers and docks, and dredging and filling have generated similar effects. Combined, these factors have led to increased sediment and nutrient levels in estuaries and, in turn, declining SAV abundance around the world.

North Carolina is home to the highest SAV acreage on the Atlantic seaboard. Most of North Carolina's acreage is located within the A-P estuary where six rivers flow into the Albemarle, Pamlico, Back, Bogue, Core, Croatan, Currituck, and Roanoke Sounds. The estuary is home to 14 common species of SAV that occur in beds of subtidal waters that are generally less than two meters deep. Based on aerial surveying of SAV that occurred between 2006 and 2008 and then again between 2012 and 2014 by the Albemarle-Pamlico National Estuary Partnership (APNEP), Field et al. (2020) estimate that SAV coverage decreased by 5.6% between 2006 and 2013 in the high-salinity regions of the A-P estuary. These same data can be used to measure the areal extent of all SAV in the A-P estuary, which we estimate to be 130,418 acres.[3] In the absence of more recent data, we use this estimate to characterize "baseline" SAV coverage for the A-P estuary in the current analysis, although we recognize that SAV acreage may have further declined between 2013 and the present. Figure 1-1 provides a map of SAV coverage in the estuary.

[3] The first APNEP aerial surveying between 2006 and 2008 allowed for mapping of both the high- and low-salinity components of the SAV resource within the A-P estuary. The 2012-2014 surveying did not include low-salinity areas or the high-salinity region within the Core Sound due to poor water clarity limiting aerial imagery acquisition. For the purposes of our analysis, we utilize the most recent data (2012-2014) whenever available but revert to the 2006-2008 data for measuring extent of low salinity SAV and SAV located in the Core Sound. This approach implied 130,418 total acres of high- and low-salinity SAV of SAV in the A-P estuary.

Figure 1-1: Map of SAV in the Albemarle-Pamlico Estuary



Credit: Tim Ellis, APNEP.

Section 2: Economic Valuation of SAV

In this report, we quantify the economic losses associated with declines in SAV coverage over the next decade. Our approach to monetizing these losses is rooted in the economic concept of value (Freeman, 2003). Economists assume that the value of a resource is tied to its ability to satisfy the needs and wants of people. This framework implies that the value society attributes to an environmental resource is not tied to its intrinsic value but rather to its instrumental value – that is, its ability to enhance the well-being of people and what they need and want. This anthropogenic concept is operationalized through the concept of "willingness to pay," which is the maximum amount of goods and services that people are willing to forego for a change in service flows provided by environmental resources. Willingness to pay is typically measured in monetary terms so that it can be easily aggregated across individuals and value categories and compared to the social cost of providing these service flows.

There are different types of ecosystem services that environmental resources like SAV generate. In the context of SAV and the A-P estuary, some are tied to direct use, such as profits from commercial fishing and the enjoyment that recreational anglers derive from fishing. Other use values are more indirect, such as SAV's contribution to shoreline stabilization and the amenity values from living adjacent to the estuary. Both of these values might be capitalized into residential property values. A third category of use-related benefits are tied to SAV's contribution to regulating service flows provided by the natural environment. Examples include SAV's role in regulating the nitrogen, sediment and carbon cycles. Apart from use-related values, SAV can also generate nonuse related values, or values that are independent of direct or indirect use. Nonuse values can be motivated by a desire to preserve environmental resources for future generations or an ethic that some resources generate social value through their very existence in their natural state.

Some of the aforementioned values are captured through market transactions. For example, commercial fishermen's profits are determined by the costs they incur to catch fish and the revenue they derive from selling them. Many of these values, however, are not captured directly through market transactions. To quantify in monetary terms these values, environmental economists have developed a suite of nonmarket valuation methods (Freeman et al., 2014). These methods often examine the price or demand for marketed goods – residential houses or recreational trips – that are closely related to nonmarketed goods – SAV or environmental quality. By leveraging maintained assumptions about the relationship between marketed and nonmarketed goods, one can infer the willingness to pay for changes in nonmarketed goods from changes in marketed goods. In addition to these revealed preference methods, economists also use stated preference methods to quantify nonuse or use-related values that are difficult to quantify. Stated preference methods typically rely on survey methods where respondents are presented with hypothetical scenarios about changes in environmental service flows.

Implementation of nonmarket valuation studies often requires original data collection and analysis that is costly in terms of both time and money. For the current study, however, we rely on benefit transfer methods (Johnston et al., 2015). These methods, which are widely used by federal and state agencies as well as private entities in regulatory and litigation contexts, adapt or transfer benefit estimates from published studies to a different but related policy context. Because the match between the published studies and the policy context is often imperfect, spatial and temporal adjustments are typically made to the transferred values to make them more suitable to the current valuation context.

The economic losses from SAV loss are substantial and diverse (Dewsbury, et al., 2016). In this report, we do not attempt to quantify all economic losses from declines in SAV coverage but rather focus our attention on four important categories:

1) **Commercial fisheries** – we estimate market losses (i.e., profit declines) for blue crab fishermen arising from SAV coverage loss in the A-P estuary. Blue crab depend heavily on SAV throughout their life cycles and are one of the most important fishery species in the estuary.
2) **Recreational fishing** – we quantify the nonmarket losses to anglers from catching fewer spotted seatrout and red drum – two of the most frequently targeted species in the A-P estuary – as a result of SAV coverage losses.
3) **Residential property values** – we quantify how residential property values within 500 meters of the A-P estuary will decline as a result of SAV coverage losses.
4) **Carbon sequestration** – we estimate the market and nonmarket losses associated with the reduction in carbon sequestration resulting from SAV coverage loss.

For all of these categories, we quantify economic losses over the next decade for four alternative scenarios that assume a gradual decline in SAV coverage relative to a baseline of 130,418 acres. In particular, Table 2-1 summarizes the alternative scenarios we consider.

Table 2-1:
SAV Coverage Loss Scenarios

SAV Coverage Loss	
Annual Loss (%)	Accumulated Loss over Decade (%)
0.5	5
1.5	15
2.5	25
5.0	50

Because these scenarios generate differential impacts across a 10-year period, a practical issue is how we aggregate these impacts to generate a summary measure of loss. In this report, we employ the net present value (*NPV*) framework and, consistent with guidelines from North Carolina's Office of State Budget and Management as well the federal government's Office of Management and Budget, employ a three percent discount rate.

This implies that we use the following equation to construct the net present value of alternative SAV loss scenarios:

$$NPV = \sum_{t=1}^{10} \frac{Loss_t}{(1+r)^t},$$

where $Loss_t$ is the economic loss in year t and r is the social discount rate (i.e., r = .03). Throughout the report, all losses are recorded in 2019 dollars.

Section 3: Bioeconomic Modeling of SAV / Catch Relationship

In this section, we provide estimates of population decline and associated catch loss in response to gradual SAV loss over a 10-year period for baseline (i.e., no SAV loss) and the four SAV loss scenarios identified in Table 2-1 for blue crab, spotted seatrout, and red drum.[4] These three species are economically important commercial and recreational fishery species in North Carolina and rely heavily on SAV beds for shelter and nurseries.

The estimates of population decline and associated catch loss were obtained using stochastic forward projections based on population dynamic models, which describe how population size changes over time as controlled by natural mortality, fishing mortality and recruitment. (i.e., the addition of new individuals to the population). We assume that natural mortality (i.e., removals from the stock due to natural causes, such as predation and disease) and fishing mortality (i.e., removals from the stock due to fishing activities) are constant, and recruitment level is a function of SAV acreage during the projected years. Therefore, the reduction in projected population size and catches can only result from SAV loss, which affects the recruitment strength. Natural morality is typically assumed to be known in the assessment models as it is notoriously difficult to estimate. We used the best available information for the projections. The values of natural mortality, fishing mortality and other parameters (e.g., initial abundance) used in the projections are from fishery management population assessments (i.e., stock assessment) reports (NCDMF, 2014 & 2018; SEDAR, 2015). We recognize that a range of factors can influence recruitment strength in a positive or negative manner, such as the size of the spawning stock, weather patterns, and water quality, among others.

The reduction in recruitment strength over the projected years was determined by SAV loss, as well as the SAV enhancement information collected from published scientific studies and fisheries-independent surveys conducted in North Carolina waters. The arithmetic mean enhancement of Young-of-the-Year blue crabs in SAV versus unstructured habitat is 4.77 crabs/m^2, and the geometric mean is 2.12 crabs/m^2 (Table 3-1). The data are from studies in Pamlico Sound, North Carolina, as well as the lower and upper parts of Chesapeake Bay, and generally used drop-traps or suction sampling to sample crabs. The arithmetic mean enhancement of young-of-the-year spotted seatrout and red drum in SAV versus unstructured habitats are shown in Table 3-2 and 3-3, respectively. The data are from North Carolina Juvenile Fish Surveys conducted by NCDMF and Powers (2012). Life history information and justification regarding the seagrass fisheries enhancement data can be found in the Appendix.

[4] The Appendix includes a more detailed discussion of how the population projections reported in this section were generated.

Table 3-1:
Density of Young-of-the-Year Blue Crabs on SAV Versus Unstructured Habitats. The arithmetic mean enhancement in SAV versus unstructured habitats is 4.77 crabs/m^2, and the Geometric mean is 2.12 crabs/m^2

Reference	SAV (ind./m^2)	SAV SE	Control (ind./m^2)	Control SE	Enhancement (ind./m^2)	Gear	Seasons	Years
Pile et. al. 1996	12.56	6.12	2.27	0.38	10.29	Suction	3	1983-92
Etherington & Eggleston 1990	12.5	5.4	1.3	0.08	11.2	Suction	2	1996
Doctor et al. 2012	0.56	0.001	0	na	0.56	Drop-net	1	2007
Doctor et al. 2012	0.67	0.008	0.16	0.0006	0.51	Drop-net		2008
Doctor et al. 2012	1.89	1.35	0.056	0.0003	1.29	Drop-net	1	2009

Note: Young-of-the-Year blue crabs are generally 0+ age class consisting of C1-5 stages.

Table 3-2:
Density of Young-of-the-Year Spotted Seatrout in SAV Versus Unstructured Habitats in North Carolina Estuarine Waters. The arithmetic mean enhancement in SAV versus unstructured habitats is 0.00216 fish/m^2, and the Geometric mean is 0.000050 fish/m^2

Reference	SAV (ind./m^2)	SAV SE	Control (ind./m^2)	Control SE	Enhancement (ind./m^2)	Gear	Seasons	Years
NCDMF P100	0.000112	0.000112	0	0	0.000113	Seine	2	2015
NCDMF P100	0.000403	0.000259	0	0	0.000403	Seine	2	2014
NCDMF P100	0.000155	0.00010	0.00004	0.00004	0.000060	Seine	2	2011
NCDMF P123	0.000527	0.00040	0.00007	0.00006	0.000045	Seine	2	2016
NCDMF P123	0.002283	0.00020	0	0	0.002283	Seine	2	2015
NCDMF P123	0.001903	0.001554	0	0	0.001903	Seine	2	2013
NCDMF P123	0.001269	0.001389	0	0	0.001269	Seine	2	2012
NCDMF P123	0.003045	0.002691	0	0	0.003045	Seine	2	2011
Powers 2012	0.015010	0.010090	0.00467	0.00269	0.010339	Seine	2	2009-10

Note: Young-of-the-Year spotted seatrout are generally 0+ age class consisting of 30-160 mm total length, TL.

Table 3-3:
Density of Young-of-the-Year Red Drum in SAV Versus Unstructured Habitats in North Carolina Estuarine Waters. The arithmetic mean enhancement in SAV versus unstructured habitats is 0.000309 fish/m^2, and the Geometric mean is 0.002193 fish/m^2

Reference	SAV (ind./m^2)	SAV SE	Control (ind./m^2)	Control SE	Enhancement (ind./m^2)	Gear	Seasons	Years
NCDMF P100	0.000857	0.000658	0.000285	0.000887	0.000572	Seine	Fall	2011-14
NCDMF P123	0.010458	0.009794	0.004112	0.006945	0.005595	Seine	Fall	2009-16
Powers 2012	0.008019	0.007610	0.004912	0.004103	0.003109	Seine	Fall	2009-10

Note: Young-of-the-Year red drum are generally 0+ age class consisting of 11-104 mm total length, TL.

The population dynamics model used to project reductions in the fishery population due to loss of SAV are different for blue crab versus spotted seatrout and red drum due to the differences in their life histories and population structure. For example, blue crabs grow by molting, whereas fish grow continuously, which permits computing growth and survivorship by age-classes. For blue crab, the mathematical functions used to describe crab population dynamics in the projection are the same as those used in the stock assessment model. The model tracks population dynamics of recruits (<127 mm) and those individuals fully recruited to the fishery (>127mm). A stochastic, 10-year population projection was conducted starting from the terminal year of the population assessment (i.e., 2016), and under five scenarios of recruitment levels in response to the five SAV loss scenarios. We assume that the estimated SAV acreage (130,418 acres) can support the estimated recruitment of the terminal year of assessment (i.e., 136.57 million individual crabs in 2016; NCDMF, 2018), and SAV loss will result in a reduction of recruitment strength. The mean crab recruitment levels over the projected 10 years for each SAV loss scenario were calculated based on the average ratio between the density of Young-of-the-Year blue crabs on unstructured and SAV habitats:

$$R_y = R_{y-1} * (1 - loss_{\%}) + R_{y-1} * ratio * loss_{\%}$$

where R_y is the mean recruitment of projected year y, $loss_{\%}$ is the percentage of SAV loss, and $ratio$ is the ratio between the density of Young-of-the-Year blue crabs on unstructured and SAV habitats derived from Table 3-1.

For spotted seatrout and red drum, an age-structured population dynamics model was used for the projections. Since spotted seatrout and red drum in North Carolina waters are a portion of the stock units being assessed and managed, their initial abundance in projections was not calibrated to the estimated abundance of the terminal year of assessment. Instead, the projections were conducted starting from an equilibrium condition with recruitment level derived from the mean density of Young-of-the-Year in SAV and the total estimated SAV acreage.

The uncertainty in SAV enhancement estimates was incorporated in the projections. Projected catches were calculated using a Baranov catch equation given assumed fishing mortality (Baranov, 1918). The mean total catch over the projected 10 years for the three species is summarized in Tables 3-4, 3-5 and 3-6, respectively.

Table 3-4:
Mean Total Catch of Blue Crab Over the Projected 10 Years
(in millions of individuals)

Year	Baseline (No SAV loss)	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	63.25	63.25	63.24	63.24	63.24
2	39.68	39.68	39.62	39.53	39.44
3	37.16	37.02	36.67	36.28	35.48
4	36.89	36.60	35.93	35.25	33.71
5	36.86	36.41	35.44	34.46	32.23
6	36.86	36.25	34.98	33.71	30.84
7	36.86	36.09	34.53	32.99	29.51
8	36.86	35.94	34.08	32.28	28.24
9	36.86	35.78	33.64	31.58	27.02
10	36.86	35.63	33.20	30.90	25.86

Table 3-5:
Mean Total Catch of Spotted Seatrout Over the Projected 10 Years
(in pounds)

Year	Baseline (No SAV loss)	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	605,639	605,639	605,639	605,639	605,639
2	605,639	605,603	605,530	605,458	605,278
3	605,639	605,002	603,701	602,440	599,260
4	605,639	603,965	600,565	597,295	589,142
5	605,639	602,655	596,629	590,881	576,738
6	605,639	601,191	592,266	583,822	563,349
7	605,639	599,647	587,699	576,496	549,741
8	605,639	598,066	583,067	569,134	536,376
9	605,639	596,472	578,440	561,847	523,463
10	605,639	594,875	573,849	554,689	511,088

Table 3-6:
Mean Total Catch of Red Drum Over the Projected 10 Years
(in pounds)

Year	Baseline (No SAV loss)	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	10,777,995	10,777,995	10,777,995	10,777,995	10,777,995
2	10,777,995	10,772,271	10,759,755	10,748,452	10,717,797
3	10,777,995	10,757,731	10,713,607	10,674,001	10,567,598
4	10,777,995	10,734,541	10,640,357	10,556,393	10,333,174
5	10,777,995	10,711,468	10,568,205	10,441,724	10,110,472
6	10,777,995	10,688,509	10,497,136	10,329,922	9,898,905
7	10,777,995	10,665,666	10,427,133	10,220,915	9,697,916
8	10,777,995	10,642,937	10,358,179	10,114,633	9,506,977
9	10,777,995	10,620,321	10,290,260	10,011,009	9,325,584
10	10,777,995	10,597,818	10,223,360	9,909,974	9,153,261

Section 4: Commercial Fisheries

In 2018, the total landed value of all commercial fisheries species in North Carolina was $77,885,276 (NCDMF, 2018), with blue crab and shrimp accounting for 25.2% and 25.7% of total value, respectively. Using the IMPLAN software package, Edwards et al. (2021) estimate that the North Carolina commercial seafood industry generates an economic impact[5] of nearly $300 million and 5,528 jobs annually. The economic impact from blue crab is substantial at over $46 million per year and 886 jobs annually. The productivity of commercial fisheries is closely tied with the health of marine ecosystems, particularly estuary health. SAV provides critical nursery habitat for blue crab and other commercially and recreationally important species (Barbier et al., 2011; Johnston et al., 2002; Sogard, 1992; Short and Wyllie-Echeverria, 1996; Orth et al., 2006; Heck, Hays, and Orth, 2003).[6] The presence of SAV is particularly important to blue crabs because seagrass beds provide more food and protection for juvenile blue crabs than other available habitat (Anderson, 1989). We provide an estimate of the potential economic losses associated with a decline in SAV by modelling the relationship between SAV abundance and distribution and commercial fishery productivity for the blue crab fishery.

We estimated changes to the production of the North Carolina blue crab population associated with four different SAV loss scenarios summarized in Table 2-1. Catch abundance is converted from individuals to pounds using the width-weight relationship and mean size of the commercial catch of about 0.323 lb/individual. Estimates on percentage change in annual catch were obtained using the forward projections summarized in Section 3. Estimated total landings in millions of pounds and percent reduction in landings under each of the scenarios can be found in Tables 4-1 and 4-2, respectively.

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[5] Economic impacts represent value-added income for 2019 in four different sectors – commercial fishing, processors and dealers, restaurants and retail. Value-added is total output for the commercial fishing sector and sales minus the cost of non-labor inputs for other sectors. Jobs from economic impact analyses (EIA) represent full-time positions directly employed or supported by wild-caught North Carolina seafood.

[6] Penaeid shrimp (*Penaeus* spp.) are commercially and recreationally harvested, are the shrimp most associated with seafood, and rely heavily on estuarine salt marsh and shallow muddy-sand habitat during their early life history (Boesch and Turner, 1984; Orth et al., 1984). Conversely, *Palaemonetes* "grass" shrimp (*Palaemonetes spp*.), rely heavily on seagrass habitats where they serve as prey for upper trophic levels such as juvenile fish, and graze on epiphytes on seagrass blades (Morgan, 1980; Kneib, 1987). Thus, given the lack of strong dependence on seagrass by early stages of *Penaeus* spp., and the lack of commercial and recreational harvest on the relatively small spp. *Palaemonetes* that rely heavily on seagrass, we opted not include Penaeid shrimp in this study.

Table 4-1:
Estimated Total Blue Crab Landings
(millions of pounds)

Year	Baseline	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	20.43	20.43	20.43	20.43	20.42
2	12.82	12.82	12.80	12.77	12.74
3	12.00	11.96	11.84	11.72	11.46
4	11.92	11.82	11.61	11.38	10.89
5	11.91	11.76	11.45	11.13	10.41
6	11.91	11.71	11.30	10.89	9.96
7	11.91	11.66	11.15	10.65	9.53
8	11.91	11.61	11.01	10.42	9.12
9	11.91	11.56	10.87	10.20	8.73
10	11.91	11.51	10.72	9.98	8.35

Table 4-2:
Projected % in Change Blue Crab Catch

Year	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	0.00%	0.00%	0.01%	0.02%
2	0.00%	0.16%	0.40%	0.62%
3	0.38%	1.33%	2.36%	4.52%
4	0.81%	2.60%	4.46%	8.62%
5	1.23%	3.86%	6.52%	12.56%
6	1.66%	5.11%	8.54%	16.33%
7	2.08%	6.33%	10.51%	19.94%
8	2.50%	7.54%	12.44%	23.39%
9	2.92%	8.74%	14.33%	26.69%
10	3.34%	9.92%	16.17%	29.85%

Change in fishery revenue is found by multiplying the price per pound of blue crab by the estimated change in blue crab landings attributable to SAV losses for each scenario. Price data for blue crab is obtained from NOAA fisheries annual landings data for the State of

North Carolina.[7] Average ex-vessel price per pound is calculated by dividing total landings value by total landings pounds. Because there is considerable fluctuation of blue crab price over the past decade, we use the ten-year average price of $1.12 per pound.[8] Should the price of blue crab increase when the supply of crab decreases, we would expect loss estimates to be larger. For each scenario, the unadjusted change in revenues each year can be found in Table 4-3.

Table 4-3:
Unadjusted Annual Change in Blue Crab Revenue
(millions of 2019 US dollars)

Year	0.5% Annual SAV Loss	1.5% Annual SAV Loss	2.5% Annual SAV Loss	5% Annual SAV Loss
1	$0.00	$0.00	$0.00	$0.00
2	$0.00	$0.02	$0.06	$0.09
3	$0.05	$0.18	$0.32	$0.61
4	$0.11	$0.35	$0.60	$1.15
5	$0.16	$0.52	$0.87	$1.67
6	$0.22	$0.68	$1.14	$2.18
7	$0.28	$0.84	$1.40	$2.66
8	$0.33	$1.01	$1.66	$3.12
9	$0.39	$1.17	$1.91	$3.56
10	$0.45	$1.32	$2.16	$3.98
Total Change	$1.99	$6.09	$10.11	$19.02

To determine the net present value of fishery revenue losses, we use the real price of blue crab and a 3% annual discount rate. With no change in SAV coverage, the estimated total revenue over the next ten years is $144 million. The results in Table 4-4 imply that a 0.5 percent annual loss of SAV coverage results in a $1.59 million reduction in the net present value of blue crab fishermen's revenues. The revenue loss jumps to $15.25 million when SAV coverage drops to 5 percent per year.

Table 4-4 also reports the declines in blue crab catch (i.e., landings) for each scenario over the next decade. These declines range from 1.8 million pounds (0.5 percent annual SAV loss) to 17 million pounds (5 percent annual SAV loss).

Finally, Table 4-4 reports the effects of SAV loss on fishermen profits. To calculate these changes, we leverage the findings of Van Houtven et al. (2016). Van Houtven et al. estimate profits account for 56 percent of gross revenues in the Albemarle Sound and 32 percent of

[7] NOAA Commercial Fishery Landings database retrieved at: https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200::::::

[8] Blue crab price may fluctuate with supply of blue crab, supply of substitute species, and consumer demand. Price is calculated by taking the average price between 2010 and 2019. Prices are adjusted to 2019 US dollars using the U.S. Consumer Price Index.

gross revenues in the Pamlico Sound. For the current analysis, we therefore assume the average value of 43 percent represents the percentage of revenue equal to profits for blue crab. With no change in SAV coverage, the estimated profit generated over the next decade is $65 million.

Under the most conservative scenario of 0.5 percent annual loss of SAV, the net present value of blue crab fishermen's profits falls by $0.69 million. These losses increase with SAV losses. A 5 percent annual loss in SAV coverage reduces fishermen profits by $6.62 million. This represents a 10.2% reduction in expected profits. The loss estimates presented here are conservative because we only consider blue crab. SAV also provides nursery habitat for gag grouper, snapper, weakfish, Atlantic croaker, bluefish, striped mullet, white mullet, spot, silver perch, summer flounder, white grunt, southern flounder, hardshell clams, pinfish, herrings, shrimp, and bay scallops (South Atlantic Fishery Management Council, 1998). Larvae and juveniles of many of these species appear in eelgrass beds in spring and early summer, while other species use the beds temporarily to forage, spawn, or escape predation (Stephan and Bigford, 1997). It is likely that a decline in SAV would also reduce catch of these species although some of these species no longer provide viable fisheries due to low stock size, such as weakfish and bay scallops.

Table 4-4:
Change in Landings, Revenue, and Profits for the Blue Crab Fishery

Change in:	0.5% Annual Loss	1.5% Annual Loss	2.5% Annual Loss	5% Annual Loss
Landings (millions of pounds)	1.78	5.43	9.03	16.98
Undiscounted Change in Revenue (millions)	$1.99	$6.09	$10.11	$19.02
Discounted Change in Revenue (millions)	$1.59	$4.87	$8.10	$15.25
Undiscounted Profit Losses (millions)	$0.86	$2.64	$4.39	$8.25
Discounted Profit Losses (millions)	$0.69	$2.11	$3.52	$6.62

Section 5: Recreational Fishing

Data collected by the National Oceanic and Atmospheric Administration (NOAA) suggest that recreational anglers have fished in the A-P estuary on roughly 24 million user days over the past decade (2010-2019). The majority of these user days involve private/rental boats (57%) or shoreline fishing (42%), with the rest involving for-hire/charter boats (<1%). The average angler spends $68 per user day, implying total trip expenditures of $162.7 million per year (2019 dollars). NOAA's economic modeling using the IMPLAN software package suggests that these annual expenditures translate into total economic impacts of 2,269 jobs, $222 million in sales, and $78 million in income for local economies (Lovell et al., 2020). As suggested by Table 5-1, the primary fish species targeted and caught over the past decade were spotted seatrout, flounder spp, red drum, and striped bass.

Table 5-1:
Target and Caught Species in the Albemarle- Pamlico Estuary, 2010-2019

Panel A - Primary Targeted Species (Percentage of Total Trips)	
No Target	47.0%
Spotted Seatrout	17.7%
Flounder Spp	13.3%
Red Drum	7.8%
Striped Bass	6.3%
Other Species	7.8%
Panel B - Catch (Percentage of Total Fish Caught)	
Spotted Seatrout	34.2%
Flounder Spp	13.3%
Red Drum	3.2%
Striped Bass	4.3%
Other Species	22.6%

Because SAV serves as a rich aquatic habitat for adult fish to spawn and juvenile fish to mature, recreational anglers in the A-P estuary are likely to benefit from SAV enhancement. However, the current nonmarket valuation literature does not include direct value estimates of SAV abundance to anglers. Following Massey et al. (2017), we assume that anglers benefit from SAV through increased fish abundance and higher catch rates. Under this maintained assumption, we then estimate the value of changes in SAV abundance through a two-step procedure. First, we assume that total and recreational catch for spotted seatrout and red drum vary proportionally and leverage the total catch forecasts described in Section 3 to predict changes in recreational catch over the next decade. Because anglers' welfare is enhanced through higher catch rates (Johnston et al., 2006), we can monetize how recreational anglers value changes in SAV through changes in catch rates assuming overall fishing effort is maintained at current levels.

Our valuation approach relies on the following valuation function:

$$\Delta V = UD_{AP} \times \Delta C_{AP} \times WTP_{Fish} ,$$

where the change in value induced by a change in SAV relies on three factors: 1) the number of user days in the A-P estuary, UD_{AP}; 2) the change in catch rates per used day induced by the change in SAV in the estuary for each species, ΔC_{AP}; and 3) angler's willingness to pay (WTP) to catch an additional fish, WTP_{Fish}. Below we discuss how each of these inputs are specified.

1) **User days** – The number of angler user days (including shoreline, private/rental boating and for-hire/charter boating) was constructed from NOAA's Marine Recreational Information Program's (MRIP) intercept data with the assistance of Dr. Andrew Cathey, Biologist Supervisor for the North Carolina Division of Marine Fisheries. This data is now collected through a probability-based on-site survey where anglers are intercepted at randomly selected fishing sites (e.g., docks, marinas) throughout the U.S. We focus on intercepted anglers at sites in the A-P estuary and construct annualized aggregate user day estimates from 2010 through 2019. These estimates relied on two alternative definitions of the spatial boundaries of the estuary that differ in their treatment of the nearshore waters of the ocean side of the Outer Banks. Fish that spawn and mature inside the A-P estuary can migrate and be caught nearshore in the Atlantic Ocean, so we generate separate recreational loss estimates that either ignore or account for these linkages. We therefore consider two spatial definitions of the estuary: 1) one that is limited to the sound side of the A-P estuary; and 2) a second that also includes the nearshore waters of the ocean side of the Outer Banks out to three nautical miles from the coastline. User day estimates under these two spatial definitions are reported in Table 5-2. Since there is considerable year-to-year fluctuations in these estimates due to a variety of factors (e.g., weather, sampling variability) and no clear long-run trend, we use the 10-year average of user days to parameterize UD_{AP} in our analysis. As Table 5-2 suggests, including the ocean side nearshore of the Outer Banks implies significantly more angler participation.

Table 5-2:
User Days

Year	A-P Estuary Only	A-P Estuary + Ocean Nearshore
2010	2,704,913	9,968,617
2011	2,470,055	8,368,725
2012	2,336,705	7,050,718
2013	2,190,695	6,716,867
2014	1,859,640	7,183,182
2015	2,058,059	8,757,949
2016	2,014,380	11,252,055
2017	3,506,658	11,542,821
2018	1,936,018	8,665,643
2019	2,835,377	8,340,435
Mean	2,391,250	8,784,701

2) **Change in catch rates** – MRIP also collects catch data (both keep and release) for several species in the estuary. As suggested by Table 5-1, the three most commonly targeted and caught species from 2010 through 2019 are spotted seatrout, flounder, red drum, and striped bass. In the current analysis, we focus exclusively on how changes in SAV density affect spotted seatrout and red drum. We do not consider the effects of SAV on flounder for two reasons: 1) their settlement and juvenile stages do not demonstrate a strong association with seagrass or submerged vegetation in North Carolina;[9] and 2) flounder has been significantly overfished in the A-P estuary for decades, and new regulations (including seasonal closures) have been put in place to reduce commercial and recreational harvest (NCDMF, 2019). We also do not consider the effects of SAV on striped bass because of its limited dependence on SAV during its early years.[10] Table 5-3 reports total catch for spotted seatrout and red drum for the

[9] For example, Burke et al. (1991) characterized settlement and early juvenile abundance patterns of 0-group summer flounder (*Paralichthys dentatus*) and southern flounder (*P. lethostigma*) in the Newport and North Rivers, NC and found that newly settled southern flounder were concentrated on tidal flats towards the head of the estuary, while the greatest numbers of summer flounder were captured on tidal flats in the middle reach of the system. They observed ontogenetic habitat shifts whereby southern flounder appeared to move upstream to oligohaline riverine habitat and summer flounder appeared to move to high salinity salt marsh habitat. Similarly, Walsh et al. (1999) characterized the distribution and abundance of flatfish species (< 150 mm standard length) as a function of habitat characteristics in the Newport River and Back Sound estuaries in NC and found highest densities of all species in the upper, lower salinity zones of the estuaries, with high densities of *P. lethostigma* and *P. dentatus* on muddy substrates sand flats, respectively.

[10] Striped bass spawning in North Carolina occurs predominantly in the relatively fresh waters of Albemarle Sound (AS) and the Roanoke River (RR) (Hassler and Brown, 1981). For the AS–RR stock, most juvenile and small mature striped bass remain in the AS–RR throughout the year (Carmichael et. al., 1998; Jiang et al., 2007; Harris and Hightower, 2017). Striped bass prefer to spawn among the rocky rapids near the "fall line" where rivers make the transition from the hilly piedmont to the relatively flat coastal plain. Each spring, adult striped bass swim from the Atlantic Ocean and Albemarle Sound into the Roanoke River to spawn, about 200 km from the sound. Most striped bass spawning begins when the water temperature reaches 17°C. After spawning, the semi-buoyant fertilized eggs must drift in the water for two or three days before they hatch.

alternative spatial definitions of the A-P estuary. Notably, total catch is only modestly higher for spotted seatrout but significantly higher for red drum when the ocean side nearshore of the Outer Banks is included.

Table 5-3:
Total Catch – Spotted Seatrout and Red Drum

	Spotted Seatrout		**Red Drum**	
Year	A-P Estuary Only	A-P Estuary + Ocean Nearshore	A-P Estuary Only	A-P Estuary + Ocean Nearshore
2010	196,891	199,117	37,804	74,296
2011	335,936	347,819	20,227	26,101
2012	768,465	786,733	10,437	43,767
2013	676,269	694,917	102,068	317,126
2014	186,593	210,259	72,434	174,102
2015	8,690	9,694	6,455	54,425
2016	203,101	225,708	38,593	96,816
2017	596,363	693,893	81,744	253,103
2018	70,602	183,118	7,811	191,096
2019	1,048,309	1,067,357	3,383	17,929
Mean	409,122	441,862	38,096	124,876

We then divide total catch by user days to arrive at catch rates for each species. Catch rates are reported in Tables 5-4. Baseline catch rates are generally lower when the ocean side nearshore of the Outer Banks is included in the spatial boundary of the A-P estuary because of the much higher number of user days. We again use the average catch rates across the 10-year period for each species and spatial definition of the estuary to calibrate baseline catch rates.

During this time, there must be enough flow in the river to keep the eggs afloat or they will sink to the river bottom and be covered by sediment. After hatching, yolk-sac stage-larvae are carried by currents to nursery areas in the lower Roanoke River and western Albemarle Sound, such as small, shallow creeks. Young-of-year (YOY) striped bass remain in the relatively fresh water of Albemarle Sound and shallow creeks systems and spend the next four years maturing in Albemarle Sound (Carmichael et. al., 1998). We are not aware of any data that suggests a strong dependence upon SAV during their YOY stage.

Table 5-4:
Catch Rates – Spotted Seatrout and Red Drum

	Spotted Seatrout		Red Drum	
Year	A-P Estuary Only	A-P Estuary + Ocean Nearshore	A-P Estuary Only	A-P Estuary + Ocean Nearshore
2010	0.073	0.020	0.014	0.007
2011	0.136	0.042	0.008	0.003
2012	0.329	0.112	0.004	0.006
2013	0.309	0.103	0.047	0.047
2014	0.100	0.029	0.039	0.024
2015	0.004	0.001	0.003	0.006
2016	0.101	0.020	0.019	0.009
2017	0.170	0.060	0.023	0.022
2018	0.036	0.021	0.004	0.022
2019	0.370	0.128	0.001	0.002
Mean	0.163	0.054	0.016	0.015

The biological model forecasts percentage reductions in total catch over a 10-year period across alternative SAV loss scenarios. These forecasts are reported in Table 5-5. Percentage reductions in recreational catch rates relative to baseline are assumed to equal these reductions in all SAV loss scenarios.

Table 5-5:
Percentage Change in Total Catch

SAV Loss Scenario	0.5% Annual Loss	1.5% Annual Loss	2.5% Annual Loss	5% Annual Loss
Spotted Seatrout Percent Catch Loss in Year:				
1	0.00%	0.00%	0.00%	0.00%
2	0.01%	0.02%	0.03%	0.06%
3	0.11%	0.32%	0.53%	1.05%
4	0.28%	0.84%	1.38%	2.72%
5	0.49%	1.49%	2.44%	4.77%
6	0.73%	2.21%	3.60%	6.98%
7	0.99%	2.96%	4.81%	9.23%
8	1.25%	3.73%	6.03%	11.44%
9	1.51%	4.49%	7.23%	13.57%
10	1.78%	5.25%	8.41%	15.61%
Red Drum Percent Catch Loss in Year:				
1	0.00%	0.00%	0.00%	0.00%
2	0.05%	0.17%	0.27%	0.56%
3	0.19%	0.60%	0.96%	1.95%
4	0.40%	1.28%	2.06%	4.13%
5	0.62%	1.95%	3.12%	6.19%
6	0.83%	2.61%	4.16%	8.16%
7	1.04%	3.26%	5.17%	10.02%
8	1.25%	3.90%	6.15%	11.79%
9	1.46%	4.53%	7.12%	13.48%
10	1.67%	5.15%	8.05%	15.07%

3) **Willingness to pay for an additional caught fish** – To calibrate an angler's willingness to pay to catch an additional game fish, we rely on Haab et al.'s (2012) analysis of marine recreational fishing in the Southeast and Gulf of Mexico. They use 2000 MRIP data to estimate the marginal value of catching alternative fish species and find that the willingness to pay to catch an additional spotted seatrout is $13.41, whereas the willingness to pay to catch an additional red drum is $21.98 (2019 dollars). These estimates are in line with Johnston et al.'s (2006) meta-analysis results that found an average willingness to pay to catch one additional small game fish of $20.06 across 391 value estimates derived from 48 studies. We therefore use the

willingness to pay estimates from the Haab et al. study to monetize catch rate declines in the current study.

Finally, in Table 5-6, we report our estimates of aggregate annual losses (ΔV) associated with the alternative SAV loss scenarios over a 10-year period. Loses were calculated annually, discounted back to 2019 dollars using a three percent discount rate and the net present value reported in Section 2. These results suggest that when the analysis is limited spatially to the A-P estuary only, total losses over the next decade for the two species range from \$0.5 to \$4.6 million across the alternative SAV loss scenarios. The vast majority of these losses (roughly 90 percent) are associated with declining catch rates for the spotted seatrout. If we increase the spatial scale of analysis to include the ocean side nearshore of the Outer Banks, we find annual losses increase to between \$0.7 and \$6.6 million.

Table 5-6:
Discounted Recreational Fishing Losses Over the Next Decade

SAV Loss Scenario	0.5% Annual Loss	1.5% Annual Loss	2.5% Annual Loss	5% Annual Loss
A-P Estuary Only Specification				
Spotted Seatrout Losses	\$0.304	\$0.908	\$1,469	\$2,794
Red Drum Losses	\$0.053	\$0.165	\$0.261	\$0.504
Total Losses	\$0.357	\$1.073	\$1.731	\$3.298
A-P Estuary + Ocean Nearshore Specification				
Spotted Seatrout Losses	\$0.368	\$1.099	\$1.778	\$3.380
Red Drum Losses	\$0.178	\$0.555	\$0.880	\$1.696
Total Losses	\$0.547	\$1.654	\$2.658	\$5.076

Although substantial, these losses are likely a conservative estimates of total recreational fishing losses because they ignore other popular species (e.g., flounder) that may be negatively affected by reductions in SAV abundance.

Section 6: Residential Property Values

Data from Zillow suggest that there are over 27,000 residential properties within 500 meters of A-P estuary shoreline that is in close proximity to SAV. These properties are estimated to be worth almost $8.3 billion and generate roughly $50 million in tax revenue for local counties every year.[11] Research by Guignet et al. (2017) suggests that SAV ecosystem services like improved water quality, increased fish and waterfowl populations, and reduced coastal erosion significantly enhance these values. In order to quantify the economic losses to residential property owners resulting from SAV losses, we transfer the SAV capitalization rates estimated by Guignet et al. from their Chesapeake Bay application to the A-P estuary. Our estimated losses are substantial and range from $2 to $23 million over the next decade depending on the SAV loss scenario considered.

Guignet et al. (2017) investigate how SAV in the Chesapeake Bay influence property values for almost 200,000 residential properties in eleven Maryland counties over a 13-year period (1996-2008). They identify the effects of SAV by comparing property values within 500 meters of the shoreline and in close proximity to SAV to other properties within 500 meters of the shore but not in close proximity to SAV.[12] As reported in Table 6-1, Guignet et al. find a 6.2 percent capitalization effect for waterfront residential properties near a SAV bed. For non-waterfront properties less than 200 meters from shoreline with SAV, property values increase by 6.44 percent.[13] And for residential properties between 200 and 500 meters of shoreline with SAV, Guignet et al. estimate a capitalization effect of 2.09 percent.[14] These capitalization rates imply that SAV generates about $1.7 million in additional tax revenues for local counties each year.

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[11] For counties along the A-P watershed, the current residential property tax rate ranges from 0.33% (Carteret County) to 0.94% (Tyrrell County), and the average tax rate is roughly 0.6%. Multiplying this average rate by the total assessed value of $8.3 billion implies annual tax revenue of $50 million for local counties. It is worth noting that local municipalities typically levy a residential property tax on top of the county tax. This implies our tax revenue estimates are conservative.

[12] Guignet et al. (2017) define proximity to SAV for each property by identifying each property's nearest shoreline and then determining whether SAV is within 50 meters of that point.

[13] Guignet et al. (2017) report that although the estimated capitalization effects are larger for non-waterfront properties within 200 meters of the shoreline relative to waterfront properties, the difference is not statistically significant.

[14] Guignet et al. (2017) also examined whether these capitalization rates were heterogeneous depending on the density of SAV beds. They estimated models that differentiated SAV beds by four different categories: very sparse (<10% coverage); sparse (10-40%); moderate (40-70%); and dense (70-100%). They found capitalization rates that were very similar to those reported in Table 6-1 and not statistically different across the SAV categories.

Table 6-1:
Estimated Capitalization Effects from Guignet et al. (2017)

Percentage Effect of SAV on:	
Waterfront Residential Properties	6.20%
Non-Waterfront Residential Properties between 0-200 Meters from the Shoreline	6.44%
Non-Waterfront Residential Properties between 200-500 Meters from the Shoreline	2.09%

As reported in Table 1, model 1.B, p 32 of Guignet et al. (2017).

We use these capitalization rates to assess property value losses from SAV declines in the A-P estuary in the following way. We first collected 2014 assessed values[15] for all residential properties within 500 meters of shoreline in the A-P watershed from Zillow. For each property, Zillow identified whether it is waterfront, and we used GIS software to determine whether it was within 50 meters of a SAV bed. For non-waterfront properties, we determined whether they were located within 0-200 meters of shoreline within 50 meters of SAV or within 200-500 meters of shoreline within 50 meters of SAV. Table 6-2 summarizes our findings. In total, we find that over 27,000 residential properties located within 500 meters of the A-P estuary's shore and a SAV bed are worth $8.3 billion. 922 waterfront properties worth $479 million are within 50 meters of a SAV bed, another 6,657 non-waterfront properties worth $2.1 billion are between 0 and 200 meters, and 19,563 non-waterfront properties worth $5.7 billion are located between 200 and 500 meters of a SAV bed. Using the capitalization rates from Table 6-1, the capitalized value of SAV in all North Carolina residential properties in the A-P watershed is worth roughly $286 million.

[15] We investigated the relationship between assessed values and transaction sale prices for residential properties using Zillow data and found general convergence, with aggregate property value differences being less than two percent.

Table 6-2:
Total Assessed Residential Property Values
(millions of 2019 dollars)

Assessed Value for:	
Waterfront Residential Properties near SAV	$479
All Non-Waterfront Residential Properties between 0-200 Meters from the Shoreline near SAV	$2,146
All Non-Waterfront Residential Properties between 200-500 Meters from the Shoreline near SAV	$5,676
Total Assessed Value for Residential Properties within 500 meters of SAV	$8,300

Table 6-3 reports the predicted property value impacts over the next decade for the alternative SAV loss scenarios considered in this report. These estimates were calculated in three steps. First, the undiscounted capitalization effects associated with the alternative SAV loss scenarios were calculated for each of the next ten years separately using the capitalization rates in Table 6-1 and the property values in Table 6-2. Second, each of these changes in property values were translated into annual losses assuming a constant real payout stream and a three percent discount rate. Finally, these annual losses were discounted and summed back to current 2019 dollars using the net present value formula described in Section 2 assuming a three percent discount rate. The estimated property value losses over the next decade range from roughly $2.0 to $22.6 million.

Table 6-3:
Present Discounted Value of Property Value Losses from SAV Reductions Over the Next Decade
(millions of 2019 dollars)

Percentage Annual Reduction in SAV	Loss
0.5%	$2.0
1.5%	$7.0
2.5%	$11.5
5.0%	$22.6

Table 6-4 also reports the undiscounted county tax revenue losses over the next decade for the different scenarios. These range from $500,000 to $4.7 million.

Table 6-4:

Undiscounted County Tax Revenue Losses from SAV Reductions Over the Next Decade

(millions of 2019 dollars)

Percentage Annual Reduction in SAV	Loss
0.5%	$0.5
1.5%	$1.4
2.5%	$2.4
5.0%	$4.7

Section 7: SAV and Carbon Storage and Sequestration

SAV stores and sequesters carbon, a valuable regulating service. Van Houtven et al. (2016) estimated the economic value of the amount of carbon storage in above-ground SAV biomass and subsurface sediment as well as the amount of carbon sequestered each year. When we update their bounds using more recent data on SAV acreage in the A-P estuary and US EPA's most recent estimate social cost of carbon (US EPA, 2017), we find that the value of stored carbon to range between $163 and $419 million. Our updated value of sequestered carbon is estimated to vary between $12.2 and $31.4 million per year.

In this section, we estimate similar bounds for the alternative SAV loss scenarios described in Section 2. For each scenario, we assume that the lost SAV acreage no longer sequesters carbon, although the carbon already stored underneath lost SAV does not decay over the next decade. This durability assumption for stored carbon arises in part because we are unaware of credible estimates of stored carbon decay rates from lost SAV in the published literature. Although assuming zero decay of stored carbon suggests our estimates may be conservative, we do not believe it introduces substantial bias because these decay rates are generally thought to be low (Fourqurean et al., 2012).

Our bounds rely on different assumptions about the type of SAV coverage that sequesters carbon. Following Van Houtven et al. (2016), the lower bound estimate conservatively assumes that only continuous SAV coverage in the A-P estuary sequester carbon. Alternatively, our upper bound estimate assumes that all SAV coverage, both continuous and patchy, sequesters carbon.

Our analysis updates the data used in Van Houtven et al.'s study in two important ways. First, we update estimates of continuous SAV coverage in the A-P estuary using the most recently published maps from APNEP. The maps imply 50,644 acres of continuous SAV compared to 130,418 of total SAV coverage in the A-P estuary. Van Houtven et al. (2016) leveraged studies from Cebrian (2002) and Duarte et al. (2010) from Virginia to estimate an average annual SAV sequestration rate of 1.26 tons of carbon per acre.[16] Multiplying the number of SAV acres by the annual sequestration rate implies an estimated annual sequestration per year. In the lower and upper bound scenarios, 64,000 tons and 164,000 tons of carbon are sequestered per year, respectively (Table 7-1).

[16] Van Houtven et al. (2016) utilizes 22 observations from the published literature to estimate a median sequestration rate of 1.26 tons of carbon per acre per year. To be sure, there are more recent estimates of carbon sequestration from SAV in North Carolina and Virginia (e.g., Greiner et al., 2016), but most of these studies focus on restored as opposed to naturally occurring SAV where sequestration and storage rates are likely to be very different.

Table 7-1:
Total Carbon Storage and Sequestration in SAV

	SAV Area (acres)	Carbon Sequestration per Year (000s of tons)
Continuous SAV	50,644	64
All SAV	130,418	164

Second, we update the social cost of carbon (SCC) estimate using US EPA's most recent published estimates (US EPA, 2017). The SCC represent the marginal global costs to society of an additional ton of carbon dioxide (CO_2) released into the atmosphere. Assuming a three percent social discount rate, US EPA estimates the current SCC equals roughly $52 per ton in 2019 dollars. Moreover, the agency predicts the SCC will rise in real terms by 1.76 percent per year over the next decade. Recognizing that 3.7 tons of CO_2 equals one ton of carbon.[17], the social cost of an additional ton of carbon released into the atmosphere over the next decade ranges from $191 to $223 per ton as reported in Table 7-2.

Table 7-2:
Social Cost of Carbon (SCC)
Over Time

Year	SCC
1	$191
2	$194
3	$197
4	$201
5	$204
6	$208
7	$212
8	$215
9	$219
10	$223

With these updated inputs, we estimate the total economic loss over the next decade for the four alternative SAV loss scenarios summarized in Table 2-1. For each year and scenario, we first calculate undiscounted annual losses by multiplying the predicted lost SAV acreage by the corresponding social cost of carbon reported in Table 7-2. We then discount these losses back to current dollars using a three percent social discount rate and the net present value formula reported in Section 2. As reported in Table 7-3, the lower

[17] The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

bound estimates range from $3 to $31 million and the upper bound estimates range from $8 to $80 million.

Table 7-3:
Discounted Value of Lost Carbon Sequestration Over the Next Decade

Scenario	Total Decadal SAV Loss (%)	Lost Carbon Sequestration Value (millions of 2019 dollars)
Lower Bound / Continuous SAV		
	5	$3.1
	15	$6.2
	25	$15.6
	50	$31.2
Upper Bound / All SAV		
	5	$8.0
	15	$16.0
	25	$40.0
	50	$80.0

Section 8: Aggregate Losses

SAV provides ecosystem services that are valuable to people. When SAV is reduced, the value of these services is also reduced. Sections, 4, 5, 6, and 7 quantify four separate categories of losses for four different SAV loss scenarios. In this section we report aggregate losses across the four categories of commercial fisheries, recreational fisheries, coastal property values, and carbon sequestration.

We construct lower and upper bounds of aggregate losses by summing up the lower bound (i.e., most conservative) and upper bound (most inclusive) estimates from each category. One concern with simply adding together economic losses across the four categories is the possibility of double counting – adding together value categories that capture the same underlying service flow. In the current analysis, the estimated property value losses may partially capture recreational fishing losses if those who live near the A-P estuary shoreline also fish. In other words, recreational anglers may choose to live near the coast, implying that their willingness to pay to catch additional fish is partially capitalized into residential property values. To avoid this double counting possibility, our lower bound estimate nets out recreational losses for the 22 percent of anglers who reside in zip codes that border the A-P estuary shoreline.[18]

Table 8-1 reports lower and upper bound estimates of economic losses under the alternative SAV loss scenarios. The table also reports midpoint estimates which average the two bounds and perhaps represent the most defensible point estimate of economic losses. Aggregate losses over the next decade range from $6.07 million under the 5% decadal SAV decline and conservative modelling assumptions to $114.30 million under 50% decadal loss of SAV coverage. Across the four SAV loss scenarios, carbon sequestration losses represent over half of aggregate losses, and property value represent over one-quarter of aggregate losses.

These estimates can be used to construct a back-of-the-envelope estimate of the net present value of economic losses from an additional lost acre of SAV at some point over the next decade. If we divide the midpoint total loss estimate by the corresponding lost acreage for each scenario, our results suggest the average economic loss per lost acre is approximately $1,290. It should be noted that this loss per acre estimate only accounts for losses over the next decade. If we accounted for losses beyond the next 10 years or assumed the acre was lost today versus at some point over the next decade, our loss estimates would be larger.

[18] It is also possible that those who profit from commercial fishing boats choose to live near the A-P estuary's shoreline and that some of their profits are capitalized into housing prices. Moreover, recreational anglers who do not live near the coast may bid up the price of shoreline rental properties, implying that part of their willingness to pay is captured in our property value estimates. In both cases, however, we do not have reliable data that allow us to make a reasonable adjustment. If anything, this limitation implies that our lower bound estimate for aggregate losses may be too high.

Additionally, it is worth emphasizing that our-back-of-the-envelope calculation and all losses reported in Table 8-1 only account for the four categories of losses that we could readily quantify. In the next section, we discuss categories of losses that are not captured in our loss estimates.

Table 8-1:
Aggregate Economic Losses from SAV Coverage Declines
(millions of 2019 dollars)

5% Decadal SAV Loss (6,521 lost acres)			
Category	Lower Bound	Upper Bound	Midpoint
Commercial Fishing	$0.69	$0.69	$0.69
Recreational Fishing	$0.36	$0.55	$0.45
Property Value	$1.98	$1.98	$1.98
Carbon	$3.12	$8.00	$5.56
Aggregate Losses	$6.07	$11.22	$8.64
15% Decadal SAV Loss (19,563 lost acres)			
Category	Lower Bound	Upper Bound	Midpoint
Commercial Fishing	$2.11	$2.11	$2.11
Recreational Fishing	$1.07	$1.65	$1.36
Property Value	$7.03	$7.03	$7.03
Carbon	$6.24	$16.00	$11.12
Aggregate Losses	$16.22	$26.79	$21.50
15% Decadal SAV Loss (32,605 lost acres)			
Category	Lower Bound	Upper Bound	Midpoint
Commercial Fishing	$3.52	$3.52	$3.52
Recreational Fishing	$1.73	$2.66	$2.20
Property Value	$11.51	$11.51	$11.51
Carbon	$15.61	$40.00	$27.80
Aggregate Losses	$31.99	$57.69	$44.84
50% Decadal SAV Loss (65,209 lost acres)			
Category	Lower Bound	Upper Bound	Midpoint
Commercial Fishing	$6.62	$6.62	$6.62
Recreational Fishing	$3.30	$5.08	$4.19
Property Value	$22.61	$22.61	$22.61
Carbon	$31.22	$79.99	$55.61
Aggregate Losses	$63.02	$114.30	$88.66

Note: Only 78 percent of recreational fishing benefits are included in the lower bound estimates of aggregate losses to avoid double counting.

Section 9: Limitations, Data Gaps, and Potential Future Research

The quantitative findings of our study are limited to four categories of ecosystem services where data is readily available and modeling relationships between SAV abundance and economic value is established. At various points in previous sections, we identified some of the shortcomings of our different analyses that were due in part to data or modeling gaps. This section identifies priorities for future research that would result in refinements to the current analysis. We then discuss some of the economic values generated by SAV that we did not quantify. We also discuss important data and modeling gaps that must be filled with future research so that these values can be quantified.

9.1: Biological Modeling of SAV / Catch Relationship

There are two main data gaps that we believe would strengthen future efforts to model the SAV / catch relationship:

1) Juvenile Fish Abundance in SAV. For juvenile red drum and spotted seatrout, fisheries-independent sampling appears to under sample large areas of relatively high salinity SAV beds behind the Outer Banks, which suggests that estimates of mean fish enhancement by SAV may be conservative. For example, of the total acreage of SAV identified in this study (130,418 acres), ~ 80% (104,070 acres) of SAV is located in relatively high salinity areas (D. Field, pers. comm.). Although high salinity SAV beds are sampled by Program 123, there is a large spatial gap in sampling between Outer Banks stations and the White Oak and New River sampling stations (Figure A1 in the Appendix). Although not directly comparable because of differences in gear types and likely recruitment patterns between Gulf of Mexico and western Atlantic, mean density of red drum (< 40 mm SL) collected with a benthic sled in Galveston Bay, Texas was 0.14 fish/m^2 compared to ~ 0.0005 fish/m^2 in unstructured estuarine bottoms (i.e., SAV enhancement value of 0.135 fish/m^2 (Stunz et al., 2002)). The mean SAV enhancement value for early juvenile red drum in the present study for NC was 0.000309 fish/m^2. Similarly, Rooker and Holt (1997) sampled relatively high salinity seagrass beds with the Aransas Estuary, Texas using a benthic sled, and found mean densities of early juvenile red drum that ranged from 0.70 fish/m^2 in *Halodule wrightii*, to 0.19 fish/m2 in *Thalassia testudinum*. We re-emphasize that SAV enhancement estimates from this study in NC were based on standardized beach seines as compared to standardized benthic sled tows as used in the Texas example. Nevertheless, it is important to provide perspective on why estimates of SAV enhancement for red drum, and perhaps spotted seatrout, may be biased low due to the large spatial gap in standardized sampling between the Outer Banks and White Oak and New Rivers (Figure 1).

2) YOY Blue crab abundance in SAV. There is a large data gap for annual Young-of-the-Year (YOY) indices of abundance for blue crab in North Carolina. For example, NC DMF Program 120 uses a trawl net to sample tidal creeks with a focus on estimating

relative abundance of shrimp. This survey dates back to 1987 and is generally conducted during May-July. Peak post-larval settlement of blue crab in Pamlico Sound occurs in August-September (Eggleston et al., 2010). Thus, the best months to sample YOY blue crab would be in October-November of each year before post-settlement processes such as predation and immigration have had time to alter relative crab abundance. There is no sampling program for YOY blue crabs in SAV in Pamlico Sound. Thus, aa more precise estimate of YOY blue crab abundance in SAV than would be generated via P120 would be to use a targeted sampling approach (e.g., sweep net or suction sampling) to sample crabs in SAV in October-November.

9.2: Commercial Fisheries

We identify three areas where the current analysis could be substantially improved:

1) The commercial fisheries analysis focuses exclusively on blue crab which represents about 15 percent of commercial fishing's economic impact in the A-P estuary. An obvious refinement to the current analysis would be to include more commercial species with important links to SAV. This will require additional biological modeling of the SAV / catch relationship as well as additional economic analysis of commercial fishermen's profits. New data to support such analyses will need to be collected in some cases.

2) The current analysis focuses on how SAV benefits commercial anglers, but SAV also benefits individuals who consume commercially harvested fish. Future research could quantify these consumption benefits by estimating what consumers are willing to pay for fresh fish from the A-P estuary. Such analysis will likely require novel sales data collection for dockside and store-bought fish.

3) Some fish species spend only part of their life cycles in SAV in the A-P estuary before migrating elsewhere. To the degree that these species are harvested elsewhere, the current analysis does not account for the economic losses arising from SAV acreage declines. A better understanding of and accounting for the impact of SAV on migratory species could imply larger economic damages than those reported here. Massey et al. (2017) conduct such an analysis for the Chesapeake Bay. We should note that this concern applies equally to species that are important for recreational fisheries.[19]

9.3: Recreational Fishing

We identify two areas where improvements of the current analysis could be achieved:

[19] On the recreational side, we partially account for species migration outside the A-P estuary through our bounding exercise that includes and excludes the nearshore Atlantic Ocean waters of the Outer Banks. That said, some species migrate to other locations as well and are therefore not accounted for in analysis.

1) Similar to the commercial fishing analysis, the recreational fishing analysis is limited in scope in terms of the species studied – red drum and spotted seatrout. These species account for less than half of recreational catch. Future research could account for additional popular species such as striped bass and flounder spp.

2) The estimated willingness to pay for recreationally caught fish comes from a single study (Haab et al., 2012) using data that is now almost twenty years old. Estimating willingness to pay with more recent data from the A-P estuary would seem to be a fruitful line of research.

9.4: Property Values

We identify the following three areas where improvements to the current property value analysis could be made:

1) At its core, this analysis employs a benefits transfer from the Chesapeake Bay to the A-P estuary by leveraging the economic study of Guignet et al. (2017). Although there are good reasons to believe this transfer is sound, it is also possible that there are unique features of the A-P estuary that imply that SAV is capitalized into property values at different rates than what were estimated in the Chesapeake Bay. Therefore, a new property value study using data from the A-P estuary may be warranted if for no other reason but to validate the estimates reported in Guignet et al. Most if not all of the property value and SAV data needed for such an analysis have already been assembled for this project.

2) In addition to proximity to SAV affecting property values, the *quality* of SAV can also affect property values. Dense and patchy SAV generate different ecosystem services and, in principle, can imply different economic values. Guignet et al. investigate this question in the Chesapeake Bay but do not find significantly different capitalization rates for dense and patchy SAV. However, the importance of this issue suggests that further study is warranted and may affect aggregate property value loss estimates.

3) Many residential property owners invest in hardened or natural structures to stabilize their shoreline and protect their property from flooding and storm surge.[20] These expenditures can be thought of us defensive expenditures that represent a lower-bound estimate on what residential property owners are willing to pay to avoid the effects of shoreline loss, flooding, and storm surge (Freeman et al., 2014). If the relationship among SAV loss, shoreline loss, flooding, and storm surge can be established, these expenditures can be informative about the economic losses associated with SAV loss. Peterson et al. (2019) use GIS maps to quantify the miles

[20] The most common shoreline stabilization tool used is bulkheads, but North Carolina property owners are also able to plant vegetation and construct marsh toe protection revetments, sills, groins, breakwaters, and riprap revetments (NCDEQ, 2020). The costs of shoreline stabilization measures vary depending on materials used and site conditions. Living shorelines range in cost from $75 per square foot when using recycled oysters up to $350 per foot when using granite. The cost of bulkheads range from $200 to $400 per foot. Breakwaters and riprap start at $90 per foot (Allen, 2019).

of hardened shoreline on private property in Georgia's six coastal counties, and similar methods could be adopted with North Carolina data. Using engineering estimates of the costs of building these hardened structures (Allen, 2019), one could then construct an estimate of total defensive expenditures on residential land in North Carolina. Assuming the relationship between SAV loss and shoreline stabilization, flooding, and storm surge can be credibly estimated, the shoreline stabilization and avoided flooding and storm surge value of SAV could be estimated.

9.5: Carbon Sequestration and Storage

Here we identify four areas where or carbon sequestration and storage loss estimates could be improved:

1) There is a robust literature on estimating the amount of carbon sequestered and stored in SAV, and many of these studies have been fielded in Virginia and North Carolina in recent years(e.g., Greiner et al., 2016). Following Van Houtven et al. (2016), our estimates of stored and sequestered carbon on a per acre basis are based on older studies (Cebrian, 2002; Duarte et al., 2010). Our cursory reading of this more recent literature is that it focuses on restored SAV which, for a variety of reasons, might sequester and store carbon at different rates than naturally-occurring SAV. A meta-analysis of this growing literature seems long overdue, and perhaps a natural scientist (as opposed to an economist) with a deeper understanding of this literature and the methods employed would be better positioned to lead such a study.

2) A related issue worthy of investigation is the durability of carbon stored beneath lost SAV. In the current analysis, we assume this stored carbon does not decay for at least a decade (Fourqurean et al., 2012), but our sense is that this assumption deserves further scrutiny given its importance for assessing the the carbon losses from lost SAV. We could not identify a credibly study that calculates carbon storage decay rates for SAV, although it is possible that an ecologist more familiar with the literature might be able to do so.

3) Most of the existing estimates of the amount of carbon sequestered and stored by SAV are for dense as opposed to patchy SAV. A better understanding of how much carbon is sequester and stored by SAV type would permit us to refine the rather large bounds reported in Section 8.

4) The Biden Administration has announced its intentions to revise the social cost of carbon, and the conventional wisdom is that the updated estimate will be larger than the one used in this report (Eilperin and Dennis, 2021). If this indeed turns out to be the case, the economic losses reported here can and should be updated.

9.6: Additional SAV Values

The current SAV analysis quantifies SAV losses through four channels: 1) commercial fisheries; 2) recreational fishing; 3) property values; and 4) carbon sequestration and storage. As discussed in Dewsbury et al. (2016), however, losses in SAV coverage would generate economic losses through additional channels as well. These channels include: 1) recreational losses such as waterfowl hunting, waterfowl watching, and boating that does not involve angling; 2) erosion control for undeveloped shorelines; 3) nutrient cycling; and 4) sediment retention. Whether losses associated with these categories of ecosystem services are significant relative to the four categories of losses identified in this report is uncertain and certainly worthy of future research. In the remainder of this section, we discuss two categories of potential losses – waterfowl hunting and watching and erosion control – that are economically meaningful in the A-P estuary. We identify data and modeling gaps that must be filled in order to quantify the economic losses resulting from SAV coverage loss.

9.7: SAV and Waterfowl

The diversity of habitats in the A-P estuary provide food and refuge for many recreationally valuable bird species. Seagrasses are home to small fish, crabs, aquatic insects, turtles, and other animals that are important food sources for birds in the estuary. Wintering waterfowl such as geese, swans, and loons live in the estuary for roughly four months of the year, and species such as mergansers, buffleheads, grebes, and redhead ducks use SAV as a food source throughout the year. Duck species such as redheads and diving ducks directly eat the roots, stems and leaves of seagrass. Declines in the quality of shallow-water estuarine habitat have been shown to have negative impacts on migratory waterfowl, especially duck species (Perry and Deller, 1996).

Ducks and other waterfowl that rely on SAV are important species to wildlife recreators in North Carolina. Migratory birds accounted for 22% of North Carolina's 7,608 hunting days and 27% of hunters in 2011. In 2011, hunting-related expenditures in North Carolina totaled $525 million dollars, of which migratory bird hunting involved $93 million (US FWS, 2014). When comparing per capita trip expenditures across types of hunting, expenditures were highest for migratory bird hunters at an average trip expenditure per hunter of $1,000. More recent surveys for the North Carolina Wildlife Resources Commission indicate that most migratory bird hunting targets waterfowl, and most waterfowl hunting occurs near North Carolina's coastal estuaries (NCWRC, 2018).

Approximately 50,542 hunters harvested duck species and 12,653 harvested Canadian geese in 2016-2017 (NCWRC, 2019). Duck harvest occurs most frequently along the coast in Currituck, Dare, Hyde, Pamlico, and Carteret counties. County estimates derived from 5-year average annual NC hunter harvest surveys indicate duck harvest per huntable square mile is highest in Currituck (197-245) and Hyde Counties (148-196) (NCWRC, 2018).

Like recreational anglers, bird hunters are willing to pay more than their actual monetary expenditures for recreational trips. This difference between total willingness to pay and monetary expenditures is what economists refer to as "consumer surplus," or the net benefits of bird hunting trips. The Recreation Use Value Database (RUVD) uses estimates from 30 economic valuation studies of waterfowl hunting in the Southeast to calculate the mean value of consumer surplus per day of waterfowl hunting at $76.32 per day.[21] (Rosenberger, 2016). The total consumer surplus generated from migratory bird hunting in North Carolina can be roughly estimated by multiplying total hunting days by the consumer surplus per hunting day. The back of the envelope value for total consumer surplus generated from waterfowl hunting annually in North Carolina is $127,740.

Although hunting is the highest valued recreational opportunity for waterfowl, wildlife-watching activities also generate considerable expenditures and surplus. Results from the 2011 National Survey of Fishing, Hunting and Wildlife-Associated Recreation found that wildlife watchers throughout the state of North Carolina spent the equivalent of $1.05 billion on 9.28 million days on activities such as watching, feeding, and photographing wildlife (US FWS, 2014). The estimated consumer surplus per day from wildlife viewing activities is $66.78 (Rosenberger, 2016), which translates into a total consumer surplus value of roughly $619 million. Unfortunately, data are not available to determine what percentage of this total is attributable to recreation in the A-P estuary.

The A-P estuary is an important habitat for NC waterfowl, but the relationship between SAV abundance and waterfowl populations in the estuary remains poorly understood. There is also limited research establishing the connection between bird populations and consumer surplus derived from waterfowl-based recreation activities. Although we understand that SAV is important to waterfowl populations and that waterfowl hunting and watching is valuable to recreators in North Carolina, additional research is needed to quantify the economic losses to hunters and wildlife-watchers arising from SAV decline. Having said this, it is worth noting that some of these losses could be picked up in our residential property value losses to the degree that owners of these properties engage in these activities and, as a result bid up nearshore property values.

9.8: SAV and Coastal Erosion

There are approximately 1,200 miles of estuarine shoreline in North Carolina compared to 325 miles of oceanfront shoreline. Estuarine shoreline erosion, the process of wearing away of shoreline sediments is usually caused by wave action but can also be caused by human activities like boating. Long-term processes like sea-level rise also threaten estuarine shorelines. Historically, estuarine shorelines in North Carolina have been eroding at a rate of 1.6 meters per year (Eulie et al., 2018). Between 1993 and 2008, shoreline recession consumed approximately 50 square miles of coastal land (Riggs and Ames, 2003).

There is a growing body of literature suggesting SAV provides regulating services in the form of coastal erosion control (Dewsbury et al., 2016). Seagrass provides coastal protection by attenuating wave energy (Koch et al., 2009), reducing current velocities, and stabilizing sediment (Ondiviela et al., 2014, Duarte et al., 2013; Koch et al., 2006).

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[21]Adjusted to 2019 dollars using U.S. Consumer Price Index.

Attenuation of wave energy results in smaller waves reaching the adjacent shoreline (Fonseca and Cahalan 1992; Koch, 1996; Prager and Halley, 1999). Additionally, beaching of seagrass debris may play an important role in the formation of coastal dunes (Hemminga & Nieuwenhuize, 1990) and the long-run stability of coastal barrier islands.

Private and public landowners can invest in shoreline stabilization projects that prevent coastal erosion. These project expenditures can be interpreted as defensive expenditures, and we outlined in Section 9.4 a strategy for estimating them on private, residential land. An additional avenue for assessing these defensive expenditures would consider public spending on shoreline stabilization policies. A recent article in *Coastal Review Online* (CRO Staff, 2020) summarizes nine publicly funded projects that were recently awarded millions of dollars to construct hardened structures and living shorelines to protect and stabilize coastlines.[22] For example:

- The North Carolina Department of Environmental Quality (DEQ) has been awarded more than $1.1 million and $0.83 in matching funds to engineer projects to protect the Rachel Carson Reserve and the town of Beaufort.
- Carteret County Shore Protection Office was awarded $1.5 million (and matching funds) to construct living shorelines to stabilize 3,800 linear feet of estuarine shoreline that is vulnerable to erosion. Grant funding is also being used to fund the protection of road infrastructure and education infrastructure.
- The North Carolina Coastal Federation, partnering with N.C. Department of Transportation and Carteret Community College, received a total of $5.6 million to construct three large living shorelines that will protect community infrastructure and causeways serving as important evacuation routes.

One factor that makes it challenging to assess whether these project expenditures represent a lower bound on society's willingness to pay to avoid coastal erosion is the cost-sharing arrangements between local and federal parties. In particular, the federal government, as opposed to the local community, often covers most of these costs. A priori, it is not clear whether the federal government's contribution should be counted towards what society is willing to pay. On the one hand, the federal government's allocations could be correcting for externalities and spillover effects that local communities are not fully accounting for. On the other hand, the federal government's contribution could be due to rent seeking behavior by local communities. A careful analysis of each project is therefore necessary before a determination can be made.[23]

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[22] Our efforts to identify a more comprehensive historical record of shoreline stabilization projects turned up empty. Most projects require a permit from the US Army Corps of Engineers, but our review of their permitting website suggested that the data associated with each project has not been collated into a common data set and that cost data for individual projects is generally unavailable. The Living Shorelines Academy maintains a database of living shoreline projects in North Carolina, although cost data for individual projects are not available.

[23] An additional concern with such an analysis would be how to combine these estimates with similar estimates for private lands (see section 9.4) where the possibility for double counting seems real.

Section 10: Conclusion

The SAV located in the Albemarle-Pamlico (A-P) estuary provides significant market and nonmarket value to the state of North Carolina. Recent analysis by Field et al. (2020) suggests that SAV coverage in the A-P estuary has declined over the last 15 years. The current report provides some perspective on the economic losses associated with these declines as well as the potential losses from accelerated SAV loss that is more in line with global trends.[24] (Waycott et al., 2009). We consider four SAV loss scenarios over the next decade – 5, 15, 25, and 50 percent losses – and use market and nonmarket valuation methods to quantify the annual economic losses for four categories of ecosystem services: 1) commercial fishing; 2) recreational fishing; 3) residential property value losses; and 4) carbon sequestration.

The key findings from our analysis are:

- Our estimate of economic losses increases proportionately with declines in SAV acreage and is roughly $1,290 per lost acre. There are relatively few reliable studies that quantify commercial fishing, recreational fishing, property value, or carbon storage and sequestration losses from SAV, and our estimate is the first to account for all four categories of losses over a decadal scale. For several reasons that we summarize below, we caution that our estimate should be interpreted as an incomplete and conservative estimate of the total benefits of SAV.
- Table 1 reports upper bound, lower bound and midpoint estimates of aggregate economic losses over the next decade across the four categories we considered from alternative SAV loss scenarios.

Table 10-1:
Aggregate Economic Losses from SAV Coverage Declines
(millions of 2019 dollars)

Scenario	Lower Bound Estimate	Upper Bound Estimate	Midpoint Estimate
5 Percent Decadal Loss	$6.07	$11.22	$8.64
15 Percent Decadal Loss	$16.22	$26.79	$21.50
25 Percent Decadal Loss	$31.99	$57.69	$44.84
50 Percent Decadal Loss	$63.02	$114.30	$88.66

- Our midpoint estimate of total economic losses associated with a 5 percent decadal loss in SAV is $8.7 million per year (2019 dollars), whereas our midpoint estimate of economic losses with a 50 percent decadal loss is $88.7 million per year.
- Over half of these economic losses are due to declines in sequestered carbon. Our midpoint carbon sequestration loss estimates range from $5.6 million per year (5 percent decadal loss) to $55.6 million per year (50 percent decadal loss).

[24] The most recent global census estimates 7 percent of seagrass habitat is lost worldwide per year (UNEP, 2020).

- Declines in SAV result in reduced nursery habitat for blue crab and thus reduce the health of the commercial blue crab fishery. Midpoint profit loss estimates for the blue crab commercial fishery range from $0.7 million (5 percent decadal loss) to $6.6 million (50 percent decadal loss).
- The midpoint recreational fishing annual losses, which are limited to declines in catch for spotted seatrout and red drum, range from $0.5 million under the 5 percent decadal loss scenario to $4.2 million under the 50 percent decadal loss scenario.
- Annual losses associated with residential property values are substantial and range from $2.0 million under the 5 percent decadal scenario to $22.6 million under the 50 percent decadal loss scenario. These losses are more the one-quarter of total losses.

These losses are economically large and significant. They do not, however, capture the full market and nonmarket losses from declines in SAV coverage. For example, our loss estimates for commercial and recreational fisheries are limited to three species – blue crab, red drum, and spotted seatrout – although other species would be negatively affected by SAV declines. Moreover, we only quantify those nutrient filtration benefits that impact commercial fisheries, recreational fisheries, and property values even though SAV filters nutrients and improves water quality throughout the A-P estuary. An additional limitation is that we only monetize coastal erosion losses for SAV near residential properties although much SAV is located along undeveloped shorelines. We also do not quantify losses to waterfowl hunters and nature watchers. We hope the data and biological modeling gaps that limited us from quantifying these additional losses will be filled with future research.

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Appendix: Fisheries: Life History, SAV Enhancement Data & Population Projection Modeling

This appendix describes in greater detail the data and modeling efforts used to generate population projections for how SAV coverage losses will impact total catch in the A-P estuary for three species – blue crab, spotted seatrout, and red drum. The initial three sections describe fisheries and SAV data sources, and the final two sections describe the modeling efforts.

Section A1: Life History

A). Blue Crab Life History. **–** The blue crab is one of the most economically important fishery species in North Carolina (NC DMF 2018). Blue crab mating typically occurs from May to October in both the mesohaline and oligohaline portions of Pamlico Sound (Medici et al. 2006, Eggleston et al. 2015). Males couple with pre-pubescent females prior to their terminal molt. Directly after molting, mating occurs while the female is in a soft-shell state. After mating, inseminated females begin migration to higher salinity areas of the estuary and enter the ocean where they subsequently release their larvae. The larvae remain in ocean waters for ~ 30 days, after which they recruit into Pamlico Sound via storm-driven transport, or a combination of wind forcing and selective-tidal-stream-transport (Reyns et al. 2007, Eggleston et al. 2010). In the absence of tropical storms, the majority of post-larval blue crabs disperse through Oregon or Hatteras Inlets into the Pamlico Sound, after which they settle into near-inlet nursery habitats dominated primarily by seagrass (Etherington and Eggleston 2000, 2003). Following recruitment, post-settlement instars often undergo a density-dependent secondary dispersal by drifting across-sound and settling in near-shore nursery habitats dominated by shallow detrital habitat (Etherington and Eggleston 2000, 2003; Blackmon and Eggleston 2001; Reyns et al. 2006, 2007). After initial settlement in seagrass as megalopae and growth into first and second stage crabs, they begin to emigrate into nearby benthic habitats (Etherington and Eggleston 2000, 2003). Concern for the blue crab stock in North Carolina is due to reduced landings of hard blue crabs during 2007-2017, following record-high landings observed during 1996-1999 (NC DMF 2018). The most recent blue crab stock assessment for 2018 showed significant decreases in recruitment of juvenile and adult blue crabs to the population, indicating possible recruitment limitation (NC DMF 2018).
B). Spotted Seatrout and Red Drum. -- We combined both spotted seatrout (*Cynoscion nebulosus*) and red drum (*Sciaenops ocellatus*) in this section because juveniles of both species are often collected by the same sampling gear and programs. The data sources rely heavily on fisheries-independent sampling programs conducted by the NC Division of Marine Fisheries (NC DMF).

Spotted seatrout spawning occurs several times during a single season from late April to early October in the deep parts of bays and adjacent grass beds in North Carolina. Spotted seatrout can spawn, develop and spend its entire life in the estuarine environment. Spotted seatrout mature between age one and three and can live as long as 10 years. (NC DMF 2012. In Pamlico Sound, spawning times can be identified by the low frequency, drumming sounds of spotted seatrout heard from June until August, and peaking in July (Luczkovich et al. 2008, Ricci et al. 2018). Unlike the majority of other sciaenid species, adult spotted seatrout spawn within estuaries as opposed to the continental shelf (Smith et al. 2008). Larvae settle to benthic habitats after ~ 14 days in the water column, with seagrass being a key settlement habitat (Jones 2014). Winterkill of juvenile and adult spotted seatrout at its northern limits of distribution is related to the severity of low water temperatures (Ellis et al. 2017).

<u>Red drum</u> spawning occurs near mouths of bays, passes, and coastal ocean waters (Bacheler et al. 2008). Ross et al. (1995) determined that peak spawning occurred in August and September in North Carolina. Red drum larvae use tidal or wind-driven currents for transport, and early juveniles settle along marsh edges with muddy or sandy bottoms, or in seagrass meadows composed of shoal grass *Halodule wrightii, Ruppia maritima, or Zostera marina in NC, or* turtle grass *Thalassia testudinum* in Texas (Stunz et al. 2002, Powers 2012, Bacheler et al. 2008). Larger juveniles are often found in the upper reaches of estuaries and low-salinity coastal creeks and bays (Ross et al. 1995). Juvenile and sub-adult red drum remain in shallow estuarine habitats during the first 1–2 years of life except during periods of extremely cold weather in winter when fish may temporarily leave shallow-water habitats for deeper channels (Wenner et al. 1990).

Section A2: SAV Enhancement Data

<u>A). Blue Crab Data</u> – The arithmetic mean enhancement of 0+ blue crabs (C1-C5 stages) in SAV versus unstructured habitats is 4.77 crabs/m^2, and the geometric mean is 2.12 crabs/m^2 (Table A1). The data are from studies in Pamlico Sound, North Carolina, as well as the lower and upper parts of Chesapeake Bay, and generally used drop-traps or suction sampling to sample crabs. For example, Etherington and Eggleston (2000) used suction sampling to quantify the density of J1-J5 instar blue crabs in four different nursery habitat types throughout Pamlico Sound, and found that densities were nearly 10-times higher in seagrass than unstructured habitats. Etherington and Eggleston (2003) subsequently quantified the density of juvenile blue crabs in a variety of complex habitats throughout Pamlico Sound for another four years, however those data are not included in our current estimates of crab enhancement by seagrass because sampling of unstructured habitats was dropped after 1996 given the lack of appreciable numbers of crabs in this habitat. In the lower portion of Chesapeake Bay, Pile et al. (1996) used suction sampling and found that early instar blue crabs were ~ 6-times higher in seagrass than unstructured habitat. The Maryland Department of Natural Resources (summarized in Doctor et al. 2012) used drop-traps in the upper portion of Chesapeake Bay and found that juvenile blue crabs were also ~ 6-times higher in seagrass in unstructured habitat. Mean crab densities from the upper Chesapeake Bay were significantly lower than the lower portion of Chesapeake Bay, however, including the data from Doctor et al. (2012) will generate a very conservative estimate of blue crab enhancement by seagrass, and help account for the observation that blue crab recruitment in North Carolina diminishes as one moves away from the inlet sources of megalopae (E. Voigt, NC State University, unpubl. data).

Lipcius et al. (2005) also sampled juvenile blue crabs in the lower portion of Chesapeake Bay, and found that the density of blue crab juveniles was an order-of-magnitude greater in seagrass than unstructured habitat. Lipcius et al. (2005) sampled crabs in seagrass using suction sampling, and sampled crabs in unstructured habitat using a trawl. They applied a correction factor of 22% efficiency to the trawl catches. We did not use the enhancement data from Lipcius et al. (2005) in our estimates for North Carolina because of the use of the two different gear types. This trend of much higher juvenile crab densities in seagrass versus unstructured habitats, however, may not apply throughout the east coast of the U.S. For example, studies by Wilson et al. (1990) in southern New Jersey collected blue crabs from eelgrass (*Zostera marina*), adjacent un-vegetated substrate, macroalgae (*Viva lactuca*), and a *Spartina alterniflora* marsh creek with a suction sampler from July 1986 to March 1988 in 19-day and two-night sampling trials. The overall average density of juvenile blue crabs was low (0-3 ind./m^2) compared to densities in Chesapeake Bay or the Gulf of Mexico, and there was little evidence of different nursery values among habitats. We did not use seagrass enhancement data from Wilson et al. (1990) in this study because we were restricting our geographic coverage to North Carolina and Virginia to best approximate blue crab enhancement for North Carolina seagrass beds.

B). Spotted Seatrout and Red Drum Data

Juvenile Anadromous Survey (NC DMF Program 100) – One of the longest ongoing surveys for juvenile spotted seatrout and red drum in North Carolina is the Juvenile Anadromous Survey (Program 100) in the Albemarle Sound and its tributaries. This survey was designed to determine the relative abundance, growth, and distribution of river herring (*Alosa sp.*) and striped bass (*Morone saxatilis*), but also captures spotted seatrout and red drum juveniles. This fixed-station survey (meaning the same stations are sampled the same number of times throughout the year, every year) began in 1971 and uses a 60-foot bag seine and an 18-foot head rope bottom trawl. In 2016, seine and trawl stations were added in the Tar/Pamlico, Neuse, and Cape Fear rivers to monitor juvenile striped bass abundance and their habitat.

Red Drum Juvenile Seine Survey (NC DMF Program 123) – In 1991, the NCDMF began a fall seining survey to generate a Juvenile Abundance Index (JAI) for age-0 red drum and to identify and characterize red drum nursery areas. The NCDMF uses the JAI to assess recruitment and as a tuning index for the North Carolina red drum stock assessment (Vaughan and Carmichael 2000, Takade and Paramore 2007). This survey is conducted at 21 fixed sampling sites throughout coastal North Carolina (Figure A1) during September through November for each year. Each of these sites was sampled in approximately two-week intervals for a total of six samples per site with an 18.3 m (60 ft) x 1.8 m (6 ft) beach seine with 3.2 mm (1/8 in) mesh in the 1.8 m x 1.8 m bag. A one "quarter sweep" pull was conducted at each location. This sweep was done by stationing one end of the net onshore and stretching it perpendicularly as far out as water depth allowed. The deep end was brought ashore in the direction of the tide or current, resulting in the sweep of a quarter-circle quadrant. The sweep covered an area of 225 m^2. All species were counted and identified; also recorded were salinity (ppt), water temperature (^oC), tidal state or water level, and presence of SAV. Locations of fixed stations were determined in 1990 based on previous catch rates and practicality for beach seining (Ross et. al. 1995). The total number of Young-of-the-Year red drum and spotted seatrout caught by a 225 m^2 sample were used to generate a SAV enhancement density (#/m^2).

Supplement to Program 123 – Powers (2012) supplemented data collected by NC DMF Program 123 by applying the same beach/bag seine sampling methods as Program 123, but along a down-river to up-river sampling design in the Pamlico River, North Carolina (Figure A2). Samples were collected twice per month during October-November 2009, and August-November 2010. As with Program 123, total bottom area sampled was approximately 255 m^2 for each sweep, and environmental data (water temperature, salinity, depth, bottom type, and SAV) were recorded.

Section A3: Caveats to SAV Enhancement Data

One of the strengths of this study is identification of data gaps. For juvenile red drum and spotted seatrout, fisheries-independent sampling appears to under sample large areas of relatively high salinity SAV beds behind the Outer Banks, which suggests that estimates of mean fish enhancement by SAV may be conservative. For example, of the total acreage of SAV identified in this study (130,418 acres), ~ 80% (104,070 acres) of SAV is located in relatively high salinity areas (D. Field, pers. comm.). Although high salinity SAV beds are sampled by Program 123, there is a large spatial gap in sampling between Outer Banks stations and the White Oak and New River sampling stations (Figure A1). Although not directly comparable because of differences in gear types and likely recruitment patterns between Gulf of Mexico and western Atlantic, mean density of red drum (< 40 mmSL) collected with a benthic sled in Galveston Bay, Texas was 0.14 fish/m^2 compared to ~ 0.0005 fish/m^2 in unstructured estuarine bottoms (i.e., SAV enhancement value of 0.135 fish/m^2 (Stunz et al. 2002)). The mean SAV enhancement value for early juvenile red drum in the present study for NC was 0.000309 fish/m^2. Similarly, Rooker and Holt (1997) sampled relatively high salinity seagrass beds with the Aransas Estuary, Texas using a benthic sled, and found mean densities of early juvenile red drum that ranged from 0.70 fish/m^2 in *Halodule wrightii*, to 0.19 fish/m^2 in *Thalassia testudinum*. We re-emphasize that SAV enhancement estimates from this study in North Carolina were based on standardized beach seines as compared to standardized benthic sled tows as used in the Texas example. Nevertheless, it is important to provide perspective on why estimates of SAV enhancement for red drum, and likely spotted seatrout, may be biased low due to the large spatial gap in standardized sampling between the Outer Banks and White Oak and New Rivers (Figure A1).

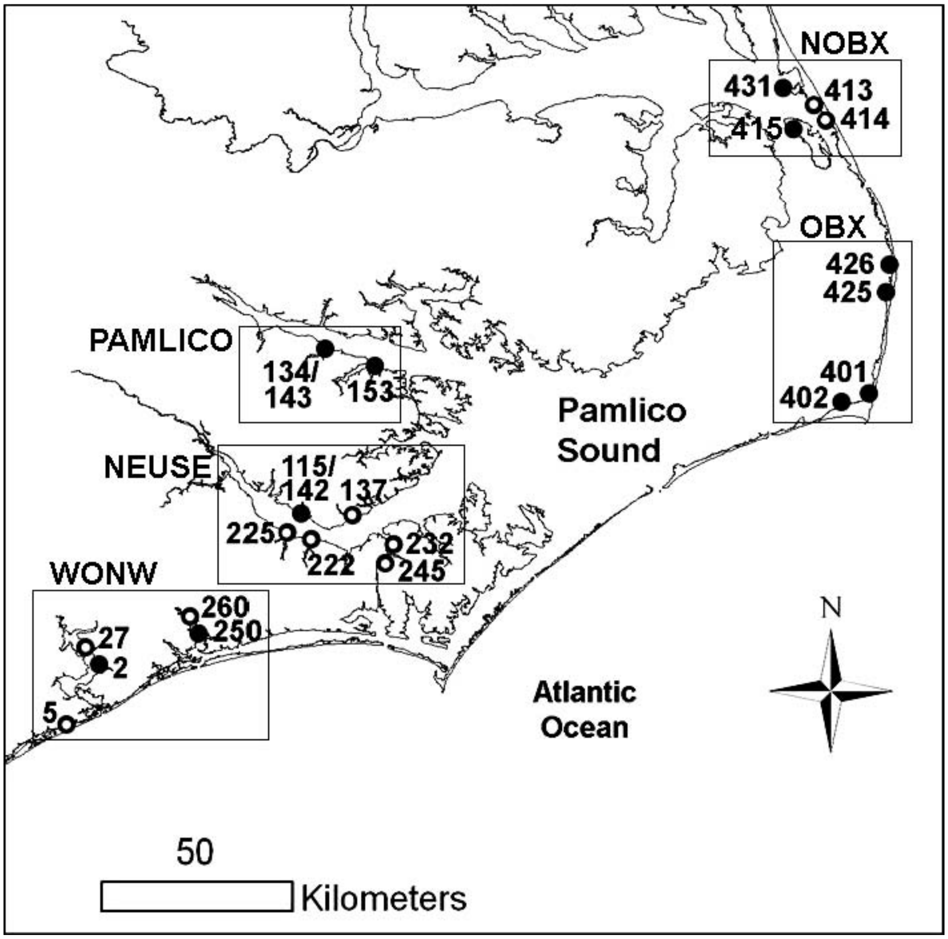

Figure A1. Adapted from Bacheler et al. 2008. Map of stations sampled by beach seine in North Carolina during 1991–2006 to determine age-0 red drum abundance. Boxes surround stations within each of five regions (NOBX = northern Outer Banks, OBX = Outer Banks, PAMLICO = Pamlico River, NEUSE = Neuse River, and WONW = White Oak–New rivers). Open circles indicate fixed stations with high red drum catch per unit effort (CPUE; number captured per seine haul; n =10 stations), and filled circles indicate fixed stations with low CPUE (n = 11 stations).

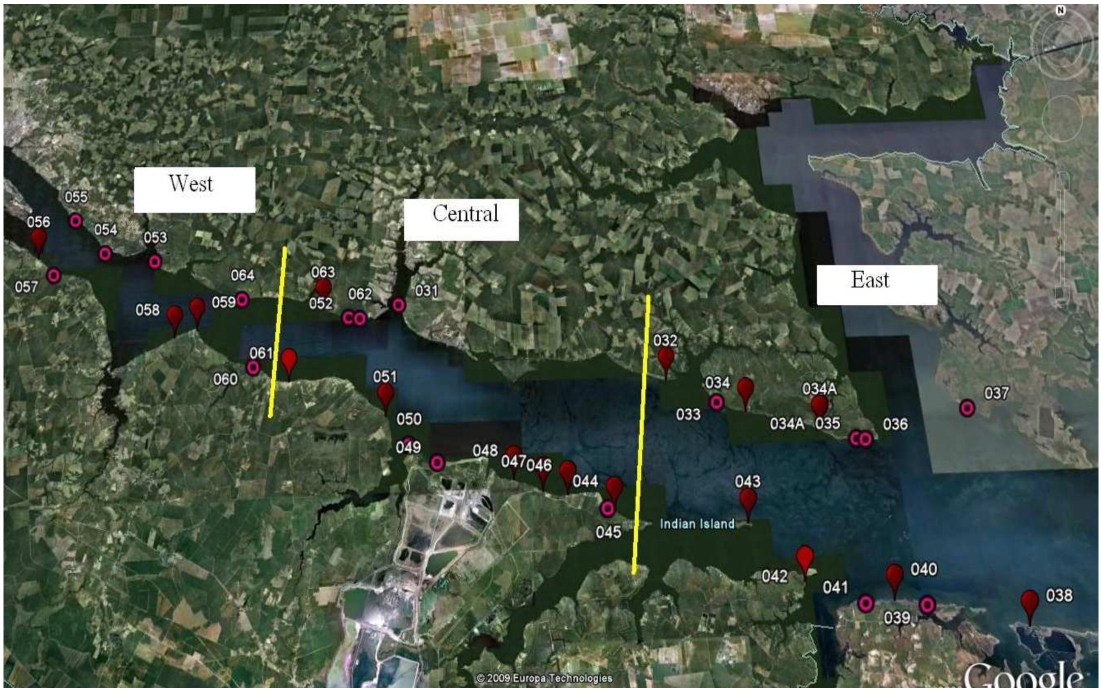

Figure A2. Adapted from Powers 2012. The 65 km study site of the Pamlico River from the Fork Point Island to the mouth of the Pungo River, North Carolina and the three sections West, Central and East and all 36 sub-sites. Red marks represented potential sites not selected by the random number generator, and pink circles (six stations within each section) represent sites that were included in the study.

Section A4: Population Projection Modeling

The goal of this portion of the project is to provide estimates of population decline and associated catch loss in response to SAV loss over a 10-year period, and under five scenarios of seagrass loss, for the following species: (i) blue crab, spotted seatrout, and red drum. The seagrass loss scenarios are as follows:

1. 0% SAV loss each year for 10 years (baseline scenario)
2. 0.5% SAV loss each year for 10 years
3. 1.5% SAV loss each year for 10 years
4. 2.5% SAV loss per year over 10 years
5. 5% SAV loss per year over 10 years

The fishery population projection estimates below were obtained using forward projections based on the most recent stock assessment of each species.

A). Blue Crab – The most recent stock assessment was conducted in 2018. A sex-specific, two-stage model was applied to available data to assess the status of North Carolina's blue crab stock during 1995-2016 (NCDMF 2018). We used the estimated parameters and population quantities, (i.e., natural mortality, fishing mortality) of the most recent three years, and recruitment and abundance of the terminal year (2016), to compute forward population projections under varying scenarios of SAV loss. The mathematical functions used to describe crab population dynamics in the projection were the same as those used in the stock assessment model. The model tracks population dynamics of recruits (<127 mm) and those individuals fully recruited to the fishery (>127mm) explicitly. A stochastic 10-year population projection was conducted starting from the terminal year of the assessment (i.e., 2016), under five scenarios of recruitment levels in response to the five SAV loss scenarios. We assumed that the estimated SAV (130,418 acres) can support the estimated recruitment of the terminal year of assessment (i.e., 136.57 million individual crabs in 2016), and SAV loss will result in a reduction of recruitment strength. The mean crab recruitment levels projected over 10 years for each SAV loss scenarios were calculated based on the average ratio between the density of Young-of-the-Year blue crabs on unstructured and SAV habitats derived from Table A1. The arithmetic mean and variance of the ratio are 0.138 and 0.011, respectively.

For the baseline scenario where there is no SAV loss for the projected years, the mean recruitment over 10 years is the estimated recruitment of 2016 (subject to fluctuation quantified by the uncertainty estimated from the assessment model). For SAV loss scenarios, the recruitment levels over the projected years are calculated as:

$$R_y = R_{y-1} * (1 - loss_{\%}) + R_{y-1} * ratio * loss_{\%}$$

where R_y is the mean recruitment of projected year y, $loss_{\%}$ is the percentage of SAV loss, and $ratio$ is the ratio between the density of Young-of-the-Year blue crabs on unstructured and SAV habitats derived from Table A1.

The population projection was repeated 10,000 times with stochastic draws of recruitment in 2016 and SAV enhancement ratio. The SAV enhancement ratio was drawn from a normal distribution (mean = 0.138; variance = 0.011). Fishing pressure over the projected years was assumed to be stable and equal to the average fishing pressure of the most recent three years estimated from the assessment.

The mean and CV of total catch and abundance over the projected 10 years are summarized in Table A2a – A2d. The projected catches of year 1 are very similar among the five scenarios. This is because the number of post-recruits in year 1 is the same among scenarios (recruits are different among scenarios), and selectivity of recruits is low (0.025; NCDMF, 2018). As the recruits in year 1 became fully recruited to the fishery in year 2, reduction of recruitment strength due to SAV loss begin to take effect. The sharp decline in catch from year 1 to year 2 is driven by the low recruitment in 2016.

Table A1. Density of Young-of-the-Year blue crabs (generally 0+ age class consisting of C1-5 stages) on SAV versus unstructured habitats. The arithmetic mean enhancement in SAV versus unstructured habitats is 4.77 crabs/m², and the geometric mean is 2.12 crabs/m²

Reference	SAV (ind./m²)	SAV SE	Control (ind./m²)	Control SE	Enhancement (ind./m²)	Gear	Seasons	Years
Pile et. al. 1996	12.56	6.12	2.27	0.38	10.29	Suction	3	1983-92
Etherington & Eggleston 1990	12.5	5.4	1.3	0.08	11.2	Suction	2	1996
Doctor et al. 2012	0.56	0.001	0	na	0.56	Drop-net	1	2007
Doctor et al. 2012	0.67	0.008	0.16	0.0006	0.51	Drop-net		2008
Doctor et al. 2012	1.89	1.35	0.056	0.0003	1.29	Drop-net	1	2009

Table A2a. The mean of total catch of blue crabs (million individuals) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	63.246	63.247	63.244	63.238	63.235
2	39.683	39.684	39.619	39.526	39.437
3	37.162	37.022	36.668	36.284	35.483
4	36.893	36.596	35.933	35.246	33.713
5	36.864	36.410	35.440	34.459	32.234
6	36.861	36.250	34.979	33.713	30.842
7	36.861	36.093	34.526	32.986	29.512
8	36.861	35.938	34.080	32.275	28.240
9	36.861	35.783	33.639	31.579	27.023
10	36.861	35.628	33.204	30.899	25.859

Table A2b. The standard deviation of total catch of blue crabs (million individuals) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	0.709	0.717	0.711	0.711	0.706
2	7.676	7.766	7.689	7.683	7.616
3	8.421	8.487	8.337	8.265	8.030
4	8.501	8.531	8.309	8.167	7.764
5	8.509	8.503	8.210	8.000	7.438
6	8.510	8.467	8.105	7.828	7.119
7	8.510	8.430	8.001	7.660	6.813
8	8.510	8.394	7.897	7.495	6.519
9	8.510	8.358	7.795	7.333	6.239
10	8.510	8.322	7.695	7.175	5.971

Table A2c. The mean of total abundance of blue crabs (million individuals) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	246.956	247.016	246.858	246.583	246.486
2	203.758	203.253	201.855	200.296	197.229
3	199.137	197.810	194.773	191.596	184.597
4	198.643	196.469	191.776	186.998	176.199
5	198.590	195.570	189.245	182.917	168.558
6	198.585	194.722	186.793	178.969	161.288
7	198.584	193.882	184.377	175.110	154.336
8	198.584	193.046	181.993	171.336	147.685
9	198.584	192.214	179.640	167.642	141.320
10	198.584	191.385	177.317	164.029	135.230

Table A2d. The standard deviation of total abundance of blue crabs (million individuals) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	31.545	31.929	31.636	31.640	31.424
2	44.318	44.719	44.037	43.769	42.794
3	45.684	45.909	44.839	44.196	42.312
4	45.830	45.859	44.406	43.390	40.636
5	45.846	45.677	43.849	42.471	38.903
6	45.847	45.482	43.284	41.557	37.230
7	45.847	45.286	42.726	40.662	35.628
8	45.847	45.091	42.174	39.786	34.096
9	45.847	44.897	41.630	38.929	32.629
10	45.847	44.703	41.093	38.091	31.226

B). Spotted Seatrout – An age-structured, population dynamics model was used to compute forward population projections under varying scenarios of SAV loss. A stochastic 10-year projection was conducted starting from an equilibrium condition with recruitment level derived from the mean density of Young-of-the-Year spotted seatrout in SAV (i.e., 0.00274 (ind./m^2) (Table A3) and the total estimated extend of SAV (130,418 acres). We assume that the estimated SAV area supports the equilibrium recruitment levels of seatrout, and SAV loss will result in a reduction of recruitment strength. The projections were conducted for five scenarios of recruitment level, which were assumed to be a function the five SAV loss scenarios. For the baseline scenario where there is no SAV loss for the projected years, the mean recruitment over 10 years is the equilibrium recruitment:

$$R_{equilibrium} = 0.00274 * 130418 * 4046.86 = 2132734$$

For SAV loss scenarios, the recruitments over the projected years are calculated as

$$R_y = 0.00274 * SAV * (1 - loss_{\%}) - 0.00216 * SAV * loss_{\%}$$

where R_y is the mean recruitment of projected year y, $loss_{\%}$ is the percentage of SAV loss, and 0.00216 is the mean enhancement of the density of Young-of-the-Year spotted seatrout from unstructured habitats to SAV habitats.

The projection was repeated 10,000 times with stochastic draws of equilibrium recruitment (sd = 0.00118) and enhancement (mean = 0.00216; sd = 0.00122). Fishing pressure over the projected years is assumed to be stable (i.e., constant across projected years with instantaneous fishing mortality = 0.4; the 2012 estimate from the assessment report). Asymptotic fishery selectivity and age-specific natural mortality rates from the recent assessment report were used. The mean and CV of total catch and abundance over the projected 10 years are summarized in Table A4a-4d.

Table A3. Density of Young-of-the-Year spotted seatrout (generally 0+ age class consisting of 30-160 mm total length, TL) in SAV versus unstructured habitats in North Carolina estuarine waters. The arithmetic mean enhancement in SAV versus unstructured habitats is 0.00216 fish/m^2, and the geometric mean is 0.000050 fish/m^2

Reference	SAV (ind./m^2)	SAV SE	Control (ind./m^2)	Control SE	Enhancement (ind./m^2)	Gear	Seasons	Years
NCDMF P100	0.000112	0.000112	0	0	0.000113	Seine	2	2015
NCDMF P100	0.000403	0.000259	0	0	0.000403	Seine	2	2014
NCDMF P100	0.000155	0.00010	0.00004	0.00004	0.000060	Seine	2	2011
NCDMF P123	0.000527	0.00040	0.00007	0.00006	0.000045	Seine	2	2016
NCDMF P123	0.002283	0.00020	0	0	0.002283	Seine	2	2015
NCDMF P123	0.001903	0.001554	0	0	0.001903	Seine	2	2013
NCDMF P123	0.001269	0.001389	0	0	0.001269	Seine	2	2012
NCDMF P123	0.003045	0.002691	0	0	0.003045	Seine	2	2011
Powers 2012	0.015010	0.010090	0.00467	0.00269	0.010339	Seine	2	2009-10

Table A4a. The mean of total catch of spotted seatrout (pounds) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	605639.3	605639.3	605639.3	605639.3	605639.3
2	605639.3	605603.2	605529.6	605458.2	605277.7
3	605639.3	605001.9	603700.8	602440.6	599259.7
4	605639.3	603964.9	600565.1	597295.4	589142.4
5	605639.3	602654.8	596629.4	590880.6	576738.2
6	605639.3	601191.3	592265.9	583822.2	563348.6
7	605639.3	599646.6	587698.6	576495.7	549740.6
8	605639.3	598066	583067.3	569133.7	536376
9	605639.3	596471.8	578439.8	561847.2	523463.2
10	605639.3	594874.8	573849	554689	511088.1

Table A4b. The coefficient of variation of total catch of spotted seatrout over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	0.400	0.400	0.400	0.400	0.400
2	0.400	0.400	0.400	0.400	0.400
3	0.400	0.400	0.400	0.400	0.401
4	0.400	0.400	0.400	0.401	0.403
5	0.400	0.400	0.401	0.402	0.405
6	0.400	0.400	0.401	0.403	0.409
7	0.400	0.401	0.402	0.405	0.413
8	0.400	0.401	0.403	0.407	0.417
9	0.400	0.401	0.403	0.408	0.422
10	0.400	0.401	0.404	0.410	0.427

Table A4c. The mean of total abundance of spotted seatrout (individual) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	2546713	2542667	2534402	2526387	2506116
2	2546713	2537180	2517831	2499233	2452895
3	2546713	2530925	2499084	2468753	2394338
4	2546713	2524355	2479569	2437303	2335249
5	2546713	2517660	2459866	2405844	2277526
6	2546713	2510924	2440229	2374795	2221937
7	2546713	2504185	2420777	2344340	2168763
8	2546713	2497462	2401562	2314556	2118070
9	2546713	2490764	2382609	2285473	2069822
10	2546713	2484095	2363927	2257095	2023943

Table A4d. The coefficient of variation of total abundance of spotted seatrout over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	0.400	0.400	0.400	0.400	0.401
2	0.400	0.400	0.401	0.402	0.404
3	0.400	0.400	0.401	0.403	0.407
4	0.400	0.401	0.402	0.404	0.411
5	0.400	0.401	0.402	0.406	0.415
6	0.400	0.401	0.403	0.408	0.420
7	0.400	0.401	0.404	0.410	0.425
8	0.400	0.402	0.405	0.411	0.431
9	0.400	0.402	0.406	0.414	0.437
10	0.400	0.402	0.406	0.416	0.443

C). Red Drum – An age-structured, population dynamics model was used to compute the forward population projections based on SAV loss scenarios. A stochastic 10-year projection was conducted starting from an equilibrium condition with recruitment levels derived from mean density of Young-of-the-Year red drum in SAV (i.e., 0.00644 (ind./m^2) (Table A5), and the total estimated extent of SAV (130,418 acres). We assumed that the estimated SAV area supports the equilibrium recruitment, and SAV loss will result in a reduction of recruitment strength. The projection was conducted for five scenarios of recruitment level, which was assumed to be a function of SAV corresponding to the five SAV loss scenarios. For the baseline scenario where there is no SAV loss for the projected years, the mean recruitment over 10 years is the equilibrium recruitment:

$$R_{equilibrium} = 0.00644 * 130418 * 4046.86 = 3401388$$

For SAV loss scenarios, the recruitments over the projected years are calculated as

$$R_y = 0.00644 * SAV * (1 - loss_{\%}) - 0.00309 * SAV * loss_{\%}$$

where R_y is the mean recruitment of projected year y, $loss_{\%}$ is the percentage of SAV loss, and 0.00309 is the mean enhancement of the density of Young-of-the-Year red drum from unstructured habitats to SAV habitats.

The projection was repeated 10,000 times with stochastic draws of equilibrium recruitment (sd = 0.00414) and enhancement (mean = 0.00309; sd = 0.00494). Fishing pressure over the projected years is assumed to be stable, i.e., constant across projected years with instantaneous fishing mortality = 0.7 (SEADAR44). A dome-shaped fishery selectivity and age-specific natural mortality rates from the assessment report were used. The mean and CV of total catch and abundance over the projected 10 years are summarized in Table A6a-6d.

Table A5. Density of Young-of-the-Year red drum (generally 0+ age class consisting of 11-104 mm total length, TL) in SAV versus unstructured habitats in North Carolina estuarine waters. The arithmetic mean enhancement in SAV versus unstructured habitats is 0.000309 fish/m², and the geometric mean is 0.002193 fish/m²

Reference	SAV (ind./m²)	SAV SE	Control (ind./m²)	Control SE	Enhancement (ind./m²)	Gear	Seasons	Years
NCDMF P100	0.000857	0.000658	0.000285	0.000887	0.000572	Seine	Fall	2011-14
NCDMF P123	0.010458	0.009794	0.004112	0.006945	0.005595	Seine	Fall	2009-16
Powers 2012	0.008019	0.007610	0.004912	0.004103	0.003109	Seine	Fall	2009-10

Table A6a. The mean of total catch of red drum (pounds) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	10777995	10777995	10777995	10777995	10777995
2	10777995	10772271	10759755	10748452	10717797
3	10777995	10757731	10713607	10674001	10567598
4	10777995	10734541	10640357	10556393	10333174
5	10777995	10711468	10568205	10441724	10110472
6	10777995	10688509	10497136	10329922	9898905
7	10777995	10665666	10427133	10220915	9697916
8	10777995	10642937	10358179	10114633	9506977
9	10777995	10620321	10290260	10011009	9325584
10	10777995	10597818	10223360	9909974	9153261

Table A6b. The coefficient of variation of total catch of red drum over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	0.528	0.528	0.528	0.528	0.528
2	0.528	0.528	0.528	0.529	0.529
3	0.528	0.528	0.529	0.530	0.531
4	0.528	0.529	0.530	0.531	0.534
5	0.528	0.529	0.531	0.533	0.538
6	0.528	0.529	0.532	0.535	0.542
7	0.528	0.529	0.533	0.537	0.546
8	0.528	0.530	0.534	0.539	0.551
9	0.528	0.530	0.535	0.542	0.556

10	0.528	0.530	0.536	0.544	0.562

Table A6c. The mean of total abundance of red drum (individual) over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	16189684	16181631	16164025	16148124	16104999
2	16189687	16167029	16117746	16073579	15955216
3	16189690	16148696	16060040	15981265	15772920
4	16189692	16128479	15996904	15881062	15578959
5	16189695	16107475	15931886	15778782	15385360
6	16189697	16085764	15865257	15674871	15192908
7	16189699	16063413	15797241	15569692	15002201
8	16189701	16040468	15727998	15463502	14813612
9	16189703	16016973	15657677	15356538	14627466
10	16189705	15992970	15586416	15249019	14444047

Table A6d. The coefficient of variation of total abundance of red drum over the projected 10 years

Projected year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
1	0.528	0.528	0.528	0.529	0.529
2	0.528	0.528	0.529	0.529	0.530
3	0.528	0.528	0.529	0.530	0.532
4	0.528	0.529	0.530	0.531	0.533
5	0.528	0.529	0.530	0.532	0.535
6	0.528	0.529	0.531	0.533	0.538
7	0.528	0.529	0.531	0.535	0.540
8	0.528	0.529	0.532	0.536	0.543
9	0.528	0.529	0.533	0.537	0.545
10	0.528	0.530	0.533	0.539	0.548

D). Modeling limitation and future research – The projection results reported herein should be considered in light of some limitations. The projections are based on the point estimates of life history and fishery parameters from the stock assessment reports, e.g., natural mortality and fishing mortality. Thus, they are subject to uncertainties that are not included in the projections. Future research should include a sensitivity analysis to test a range of possible values for these parameters. The approaches used for blue crab, spotted seatrout, and red drum are different due to the differences in their life histories and population structure. For blue crab, the population is structured by two stages, recruits and post-recruits. The definition of recruitment in the population dynamic model is broader than the Young-of-the-Year defined in Table A1, which is used to link recruitment strength and its habitat. However, it is likely that they are correlated. The projection for blue crab started from the most recent estimation of its stock level. However, for spotted seatrout and red drum in North Carolina waters, they are a portion of the stock units being assessed and managed. Therefore, their projections started from assumed equilibrium conditions, and their projected quantities should not be interpreted in conjunction with their assessments. Our estimates of the impacts of SAV on these species may be conservative and underestimate the benefits of SAV as we only considered the impacts on their early life stage, i.e., recruitment dynamics. Future research should consider the potential impacts on more biological processes throughout the life cycle, e.g., growth and movement.

Section A5: Appendix References

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