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A BIOLOGICAL AND ECONOMIC EVALUATION OF IMPERILED MARINE FISH STOCKS AND THE STOCK ASSESSMENT PROCESS IN NORTH CAROLINA

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An evaluation of the biological and economic benefits of improving the status of eight North Carolina stocks

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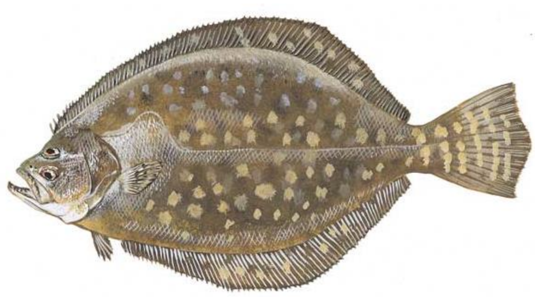
Introduction

Seventeen marine fish stocks of ecological and economic importance are currently listed as “depleted” or as stocks of “concern” by the North Carolina Department of Environmental Quality’s Division of Marine Fisheries (DMF; NCDMF 2016b). Many of these potentially imperiled stocks are of significant recreational and commercial importance to North Carolina residents and visitors. Fisheries stakeholders have raised serious concerns about current Fishery Management Plans (FMPs) that fail to promote stock recovery and sustainable fishing practices. In this study, we explored the potential biological and economic benefits of improving the status of eight North Carolina stocks.

To explore the potential biological response of a stock to alternative fishing mortality scenarios, current conditions were obtained from existing stock assessments and published studies. Stock abundance was then projected forward in time under a series of alternative fishing mortality scenarios. Projection models were tailored to each stock in order to best utilize all current and available stock assessment information and to address unique stakeholder concerns for each stock. Biological modeling methods, results, and discussion are presented on a stock-by-stock basis.

Economic benefits and impacts for each scenario are also explored on a stock-by-stock basis. Insufficient data were available to generate a biological projection model for the Eastern oyster; therefore, economic modeling was based on scenarios that explored potential reduction in the area closed to shellfish harvest, expansion of cultch plantings on public bottom, or expansion of oyster aquaculture on private/leased bottom.

Southern Flounder



(*Paralichthys lethostigma*)[1]

Southern flounder (*Paralichthys lethostigma*) occur in riverine, estuarine, and coastal waters along the East Coast of North America from Virginia south to the Loxahatchee River on the Atlantic Coast of Florida (NCDMF 2013c). They are also common along the Gulf of Mexico coastline from the Caloosahatchee River estuary in Florida west to Texas and south into northern Mexico. The southern flounder stock supports significant commercial and recreational fisheries in North Carolina. Southern flounder management in North Carolina is informed by state-specific stock assessments conducted by NCDMF staff, although a South Atlantic regional assessment is currently underway. A fishing mortality threshold F25% and target F35% were established with Amendment 1 of the southern flounder FMP (NCDMF 2013b). The most recent stock assessment conducted in 2014 indicated that the stock was overfished and that overfishing was occurring (NCDMF 2014a).

Stock Projection Methods

The 2014 stock assessment model was a sex-specific, integrated (length- and age-based) assessment model conducted in the computer program Stock Synthesis (Methot and Wetzel 2013). In this study, stock conditions in the terminal assessment year of 2013 were projected forward 40 years in that same program to estimate biological and economic benefits. Seven potential fishing mortality scenarios were explored (Table 1).

[1] Image source: South Carolina Department of Natural Resources. http://www.dnr.sc.gov/marine/species/southernflounder.html

Table 1. Alternative fishing mortality scenarios explored for southern flounder.

Scenario	Fishing Mortality (F)	Relative Fishing Mortality Options
1	F_{2013} (equivalent to F9%)	
2	Target (F25%)	
3	Threshold (F35%)	
4	F17%	
5	F40%	
6	Target (F25%) with gillnet ban in 2017	<u>Option 1</u> Poundnet=0.5 Comm other=0.12 Rec inshore=0.31 Rec ocean= 0.08
7	Target (F25%) with gillnet ban in 2017	<u>Option 2</u> Poundnet=0.26 Comm other=0.06 Rec inshore=0.55 Rec ocean= 0.13

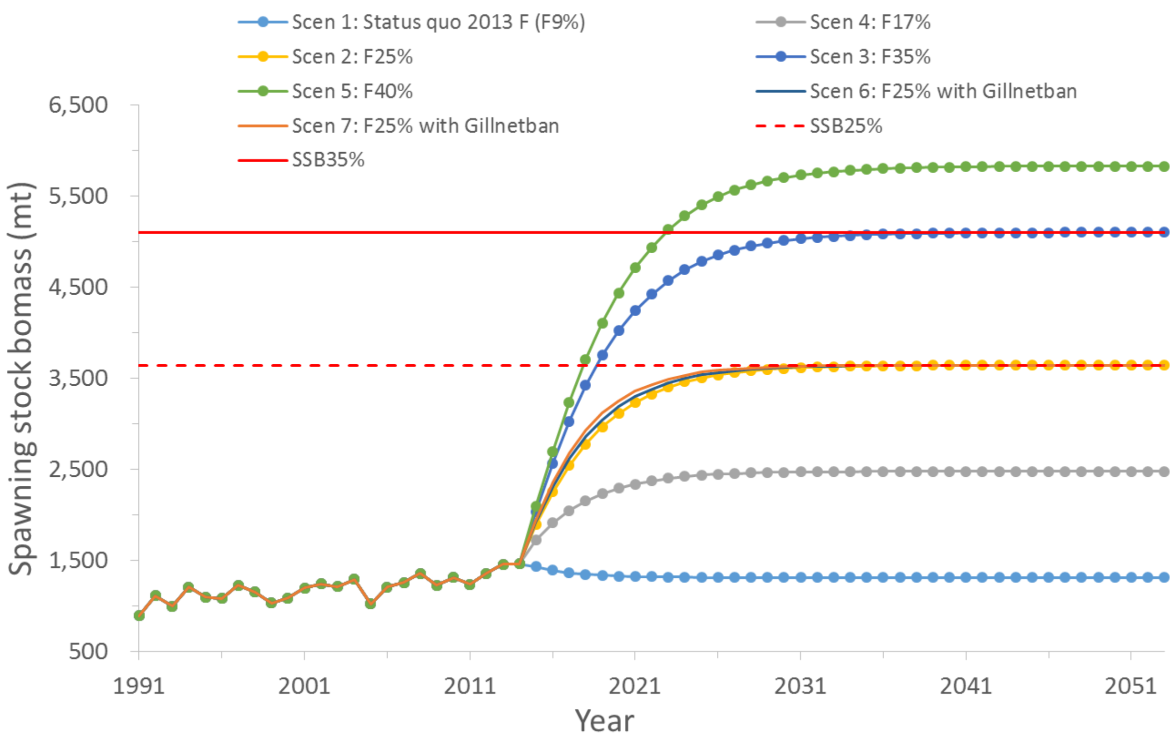
Scenarios 1-5 assumed the same relative F among fleets as was estimated in the terminal year of 2013. Scenario 1 projected forward population and fishing conditions present in the terminal year of the assessment (2013). Scenario 2 simulated the population trajectory under the threshold fishing mortality rate of F25%. Scenario 4 simulated the population trajectory under an intermediate fishing mortality rate of F17%. Scenario 3 simulated the population trajectory under the target fishing mortality rate of F35%. Scenario 5 simulated the population trajectory under a more conservative fishing mortality rate of F40%.

Two additional scenarios were conducted in which a gillnet fishery ban was enacted in 2017. Scenarios 6 and 7 differ in relative fishing mortalities among the remaining 4 fleets. Scenario 6 relative Fs were based recalculating the 2013 relative Fs among fleets, assuming no gillnet fishery. Scenario 6 assumed the proportion of total F once attributed to the gillnet fleet would be reassigned to the inshore recreational fleet.

Stock Projection Results

Spawning stock biomass was predicted to increase substantially under all scenarios except Scenario 1 which assumed 2013 status quo conditions (Figure 1).

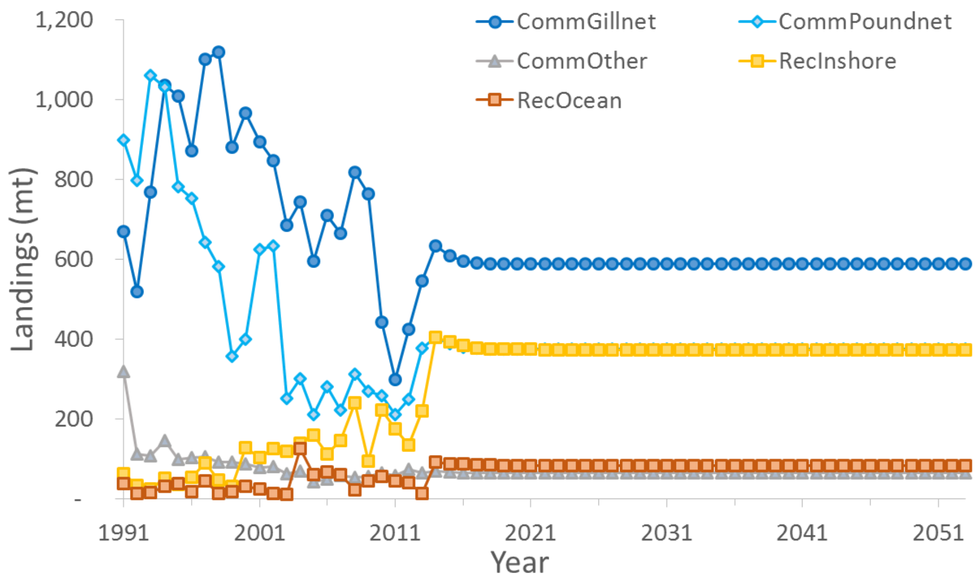
Figure 1. Projected spawning stock biomass (metric tons) under seven fishing mortality scenarios. The threshold and target spawning stock biomass levels that would correspond with the current F threshold (F25%) and target (F35%) are provided for reference.



The estimated rate of fishing mortality in 2013 was approximately equal to F9%, the F that would result in stock biomass that is 9% of the biomass the stock might achieve in an unfished state. Reducing fishing mortality to an intermediate level between current and threshold rates (F17%) is predicted to almost double spawning stock biomass. Fishing at the threshold F25% or target F35% fishing mortality rates improved stock condition by even greater amounts. As expected, the most conservative scenario of F40% achieved the largest predicted spawning stock biomass.

The projection of current conditions (Scenario 1) maintained spawning stock biomass (Figure 1) and landings at approximately the same levels by fleet as in 2013 (Figure 2).

Figure 2. Projected landings by fleet under Scenario 1 (status quo F_{2013}).



Implementation of fishing mortality rates ranging from F17% to F40% (Scenarios 2-5) resulted in increased spawning stock biomass (Figure 1), increased landings relative to 2013 levels for the recreational fleets, and slightly increased or stable landings for the commercial fleets (Figure 3, Figure 4, Figure 5, Figure 6).

Figure 3. Projected landings by fleet under Scenario 2 (F threshold = F25%).

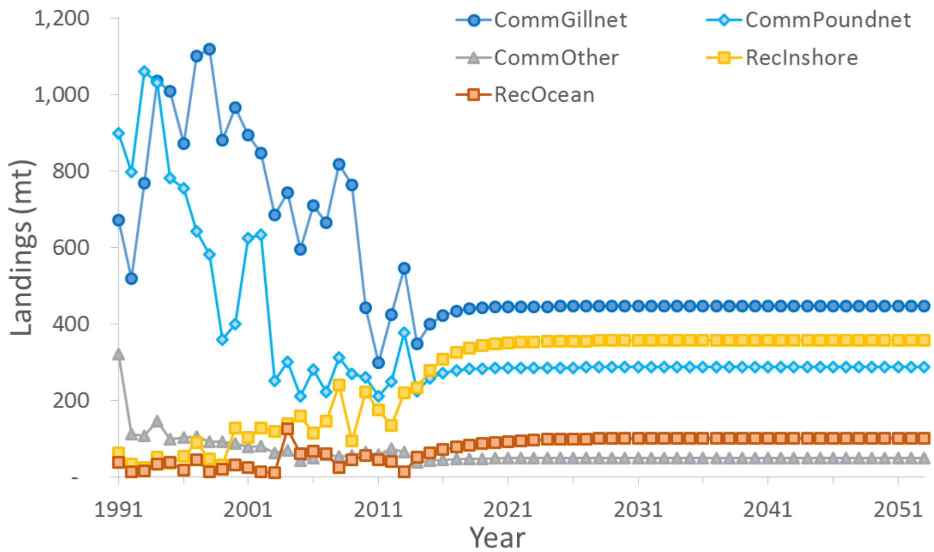


Figure 4. Projected landings by fleet under Scenario 3 (F target = F35%).

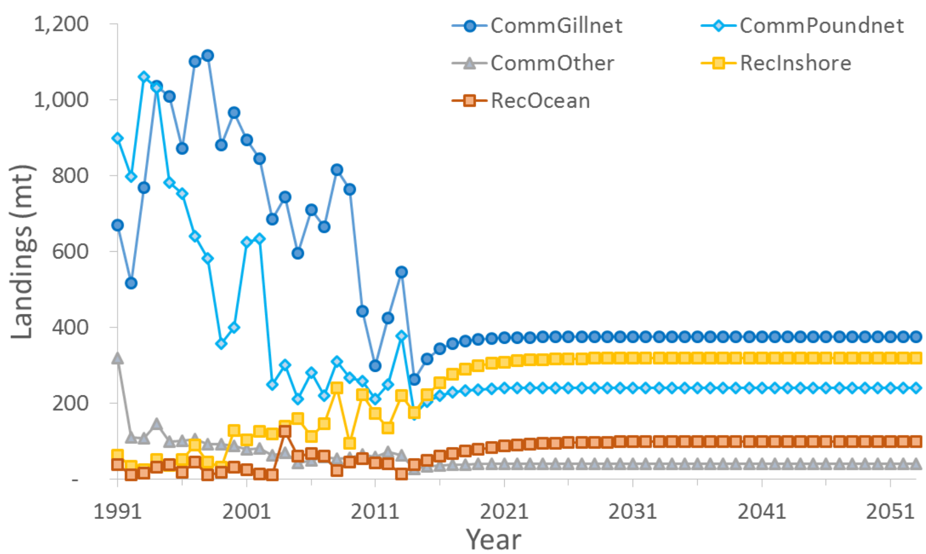


Figure 5. Projected landings by fleet under Scenario 4 (F17%).

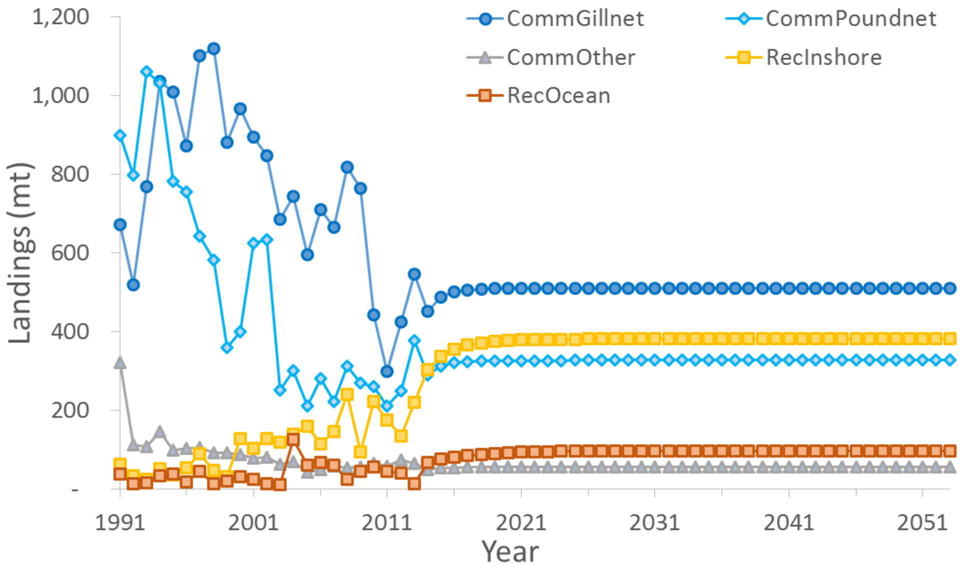
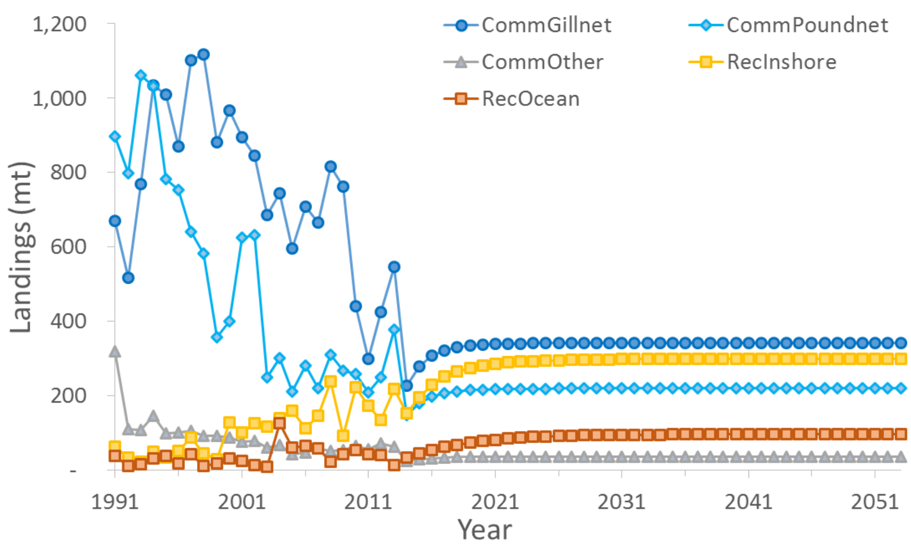


Figure 6. Projected landings by fleet under Scenario 5 (F40%).



Implementation of a gillnet fishery ban in 2017 resulted in increases in both spawning stock biomass (Figure 1) and landings relative to 2013 levels for the remaining fleets (Figure 7, Figure 8).

Figure 7. Projected landings by fleet under Scenario 6 (F25% and gillnet ban with relative F option 1).

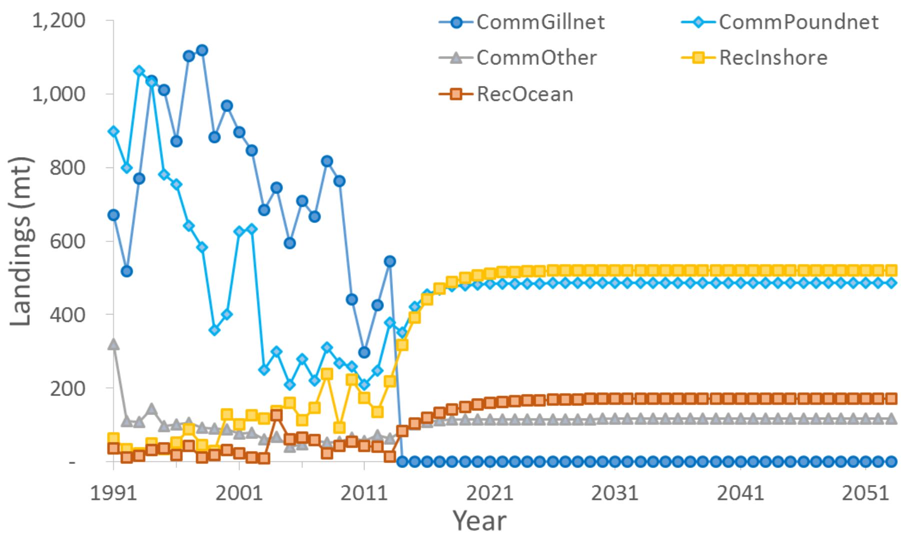
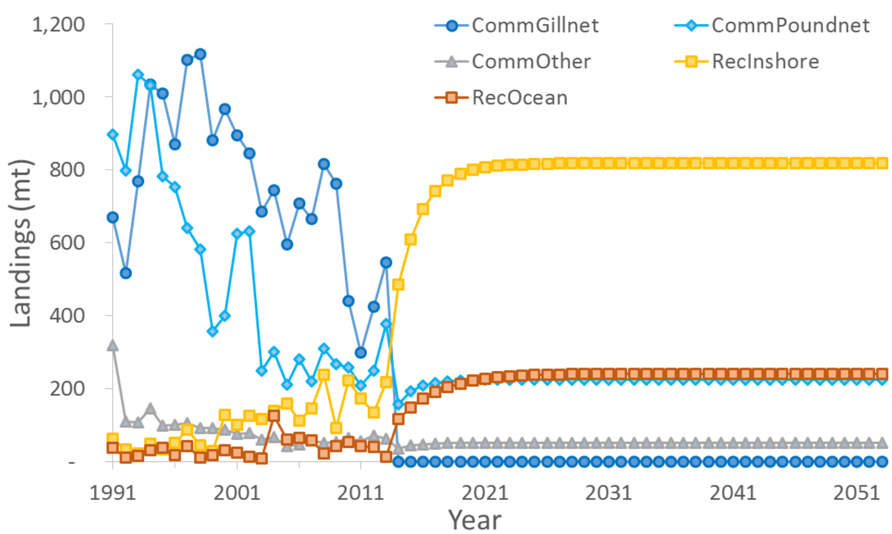


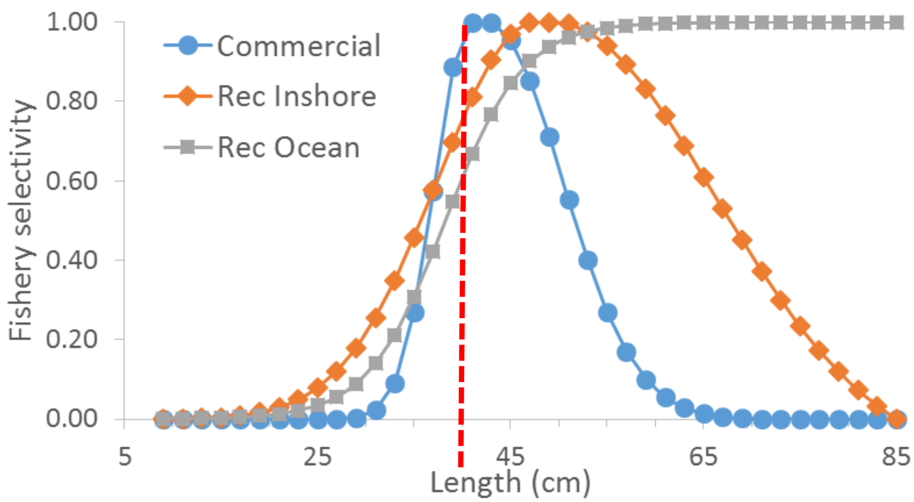
Figure 8. Projected landings by fleet under Scenario 7 (F25% and gillnet ban with relative F option 2).



Discussion

Although the stock assessment upon which these results were based was not accepted for use in management by NCDMF, the results generated by this model are valuable for demonstrating the relative potential for the stock to rebuild should fishing pressure be reduced. The modest increase in landings with fishing mortality rates of F17%-F40% (Scenarios 2-5) results largely from the lack of an obvious stock-recruitment relationship and the selectivity at length estimated by the stock assessment model. If recruitment responds positively to increase spawning stock biomass, more dramatic rebuilding may be observed; however, stock assessment results indicate remarkably stable recruitment since 1991 (2014 assessment, Figure 22). Also, the largest fleets (commercial and recreational inshore) were estimated to have dome-shaped selectivity (Figure 9), indicating that larger fish are not vulnerable to the largest southern flounder fisheries in North Carolina (ocean recreational being the exception). In these projections, as spawning stock increases with reduced fishing pressure, most of the larger fish are not vulnerable to the largest commercial and recreational fishing fleets and thus immediate benefits to the fisheries in the form of large increases in landings with increased spawning stock biomass were not realized in these scenarios. Note also that the length at 50% maturity assumed in the assessment was approximately 40 cm, indicating a significant portion of fishing mortality for most fleets occurs at larger sizes. More extreme management scenarios such as a gillnet ban would likely increase landings significantly for some or all of the remaining fleets (Scenarios 6 and 7).

Figure 9. Selectivity at length (cm) for southern flounder estimated during the last time block of the 2014 assessment. Dashed red line indicates assumed length at 50% maturity.



Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for southern flounder in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f). Regression analyses conducted by the authors to assess the potential influence of NC southern flounder landings (metric tons) on real (inflation-adjusted)[2] ex-vessel southern flounder prices in NC from 1994 to 2014 found that landings do not have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = B_0 + B_1*(1/Landings), n = 22, F=1.568, R^2 = 0.072, , t-value of (1/Landings) coefficient = 1.252). In recent years (2011-2015), commercial landings of southern flounder in North Carolina received an average ex-vessel price of $2.72/lb. in year 2015 dollars.

[2] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).

For each southern flounder scenario, the commercial landings of southern flounder in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the nominal ex-vessel price per pound of $2.72/lb. to find nominal ex-vessel revenue. It is assumed that the ex-vessel price per pounds remains constant in real terms from 2017 to 2046; that is, it is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole. For each year, nominal ex-vessel revenue is discounted[3] to its year 2015 present-value equivalent using the average long-run discount rate of r = 0.018.

For the purposes of this study, it is assumed that pound net gear are used to land southern flounder in North Carolina's sounds and estuaries. Approximately 70 percent of North Carolina's commercial landings of southern flounder came from the Albemarle and Pamlico sounds in 2011-2013 (NCDMF 2015c). Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 pound nets accounted for 55.5 percent of southern flounder landings (by weight) in North Carolina, while gill nets accounted for 32.6 percent of landings, and other gear accounted for 11.9 percent of landings.

The number of vessels landing southern flounder in 2017 is assumed equal to the number of pound net vessels operating in North Carolina in 2014, or 110 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of pound net trips made in North Carolina in 2014, or 2,346 trips (NCDMF 2015a); this gives an average of 21.3 pound net trips per vessel per year operating in the pound net fishery in 2017.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating pound net vessels in North Carolina in 2014, or 105 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Commercial fishing activity supports both "direct" economic impacts on the fish-harvesting sector as well as economic "multiplier" effects. Economic multiplier effects include "upstream" economic impacts and "downstream" economic impacts. Upstream economic impacts are impacts on firms that supply and service the fish-harvesting sector, such as fuel suppliers, gear suppliers, bait/ice suppliers, and vessel repair businesses. Downstream economic impacts are impacts on firms that purchase from the fish-harvesting sector, such as seafood dealers/processors, wholesalers/distributors, grocers and restaurants.

Upstream economic impacts have two subcategories, indirect impacts and induced impacts. Indirect upstream impacts reflect the economic activity of firms that supply and

[3] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

service fishing vessels. Induced upstream impacts reflect additional economic activity due to the household spending supported by the direct and indirect impacts. Economic impacts are typically measured using economic input-output analysis (Miller and Blair 1985). The NOAA-NMFS Interactive Fisheries Economic Impacts Tool for Fishery Industry Impacts (NOAA-NMFS 2016b) provides state-specific economic multipliers that can be used to calculate economic impacts for five economic sectors: fishermen/harvesters, primary seafood dealer/processors, secondary seafood wholesalers/distributors, grocers, and restaurants. For each economic sector, multipliers are provided for four measures of economic activity: sales, employment, labor income, and value added. The labor income multiplier captures wages, salaries, benefits, proprietary (sole proprietor and partnership) income, and associated FICA and income taxes. The value added multiplier includes labor income, other property type income (rent, interest income, dividend income, and associated taxes), indirect business taxes (sales taxes, excise taxes, government license fees, etc.), and corporate profits taxes. The employment multiplier includes both part-time and full-time jobs. All multipliers are converted to a "per dollar of ex-vessel sales basis." The upstream economic impacts of commercial fishing activity are calculated using the multipliers for the fish harvesting sector in North Carolina.

All flounder landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 41.43 percent of flounder sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed that 58.57 percent of flounder sold by North Carolina seafood dealers is sold to in-state buyers. These sales to North Carolina seafood dealer/processors and subsequent sales to in-state buyers support downstream economic impacts within North Carolina. These impacts are measured using economic input-output analysis and the multipliers from the NOAA-NMFS Interactive Fisheries Economic Impacts Tool for Fishery Industry Impacts. The downstream multipliers are constructed in such a way that the economic impacts occurring in a given sector (such as wholesalers) do not double-count the economic impacts in sectors occurring either earlier (such as seafood dealers) or later (such as grocers) in the supply chain. The multipliers for North Carolina are converted to a "per dollar of ex-vessel sales" basis. The downstream economic impacts occurring within North Carolina of North Carolina commercial fishing activity are calculated using the North Carolina multipliers for the seafood dealer/processor, wholesaler/distributor, grocer and restaurant sectors.

For both upstream and downstream economic impacts, the economic multipliers are used to calculate both direct economic impacts (which do not include multiplier effects) and total economic impacts (which do include multiplier effects). The multiplier effects include both indirect economic impacts (the effects of additional spending by firms) and induced economic impacts (the effects of additional spending by households). Economic impacts are calculated for each species considered in this study, by year, for each scenario. Landings, ex-vessel revenue, and each type of economic impact (except employment) for each year are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic impacts measure the gross economic effects of fishing activity. "Producer surplus" is one measure of the net economic effect of fishing activity. This study calculates producer surplus for the harvesting sector. For competitive upstream and downstream markets, producer surplus in the harvesting sector captures most of the producer surplus due to commercial fishing activity. For the harvesting sector, producer surplus is defined as ex-vessel revenue less variable/operating/trip costs. In a multi-species fisheries, such as the southern flounder pound net fishery (and the gill net and trawl fisheries), a fishing trip is made, and operating costs are incurred, even if no southern flounder are caught, because the (expected) revenues from landings of other species cover the variable costs of the trip. As a result, if southern flounder are caught, trip revenues increase without an increase in trip operating costs. Hence, if flounder landings can be accommodated with no change in the number of vessels or vessel trips, then the ex-vessel revenue from flounder landings flows directly to producer surplus.

As southern flounder landings vary from year to year and from scenario to scenario according to the biological projection model, several criteria are used to determine whether there would be any changes in the number of vessels operating in the fishery (and associated changes in the numbers of captain and crew) or any changes in the number of trips taken per vessel.

If southern flounder landings decrease, it is assumed that vessels remain in the fishery and the number of trips does not change because pound nets catch species other than flounder, and other gear can be used on the vessels to catch other species. Of course, ex-vessel revenues, producer surplus, and downstream economic impacts (impacts on seafood dealers/processors, wholesalers/distributors, groceries and restaurants) would decrease, but changes in upstream economic impacts (impacts on firms that supply and service the fishing vessels) would be negligible, as the same number of vessels continues to make the same number of trips.

If southern flounder landings increase, the economic model determines whether the existing number of vessels and trips can accommodate the increased landings. The maximum catch weight per pound net trip is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016) for the average 25' pound net vessel fishing the sounds and bays (NCDMF 2015a, Hadley and Wiegand 2014). Multiplying the number of trips by 2,000 pounds per trip gives the capacity of the existing trips. If increased landings do not exceed the capacity of the existing vessels and trips, then an increase in landings increases ex-vessel value, producer surplus, and downstream economic impacts, but it does not increase upstream impacts, which depend on the number of vessels, trips and crew, which do not change in this case.

If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 25.5 pound net trips per vessel per year, the maximum annual average number of observed trips per vessel for vessels making pound net trips over the period 1994-2014 (NCDMF 2015a). The increase in the number of trips increases ex-vessel value, producer surplus, downstream economic impacts, and upstream impacts associated with the additional operating costs of the additional trips. (Economic impacts associated with vessel fixed costs and crew do not increase, because the number of vessels and crew have not increased.)

It is assumed that the operating costs of pound net vessels working in North Carolina sounds are similar to the operating costs of average-length gill net / crab pot vessels operating in Albemarle and Pamlico sounds, or $531 per trip in 2015 dollars, as reported by Hadley and Wiegand (2014), based on a 2013 survey of fishermen (Table 2). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in flounder landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 2 is considered part of producer surplus.

Table 2. Trip Expenses (Operating Costs), Pound Net Vessels (2015 dollars)

Expense	**Item**
$167.56	Fuel and Oil
$5.35	Ice
$18.65	Groceries
$100.62	Bait
$5.45	Other
$233.72	Captain and Crew (assumes 1/3 annual captain/crew expense of $14,934 allocated to pound net trips, 2/3 crab pot trips)
$531.34	Total Expenses per Trip (@ 21.3 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings. (However, for most scenarios, the capacity of the existing vessels is sufficient to accommodate even greatly increased landings.) An increase in the number of vessels increases ex-vessel value, producer surplus, downstream economic impacts, and upstream impacts associated with the operating costs, fixed/capital costs, and captain/crew costs of the vessels added to the fishery.

Economic results for the southern flounder commercial fishery by scenario, and differences across scenarios, are presented in Tables A1-A2.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the southern flounder recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity.

Estimates of consumer surplus per flounder caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 3. The mean of the values in the table, or $16.33 per fish, is used in this study as the consumer surplus per flounder caught by recreational anglers.

Table 3. Southern Flounder-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
Agnello (1989)	Travel cost	NY-FL	$20.29
USEPA (2004)	nested RUM	NY-VA	$10.97
Kirkley et al. (1999) summer flounder	CV open-ended	VA	$15.60
McConnell and Strand (1992)	CV dichotomous choice	NY-FL	$6.89
Hicks et al. (1999)	nested RUM	ME-VA	$6.96
USEPA (2004)	non-nested RUM	NC-FL	$37.29

The economic impacts of the recreational southern flounder fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of southern flounder recreational catch by mode (Table 4) is calculated from catch by mode data for southern flounder caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 4. Recreational Catch and Trips by Mode—Southern Flounder

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	SOUTHERN FLOUNDER	MAN-MADE	3,434	0.0490	2,678	0.7798
2014	SOUTHERN FLOUNDER	BEACH/BANK	2,952	0.0421	2,759	0.9346
2014	SOUTHERN FLOUNDER	CHARTER BOAT	1,617	0.0231	1,610	0.9957
2014	SOUTHERN FLOUNDER	PRIVATE/RENTAL BOAT	62,043	0.8857	61,244	0.9871

Spending by recreational anglers and associated upstream economic impacts by fishing mode and by geographic region are provided for 2012 by Lovell et al. (2013). Data on four types of economic impact are provided: sales, employment, labor income, and value added. The Lovell et al. data for the South Atlantic region are used in this study. The numbers of angler trips by mode for North Carolina in 2012 (similar to the trip data presented in Table 4 for year 2014) are obtained from NOAA-NMFS (2016c). These data are combined to calculate economic multipliers by mode on a "per recreational fishing trip" basis. It is assumed that these multipliers remain constant across years 2017-2046.

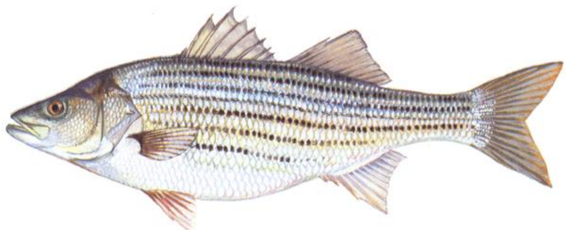
Recreational fish catch is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. This assumes that catch per trip remains constant as catch increases (i.e., bag limits remain fixed), so increased catch is accommodated by an increase in the number of recreational trips. [If the alternative assumption is made that changes in catch are accommodated by changes in catch per trip while the number of trips remains constant, then consumer surplus varies across scenarios from its baseline level as catch changes (as shown in the results), but the economic impacts of the fixed number of trips would remain constant at the baseline level (the economic impacts for all scenarios would be the same as that shown for the baseline scenario).] The economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the southern flounder recreational fishery by scenario, and differences across scenarios, are presented in Tables A3-A4.

Discussion

For southern founder, all alternative management scenarios 2-7 reduce commercial fishery landings, producer surplus, and economic impacts by 13 percent (scenario 4) to 73 percent (scenario 7) relative to baseline scenario 1. However, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected as fishermen continue to land other species in the multi-species fishery. Results are mixed across scenarios for the recreational southern flounder fishery. In scenarios 2, 3 and 5, catch, consumer surplus and economic impacts fall from 1 percent (scenario 2) to 16 percent (scenario 5), while in scenarios 4, 6 and 7, these same economic variables increase from 4 percent (scenario 4) to 130 percent (scenario 7). In scenarios 6 and 7, the gains in recreational consumer surplus are 30 percent/$32 million (scenario 6) to 130 percent/$135 million (scenario 7) larger than the losses in commercial producer surplus.

Striped bass – Central Southern Management Area



(*Morone saxatilis)*[4]

Striped bass (*Morone saxatilis*) are distributed along the Atlantic Coast of the United States from St. Lawrence River, Canada, to St. Johns River, Fla. (NCDMF 2016d). Striped bass are anadromous and are therefore found in both freshwater and saltwater, often around piers, jetties, and rocks.

There are two geographic management units and four striped bass stocks included in Amendment 1 to the North Carolina Estuarine Striped Bass Fishery Management Plan (FMP) (NCDMF 2013b). The northern management unit is comprised of two harvest management areas; the Albemarle Sound Management Area (ASMA) and the Roanoke River Management Area (RRMA). The striped bass stock in these two harvest management areas is referred to as the Albemarle Sound/Roanoke River (A/R) stock, and its spawning grounds are located in the Roanoke River in the vicinity of Weldon, NC.

The southern geographic management unit is the Central Southern Management Area (CSMA) and includes all internal coastal, joint and contiguous inland waters of North Carolina south of the ASMA to the South Carolina state line. There are spawning stocks in each of the major river systems within the CSMA; the Tar/Pamlico, the Neuse, and the Cape Fear. Spawning grounds are not clearly defined in these systems as access to spawning areas may be influenced by river flows as well as dams that impede migration to historical spawning areas. The CMSA striped bass harvest is, on average, about 15 percent of the yearly harvest taken from internal waters in North Carolina, with the other 85 percent coming from the Albemarle Sound Management Area (ASMA) and Roanoke River Management Area (RRMA).

The CSMA stock of striped bass in North Carolina has faced serious challenges to recovery despite an extensive hatchery program (NCDMF 2013a). Recent research indicates that, although some striped bass survive to spawning age in the region, the CSMA stock is largely, if not solely, supported by the a stocking program (Callihan et al. 2014, Rachels and Ricks 2015).

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[4] Image Source: NCDMF. 2016. http://portal.ncdenr.org/web/mf/bass_striped

CSMA striped bass management in North Carolina has historically been informed by a region-specific catch curve-based stock assessment conducted by NCDMF staff and by system-specific population modeling such as that conducted in the Neuse River (Rachels and Ricks 2015). More recent tagging and population modeling conducted for the Neuse River by researchers at North Carolina State University provided updated mortality estimates and a population modeling framework that may help predict the Neuse River stock's response to potential management alternatives (Bradley 2016).

Stock Projection Methods

An age-structured population model created by Bradley (2016) for striped bass in the Neuse River was modified to generate a time series of stock abundance and catch at age in response to alternative fishing mortality scenarios (Table 5). Scenario 1 projected forward conditions estimated from Bradley's 2013-2015 study. Scenarios 2-5 assumed a 10%, 25%, 50%, and 75% reduction in commercial and recreational fishing mortalities. Scenario 6 assumed status quo recreational fishing mortality and a 79% reduction in commercial fishing mortality to achieve a Total Allowable Catch (TAC) of ~3,375 lbs in the Neuse. All scenarios assumed the same discard mortality rates for both fleets.

As in Bradley (2016), the model was seeded with 100,754 stocked fish as juveniles. Population abundance at age was projected forward assuming exponential mortality to estimate the equilibrium age structure after 40 years. Juveniles experienced an instantaneous total mortality (Juv Z) of 1.09, age 2s experienced natural (M) and discard mortality from the commercial (Comm Disc F) and recreational (Rec Disc F) fleets, and ages 3+ experienced natural mortality (M), commercial (Comm F) and recreational (Rec F) harvest mortality, and commercial and recreational discard mortality. Scenario 1 equilibrium age structure achieved after 40 years was assumed as the starting abundance at age for Scenarios 2-6 projections to simulate the change in the stock from current conditions under different fishing mortality scenarios. Annual landings by fleet in numbers were estimated using the Baranov catch equation (Quinn and Deriso 1999). Commercial landings in pounds were calculated by multiplying commercial catch at age by average weight at age for ages 3+ reported in the Albemarle Sound/Roanoke River stock assessment for 1991-2008 (Table 14; NCDMF 2013a).

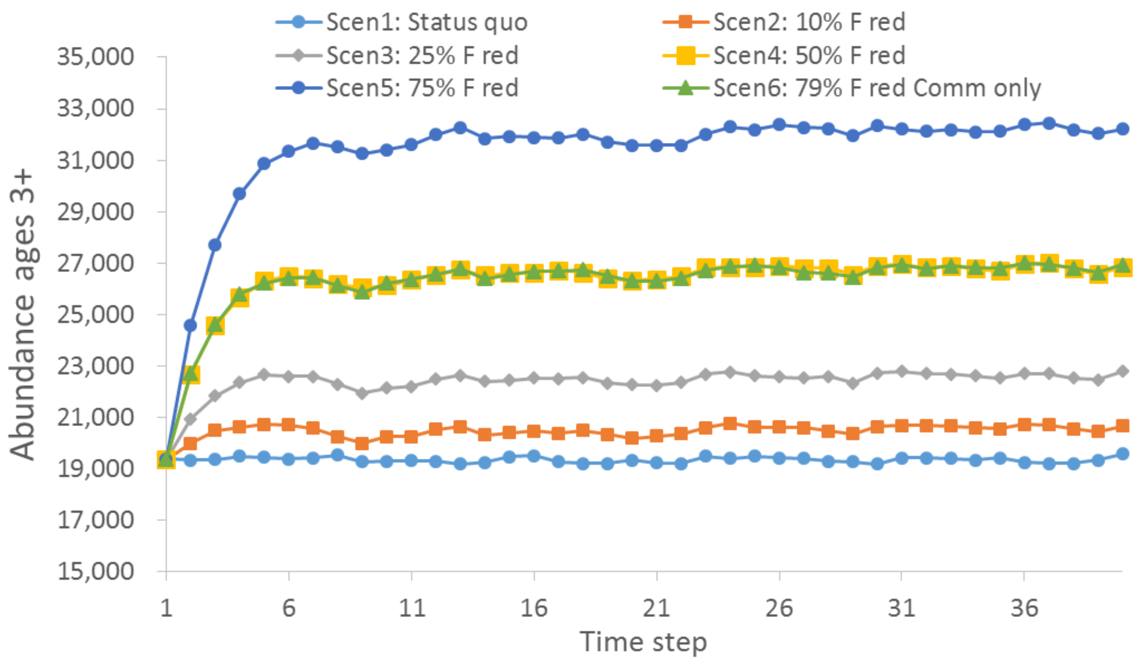
Table 5. Alternative fishing mortality scenarios explored for Neuse River striped bass.

Scenario	Juv Z	Comm F	Comm Disc F	Rec F	Rec Disc F	M	Stocking (#fish)
1	1.09	0.20	0.15	0.12	0.064	0.25	100,754
2	1.09	0.18	0.15	0.11	0.064	0.25	100,754
3	1.09	0.15	0.15	0.09	0.064	0.25	100,754
4	1.09	0.10	0.15	0.06	0.064	0.25	100,754
5	1.09	0.05	0.15	0.03	0.064	0.25	100,754
6	1.09	0.04	0.15	0.02	0.064	0.25	100,754

Stock Projection Results

Abundance of age 3+ striped bass in the Neuse River was predicted to increase under all scenarios except Scenario 1 which assumed status quo conditions from the time of the Bradley study, namely 2013-2015 (Figure 10).

Figure 10. Projected abundance of age3+striped bass in the Neuse River under six fishing mortality scenarios. Scenario 1 = Status quo, Scenarios 2-5 = 10%, 25%, 50%, and 75% reduction in commercial and recreational fishing mortalities, Scenario 6 = Status quo recreational fishing mortality and a 79% reduction in commercial fishing mortality.



Projected abundance increased with reductions in fishing mortality; however substantial reductions in fishing mortality on one or both fleets (50-79%) was required to see total age 3+ abundance increase by 60-70% from current levels. Reducing the commercial TAC in the Neuse to ~3,375 lbs (~80% reduction in commercial fishing mortality) achieved approximately the same age 3+ abundance as reducing both recreational and commercial fishing mortality by half.

The projection of current conditions (Scenario 1) maintained age 3+ abundance (Figure 10) and landings (Figure 11, Figure 12) at approximately the same levels by fleet as status quo. Implementation of reduced fishing mortality rates ranging from 10% to 50% for both fleets (Scenarios 2-4) resulted in small increases in abundance Figure 1and landings. Reduction of fishing mortality by 75% for both fleets (Scenario 5) produced substantially greater gains in abundance, but required a reduction in landings relative to current levels for each fleet. Scenario 6 produced abundance levels approximately equal to that of Scenario 4 and resulted in a doubling of recreational catch, but required a substantial reduction in commercial landings.

Figure 11. Projected commercial landings under six fishing mortality scenarios outlined in Table 5.

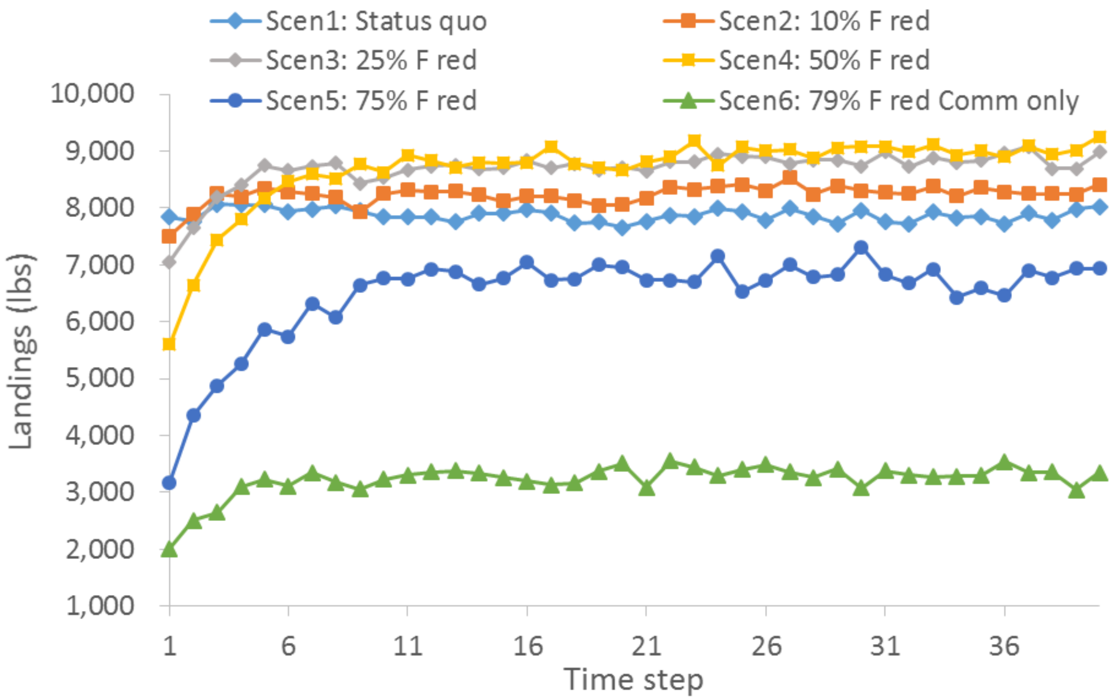
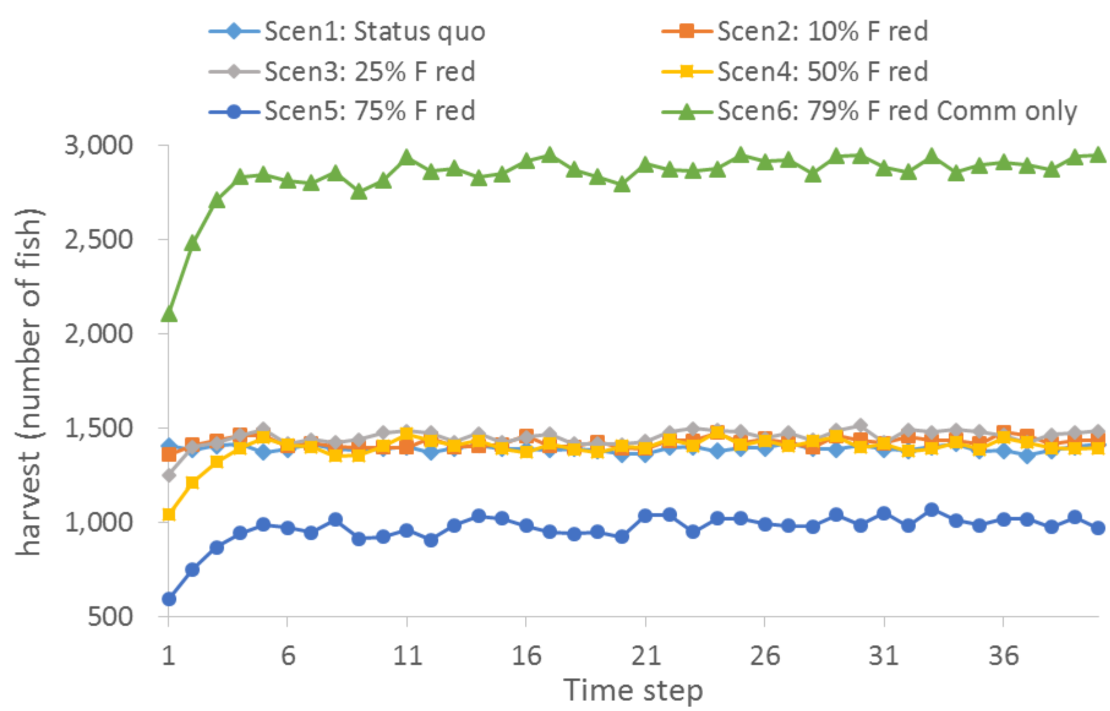


Figure 12.Projected recreational harvest under six fishing mortality scenarios outlined in Table 5.



Discussion

This model produced status quo (Scenario 1) estimates of abundance and landings for the Neuse similar to other studies. Scenario 1 estimated an age 3+ abundance of approximately 19,000 fish, similar to 2014 abundance estimates produced by the latest assessment (17,655 fish; Rachels and Ricks 2015). Also, landings estimated by this model (Figure 11, Figure 12) were similar in range to reported Neuse commercial (e.g., 2009 8,285 lbs) and recreational (2004-2008 average 1,994 fish) estimated landings and harvest (NCDMF 2013a).

Discard mortality rates assumed by Bradley (2016) were substantial, approximately 50-75% of the directed fishing mortality rates for the recreational and commercial fleets respectively. Note, however, that the results of this model rely on the assumption that discard mortality rates remained the same in each scenario. Discard at age patterns will likely change with any new management action; therefore, these results should be considered rough guidelines as to how the stock might respond to fishing mortality reductions. Changes in fishing gears or fishing practices could also have a positive impact on release mortality.

Additional reductions in juvenile and adult natural mortality may help improve the ability of spawners to successfully reproduce in the Neuse River in the absence of a stocking programs. Although the exact cause of high natural mortality rates is unknown, it is possible that improvements in water quality (Bradley 2016) and expanded access to spawning areas through the removal of manmade obstructions (e.g., dams and causeways) may improve spawning conditions for striped bass (Burdick and Hightower 2006). Assuming that these factors cannot be readily improved, the results of this and other recent studies (Bradley 2016) indicate that large reductions in fishery exploitation will be needed to improve the condition of the stock as previously suggested by Rachels and Ricks (2015).

Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for striped bass in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f).[5] Regression analyses conducted by the authors to assess the potential influence of NC striped bass landings (metric tons) on real (inflation-adjusted)[6] ex-

[5] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).
[6] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

vessel striped bass prices in NC from 1994 to 2014 found that landings do have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = 1.7399 + 64.661*(1/Landings), n = 22, F = 15.77, R^2 = 0.441, t-value of (1/Landings) coefficient = 3.971). This regression relationship is used to calculate nominal ex-vessel price for each projection year 2017-2046. It is assumed that this regression relationship remains constant over the projection period 2017-2046; that is, it is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole.

For each striped bass scenario, the commercial landings of striped bass in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the ex-vessel price from the regression relationship to find nominal ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.

For the purposes of this study, it is assumed that vessels with costs similar to the costs of vessels using gill net gear are used to land striped bass in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 gill nets accounted for 84 percent of striped bass landings (by weight) in North Carolina, while other gear accounted for 16 percent of landings.

The number of vessels potentially landing striped bass in 2017 is assumed equal to the number of gill net vessels operating in the CSMA of North Carolina in 2013, or about 185 vessels (NCDMF 2013b). Assuming an average of 19.57 gill net trips per vessel per year operating in the North Carolina gill net fishery in 2017 (NCDMF 2015a), the number of trips made by these vessels in the CMSA in 2017 is approximately 3,620 trips.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating gill net vessels in the CMSA of North Carolina in 2013, or 168 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial striped bass fishery are determined using the methodology described for southern flounder. All striped bass landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 25.75 percent of generic finfish sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 74.25 percent of striped bass sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Downstream economic impacts are measured using the methodology described for southern flounder. The maximum catch weight per trip landing striped bass is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016), the average capacity of a 25' gill net vessel fishing the sounds and bays of North Carolina (NCDMF 2015a, Hadley and Wiegand 2014). If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 24.5 trips per vessel per year, the maximum annual average number of observed trips per vessel for 25'-35' gill net vessels over the period 1994-2014 (NCDMF 2015a).

It is assumed that the operating costs of vessels landing striped bass in North Carolina sounds are similar to the operating costs of average-length gill net / trawl vessels operating in Core Sound, or $180 per trip in 2015 dollars, as reported by Crosson (2007), based on a 2006 survey of fishermen (Table 6). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in striped bass landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 6 is considered part of producer surplus.

Table 6. Trip Expenses (Operating Costs), Vessels Landing Striped bass (2015 dollars)

Expense	Item
$133.25	Fuel and Oil
$3.00	Ice
$3.01	Groceries
$21.21	Bait
$0.05	Other
$19.89	Captain and Crew (assumes $390 average annual hired captain/crew expense allocated to striped bass trips)
$180.39	Total Expenses per Trip (@ 19.6 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings.

Economic results for the striped bass commercial fishery by scenario, and differences across scenarios, are presented in Tables A5-A6.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the striped bass recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity. The methodology described for southern flounder is used to estimate the consumer surplus and impacts of the recreational striped bass fishery.

Estimates of consumer surplus per striped bass caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 7. The mean of the values in the table, or $8.19 per fish, is used in this study as the consumer surplus per striped bass caught by recreational anglers.

Table 7. Striped bass-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
USEPA (2004)	nested RUM	NY-VA	$19.71
Bockstael, McConnell and Strand (1989)	travel cost	MD	$2.83
Gautam and Steinbeck (1998)	trav.cost, non-nest RUM	ME-CT	$7.10
Schuhmann and Schwabe (2004)	RUM	NC-catch and release	$3.11

The economic impacts of the recreational striped bass fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of striped bass recreational catch by mode (Table 8) is calculated from catch by mode data for striped bass caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 8. Recreational Catch and Trips by Mode—Striped bass

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	STRIPED BASS	MAN-MADE	1,037	0.0101	609	0.5873
2014	STRIPED BASS	BEACH/BANK	0	0.0000	0	0.0000
2014	STRIPED BASS	CHARTER BOAT	2,188	0.0212	606	0.2770
2014	STRIPED BASS	PRIVATE/RENTAL BOAT	99,842	0.9687	33,229	0.3328

Recreational fish catch in the CMSA is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. Economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the striped bass recreational fishery by scenario, and differences across scenarios, are presented in Tables A7-A8.

Discussion

For striped bass, alternative management scenarios 2-4 increase commercial fishery landings, producer surplus, and economic impacts by 4 percent (scenario 2) to 9 percent (scenario 3) relative to baseline scenario 1. Scenarios 5 and 6 reduce these same economic measures from 20 percent (scenario 5) to 60 percent (scenario 6). In all scenarios, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected, as fishermen continue to land other species in the multi-species fishery. For the recreational striped bass fishery, catch, consumer surplus and economic impacts increase in scenarios 2, 3 and 6, from 2 percent (scenario 2) to 103 percent (scenario 6). These same economic variables decrease in scenarios 4 and 5, from less than 1 percent (scenario 4) to 32 percent (scenario 5). Scenario 3 provides modest gains for both commercial and recreational fisheries. In scenario 6, commercial fishery producer surplus losses of 60 percent ($187 thousand) are more than offset by recreational fishery gains of 103 percent ($264 thousand).

Weakfish (Gray Trout)

(*Cynoscion regalis*)[7]

Weakfish (*Cynoscion regalis*) occur along the Atlantic coast of North America from Nova Scotia to southeastern Florida, but are more common from New York to North Carolina. Weakfish winter offshore primarily between Chesapeake Bay and Cape Lookout, North Carolina. In the spring, weakfish migrate northward and inshore to sounds, bays, and estuaries, where they feed primarily on shrimp, other crustaceans, and small fish found near eelgrass beds.

As a migratory stock, weakfish are assessed and managed coastwide by the Atlantic States Marine Fisheries Commission (ASMFC). The most recent benchmark stock assessment was conducted in 2016 (ASMFC 2016). This assessment determined that the stock was depleted assuming a benchmark spawning stock biomass threshold of SSB30% (6,880 mt), or 30% of spawning stock achieved under conditions of average natural mortality and no fishing. Significant increases in natural mortality were estimated to have occurred in the last decade.

Stock Projection Methods

Using terminal year conditions estimated by the 2016 assessment, the weakfish stock was projected forward in time 40 years under nine alternative fishing and natural mortality scenarios (Table 9).

Scenario 1 projects the stock forward under the assumption of continued poor conditions, namely continued high natural mortality (M), low recruitment (R), and status quo (2014) commercial fishing (Comm F) and recreational fishing (Rec F) mortalities. Scenario 2 projects the stock forward assuming a complete moratorium and a stock recruitment relationship but continued high natural mortality. Scenarios 3-7 assume more optimistic, average natural mortality conditions and reduced fishing pressure of varying degrees (10-100% reduction in F for both fleets starting in 2017). Scenarios 8 and 9 assume the most optimistic natural mortality rates such that historically low rates returns in 2017. Scenario 8 differs from 9 in that Scenario 8 assumes status quo fishing

7 Image source: ASMFC. 2016a.

mortalities and Scenario 9 assumes a 50% reduction in fishing mortality for both fleets beginning in 2017.

Table 9. Alternative fishing and natural mortality scenarios explored for weakfish.

Scenario	Comm F	Rec F	M	R
1	Status quo (2014)	Status quo (2014)	M=0.84 (2014)	2010-2014 average
2	F=0 starting in 2017	F=0 starting in 2017	M=0.84 (2014)	S-R relationship
3	Status quo (2014)	Status quo (2014)	Time series average	S-R relationship
4	10% reduction starting in 2017	10% reduction starting in 2017	Time series average	S-R relationship
5	25% reduction starting in 2017	25% reduction starting in 2017	Time series average	S-R relationship
6	50% reduction starting in 2017	50% reduction starting in 2017	Time series average	S-R relationship
7	F=0 starting in 2017	F=0 starting in 2017	Time series average	S-R relationship
8	Status quo (2014)	Status quo (2014)	M=0.15 (M prior to ~1995)	S-R relationship
9	50% reduction starting in 2017	50% reduction starting in 2017	M=0.15 (M prior to ~1995)	S-R relationship

For each scenario, the population was projected forward assuming exponential mortality of each cohort, the mortality rates listed in Table 9, and terminal year selectivities at age for each fleet estimated by the 2016 stock assessment. Commercial landings in pounds were calculated by multiplying commercial catch at age in numbers by average weight at age for ages 1-6+ reported in 2016 assessment. Spawning stock biomass was estimated assuming weights at age and maturity at age reported in the 2016 stock assessment. Recruitment for Scenarios 2-9 was predicted using a Beverton-Holt stock recruitment function estimated from assessment predictions of spawning stock biomass and recruitment (alpha = 0.0059, beta = 0.00026). The proportion of total coastwide landings in 2014 was used to estimate the proportion of total projected landings that should be assigned to North Carolina (51% of commercial landings and 42% of total recreational landings).

Stock Projection Results

Weakfish spawning stock biomass is seriously challenged by high recent natural mortality rates and is not projected to increase unless lower natural mortality rates return as shown by Scenarios 1 and 2 (Figure 13, Figure 14)). Note Figure 13 displays all scenarios in one plot, whereas

Figure 14 zooms in on just Scenarios 1-7. Scenarios 3-7 show how the weakfish stock might rebuild under current fishing conditions and a various reductions in fishing mortality assuming average natural mortality rates return. Scenarios 8 and 9 predict the potential rebuilding of the weakfish stock under historically low natural mortality rates in the presence of current and halved fishing mortality rates, respectively.

Figure 13. Projected spawning stock biomass (mt) for weakfish under all alternative scenarios.

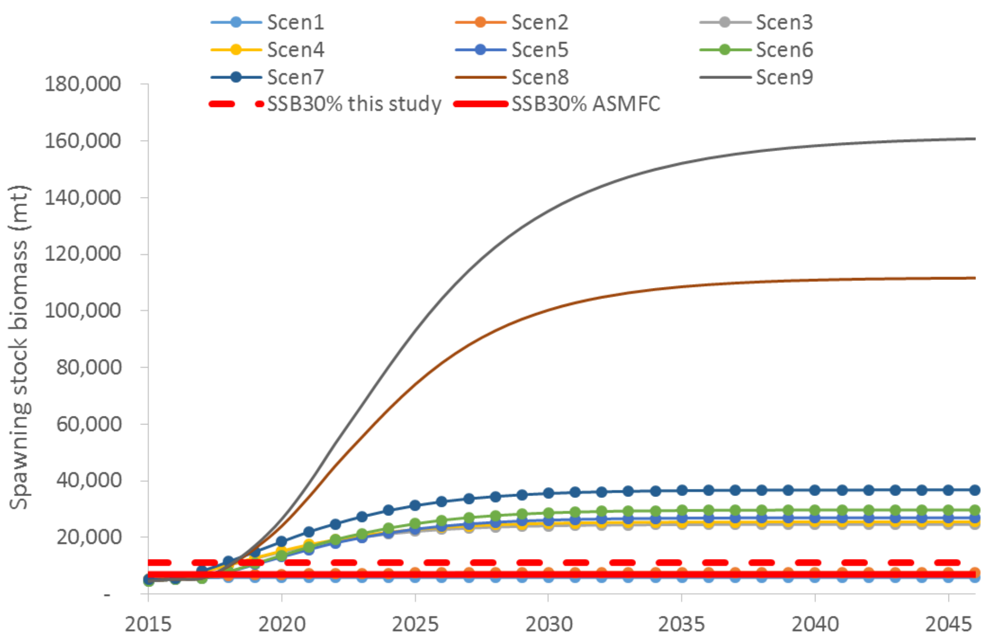
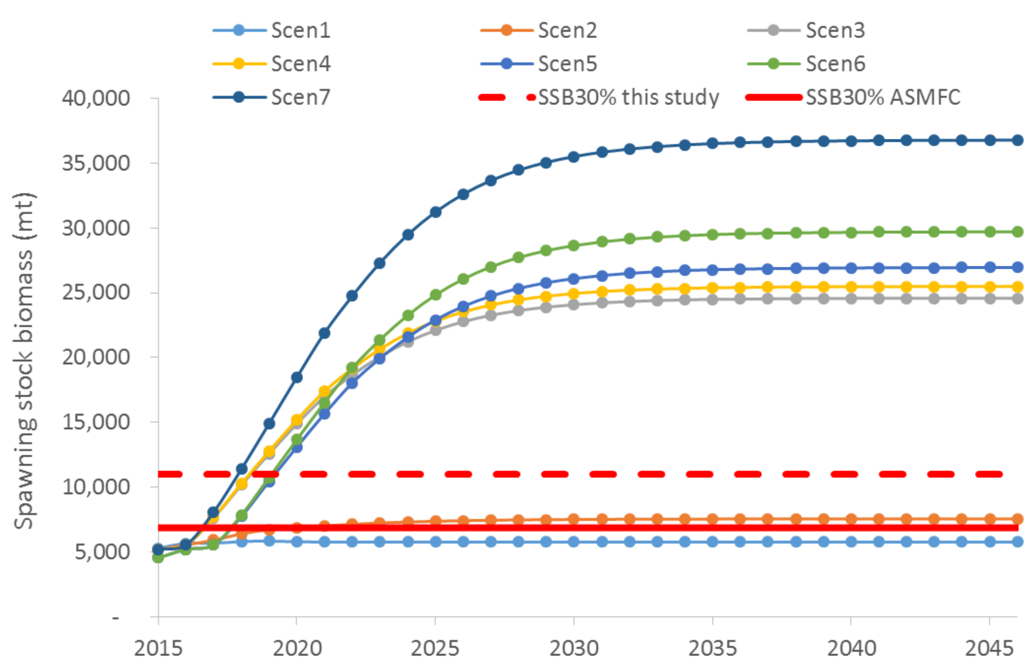


Figure 14. Projected spawning stock biomass (mt) for weakfish under a subset (Scenarios 1-7) of alternative scenarios.



The spawning stock biomass at SSB30% specified in the weakfish FMP (6,880 mt) was achieved by Scenarios 2-9 (Figure 14). However, threshold SSB could only be surpassed if a complete moratorium is enacted (Scenario 2) or higher natural mortality rates returned (Scenarios 3-9). The SSB30% threshold calculated from these projections (11,034 mt) could only be achieved with Scenarios 3-9 in which average or historically low natural mortality rates return. This study approximates several of the projections conducted for the 2016 assessment; however, SSB30% calculations differ slightly between this study and that of the assessment because a complete description how assessment projections were conducted was not included in the report nor was code provided.

Weakfish landings remained stable under status quo (Scenario 1) conditions (Figure 15, Figure 16). Scenario 3 demonstrates how landings under current fishing mortality rates could increase if natural mortality were lowered to the time series average. Scenarios 4-6 demonstrate how landings could increase with reductions in fishing mortality rates assuming time series average natural mortality rates return; however, higher reductions in fishing mortality resulted in lower landings. Scenarios and 8 and 9 predict large increases in landings with status quo or a 50% reduction in fishing mortality and a concurrent return to historically low natural mortality rates.

Figure 15. Projected commercial weakfish landings (mt) under Scenarios 1 and 3-6. Complete moratorium Scenarios 2 and 7 are not displayed.

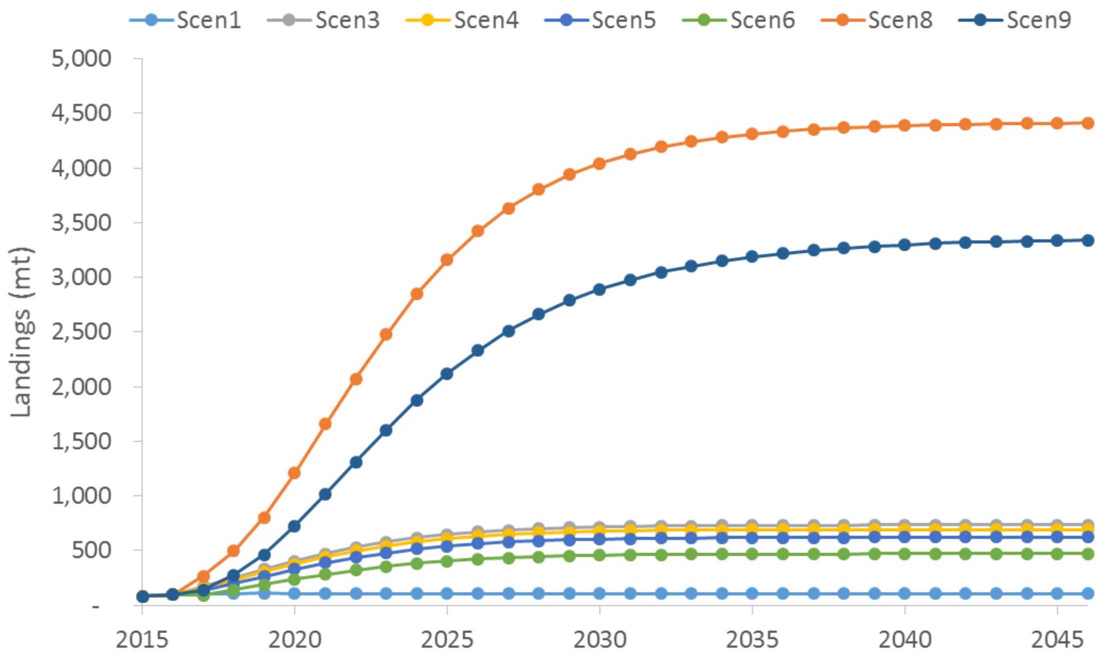
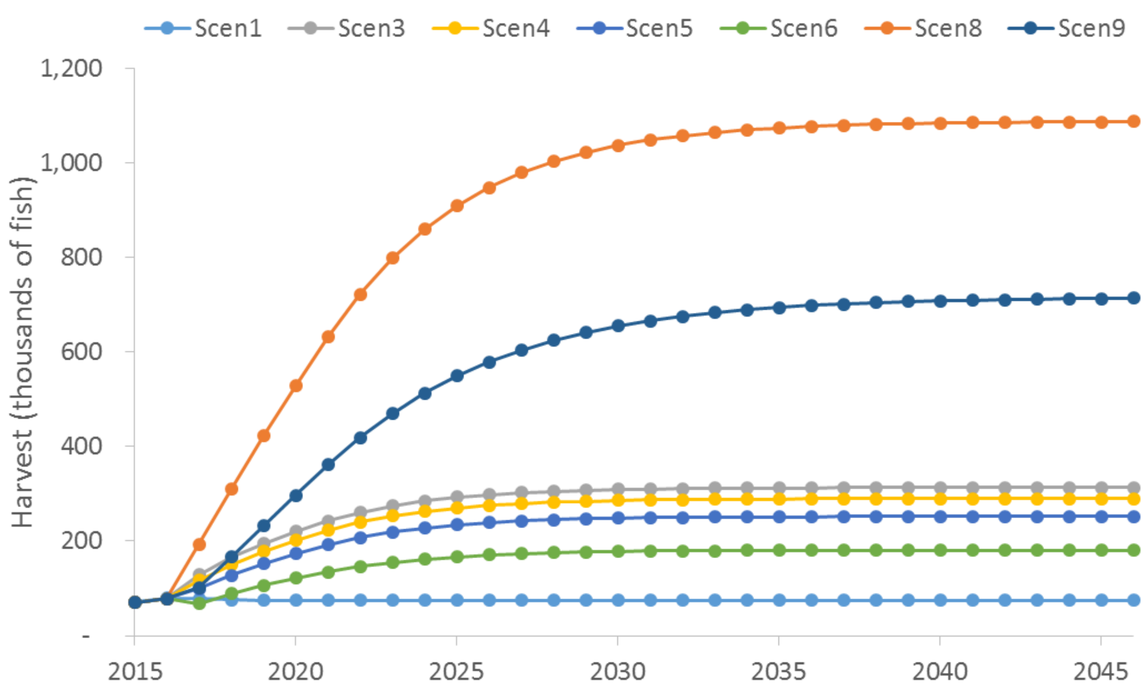


Figure 16. Projected recreational weakfish harvest (thousands of fish) under Scenarios 1 and 3-6. Complete moratorium Scenarios 2 and 7 are not displayed.



Discussion

The rebuilding potential of the weakfish stock relies heavily on lowering of natural mortality. Scenario 2 shows how even in the complete absence of fishing pressure, this stock can barely rebuild unless natural mortality is reduced significantly.

Although there is no empirical evidence that natural mortality for weakfish is high (e.g., evidence of disease or increased prevalence of weakfish in predator diets), the concept that natural mortality has increased was accepted as the most plausible explanation for continued stock declines despite reduced fishing pressure (ASMFC 2016). Concerns have been raised that bycatch of age 0 weakfish by commercial fishing operations is high and negatively affecting the stock. The 2016 assessment model does not include age 0 fish; therefore, explicit modeling of juvenile bycatch could not be explored in this study. Although commercial discards have historically been quite high, since the adoption of bycatch reduction targets and bycatch reduction devices discard estimates produced for the assessment have dropped (Table 10). The breakdown of commercial discards by fleet indicates that otter trawls make up the majority of current weakfish discards (see also 2016 assessment Figure 4.1.5). Available data suggests shrimp trawl bycatch is thought to make up an insignificant fraction of total removals (2016 assessment Figure 5.1.2).

Table 10. Total estimated weakfish discards (mt) from gillnet and otter trawl fisheries.

Year	Gillnets	Otter Trawls	Total
1982	22	288	310
1983	28	358	386
1984	28	312	340
1985	28	368	396
1986	37	280	317
1987	37	264	301
1988	36	223	260
1989	38	174	212
1990	55	537	592
1991	65	430	496
1992	67	397	464
1993	96	416	512
1994	143	213	356
1995	58	347	405
1996	71	427	498
1997	154	116	270
1998	163	118	280
1999	114	117	232
2000	73	83	156
2001	55	74	129
2002	52	74	126
2003	3	102	105
2004	3	34	38
2005	3	45	48
2006	3	36	39
2007	4	38	42
2008	3	41	44
2009	4	52	56
2010	2	38	40
2011	3	49	52
2012	2	42	44
2013	2	26	28
2014	3	42	45

Unless bycatch is being underestimated by several orders of magnitude, the major source of recent mortality (or at least absence of older weakfish in the catch and surveys) is still unknown.

Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for weakfish in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f).[8] Regression analyses conducted by the authors to assess the potential influence of NC weakfish landings (pounds) on real (inflation-adjusted)[9] ex-vessel weakfish prices in NC from 1994 to 2014 found that landings do have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = 0.76968 + 44442.85*(1/Landings), n = 22, F = 117.8, R^2 = 0.85, t-value of (1/Landings) coefficient = 10.85). This regression relationship is used to calculate nominal ex-vessel price for each projection year 2017-2046. It is assumed that this regression relationship remains constant over the projection period 2017-2046; that is, it is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole.

For each weakfish scenario, the commercial landings of weakfish in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the ex-vessel price from the regression relationship to find nominal ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.

For the purposes of this study, it is assumed that vessels with costs similar to the costs of vessels using gill net gear are used to land weakfish in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 gill nets accounted for 90 percent of weakfish landings (by weight) in North Carolina, while other gear accounted for 10 percent of landings.

The number of vessels potentially landing weakfish in 2017 is assumed equal to the number of gill net vessels operating in North Carolina in 2014, or 1340 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of gill net trips made in North Carolina in 2014, or 26,228 trips (NCDMF 2015a); this gives an average of 19.57 gill net trips per vessel per year operating in the gill net fishery in 2017.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating gill net vessels in North Carolina in 2014, or 1214 captain

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[8] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).

[9] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial weakfish fishery are determined using the methodology described for southern flounder. All weakfish landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 25.75 percent of generic finfish sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 74.25 percent of weakfish sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Downstream economic impacts are measured using the methodology described for southern flounder. The maximum catch weight per trip landing weakfish is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016), the average capacity of a 25' gill net vessel fishing the sounds and bays of North Carolina (NCDMF 2015a, Hadley and Wiegand 2014). If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 24.5 trips per vessel per year, the maximum annual average number of observed trips per vessel for 25'-35' gill net vessels over the period 1994-2014 (NCDMF 2015a).

It is assumed that the operating costs of vessels landing weakfish in North Carolina sounds are similar to the operating costs of average-length gill net / crab pot vessels operating in Albemarle and Pamlico sounds, or $531 per trip in 2015 dollars, as reported by Hadley and Wiegand (2014), based on a 2013 survey of fishermen (Table 11). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in weakfish landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 11 is considered part of producer surplus.

Table 11. Trip Expenses (Operating Costs), Vessels Landing Weakfish (2015 dollars)

Expense	Item
$167.56	Fuel and Oil
$5.35	Ice
$18.65	Groceries
$100.62	Bait
$5.45	Other
$233.72	Captain and Crew (assumes 1/3 annual captain/crew expense of $14,934 allocated to weakfish trips, 2/3 crab pot trips)
$531.34	Total Expenses per Trip (@ 19.57 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings.

Economic results for the weakfish commercial fishery by scenario, and differences across scenarios, are presented in Tables A9-A10.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the weakfish recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity. The methodology described for southern flounder is used to estimate the consumer surplus and impacts of the recreational weakfish fishery.

Estimates of consumer surplus per weakfish caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 12. The mean of the values in the table, or $12.37 per fish, is used in this study as the consumer surplus per weakfish caught by recreational anglers.

Table 12. Weakfish-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
Agnello (1989)	Travel cost	NY-FL	$6.34
USEPA (2004)	RUM	NY-VA	$18.39

The economic impacts of the recreational weakfish fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of weakfish recreational catch by mode (Table 13) is calculated from catch by mode data for weakfish caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 13. Recreational Catch and Trips by Mode—Weakfish

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	WEAKFISH	MAN-MADE	67,004	0.2179	23,560	0.3516
2014	WEAKFISH	BEACH/BANK	4,955	0.0161	3,650	0.7366
2014	WEAKFISH	CHARTER BOAT	6,460	0.0210	3,217	0.4980
2014	WEAKFISH	PRIVATE/RENTAL BOAT	229,115	0.7450	47,265	0.2063

Recreational fish catch is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. Economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

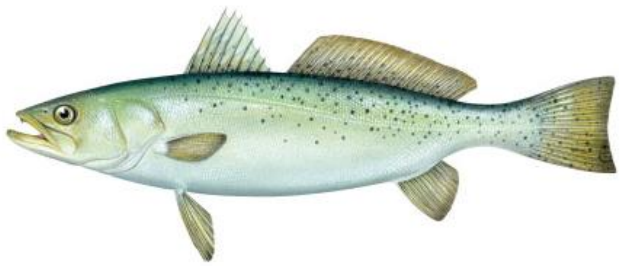
Economic results for the weakfish recreational fishery by scenario, and differences across scenarios, are presented in Tables A11-A12.

Discussion

For weakfish, alternative management scenarios 2 and 7 result in 100 percent reductions in commercial fishery landings, producer surplus, relative to baseline scenario 1. Scenarios 3-6, 8 and 9 increase these same economic measures from 2-fold (scenario 6) to 24-fold (scenario 8). In all scenarios, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected, as existing fishing trips and vessels are sufficient to land the increased catches. For the recreational weakfish fishery, similar to the commercial fishery, catch, consumer surplus and economic impacts suffer 100 percent reductions in scenarios 2 and 7. However, in scenarios 3-6, 8 and 9 these same economic measures increase from 114 percent (scenario 6) to 11-fold (scenario 8). Scenarios 8 and 9 produce large (6- to 24-fold, or

$90-$250 million) increases in both commercial producer surplus and recreational consumer surplus in weakfish fisheries.

Spotted seatrout



(*Cynoscion nebulosus*)[10]

Historically, spotted seatrout landings occurred along Florida's east coast and in North Carolina waters (ASMFC 2016b). Spotted seatrout are found primarily in estuaries, but move to nearshore ocean waters during cold periods. Adults are typically found in grass beds, oyster beds, creek mouths, drop-offs, and near structures such as jetties, stumps, pilings, and wrecks, where they feed primarily on shrimp and fish. They are most abundant in depths of less than ten feet.

Spotted seatrout (*Cynoscion nebulosus*) are assessed as a combined Virginia/North Carolina stock by DMF. The FMP established a fishing mortality rate threshold of F20% (NCDMF 2012). A target of F30% and complimentary spawning stock biomass threshold and targets are outlined in the 2014 stock assessment which indicated that the stock was not overfished and that overfishing was not occurring (NCDMF 2014b). However, projections may help shed light on the potential for improvements in stock status.

Stock Projection Methods

The 2014 stock assessment was a sex-specific, integrated (length- and age-based) assessment model conducted in the computer program Stock Synthesis. Stock assessment results obtained from 2014 assessment report along with additional output kindly provided by DMF staff (Laura Lee, *pers. comm.*) were used to project the population forward 40 years under 14 fishing mortality scenarios.

All modeling scenarios assumed that 2012 fishing and natural mortalities continued through 2013. A cold stun was simulated in 2014 such that resulting recruitment was halved (Figure 1; NCDMF 2014c). Natural mortality at age during the cold stun was increased such that catches in 2014 were a 35% decrease from the previous year based on historical landings and harvest reported relative to known cold stun events (Figure 3.7; NCDMF 2014b). In subsequent years, fishing mortality and recruitment varied by scenario (Table 14).

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[10] Image source: ASMFC 2016b.

Table 14. Alternative fishing mortality scenarios explored for spotted seatrout. Comm F = instantaneous commercial (estuarine and ocean) fishing mortality, Rec F = instantaneous recreational fishing mortality.

Scenario	Comm F	Rec F
1	Status quo (2012)	Status quo (2012)
2	10% reduction starting in 2014	10% reduction starting in 2014
3	25% reduction starting in 2014	25% reduction starting in 2014
4	50% reduction starting in 2014	50% reduction starting in 2014
5	75% reduction starting in 2014	75% reduction starting in 2014
6	F=0 starting in 2014	F=0 starting in 2014
7	Status Quo (2012) with 15" min size starting in 2014	Status Quo (2012) with 15" min size starting in 2014
8	Status Quo (2012) with 15-24" slot limit starting in 2014	Status Quo (2012) with 15-24" slot limit starting in 2014
9	Status quo (2012)	Status quo (2012)
10	10% reduction starting in 2014	10% reduction starting in 2014
11	10% reduction starting in 2014	10% reduction starting in 2014
12	50% reduction starting in 2014	50% reduction starting in 2014
13	75% reduction starting in 2014	75% reduction starting in 2014
14	F=0 starting in 2014	F=0 starting in 2014

Scenarios 1 and 9 simulate status quo (2012) fishing mortality rates assuming average 2008-2012 recruitment or a Ricker stock-recruitment relationship, respectively (alpha = 8.5. beta = 0.0012). Although a Ricker stock-recruitment relationship is not ideal for this species, the Beverton-Holt relationship was not estimable for this population; in order to roughly demonstrate the potential benefits of increase in recruitment with increased stock size and reduced fishing pressure, this relationship was used. However, results should be interpreted with caution, especially at larger stock sizes.

Scenarios 2-6 and 10-14 simulate reductions in fishing mortality rates from 2014 forward for both fleets of 10%, 25%, 50%, and 75%, assuming average 2008-2012 recruitment or a Ricker stock-recruitment relationship, respectively, for each set. Scenarios 7 and 8 simulate stock response to status quo 2012 fishing mortality rates with the additional assumption of a minimum size of 15 inches for both commercial and recreational fisheries (Scenario 7) or a slot limit of 15-24 inches (Scenario 8) in 2014 and recent average recruitment.

For each scenario, the population was projected forward assuming exponential mortality of each cohort, the relative mortality rates listed in Table 14, and terminal year selectivities for each fleet estimated by the 2014 stock assessment. The estimates of 2012 fishing mortality by fleet provided by DMF staff did not reproduce the reported catches by fleet in 2012. Therefore, 2012 fishing mortality rates by fleet were solved for assuming fleet-specific selectivity and natural mortality at age reported in the assessment were correct.

Commercial landings in pounds were calculated by multiplying commercial catch at age in numbers by average weight at age for ages 1-9. Spawning stock biomass was estimated assuming weights at age and maturity at age. Quantities estimated by or input to the assessment as at-length values were converted to at-age values using von Bertalanffy growth parameters estimates reported in the 2014 assessment. Values were averaged across sexes. The proportion of coastwide commercial and recreational reported landings and harvest in 2014 was used to estimate the proportion of total projected removals that should be assigned to North Carolina (approximately 80% for both fleets).

Stock Projection Results

Spawning stock biomass was predicted to respond positively to reduced fishing pressure (Figure 17, Figure 18). In situations where status quo (2012) fishing mortality rates were maintained (Scenarios 1 and 9) after the 2014 cold stun, spawning stock biomass was predicted to increase but not meet or exceed the SSB20% threshold outlined in the FMP. However, spawning stock biomass exceeded the management threshold for Scenarios 7 and 8 in which 2012 fishing mortality rates were maintained but a 15 inch minimum size or 15-24 inch slot limit was instituted in 2014.

Figure 17a. Projected spawning stock biomass (mt) for spotted seatrout under Scenarios 1-8.

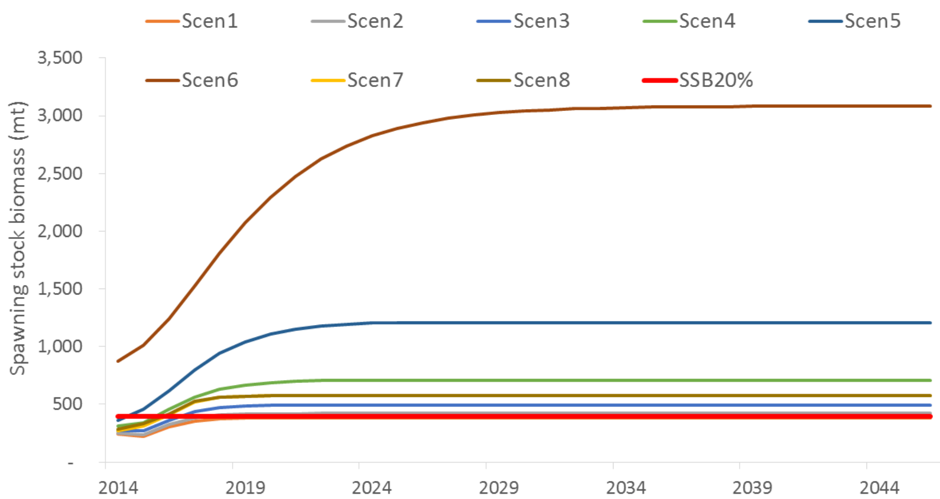


Figure 17b. A subset of scenarios (Scenario 6 removed). The spawning stock biomass threshold of 20% is provided for reference.

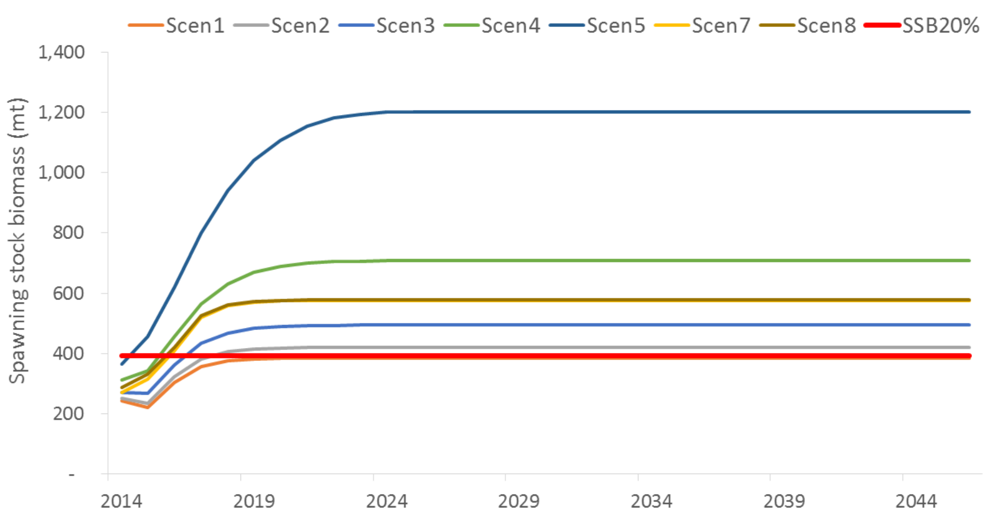
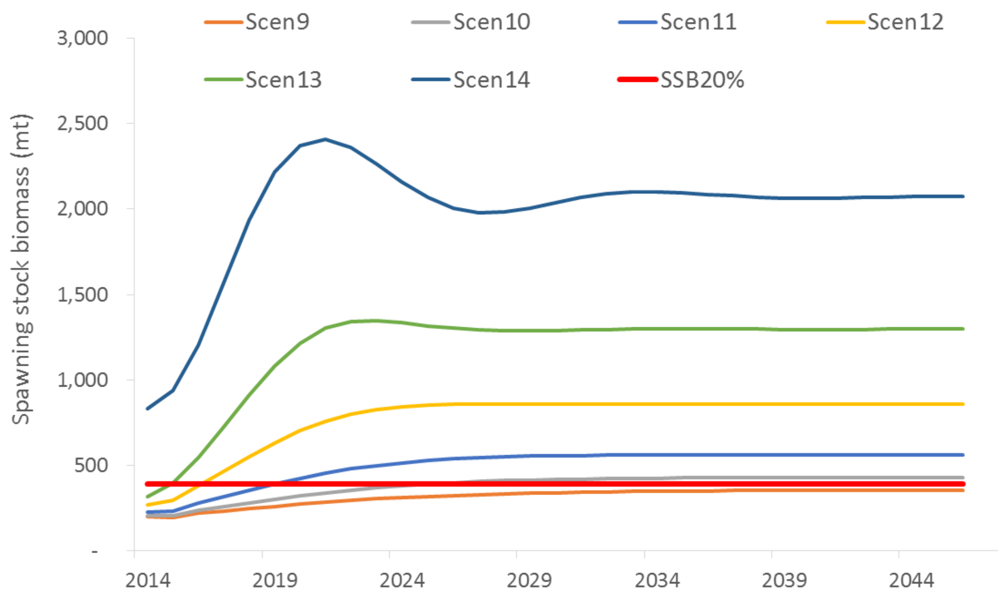


Figure 18. Projected spawning stock biomass (mt) for spotted seatrout under Scenarios 9-14. The spawning stock biomass threshold of 20% is provided for reference.



Scenarios 2-5 and 10-13 demonstrate how spawning stock biomass might increase under reduced fishing mortality scenarios and meet or exceed the SSB20% threshold with different assumptions about recruitment (average vs. stock-recruitment relationship, respectively). Scenarios 6 and 14 projected large increases in spawning stock biomass under a complete moratorium with different assumptions about recruitment (average vs. stock-recruitment relationship, respectively).

Given predicted increases in spawning stock biomass following the 2014 cold stun for all scenarios, commercial landings were predicted to increase over the first few years of the projections and then level off given no additional cold stuns were simulated (Figure 19, Figure 20). Among scenarios that assumed constant average recruitment following the cold stun, scenarios with severe reductions in fishing mortality (50-75%) produced the most positive response of the stock and the lowest landings. Scenarios with increased minimum size (Scenarios 7 and 8) resulted in stock levels exceeding SSB20% and the highest commercial landings. Among scenarios that assumed a Ricker stock-recruitment relationship following the cold stun, reductions in fishing mortality increased landings until reductions reached extremely high levels (75%). Scenarios that assumed a stock-recruitment relationship generally produced higher landings given the same fishing mortality scenario.

Figure 19. Projected commercial spotted seatrout landings (mt) under Scenarios 1-8. Moratorium Scenario 6 is not displayed.

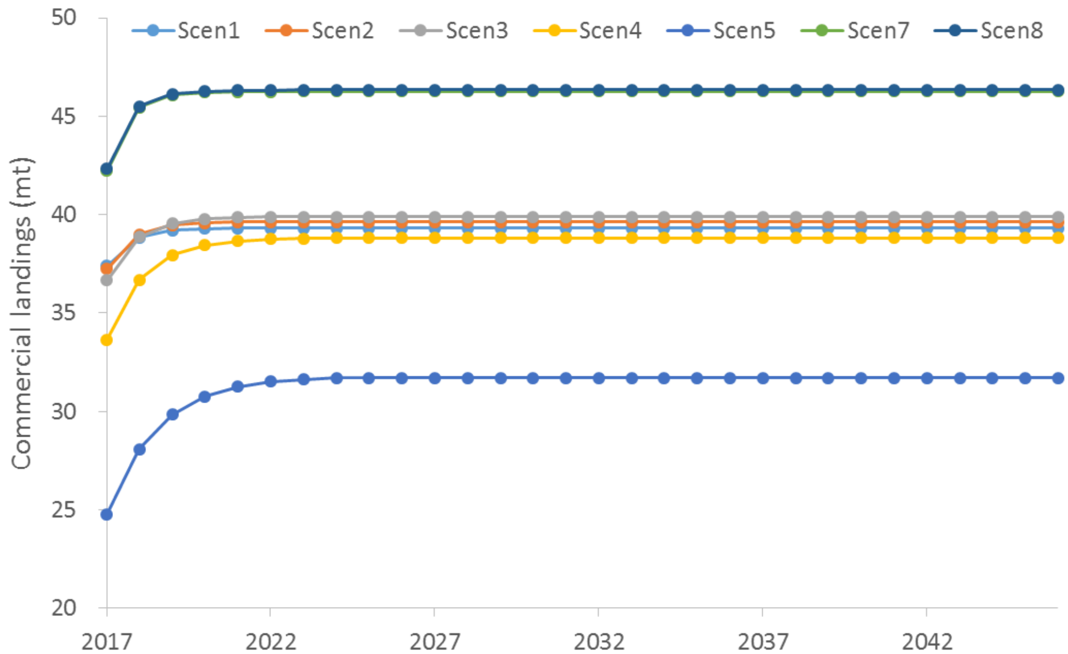
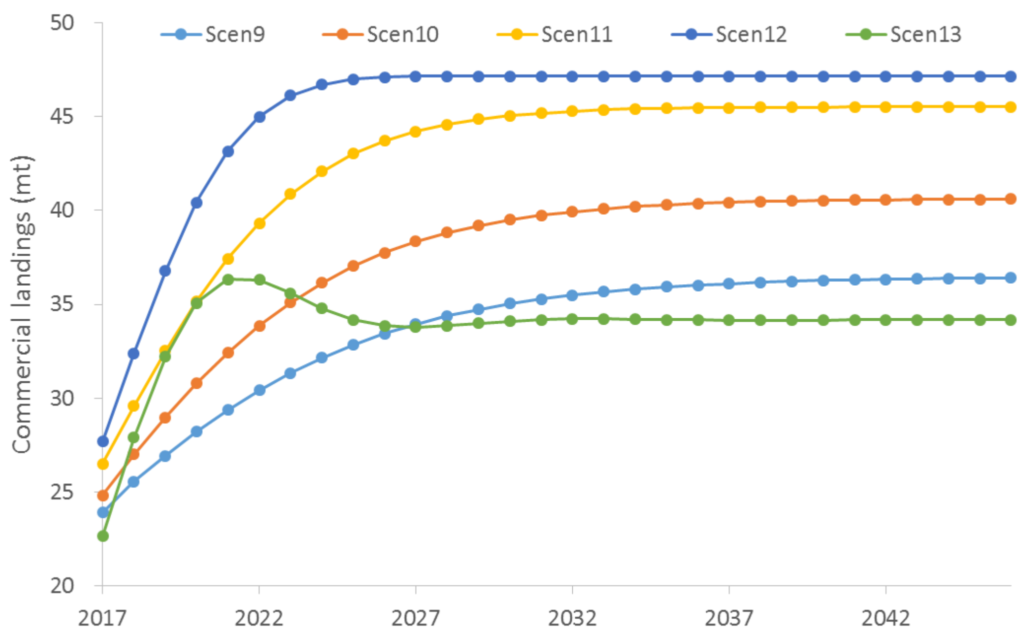


Figure 20. Projected commercial spotted seatrout landings (mt) under Scenarios 9-13.



Given predicted increases in spawning stock biomass following the 2014 cold stun for all scenarios, recreational harvest was predicted to increase over the first few years of the projections and then level off given no additional cold stuns were simulated (Figure 21, Figure 22). Among scenarios that assumed constant average recruitment following the cold stun, increasing reductions in fishing mortality produced larger reductions in harvest; scenarios with increased minimum size (Scenarios 7 and 8) produced relatively lower harvest in contrast with the commercial fleet because harvest is presented in numbers vs. pounds (i.e., fewer but larger fish are predicted to be caught with an increase in minimum size). Among scenarios that assumed a Ricker stock-recruitment relationship following the cold stun, reductions in fishing mortality resulted in increased harvest until reductions reached extremely high levels (50-75%). Scenarios that assumed a stock-recruitment relationship generally produced higher harvest given the same fishing mortality scenario.

Figure 21. Projected recreational spotted seatrout harvest (thousands of fish) under Scenarios 1-8. Moratorium Scenario 6 is not displayed.

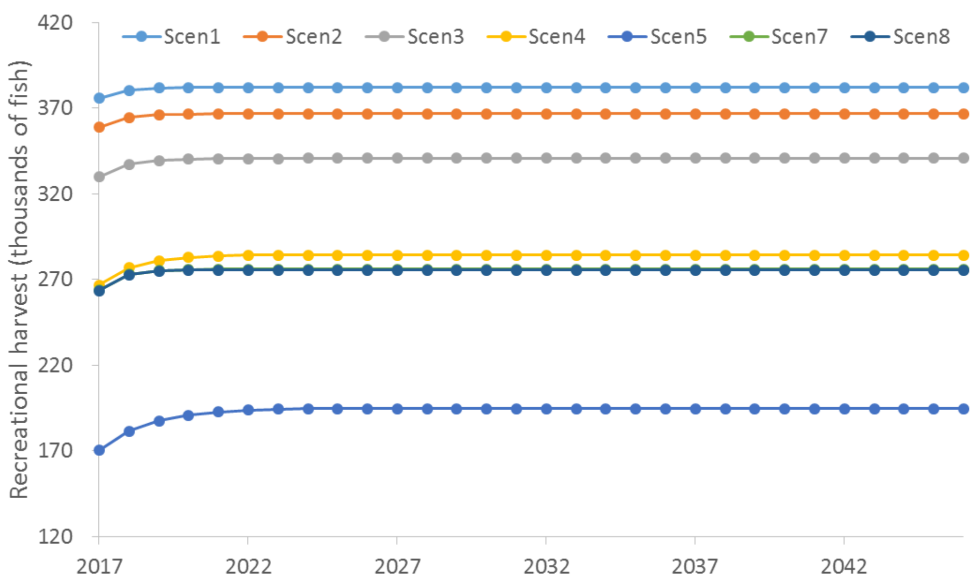
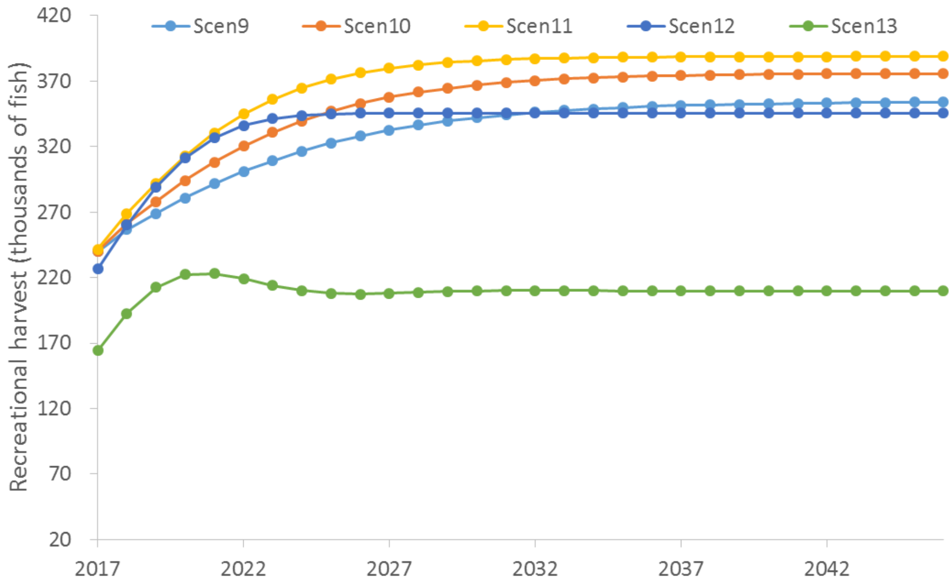


Figure 22. Projected recreational spotted seatrout harvest (thousands of fish) under Scenarios 9-13.



Discussion

Estimating spotted seatrout response to management actions was difficult given discrepancies among terminal year fleet-specific fishing mortality rates reported in the assessment and reported catch. In addition, there is great uncertainty regarding how the stock might respond to cold stun events such as that observed in 2014. Assuming these projection models are parameterized correctly, this study indicates that the stock and the fisheries could benefit from moderate reductions in fishing mortality or an increase in minimum size. Spotted seatrout grow and mature quickly and are thought to be about 50% mature at 27 cm or approximately age 1. The length at 50% selectivity for all three fleets estimated in the assessment was at (recreational) or slightly above (commercial) 27cm. However, reducing fishing mortality or increasing minimum size to at least 15 inches (as in Florida) might relieve fishing pressure on age 1 fish and allow more fish to spawn before becoming susceptible to both fisheries.

Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for spotted seatrout in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f). Regression analyses conducted by the authors to assess the potential influence of NC spotted seatrout landings (metric tons) on real (inflation-adjusted)[11] ex-vessel spotted seatrout prices in NC from 1994 to 2014 found that landings do not have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = B_0 + B_1*(1/Landings), n = 22, F=0.826, R^2 = 0.040, , t-value of (1/Landings) coefficient = 0.91). In recent years (2011-2015), commercial landings of spotted seatrout in North Carolina received an average ex-vessel price of $2.21/lb. in year 2015 dollars. It is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole over the projection period 2017-2046.

For each spotted seatrout scenario, the commercial landings of spotted seatrout in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the ex-vessel price $2.21/lb. to find nominal ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.[12]

For the purposes of this study, it is assumed that vessels with costs similar to the costs of vessels using gill net gear are used to land spotted seatrout in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 gill nets accounted for 93 percent of spotted seatrout landings (by weight) in North Carolina, while other gear accounted for 7 percent of landings.

The number of vessels potentially landing spotted seatrout in 2017 is assumed equal to the number of gill net vessels operating in North Carolina in 2014, or 1340 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of gill net trips made in North Carolina in 2014, or 26,228 trips (NCDMF 2015a); this gives an average of 19.57 gill net trips per vessel per year operating in the gill net fishery in 2017.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating gill net vessels in North Carolina in 2014, or 1214 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial spotted seatrout fishery are determined using the methodology described for southern flounder. All spotted seatrout landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 25.75 percent of generic finfish sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 74.25 percent of spotted seatrout sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North

[11] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).
[12] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Downstream economic impacts are measured using the methodology described for southern flounder. The maximum catch weight per trip landing spotted seatrout is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016), the average capacity of a 25' gill net vessel fishing the sounds and bays of North Carolina (NCDMF 2015a, Hadley and Wiegand 2014). If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 24.5 trips per vessel per year, the maximum annual average number of observed trips per vessel for 25'-35' gill net vessels over the period 1994-2014 (NCDMF 2015a).

It is assumed that the operating costs of vessels landing spotted seatrout in North Carolina sounds are similar to the operating costs of average-length gill net / crab pot vessels operating in Albemarle and Pamlico sounds, or $531 per trip in 2015 dollars, as reported by Hadley and Wiegand (2014), based on a 2013 survey of fishermen (Table 15). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in spotted seatrout landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 15 is considered part of producer surplus.

Table 15. Trip Expenses (Operating Costs), Vessels Landing Spotted seatrout (2015 dollars)

Expense	**Item**
$167.56	Fuel and Oil
$5.35	Ice
$18.65	Groceries
$100.62	Bait
$5.45	Other
$233.72	Captain and Crew (assumes 1/3 annual captain/crew expense of $14,934 allocated to spotted seatrout trips, 2/3 crab pot trips)
$531.34	Total Expenses per Trip (@ 19.57 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings.

Economic results for the spotted seatrout commercial fishery by scenario, and differences across scenarios, are presented in Tables A13-A14.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the spotted seatrout recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity. The methodology described for southern flounder is used to estimate the consumer surplus and impacts of the recreational spotted seatrout fishery.

Estimates of consumer surplus per spotted seatrout caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 16. The mean of the values in the table, or $13.31 per fish, is used in this study as the consumer surplus per spotted seatrout caught by recreational anglers.

Table 16. Spotted seatrout-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
USEPA (2004) sm. gamefish	RUM	NC,SC,GA,FL	$15.24
USEPA (2004) Seatrout	RUM	Gulf Coast	$15.21
McConnell and Strand (1994) sm. gamefish	CV (dichotomous choice)	NY-FL	$26.95
Hicks et al. (1999) sm. gamefish	nested RUM	ME-VA	$4.85
Whitehead and Haab (1999) sm. game	RUM	NC-LA	$4.32

The economic impacts of the recreational spotted seatrout fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of spotted seatrout recreational catch by mode (Table 17) is calculated from catch by mode data for spotted seatrout caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 17. Recreational Catch and Trips by Mode—Spotted seatrout

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	SPOTTED SEATROUT	MAN-MADE	139,960	0.117	44,280	0.3164
2014	SPOTTED SEATROUT	BEACH/BANK	98,608	0.083	30,934	0.3137
2014	SPOTTED SEATROUT	CHARTER BOAT	15,045	0.013	4,698	0.3123
2014	SPOTTED SEATROUT	PRIVATE/RENTAL BOAT	941,002	0.788	204,870	0.2177

Recreational fish catch is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. Economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

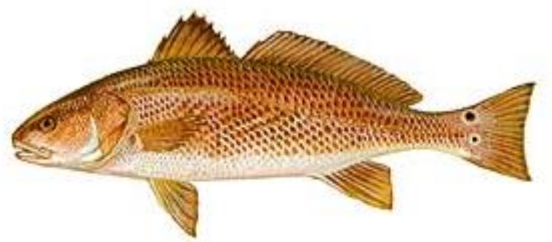
Economic results for the spotted seatrout recreational fishery by scenario, and differences across scenarios, are presented in Tables A15-A16.

Discussion

For spotted seatrout, alternative management scenarios 4-6, 9-10, and 13-14 decrease commercial fishery landings, producer surplus, and economic impacts. Scenarios 6 and 14 result in 100 percent commercial fishery losses, with scenarios 4, 5, 9-10 and 13 producing losses from 2 percent (scenario 4) to 20 percent (scenario 5). By contrast, scenarios 2-3, 7-8, 11-12 produce economic gains for the commercial fishery ranging from 1 percent (scenario 2) to 17 percent(scenarios 7 and 8). In all scenarios, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected, as fishermen continue to land other species in the multi-species fishery. The recreational spotted seatrout fishery experiences reductions in catch, consumer surplus and economic impacts in all scenarios, from 100 percent losses in scenarios 6 and 14, to only 4-5 percent losses in scenarios 2 and 11. Scenario 8 produces the largest gain

(17 percent, $765 thousand) in commercial producer surplus but at the cost of a much larger loss (28 percent, $32 million) in recreational consumer surplus.

Red drum



(*Sciaenops ocellatus*)[13]

Historically, red drum (*Sciaenops ocellatus*) inhabited coastal waters from Massachusetts through Florida, although abundance appears to be lower north of the Chesapeake Bay in recent years (ASMFC 2016d). Juveniles are most abundant in estuarine waters and inlets, while fish older than age four inhabit deeper waters. The adult fish migrate seasonally, moving offshore or south in the winter and inshore or north in the spring.

The red drum stock is assessed and managed at the coastwide level by the Atlantic States Marine Fisheries Commission. The most recent benchmark stock assessment was conducted in 2009 (SEDAR 2009). A new benchmark assessment will be completed in late 2016, but the results are not yet available. The 2009 assessment determined that the northern stock (Massachusetts to North Carolina) was likely not experiencing overfishing based on a fishing mortality threshold of F30% and a target of F40%. Assessment results were deemed too uncertain to make an overfished determination.

Stock Projection Methods

Results of the base run used for management and reported in the 2009 assessment (SEDAR 2009) report could not be reproduced given the code found in the report's appendix or in the ASMFC archives; reproducibility issues were confirmed by current ASMFC staff working on the 2016 red drum assessment (Jeff Kipp, *pers. comm.*). Although the exact base run results used for management could not be reproduced, the available code was similar enough to the true base run that reasonable projections could be generated for the purposes of this study.

Conditions in 2007, the terminal year of the 2009 assessment, for the northern stock were projected forward for 40 years under five alternative fishing mortality scenarios (Table 18).

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[13] Image source: NCDMF. Fish Identification web page: http://portal.ncdenr.org/web/mf/coastal-5

Table 18 Alternative fishing mortality scenarios explored for red drum. Comm F = instantaneous commercial fishing mortality, Rec F = instantaneous recreational fishing mortality, M = natural mortality on ages 2+, R = recruitment of age 1 fish to the stock.

Scenario	Comm F	Rec F	M	R
1	Status quo (2007)	Status quo (2007)	Status quo M at age	2004-2007 average
2	10% reduction starting in 2017	10% reduction starting in 2017	Status quo M at age	2004-2007 average
3	25% reduction starting in 2017	25% reduction starting in 2017	Status quo M at age	2004-2007 average
4	50% reduction starting in 2017	50% reduction starting in 2017	Status quo M at age	2004-2007 average
5	F=0 starting in 2017	F=0 starting in 2017	Status quo M at age	2004-2007 average

Scenario 1 projected the stock forward under the assumption that 2007 fishing and natural mortalities and 2004-2007 average recruitment was maintained. Scenarios 2-4 projected the stock forward assuming 10-50% reductions, respectively, in fishing mortality starting in 2017. Scenario 5 assumed a complete moratorium starting in 2017.

For each scenario, the population was projected forward assuming exponential mortality of each cohort, the mortality rates listed in Table 18, and terminal year selectivities at age for each fleet estimated by the 2009 stock assessment. Commercial landings in pounds were calculated by multiplying commercial catch at age in numbers by average weight at age for ages 1-7+ reported in the 2009 assessment. Spawning stock biomass was estimated assuming weights at age and maturity at age reported in the 2009 stock assessment. Average recruitment between 2004 and 2009 was assumed for all runs. The proportion of average coast-wide landings between 2003 and 2007 was used to estimate the proportion of total projected landings that should be assigned to North Carolina (96% of northern stock commercial landings and 73% of northern stock recreational landings).

Stock Projection Results

The results of the 2009 red drum stock assessment indicated that catch at age (Figure 23) and resulting fishing mortality (Figure 24) for ages 1-2 was extremely high.

Figure 23. Estimated proportion of red drum ages 1-2 in the catch by fleet.

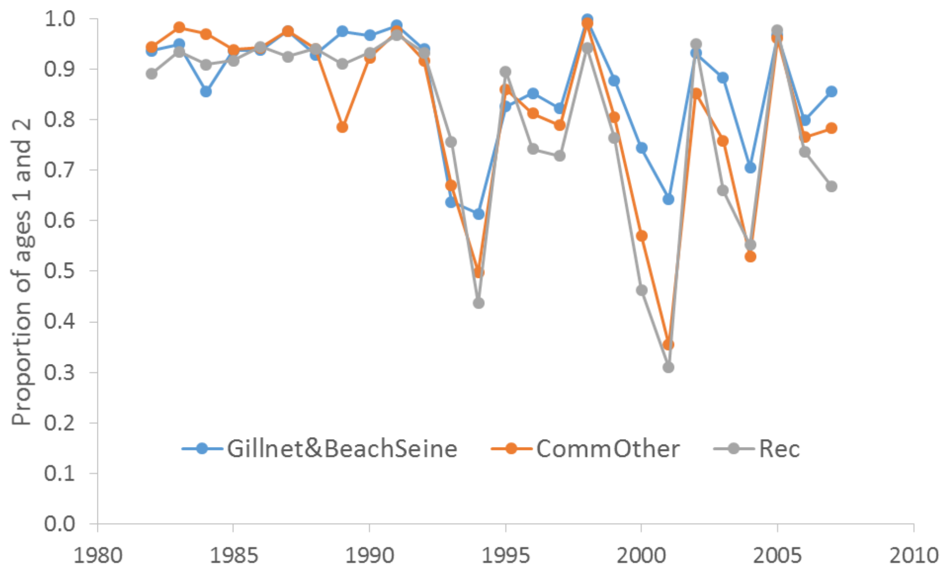
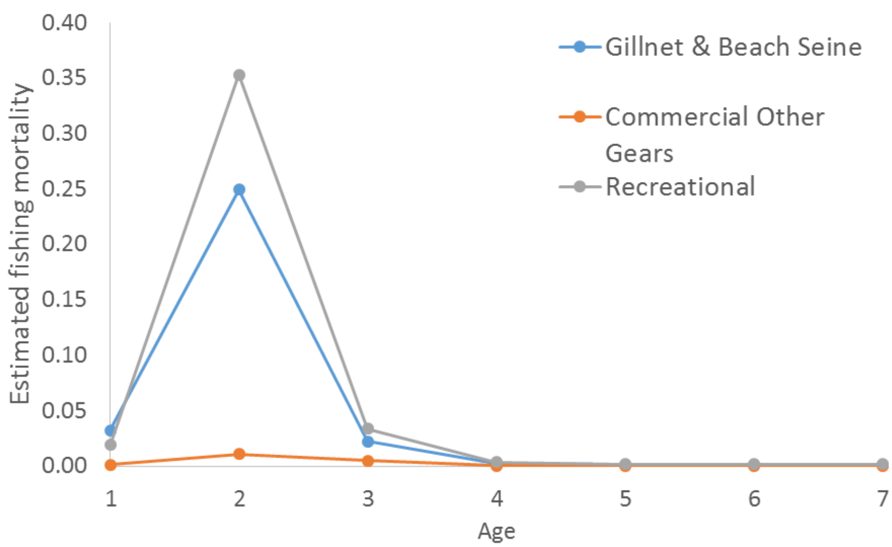
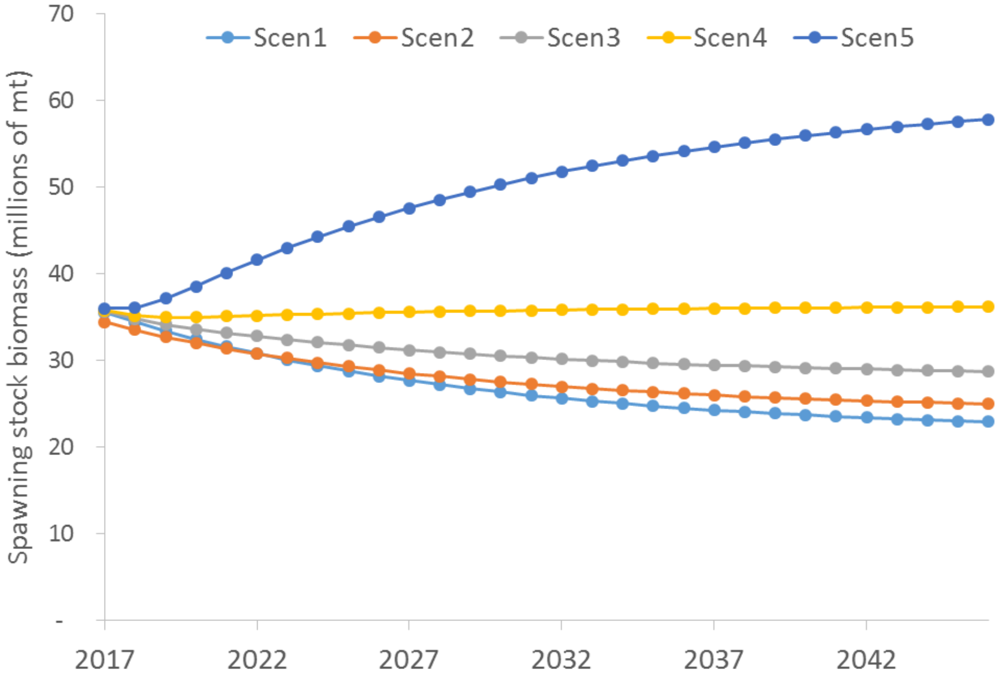


Figure 24. Estimated fishing mortality at age by fleet for red drum in 2007.



Therefore, under conditions of constant average recruitment, it should not be surprising that the stock is projected to decline from 2017 levels to a stable equilibrium abundance at age (Figure 25). Only scenarios with extreme reductions in fishing mortality (50%, Scenario 4) or a fishing moratorium (Scenario 5) would achieve stable or increasing abundance, respectively.

Figure 25. Projected spawning stock biomass (mt) of red drum under five fishing mortality scenarios.



Given the predicted spawning stock biomass trajectories, red drum landings and harvest were projected to decline from 2017 levels with increasing reductions in fishing mortality (Figure 26, Figure 27).

Figure 26. Projected red drum commercial landings (mt) in North Carolina under four alternative fishing mortality scenarios.

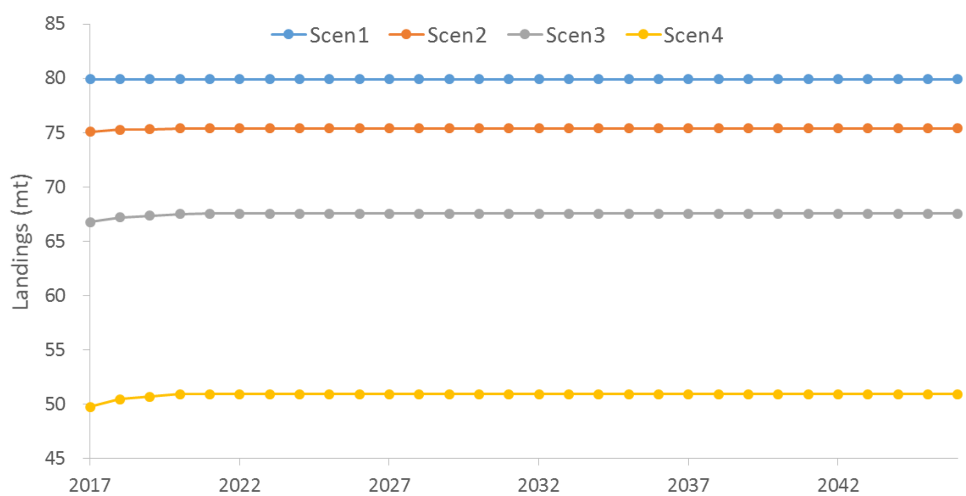
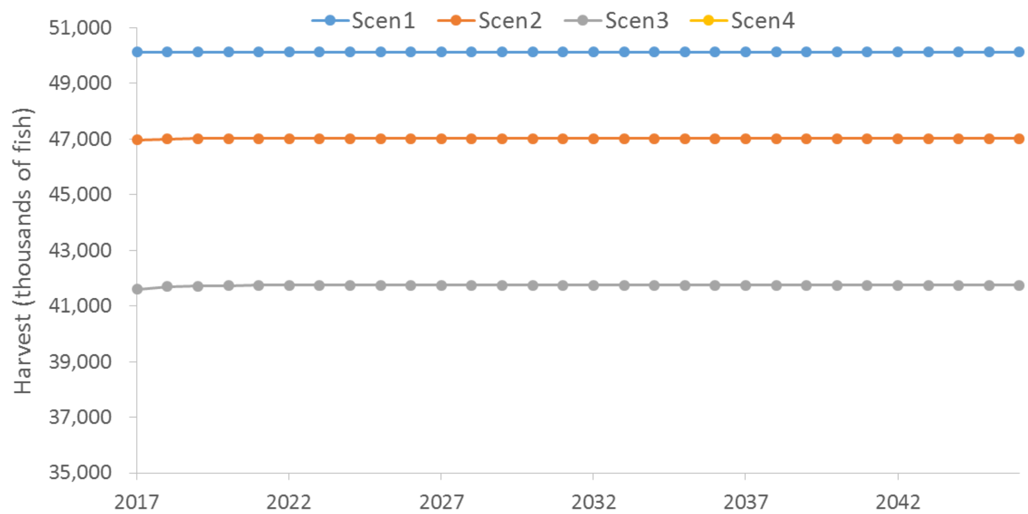


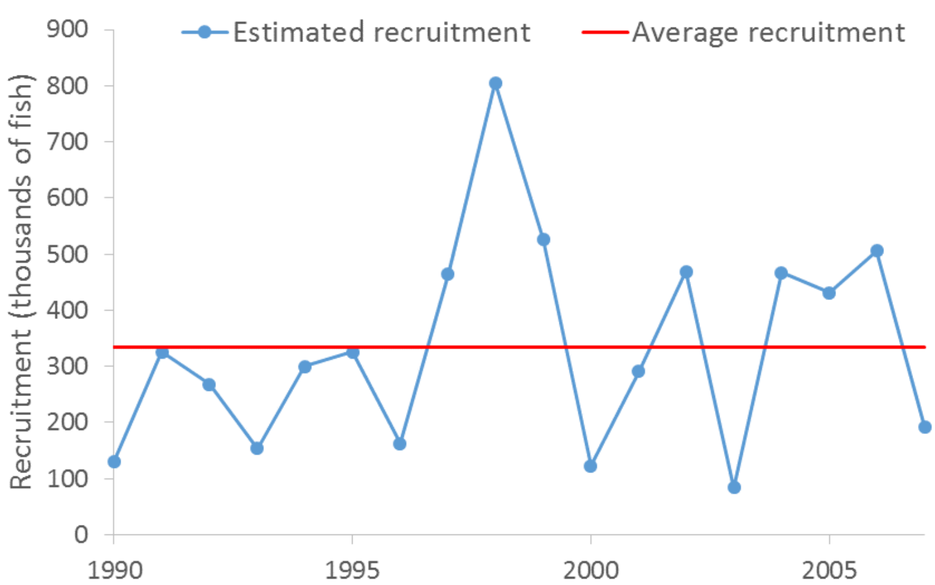
Figure 27. Projected recreational harvest of red drum (thousands of fish) in North Carolina under four alternative fishing mortality scenarios.



Discussion

The red drum stock is believed to be only 50% mature at age 4 and not fully mature until age 5; therefore, estimated high rates of fishing mortality on ages 1-2 fish should not be sustainable. If the stock assessment is correct, the northern stock has been maintained by a few large recruitment pulses in the last decade of the time series (Figure 28).

Figure 28. Estimated recruitment of red drum, 1990-2007.



However, the stock may not be able to sustain itself under current fishing pressure long-term without frequent bouts of above average recruitment as indicated by these projections. The stock would greatly benefit from an increase in minimum size.

Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for red drum in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f). Regression analyses conducted by the authors to assess the potential influence of NC red drum landings (metric tons) on real (inflation-adjusted)[14] ex-vessel red drum prices in NC from 1994 to 2014 found that landings do not have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = $B_0 + B_1$*(1/Landings), n = 22, F=0.9507, R^2 = 0.045, t-value of (1/Landings) coefficient = 0.975). In recent years (2011-2015), commercial landings of red drum in North Carolina received an average ex-vessel price of $2.09/lb. in year 2015 dollars. It is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole over the projection period 2017-2046.

For each red drum scenario, the commercial landings of red drum in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the ex-vessel price $2.09/lb. to find nominal ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.[15]

For the purposes of this study, it is assumed that vessels with costs similar to the costs of vessels using gill net gear are used to land red drum in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 gill nets accounted for 93 percent of red drum landings (by weight) in North Carolina, while other gear accounted for 7 percent of landings.

The number of vessels potentially landing red drum in 2017 is assumed equal to the number of gill net vessels operating in North Carolina in 2014, or 1340 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of gill net trips made in North Carolina in 2014, or 26,228 trips (NCDMF 2015a); this gives an average of 19.57 gill net trips per vessel per year operating in the gill net fishery in 2017.

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[14] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).
[15] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating gill net vessels in North Carolina in 2014, or 1214 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial red drum fishery are determined using the methodology described for southern flounder. All red drum landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 25.75 percent of generic finfish sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 74.25 percent of red drum sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Downstream economic impacts are measured using the methodology described for southern flounder. The maximum catch weight per trip landing red drum is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016), the average capacity of a 25' gill net vessel fishing the sounds and bays of North Carolina (NCDMF 2015a, Hadley and Wiegand 2014). If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 24.5 trips per vessel per year, the maximum annual average number of observed trips per vessel for 25'-35' gill net vessels over the period 1994-2014 (NCDMF 2015a).

Red drum are most frequently caught in Pamlico, Core, Bogue sounds, and Pamlico/Neuse River (NCDMF 2008). It is assumed that the operating costs of vessels landing red drum in North Carolina sounds are similar to the operating costs of average-length gill net / trawl vessels operating in Core Sound, or $180.39 per trip in 2015 dollars, as reported by Crosson (2007), based on a 2006 survey of fishermen (Table 19). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in red drum landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 19 is considered part of producer surplus.

Table 19. Trip Expenses (Operating Costs), Vessels Landing Red drum (2015 dollars)

Expense	Item
$133.25	Fuel and Oil
$3.00	Ice
$3.01	Groceries
$21.21	Bait
$0.05	Other
$19.89	Captain and Crew (assumes 1/3 annual captain/crew expense of $59.66 allocated to pound net trips, 2/3 crab pot trips)
$180.39	Total Expenses per Trip

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings.

Economic results for the red drum commercial fishery by scenario, and differences across scenarios, are presented in Tables A17-A18.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the red drum recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity. The methodology described for southern flounder is used to estimate the consumer surplus and impacts of the recreational red drum fishery.

Estimates of consumer surplus per red drum caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 20. The mean of the values in the table, or $11.94 per fish, is used in this study as the consumer surplus per red drum caught by recreational anglers.

Table 20. Red drum-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
Whitehead and Haab (1999)	non-nested RUM	NC-LA	$5.48
USEPA (2004)	nested RUM	NC,SC,GA,FL	$15.24
McConnell and Strand (1994)	CV (dichotomous choice)	NY-FL	$26.95
Hicks et al. (1999)	nested RUM	ME-VA	$4.85
USEPA (2004)	nested RUM	NY-VA	$7.18

The economic impacts of the recreational red drum fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of red drum recreational catch by mode (Table 21) is calculated from catch by mode data for red drum caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 21. Recreational Catch and Trips by Mode—Red drum

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	RED DRUM	MAN-MADE	35,784	0.072	22,596	0.6315
2014	RED DRUM	BEACH/BANK	121,568	0.243	57,484	0.4729
2014	RED DRUM	CHARTER BOAT	21,268	0.043	13,228	0.6220
2014	RED DRUM	PRIVATE/RENTAL BOAT	320,643	0.642	132,655	0.4137

Recreational fish catch is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. Economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the red drum recreational fishery by scenario, and differences across scenarios, are presented in Tables A19-A20.

Discussion

For red drum, all alternative management scenarios 2-5 reduce commercial fishery landings, producer surplus, and economic impacts by 6 percent (scenario 2) to 100 percent (scenario 5) relative to baseline scenario 1. However, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected as fishermen continue to land other species in the multi-species fishery. Similar to the commercial fishery, the recreational red drum fishery experiences reductions in catch, consumer surplus and economic impacts for all scenarios 2-5, ranging from 6 percent losses (scenario 2) to 100 percent losses (scenario 5). Scenario 2 results in the smallest economic losses in terms of commercial producer surplus ($475 thousand) and recreational consumer surplus ($844 thousand) across all alternative management scenarios.

Blue crab


(*Callinectes sapidus*)[16]

Blue crabs (*Callinectes sapidus*) are found in the coastal waters of the United States from Maine southward, along both coasts of Florida, and around the Gulf of Mexico to the most southern end of Texas (NCDMR 2013a). Blue crabs are landed in the majority of North Carolina's coastal waterbodies and estuarine tributaries. Albemarle and Pamlico sounds are the two largest producers of blue crabs, accounting for about 55 percent of the total landings. Blue crabs are harvested in every month of the year, but over 80 percent of all crabs are harvested from May through October.

The North Carolina stock of blue crab is assessed and managed at the state level by NCDMF. The most recent stock assessment FMP adopted a qualitative traffic light approach to determine stock status using a series of abundance and production indicators (NCDMF 2016a). The stock was declared to be not overfished. However, a quantitative model of blue crab stock dynamics in North Carolina was developed recently that may help predict blue crab response to alternative exploitation rate scenarios (Colton 2011, Colton et al. 2014).

Stock Projection Methods

The North Carolina catch survey model developed by Colton et al. (2014) was modified to project blue crab dynamics forward 40 years under alternative exploitation rate scenarios (Table 22). A Ricker stock-recruitment function was estimated from Colton's time series of recruits and pre-recruits (alpha=34.5, beta=0.056). The Ricker formulation was chosen for two reasons: 1) blue crabs are cannibalistic and this is a common stock-recruitment relationship to assume for species with such a life history (e.g., Chesapeake Bay stock assessment; Miller et al. 2011), and 2) and because the parameters of the Beverton-Holt were not estimable in this situation for comparison.

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[16] Image source: NCDENR. http://portal.ncdenr.org/web/mf/blue-crabs

Table 22. Alternative exploitation rate scenarios explored for North Carolina blue crab. U = exploitation rate, S-R = stock-recruitment.

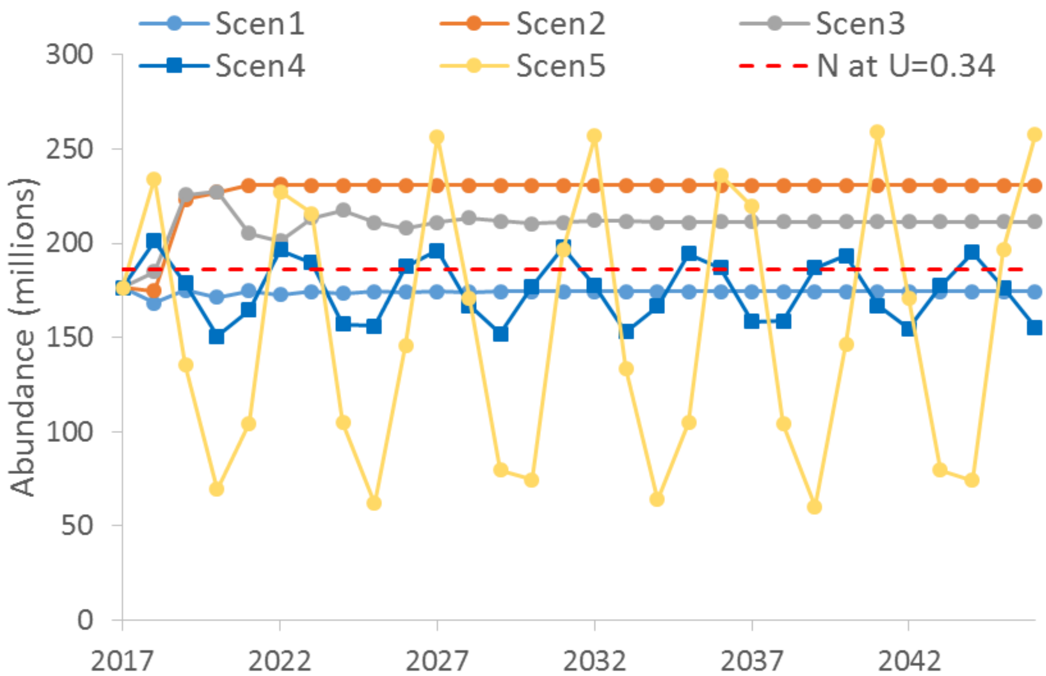
Scenario	Exploitation Rate	Natural Mortality	Recruitment
1	Status quo (U=0.58 in 2008)	0.87	S-R relationship
2	10% reduction (U=0.52) starting in 2017	0.87	S-R relationship
3	25% reduction (U=0.43) starting in 2017	0.87	S-R relationship
4	50% reduction (U=0.29) starting in 2017	0.87	S-R relationship
5	U=0 starting in 2017	0.87	S-R relationship

Scenario 1 projected the stock forward assuming the assessment's estimated 2008 exploitation rate and assumed natural mortality. Scenarios 2-5 projected stock dynamics forward assuming 10-50% reductions in exploitation rate starting in 2017. Scenario 5 assumed a fishing moratorium was instituted in 2017. Landings were calculated as exploitation rate multiplied by total abundance in a given year. Commercial landings were assumed to comprise 99% of total landings and were converted from millions of crabs to millions of pounds by dividing by three as reported in Colton 2011.

Stock Projection Results

Blue crab abundance was projected to remain stable under status quo (2008) conditions (Figure 29).

Figure 29. Projected blue crab abundance (millions) under five alternative exploitation rate scenarios. N=abundance, and U=exploitation rate.



Scenario 2 predicted abundance would increase under a 10% reduction in exploitation rate. Scenarios 3-5 show how the assumed density-dependent recruitment driven by the Ricker stock-recruitment relationship would result in lower recruitment as stock size increases (Scenario 3) and ultimately cyclic dynamics at higher stock sizes (Scenarios 4-5). Although this stock has no biological reference point in its FMP, the abundance at maximum sustainable yield estimated from the Chesapeake Bay blue crab stock assessment (0.34) is provided for reference. Only Scenarios 2 and 3 achieved long-term abundance above this reference point.

Both commercial and recreational landings were predicted to increase from status quo (2008) levels with a 10% reduction in exploitation rate (Figure 30, Figure 31). Larger reductions in exploitation rate increased stock abundance to high enough levels that density-dependent mortality caused a decline in abundance and resulting landings (Scenarios 2-4).

Figure 30. Projected commercial blue crab landings (millions of mt) under Scenarios 1-4. Complete moratorium Scenario 5 is not displayed.

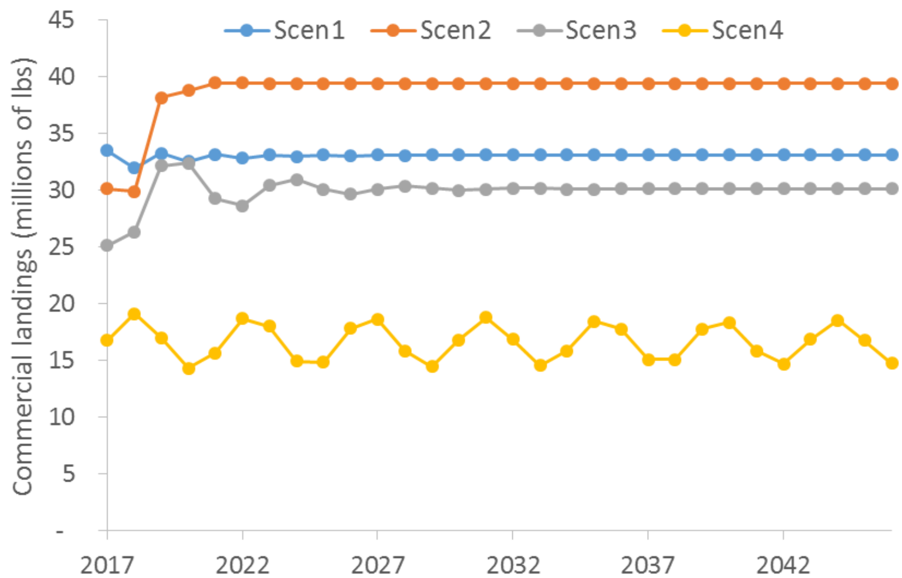
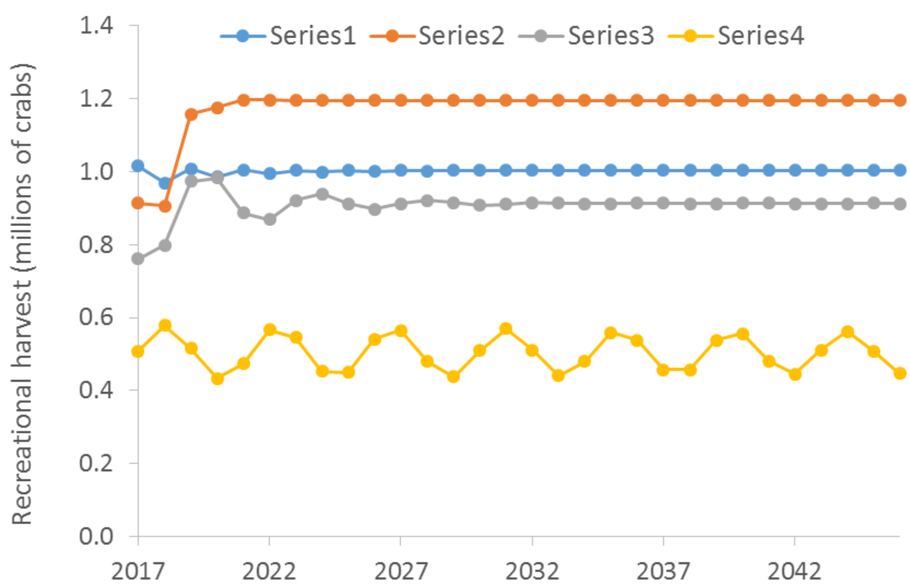


Figure 31. Projected recreational blue crab landings (millions of mt) under Scenarios 1-4. Complete moratorium Scenario 5 is not displayed.



Discussion

Projection models indicate that the current status and landings of North Carolina blue crab stock could be improved with slightly lower exploitation rates. If in reality the stock does not exhibit declines in recruitment at larger stock sizes as predicted by the Ricker stock-recruitment function, gains in stock abundance and landings could potentially be even higher.

Current management relies on qualitative reference points determined by an ad hoc traffic light approach. Colton et al. (2104) and this study indicated that quantitative approaches to modeling and setting biological reference points for this stock are possible and could be used to inform future management of this valuable stock.

Economic Impacts – Commercial Fisheries

Blue crab is the most economically-important species for commercial fisheries in North Carolina (NCDMF 2013a). Blue crabs are targeted and landed by commercial fisheries in three main market segments; hard, peeler, and soft crabs. Hard crabs account for 97 percent of the total blue crab harvest. Annual average North Carolina hard crab landings 1994-2014 were 40 million pounds/yr, while peeler crab landings averaged 0.8 million pounds/yr, and soft crabs averaged 0.6 million pounds/yr (NCDMF 2015a).

The present study estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period.

Average nominal dockside (ex-vessel) prices for blue crabs (weighted-average price of hard, peeler and soft crabs combined) in in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed (hard, peeler and soft crabs combined) in N.C. for each year (NCDMF 2016f). Regression analyses conducted by the authors to assess the potential influence of NC blue crabs landings (metric tons) on real (inflation-adjusted)[17] ex-vessel blue crabs prices in NC from 1994 to 2014 found that landings do not have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = $B_0 + B_1$*(1/Landings), n = 22, F=0.3552, R^2 = 0.0174, , t-value of (1/Landings) coefficient = 0.5959).

The weighted-average (across market segments) ex-vessel price per pound for blue crabs in projection year 2017 used in the present study, $1.06/lb. in 2015 dollars, is determined by multiplying the average real (year 2015) price of crabs for each market segment for recent years 2011-2015 by the average proportion of total blue crab landings attributable to each market segment for years 2011-2015 and summing over market segments (Table 23). It is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole over the projection period 2017-2046.

[17] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).

Table 23. Average Blue Crab Price/Lb. (Averaged across Market Segments)

Market Segment	Ave Real (2015) Price/Lb., 2011-2015	Ave. Proportion of Total N.C. Blue Crab Landings 2011-2015
Hard shell	$0.96	0.965754
Soft shell	$5.67	0.01337
Peeler	$2.84	0.020875
Weighted average real (year 2015 dollars) price/lb. = $1.06		

For each blue crabs scenario, total (hard, soft and peeler combined) commercial landings of blue crabs in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the average (across market segments) ex-vessel price $1.06/lb. to find nominal annual ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.[18]

Crab pots, crab trawls, and peeler pots are the major gears used in the directed commercial crab fisheries in North Carolina. Over time, crab pots have become the most preferred gear used to catch hard crabs (NCDMF 2013a). It is illegal to use shrimp trawl or dredge gear to land blue crabs, except as incidental catch during lawful shrimp or oyster harvest. For the purposes of this study, it is assumed that vessels using crab pot gear land all blue crabs in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 crab pots accounted for 95.7 percent of blue crabs landings (by weight) in North Carolina, while other gear accounted for 4.3 percent of landings.

The number of vessels potentially landing blue crabs in 2017 is assumed equal to the number of crab pot vessels operating in North Carolina in 2014, or 975 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of crab pot trips made in North Carolina in 2014, or 50,525 trips (NCDMF 2015a); this gives an average of 51.82 crab pot trips per vessel per year operating in the gill net fishery in 2017.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating crab pot vessels in North Carolina in 2014, or 813 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial blue crabs fishery are determined using the methodology described for southern flounder. All blue crabs

[18] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 52.83 percent of blue crabs sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 47.17 percent of blue crabs sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Blue crab processing has been historically an important component of the downstream economic impacts of the North Carolina blue crab fishery. Processing facilities, otherwise known as “picking houses”, extract and package crab meat which is later sold in state, national, and international markets. Some facilities also clean and freeze crabs, leaving the shell intact. However, in-state crab processing has faced increasing challenges from an increasing percentage of raw crabs been sent out of state for processing, increasing use of "live basket" marketing that bypasses processing, and more stringent HACCP regulations that increase processing costs (NCDMF 2013b).

Downstream economic impacts are measured using a methodology similar to that described for southern flounder. The maximum catch weight per trip for crab pot vessels is limited by the vessel's capacity to carry crab pot gear. The maximum catch weight per crab pot vessel trip is estimated to be 750 lbs./trip for a 15' vessel, 1500 lbs./trip for a 25' vessel, and 5000 lbs./trip for a 35' vessel (O'Neal's Fish House, personal communication, 2016). Weighting these trip capacities by the proportion of N.C. crab pot fishing vessels in each length category (NCDMF 2015a) produces a weighted-average maximum catch weight per crab pot vessel trip of 1,227 lbs./trip. If landings exceed the capacity of the year 2017 trips, then each existing vessel is assumed to increase its number of trips to 61.45 trips per vessel per year, the maximum annual average number of observed trips per vessel for crab pot vessels over the period 1994-2014 (NCDMF 2015a).

It is assumed that the operating costs of vessels landing blue crabs in North Carolina sounds are similar to the operating costs of average-length crab pot vessels operating in Albemarle and Pamlico sounds, or $489.76 per trip in 2015 dollars, as reported by Hadley and Wiegand (2014), based on a 2013 survey of fishermen (Table 24). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in blue crabs landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 24 is considered part of producer surplus.

Table 24. Trip Expenses (Operating Costs), Vessels Landing Blue crabs (2015 dollars)

Expense	**Item**
$167.56	Fuel and Oil
$5.35	Ice
$18.65	Groceries
$100.62	Bait
$5.45	Other
$192.13	Captain and Crew (assumes 2/3 annual captain/crew expense of $14,934 allocated to crab pot trips, 1/3 to trips using other gear)
$489.76	Total Expenses per Trip (@ 51.82 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate increased landings.

Economic results for the blue crabs commercial fishery by scenario, and differences across scenarios, are presented in Tables A21-A22.

Economic Impacts – Recreational Fisheries

Blue crabs are not a major target species for most recreational anglers fishing in North Carolina, but blue crabs are harvested recreationally by a variety of means, including crab pots (rigid and collapsible), gill nets, shrimp trawls, trot-lines, hand-lines, and dip nets (NCDMF 2013b).

Most recreational fishermen targeting blue crabs use commercial gear authorized for use through the N.C. Recreational Commercial Gear License (RCGL). RCGL fishermen land blue crabs primarily using four different gears: crab pots, shrimp trawl, gill nets, or trotline (NCDMF 2013b). Blue crab harvest from RCGL holders is considerably less than the blue crab commercial harvest (less than 1% of total blue crab harvest). The bag limit on recreationally caught crabs is 50 per person per day, not to exceed 100 crabs per vessel. A survey of RCGL holders conducted in 2008 by the NCDMF indicated that blue crabs were the most abundant species landed (by weight) by RCGL participants, accounting for 23% (110,234 pounds) of the total poundage (482,082 pounds) landed (NCDMF 2013b). Of these landings, 92.6% were caught using crab pots, 2.7% using small mesh gill nets, 2.0% using shrimp trawls, 1.7% using large mesh gill nets, and 1.0% using fish pots. The peak months for recreational blue crab harvest were June (18%), July (21%), August (17%), and September (14%). RCGL holders using crab pots used an average of 4 pots per license.

Recreational fishermen possessing a Coastal Recreational Fishing License (CRFL) may target blue crabs recreationally using gear that are exempt from the RCGL, including collapsible crab traps, cast nets, dip nets, hand-lines, and seines (less than 30 feet).

From 2007 to 2010, NCDMF surveyed approximately 20 percent of CRFL holders on their participation in saltwater fishing activities including gigging, use of a cast net, shellfish collection, and crabbing (NCDMF 2013b). The results of the survey for crabbing participants extrapolated across all CRFL holders indicated that approximately 71,000-85,000 individuals participated in CRFL recreational crabbing statewide at that time; however, the associated crab harvest under a CRFL using RCGL-exempt gear is unknown (The bag limit on recreationally caught crabs is 50 per person per day.).

In addition, one pot per person may be attached to the shore along privately owned land or to a privately owned pier without possessing a valid RCGL. In a study conducted in 2002, it was estimated that nearly 30 percent of coastal waterfront landowners harvest blue crabs from their property, accounting for an estimated harvest of 279,434 pounds/yr of blue crab (Vogelsong et al. 2003). The bag limit on recreationally caught crabs is 50 per person per day, but the current recreational harvest from privately owned coastal property unknown (NCDMF 2013b).

Given the available information, the present study will focus on the economic impacts of the RCGL recreational blue crab fishery as a lower bound on the economic impacts of all recreational blue crab fishing activity in the state. The economic analysis develops estimates of the economic impacts (sales, income and jobs) supported by the RCGL blue crab fishing activity. There are currently no known estimates of the consumer surplus (recreation enjoyment value) associated with RCGL blue crab fishing, so consumer surplus estimates are not provided.

The RCGL blue crab fishery produces only upstream economic impacts, rather than both upstream and downstream, because RCGL landings are not sold commercially. The upstream economic impacts of RCGL fishing activity depend on the number of RCGL fishing trips rather than the number or pounds of crabs landed. Data from 2002-2008 collected by the NCDMF RCGL Program are used to estimate the relationship between the number of RCGL blue crab trips and RCGL blue crab landings in pounds. Regression analyses conducted by the authors found that RCGL blue crab trips do have a statistically significant relationship with RCGL blue crab landings in pounds (best-fitting model: Trips = -60570.7 + 7463.3*ln(Pounds) (n = 7, F=9.45, R^2 = 0.6540, , t-value of ln(Pounds) coefficient = 3.07). The sample size is small, but this relationship is used in the absence of better information.

For each year 2017-2046 of each scenario, the regression relationship is used to estimate the number of RCGL blue crab trips based on RCGL blue crab landings in pounds from the biological projection model. The NCDMF RCGL Program collected trip and expenditure data on the 2,096 RCGL trips that landed blue crabs in 2007 (Table 25). The average expenditure per trip was $185.73/trip in 2015-year dollars.

Table 25. Trip and Expenditure Data for 2,096 RCGL Trips Landing Blue Crabs (2015 dollars)

Trip Type	Overnight Trips	Day Trips
Proportion of RCGL trips	0.35	0.65
Nights per Trip	4.7	0
Ave miles travelled	150.77	28.29
Ave fisherpersons per trip	2.13	1.89
Lodging	$115.59	$0.00
Food	$121.36	$13.49
Ice	$15.60	$3.84
Bait	$17.25	$5.09
Fuel and Oil	$73.17	$39.17
Equip Rental	$73.32	$0.00
Total Expenses per Trip	$416.30	$61.59
Weight-average Total Expenditures per Trip	$185.73	

Nominal annual direct expenditures by RCGL recreational fishermen in each year 2017-2046 are calculated by multiplying the estimated number of RCGL trips in each year by $185.73/trip. Upstream economic multiplier effects are calculated for sales and employment based on economic multipliers of $71.28 (year-2007 dollars, or $80.58 in year-2015 dollars) in indirect and induced (multiplier effect) spending per RCGL blue crab trip, and 0.00143 indirect and induced jobs per RCGL blue crab trip, based on economic impact estimates provided by the NCDMF RCGL Program for the 2046 blue crab trips in the 2007 RCGL survey data (NCDMF 2013b). These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the blue crab RCGL fishery by scenario, and differences across scenarios, are presented in Table A23.

Discussion

For blue crab, alternative management scenarios 3-5 decrease commercial fishery landings, producer surplus, and economic impacts. Scenarios 4 and 5 result in 100 percent commercial fishery losses, while scenario 3 produces a 32 percent loss in producer surplus with only 10 percent losses in landings and economic impacts. (Unlike finfish fishing trips, blue crab fishing trips are relatively species-specific and would not be made if blue crab trip revenue falls below blue crab trip cost. As a result, unlike the finfish species considered in this study, only that portion of blue crab ex-vessel revenue beyond a certain threshold flows to producer surplus. As a result, when ex-vessel revenues fall, producer surplus falls by a greater proportion.) In contrast, scenario 2 increases commercial fishery producer surplus by 47 percent with only 17 percent increases in landings and economic impacts. In scenario 2, the increase in catch is large enough to require that additional blue crab fishing trips be made per vessel, but not large enough to require that additional vessels enter the fishery. Similar to the commercial fishery, the recreational commercial gear license (RCGL) blue crab fishery experiences reductions in catch and economic impacts in scenarios 3-5. Scenario 5 results in 100 percent losses. Scenario 4 results in a 50 percent decrease in catch and a 15 percent decrease in economic impacts. Scenario 3 results in a 9 percent decrease in catch and a 2 percent decrease in economic impacts. In contrast, Scenario 2 results in a 17 percent increase in catch and a 3 percent increase in economic impacts in the RCGL fishery. Scenario 2 has positive economic effects for both the commercial and RCGL blue crab fisheries, resulting in a $112 million (47 percent) increase in the commercial producer surplus and a 1.7 million pound (17 percent) increase in RCGL catch relative to baseline scenario 1.

Atlantic croaker

(*Micropogonias undulates*)[19]

Atlantic croaker (*Micropogonias undulates*) is a migratory fish found from the Gulf of Maine to Argentina. Along the Atlantic Coast of the United States, Atlantic croaker are most abundant in the mid-Atlantic region (ASMFC 2016c). The Atlantic croaker stock is managed at the coastwide level by the Atlantic States Marine Fisheries Commission (ASMFC 2016c). The most recent benchmark stock assessment was conducted in 2010 (ASMFC 2010). The assessment determined that the stock was not experiencing overfishing. Although estimates of biomass and their associated overfished reference points were not accepted for use in management, estimated spawning stock biomass in the terminal year of the assessment (2008) was above the suggested threshold of SSB20%.

Stock Projection Methods

The 2010 stock assessment was a hybrid between an age-structured surplus production model and a statistical catch-at-age model custom built for Atlantic croaker. Stock assessment results obtained from 2010 assessment report along with additional output kindly provided by ASMFC staff (Katie Drew, *pers. comm.*) were used to project the population forward 40 years under eight fishing mortality and shrimp trawl bycatch scenarios. All modeling scenarios assumed that 2008 fishing and natural mortalities from the base run continued through 2016. In subsequent years, fishing mortality and shrimp trawl bycatch varied by scenario (Table 26).

Scenario 1 projects the stock forward under the assumption of 2008 natural mortality at age, status quo (2008) commercial fishing (Comm F), scrap/bait fishing (Scrap F), recreational fishing (Rec F), and recreational fishing discard (Rec Disc F) mortalities. In addition, 2008 estimated age 0 removals due to shrimp trawl bycatch were subtracted from the recruitment estimated by a Beverton-Holt stock recruitment function (alpha = 29,616, beta = 0.00005065). Scenarios 2-4 assume reductions in fishing mortality across all fleets of 25%, 50%, and 75% starting in 2017. Scenario 5 projects the stock forward similarly to Scenario 1, but assumes a complete fishing moratorium. Scenario 6 is the same as Scenario 1 (status quo) with the exception that the shrimp trawl bycatch

[19] Image source: ASMFC 2016c.

removals were doubled to represent the potential effects of underestimating bycatch removals. Scenarios 7 and 8 demonstrate the effect of eliminating shrimp trawl bycatch of age 0 fish (either the estimated 2008 removals or double that amount) starting in 2017.

Table 26. Alternative fishing mortality rate and shrimp trawl bycatch scenarios explored for Atlantic croaker.

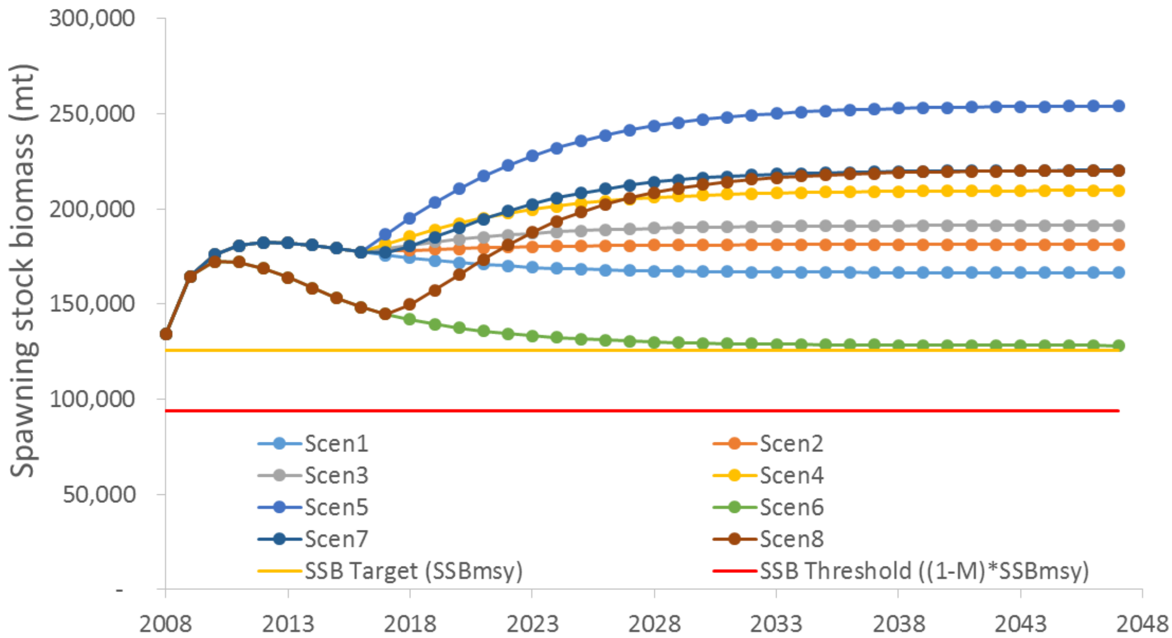
Scenario	Comm F	Scrap F	Rec F	Rec Disc F	Shrimp Trawl Bycatch
1	Status quo (2008)	Status quo (2008)	Status quo (2008)	Status quo (2008)	Estimated age0 removals (2008)
2	10% reduction starting in 2017	10% reduction starting in 2017	10% reduction starting in 2017	10% reduction starting in 2017	Estimated age0 removals (2008)
3	25% reduction starting in 2017	25% reduction starting in 2017	25% reduction starting in 2017	25% reduction starting in 2017	Estimated age0 removals (2008)
4	50% reduction starting in 2017	50% reduction starting in 2017	50% reduction starting in 2017	50% reduction starting in 2017	Estimated age0 removals (2008)
5	F=0 starting in 2017	F=0 starting in 2017	F=0 starting in 2017	F=0 starting in 2017	Estimated age0 removals (2008)
6	Status quo (2008)	Status quo (2008)	Status quo (2008)	Status quo (2008)	Double estimated age0 removals (2008)
7	Status quo (2008)	Status quo (2008)	Status quo (2008)	Status quo (2008)	Estimated age0 removals (2008) through 2016, no shrimp trawl bycatch 2017+
8	Status quo (2008)	Status quo (2008)	Status quo (2008)	Status quo (2008)	Double estimated age0 removals (2008) through 2016, no shrimp trawl bycatch 2017+

For each scenario, the population was projected forward assuming exponential mortality of each cohort, the mortality rates listed in Table 26, and terminal year selectivities at age for each fleet estimated by the 2010 stock assessment. Commercial landings in pounds were calculated by multiplying commercial catch at age in numbers by weight at age for ages 0-15+ reported in 2010 assessment. Spawning stock biomass was estimated assuming weight at age and maturity at age reported in the 2010 stock assessment. The average proportion of total coast-wide landings from 2004-2008 was used to estimate the proportion of total projected landings that should be assigned to North Carolina (41% of commercial landings and 4% of total recreational landings).

Stock Projection Results

Atlantic croaker spawning stock biomass (SSB) was projected to increase slightly but stabilize above the SSB target (around 166,000) mt under 2008 conditions, including 2008 levels of estimated shrimp trawl bycatch removals (Figure 32). In contrast, Scenario 6, which assumed double the level of shrimp trawl removals of age 0 fish, resulted in SSB that declined to the target.

Figure 32. Projected Atlantic croaker spawning stock biomass (mt) under eight alternative fishing mortality rate and shrimp trawl bycatch scenarios.



Higher stable SSB levels were achieved under reduced fishing mortality Scenarios 2-5, and under Scenarios 7 and 8 which assumed shrimp trawl bycatch of croaker ended in 2017.

Scenarios 7 and 8 indicated that both commercial and recreational landings might increase above status quo (2008) levels with reductions shrimp trawl bycatch (Figure 33, Figure 34).

Figure 33. Projected commercial Atlantic croaker landings (lbs) under fishing mortality Scenarios 1-4, and 6-8. Complete moratorium Scenarios 5 is not displayed.

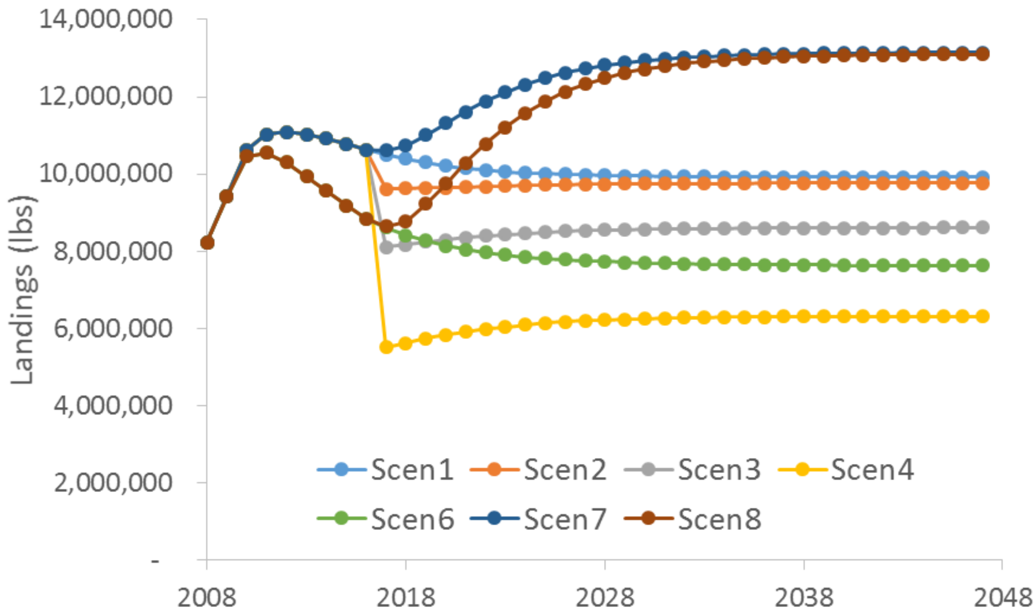
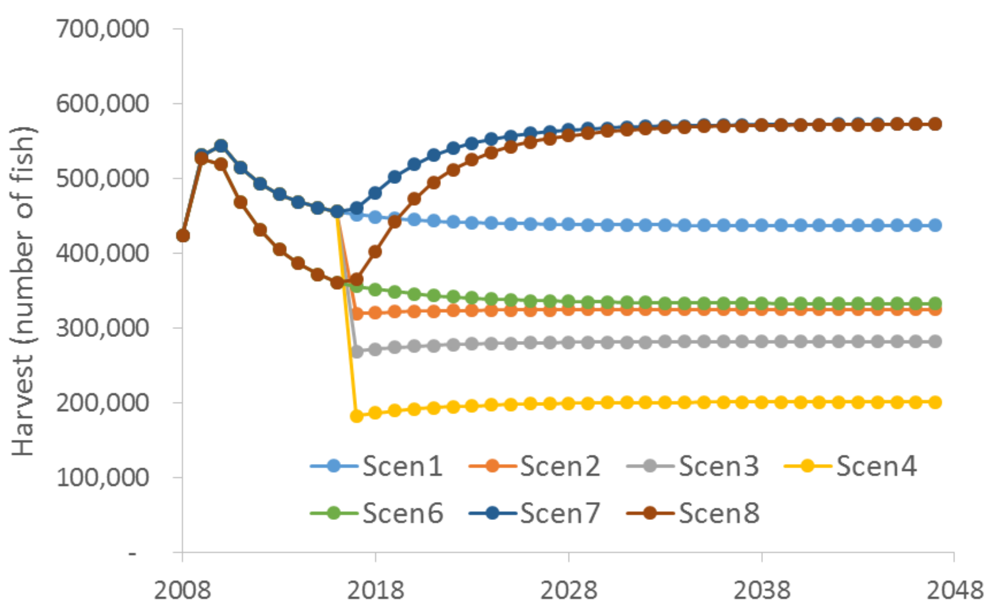


Figure 34. Projected recreational Atlantic croaker harvest (number of fish) under fishing mortality Scenarios 1-4 and 6-8. Complete moratorium Scenarios 5 is not displayed.



Discussion

The 2010 Atlantic croaker assessment suffered greatly from a lack of age sampling of the catch and from inadequate characterization of bycatch removals, in particular from the shrimp trawl fleet (ASMFC 2010). In the peer review of this assessment and in this study, the potential to under or overestimate the magnitude of the population and its response to management is great given so much uncertainty in shrimp trawl bycatch. Although there is a high amount of uncertainty with regards to how the stock might respond to fishing mortality and bycatch mortality reductions, the simple projections provided in this report indicate that a reduction in either fishing mortality or shrimp trawl bycatch could have a positive impact on the stock. However, if shrimp trawl bycatch is indeed two or more times higher in magnitude than estimated 2008 levels, the stock risks dropping below the SSB reference points proposed in the 2010 assessment.

Economic Impacts – Commercial Fisheries

The economic analysis estimates the economic impacts of commercial landings for the 30-year projection period 2017-2046. The analysis also estimates the producer surplus of harvesters over the projection period. Average nominal dockside (ex-vessel) prices for Atlantic croaker in North Carolina for each year 1994-2014 are found by dividing nominal dollar value landed in N.C. by pounds landed in N.C. for each year (NCDMF 2016f).[20] Regression analyses conducted by the authors to assess the potential influence of NC Atlantic croaker landings (metric tons) on real (inflation-adjusted)[21] ex-vessel Atlantic croaker prices in NC from 1994 to 2014 found that landings do have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = 0.30934 + 522.27*(1/Landings), n = 22, F = 107.25, R^2 = 0.843, t-value of (1/Landings) coefficient = 10.36). This regression relationship is used to calculate nominal ex-vessel price for each projection year 2017-2046. It is assumed that this regression relationship remains constant over the projection period 2017-2046; that is, it is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole.

For each Atlantic croaker scenario, the commercial landings of Atlantic croaker in North Carolina in metric tons (mt) from the biological model for each year 2017 to 2046 are converted to pounds and multiplied by the ex-vessel price from the regression relationship to find nominal ex-vessel revenue. The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.

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[20] Dollars are deflated to year 2015 dollars using the GDP Implicit Price Deflator (US Federal Reserve 2016).

[21] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

For the purposes of this study, it is assumed that vessels with costs similar to the costs of vessels using gill net gear are used to land Atlantic croaker in North Carolina's sounds and estuaries. Data on landings by gear by species (NOAA-NMFS 2016a) indicate that in 2015 gill nets accounted for 91 percent of Atlantic croaker landings (by weight) in North Carolina, while other gear accounted for 9 percent of landings.

The number of vessels potentially landing Atlantic croaker in 2017 is assumed equal to the number of gill net vessels operating in North Carolina in 2014, or 1340 vessels (NCDMF 2015a). The number of trips made by these vessels in 2017 is equal to the number of gill net trips made in North Carolina in 2014, or 26,228 trips (NCDMF 2015a); this gives an average of 19.57 gill net trips per vessel per year operating in the gill net fishery in 2017.

The number of captain and crew operating these vessels in 2017 is equal to the number of captain and crew operating gill net vessels in North Carolina in 2014, or 1214 captain and crew (NCDMF 2015a) (the number of captain and crew can be less than the number of vessels because some captain and crew service more than one vessel).

Economic impacts and producer surplus for the commercial Atlantic croaker fishery are determined using the methodology described for southern flounder. All Atlantic croaker landed by North Carolina commercial fishermen must be sold to a North Carolina-licensed seafood dealer/processor. Hadley and Crosson (2010) found that 25.75 percent of generic finfish sold by North Carolina seafood dealers was sold to out-of-state buyers; hence, it is assumed here that 74.25 percent of Atlantic croaker sold by North Carolina seafood dealers is sold to in-state buyers. Harvester sales to North Carolina seafood dealer/processors support upstream economic impacts, and subsequent sales by dealer/processors to in-state buyers support downstream economic impacts within North Carolina.

Downstream economic impacts are measured using the methodology described for southern flounder. The maximum catch weight per trip landing Atlantic croaker is estimated to be 2,000 pounds per trip (O'Neal's Fish House, personal communication, 2016), the average capacity of a 25' gill net vessel fishing the sounds and bays of North Carolina (NCDMF 2015a, Hadley and Wiegand 2014). If landings exceed the capacity of the existing trips, then each existing vessels is assumed to increase its number of trips to 24.5 trips per vessel per year, the maximum annual average number of observed trips per vessel for 25'-35' gill net vessels over the period 1994-2014 (NCDMF 2015a).

It is assumed that the operating costs of vessels landing Atlantic croaker in North Carolina sounds are similar to the operating costs of average-length gill net / crab pot vessels operating in Albemarle and Pamlico sounds, or $531.34 per trip in 2015 dollars, as reported by Hadley and Wiegand (2014), based on a 2013 survey of fishermen (Table 27). It is assumed that fishing vessels employ otherwise non-idle labor, so captain and crew costs are included in operating costs and reflect the wages of captain and crew in their next-best jobs. However, Hadley and Wiegand (2014) found that NC commercial fishing vessels typically (although not exclusively) use a share system to pay captain and crew, with the captain and crew (combined) receiving about 50 percent of trip ex-vessel revenues net of other trip expenses. Hence, an increase in Atlantic croaker landings would produce an increase in captain and crew share. Any captain and crew share beyond that reported in Table 27 is considered part of producer surplus.

Table 27. Trip Expenses (Operating Costs), Vessels Landing Atlantic croaker (2015 dollars)

Expense	**Item**
$167.56	Fuel and Oil
$5.35	Ice
$18.65	Groceries
$100.62	Bait
$5.45	Other
$233.72	Captain and Crew (assumes 1/3 annual captain/crew expense of $14,934 allocated to Atlantic croaker trips, 2/3 to crab pot trips)
$531.34	Total Expenses per Trip (@ 19.57 trips/yr/vessel)

If landings exceed the capacity of the existing vessels operating at the maximum number of trips per year, then additional vessels are added to the fishery to accommodate the increased landings.

Economic results for the Atlantic croaker commercial fishery by scenario, and differences across scenarios, are presented in Tables A24-A25.

Economic Impacts – Recreational Fisheries

The economic analysis estimates the consumer surplus (recreation enjoyment value) of recreational anglers participating in the Atlantic croaker recreational fishery and the economic impacts (sales, income and jobs) supported by the recreational fishing activity. The methodology described for southern flounder is used to estimate the consumer surplus and impacts of the recreational Atlantic croaker fishery.

Estimates of consumer surplus per Atlantic croaker caught by recreational anglers along the U.S. Atlantic Coast are presented in Table 28. The mean of the values in the table, or $8.79 per fish, is used in this study as the consumer surplus per Atlantic croaker caught by recreational anglers.

Table 28. Atlantic croaker-- Consumer Surplus per fish

Source	Estimation Method	Study Location	Year 2015 $'s per fish
Kirkley et al. (1999)	CV (open ended)	VA	$10.10
USEPA (2004)	RUM	NC,SC,GA,FL	$9.07
McConnell and Strand (1994)	CV (dicho-choice)	NY-FL	$3.02
Hicks et al. (1999)	nested RUM	ME-VA	$3.34
Schuhmann (1998)	non-nested RUM	MD,NC	$18.40

The economic impacts of the recreational Atlantic croaker fishery are calculated for four fishing modes: fishing from a beach or bank, fishing from man-made locations (such as a pier or dock), fishing from charter or head boats, and fishing from privately-owned or rental boats. The percent of Atlantic croaker recreational catch by mode (Table 29) is calculated from catch by mode data for Atlantic croaker caught in North Carolina in 2014 (NOAA-NMFS 2016c).

Table 29. Recreational Catch and Trips by Mode—Atlantic croaker

Year	Common Name	Fishing Mode	Total Catch (A+B1+B2)	Pct Catch by Mode	Directed Trips by Mode	Trips per Fish Caught by Mode
2014	ATLANTIC CROAKER	MAN-MADE	1,269,623	0.3900	182,542	0.1438
2014	ATLANTIC CROAKER	BEACH/BANK	396,432	0.1218	76,123	0.1920
2014	ATLANTIC CROAKER	CHARTER BOAT	12,036	0.0037	3,467	0.2881
2014	ATLANTIC CROAKER	PRIVATE/RENTAL BOAT	1,577,353	0.4845	273,049	0.1731

Recreational fish catch is multiplied by trips-per-fish-caught by mode to determine the number of recreational trips by mode. Economic multipliers per recreational trip by mode are multiplied by the number of recreational trips by mode and then summed across modes to calculate direct angler expenditures (direct economic impacts) and total economic impacts (including direct expenditures, and indirect and induced economic impacts) for each year for each scenario. These expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the Atlantic croaker recreational fishery by scenario, and differences across scenarios, are presented in Tables A26-A27.

Discussion

For Atlantic croaker, alternative management scenarios 2-6 decrease commercial fishery landings, producer surplus, and economic impacts. Scenario 5 results in 100 percent commercial fishery losses, with scenarios 2-4 and 6 producing losses ranging from 3 percent (scenario 2) to 39 percent (scenario 4). By contrast, scenarios 7 and 8 produce economic gains for the commercial fishery of 25 percent and 19 percent, respectively. In all scenarios, the numbers of commercial participant fishermen, fishing trips and fishing vessels are not affected, as fishermen continue to land other species in the multi-species fishery. Similar to the commercial fishery, the recreational Atlantic croaker fishery experiences reductions in catch, consumer surplus and economic impacts scenarios 2-6, from 100 percent losses in scenario 5 to only 23 percent losses in scenarios 6. Scenarios 7 and 8 produce gains for the recreational fishery of 25 percent and 21 percent, respectively. Scenarios 7 and 8 produce gains in both commercial producer surplus (19-25 percent gains, $13-17 million) and recreational consumer surplus (21-25 percent gains, $19-22 million).

Eastern Oyster

(*Crassostrea virginica*)[22]

The eastern oyster (*Crassostrea virginica*) occurs naturally along the east coast of North America from Canada to the Gulf of Mexico (NCDMF 2016b). In North Carolina, oysters are found from the southern Albemarle Sound southward through Croatan, Roanoke, and Pamlico sounds and the estuaries of the southern part of the state to the South Carolina border. The Eastern oyster can tolerate a wide range of salinity, temperature, turbidity, and dissolved oxygen levels, making it well adapted to estuarine conditions. In 2013, oysters represented about 4.2 percent of the total value of commercially landed species in North Carolina, making them the fifth most commercially important species in the state (NCDMF 2016b). Oysters are an important source of income for commercial fishermen in winter months when other species are less available.

Oysters are managed under Fishery Management Plans (FMPs) developed by the North Carolina Division of Environmental Quality (NCDEQ) (NCDMF 2016b). These plans are approved and adopted by the North Carolina Marine Fisheries Commission (NCMFC), which subsequently promulgates rules to regulate oyster harvest in coastal waters, including oyster aquaculture. The NCMFC has authority to regulate harvest times, areas, gear, seasons, size limits, and quantities of shellfish harvested and possessed. The NCMFC delegates authority to implement regulations to the North Carolina Division of Marine Fisheries (NCDMF).

The NCDMF has designated Eastern oyster as a species of concern (NCDMF 2016b). North Carolina commercial oyster landings have been in decline for most of the past century. This decline was likely initiated by overharvest and compounded by habitat disturbance, pollution, and biological and environmental stressors (NCDMF 2016b).

[22] Image source: NCDMF 2016b.

There are insufficient data to conduct a traditional stock assessment for the Eastern oyster in North Carolina. Until that time, the NCDMF Oyster Plan Development Team has recommended that the status of Eastern oyster in North Carolina continue to be defined as a species of concern (NCDMF 2016b).

Stock Projection Methods

Oysters typically reach maturity by their second summer season (NCDMF 2016b). A single mature oyster produces between 2 and 45 million eggs per spawn and may spawn more than once per summer season. Oyster larvae may travel up to 30 miles, driven by prevailing currents and flushing rates of estuaries, before attaching to a substrate. Oysters reach marketable size (2.5 inches) in 1.5-2 years in the Gulf of Mexico, 2-3 years in North Carolina, and 4-5 years in Long Island Sound. Given these biological parameters, the present study assumes that oyster recruitment is effectively density-independent and is determined by water/weather conditions and the availability of suitable substrate for larval settlement. The availability of suitable substrate depends on the degree of disturbance of existing public bottom oyster reef habitat by harvesting activities, the extent of oyster reef sanctuary habitat, and the extent of private/leased-bottom oyster aquaculture areas.

Five scenarios are considered. Scenario 1 (status quo / baseline) assumes that the environmental conditions, oyster reef habitat and sanctuary conditions, and private bottom areas in existence in 2014/2015 continue for the model projection period 2017-2046. Scenario 2 assumes that land use policy in coastal areas is successful in reducing runoff/pollutants entering estuarine areas over 10 years to an extent sufficient to reduce Shellfish Prohibited/Restricted Area acreage by 75 percent, opening additional areas to public bottom shellfish culture. Scenario 3 assumes that oyster cultch plantings are increased over 10 years to an extent sufficient to triple yield (oysters per trip) on public bottom. Scenario 4 assumes that North Carolina private/leased oyster production grows at 50 percent of the rate at which Virginia private oyster production grew from 2005 to 2015. In Scenario 4, private/leased bottom acreage increases from 1,677 acres in 2017 to 22,436 acres in 2027 as public bottom decreases from 1,775,255 acres to 1,754,496 acres (a decrease of 1.17 percent). Scenario 5 assumes that North Carolina private/leased oyster production grows at 100 percent of the rate at which Virginia private oyster production grew from 2005 to 2015. In Scenario 5, private/leased bottom acreage increases from 1,677 acres in 2017 to 175,614 acres in 2027 as public bottom decreases from 1,775,255 acres to 1,601,318 acres (a decrease of 9.80 percent).

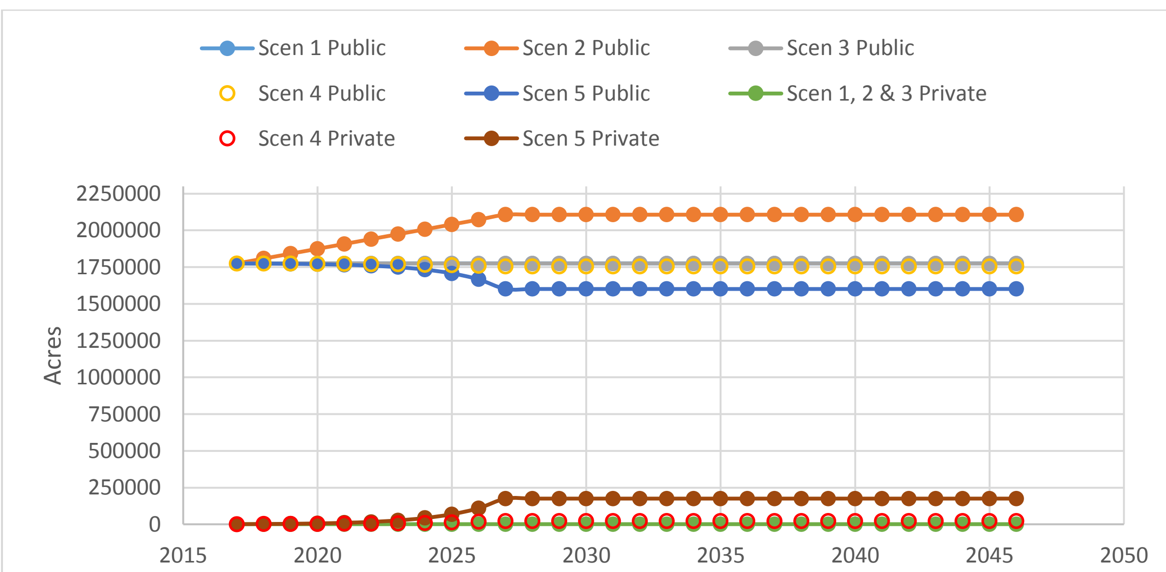
Table 30. Alternative Scenarios for Eastern Oyster in North Carolina.

Scenario	Description
1	Status Quo 2014/2015 (baseline)
2	Reduce runoff/pollutants over 10 years to reduce Shellfish Prohibited/Restricted Area by 75%
3	Increase oyster cultch plantings sufficiently to triple yield (oysters/trip) of public bottom in 10 years
4	NC oyster aquaculture grows next 10 years at 50% of Virginia's aquaculture growth rate 2005 to 2015
5	NC oyster aquaculture grows next 10 years at Virginia's aquaculture growth rate 2005 to 2015

Stock Projection Results

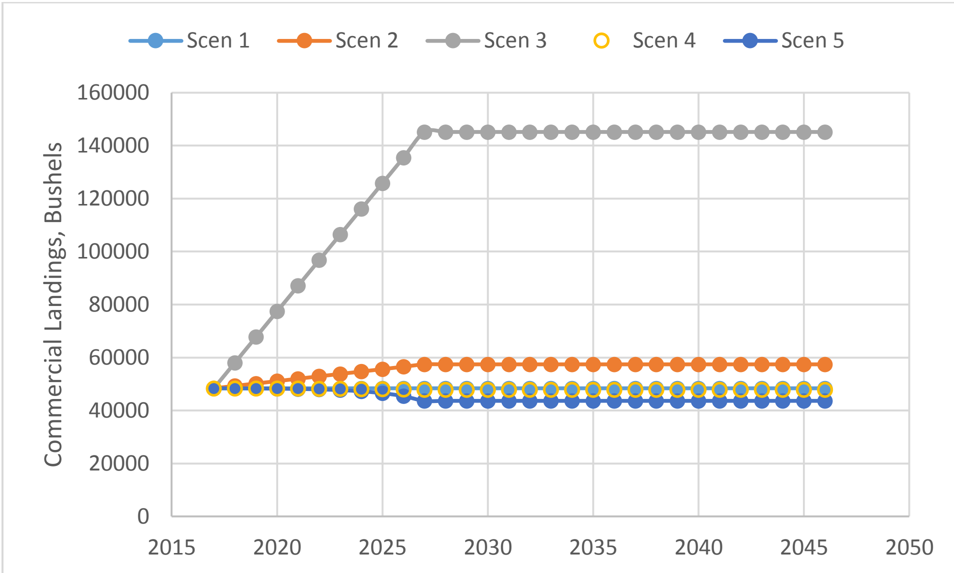
Figure 35 presents oyster public bottom acreage and oyster private/leased bottom acreage under the five management scenarios. Scenario 2 results in an 18.7 percent increase in public bottom acreage, while Scenario 5 results in a 9.8 percent decrease in public bottom acreage, and Scenarios 1, 3 and 4 result in minor or no change in public bottom acreage. Scenario 4 results in a 13-fold increase in private/leased bottom acreage, while Scenario 5 results in a 105-fold increase in private/leased bottom acreage, and Scenarios 1-3 result in no change in private/leased bottom acreage.

Figure 35. Projected Eastern oyster acreage, public vs. private/leased bottom, under five alternative management scenarios.



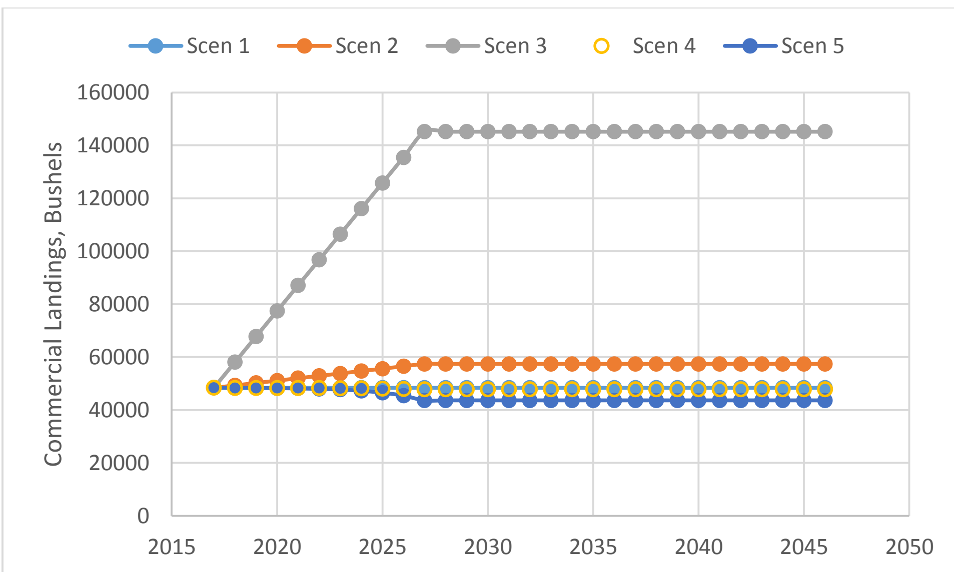
Figures 36 presents commercial oyster harvest (bushels) by hand harvest from public bottom for the five management scenarios under the assumption that hand harvest maintains its approximate 50 percent share of the current (2014-2015) total oyster harvest from public bottom in projection years 2017-2046. Hand harvest from public bottom remains at its baseline level in Scenario 1, increases by 18.7 percent in Scenario 2, increases by 300 percent in Scenario 3, decreases by 1.2 percent in Scenario 4, and decreases by 10.0 percent in Scenario 5.

Figure 36. Projected Eastern oyster hand harvest commercial landings (bushels) under five alternative management scenarios.



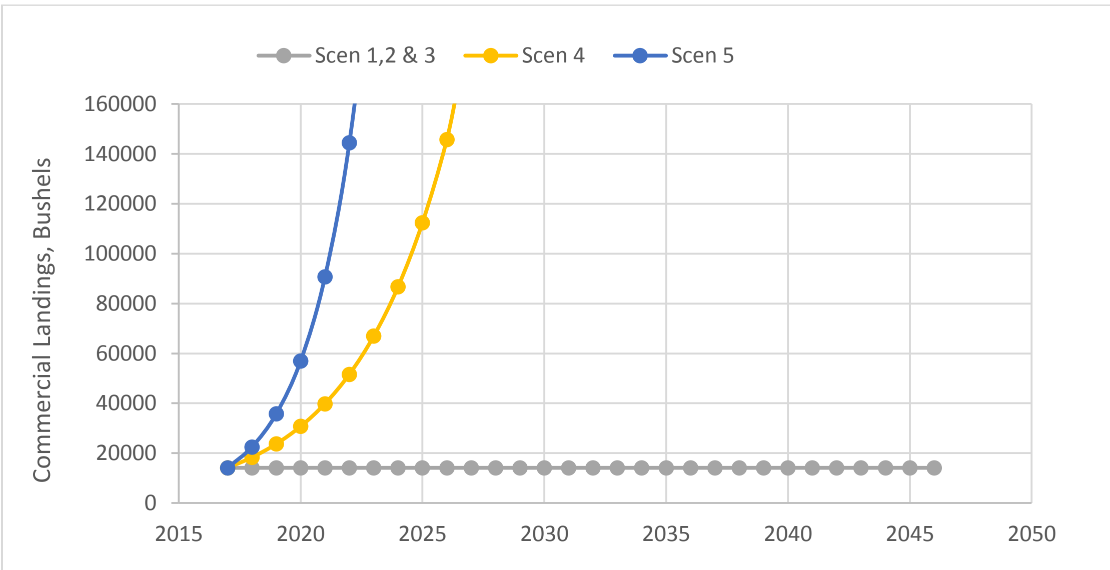
Figures 37 presents commercial oyster harvest (bushels) by mechanical harvest from public bottom for the five management scenarios under the assumption that mechanical harvest maintains its approximate 50 percent share of the current (2014-2015) total oyster harvest from public bottom in projection years 2017-2046. Mechanical harvest from public bottom remains at its baseline level in Scenario 1, increases by 18.7 percent in Scenario 2, increases by 300 percent in Scenario 3, decreases by 1.2 percent in Scenario 4, and decreases by 10.0 percent in Scenario 5.

Figure 37. Projected Eastern oyster mechanical harvest commercial landings (bushels) under five alternative management scenarios.



Figures 38 presents commercial oyster harvest (bushels) from private/leased bottom under the five management scenarios for projection years 2017-2046. Harvest from private/leased bottom remains at its baseline level of 14,123 bushels/yr in Scenarios 1-3, increases by 13-fold in Scenario 4 (to a plateau of 188,948 bushels/yr in 2027), and increases by 105-fold in Scenario 5 (to a plateau of 1,478,946 bushels/yr in 2027).

Figure 38. Projected Eastern oyster private lease aquaculture commercial landings (bushels) under five alternative management scenarios.



Discussion

Relative to results for baseline Scenario 1, Scenario 2 results indicate that reducing runoff/pollutants over 10 years to reduce Shellfish Prohibited/Restricted Area by 75 percent would increase annual oyster harvest from public bottom by less than 20 percent and would likely have little effect on harvest from private/leased bottom. Reducing runoff/pollutants by an amount sufficient to reduce Prohibited/Restricted Area by 75 percent could have high costs relative to the benefit from additional oyster harvest. Of course, increases in the Prohibited/Restricted Area due to increases in runoff/pollutants could negatively affect oyster harvest, but this possibility is not pursued further here.

Results for Scenario 3 indicate that increasing cultch plantings could greatly increase oyster harvest from public bottom. Harvest results for this scenario assume that current regulations on oyster harvest per trip would be relaxed to allow greater landings per trip as oyster production on public bottom increases. In 2015 NCDMF planted 210,272 bushels of cultch material on 41 acres of public bottom (NCCF 2016). Recurring funds for the cultch planting program have been increased to allow NCDMF to more than double its cultch planting effort in 2016. (NCCF 2016). Cultch planting costs per acre are uncertain and could vary widely by location and type of cultch material; however, the economic benefits are potentially large. At a mean population density for cultch-planted sites of 247 oysters per square meter (NCDMF 2016b), 4047 square meters per acre, and 3 years to reach harvestable size, an acre of cultch-planted public bottom could sustainably produce over 300,000 oysters per year. At recent market prices of $0.35 per oyster, an acre of cultch-planted public bottom could produce over $100,000 in revenue per year.

Results for Scenarios 4 and 5 indicate that expanding oyster aquaculture could greatly increase oyster production in North Carolina while requiring less than 10 percent of current public bottom acreage. While such large increases in production have the potential to negatively affect oyster prices, evidence from Virginia indicates that even very large increases in production have had little negative effect on prices (Hudson and Murray 2016.). If mechanical harvesting on the lease site does not pose a threat to critical habitats or nearby resources, aquaculture producers may use mechanical methods to harvest oysters even if public bottom mechanical harvest is prohibited in the general area (NCDMF 2016b). Leaseholders may also harvest oysters during the closed oyster season, and harvest during this period is increasing (NCDMF 2016b).

All Scenarios assume that oyster sanctuary acreage remains at the 2015 level throughout the projection period 2017-2046. As of 2015, the Oyster Sanctuary program consisted of 15 permitted sites, including 13 completed or under development, and two in design (NCDMF 2016b). Existing sanctuaries are spread throughout Pamlico Sound in locations near Pea Island, Hatteras Island, Ocracoke, West Bay, Point of Marsh, Turnagain Bay, Pamlico Point, Deep Bay, Bluff Point, Engelhard, Long Shoal River, Stumpy Point, Roanoke Island. New sanctuaries are planned for the Neuse and Cape Fear rivers. Should oyster sanctuary acreage increase significantly, oyster yield per acre on public bottom could increase significantly relative to the yields assumed in the present study. However, the magnitude of the change in yield is highly uncertain at this time and is not pursued further here.

Economic Impacts – Commercial Fisheries

The economic analysis develops estimates of the producer surplus and economic impacts of commercial oyster harvest for the 30-year projection period 2017-2046. The analysis considers three harvest sectors: hand harvest on public bottom, mechanical harvest on public bottom, and aquaculture production on private/leased bottom. The NCDMF administers a shellfish lease program whereby state residents may apply to lease estuarine bottom and water columns for the commercial (aquaculture/mariculture) production of shellfish (NCDMF 2016b).

All oyster scenarios begin by assuming that the oyster habitat acreage situation in 2017 is equal to the situation in 2014-2015. In 2014-2015 in North Carolina, there were 1,775,255 acres of sound and estuarine oyster habitat open to public harvest ("public bottom") (NCDMF 2016b). There were an additional 1,677 acres in private/lease oyster aquaculture ("private bottom"). In addition, there were 147 acres of completed oyster sanctuary, off limits to harvest. Finally, 442,106 acres were closed to oyster harvest for public health or other reasons.

Commercial oyster harvest from private/leased bottom in 2013 (14,123 bushels) is subtracted from total commercial oyster harvest in 2013 (110,892 bushels) to determine commercial oyster harvest from public bottom in 2013 (96,769 bushels). The major gears used to commercially harvest oysters in NC are oyster hand/tongs/rakes and mechanical methods, primarily oyster dredges. Hand harvest methods have accounted for approximately 50 percent of oyster harvest over the period from 2009 through 2013; hence, approximately 48,384 bushels of acres were harvested by hand and 48,384 bushels were harvested by mechanical methods in 2013. These values are used as the initial, year 2017 annual oyster harvest amounts for public bottom in all five scenarios. Assuming half of the commercial oyster harvest from public bottom in 2013 was harvested by hand and half by mechanical methods, then an average of 0.02725 bushels per acre of public bottom were harvested by either hand or mechanical methods. There is currently a maximum daily harvest limit or 50 bushels per fishing operation on public bottom. On private/leased bottom in year 2013, 14,123 bushels were harvested from 1,677 acres, or 8.42 bushels per acre of private/leased bottom (NCDMF 2016b).

Hand harvest trips on public bottom have averaged 4.25 bushels of oysters per trip in recent years (NCDMF 2016b), while mechanical harvest trips have averaged 7 bushels per trip. Dividing 2013 oyster harvest in bushels by bushels per trip gives estimates of 11,385 hand harvest trips and 6,912 mechanical harvest trips in 2013. These values are used as the initial, year 2017 numbers of hand harvest and mechanical trips in all five scenarios. Although many commercial oyster fishermen participate in multiple fisheries over the course of a typical year, NCDMF (2016b) found that on trips recording landings of oysters in 2013, oysters made up the vast majority (98 percent) of the total ex-vessel value of the trip.

Regression analyses conducted by the authors to assess the potential influence of NC oyster harvest (bushels) on real (inflation-adjusted) ex-vessel oyster price/bushel in NC from 1994 to 2014 found that harvest does not have a statistically significant effect on ex-vessel price (best-fitting model: Real Price = B0 + B1*(Bushels), n = 22, F=0.818, R^2 = 0.0392, t-value of (Bushels) coefficient = 0.904). As additional evidence that oyster price is relatively non-responsive to oyster harvest, the average price per bushel of oysters in Virginia changed little from 2005 to 2015 as oyster harvest and sales by Virginia aquaculture producers increased from 800,000 oysters/year to 35,000,000 oysters/year. The present study uses an average price of $32.00 per bushel based on ex-vessel oyster prices in North Carolina 2011-2015.

For each scenario, commercial oyster harvest (bushels) for each harvest sector and each year 2017 to 2046 is multiplied by the average price per bushel of $32.00/bushel to find real annual ex-vessel/farm gate revenue. (It is assumed that the ex-vessel price rises at the average rate of inflation in the economy as a whole over the projection period 2017-2046.) The average long-run discount rate of r = 0.018 is used to discount nominal ex-vessel revenue to year-2015 present value for each year.[23]

An average of 940 commercial fishermen participated in the oyster fishery on public bottom in 2013-2014 (NCDMF 2016b), with approximately 730 fishermen using hand harvest methods and 210 fishermen using mechanical harvest gear. However, in 2013, across both the hand harvest and mechanical harvest sectors combined, 43 percent of participants earned less than $1,000/year in ex-vessel revenue, while almost half of the oyster harvest value (47 percent) could be attributed to the 107 individuals each recording more than $10,000/year in ex-vessel value of oyster landings. The methods used in this study to estimate the numbers of commercial oyster fishermen attempt to estimate the numbers of fishermen with substantial oyster landings, based on the relationship between fishing jobs supported and ex-vessel revenue for the type of vessels used to land oysters (Crosson 2010). Based on this relationship, approximately 82 jobs (including approximately 52 direct fishing jobs and 30 multiplier effect jobs) were supported by hand harvest landings in 2013, with an additional 82 jobs (including approximately 52 direct fishing jobs and 30 multiplier effect jobs) supported by mechanical harvest landings; these values are used for the number of commercial oyster harvest from public bottom jobs supported in the initial (baseline) year 2017 of the oyster projection scenarios. For the private/leased bottom oyster harvest sector, in 2013 there were 108 private/leased bottom shellfish aquaculture operations in North Carolina (NCDMF 2016b) directly employing an estimated 121 persons (see below). The initial (baseline) year 2017 of the oyster projection scenarios uses 121 jobs as the estimate of direct employment in the private/leased bottom shellfish aquaculture sector in North Carolina (with additional jobs supported by economic multiplier effects, as described below).

Oyster production activity supports both upstream and downstream economic impacts within the state of North Carolina. For example, 183 seafood dealers sold oysters in 2013, with 64 of these dealers reporting oyster sales greater than $10,000 in 2013 (NCDMF 2016b). Upstream and downstream economic impacts are estimated using economic multipliers for each harvest sector, as described below.

For the commercial hand harvest sector, economic impacts are determined by multiplying ex-vessel revenue by total impact multipliers for sales, jobs, and labor income derived from economic impact results for 2009 (deflated to 2015) that reflect smaller gill net, hand, tong, rake vessels (Crosson 2010). Producer surplus per trip is determined by subtracting costs per trip from ex-vessel revenues per trip. Ex-vessel revenues per trip are equal to bushels per hand harvest trip multiplied by ex-vessel price per bushel. Costs per hand harvest trip are assumed to be $60/trip (deflated to 2015) for gasoline only based on Crosson (2010) and Crosson (2007). Producer

[23] Present values are calculated using an average long-run discount rate of r = 0.018; this rate is the average of the long-run rates used by the U.S. Congressional Budget Office (USCBO 2014) (r = 0.022), U.S. Office of Management and Budget (USOMB 2016) (r = 0.015), and U.S. Internal Revenue Service (USIRS 2016) (r = 0.016).

surplus per year for hand harvest trips is determined by multiplying hand harvest producer surplus per trip by hand harvest trips per year.

For the commercial mechanical harvest sector, economic impacts are determined by multiplying ex-vessel revenue by total impact multipliers for sales, jobs, and labor income derived from economic impact results for 2013 (deflated to 2015) that reflect gill net, oyster dredge, shrimp trawl vessels (Hadley and Wiegand 2014). Producer surplus per trip is determined by subtracting costs per trip from ex-vessel revenues per trip. Ex-vessel revenues per trip are equal to bushels per mechanical harvest trip multiplied by ex-vessel price per bushel. Costs per mechanical harvest trip are assumed to be $120.34/trip (deflated to 2015) based on Crosson (2010) and Crosson (2007). Producer surplus per year for mechanical harvest trips is determined by multiplying mechanical harvest producer surplus per trip by mechanical harvest trips per year.

In 2013, the 108 private/leased bottom shellfish aquaculture operations in North Carolina occupied a total of 1,677 acres and produced a total of 14,123 bushels of oysters (NCDMF 2016b). Shellfish leaseholds may produce both oysters and clams. For the period of 2003-2013, roughly 40 percent of all private culture operations harvested only oysters.

Over 90 percent of all shellfish lease applications in North Carolina from 2012-2014 have been for shellfish culture within the water column (as opposed to on the bottom) (NCDMF 2016b). Table 31 presents the estimated costs of growing shellfish in the water column in North Carolina in 2013-2014 (NCDMF 2016b).

Table 31. Oyster Aquaculture Costs (2015 dollars)

Item	Cost
Bottom lease application fee	$200 (one time)
Water column application fee	$100 (one time)
Bottom lease rental fee	$10/acre/year
Seed cost: • one-million 8-15mm seed • one million 15-30mm seed	 $15,444 $30,888
Equipment cost (for one million oysters): • Long-line float bag system: grow out bags, ground tackle/line, buoys, associated gear • Bottom cage system: 700 cages at $80-$150/each	 $41,184 $57,657-$108,107
Optional floating upweller	$3,089-$10,296

For the commercial private/leased bottom aquaculture sector, direct employment is determined by a relationship between oyster aquaculture jobs and farm gate revenue for the Virginia oyster aquaculture industry from 2005-2014. The estimated relationship is: Jobs = 119 + 5.34*(Millions Farm Gate Revenue), n = 10, F=10.584, R^2 = 0.57, t-value of revenue coefficient = 3.253). Multiplier effects on employment are determined by subtracting the direct employment multiplier for jobs from the total employment multiplier for jobs (Murray and Hudson 2013) and multiplying the result by farm gate revenue. Total economic impacts for sales and labor income are determined by multiplying farm gate revenue by total impact multipliers for sales and labor income derived from economic impact results for 2012 for Virginia oyster aquaculture farms (Murray and Hudson 2013).

For the purposes of this study, a producer surplus value of $0.23 per dollar of farm gate oyster revenue is used based on Virginia oyster aquaculture farm operations in 2012 (Murray and Hudson 2013).

Each acre of oyster sanctuary removes nitrogen pollutants from water, valued at $1,741 per year (2015 dollars) (Grabowski et al. 2012). In addition, each acre of oyster sanctuary provides fish habitat that supports an estimated $1,772 per year (2015 dollars) in additional commercial finfish landings (Peterson et al. 2003, Grabowski and Peterson 2007, Grabowski et al. 2012).

Expenditures and impacts (except employment impacts) are discounted to 2015 values and summed across years 2017 to 2046 for each scenario. Employment impacts (number of jobs) are reported for year 2046 for each scenario.

Economic results for the oyster fishery, by harvest sector and by scenario, and differences across scenarios, are presented in Tables A28-A32.

Economic Impacts – Recreational Fisheries

Oysters are commonly harvested recreationally in North Carolina from October to May by hand, rake, and tong. The limit allowed for personal consumption is one bushel of oysters per person, not to exceed two bushels per vessel (NCDMF 2016b).

NCDMF collects data on recreational fishing in conjunction with the federal government's Marine Recreational Information Program (MRIP) (NCDMF 2016b). However, MRIP collects information on finfish only. The state requires a Coastal Recreational Fishing License (CRFL) for recreational saltwater fishing in state waters, but specifically exempts recreational shellfish gathering from this requirement. Currently, the NCDMF has limited data on recreational oyster fishing.

Shellfish gears were not authorized under the Recreational Gear License (RCGL) Program due to the ability of any North Carolina resident to purchase a commercial shellfish license (at a lower cost than a RCGL) to take shellfish in commercial quantities for recreational purposes (NCDMF 2016). As a result, recreational harvest from a commercial shellfish license does not get recorded because it is not sold to a seafood dealer.

Due to these considerations, there is much uncertainty regarding the recreational oyster harvest and associated recreation value in North Carolina, and these issues are not pursued further here.

Discussion

For Eastern oyster, it is assumed in all scenarios for all years 2017-2046 that the percentage of the catch from public bottom taken by hand is approximately 50 percent, the value from 2014-2015, with the remaining 50 percent of the catch from public bottom taken by mechanical gear. Under this assumption, scenario 2 increases harvest, producer surplus and economic impacts in each sector by approximately 15 percent ($3.5 million increase in producer surplus in hand-harvest sector, $2.7 million increase in producer surplus in mechanical harvest sector). Scenario 3 increases harvest and economic impacts by 1.6-fold in each sector, while increasing producer surplus by 3.3-fold ($76 million) in the hand-harvest sector and by 4.3-fold ($76 million) in the mechanical harvest sector. (The mechanical harvest sector has a lower level of producer surplus in the baseline scenario, compared to the hand-harvest sector.) In contrast, scenario 4 reduces harvest, economic impacts and producer surplus by about 1 percent in each sector ($200 thousand loss in producer surplus in the hand-harvest sector, $155 thousand loss in the mechanical harvest sector). Scenario 5 results in a 7 percent decrease in harvest, producer surplus and economic impacts for each sector ($1.6 million reduction in producer surplus for the hand-harvest sector, $1.2 million reduction for the mechanical harvest sector). The private bottom/lease aquaculture sector experiences no change from baseline in alternative scenarios 2 and 3. In scenario 4, the aquaculture sector experiences a 9.3-fold increase in production and an 8.7-fold increase in farm gate revenue and producer surplus ($89 million increase in producer surplus). In scenario 5, the aquaculture sector experiences a 75-fold increase in production and a 69-fold increase in farm gate revenue and producer surplus ($710 million increase in producer surplus). Scenarios 4 and 5 indicate that a $90-$700 million increase in oyster aquaculture producer surplus may be possible with a loss of only $350 thousand - $3.8 million (1-7 percent) in producer surplus in the public bottom sectors combined. If increased cultch plantings on public bottom and increased oyster sanctuary acreage increase the productivity of public bottom, then perhaps the gains in aquaculture sector producer surplus can be had with no net loss of producer surplus in the public bottom sectors. Under all scenarios, oyster sanctuary acreage is assumed to remain at 147 acres (the area existing in 2014-2015). This area supports an estimated $7.8 million/year in additional finfish ex-vessel revenue (finfish nursery area effects) and an estimated $7.7 million/year in water quality improvement value (nitrogen reduction effects). Should oyster sanctuary acreage increase, these benefits would likely increase, as well.

Conclusions

Biological projection models indicated that six of the seven wild stocks considered in this study should increase in abundance or spawning stock biomass if fishing mortality is reduced from status quo levels. The magnitude of the decrease in fishing mortality necessary to elicit meaningful stock increases differed by species, ranging from small (e.g., blue crab) to substantial (e.g., southern flounder). The manner in which fishing mortality reductions are achieved would have significant impacts on the exact response of the stock, time to achieve desired management goals, and ultimate success of any new fishery policies.

One exception to our overarching results was weakfish. Our projections and those of the recent stock assessment indicated that, even in the complete absence of fishing mortality, this stock can barely rebuild unless natural mortality is reduced significantly. Although there is no empirical evidence that natural mortality for weakfish is high, quantitative evidence supporting a plausible alternative explanation has not been identified. Commercial discards of age 0 weakfish have historically been high and likely influenced stock dynamics in the 1980s and 1990s. However, sampling data indicate that total discards have trended downward since the adoption of bycatch reduction devices and policies. Thus, the increasing trend in total weakfish mortality cannot be due to bycatch alone unless commercial sampling is severely biased. Quantification of the source of the current spike in natural mortality and its implications merits investment of scientific resources if this stock is to be rebuilt (see also Report #3: An evaluation of the marine stock assessment program in North Carolina).

Although bycatch may not be the leading cause of recent increases in total mortality for weakfish, our results and those of the most recent stock assessment indicated that bycatch mortality has the potential to significantly impact Atlantic croaker dynamics. Adequate characterization of croaker bycatch, especially in the penaeid shrimp trawl fishery, is a continuing challenge to assessment and management (see also Report #3: An evaluation of the marine stock assessment program in North Carolina). Given many of the largest fisheries in North Carolina use gear that do not exclusively or primarily target their species of interest, increased sampling to better characterize and regulate bycatch across all major fisheries is warranted (see also Report #2: Effects of the shrimp trawl fishery on three non-target stocks in North Carolina: Atlantic croaker, weakfish, and blue crab).

Similar to weakfish, assessment of two other species examined in this study suffer from uncertainty in sources of natural mortality, namely spotted seatrout and Neuse River striped bass. Spotted seatrout experience significant winter die off events during extended harsh winters; however, the exact nature of the stock’s response has not been thoroughly studied or modeled. Also, the Neuse River striped bass stock appears unlikely to rebound without significant reductions in natural and fishing mortality rates. If improvements in the status of these two important stocks are to be achieved, more data and research must be directed to the problem of identifying the exact sources of mortality and how they affect stock dynamics (see also Report #2: Effects of the shrimp trawl fishery on three non-target stocks in North Carolina: Atlantic croaker, weakfish, and blue crab).

Many biological projection scenarios explored in this study predicted both increased stock biomass and increased landings or harvest with reduced fishing mortality rates, resulting in benefits to both the stock and the fisheries; however, this was not true for all species under all scenarios. The range of potential economic effects was large in terms of both direction and magnitude. For a given species, some scenarios increase economic surplus and impacts while others decrease these economic measures. The range in magnitude can be very great, indeed: for weakfish, one scenario reduces commercial catch by 100 percent, while another scenario increases commercial catch by 24-fold. In some cases, the direction of the effect is the same for both the commercial and the recreational sectors, in other cases the effects work in opposite directions.

For some species under some scenarios, such as southern flounder scenarios 6 and 7, economic losses in the commercial sector are more than offset by gains to the recreational sector. In other cases, such as Atlantic croaker scenarios 7 and 8, both commercial and recreational sectors gain. For red drum, both sectors experience economic losses under all scenarios (losses for both sectors are smallest under scenario 2).

The multispecies and multi-gear nature of North Carolina's inshore finfish fisheries combined with, in many cases, considerable excess capacity in catch per trip and catch per vessel per year, imply that changes in fish catch reduce producer surplus and downstream economic impacts (impacts on processors, distributors, grocers and restaurants) proportionately but often have little effect on upstream economic impacts (impacts on fishing vessel suppliers). The number of trips remains relatively constant in the face of changes in landings of a particular species because landings of other species are sufficient to support the trips, sometimes with a gear change. An exception to this pattern is the blue crab fishery, where the number of crab pot gear trips is more likely to change with crab landings, as pot gear is more species-specific and the catch of other, non-crab species is less likely to support pot gear trips in the absence of crab catch.

Economic gains to the state of North Carolina in the southern flounder, weakfish, and blue crab fisheries under some alternative management scenarios could be very large—over $100 million per year. Economic gains to the state from restoring oyster habitat and associated fisheries could approach $75 million per year, and expansion of oyster aquaculture activity on leased bottom could be in the hundreds of millions of dollars per year if industry expansion in the state follows patterns similar to recent patterns in Virginia.

A lack of data for the recreational blue crab and recreational oyster fisheries limited our ability to calculate economic surplus and impacts for these sectors. Additional data collection targeting the recreational sectors of these fisheries would improve assessment efforts.

The analysis and results for each species assume that landings of all other species remain at their baseline levels. Should there be simultaneous, large changes in the landings of multiple species, then the numbers of participating fishermen, trips and vessels could undergo larger changes, as it would become more likely that catch capacities would be exceeded (in the case of larger landings) or vessels would not be able to cover trip costs from landings of substitute species (in the case of smaller landings). The analysis of changes in the landings of multiple species simultaneously is beyond the scope of the present study.

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Appendix

Table A-1. Southern Flounder Commercial Fishery Results 1

Southern Flounder
Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	67,859,027	110	2,346	105
Scenario 2	51,448,673	110	2,346	105
Scenario 3	43,208,457	110	2,346	105
Scenario 4	58,904,324	110	2,346	105
Scenario 5	39,378,874	110	2,346	105
Scenario 6	39,734,023	110	2,346	105
Scenario 7	18,262,622	110	2,346	105
Sc 2 - Sc 1	-16,410,354	0	0	0
Sc 3 - Sc 1	-24,650,570	0	0	0
Sc 4 - Sc 1	-8,954,703	0	0	0
Sc 5 - Sc 1	-28,480,153	0	0	0
Sc 6 - Sc 1	-28,125,005	0	0	0
Sc 7 - Sc 1	-49,596,405	0	0	0

Table A-2. Southern Flounder Commercial Fishery Results 2

Southern Flounder

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$139,860,680	$139,860,680	$349,066,482	$153,397,476	$252,706,412	177
Scenario 2	$105,970,321	$105,970,321	$264,482,392	$116,226,946	$191,471,825	134
Scenario 3	$88,954,869	$88,954,869	$222,014,958	$97,564,607	$160,727,559	113
Scenario 4	$121,371,514	$121,371,514	$302,920,931	$133,118,786	$219,299,376	154
Scenario 5	$81,051,698	$81,051,698	$202,290,101	$88,896,507	$146,447,764	103
Scenario 6	$81,834,869	$81,834,869	$204,244,751	$89,755,479	$147,862,831	104
Scenario 7	$37,612,373	$37,612,373	$93,873,551	$41,252,789	$67,959,686	48
Sc 2 - Sc 1	-$33,890,359	-$33,890,359	-$84,584,090	-$37,170,529	-$61,234,587	-42
Sc 3 - Sc 1	-$50,905,812	-$50,905,812	-$127,051,524	-$55,832,869	-$91,978,854	-64
Sc 4 - Sc 1	-$18,489,166	-$18,489,166	-$46,145,551	-$20,278,690	-$33,407,036	-23
Sc 5 - Sc 1	-$58,808,982	-$58,808,982	-$146,776,381	-$64,500,969	-$106,258,649	-74
Sc 6 - Sc 1	-$58,025,811	-$58,025,811	-$144,821,731	-$63,641,997	-$104,843,582	-73
Sc 7 - Sc 1	-$102,248,307	-$102,248,307	-$255,192,930	-$112,144,687	-$184,746,727	-129

Table A-3. Southern Flounder Recreational Fishery Results 1

Southern Flounder
Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	730,460	627,931	343,958	13,197,409	14,899,758
Scenario 2	720,696	619,538	339,361	13,021,000	14,700,595
Scenario 3	653,586	561,848	307,760	11,808,523	13,331,718
Scenario 4	759,224	652,659	357,503	13,717,108	15,486,495
Scenario 5	614,553	528,294	289,380	11,103,291	12,535,518
Scenario 6	1,092,877	939,480	514,613	19,745,303	22,292,273
Scenario 7	1,676,456	1,441,147	789,409	30,288,986	34,195,998
Sc 2 - Sc 1	-9,764	-8,393	-4,598	-176,408	-199,163
Sc 3 - Sc 1	-76,873	-66,083	-36,198	-1,388,886	-1,568,040
Sc 4 - Sc 1	28,765	24,727	13,545	519,700	586,736
Sc 5 - Sc 1	-115,907	-99,638	-54,578	-2,094,117	-2,364,240
Sc 6 - Sc 1	362,418	311,548	170,655	6,547,894	7,392,515
Sc 7 - Sc 1	945,997	813,216	445,450	17,091,577	19,296,240

Table A-4. Southern Flounder Recreational Fishery Results 2

Southern Flounder Recreational Fishery

Scenario	Cumulative 2017-2046 Angler Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$184,453,754	$829,532,334	$1,012,671,596	$345,491,111	$587,658,606	403
Scenario 2	$181,349,320	$815,570,954	$995,627,905	$339,676,349	$577,768,063	404
Scenario 3	$164,137,123	$738,163,619	$901,131,034	$307,437,044	$522,931,037	370
Scenario 4	$191,381,849	$860,689,619	$1,050,707,602	$358,467,778	$609,731,099	422
Scenario 5	$154,194,738	$693,450,351	$846,546,234	$288,814,458	$491,255,192	349
Scenario 6	$274,988,133	$1,236,686,933	$1,509,715,388	$515,066,531	$876,095,710	612
Scenario 7	$421,999,081	$1,897,830,076	$2,316,821,818	$790,425,392	$1,344,463,779	937
Sc 2 - Sc 1	-$3,104,435	-$13,961,380	-$17,043,691	-$5,814,761	-$9,890,543	1
Sc 3 - Sc 1	-$20,316,631	-$91,368,715	-$111,540,561	-$38,054,067	-$64,727,569	-33
Sc 4 - Sc 1	$6,928,094	$31,157,285	$38,036,006	$12,976,667	$22,072,493	19
Sc 5 - Sc 1	-$30,259,017	-$136,081,983	-$166,125,362	-$56,676,652	-$96,403,413	-53
Sc 6 - Sc 1	$90,534,379	$407,154,599	$497,043,792	$169,575,421	$288,437,104	210
Sc 7 - Sc 1	$237,545,327	$1,068,297,741	$1,304,150,223	$444,934,282	$756,805,173	534

Table A-5. Striped Bass Commercial Fishery Results 1

Striped Bass

Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	236,565	185	3620	168
Scenario 2	246,418	185	3620	168
Scenario 3	258,691	185	3620	168
Scenario 4	256,492	185	3620	168
Scenario 5	192,045	185	3620	168
Scenario 6	95,796	185	3620	168
Sc 2 - Sc 1	9,853	0	0	0
Sc 3 - Sc 1	22,126	0	0	0
Sc 4 - Sc 1	19,926	0	0	0
Sc 5 - Sc 1	-44,521	0	0	0
Sc 6 - Sc 1	-140,770	0	0	0

Table A-6. Striped Bass Commercial Fishery Results 2

Striped Bass

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvester Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$313,531	$313,531	$852,434	$373,959	$605,418	0
Scenario 2	$325,743	$325,743	$885,634	$388,524	$628,998	0
Scenario 3	$340,999	$340,999	$927,114	$406,721	$658,458	1
Scenario 4	$336,306	$336,306	$914,353	$401,123	$649,395	1
Scenario 5	$250,597	$250,597	$681,327	$298,896	$483,894	0
Scenario 6	$126,594	$126,594	$344,186	$150,993	$244,449	0
Sc 2 - Sc 1	$12,211	$12,211	$33,201	$14,565	$23,580	0
Sc 3 - Sc 1	$27,468	$27,468	$74,680	$32,762	$53,039	0
Sc 4 - Sc 1	$22,774	$22,774	$61,919	$27,164	$43,976	0
Sc 5 - Sc 1	-$62,934	-$62,934	-$171,107	-$75,064	-$121,524	0
Sc 6 - Sc 1	-$186,937	-$186,937	-$508,248	-$222,966	-$360,970	0

Table A-7. Striped Bass Recreational Fishery Results 1

Striped Bass

Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	420	0	886	40,441	41,747
Scenario 2	429	0	905	41,278	42,611
Scenario 3	437	0	921	42,048	43,407
Scenario 4	419	0	884	40,354	41,658
Scenario 5	287	0	607	27,677	28,571
Scenario 6	854	0	1,801	82,182	84,837
Sc 2 - Sc 1	9	0	18	837	864
Sc 3 - Sc 1	17	0	35	1,607	1,659
Sc 4 - Sc 1	-1	0	-2	-87	-90
Sc 5 - Sc 1	-133	0	-280	-12,765	-13,177
Sc 6 - Sc 1	434	0	915	41,741	43,090

Table A-8. Striped Bass Recreational Fishery Results 2

Striped Bass

Recreational Fishery

Scenario	Cumulative 2017-2046 Angler Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$259,033	$769,261	$921,180	$310,747	$532,165	0
Scenario 2	$264,176	$784,534	$939,470	$316,917	$542,731	0
Scenario 3	$268,642	$797,795	$955,350	$322,274	$551,905	0
Scenario 4	$257,206	$763,834	$914,682	$308,555	$528,412	0
Scenario 5	$175,748	$521,925	$624,999	$210,834	$361,061	0
Scenario 6	$523,525	$1,554,732	$1,861,773	$628,043	$1,075,545	1
Sc 2 - Sc 1	$5,143	$15,273	$18,290	$6,170	$10,566	0
Sc 3 - Sc 1	$9,608	$28,535	$34,170	$11,527	$19,740	0
Sc 4 - Sc 1	-$1,827	-$5,426	-$6,498	-$2,192	-$3,754	0
Sc 5 - Sc 1	-$83,285	-$247,336	-$296,182	-$99,913	-$171,104	0
Sc 6 - Sc 1	$264,492	$785,472	$940,593	$317,296	$543,380	0

Table A-9. Weakfish Commercial Fishery Results 1

Weakfish

Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	7,125,165	1,340	26,228	1,214
Scenario 2	0	1,340	26,228	1,214
Scenario 3	42,393,709	1,340	26,228	1,214
Scenario 4	39,909,418	1,340	26,228	1,214
Scenario 5	35,632,008	1,340	26,228	1,214
Scenario 6	26,756,388	1,340	26,228	1,214
Scenario 7	0	1,340	26,228	1,214
Scenario 8	227,623,140	1,340	26,228	1,214
Scenario 9	164,185,638	1,340	26,228	1,214
Sc 2 - Sc 1	-7,125,165	0	0	0
Sc 3 - Sc 1	35,268,544	0	0	0
Sc 4 - Sc 1	32,784,253	0	0	0
Sc 5 - Sc 1	28,506,843	0	0	0
Sc 6 - Sc 1	19,631,223	0	0	0
Sc 7 - Sc 1	-7,125,165	0	0	0
Sc 8 - Sc 1	220,497,975	0	0	0
Sc 9 - Sc 1	157,060,473	0	0	0

Table A-10. Weakfish Commercial Fishery Results 2

Weakfish

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$5,165,508	$5,165,508	$14,044,059	$6,161,076	$9,974,420	8
Scenario 2	$0	$0	$0	$0	$0	0
Scenario 3	$24,989,274	$24,989,274	$67,941,207	$29,805,552	$48,253,436	44
Scenario 4	$23,568,824	$23,568,824	$64,079,266	$28,111,333	$45,510,595	42
Scenario 5	$21,130,359	$21,130,359	$57,449,532	$25,202,894	$40,802,003	38
Scenario 6	$16,091,740	$16,091,740	$43,750,459	$19,193,162	$31,072,601	29
Scenario 7	$0	$0	$0	$0	$0	0
Scenario 8	$126,933,752	$126,933,752	$345,109,356	$151,398,178	$245,104,746	258
Scenario 9	$91,186,625	$91,186,625	$247,919,539	$108,761,370	$176,078,262	196
Sc 2 - Sc 1	-$5,165,508	-$5,165,508	-$14,044,059	-$6,161,076	-$9,974,420	-8
Sc 3 - Sc 1	$19,823,766	$19,823,766	$53,897,148	$23,644,476	$38,279,016	37
Sc 4 - Sc 1	$18,403,316	$18,403,316	$50,035,207	$21,950,257	$35,536,176	34
Sc 5 - Sc 1	$15,964,851	$15,964,851	$43,405,472	$19,041,818	$30,827,583	30
Sc 6 - Sc 1	$10,926,232	$10,926,232	$29,706,400	$13,032,086	$21,098,181	21
Sc 7 - Sc 1	-$5,165,508	-$5,165,508	-$14,044,059	-$6,161,076	-$9,974,420	-8
Sc 8 - Sc 1	$121,768,244	$121,768,244	$331,065,297	$145,237,102	$235,130,326	251
Sc 9 - Sc 1	$86,021,117	$86,021,117	$233,875,480	$102,600,294	$166,103,842	188

Table A-11. Weakfish Recreational Fishery Results 1

Weakfish

Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	489,479	36,197	47,192	1,673,737	2,246,605
Scenario 2	0	0	0	0	0
Scenario 3	1,871,683	138,412	180,453	6,400,074	8,590,622
Scenario 4	1,728,661	127,836	166,664	5,911,021	7,934,182
Scenario 5	1,498,823	110,839	144,505	5,125,108	6,879,274
Scenario 6	1,069,991	79,127	103,160	3,658,751	4,911,029
Scenario 7	0	0	0	0	0
Scenario 8	6,014,045	444,744	579,827	20,564,563	27,603,179
Scenario 9	3,794,127	280,579	365,800	12,973,726	17,414,232
Sc 2 - Sc 1	-489,479	-36,197	-47,192	-1,673,737	-2,246,605
Sc 3 - Sc 1	1,382,203	102,215	133,261	4,726,338	6,344,017
Sc 4 - Sc 1	1,239,181	91,638	119,472	4,237,285	5,687,577
Sc 5 - Sc 1	1,009,343	74,642	97,313	3,451,371	4,632,669
Sc 6 - Sc 1	580,512	42,929	55,968	1,985,015	2,664,424
Sc 7 - Sc 1	-489,479	-36,197	-47,192	-1,673,737	-2,246,605
Sc 8 - Sc 1	5,524,566	408,546	532,635	18,890,826	25,356,573
Sc 9 - Sc 1	3,304,648	244,381	318,608	11,299,989	15,167,627

Table A-12. Weakfish Recreational Fishery Results 2

Weakfish

Recreational Fishery

Scenario	Cumulative 2017-2046 Angler Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$21,059,733	$36,420,049	$47,279,911	$16,555,956	$27,682,822	20
Scenario 2	$0	$0	$0	$0	$0	0
Scenario 3	$78,888,983	$136,428,161	$177,108,801	$62,018,000	$103,698,830	82
Scenario 4	$72,830,729	$125,951,203	$163,507,786	$57,255,348	$95,735,311	76
Scenario 5	$63,107,949	$109,136,930	$141,679,772	$49,611,855	$82,954,809	66
Scenario 6	$45,003,041	$77,826,864	$101,033,558	$35,378,814	$59,156,077	47
Scenario 7	$0	$0	$0	$0	$0	0
Scenario 8	$249,544,127	$431,553,875	$560,236,162	$196,177,301	$328,023,421	284
Scenario 9	$156,460,371	$270,577,713	$351,259,550	$123,000,183	$205,665,694	187
Sc 2 - Sc 1	-$21,059,733	-$36,420,049	-$47,279,911	-$16,555,956	-$27,682,822	-20
Sc 3 - Sc 1	$57,829,250	$100,008,112	$129,828,890	$45,462,044	$76,016,008	62
Sc 4 - Sc 1	$51,770,995	$89,531,154	$116,227,876	$40,699,392	$68,052,489	56
Sc 5 - Sc 1	$42,048,216	$72,716,880	$94,399,861	$33,055,899	$55,271,986	46
Sc 6 - Sc 1	$23,943,308	$41,406,815	$53,753,647	$18,822,858	$31,473,255	28
Sc 7 - Sc 1	-$21,059,733	-$36,420,049	-$47,279,911	-$16,555,956	-$27,682,822	-20
Sc 8 - Sc 1	$228,484,394	$395,133,825	$512,956,251	$179,621,345	$300,340,599	265
Sc 9 - Sc 1	$135,400,638	$234,157,664	$303,979,639	$106,444,227	$177,982,872	167

Table A-13. Spotted Seatrout Commercial Fishery Results 1

Spotted Seatrout

Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	2,594,816	1,340	26,228	1,214
Scenario 2	2,614,606	1,340	26,228	1,214
Scenario 3	2,629,485	1,340	26,228	1,214
Scenario 4	2,548,125	1,340	26,228	1,214
Scenario 5	2,066,290	1,340	26,228	1,214
Scenario 6	0	1,340	26,228	1,214
Scenario 7	3,047,587	1,340	26,228	1,214
Scenario 8	3,053,026	1,340	26,228	1,214
Scenario 9	2,225,765	1,340	26,228	1,214
Scenario 10	2,482,234	1,340	26,228	1,214
Scenario 11	2,814,012	1,340	26,228	1,214
Scenario 12	2,988,085	1,340	26,228	1,214
Scenario 13	2,230,708	1,340	26,228	1,214
Scenario 14	0	1,340	26,228	1,214
Sc 2 - Sc 1	19,790	0	0	0
Sc 3 - Sc 1	34,669	0	0	0
Sc 4 - Sc 1	-46,690	0	0	0
Sc 5 - Sc 1	-528,526	0	0	0
Sc 6 - Sc 1	-2,594,816	0	0	0
Sc 7 - Sc 1	452,771	0	0	0
Sc 8 - Sc 1	458,211	0	0	0
Sc 9 - Sc 1	-369,051	0	0	0
Sc 10 - Sc 1	-112,582	0	0	0
Sc 11 - Sc 1	219,196	0	0	0
Sc 12 - Sc 1	393,269	0	0	0
Sc 13 - Sc 1	-364,108	0	0	0
Sc 14 - Sc 1	-2,594,816	0	0	0

Table A-14. Spotted Seatrout Commercial Fishery Results 2

Spotted Seatrout

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$4,347,673	$4,347,673	$11,820,517	$5,185,617	$8,395,208	7
Scenario 2	$4,380,288	$4,380,288	$11,909,191	$5,224,517	$8,458,186	7
Scenario 3	$4,404,433	$4,404,433	$11,974,837	$5,253,316	$8,504,810	7
Scenario 4	$4,263,940	$4,263,940	$11,592,863	$5,085,745	$8,233,523	6
Scenario 5	$3,451,227	$3,451,227	$9,383,246	$4,116,395	$6,664,201	5
Scenario 6	$0	$0	$0	$0	$0	0
Scenario 7	$5,104,005	$5,104,005	$13,876,845	$6,087,720	$9,855,660	8
Scenario 8	$5,112,895	$5,112,895	$13,901,013	$6,098,322	$9,872,825	8
Scenario 9	$3,678,513	$3,678,513	$10,001,195	$4,387,487	$7,103,083	6
Scenario 10	$4,097,682	$4,097,682	$11,140,838	$4,887,444	$7,912,484	7
Scenario 11	$4,649,319	$4,649,319	$12,640,638	$5,545,400	$8,977,677	8
Scenario 12	$4,957,395	$4,957,395	$13,478,239	$5,912,853	$9,572,561	8
Scenario 13	$3,725,220	$3,725,220	$10,128,182	$4,443,196	$7,193,272	6
Scenario 14	$0	$0	$0	$0	$0	0
Sc 2 - Sc 1	$32,615	$32,615	$88,674	$38,901	$62,978	0
Sc 3 - Sc 1	$56,760	$56,760	$154,320	$67,699	$109,601	0
Sc 4 - Sc 1	-$83,733	-$83,733	-$227,655	-$99,871	-$161,686	0
Sc 5 - Sc 1	-$896,446	-$896,446	-$2,437,272	-$1,069,222	-$1,731,007	-1
Sc 6 - Sc 1	-$4,347,673	-$4,347,673	-$11,820,517	-$5,185,617	-$8,395,208	-7
Sc 7 - Sc 1	$756,332	$756,332	$2,056,328	$902,103	$1,460,452	1
Sc 8 - Sc 1	$765,222	$765,222	$2,080,496	$912,706	$1,477,617	1
Sc 9 - Sc 1	-$669,160	-$669,160	-$1,819,322	-$798,130	-$1,292,125	0
Sc 10 - Sc 1	-$249,991	-$249,991	-$679,680	-$298,173	-$482,725	0
Sc 11 - Sc 1	$301,646	$301,646	$820,121	$359,784	$582,469	1
Sc 12 - Sc 1	$609,722	$609,722	$1,657,722	$727,236	$1,177,353	1
Sc 13 - Sc 1	-$622,453	-$622,453	-$1,692,335	-$742,421	-$1,201,936	-1
Sc 14 - Sc 1	-$4,347,673	-$4,347,673	-$11,820,517	-$5,185,617	-$8,395,208	-7

Table A-15. Spotted Seatrout Recreational Fishery Results 1

Spotted Seatrout

Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	1,342,061	945,541	144,265	9,023,165	11,455,032
Scenario 2	1,287,914	907,393	138,444	8,659,118	10,992,869
Scenario 3	1,195,570	842,332	128,518	8,038,251	10,204,670
Scenario 4	995,804	701,588	107,044	6,695,150	8,499,585
Scenario 5	678,044	477,712	72,886	4,558,735	5,787,376
Scenario 6	0	0	0	0	0
Scenario 7	968,207	682,145	104,077	6,509,610	8,264,039
Scenario 8	966,833	681,177	103,930	6,500,373	8,252,313
Scenario 9	1,157,622	815,596	124,439	7,783,115	9,880,771
Scenario 10	1,230,741	867,111	132,299	8,274,720	10,504,871
Scenario 11	1,288,997	908,155	138,561	8,666,395	11,002,107
Scenario 12	1,175,541	828,220	126,365	7,903,589	10,033,715
Scenario 13	734,221	517,291	78,925	4,936,435	6,266,872
Scenario 14	0	0	0	0	0
Sc 2 - Sc 1	-54,147	-38,149	-5,820	-364,047	-462,163
Sc 3 - Sc 1	-146,491	-103,210	-15,747	-984,914	-1,250,362
Sc 4 - Sc 1	-346,257	-243,954	-37,221	-2,328,015	-2,955,447
Sc 5 - Sc 1	-664,017	-467,830	-71,379	-4,464,430	-5,667,656
Sc 6 - Sc 1	-1,342,061	-945,541	-144,265	-9,023,165	-11,455,032
Sc 7 - Sc 1	-373,854	-263,397	-40,187	-2,513,555	-3,190,993
Sc 8 - Sc 1	-375,228	-264,364	-40,335	-2,522,792	-3,202,719
Sc 9 - Sc 1	-184,439	-129,945	-19,826	-1,240,050	-1,574,261
Sc 10 - Sc 1	-111,320	-78,430	-11,966	-748,445	-950,161
Sc 11 - Sc 1	-53,064	-37,386	-5,704	-356,770	-452,925
Sc 12 - Sc 1	-166,520	-117,321	-17,900	-1,119,576	-1,421,317
Sc 13 - Sc 1	-607,840	-428,250	-65,340	-4,086,730	-5,188,160
Sc 14 - Sc 1	-1,342,061	-945,541	-144,265	-9,023,165	-11,455,032

Table A-16. Spotted Seatrout Recreational Fishery Results 2

Spotted Seatrout

Recreational Fishery

Scenario	Cumulative 2017-2046 Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$115,535,021	$159,474,023	$199,846,366	$67,324,806	$114,765,259	82
Scenario 2	$110,866,562	$153,030,107	$191,771,113	$64,604,392	$110,127,904	78
Scenario 3	$102,901,827	$142,036,313	$177,994,137	$59,963,165	$102,216,235	73
Scenario 4	$85,664,416	$118,243,360	$148,177,775	$49,918,546	$85,093,670	61
Scenario 5	$58,250,261	$80,403,357	$100,758,220	$33,943,712	$57,862,164	42
Scenario 6	$0	$0	$0	$0	$0	0
Scenario 7	$83,323,894	$115,012,716	$144,129,263	$48,554,671	$82,768,741	59
Scenario 8	$83,205,528	$114,849,335	$143,924,520	$48,485,697	$82,651,164	59
Scenario 9	$98,379,539	$135,794,157	$170,171,721	$57,327,928	$97,724,076	76
Scenario 10	$104,508,555	$144,254,093	$180,773,369	$60,899,441	$103,812,257	80
Scenario 11	$109,589,380	$151,267,202	$189,561,912	$63,860,150	$108,859,231	83.0
Scenario 12	$100,413,158	$138,601,181	$173,689,369	$58,512,963	$99,744,147	73.7
Scenario 13	$63,123,586	$87,130,051	$109,187,840	$36,783,507	$62,703,020	44.8
Scenario 14	$0	$0	$0	$0	$0	0
Sc 2 - Sc 1	-$4,668,459	-$6,443,916	-$8,075,253	-$2,720,414	-$4,637,355	-3
Sc 3 - Sc 1	-$12,633,193	-$17,437,710	-$21,852,229	-$7,361,640	-$12,549,024	-9
Sc 4 - Sc 1	-$29,870,605	-$41,230,663	-$51,668,591	-$17,406,260	-$29,671,589	-21
Sc 5 - Sc 1	-$57,284,760	-$79,070,666	-$99,088,146	-$33,381,093	-$56,903,095	-40
Sc 6 - Sc 1	-$115,535,021	-$159,474,023	-$199,846,366	-$67,324,806	-$114,765,259	-82
Sc 7 - Sc 1	-$32,211,127	-$44,461,307	-$55,717,104	-$18,770,135	-$31,996,518	-23
Sc 8 - Sc 1	-$32,329,493	-$44,624,688	-$55,921,846	-$18,839,109	-$32,114,095	-23
Sc 9 - Sc 1	-$17,155,482	-$23,679,866	-$29,674,645	-$9,996,878	-$17,041,182	-6
Sc 10 - Sc 1	-$11,026,466	-$15,219,930	-$19,072,998	-$6,425,365	-$10,953,001	-1
Sc 11 - Sc 1	-$5,945,641	-$8,206,821	-$10,284,455	-$3,464,656	-$5,906,027	1.4
Sc 12 - Sc 1	-$15,121,862	-$20,872,842	-$26,156,998	-$8,811,843	-$15,021,112	-7.8
Sc 13 - Sc 1	-$52,411,434	-$72,343,972	-$90,658,526	-$30,541,299	-$52,062,239	-36.8
Sc 14 - Sc 1	-$115,535,021	-$159,474,023	-$199,846,366	-$67,324,806	-$114,765,259	-82

Table A-17. Red Drum Commercial Fishery Results 1

Red Drum

Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	5,284,793	1,340	26,228	1,214
Scenario 2	4,984,797	1,340	26,228	1,214
Scenario 3	4,463,237	1,340	26,228	1,214
Scenario 4	3,364,287	1,340	26,228	1,214
Scenario 5	0	1,340	26,228	1,214
Sc 2 - Sc 1	-299,996	0	0	0
Sc 3 - Sc 1	-821,556	0	0	0
Sc 4 - Sc 1	-1,920,506	0	0	0
Sc 5 - Sc 1	-5,284,793	0	0	0

Table A-18. Red Drum Commercial Fishery Results 2

Red Drum

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$8,367,792	$8,367,792	$22,750,476	$9,980,548	$16,157,921	13
Scenario 2	$7,892,229	$7,892,229	$21,457,508	$9,413,328	$15,239,625	12
Scenario 3	$7,066,050	$7,066,050	$19,211,281	$8,427,917	$13,644,302	11
Scenario 4	$5,325,389	$5,325,389	$14,478,745	$6,351,771	$10,283,144	8
Scenario 5	$0	$0	$0	$0	$0	0
Sc 2 - Sc 1	-$475,563	-$475,563	-$1,292,968	-$567,220	-$918,296	-1
Sc 3 - Sc 1	-$1,301,742	-$1,301,742	-$3,539,195	-$1,552,631	-$2,513,619	-2
Sc 4 - Sc 1	-$3,042,403	-$3,042,403	-$8,271,731	-$3,628,777	-$5,874,777	-5
Sc 5 - Sc 1	-$8,367,792	-$8,367,792	-$22,750,476	-$9,980,548	-$16,157,921	-13

Table A-19. Red Drum Recreational Fishery Results 1

Red Drum

Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	107,804	366,240	64,073	965,980	1,504,097
Scenario 2	101,114	343,513	60,097	906,037	1,410,761
Scenario 3	89,764	304,953	53,351	804,333	1,252,401
Scenario 4	66,646	226,415	39,611	597,183	929,855
Scenario 5	0	0	0	0	0
Sc 2 - Sc 1	-6,690	-22,727	-3,976	-59,943	-93,336
Sc 3 - Sc 1	-18,040	-61,287	-10,722	-161,647	-251,696
Sc 4 - Sc 1	-41,158	-139,825	-24,462	-368,797	-574,242
Sc 5 - Sc 1	-107,804	-366,240	-64,073	-965,980	-1,504,097

Table A-20. Red Drum Recreational Fishery Results 2

Red Drum

Recreational Fishery

Scenario	Cumulative 2017-2046 Angler Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$13,606,198	$45,810,402	$60,246,663	$21,564,222	$35,700,873	25
Scenario 2	$12,761,750	$42,967,247	$56,507,543	$20,225,870	$33,485,152	23
Scenario 3	$11,329,853	$38,146,225	$50,167,269	$17,956,482	$29,728,042	21
Scenario 4	$8,411,358	$28,320,010	$37,244,512	$13,331,011	$22,070,295	15
Scenario 5	$0	$0	$0	$0	$0	0
Sc 2 - Sc 1	-$844,448	-$2,843,154	-$3,739,119	-$1,338,351	-$2,215,722	-2
Sc 3 - Sc 1	-$2,276,346	-$7,664,176	-$10,079,393	-$3,607,740	-$5,972,831	-4
Sc 4 - Sc 1	-$5,194,841	-$17,490,392	-$23,002,150	-$8,233,211	-$13,630,578	-10
Sc 5 - Sc 1	-$13,606,198	-$45,810,402	-$60,246,663	-$21,564,222	-$35,700,873	-25

Table A-21. Blue Crab Commercial Fishery Results 1

Blue Crab
Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	992,063,283	975	50,525	813
Scenario 2	1,162,837,422	975	52,724	813
Scenario 3	897,907,323	975	50,525	813
Scenario 4	0	975	0	813
Scenario 5	0	975	0	813
Sc 2 - Sc 1	170,774,139	0	2,199	0
Sc 3 - Sc 1	-94,155,960	0	0	0
Sc 4 - Sc 1	-992,063,283	0	-50,525	0
Sc 5 - Sc 1	-992,063,283	0	-50,525	0

Table A-22. Blue Crab Commercial Fishery Results 2

Blue Crab

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$237,685,866	$800,151,469	$1,867,236,506	$650,847,816	$1,031,696,675	1,685
Scenario 2	$349,678,391	$933,893,096	$2,539,856,006	$809,681,849	$1,405,717,805	1,944
Scenario 3	$160,644,442	$723,110,045	$1,687,452,346	$571,726,621	$899,450,744	1,606
Scenario 4	$0	$0	$0	$0	$0	813
Scenario 5	$0	$0	$0	$0	$0	813
Sc 2 - Sc 1	$111,992,525	$133,741,627	$672,619,500	$158,834,033	$374,021,130	260
Sc 3 - Sc 1	-$77,041,424	-$77,041,424	-$179,784,159	-$79,121,195	-$132,245,931	-79
Sc 4 - Sc 1	-$237,685,866	-$800,151,469	-$1,867,236,506	-$650,847,816	-$1,031,696,675	-872
Sc 5 - Sc 1	-$237,685,866	-$800,151,469	-$1,867,236,506	-$650,847,816	-$1,031,696,675	-872

Table A-23. Blue Crab Recreational Commercial Gear Fishery Results

Blue Crab

Recreational Commercial Gear Fishery

Scenario	Cumulative 2017-2046 RCGL Catch Total Pounds	Cumulative 2017-2046 RCGL Consumer Surplus 2015 $'s	Cumulative 2017-2046 RCGL Direct Expenditures PV 2015 $'s	Cumulative 2017-2046 RCGL Total Sales Impacts PV 2015 $'s	In year 2046 Total Employment Impacts (Jobs)
Scenario 1	10,020,841	N/A	$145,026,444	$207,944,959	49
Scenario 2	11,745,833	N/A	$149,814,244	$214,809,906	51
Scenario 3	9,069,772	N/A	$141,797,599	$203,315,306	48
Scenario 4	5,039,018	N/A	$123,278,224	$176,761,455	41
Scenario 5	0	N/A	$0	$0	0
Sc 2 - Sc 1	1,724,992	N/A	$4,787,800	$6,864,948	2
Sc 3 - Sc 1	-951,070	N/A	-$3,228,845	-$4,629,652	-1
Sc 4 - Sc 1	-4,981,823	N/A	-$21,748,219	-$31,183,503	-9
Sc 5 - Sc 1	-10,020,841	N/A	-$145,026,444	-$207,944,959	-49

N/A = Not available.

Table A-24. Atlantic Croaker Commercial Fishery Results 1

Atlantic Croaker

Commercial Fishery

Scenario	Cumulative 2017-2046 Landings Pounds	Vessels in yr 2046	Trips in yr 2046	Participants in yr 2046
Scenario 1	300,276,448	1,340	26,228	1,214
Scenario 2	291,759,772	1,340	26,228	1,214
Scenario 3	255,128,065	1,340	26,228	1,214
Scenario 4	184,589,642	1,340	26,228	1,214
Scenario 5	0	1,340	26,228	1,214
Scenario 6	233,939,181	1,340	26,228	1,214
Scenario 7	377,701,630	1,340	26,228	1,214
Scenario 8	362,673,857	1,340	26,228	1,214
Sc 2 - Sc 1	-8,516,676	0	0	0
Sc 3 - Sc 1	-45,148,383	0	0	0
Sc 4 - Sc 1	-115,686,806	0	0	0
Sc 5 - Sc 1	-300,276,448	0	0	0
Sc 6 - Sc 1	-66,337,267	0	0	0
Sc 7 - Sc 1	77,425,182	0	0	0
Sc 8 - Sc 1	62,397,409	0	0	0

Table A-25. Atlantic Croaker Commercial Fishery Results 2

Atlantic Croaker

Commercial Fishery

Scenario	Cumulative 2017-2046 Harvesters Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Ex-Vessel Revenue PV 2015 $'s	Cumulative 2017-2046 Total Impact Sales PV 2015 $'s	Cumulative 2017-2046 Total Impact Labor Income PV 2015 $'s	Cumulative 2017-2046 Total Impact Value Added PV 2015 $'s	In yr 2046 Total Impact Employment (jobs)
Scenario 1	$70,523,758	$70,523,758	$191,741,031	$84,116,070	$136,178,970	105
Scenario 2	$68,350,643	$68,350,643	$185,832,736	$81,524,123	$131,982,761	104
Scenario 3	$59,680,283	$59,680,283	$162,259,633	$71,182,691	$115,240,591	91
Scenario 4	$43,072,347	$43,072,347	$117,105,731	$51,373,844	$83,171,232	67
Scenario 5	$0	$0	$0	$0	$0	0
Scenario 6	$55,067,265	$55,067,265	$149,717,691	$65,680,589	$106,333,010	81
Scenario 7	$87,817,421	$87,817,421	$238,759,299	$104,742,807	$169,572,445	140
Scenario 8	$83,712,313	$83,712,313	$227,598,271	$99,846,506	$161,645,622	139
Sc 2 - Sc 1	-$2,173,114	-$2,173,114	-$5,908,295	-$2,591,947	-$4,196,210	-2
Sc 3 - Sc 1	-$10,843,475	-$10,843,475	-$29,481,399	-$12,933,379	-$20,938,380	-14
Sc 4 - Sc 1	-$27,451,411	-$27,451,411	-$74,635,300	-$32,742,226	-$53,007,738	-38
Sc 5 - Sc 1	-$70,523,758	-$70,523,758	-$191,741,031	-$84,116,070	-$136,178,970	-105
Sc 6 - Sc 1	-$15,456,493	-$15,456,493	-$42,023,340	-$18,435,482	-$29,845,960	-24
Sc 7 - Sc 1	$17,293,664	$17,293,664	$47,018,268	$20,626,737	$33,393,475	34
Sc 8 - Sc 1	$13,188,556	$13,188,556	$35,857,240	$15,730,436	$25,466,651	34

Table A-26. Atlantic Croaker Recreational Fishery Results 1

Atlantic Croaker

Recreational Fishery

Scenario	Cumulative 2017-2046 Catch Man-Made (fish)	Cumulative 2017-2046 Catch Beach/Bank (fish)	Cumulative 2017-2046 Catch Charter Boat (fish)	Cumulative 2017-2046 Catch Private/Rental Boat (fish)	Cumulative 2017-2046 Catch Total (fish)
Scenario 1	5,150,271	1,608,140	48,824	6,398,588	13,205,824
Scenario 2	3,798,994	1,186,213	36,014	4,719,790	9,741,011
Scenario 3	3,281,101	1,024,504	31,105	4,076,371	8,413,081
Scenario 4	2,324,395	725,778	22,035	2,887,780	5,959,988
Scenario 5	0	0	0	0	0
Scenario 6	3,950,301	1,233,457	37,449	4,907,771	10,128,977
Scenario 7	6,499,696	2,029,490	61,617	8,075,087	16,665,890
Scenario 8	6,323,203	1,974,381	59,944	7,855,815	16,213,343
Sc 2 - Sc 1	-1,351,277	-421,928	-12,810	-1,678,798	-3,464,813
Sc 3 - Sc 1	-1,869,170	-583,637	-17,720	-2,322,217	-4,792,743
Sc 4 - Sc 1	-2,825,876	-882,362	-26,789	-3,510,809	-7,245,836
Sc 5 - Sc 1	-5,150,271	-1,608,140	-48,824	-6,398,588	-13,205,824
Sc 6 - Sc 1	-1,199,970	-374,683	-11,376	-1,490,818	-3,076,847
Sc 7 - Sc 1	1,349,426	421,350	12,793	1,676,498	3,460,066
Sc 8 - Sc 1	1,172,932	366,241	11,119	1,457,226	3,007,518

Table A-27. Atlantic Croaker Recreational Fishery Results 2

Atlantic Croaker

Recreational Fishery

Scenario	Cumulative 2017-2046 Angler Consumer Surplus PV 2015 $'s	Cumulative 2017-2046 Direct Angler Expenditures PV 2015 $'s	Cumulative 2017-2046 Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Total Labor Income impacts PV 2015 $'s	Cumulative 2017-2046 Total Value Added Impacts PV 2015 $'s	In year 2046 Total Employment Impacts Jobs
Scenario 1	$88,006,607	$129,728,291	$167,093,401	$55,365,491	$94,729,519	69
Scenario 2	$64,814,147	$95,540,879	$123,059,128	$40,774,974	$69,765,365	52
Scenario 3	$55,927,314	$82,441,026	$106,186,177	$35,184,214	$60,199,658	45
Scenario 4	$39,555,896	$58,308,336	$75,102,648	$24,884,855	$42,577,611	32
Scenario 5	$0	$0	$0	$0	$0	0
Scenario 6	$67,589,697	$99,632,246	$128,328,915	$42,521,089	$72,752,942	53
Scenario 7	$110,256,708	$162,526,597	$209,338,469	$69,363,166	$118,679,329	91
Scenario 8	$106,650,520	$157,210,807	$202,491,593	$67,094,491	$114,797,660	91
Sc 2 - Sc 1	-$23,192,460	-$34,187,412	-$44,034,273	-$14,590,517	-$24,964,155	-18
Sc 3 - Sc 1	-$32,079,292	-$47,287,265	-$60,907,223	-$20,181,278	-$34,529,862	-25
Sc 4 - Sc 1	-$48,450,710	-$71,419,955	-$91,990,752	-$30,480,637	-$52,151,909	-37
Sc 5 - Sc 1	-$88,006,607	-$129,728,291	-$167,093,401	-$55,365,491	-$94,729,519	-69
Sc 6 - Sc 1	-$20,416,910	-$30,096,045	-$38,764,486	-$12,844,402	-$21,976,578	-17
Sc 7 - Sc 1	$22,250,102	$32,798,307	$42,245,069	$13,997,674	$23,949,809	21
Sc 8 - Sc 1	$18,643,913	$27,482,516	$35,398,193	$11,728,999	$20,068,140	21

Table A-28. Easter Oyster Fishery Acreage Results

Eastern Oyster

Scenario	Shellfish Open Acres Yr 2046	Shellfish Closed Acres Yr 2046	Public Shellfish Culture Acres Yr 2046	Private Shellfish (clam and oyster) Culture Acres Yr 2046	Oyster Reef Sanctuary Acres Yr 2046
Scenario 1	1,776,932	442,106	1,775,255	1,677	147
Scenario 2	2,108,512	110,527	2,106,835	1,677	147
Scenario 3	1,776,932	442,106	1,775,255	1,677	147
Scenario 4	1,776,932	442,106	1,754,496	22,436	147
Scenario 5	1,776,932	442,106	1,601,318	175,614	147
Sc 2 - Sc 1	331,580	-331,580	331,580	0	0
Sc 3 - Sc 1	0	0	0	0	0
Sc 4 - Sc 1	0	0	-20,759	20,759	0
Sc 5 - Sc 1	0	0	-173,937	173,937	0

Table A-29. Easter Oyster Hand Harvest Fishery Results

Eastern Oyster Scenario	Cumulative 2017-2046 Public Bottom Hand Harvest Bushels	Cumulative 2017-2046 Public Bottom Hand Harvest Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Public Bottom Hand Harvest Ex-Ves Rev PV 2015 $'s	Cumulative 2017-2046 Public Bottom Hand Harvest Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Public Bottom Hand Harvest Total Labor Income Impacts PV 2015 $'s	In year 2046 Public Bottom Hand Harvest Total Employment Impacts Jobs
Scenario 1	1,451,535	$22,728,341	$35,193,594	$50,470,629	$22,232,330	82
Scenario 2	1,672,946	$26,195,227	$40,308,475	$57,805,806	$25,463,478	97
Scenario 3	3,822,376	$98,595,237	$89,963,069	$129,014,748	$56,831,041	246
Scenario 4	1,438,766	$22,528,395	$34,904,099	$50,055,469	$22,049,451	81
Scenario 5	1,349,174	$21,125,565	$32,896,584	$47,176,519	$20,781,273	74
Sc 2 - Sc 1	221,411	$3,466,886	$5,114,881	$7,335,177	$3,231,148	15
Sc 3 - Sc 1	2,370,841	$75,866,896	$54,769,475	$78,544,119	$34,598,712	164
Sc 4 - Sc 1	-12,769	-$199,946	-$289,495	-$415,160	-$182,878	-1
Sc 5 - Sc 1	-102,361	-$1,602,776	-$2,297,010	-$3,294,109	-$1,451,056	-8

Table A-30. Easter Oyster Mechanical Harvest Fishery Results

Eastern Oyster Scenario	Cumulative 2017-2046 Public Bottom Mechanical Harvest Bushels	Cumulative 2017-2046 Public Bottom Mechanical Harvest Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Public Bottom Mechanical Harvest Ex-Ves Rev PV 2015 $'s	Cumulative 2017-2046 Public Bottom Mechanical Harvest Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Public Bottom Mechanical Harvest Total Labor Income Impacts PV 2015 $'s	In year 2046 Public Bottom Mechanical Harvest Total Employment Impacts Jobs
Scenario 1	1,451,535	$17,563,706	$35,193,594	$55,868,477	$24,610,084	82
Scenario 2	1,672,946	$20,242,800	$40,308,475	$63,988,154	$28,186,804	97
Scenario 3	3,822,376	$93,430,602	$89,963,069	$142,812,913	$62,909,138	246
Scenario 4	1,438,766	$17,409,195	$34,904,099	$55,408,916	$24,407,647	81
Scenario 5	1,349,174	$16,325,134	$32,896,584	$52,222,062	$23,003,836	74
Sc 2 - Sc 1	221,411	$2,679,094	$5,114,881	$8,119,676	$3,576,720	15
Sc 3 - Sc 1	2,370,841	$75,866,896	$54,769,475	$86,944,436	$38,299,054	164
Sc 4 - Sc 1	-12,769	-$154,512	-$289,495	-$459,562	-$202,437	-1
Sc 5 - Sc 1	-102,361	-$1,238,572	-$2,297,010	-$3,646,415	-$1,606,247	-8

Table A-31. Easter Oyster Private/Leased Bottom Aquaculture Results

Eastern Oyster

Scenario	Cumulative 2017-2046 Private/Leased Bottom Bushels	Cumulative 2017-2046 Private/Leased Bottom Producer Surplus PV 2015 $'s	Cumulative 2017-2046 Private/Leased Bottom Ex-Ves Rev PV 2015 $'s	Cumulative 2017-2046 Private/Leased Bottom Total Sales Impacts PV 2015 $'s	Cumulative 2017-2046 Private/Leased Bottom Total Labor Income Impacts PV 2015 $'s	In year 2046 Private/Leased Bottom Total Employment Impacts Jobs
Scenario 1	423,690	$2,362,719	$10,272,693	$21,080,423	$10,700,722	126
Scenario 2	423,690	$2,362,719	$10,272,693	$21,080,423	$10,700,722	126
Scenario 3	423,690	$2,362,719	$10,272,693	$21,080,423	$10,700,722	126
Scenario 4	4,369,367	$22,936,632	$99,724,489	$204,642,962	$103,879,676	209
Scenario 5	32,052,367	$165,607,442	$720,032,358	$1,477,566,402	$750,033,706	822
Sc 2 - Sc 1	0	$0	$0	$0	$0	0
Sc 3 - Sc 1	0	$0	$0	$0	$0	0
Sc 4 - Sc 1	3,945,677	$20,573,913	$89,451,796	$183,562,539	$93,178,954	83
Sc 5 - Sc 1	31,628,677	$163,244,723	$709,759,665	$1,456,485,979	$739,332,984	697

Table A-32. Easter Oyster Sanctuary Impacts Results

Eastern Oyster

Scenario	Cumulative 2017-2046 Additional Commercial Fishery Ex-Vessel Value Due to Oyster Sanctuaries PV 2015 $'s	Cumulative 2017-2046 Water Quality Improvement Value (Nitrogen Removal) Due to Oyster Sanctuaries PV 2015 $'s
Scenario 1	$7,812,337	$7,679,608
Scenario 2	$7,812,337	$7,679,608
Scenario 3	$7,812,337	$7,679,608
Scenario 4	$7,812,337	$7,679,608
Scenario 5	$7,812,337	$7,679,608
Sc 2 - Sc 1	$0	$0
Sc 3 - Sc 1	$0	$0
Sc 4 - Sc 1	$0	$0
Sc 5 - Sc 1	$0	$0

Report 2

Effects of the shrimp trawl fishery on three non-target stocks in North Carolina: Atlantic croaker, weakfish, and blue crab

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Introduction

Shrimp trawl bycatch is a significant source of mortality for many aquatic animals worldwide (Alverson 1994). In North Carolina, catches from the penaeid shrimp fishery are typically comprised of about 80% non-shrimp species by weight and associated mortality rates for non-target species are often high (Johnson 2006, Brown 2009, 2010, 2015). An additional concern is that most fishing activity in North Carolina is conducted in the estuaries of Pamlico Sound which contains critical nursery areas for many species of juvenile fish and shellfish. The goal of this report is to outline the potential ecological and economic benefits of reducing shrimp trawl bycatch in North Carolina with particular emphasis on three of the most commonly caught non-target species, namely Atlantic croaker (*Micropogonias undulatus*), weakfish (*Cynoscion regalis*), and blue crab (*Callinectes sapidus*).

The fisheries

The commercial penaeid shrimp fishery in North Carolina is valued at over $16.8 million (NCDMF 2016b), and is the second most valuable commercial fishery in the state (Burgess and Bianchi 2004). The fishery targets three species: brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaues setiferus*), and pink shrimp (*F. duorarum*). Brown shrimp make up the majority of the harvest (Figure 1), followed by white and pink shrimp, respectively.

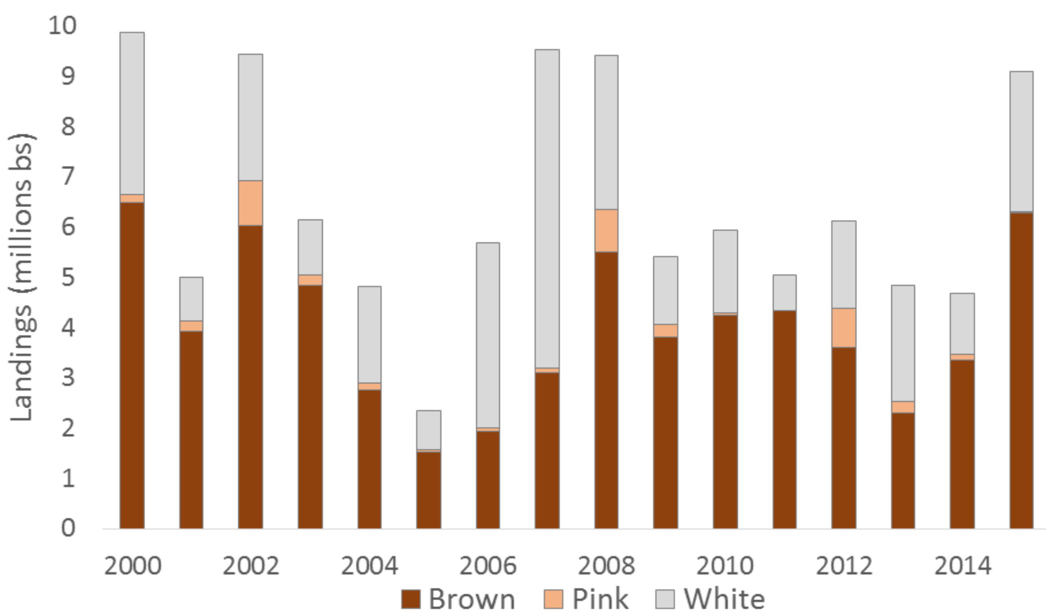

Figure 1. Recent landings (millions of lbs) of penaeid shrimp by species in North Carolina, 2000-2015.

Fishing extends from estuarine to ocean waters within state boundaries (0-3 nautical miles). Subadult and adult shrimp are targeted during movements from lower estuaries to the ocean (ASMFC 2008). Recruitment is thought to be environmentally driven, resulting in variable annual landings (NCDMF 2015).

Participation in the fishery (number of trips, vessels, and participants) declined from 2000 to about 2005, but has remained stable over the last decade (Figure 2) (NCDMF 2016b).

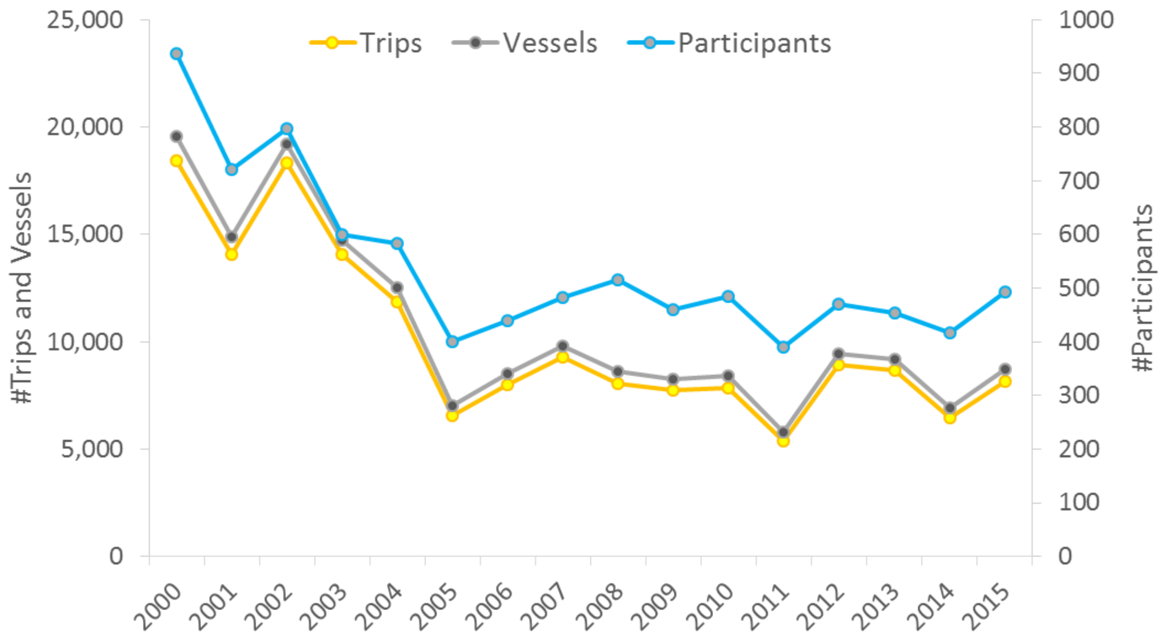

Figure 2. Number of trips, vessels, and participants in the North Carolina commercial shrimp fishery (NCDMF 2016b).

The primary gear utilized in the commercial shrimp fishery is the otter bottom trawl. Over 90% of the total commercial harvest is caught using otter trawls, but a growing percentage of vessels (approximately 3%) are switching from otter trawls to skimmer trawls in certain regions of the state (NCDMF 2015). Stationary channel nets comprise about 5% of the harvest. Approximately 75% of North Carolina commercial shrimp harvest occurs in estuarine waters and a little more than half of the total harvest comes from Pamlico Sound (NCDMF 2015).

Shrimp may also be harvested recreationally in North Carolina using commercial gear by Recreational Commercial Gear License holders (RCGL; NCDMF 2016b). RCGL holders are permitted to use commercial gear to harvest seafood for their personal consumption (NCDMF 2015). Gears used include otter trawls, skimmer trawls, seines, cast nets, shrimp pots, and shrimp pounds. On average in recent years, recreational fishermen harvested approximately 52,000 pounds of shrimp per year (NCDMF 2016a). Similar to commercial harvest, most recreational harvest occurs in Pamlico Sound.

Bycatch

Bycatch includes non-target species caught and retained for sale or consumption as well as non-target animals that are discarded due to regulations or undesirability. Many factors affect the kind and amount of bycatch in the shrimp trawl fishery, including water temperature and clarity, area, season, tow duration, and gear configuration (Murawski 1996, NCDMF 2006). Otter trawls, the primary gear used in North Carolina, have been characterized as “highly unselective” (Coale et al. 1994) relative to many other fishery gears because they employ a small net mesh size and long tow times (average 100 and 81 minutes in estuarine and ocean waters, respectively). Finfish and crustacean species caught and often discarded by the North Carolina shrimp trawl fleet include southern flounder (*Paralichthys lethostigma*), weakfish, Atlantic croaker, spot (*Leiostomus xanthurus*), blue crab, bluefish (*Pomatomus saltatrix*), Atlantic menhaden (*Brevoortia tyrannus*), southern kingfish (*Menticirrhus americanus*), and Spanish mackerel (*Scomberomorus maculatus*) (Brown 2015). In addition, endangered Atlantic sturgeon (*Acipenser oxyrinchus*) and several endangered sea turtle species are occasionally caught in shrimp trawl gear (Daniel 2013, Brown 2015). North Carolina’s Division of Marine Fisheries (DMF) has made efforts to reduce shrimp trawl bycatch through time, area and gear restrictions (NCDMF 2015). Also, bycatch reduction devices (BRDs) are required on all shrimp trawls to help reduce overall bycatch and mortality of discarded finfish and protected species (e.g., turtle excluder devices (TEDs)).

In order to assess the impacts of shrimp trawl bycatch on non-target species, accurate information must be collected on the magnitude and composition of shrimp trawl catch (NCDMF 2006). To accomplish this goal, at-sea observers are employed to collect data on the species composition and final disposition of the catch (e.g., kept vs. discarded, dead vs. released alive). In addition, observers often sample a subset of certain species caught to determine the length, weight, and (sometimes) sex distribution. Observer data are then scaled up using information such as total shrimp trawl landings, location, gear, season, and effort to estimate the total bycatch and discards. Discard data are a critical component to estimating total fishing mortality in the stock assessments for many species caught as bycatch in the shrimp trawl fishery.

However, DMF does not operate a dedicated shrimp trawl observer program. Several short-term studies have been conducted in recent years to characterize the composition of the catch (Brown 2009, 2010, 2015). An estimated 1.2% of commercial shrimp otter trawl trips in North Carolina were observed in the most recent sampling program (2012-2015). This coverage rate is similar to that achieved by NOAA Fisheries observer coverage of shrimping activity in federal waters which averages 2% of annual penaeid and rock shrimp trips in the South Atlantic and Gulf of Mexico (SEDAR 2014).

Data collected from recent shrimp otter trawl observer studies (Brown 2009, 2010, 2015), indicate that Atlantic croaker and spot make up the vast majority of the total estuarine catch by both numbers and volume (Figure 3). Shrimp averaged only 33% of the catch in numbers and 25% in weight between 2012 and 2015. Although the top ranking bycatch species after Atlantic croaker and spot varied annually, weakfish ranked in the top five bycatch species in all years and blue crab ranked in the top five in half of the study years.

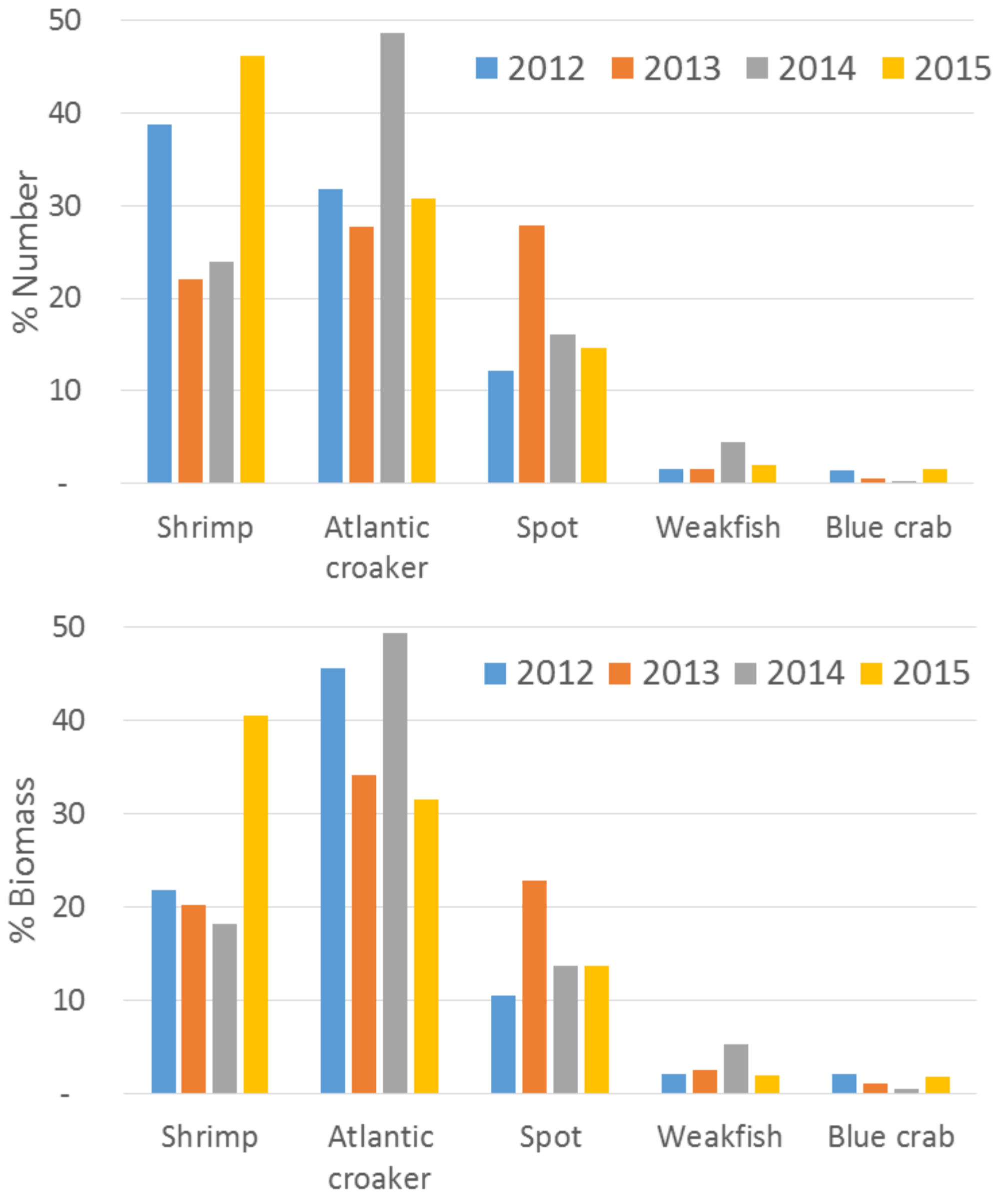

Figure 3. Percent species composition for shrimp, Atlantic croaker, spot, weakfish, and blue crab observed in the estuarine shrimp otter trawl fishery in North Carolina by number (top) and weight (bottom), 2012-2015 (Brown 2015).

Shrimp in the ocean otter trawl fishery averaged 45% of the observed catch in numbers and 16% in weight between 2012 and 2015 (Figure 4, Figure 5) (Brown 2015). In comparison, the ocean otter trawl shrimp fishery caught less Atlantic croaker and spot than the estuarine fishery (Figure 4, Figure 5).

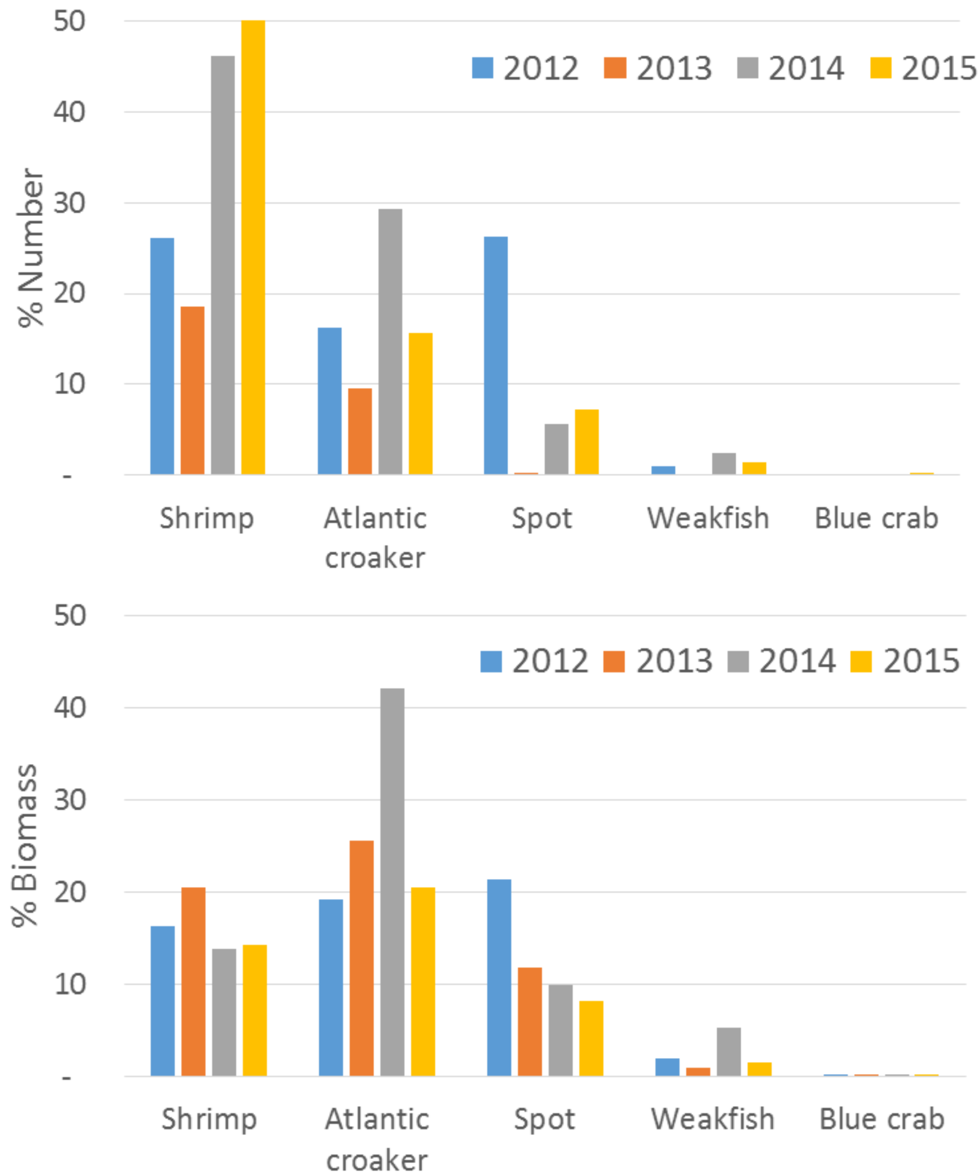

Figure 4. Percent species composition for shrimp, Atlantic croaker, spot, weakfish, and blue crab observed in the ocean shrimp otter trawl fishery in North Carolina by number (top) and weight (bottom), 2012-2015 (Brown 2015).

Weakfish were caught less frequently in ocean waters, but the percent of the catch by weight was similar likely because larger fish were being caught. Blue crab comprised only a very small portion of the ocean shrimp otter trawl bycatch (Figure 5).

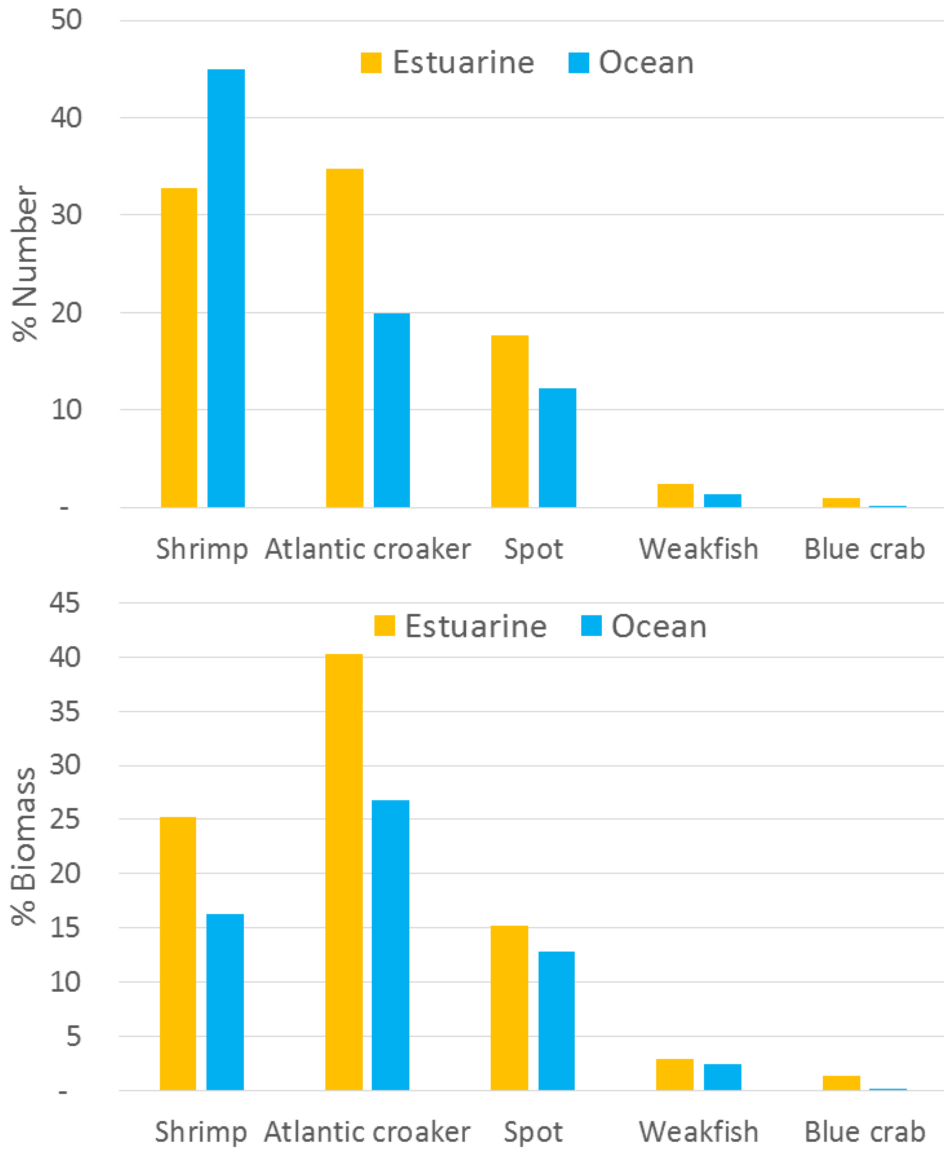

Figure 5. Average percent species composition for shrimp, Atlantic croaker, spot, weakfish, and blue crab observed in the estuarine and ocean shrimp otter trawl fishery in North Carolina by number (top) and weight (bottom), 2012-2015 (Brown 2015).

All weakfish and a small portion of blue crab bycatch sampled in recent observer studies were regulatory discards. In contrast, all Atlantic croaker, all spot, and most blue crab discards sampled were deemed unmarketable (ASMFC 2016).

Although the magnitude of bycatch caught by recreational shrimp trawls (RCGL fishermen) is low in comparison with the commercial fishery, the composition of the bycatch is notably different. According to studies conducted in the mid- to late-2000s, an average of 83% of the RCGL sampled catch was comprised of shrimp. Blue crab, flounder, spot, and Atlantic croaker made up 11%, 3%, 3%, and 1% of the catch, respectively (Figure 6) (NCDMF 2015). In Pamlico Sound, where most RCGL shrimp trawl trips were occur, approximately 82% of the sampled catch was shrimp, 18% was blue crab, and flounder, spot, and Atlantic croaker made up 2%, 2%, and 1% of the catch, respectively.

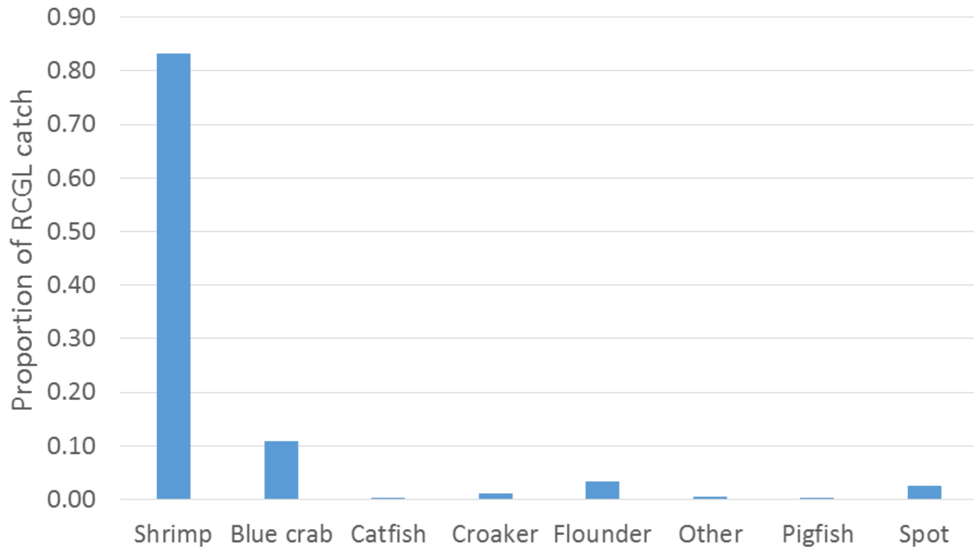

Figure 6. Average species composition of the recreational (RCGL) shrimp trawl fishery in North Carolina, 2000-20008 (NCDMF 2015).

Ecological impacts

Shrimp trawling has the potential to affect ecological processes from the population- to ecosystem-level (Crowder and Murawski 1998). Non-target species may experience immediate or delayed discard mortality and increased vulnerability to predators post-release (Murray et al. 1992, Collins et al. 2000, ASMFC 2008). If the magnitude of losses due to discard mortality are high, population-level effects may be observed as a result of growth or recruitment overfishing (Murawski 1995). Ecosystems may be affected as well through habitat disturbance or destruction, and through changes in trophic interactions due to bycatch removals (Johnson 2006). Potential ecological effects of shrimp trawling are discussed below with particular emphasis on three of the most commonly caught non-target species in North Carolina, namely Atlantic croaker, weakfish, and blue crab.

Population effects

There are three primary aspects of bycatch that affect stock dynamics:

1. the magnitude of bycatch (i.e., total numbers removed),
2. mortality rate (both immediate and delayed) associated with being caught and handled, and
3. the size/age composition of the bycatch.

These three aspects can differ by species and location of shrimp trawling activity (e.g., estuarine vs. ocean).

Magnitude

Atlantic croaker

Estimates of Atlantic croaker bycatch in the shrimp trawl fishery are highly uncertain, but certainly high, exceeding 20,000 mt in some years. In fact, concerns regarding potential estimation of the magnitude of Atlantic croaker shrimp trawl bycatch was the primary reason the 2010 stock assessment nearly failed peer review and that biomass-based reference points were not approved for use in management. Bycatch is a major concern for Atlantic croaker because coastwide dead discards have historically exceeded that of commercial landings for long periods of time (Figure 7Figure 7. Coastwide commercial landings and estimated shrimp trawl bycatch of Atlantic croaker, 1950-2008 (ASMFC 2010).).

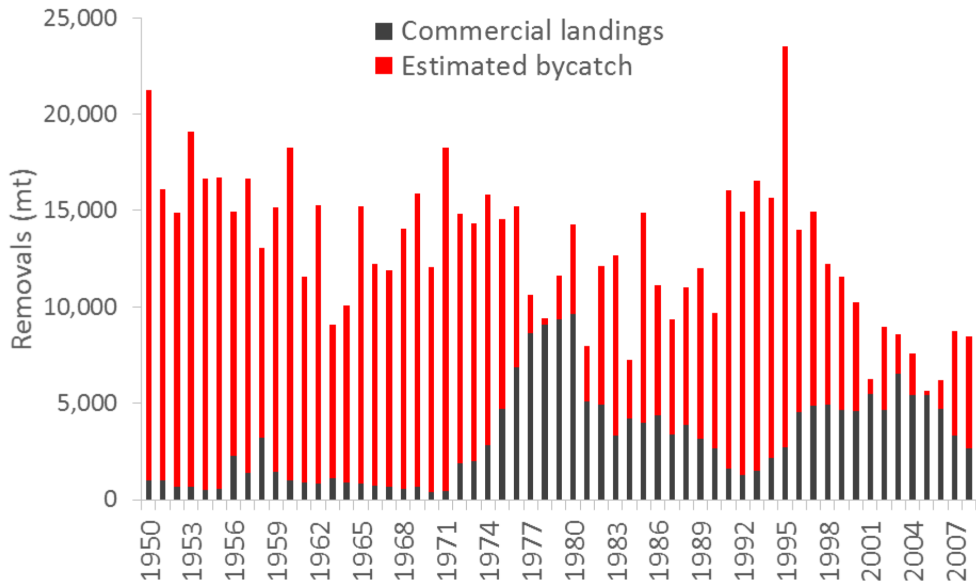

Figure 7. Coastwide commercial landings and estimated shrimp trawl bycatch of Atlantic croaker, 1950-2008 (ASMFC 2010).

Although North Carolina-specific bycatch estimates were not reported in the 2010 stock assessment, studies conducted in the 1970s indicated that shrimp trawl bycatch in North Carolina was approximately equal to food fish landings by weight (Diamond et al. 1999).

Weakfish

In contrast to Atlantic croaker, total weakfish bycatch in all fisheries is small relative to total commercial landings (Figure 8).

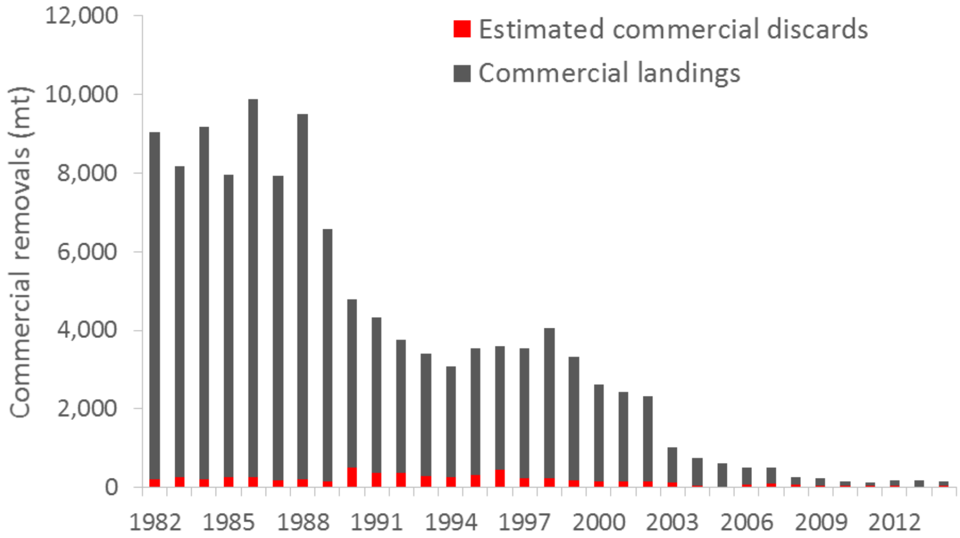

Figure 8. Coastwide commercial landings and estimated discards of weakfish, 1950-2008 (ASMFC 2016).

Although commercial discards have been relatively high in previous decades (Figure 9), total discards have declined since the adoption of bycatch reduction targets and devices.

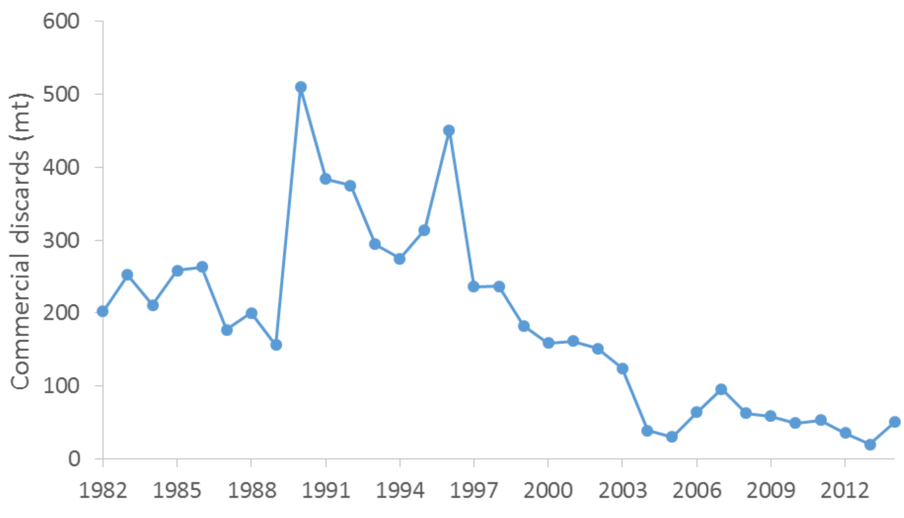

Figure 9. Coastwide commercial discards of weakfish, 1950-2008 (ASMFC 2016).

Commercial weakfish discards come primarily from the northern otter trawl fishery that occurs during the second half of the year (ASMFC 2016). Available data suggests shrimp trawl bycatch in particular makes up an insignificant fraction of total removals (ASMFC 2016, Figure 5.1.2). The 2016 stock assessment highlighted increasing natural mortality, not bycatch, as the main cause of severe stock decline, noting that “failure of the stock to recover since the late 1990s cannot be attributed to high fishing mortality alone unless bycatch and under-reported catches were much greater than those estimated, growing from about 3-4 times the estimates in 1996 to 15-20 times in the most recent years. Thus far, there is no evidence available of an Atlantic coast fishery capable of generating additional unreported weakfish discards of this magnitude” (ASMFC 2009).

If this assessment is correct, only a complete elimination of all fishing mortality (direct and indirect/bycatch) will result in stock recovery under current natural mortality conditions as shown in both the 2010 assessment and our projection models (Report #1: An evaluation of the biological and economic benefits of improving the status of seven North Carolina stocks, Figure 10, ASMFC 2016). Regardless, in light of such drastic declines, eliminating all sources of known fishing mortality in order to reduce total mortality is warranted, even if fisheries are not the ultimate cause of the problem.

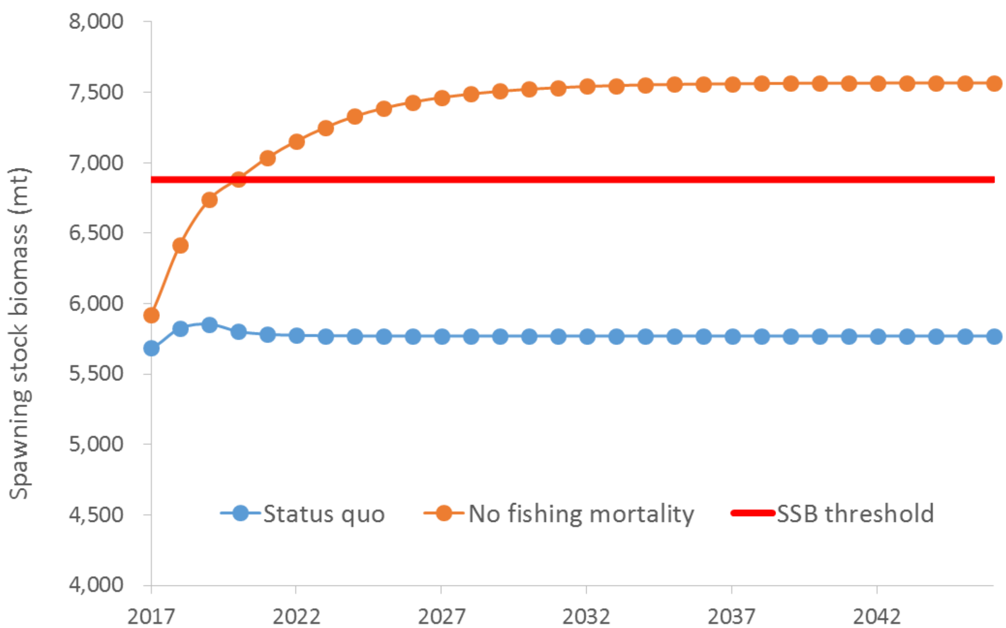

Figure 10. Projected spawning stock biomass (mt) of weakfish under status quo (2016) and no fishing mortality scenarios. See Report #1 for more details.

Blue crab

The magnitude of total blue crab bycatch in North Carolina shrimp trawl fisheries is uncertain. However, bycatch landings of blue crabs caught in shrimp trawls have averaged 207,000 lbs per year (NCDMF 2013). Although the magnitude of crabs caught in North Carolina’s estuarine shrimp trawl fishery is small in comparison to crab trap landings (average 0.5% of total landings), shrimp trawl discards of blue crab are on par with estimated recreational (CRFL) landings (NCDMF 2013), and could generate population level effects given the age composition and mortality rates of blue crab discards (see next two subsections; Johnson 2006). Given the blue crab fishery is the most valuable in the state (Burgess and Bianchi 2004, NCDMF 2016b), more attention should be paid to quantifying and estimating all sources of fishing mortality for this species.

Mortality

<u>*Atlantic croaker and weakfish*</u>

Brown (2015) found that mortality at time of capture in the North Carolina shrimp trawl fishery for Atlantic croaker, spot, and weakfish across all years and areas was 23%, 66%, and 87%, respectively. Note that Brown's estimate of weakfish mortality is lower than the 100% discard mortality assumed in the recent stock assessment (ASMFC 2016). In another bycatch study conducted in Pamlico Sound, 78% of finfish died before being returned to the water (Johnson 2006).

Although Atlantic croaker are resilient relative to other finfish caught frequently as shrimp trawl bycatch (Johnson 2006), the magnitude of Atlantic croaker caught is so large that the total effect on the population could be significant as demonstrated in the most recent stock assessment (ASMFC 2010). We predicted that elimination of shrimp trawl bycatch of age 0 fish would result in between a 32% and 71% increase in spawning stock biomass (Figure 11), depending on the true magnitude of historical bycatch levels (Report #1: An evaluation of the biological and economic benefits of improving the status of seven North Carolina stocks).

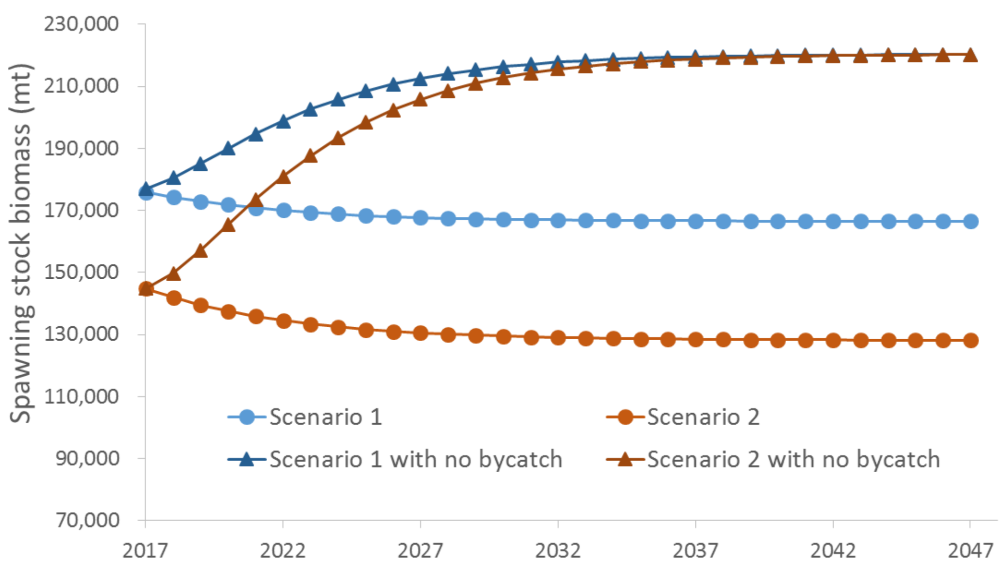

Figure 11. Projected spawning stock biomass (mt) of Atlantic croaker assuming alternative historical levels of shrimp trawl bycatch (Scenario 1 assumed 2008 bycatch estimates, Scenario 2 assumed double 2008 bycatch estimates). See Report #1 for more details.

Blue crab

Although relatively little attention is paid to blue crab bycatch in shrimp trawl fisheries, these animals are often subject to stress, injury, and mortality (Murphy and Kruse 1995, Guillory 2001). Immediate (at net) survival rates of blue crab caught in otter (94%) and skimmer trawls (92%) in North Carolina were similar and high (Coale et al. 1994). However, McKenna and Camp (1993) found that 35% of blue crabs caught in crab trawls in the Pamlico-Pungo River complex were injured and that only 64% of all crabs survived post-release (vs. 92% for pots). Blue crabs caught in shrimp gear typically experience shorter handling times than crab pots, but the larger amount of total catch in any given shrimp haul may result in greater total injuries and mortality (Guillory 2001). The molt condition of the crab also likely affects mortality such that soft and peeler crabs may experience even higher mortality rates in shrimp trawls (Guillory 2001). A tagging study of related portunid sand crabs (*Portunus pelagicus*) reported that recapture rates, which are indicative of survival, were 12-18% in trawls and much lower than that for traps which reported a 70% recapture rate (Potter et al. 1991). In addition, undamaged crabs had twice the recapture rate of damaged crabs with missing appendages, indicating that long-term survival post-release is affected by at-net injuries.

Although the magnitude of shrimp trawl bycatch of blue crabs is low relative to landings from the directed crab fishery, the cumulative effect of 36% or greater long-term discard mortality rates on the estuarine portion of the stock could be significant (Guillory 2001). Our population modeling study (Report #1: An evaluation of the biological and economic benefits of improving the status of seven North Carolina stocks) indicated that even small reductions in fishing mortality could result in increased blue crab abundance (Figure 12). Although our modeling work did not specifically incorporate bycatch mortality, it is possible that fishing mortality reductions (bycatch landings or dead discards) in the shrimp trawl fishery could positively impact stock dynamics.

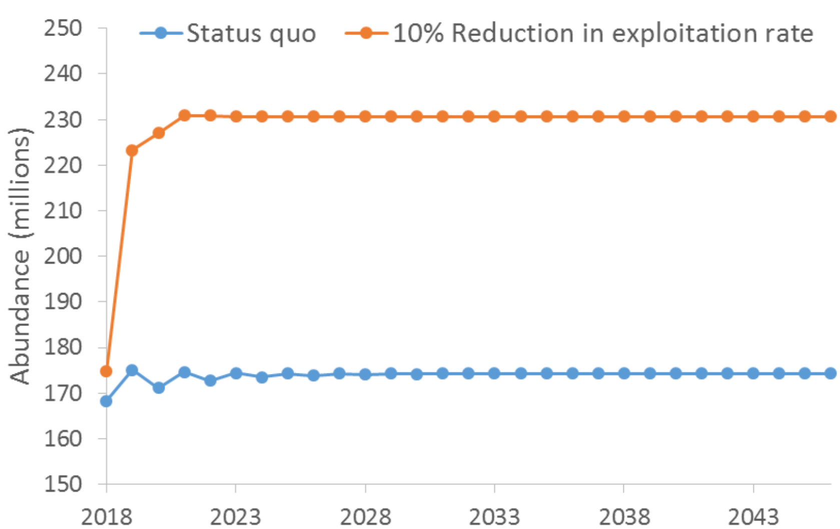

Figure 12. Projected abundance (millions) of blue crab under status quo and 10% reduction in fishery exploitation rate scenarios. See Report #1 for more details.

Size/age composition
The majority of Atlantic croaker and spot sampled in the commercial estuarine shrimp otter trawl fishery were juveniles (<7 in) (Brown 2015). The majority of weakfish sampled in the commercial estuarine shrimp otter trawl fishery were undersized (<12 in) (Brown 2015). However, a portion of fish sampled were large enough to potentially be age 1 (approx. >10 in) and possibly mature (ASMFC 2016). A higher percentage of sampled Atlantic croaker, spot, and weakfish in the ocean fishery were large enough to potentially be mature fish. No information on blue crab size distribution was collected in by Brown (2015); however, Johnson (2006) reported the average size of portunid crabs in their study was 83.5 mm, indicating shrimp trawl crab bycatch in Pamlico Sound includes both juvenile and adult crabs.

The size composition of bycatch in the shrimp trawl fishery is an important aspect to consider when assessing the potential impact of the shrimp fishery on non-target stocks. Large catches of small, juvenile animals are to be expected in North Carolina given approximately 75% of North Carolina shrimp harvest occurs in estuarine waters (NCDMF 2015) which serve as critical habitat for numerous species of juvenile fish and shellfish species (NCDMF 2016c). Some scientists and managers have argued that fishery removals of juvenile fish do not play an important role in determining overall stock dynamics because juveniles typically experience high natural mortality rates and would have died regardless. Although some of the mortality due to shrimp trawl bycatch is certainly compensatory, the extent to which discard mortality hinders recruitment of non-target stocks in the Southeast is unknown (Johnson 2006).

Restricting the shrimp trawl fishery to ocean waters as in done in neighboring states (NCDMF 2015) could benefit non-target stocks by reducing juvenile mortality and protecting nursery habitats. However, the potential for effort to shift to ocean waters should be carefully considered before management changes are enacted. If a significant portion of effort shifts from estuaries to ocean waters, increased bycatch mortality on larger/older fish may have even greater deleterious effects on non-target stocks through the removal of a greater proportion of sub-adult and mature spawning stock. Federal shrimping areas off North Carolina have already been identified as a national hot spot for shrimp bycatch (Scott-Denton et al. 2012, SEDAR 2014) and increased effort may compound the existing problem for migratory finfish such as Atlantic croaker, spot, and weakfish. If additional inshore fishing area closures are considered, effort control in the ocean fishery should accompany these management measures to prevent increased bycatch of larger, older fish. Although the relative size and age composition of blue crabs caught in North Carolina shrimp trawl fisheries is not well characterized, relative catch rates (Figure 5) indicate that restricting the fishery to ocean waters could reduce impacts on the blue crab stock.

<u>Ecosystem effects</u>
Bottom trawls used by the shrimp fishery have the potential to impact aquatic ecosystems through both habitat and trophic effects. Disturbance of soft bottom habitat can result from shrimp trawling activities, including increases in turbidity (Dellapenna et al. 2006) and short-term changes in benthic fauna populations (Sparks-McConkey and

Watling 2001). Long-term damage to submerged aquatic vegetation (SAV), hard bottom, and coral reefs can also occur (Barnette 2001). In North Carolina, otter and skimmer trawls are largely restricted to areas without sensitive submerged aquatic vegetation (NCDMF 2006, 2015), and most SAV in western portions of the Albemarle-Pamlico system is protected from shrimp trawling (Deaton et al. 2010).

Ecosystem-level trophic effects of removing large amounts of juvenile fish and crustaceans from estuarine ecosystems is largely unknown (Crowder and Murawski 1998, Johnson 2006). However, the diets of many aquatic predators depend on juvenile fish and shellfish that inhabit North Carolina's estuarine habitats where shrimp trawling occurs, including commercially and recreationally important species such as striped bass, flounders, and weakfish (Manooch 1973, Merriner 1975, Powell and Schwartz 1979). Should shrimp trawl and other fishery bycatch of juvenile fish and crustaceans result in effective decreases in potential prey for these species, predators may suffer reduced growth, condition, reproductive success, and survival.

Johnson (2006) conducted ecosystem modeling of the Neuse River Estuary and concluded that fishing and discarding of dead bycatch changed the trophic level at which many common consumers feed; in addition, these practices decreased the efficiency of energy transfer up and out of the estuary. Johnson (2006) also explored potential positive tropic effects of shrimp trawl discards by conducting laboratory mesocosm experiments of blue crab preference for discards vs. their natural prey, the hard clam, and found that blue crab preferentially chose to scavenge discards. If their results are indicative of wild conditions in North Carolina estuaries, hard clams may be benefiting from the relaxation of blue crab predation and the blue crab stock may be benefiting from the additional scavenging opportunities provided by dead discards (Johnson 2006).

Conclusions

The magnitude of shrimp trawl bycatch and its associated mortality rate for non-target species is a significant concern for North Carolina stakeholders (NCDMF 2015). However, the impacts of large, undocumented removals extend beyond state borders, potentially affecting stock dynamics at the coastwide scale. In particular, Atlantic croaker, spot, and weakfish are the most likely stocks to be negatively affected by North Carolina's shrimp trawl fishery. Uncertainty regarding the magnitude and trend in shrimp trawl bycatch led to no biomass-based reference points being adopted for management of the coastwide Atlantic croaker stock (ASMFC 2010). In addition, uncertainties regarding bycatch contributed to the long delay in initiation of a coastwide spot assessment. Hopefully, the 2016 joint assessment for these two species will shed light on current stock conditions given new sources of bycatch information. Uncertainty surrounding the cause of declines and the future of the weakfish stock is likely to remain high for some time; however, both scientists' and stakeholders' concerns regarding the magnitude and composition of weakfish bycatch in shrimp trawls and other gears could be alleviated by better data collection.

Conclusive, direct evidence of significant bycatch effects on non-target stock dynamics in North Carolina is lacking in large part because the magnitude and composition of shrimp trawl bycatch is not well characterized. Several short term studies employing at-sea observers have been conducted in recent years to supplement DMF sampling programs (Brown 2009, 2010, 2015). However, a permanent shrimp trawl bycatch monitoring program has yet to be established in North Carolina. Until a long time series of reliable shrimp trawl bycatch estimates can be produced, great uncertainty in the magnitude and composition of shrimp trawl bycatch will preclude conclusive studies of larger, population- and ecosystem-level effects on non-target stock dynamics.

Recent stock declines and low landings observed in North Carolina's top shrimp trawl bycatch stocks (e.g., Atlantic croaker, spot, weakfish, and blue crab) indicate reductions in bycatch and discard mortality could have a positive effect on stock dynamics. Bycatch and mortality reductions can be achieved in a number of different ways such as reducing tow times, gear alterations and alternatives (Coale et al. 1994, Brown and Price 2006), creation and adoption of more efficient BRDs and BRD configurations, and area and effort restrictions (NCDMF 2015). In the face of high uncertainty, a precautionary approach to fisheries management of shrimp trawl bycatch is warranted (Garcia 1995).

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Report 3

An evaluation of the marine stock assessment program in North Carolina

January 31, 2017

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Introduction

The goal of this report is to summarize the major strengths and weaknesses of the North Carolina Division of Marine Fisheries' (DMF) stock assessment program. North Carolina is a leader among East Coast states in many aspects of data collection and analysis. I have highlighted program strengths with the hope that legislative, agency, and stakeholder support for these essential programs continues. I have also highlighted some of the deficiencies in DMF's stock assessment program that contribute to stock assessment uncertainty and that could benefit from additional resources and attention. Sources of stock assessment uncertainty considered in this report include major data collection programs, stock assessment approaches, and the stock assessment process. A list of recommendations for reducing assessment uncertainty are provided for each topic and summarized in the concluding section.

Data collection to support stock assessments

Accurate reporting of the number of animals removed by fishing activities is essential to the estimation of stock status and sustainable catch levels. Most stock assessment models assume low (<10%) error in total removals (Quinn and Deriso 1999). Thus, all improvements that can be made in the accuracy of catch reporting translate directly into more accurate stock assessments.

DMF supports stock assessments through extensive fishery-dependent and fishery-independent data collection programs. Fishery-dependent data are collected from commercial, for-hire, and recreational fisheries sectors. Fishery-independent data sources include agency survey programs and life history research such as tagging and genetics programs.

Fishery-dependent data collection

Commercial landings statistics

North Carolina conducts a rigorous commercial landings statistics program. Prior to 1978, commercial landings data were voluntarily reported monthly to the National Marine Fisheries Service. In 1978, DMF entered into a cooperative program with NMFS to maintain and expand the monthly surveys. North Carolina was one of the first Atlantic states to implement trip-level (a.k.a. "trip-ticket") reporting for all state-licensed fish dealers beginning in 1994 (Figure 1). Trip-level reports include transaction date, area fished, gear used, and landed species as well as fishermen and dealer information. Hundreds of thousands of trip tickets are processed by DMF annually. Timely and accurate landings statistics support many aspects of fisheries management, including stock assessments and quota monitoring for species such as summer flounder, striped bass, black sea bass (North of Cape Hatteras), spiny dogfish, and river herring.

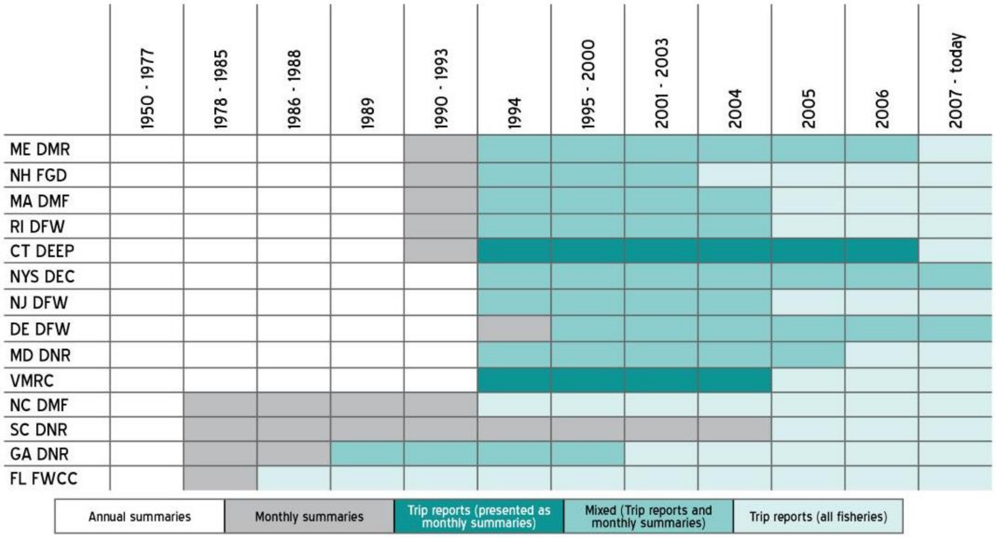


Figure 1. Changes in commercial landings reporting by Atlantic state (courtesy ACCSP). Note early adoption of trip-level reporting for all fisheries by North Carolina DMF.

Electronic reporting is now available to all fish dealers, yet paper reports are still allowed. Paper reports are limited in the level of detailed information that can be recorded (NCDMF 2016a). In contrast, electronic reporting software allows the catch of each species to be reported along with the associated gear used to harvest each portion of the catch and the specific waterbody where each harvest event occurred. When multiple gears are used or multiple areas fished, the resulting landings by species can only be accurately matched with gear and locations using an electronic report. Such information if vital for reducing uncertainty in many North Carolina assessments. All dealers should be encouraged to transition to electronic reporting as soon as possible.

An additional problem with both types of dealer reporting is that it does not include records of trips where fish were targeted but not caught. Harvester reports of both successful and unsuccessful trips are required to generate meaningful catch per unit effort (CPUE) statistics for use in stock assessments. Therefore, trends in North Carolina landings statistics should be interpreted with caution (i.e., not as indices of abundance) unless supplemental harvester reporting is initiated. Fortunately, DMF has invested heavily in fishery-independent surveys for generating indices of abundance and does not have to rely on fishery-dependent CPUE for tracking the dynamics of most (especially estuarine) stocks.

Collection of accurate and comprehensive landings statistics is more difficult than simply digitizing and summarizing landings reports. DMF staff continue to lead efforts on the East Coast to improve the collection, quality, and availability of landings statistics across the state and at the regional level through participation and leadership in the Atlantic Coastal Cooperative Statistics Program. For example, DMF is researching and validating the factors used to convert landings of finfish and shellfish into whole pounds or pounds of meat from reported quantities such as gutted pounds or bushels. The importance of landings statistics improvement projects like this is often overlooked by managers and stakeholders, yet this type of work can result in significantly improved stock assessments and should thus be encouraged and supported.

For-Hire harvest statistics

The for-hire sector includes charter, head, and party boat operations which charge fees to take anglers fishing on their vessels. Snapper/grouper permit holders operating a charter/headboat must participate in the Southeast Region Headboat Survey to help ensure their harvest is reported accurately. Other for-hire harvest is estimated by the For-Hire survey conducted through the Marine Recreational Information Program (DMF 2011). However, a complete census of commercial for-hire harvest is not currently required. In cooperation with NOAA Fisheries and ACCSP, DMF is testing the implementation of a charter boat logbook reporting system in North Carolina (anticipated certification mid-2017). Accurate reporting of all fish removals is a vital component of stock assessments; therefore, implementation of a for-hire logbook reporting system should be adopted as soon as possible.

Commercial sampling

Only weak inference can be made about the effects of fishing on a stock without information on the age and length structure of fish landed, harvested, and discarded. Therefore, rigorous and thorough biological characterization of the catch is a critical component of any fisheries statistics program aimed at supporting stock assessments and management. The two major commercial sampling programs are discussed below. However, it should be noted that DMF conducts several smaller supplemental sampling programs to address specific stock assessment and management needs.

Commercial fish house

DMF's fisheries-dependent Commercial Fish House Sampling Program began in 1982. Samplers interview fishermen to collect information on location, effort, and gear characteristics. In addition, the catch is subsampled to determine the size, weight, and (when possible) age and sex composition of species landed (Daniel 2013). Otolith sampling to determine age composition began in 1996 (ASMFC 2010). This sampling program provides vital catch composition statistics for all assessed species and should be expanded to help support stocks with uncertain or unknown status (NCDMF 2016c).

DMF should be commended for routinely sampling its scrap/bait fishery (beginning in 1986). Sampling of the scrap fishery in particular allowed species ratios to be developed to estimate total scrap landings of Atlantic croaker, a significant source of uncertainty in the assessment (ASMFC 2010). Also, North Carolina is the only state to collect biological samples of scrap/bait croaker. Sampling of unmarketable fish should be continued and enhanced if at all possible in order to better characterize this source of mortality in the croaker and other scrap/bait fish assessments.

Observer program

DMF runs both a traditional onboard Observer Program (Program 466) and an Alternative Platform (AP) observer program (Program 467) in which commercial operations are monitored at close proximity from state-owned vessels (Daniel 2013). Both programs collect information on date and time of capture, location, gear, gear configuration, effort, depth, and environmental conditions (when possible). Interactions with targeted, bycatch, and protected species and their final disposition are recorded. In the Observer Program, catch is subsampled to collect information on number, weight, and size/age composition of targeted and bycatch species.

DMF's observer program began in 2000 in the Pamlico Sound area and expanded to more areas and gears in 2004 (Boyd 2012). The program was expanded again in 2010 primarily to meet requirements of 7% minimum coverage of the large mesh and 1% minimum coverage of the small mesh gillnet fishery in internal waters specified by a lawsuit settlement over sea turtle bycatch issues. Actual coverage of the large mesh gillnet fishery varies by calculation method, management unit, and season. Total coverage in 2015 was approximately 2.5% for the small mesh gillnet fishery, but only 6.2% for the large mesh gillnet fishery when calculated using the previous year's estimated number of trips (MFC 2015). Preliminary 2016 coverage was estimated to be 6.3% in the large mesh and 2.6% in the small mesh gillnet fisheries (MFC 2016). Observation shortfalls have arisen in the past due to a combination of management unit closures, staffing challenges, and lack of fishermen cooperation (Office of the State Auditor 2016).

Observer programs collect critical information for stock assessments, but are expensive. Efforts have been made by DMF to improve observer program efficiency; however, DMF's budget for the observer program has historically been underfunded (MFC 2012). If DMF cannot meet minimum observer coverage requirements and prove low incidental take of sea turtle and Atlantic sturgeon, fisheries risk closure. Large increases in license/permit fees and annual appropriations have been used to help cover program expenses. Support for permanent and adequate funding of the observer program is critical to maintain incidental take monitoring required by federal law and to provide high quality bycatch data that will reduce stock assessment uncertainty.

In addition to gillnet bycatch, bycatch in the shrimp trawl fishery is a major source of uncertainty in several assessments, including Atlantic croaker, weakfish, and spot (ASMFC 2010, 2016). Supplementary sampling of shrimp trawl bycatch was conducted from 2012-2015 to address general concerns regarding juvenile finfish and protected species interactions with shrimp trawl gear, particularly in estuarine waters which serve as nursery habitat for many species (Brown 2015). However, percent observer coverage was extremely low (average <1% in estuarine waters and 3.4% in ocean waters) relative to the magnitude of bycatch incurred by the fishery. It is imperative that permanent funding for a comprehensive shrimp trawl observer program covering all seasons, regions, and gears be identified as soon as possible so that bycatch mortality, a significant source of stock assessment uncertainty in several assessments (e.g., Atlantic croaker, weakfish, spot), can be accurately estimated.

Recreational harvest statistics

Unlike commercial fisheries which require landings reports from dealers and/or fishermen, harvest by recreational anglers must be estimated from survey programs. DMF's Coastal Angling Program (CAP) includes a combination of mail, telephone and electronic surveys of those who hold a Coastal Recreational Fishing License and are conducted to estimate angler harvest, effort, and discards. Intercept surveys of anglers at boat docks/ramps, piers, charter facilities, beaches, banks, and in upper estuarine waters allows confirmation of fish harvest and sampling of the length and weight structure of the catch.

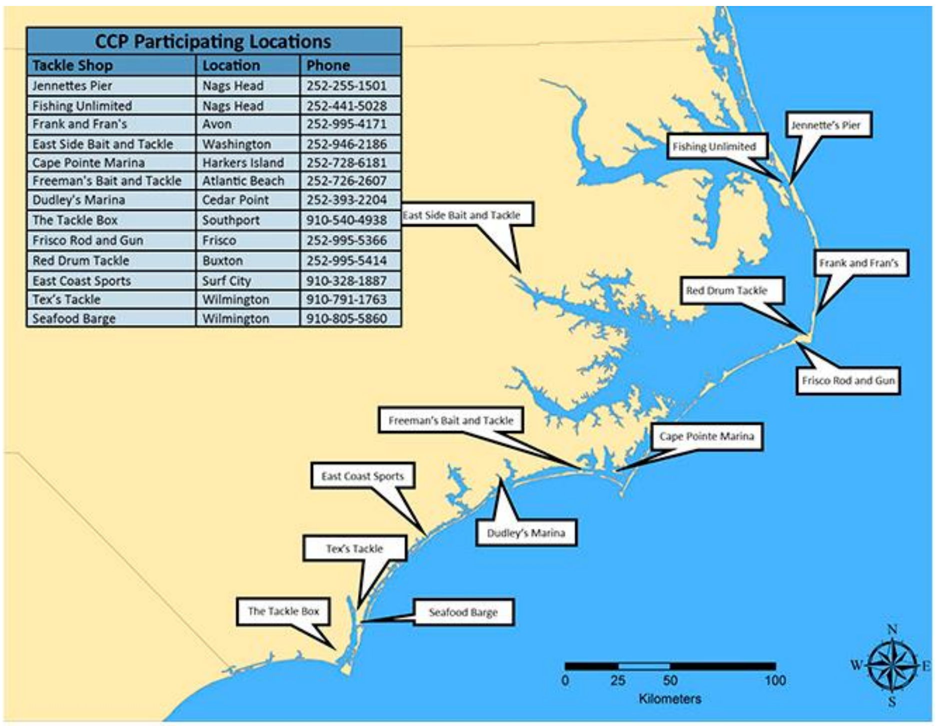
Angler sampling and survey programs are conducted in participation with the federal Marine Recreational Information Program (MRIP). DMF has taken multiple steps to improve the estimation and characterization of recreational catch independent of the federal MRIP survey (NCDMF 2016a). Due to concerns about the reliability of MRIP catch statistics and low sample sizes for several important species in North Carolina, DMF increased the annual number of anglers interviewed from 1,400 to 8,000 beginning in 1987. In 2005, the number of anglers was increased to approximately 15,000 in order to increase the precision of the catch estimates. In 2010, DMF increased the number of interviewed anglers to roughly 20,000 per year and implemented quality control measures to improve estimates of catch. CAP improvements continue with programs such as additional nighttime fisheries and private access site sampling. DMF should be commended for investing in supplemental recreational survey programs.

Major structural changes to the intercept portion of MRIP began in 2016. All coastal states, including North Carolina, will be in charge of conducting their own Access Point Angler Intercept Survey that collects information on marine recreational fishing catch and effort data in their own waters. The goal is to increase the accuracy and public acceptance of MRIP catch statistics.

However, MRIP does not adequately capture recreational harvest of anadromous species that also inhabit riverine areas of the state such as striped bass, American shad, hickory shad, and river herring. These species require additional sampling, especially in southern regions. Thus, a creel survey was begun by the NC Wildlife Resources Commission (WRC) in collaboration with DMF in 2004 to estimate recreational anadromous catch and effort in the Central/Southern Management Area (CSMA; NCDMF 2016a). The southernmost rivers were initially excluded due to low catch of striped bass, but the Cape Fear River was added in 2013 to collect information on American and hickory shad. Management of these species suffer from lack of informative data and subsequent stock assessments. Therefore, continuation of the CSMA creel survey is critical for continued and future assessment of anadromous species.

Many shellfish and crustaceans (e.g., blue crab, clam, oyster, and scallop) lack reliable stock assessments in North Carolina due in part to inadequate recreational harvest data (NCDMF 2016c). To help remedy this problem, DMF began a supplemental mail survey program in 2010 to estimate recreational harvest of shellfish and crustaceans and to collect better data on recreational harvest gears that are not well canvased by MRIP, including gigs, cast nets, and seines.

DMF also supplements the CAP/MRIP biological sampling program with a Carcass Collection Program (CCP). CCP allows anglers to donate filleted carcasses in order to collect age, size, and reproductive information for black sea bass, red and black drum, croaker, cobia, flounder, weakfish, grouper, kingfish, sheepshead, snapper, Spanish mackerel, spotted seatrout, striped bass, and triggerfish. Additional information from the CCP can be used in stock assessments to supplement biological information from observer sampling programs.


CCP Participating Locations

Tackle Shop	Location	Phone
Jennettes Pier	Nags Head	252-255-1501
Fishing Unlimited	Nags Head	252-441-5028
Frank and Fran's	Avon	252-995-4171
East Side Bait and Tackle	Washington	252-946-2186
Cape Pointe Marina	Harkers Island	252-728-6181
Freeman's Bait and Tackle	Atlantic Beach	252-726-2607
Dudley's Marina	Cedar Point	252-393-2204
The Tackle Box	Southport	910-540-4938
Frisco Rod and Gun	Frisco	252-995-5366
Red Drum Tackle	Buxton	252-995-5414
East Coast Sports	Surf City	910-328-1887
Tex's Tackle	Wilmington	910-791-1763
Seafood Barge	Wilmington	910-805-5860

Figure 2. Location of freezers for voluntary submission of biological data from recreationally harvested fish in North Carolina through the Carcass Collection Program.

Supplemental recreational survey work being conducted by DMF is critical to improving stock assessments, especially state-specific assessments that are not prioritized by MRIP at the regional level. MRIP is a coastwide survey program that is unlikely to generate accurate, precise estimates of recreational catch at the geographic or temporal scale needed for many state-specific stock assessments. Therefore, it is vital that DMF continue to supplement and expand its recreational survey programs in order to provide accurate and precise data for stock assessments.

Fishery-independent data collection

Fishery-independent survey programs are a critical component of stock assessments and are used to estimate stock trends and changes in stock structure (i.e., age or length composition). DMF conducts numerous short- and long-term survey and sampling programs across the state aimed at characterizing specific regions, species, and fishing gears. The following are short descriptions of some of the state survey and sampling programs conducted in marine waters that are most commonly used to inform DMF and regional stock assessments.

Juvenile Anadromous Trawl Survey (Program 100)

Program 100 began in 1982 with the goal of targeting juvenile alosines and striped bass in Albemarle Sound. Seven stations are sampled in the western sound, and twelve stations were added in 1984 in the central sound. The survey samples bi-weekly from mid-July to October. Biological samples and environmental data are collected with each tow. Given the gear and vessel utilized, the survey does not sample many deep areas, or sample areas with shallow water or bottom structure well. In addition to providing information Program 100 provides juvenile indices for stock assessments of several important species such as blue crab and striped bass.

Estuarine Trawl Survey (Program 120)

The Estuarine Trawl Survey (Program 120) began in the 1970s with the primary goals of identifying primary nursery areas and generating juvenile/recruitment indices for important estuarine stocks. Shallow waters south of the Albemarle Sound system are sampled primarily in May, June, with additional sampling of a subset of core sites in July. Gear and survey design changes were made over the history of the survey with 105 consistently surveyed fixed stations being sampled since 1989. Biological samples, and environmental and habitat data (since 2008) are collected with each tow. The survey does not sample deep water areas. Program 120 provides juvenile indices for stock assessments of species such as blue crab, southern flounder, and spot.

Striped Bass Independent Gill Net Survey (Program 135)

The Striped Bass Independent Gill Net Survey (Program 135) began in 1990 with the goal of monitoring the striped bass stock in Albemarle Sound and Roanoke River. Sampling sites are randomly stratified by geographic area. Gill nets of varying mesh sizes are deployed in both bottom (sink) and floating configurations. Sampling occurs in three segments, namely fall-winter, spring, and summer (discontinued in 1993). Biological samples are collected with each haul. The survey does not sample the middle of the sound or the nearshore portions in the northeast part of the sound. Program 135 provides adult indices for several assessments such as blue crab, striped bass, and southern flounder.

Pamlico Sound Trawl Survey (Program 195)

The Pamlico Sound Trawl Survey (Program 195) began in 1987 with the goal of providing long-term, fishery-independent monitoring of Pamlico Sound, eastern Albemarle Sounds, and the lower Neuse and Pamlico Rivers. Trawl stations are randomly sampled from a depth- and area-stratified framework. Sampling typically occurs over a two-week period. Months sampled have varied over time, but typically include a summer month (June or July) and an early fall month (September or October). Given the gear and vessel utilized, the survey does not sample areas with shallow water or bottom structure well. Biological samples are collected with each tow. Program 195 provides juvenile abundance indices for the stock assessments of several important species such as blue crab, Atlantic croaker, and southern flounder.

Pamlico Sound Fisheries-Independent Gill Net Survey (Program 915)

The Pamlico Sound Fisheries-Independent Gill Net Survey (Program 915) began in 2001 in Hyde and Dare counties and has since expanded to include the Neuse, Pamlico, and Pungo Rivers as well as areas in the Southern District. Sampling sites are randomly stratified by geographic area and depth. Gill nets of varying mesh sizes are deployed in both bottom (sink) and floating configurations. Bi-monthly sampling primarily occurs between March and November. Biological samples are collected with each haul. Program 915 provides abundance indices or catch-at-age information for blue crab, striped bass, red drum, southern flounder, weakfish, and spotted seatrout assessments.

Additional fishery-independent data collection programs

DMF conducts numerous short- and long-term survey and sampling programs to address important areas of assessment uncertainty, including, but not limited to:

- Striped bass electroshock sampling in the CSMA (led by WRC)
- Red drum longline survey
- Red Drum Seine Survey
- Sinking gill net survey in the Lower Cape Fear River
- Albemarle Sound Independent Gill Net Survey
- Striped mullet electroshock sampling

Also, tagging and genetics studies are conducted to help identify stock units, mortality rates, growth, and other important life history information. DMF (often in collaboration with WRC) conducts tagging programs for striped bass, red drum, spotted seatrout, and southern flounder to better characterize the migration, growth, habitat use, and status of each stock (NCWRC et al. 2012). Genetic samples are collected for several species, including striped bass, river herring, and American shad. In combination with academic studies, vital life history information is being collected by these agencies that will help reduce assessment uncertainty.

DMF has developed an extensive set of fishery-independent survey programs that have been expanded and improved over several decades. Given the amount of effort DMF expends on surveys, it might be advantageous for the agency to conduct a comprehensive evaluation of its most pressing state and regional stock assessment needs (ASMFC 2013, NCDMF 2016b) relative to the data being generated by existing programs. Given the large amount of riverine and estuarine habitat in North Carolina waters, many of the survey programs provide only indices of abundance for juvenile or subadult fish. However, these indices are often not as useful in assessments as indices of adult abundance for estimating biomass and fishing mortality, especially for longer lived species and species for which juveniles are not selected by the fishery. If reducing assessment uncertainty is top priority, DMF may find that strategic reallocation of fishery-independent survey and sampling resources toward programs that track the fished portion of the population may be more beneficial.

Recommendations

- Transition commercial dealers to electronic reporting as soon as possible.
- Encourage and fund continued studies to improve commercial landings statistics.
- Implement a for-hire census logbook program.
- Continue valuable supplemental recreational sampling programs such as the CSMA creel survey and mail survey to better characterize harvest of fish species and gears not surveyed adequately by MRIP.
- Support permanent and adequate funding of DMF's Observer Program to ensure the program exceeds the minimum percent coverage required and provides useful bycatch information for stock assessments.
- Establish a permanent and comprehensive shrimp trawl observer program covering all seasons, regions, and gears.
- Conduct a comprehensive evaluation of state and regional stock assessment needs relative to existing survey goals and designs.

Stock assessments

Assessment of North Carolina stocks is inherently challenging because of the state's complex make up of extensive estuarine, riverine, and ocean systems, and because the state straddles both the Northeast and Southeast Continental Shelf Large Marine Ecosystems. Thus, adequately characterizing stock structure is a challenge for many species in the state. Multiple assessments are or may be needed to accurately characterize population dynamics for many species in the region (e.g., striped bass, black sea bass, hard clam, etc.). Taking into account these inherent stock assessment challenges, specific comments on the strengths and weaknesses of both state-specific and regional assessments are provided below.

State-specific assessments

DMF should be commended for conducting state-specific assessments that inform local management. Stock assessments conducted by DMF range from quantitative traffic light analyses to advanced sex and age/length-structured models that employ cutting edge assessment techniques. For several stocks, DMF has attempted to utilize all available data and account for as much biological realism as possible in order to produce quantitative stock assessments that support management decisions (e.g., spotted seatrout, northern striped bass stocks).

However, some of North Carolina's most valuable species have not been adequately assessed. Despite previous modeling work (Eggleston et al. 2004) and a published catch-survey analysis-based stock assessment model for the North Carolina blue crab stock (Colton 2011, Colton et al. 2014), DMF continues to use a quantitative traffic light approach for assessing its most valuable fishery (Burgess and Bianchi 2004, NCDMF 2016a). The 2011 stock assessment lists several uncertainties that were deemed insurmountable, including lack of clarity about the unit stock, lack of discard data, limited recreational harvest estimates, variable estimates of natural mortality, differing size limits, and lack of coherence between pre-recruit and recruit indices, etc. (NCDMF 2013). However, assessments of other blue crab and crustacean stocks have overcome these challenges with creative quantitative solutions. For example, the Chesapeake Bay blue crab stock assessment employs a multi-survey catch-survey model (Miller et al. 2011). Also, the American lobster fishery utilized multiple substock applications of the catch-survey model to account for regional surveys and regulations before additional data allowed a statistical catch at length model to be adopted (ASMFC 2009). Issues regarding lack of coherence between pre-recruit and recruit abundance indices are the most troubling; index standardization techniques should be explored to account for factors affecting catchability of blue crabs of different age/size classes in available surveys which were not designed to target blue crab. Given the value of the resource to the state, movement in the direction of a quantitative assessment for blue crab should be a top priority.

Another disconcerting aspect of the blue crab assessment is the characterization of the stock assessment and management process as being “adaptive”. Comparing a series of indices to a set of annual triggers is not true adaptive management as the term has come to be applied in resource management (Walters 1986). There is no plan in the FMP for iterative decision making, model-based inference, development of objectives-based utility functions, or formal evaluation of alternative management options and harvest policies. That being said, several valuable state fisheries such as blue crab and penaeid shrimp would be prime candidates for a true adaptive resource management framework; DMF should consider moving in that direction if resources can be made available.

In addition to blue crab, the Central Southern Management Area (CSMA) striped bass stock assessment is not yet quantitative enough to provide adequate information to managers. Historically, the entire stock unit was assessed using catch curves and inspection of survey trends. CSMA striped bass has a quantitative assessment for only a portion of the area, the Neuse River, and that work is conducted by North Carolina Wildlife Resources Commission Inland Fisheries Division staff (Rachels and Ricks 2015). Hopefully, tagging research recently concluded in the Neuse River will be incorporated into the next Neuse River striped bass stock assessment (Bradley 2016). Despite scientists’ best efforts to collect data across CSMA and assess the Neuse River system, numerous research projects have shown that the current management program in the CSMA has been unsuccessful and the stock is reliant on a stocking program (Dobbs 2013, Callihan et al. 2014, Knight 2015, Bradley 2016). Without a quantitative stock assessment, managers will have the opportunity to delay action due to scientific uncertainty. It is imperative that DMF cooperate closely with WRC to expand efforts to quantify the effect of fishing effort on the stock to other portions of the CSMA and determine how fishing might be hindering recovery.

DMF’s most recent spotted seatrout assessment model accounts for many intricacies of the stock and its fisheries using a modern assessment approach (NCDMF 2014). One area for improvement would be the explicit consideration of overwinter cold weather mortality effects. Although indices of abundance already used in the model may adequately capture the historical response of the stock to overwinter mortality, the MFC may wish to respond quickly each spring to winter kill events in a way that cannot be addressed by a traditional assessment approach. DMF might want to consider conducting a simulation study using historical data to determine if some type of formalized management trigger system based on winter temperatures might be effective at lessening the negative effect of winter kills on the spotted seatrout stock.

The penaeid shrimp stocks in North Carolina are extremely valuable to both the local economy and the ecosystem (NCDMF 2015b). However, a traditional quantitative assessment has not been conducted because natural mortality is thought to be greater than fishing mortality and because recruitment is thought to be driven by environmental conditions (NCDMF 2016c). Regardless, a quantitative population modeling framework for understanding and predicting shrimp dynamics could provide useful information for understanding broader ecosystem dynamics in North Carolina estuaries. Even if fisheries reference points are not needed to adequately manage the shrimp stock, information about shrimp availability as prey could be important information for the study and management of predator stocks.

The status of several other important stocks is unknown due to lack of any (qualitative or quantitative) stock assessment. For example, an assessment has not yet been conducted for the popular sheepshead stock despite record high estimates of harvest in some recent years (NCDMF 2016a). Hickory shad has no stock assessment; however, there is no minimum size limit for this species and harvest has almost doubled between 2013 and 2015. Hard clam has no assessment and insufficient data collection despite increased landings in many areas in recent years. The level of fishing allowed relative to the lack of information for these stocks is a potentially dangerous situation. DMF risks seriously mismanaging stocks with unknown status unless reliable science can be produced to support current management decisions.

Regional assessments

The ranges of many species in North Carolina are not confined to state boundaries. Thus, the assessment and management of these species requires regional cooperation through the multi-agency initiatives. North Carolina has historically been an active participant in interstate (ASMFC) and federal (SEDAR) stock assessment processes and should be commended for recent participation or commitments to participate in assessments for species such as Atlantic croaker, spot, American eel, red drum, and (likely) cobia. Given the poor performance and potential stock unit definition issues associated with the 2014 state-specific stock assessment for southern flounder (NCDMF 2015c), DMF should be commended for moving forward with a multi-state effort to regionally assess southern flounder. One additional species that would benefit from a regional assessment effort would be southern kingfish (NCDMF 2015a, 2016b).

DMF has a responsibility to carry a large portion of the stock assessment burden in the region given North Carolina is a significant source of commercial and recreational removals for many coastal migratory stocks (NCDMF 2016a). Among the five migratory or partially migratory (spotted seatrout) stocks considered in the economic portion of this study (Report #1: An evaluation of the biological and economic benefits of improving the status of seven North Carolina stocks), North Carolina has the highest commercial removals with the exception of Atlantic croaker (Figure 3). Recreationally, North Carolina harvests the vast majority of the northern stock of red drum as well as weakfish, a seriously depleted coastwide stock (Figure 4) (ASMFC 2016).

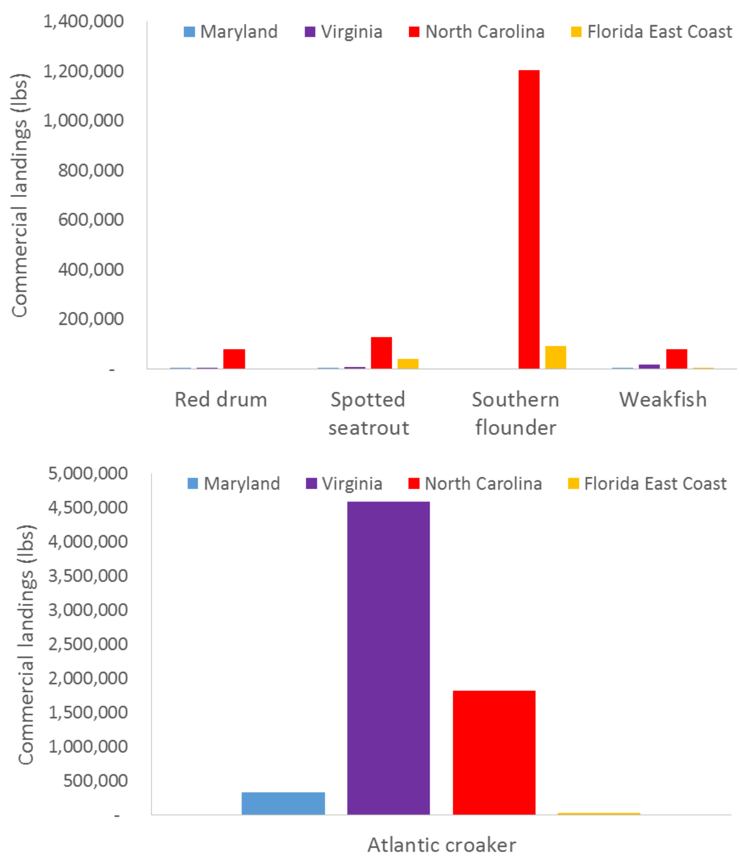


Figure 3. Commercial landings (lbs) in 2015 of red drum, spotted seatrout, southern flounder, weakfish, and Atlantic croaker from Maryland to Florida (NMFS commercial landings statistics).

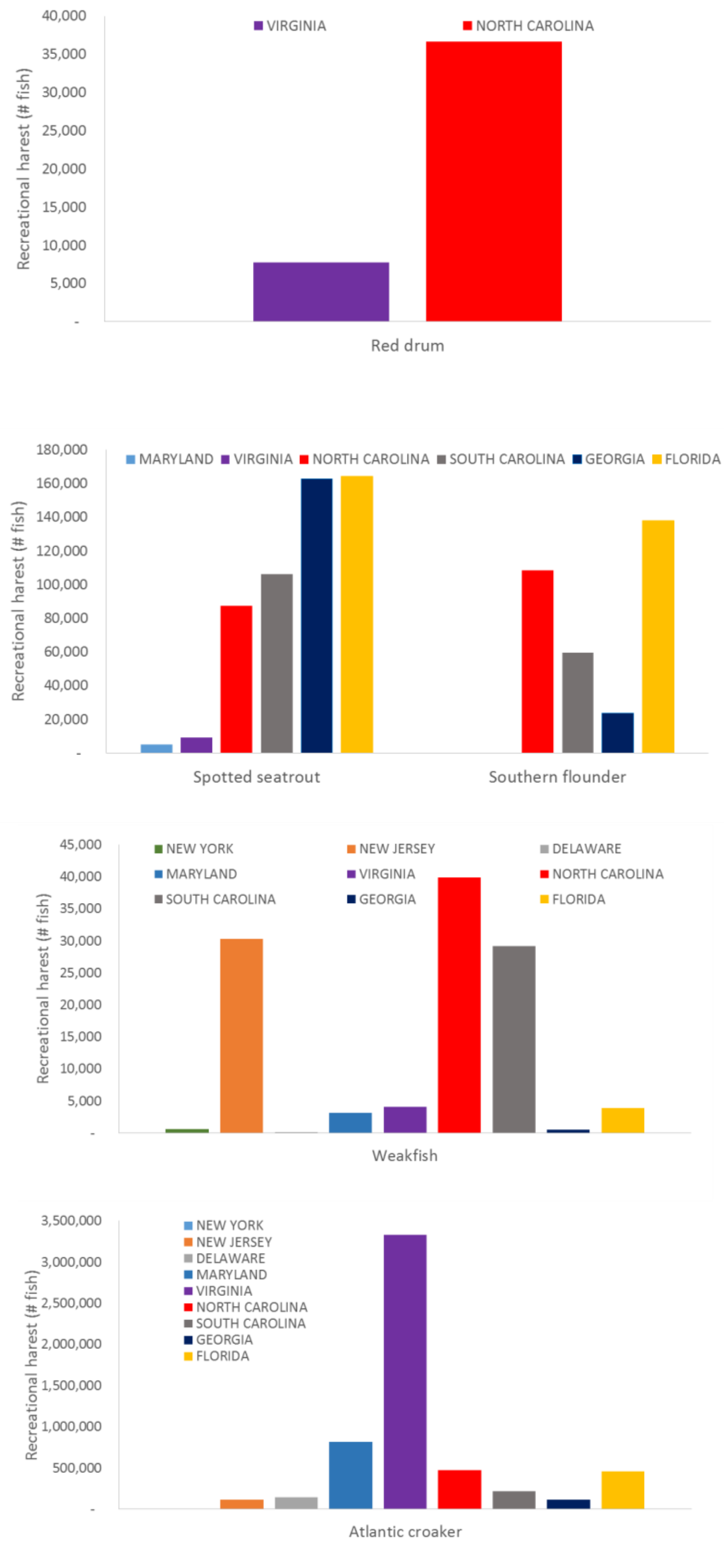


Figure 4. Recreational harvest (numbers of fish) in 2015 of red drum, spotted seatrout, southern flounder, weakfish, and Atlantic croaker by state (MRIP saltwater recreational statistics).

Several regional assessments are hindered by uncertainties due in part to North Carolina data deficiencies. For example, the 2010 Atlantic croaker assessment barely passed peer review because estimates of shrimp trawl bycatch (primarily in North Carolina estuaries where croaker is the top bycatch species by volume) were deemed inadequate (ASMFC 2010). DMF could dramatically reduce uncertainty in the Atlantic croaker assessment by providing long-term, catch-at-age and bycatch information from all sectors, especially the shrimp trawl fishery. Another major source of uncertainty in the 2010 croaker assessment was removals (total and composition) of the scrap/bait fishery. DMF should also continue to improve monitoring and sampling of the scrap/bait fishery which also catches large amounts of Atlantic croaker.

Another regional assessment that relies heavily on North Carolina data is red drum. The 2009 assessment of the northern red drum stock utilized three indices based on North Carolina surveys and one index based on the Marine Recreational Fisheries Statistics Survey (SEDAR 18 2009). The maximum age in the assessment was seven; however, the maximum age represented by the available surveys in North Carolina was age 2 (and only age 3 for the regional MRFSS index). Therefore, there was no fishery-independent data informing the assessment of trends in fish ages 4-7+. Hopefully, DMF's longline survey, which catches older fish, will prove informative in the ongoing 2016 assessment. In addition to survey data concerns, lack of adequate sampling for recreational discard age composition forced analysts to use DMF tagging study data to characterize recreational discard selectivity in the 2009 regional assessment. However, a large portion of tagging effort in that program has been historically concentrated near the mouth of the Neuse River and Ocracoke Inlet (SEDAR 18 2009). Also, most fish tagged (especially in the early part of the program) were juveniles or subadults (ages 1-4). Hopefully, sufficient recreational discard data have been collected since 2009 such that the 2016 assessment need not rely so heavily on DMF tagging data which may be affecting the assessment in unforeseen ways.

The regional weakfish stock assessment completed in 2016 indicated that the stock was seriously depleted due to a significant recent increase in natural mortality (ASMFC 2016). However, the source of increased weakfish mortality remains unknown. Tagging studies are underway, but at the present there is insufficient evidence to conclude that increases in predation or disease or decreases in food availability are causing the problem. It is possible that either the adult stock has moved outside the range of the fisheries and surveys or that bycatch mortality is significantly underestimated. It is also possible that past bycatch of weakfish affected the stock in unforeseen ways. Weakfish has historically experienced intense bycatch mortality from North Carolina fisheries. Although bycatch rates have declined with improved bycatch reduction devices and other management regulations, weakfish remains one of the top species caught by volume in the North Carolina shrimp trawl fishery (Brown 2015). The 2016 assessment only used regional (SEFSC Shrimp Trawl Observer Program) estimates of ocean shrimp trawl bycatch to gauge the potential effect of the shrimp trawl fishery on the stock. Even if adult natural mortality is the true problem facing this stock, adequate, long-term monitoring of North Carolina's estuarine and ocean bycatch would help eliminate potential uncertainty regarding the cause of high mortality in the assessment.

In addition to the species discussed above, assessment uncertainty for several other regional stocks could be reduced with increased sampling levels of discarded commercial and/or recreational catch, including, but not limited to river herring, southern flounder, American shad, black sea bass, black drum, scup, Spanish mackerel, spiny dogfish, and spot (NCDMF 2016b).

Research priorities

One way to reduce assessment uncertainty is to conduct research that directly addresses important questions or that fills critical data gaps. DMF recently published a detailed list of research priorities by species which highlights the state's most pressing scientific needs (NCDMF 2016b). This list was generated with the goal of communicating to regional academics and funding agencies the types of research that would best address assessment needs for DMF-managed species.

North Carolina fisheries have long benefited from several strong, academic fisheries science programs located in the region. Continued collaboration and communication with these academic resources will be critical for helping reduce scientific uncertainty in stock assessments and fisheries management decisions. Regular updating of these research priorities will be an important planning tool for DMF that will help ensure critical uncertainties in stock assessments are addressed.

Recommendations

- Conduct quantitative stock assessments for all stocks with FMPs. In particular, explore a catch-survey or other stage-based assessment for blue crab, North Carolina's most valuable fishery.
- Prioritize data and assessment development for stocks with unknown stock status, including sheepshead, shads, shellfish, and bivalve stocks.
- Cooperate closely with WRC to quantify the effect of fishing effort on the entire CSMA striped bass stock and determine how it might be hindering recovery.
- Shift effort from conducting state-specific stock assessments to regional stock assessments, when appropriate.
- Regularly update and distribute research priorities for each species.

Stock assessment process

In addition to data collection, processing, and analysis, the stock assessment process includes numerous procedural steps that introduce uncertainty in the outcomes. Staffing, peer review, and communication of results all contribute to the ultimate success or failure of a stock assessment and its incorporation into management.

Staffing

Quantitative fisheries data analysis and modeling expertise is a critical component of successful stock assessments. DMF should be commended for supporting a dedicated stock assessment team of permanent, full-time employees led by a senior scientist and focused on conducting state-specific assessments and contributing to regional (ASMFC or federal) stock assessments important to North Carolina. Most states do not invest in stock assessment expertise to the extent that North Carolina does.

A persistent challenge for state agencies such as DMF is having sufficient resources to attract and retain highly qualified stock assessment staff. Most stock assessment scientists hold PhD or MS degrees in the field and possess a skill set that is in high demand. The salary range offered by DMF in a November 2016 stock assessment job posting listed the annual salary range of $39,6320 - $63,372 with a recruitment range max of $44,509. Introductory level stock assessment scientist salaries offered by state agencies typically range between $40,000 and 55,000, and federal assessment jobs in the region start at around $58,000 to $60,000. However, most experienced stock assessment scientists conducting the complex, advanced analyses and modeling tasks described in recent DMF job ads typically draw salaries starting at $80,000. With relatively low salaries for junior stock assessment positions, North Carolina will constantly face retention and recruitment issues. Although DMF has been fortunate to attract talented assessment staff in the past, the state and its stakeholders should not expect the amount and quality of the work produced from high turnover departments to be on par with that of other agencies which offer higher salaries and benefit from greater institutional memory. If at all possible, DMF salary ranges should be increased to retain and attract qualified stock assessment staff.

Peer review

DMF should be thoroughly commended for conducting external peer reviews of its stock assessments. DMF typically solicits written ("desk") reviews from three reviewers for each state-specific assessment. Reviewers are asked if the assessment adequately addresses each of the assessment terms of reference. Reviewers have also been asked if the assessment is adequate for use in making management decisions.

The advantage of DMF's assessment peer review structure is that detailed opinions and advice can be sought from a wide range of experts in the field without incurring the cost of an in-person peer review workshop as is typically conducted by ASMFC or NMFS. However, the disadvantage of this approach is that reviewers cannot interact with the assessment scientists and potentially have their concerns addressed with feedback or additional analyses before providing their final determination. For the stocks most valuable to NC and its stakeholders, holding in-person independent peer review workshops may be a worthwhile investment. Seeking outside support for funding high profile stock assessments should be considered as has been done for blue crab in the Chesapeake Bay. Review workshops terms of reference could require the generation of a consensus report from the peer reviewers that may result in more constructive reviews and potentially clearer outcomes for management.

Transparency

Stock assessments, peer reviews, and associated non-confidential assessment materials should be well documented and made publically available. Consistency in reporting should be a goal for DMF stock assessments. Code and input files have been provided in appendices for some but not all recent assessments. Assuming commercial data confidentiality laws are not being violated, making base assessment models publically available encourages transparency.

Stock assessment reports are difficult to find on the DMF website and are often buried in FMPs or Marine Fisheries Commission briefing books. The stock status pages (e.g., CSMA striped bass) for each species are updated annually and could contain links to all relevant assessment materials so that policy makers and stakeholders have easy and consistent access to the valuable information DMF produces for each stock.

Recommendations

- DMF salary ranges should be increased to retain and attract qualified stock assessment staff.
- Consider holding peer review workshops for high priority stock assessments.
- Increase transparency by posting non-confidential stock assessment materials on the DMF website in an easily accessible place such as the stock status page for each species.

Conclusions

DMF conducts extensive data collection, analysis, and assessment programs to support fisheries management at both the state and regional level. Given the magnitude and diversity of ecosystems and fisheries in North Carolina, providing adequate data for modern stock assessments is a gargantuan task. DMF must juggle the often competing needs of multiple species and stakeholders when setting data collection and assessment priorities. DMF has risen to the challenge on many fronts, including fishery-dependent data collection, supplemental recreational data collection, and numerous survey and biological sampling programs. DMF's efforts in these areas should be encouraged by stakeholders and legislative budget support.

However, several deficiencies in data collection and analysis have hindered recent attempts to conduct state-specific and regional assessments. From a stock assessment scientist's perspective, I offer the following priority recommendations from the suggestions listed above because they are the most likely to reduce uncertainty for the largest number and most valuable state and regional stock assessments:

- Transition commercial dealers to electronic reporting as soon as possible.
- Support permanent and adequate funding of DMF's Observer Program.
- Establish a permanent and comprehensive shrimp trawl observer program covering all seasons, regions, and gears.
- Conduct a comprehensive evaluation of state and regional stock assessment needs relative to existing survey goals and designs.
- Prioritize data and assessment development for stocks without quantitative assessments or whose stock status is unknown, including blue crab, shellfish, sheepshead, shads, and bivalve stocks.

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