Tagging Red Drum in North Carolina: Estimating Exploitation, Mortality, Tag Retention, and Tag Reporting Rates for Increased Accuracy of Stock Assessments

Master's Project for Duke University's Nicholas School of the Environment

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Executive Summary

In the 1980's red drum (*Scianeops ocellatus*) were a heavily targeted fishery, causing high mortality rates, due to a continued lack of regulations, which prompted the first fishery management plan (FMP) by the Atlantic States Marine Fisheries Commission (ASMFC) in 1984 (Denson et al. 2002). Overfishing was still occurring as determined by a stock assessment in 1998 by the ASMFC, causing the state to write its first FMP, and decreasing the bag limit to 1 fish per day within the slot limits to further reduce fishing mortality (SEDAR 2017; Smith 2008). In 2009, the ASMFC stock status report showed red drum were no longer experiencing overfishing, but a lack of data on fishing mortality and tagging rates prompted a recommendation for implementing state tagging studies. (SEDAR 2017; Arnott et al. 2015).

This project analyzes the red drum tagging study in North Carolina, using data from fish tagged and released in 2014 by North Carolina's Division of Marine Fisheries to fill in gaps in current stock assessment model. Mortality rates were calculated using an adapted Hoenig model (Age-Independent Instantaneous Rates Model of Jiang et al. (2007) Incorporating Catch and Release Tag Returns) in Program R. Calculations are completed to determine tag retention (ϕ) and tag reporting rates (λ), while the model calculates total mortality (Z) instantaneous rates divided into natural (M), fishing (F), and tag (FA) mortality instantaneous rates. Tag retention represents the probability that a tag will survive, tag reporting rate represents the rate of all tags reported by comparing to rate of high to low reward tags reported, fishing mortality is the rate associated with numbers of fish harvested or discarded, tagging mortality is the rate associated with fish that die off due to tag infection, tag altering defensive mechanisms, etc, and lastly, natural mortality is the rate associated with numbers of fish that die of natural causes.

Tag retention was calculated to be 67.7%, and tag reporting rate was calculated to be 61.7%. Fishing mortalities ranged from 0.033-0.237, tagging mortalities ranged from 0.065-0.371, natural mortality is constant at 0.755, and total mortality ranged from 0.793-1.021.

The calculated mortalities are lower than the range of estimated red drum mortalities in the past and for the region, supporting the 2017 regional stock assessment (SEDAR 44) stating that red drum are no longer experiencing overfishing. This does not mean the stock is fully recovered, but shows that management decisions thus far have helped allow the population to recover from overfishing. Peer reviewers of SEDAR 44 recommended developing methods to become more educated on abundance and mortality of mature fish as any overfishing can be detrimental to the entire stock (SEDAR 2017). Future tagging studies implementing telemetry tags in addition to the standard tags will lead to more increased accuracy of mortality rates, to include the mature fish living offshore (Pine et al. 2003).

This project can be used as an example for analyzing tagged fish implementing catch and release data, to help improve future stock assessments.

Table of Contents

Introduction

Red drum (*Sciaenops ocellatus*) is the state saltwater fish of North Carolina and are a highly sought after and economically valuable game fish (NCDMF 2017; Porch 2009). In the last 10 years, red drum have consistently been in the top 5 most targeted fish species in the inland waters out to 3 miles offshore (NCDMF 2016). The recreational fishing sector makes up more than 60% of red drum caught in North Carolina and in 2006, the recreational angler industry spent around $50 million strictly on fishing for red drum (NCDMF 2008). More than half a million recreational trips targeting red drum directly are taken each year (NCDMF 2016). World record drum have been caught in North Carolina since the 1950's, with North Carolina still the world record holder for 10 out of 16 spots, drawing anglers to the area (NCDMF 2017; Ross et al. 1995).

Commercially, North Carolina has the highest number of landings (~90%) on the Atlantic Coast, as only states in the northern stock of red drum (New Jersey to North Carolina) have a commercial fishery (ASMFC 2017). North Carolina caps commercial landings at 250,000 pounds each year, with a calendar year starting September 1st (Arnott et al. 2015). A majority (~90%) of the red drum harvested commercially are caught with gill nets in the Pamlico Sound (SEDAR 2017; Burgess & Bianch 2004; Ross et al. 1995). Other names they are known by include redfish, spottail bass, channel drum, and juveniles (ages 1-4) are also known as puppy drum (NCDMF 2017).

Life History

Red drum are silver to red in color, with one or more black spot near the base of the caudal fin, and get their namesake from a drumming sound they produce by vibrating muscles in their swim bladders during spawning season (NCDMF 2017; ASMFC 2010). They are an estuarine-dependent species, with a range extending from Massachusetts down to Florida and into the Gulf of Mexico (Ross et al. 1995). They are bottom feeders, eating small crabs, shrimp and sometimes fish in the water column (NCDMF 2017; ASMFC 2010). Tailing is a feeding habit they occasionally exhibit when bottom feeding, where their tail is displayed above the water (NCDMF 2017).

During the first year of life, the red drum can grow up to 12-14 inches (total length), and at about 20 months many drum are already within the legal size limit for harvesting, with the minimum size being 17 inches (NCDMF 2008). The maximum size limit for keeping red drum is 27 inches, which occurs sometime before the drum reach 3 years of age, meaning majority of harvested red drum are juveniles (NCDMF 2009; Porch 2009). Maturity is reached by age 4 for females and age 3 for males, with a maximum life expectancy of 62 years (SEDAR 2017).

Spawning takes place in the fall in estuarine and coastal waters, peaking in August to September (ASMFC 2010; Ross et al. 1995). Red drum need high salinity waters (~25-35 ppt) for optimal spawning conditions, and the larvae are able to live in freshwater and high salinity waters, with optimal growth occurring in salinities of 5-10 ppt (NCDMF 2008). This optimal salinity only occurs in estuarine waters, making it primary nursery habitat for red drum (NCDMF 2008). Adult drum (ages 4+) migrate offshore, roughly 10-15 km out, after reaching maturity, returning to estuaries for spawning (Ross et al. 1995). The largest and oldest red drum are found between Cape Lookout and the Virginia Barrier Islands, at the mouth of the Chesapeake Bay, with the oldest known red drum captured at 62 years old (Ross et al. 1995). Little information is known about red drum once they mature and head offshore, making assessments on abundance and management difficult with the limited data available.

Management

The red drum commercial fishery was happening in 1930's, with fishing pressure increasing until the stock crashed after overfishing began in the 1950's (Latour et al. 2001). In the 1980's, red drum were experiencing high mortality rates from the increasing fishing effort due to a continued lack of regulations, which prompted the first fishery management plan (FMP) by the Atlantic States Marine Fisheries Commission in 1984 (Arnott et al. 2015; Denson et al. 2002).

Management started around the time the fishery crashed and the stocks were assumed to be well overfished. Restrictions on harvest in North Carolina by the state's Division of Marine Fisheries (NCDMF) were first put in place in 1976, allowing each angler to keep 2 fish larger than 32 inches in total length per day (NCDMF 2008). The Atlantic States Marine Fisheries Commission (ASMFC) made the first regional FMP in 1984, and released an amendment in 1990 where it defined optimum yield and overfishing in alignment with the Magnuson-Stevens Fishery Conservation Act (MSFCA). Up until this amendment, there was no definition for quantifying if a stock was experiencing overfishing or overfished (NCDMF, personal communication). Red drum are divided into a northern and southern stock for management by the ASMFCA and North Carolina's drum fall in the northern stock (SEDAR 2009). A moratorium on red drum in federal waters was put in place in 1990, and at the same time the state mandated that only 1 adult drum over 32 inches could be kept, but 5 juveniles could be kept each day (NCDMF 2017; Arnott et al. 2015). State regulations were changed again in 1992, only allowing the harvest of 5 fish between the sizes of 18 and 27 inches, and 1 adult over 27 inches (Smith 2008). Legal harvest of adult drum over 27 inches ended in 1998 (NCDMF, personal communication).

Overfishing was still occurring as determined by a stock assessment in 1998 by the ASMFC, causing the state to write its first FMP, and decreasing the bag limit to 1 fish per day within the slot limits to further reduce fishing mortality (SEDAR 2009; Smith 2008). In 2009, the ASMFC stock status report showed that red drum were not experiencing overfishing, but due to a lack of data and limitations of standard stock assessments, peer reviewers recommended states implement tagging studies (Arnott et al. 2015; SEDAR 2009). These tagging studies can produce accurate fishing mortality rates than can be utilized in stock assessments to increase accuracy, or be used as an indicator of stock health between stock assessments (SEDAR 2009). Lack of data on tag reporting and retention rates also prompted the tagging studies to be a priority to eliminate gaps in data (SEDAR 2009). Reliable numbers for abundance, mortality, and population size are necessary for most effective stock assessments and analysis to guide management decisions (Pine et al. 2003).

Tagging Study

Although red drum have been tagged for studies since 1983 by NCDMF, they were most recently granted funding from the North Carolina Coastal Recreational Fishing License Fund to start a multispecies tagging study to gather life history and mortality information for stock assessments, with red drum being one of the targeted species (NCDMF 2013). The main objectives of the multispecies tagging study include the following: (1) estimating tag reporting rates, tag retention rates, fishing mortality, and migration rates, (2) estimate fishing mortality by fate (harvest or release), age, and fishing sector, and (3) assess annual variation in fishing and natural mortalities. The tagging study is being conducted to fulfill the research requirement requested by the ASMFC to help improve stock assessments, because tag return models provide direct fishing mortality estimates and better estimates of natural mortality and abundance. Improved mortality and abundance rates lead to more accurate population assessments.

Assumptions associated with the tagging study are that no tags are lost, mortality of tagged fish doesn't differ from mortality of untagged fish, and that all tags are reported (NCDMF 2013). To account for tag loss, some fish were double-tagged to determine tag retention rate and account for tag loss when estimating mortalities (NCDMF 2013). Tag mortality is estimated with the model used in the analysis of this project. High reward tags ($100) are used in conjunction with low reward tags ($5) to determine the percentage of tags reported, based on another assumption that 100% of all high reward tags are reported (NCDMF 2013).

The Division of Marine Fisheries set a goal to tag 1000-5000 red drum per year from 2014-2017, with at least 1500 a year tagged by DMF employees during sampling, and 1000 per year by trained volunteers (NCDMF 2013). In an updated list of research priorities suggested for red drum by the ASMFC, they want the tagging study to be ongoing to determine migration patterns, abundance, and mortality as well as testing the use of direct estimates of fishing mortality in stock assessment models (NCDMF 2013).

Objectives

This project analyzes the red drum section of the multispecies tagging study conducted in North Carolina. Adaptations of the Brownie et al. (1985) models developed by Hoenig et al. (1998) and further adapted to include released fish in the models by Jiang et al. (2007) are used in the final assessment of all red drum tagged and released in 2014. Calculations are completed to determine tag retention (ϕ) and tag reporting rates (λ), while the model calculates total mortality (Z) instantaneous rates divided into natural (M), fishing (F), and tag (FA) mortality instantaneous rates.

The goal of this project is to calculate more accurate estimates of tag retention, tag reporting rates, fishing and natural mortality. Management of red drum requires knowing what is coming out of the population (F, M & Z) to regulate the population and ensure there is enough brood stock for sustaining the population. Results of this project will lead to more accurate data for filling in gaps in current stock assessment models, leading to an overall increased accuracy of stock assessments of red drum in North Carolina and more informed management decisions.

Methods

Tagging Protocol

Red drum for tagging were captured through a variety of survey methods such as longlines, gill nets, trammel nets, electrofishing, hook-and-line and any other methods available. As written in the NCDMF red drum tagging protocol, fish under 27 inches were tagged with wire-core internal anchor tags in a specific location behind the pelvic fin above the belly (Figure 1), while fish larger than 27 inches were tagged with stainless steel dart tags, 3-4 scale rows behind the middle of the dorsal fin (Figure 2)(NCDMF 2013). Only fish that were healthy and in great condition were tagged and released. Between NCDMF employees and volunteer taggers, roughly 2500 tags were put out in 2014, and of those, about 100 were high reward tags, and approximately 20-25% of low reward fish tagged were double-tagged.

Figure 1 (left image): A juvenile red drum has been tagged with an internal anchor tag in the belly during a South Carolina tagging study; image sourced from The Charleston Angler. Figure 2 (right image): Volunteers are tagging a mature drum with a steel dart anchor tag; image sourced from The Tailing Fin.

Data Collection

Reported tags were called in to NCDMF, where they were input into a graphical user interface for storage and organizing. Information retrieved from the reported tags included fork length, date, location, tag number, tag reward, and if the fish was harvested or released. Data from red drum tagged and released in 2014 was retrieved from NCDMF for this project. Reporting rates seemed low for volunteer-tagged fish that improper tag placement was assumed, so volunteer data was not utilized in this project. The initial assumption of low rates being associated with volunteer tagging methods was incorrect, and will be discussed later. A total of 1,410 fish were tagged and released by DMF employees for use in this project. Of the 1,410 fish, there were 86 high reward tags and approximately 161 fish double-tagged.

Reported fish were extracted from the whole data set, and tag numbers, released and recaptured dates, tag reward value, and harvested or released status were used to calculate tag retention and tag reporting rates. Recaptures for the fish tagged in 2014 was available through June 2016 and used for analysis.

Tag Retention

Tag retention (ϕ) was calculated using data from reported double-tagged fish. This number represents the probability a tag will survive (i.e. not come out of the fish). Many tagging studies make the assumption that tag loss is equal to zero, causing decreased accuracies in the final assessment (Myhre 1966). There were 34 double-tagged fish reported that were released in 2014. Retention was calculated by subtracting the proportion of tags lost to tags released from one (Equation 1).

$$\phi = 1 - \frac{T_l}{T_r} \qquad \text{(Eq. 1)}$$

Number of tags lost at recapture was represented by T_l, and number of tags released was represented by T_r (Myhre 1966). This gives the tag survival probability input necessary for the updated Hoenig model.

Tag Reporting Rate

Tag reporting rate (λ) was calculated using the reported fish separated into which fish were high and low rewards. The formula for reporting rate was used under the assumption that 100% of high reward tags were recognized and reported (Smith et al. 2011). This assumption was made because of the $100 reward associated with high reward tags that would cause a perfect return rate, based on nobody refusing that much free money. (Pollock et al 2001). Reporting rate estimates the number of low reward tags that are not reported to account for a better representation of the entire drum population. There were 1,324 and 86 low and high reward tagged fish released, respectively. Reporting rate was calculated by comparing the number of tags released and reported at both the low and high reward value (Equation 2).

$$\lambda = \frac{(R_s)(N_r)}{(R_r)(N_s)} \qquad \text{(Eq. 2)}$$

R_s was the number of low reward tags reported, N_r was the number of high reward tags released, R_r was the number of high reward tags reported, and N_s was the number of low reward tags released (Pollock et al. 2001).

Mortality Estimates – Adapted Hoenig Model

The Brownie et al. (1985) model is commonly used for evaluation of terrestrial capture-recapture studies (Pine et al. 2003). It is capable of calculating survival rates, tag recovery rates, and mortality for multiyear tagging studies, but it does not calculate mortality as instantaneous rates, which is preferred by fisheries biologists and managers (Hoenig et al. 1998). Hoenig et al. (1998) developed a new model that is a variation of the Brownie model to calculate the instantaneous fishing, natural, and total mortality rates for fish populations, and incorporates fishing effort into the model for increased accuracy of F estimates. That model does not account for catch-and-release fisheries, which is addressed and implemented into an adaptation of the Hoenig model by Jiang et al (2007). Hooking mortality was input into the adapted Hoenig model to account for any mortalities associated with release.

In this project, tagging data for North Carolina red drum was analyzed using the instantaneous tag-return Hoenig model extension (hereby referred to as adapted Hoenig model) by Jiang et al (2007), that accounts for recaptured fish that are either harvested or released.

The adapted Hoenig model can be accessed in the "fishmethods" package for Program R, as the irm_cr function ("Age-Independent Instantaneous Rates Model of Jiang et al. (2007) Incorporating Catch and Release Tag Returns")(Nelson 2016). Variables necessary for input included the calculated tag retention and reporting rate, with independent values for fish that were harvested upon recapture or released for both rates, hooking mortality rate, years of release and recapture, and a matrix of harvested versus released fish by year. F and M were both highly dependent on ϕ and λ (Latour et al. 2001). Hooking mortality was retrieved from NCDMF and ASMFC, with the rate calculated based on a literature review of hooking mortality studies on red drum along the east coast of the United States and in the Gulf of Mexico.

The matrices for harvested and released recaptured fish was executed using pivot tables in Microsoft Excel. The matrices and completed code used for analysis using the adapted Hoenig model are in Appendix 1. Variations of input years for the different output variables (Fyr, FAyr, and Myr) were tested to determine the best fitting model, as denoted by the lowest Akaike information criterion (AIC) value. The AIC value is a measure of information that informs the model user of the uncertainty that the model may have, allowing the user to select the model that best fits the given data and complexity of the model (Burnham & Anderson 2003).

Outputs of the model included *F,* tag mortality (*FA*)*, M*, *Z*, and survival (*S*). Additional information related to how the model runs can be found in the Jiang et al (2007) and Nelson (2017) publications.

Results

Tag Retention, Reporting Rate, & Hooking Mortality

Tag retention was estimated to be 67.7%, and tag reporting rate was an estimated 61.7%. Due to small sample size, ϕ and λ were estimated by combining the harvested and released fish. These numbers were applied across all three years of the matrices due to lack of time to organize the raw data for 2015 and 2016 released fish. Hooking mortality is assumed to not change over time and is 8.0%, representing the average across hook types and sizes along with associated injuries.

Estimated Mortalities

The model variation with the lowest AIC value of 1770.02 involved the following variables and their associated values: Fyr (2014,2016), FAyr (2014,2015,2016), and Myr (2014). The code for the final model run can be found in Appendix 1. The unpooled Chi-square value for this model run was less than 0.001, with a high p-value of 1, corroborating that this model was the best fit for the provided data. *F* ranged from 0.03-0.24, *FA* ranged from 0.07-0.37, *M* is constant at 0.76, and *Z* ranged from 0.79-1.02. Each years' estimated mortality, standard error and variance are located below (Table 1) and the raw output can be found in Appendix 2.

	F (Fishing Mortality)			**FA (Tag Mortality)**			**M (Natural Mortality)**		
Year	*F*	*Variance*	*Standard Error*	*FA*	*Variance*	*Standard Error*	*M*	*Variance*	*Standard Error*
2014	0.237	0.001	0.039	0.199	0.001	0.029	0.755	0.024	0.155
2015	0.237	0.001	0.039	0.371	0.017	0.131	0.755	0.024	0.155
2016	0.033	0.001	0.038	0.065	0.004	0.061	0.755	0.024	0.155

	Z (Total Mortality)			**S (Survival)**		
Year	*Z*	*Variance*	*Standard Error*	*S*	*Variance*	*Standard Error*
2014	1.008	0.034	0.185	0.365	0.005	0.068
2015	1.021	0.035	0.186	0.360	0.004	0.068
2016	0.793	0.031	0.178	0.453	0.006	0.080

Table 1: Estimated mortality and survival results including variance and standard error for fish released in 2014 and recaptured in years 2014-2016.

Discussion

Tagging Rates

Bacheler et al.'s 1983-2006 analysis of red drum used volunteer taggers, which influenced the initial assumption in this project that volunteer taggers were the cause of low retention and reporting rates. Volunteer taggers only used steel dart shoulder tags, and a quick analysis of reporting rate by tag type (steel dart) showed no significant difference between volunteer and NCDMF tagged fish, but a difference between reporting rate by tag types was present.

Bacheler et al. estimated ϕ by tag types and found steel dart and internal anchor tags to have respective rates of 74% and 91%. By combining tag types in the analysis of retention and reporting rates in this project, unintentional bias was introduced to this project. The tag retention rate for both types combined in this study (67.7%) is lower than the estimated retention for steel dart or internal anchor tags estimated by Bacheler et al. Analyzing λ and ϕ by tag type needs to implemented in the completed analysis of the multispecies tagging study.

In a study using low and high reward tags to determine λ for red drum in South Carolina and Georgia, a reporting rate of 60.1% was estimated, very similar to the 61.7% estimated λ in this study (Denson et al. 2002). Their study showed how tags with 'Reward' written on it had a similar reporting rate to tags labeled with '$100 Reward', as anglers who do not get out as much may be unaware that there are 2 different tag types. With increased awareness of the tagging program, angler behavior changes, causing anglers to look for the tags, increasing λ (Pollock et al. 2001). The most effective way to avoid problems with rewards being concentrated to one area are to tag and release small batches of fish in a variety of locations (Pollock et al. 2001).

Model Fit

Variations of the model had to be tested to determine which run provided the best fit for the data (Table 2). The top AIC-supported model estimated F as a constant from 2014-2016, annually varying FA, and a constant M. While other models had similar AIC estimates, this top-rated model appeared to be the most frugal. Other variations with higher AIC values had similar calculated mortalities, leading to the conclusion that even with the limited data, the final mortalities calculated are accurate (Table 2).

Model Variation	Fishing Mortality			Tag Mortality			Natural Mortality			AIC Value
	2014	*2015*	*2016*	*2014*	*2015*	*2016*	*2014*	*2015*	*2016*	
$F_{2014\text{-}15,2016}$; $FA_{2014,2015,2016}$; $M_{2014\text{-}16}$	**0.237**	**0.237**	**0.033**	**0.199**	**0.371**	**0.065**	**0.755**	**0.755**	**0.755**	**1770.02**
$F_{2014\text{-}15,2016}$; $FA_{2014,2015,2016}$; $M_{2014\text{-}15,2016}$	0.237	0.237	0.034	0.199	0.371	0.068	0.757	0.757	0.813	1772.02
$F_{2014,2015,2016}$; $FA_{2014,2015,2016}$; $M_{2014\text{-}16}$	0.226	0.194	0.023	0.19	0.305	0.045	0.661	0.661	0.661	1772.02
$F_{2014\text{-}15,2016}$; $FA_{2014\text{-}15,2016}$; $M_{2014\text{-}16}$	0.195	0.195	0.029	0.195	0.195	0.029	0.536	0.536	0.536	1772.04

Table 2: Varying the years of calculated mortalities altered the AIC value of the model. The brackets in the model variation column represent the variations in the code for Fyr, FAyr, and Myr, respectively. The first row is the best-fit model used for analysis.

Mortality Rates

In this study, *F* ranged from 0.03-0.24 over 2014-2016. A study done by Bacheler et al. (2008) estimated how *F* varied over the 1983-2006 tagging period as there were 2 major regulation changes during that time. The size slot limit and bag limit were both set in 1992 and in 1999 bag limit decreased from 5 fish to 1 fish (Bacheler et al. 2008). From 1983-1991 the average fishing mortality was calculated to be 2.38, from 1992-1998 was 0.59, and from 1999-2006 was 0.90 (Bacheler et al. 2008). Estimates of *F* in 2014 are lower than estimates between 1983 and 2006, showing that *F* is down in recent years to a more manageable rate.

Ross et al. (1995) estimated *Z* for red drum in North Carolina using tagged fish data collected in 1987-1990 to be 1.56-2.88. These high mortality rates indicate low survival rates of juvenile red drum to maturity (Ross et al. 1995). In South Carolina, a tagging study from 1991-1999 estimated *Z* to range from 0.97-1.85 and *F* from 0.31-0.71 (Latour et al. 2001).These mortality estimates also indicate low survival rates, in turn indicating recruitment numbers may not be high enough to sustain the population (Latour et al. 2001).

Calculated *FA* increases in the second year (2015) for an unknown reason. Further information about how the model calculates tag mortality and what can alter it will be needed to further pinpoint why this occurred.

F and abundance of red drum in the northern stock of the ASMFC managed fish shows a decreasing trend over the years, with a spike in fishing mortality occurring in 2013 (Figure 2) (SEDAR 2017). The spike is attributed to a spike in spawning stock biomass that year (SEDAR 2017). The estimated fishing mortality in this paper follows the decreasing trend, as depicted in Figure 2 by the dotted line, leading to the conclusion that North Carolina's regulations are working to keep *F* down to prevent overfishing.

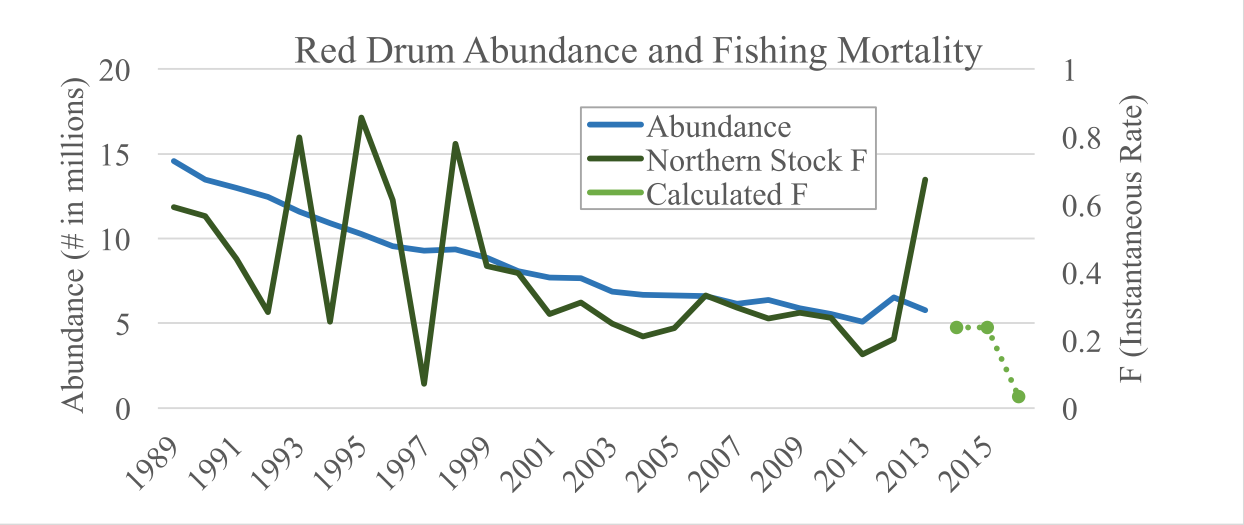

Figure 2: Graph showing abundance and recreational fishing mortality for the entire northern stock of red drum managed by the ASMFC (SEDAR 44). The light green line in the bottom right represents the calculated fishing mortality for red drum strictly in North Carolina waters.

In February of 2017, the ASMFC issued a press release stating that red drum is not experiencing overfishing. The most recent stock assessment report on red drum released by the ASMFC

(SEDAR 2017) showed that static spawning potential ratios (sSPR) of the stock between 2011 and 2013 was 43.8%, and the target threshold is 40% (ASMFC 2017). Although currently above the target threshold, is fishing effort stays constant at the present rate, it has the potential to cause stocks to decline, decreasing the sSPR to fall below the target level within the next few years (SEDAR 2017). Peer reviewers of SEDAR 44 suggest that any future management decisions that leave room for an increase in *F* be avoided until the exact population size can be determined (SEDAR 2017).

Limitations

This project assessed tagging data released in 1 year (2014) and recaptured over a 3 year (2014-2016) period. Useable results can be attained with only 2 years of data, although 3 years is suggested, and 5 or more years of data will give the most accurate mortality estimates (Pine et al. 2003). Data for 2016 is only through June, so having only half a year of returns has the capability to cause inaccuracies for calculations that year.

Assumption of 100% high reward reporting doesn't account for percentage of people who will not recognize the tag to know it holds high value if they report it. Smith et al. (2011) touched on how tag reporting rates of high reward tags is more likely to be 80-90% and how it could slightly alter mortality rates. Tagging studies are highly limited by funds available, not just for tagging, but for rewards as well (Pollock et al. 2001). Changing rewards will lead to a change in reporting behavior of anglers, so for constant and increased reporting rates as well as increasingly accurate mortality calculations, rewards to reporting tags are necessary (Pine et al. 2003).

Data collection is limited, as fishing for larger drum offshore is more difficult, and little information is known about drum that migrate offshore (Latour et al 2001). Peer reviewers of the recent ASMFC red drum stock assessment discussed how critical an accurate fishing mortality rate for fish older than 5 years is necessary, as any slight change in regulations can lead to overfishing of the older fish, which would be detrimental to the entire stock (SEDAR 2017).

Further Research

Peer reviewers of SEDAR 44 suggested that managers and scientists need to start developing ways to calculate fishing mortality and abundance of older (5+ years) red drum. As mentioned above, fishing mortality of the older fish is critical, as any amount overfishing of the older fish can be detrimental to the entire stock (SEDAR 2017).

Incorporation of the standard tagging data led to improved accuracy of fishing mortality assessments for the ASMFC regional stock assessment, and telemetry tags have the capability to improve that accuracy even further (SEDAR 2017, Pine et al. 2003, Dudgeon et al. 2015).Implementing telemetry tags with the standard reward tags increases data collection accuracy, as a reporting rate is not necessary to be able to distinguish fishing and natural mortalities (Pine et al. 2003). Telemetry tags are miniscule, with no effect on the fish, have a long battery life, use unique identification signals for each tagged individual, and the probability of relocating the tag is high because these tags have a high detection range (Pine et al. 2003). Money would be the limiting factor in a study with telemetry tags, but with improved survival, emigration, and mortality rates, the collected data, especially of older drum, is very valuable to fisheries managers.

NMFS released a climate vulnerability report on red drum, indicating the predicted climate changes will make them a highly vulnerable species. Spawning is maximized at specific temperatures and salinities, which will be dramatically altered by the changing climate, rating red drum to be extremely high in climate exposure vulnerability. They were ranked moderate with biological sensitivity and distributional vulnerability ranks, as they have a long lifespan and can travel far distances (NMFS n.y.). Further research will be necessary to fully understand the impacts the changing climate will have on red drum, to make management decisions that will include considerations such as how fishing effort and climate combined will affect mortalities and stock status.

Conclusion

Although not currently experiencing overfishing, red drum are a fish that managers still need to be cautious about when making decisions, as one wrong management decision could cause overfishing to occur. The ASMFC will be able to use this data to fulfill their research need for more accurate mortality estimates, and can implement this adapted Hoenig model for analyzing tagging data from other states in the region.

After a code is written to organize DMF's raw tagging data quicker, a more accurate analysis using 3 full years of tagged and released fish can be used to provide more accurate estimates of mortalities and tagging report and retention rates. Once all 3 years have been analyzed, the new output can be implemented in the ongoing red drum stock assessment and presented to the council for review. Ongoing tagging efforts by the state is recommended to further increase accuracy of mortality rates as a long-lived fish such as red drum need a longer time series dataset to ensure the most accurate results.

This project can be used as an example for analyzing tagged fish implementing catch and release data, to help improve future stock assessments.

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Appendix 1: Recapture matrices and completed code for adapted Hoenig model

```
harv<-matrix(c(81,-1,-1,23,0,-1,1,0,0),nrow=3,ncol=3)

rel<-matrix(c(68,-1,-1,36,0,-1,2,0,0),nrow=3,ncol=3)


irm_cr(relyrs=c(2014,2016),recapyrs=c(2014,2016),N=c(1410,0,0),recapharv=harv,recaprel=rel,
    hlambda=c(.61,.61,.61),rlambda=c(.61,.61,.61),hphi=c(.68,.68,.68),rphi=c(.68,.68,.68),
    hmrate=c(.08,.08,.08),Fyr=c(2014,2016),FAyr=c(2014,2015,2016),Myr=c(2014),
    initial=c(0.2,0.2,0.02),lower = c(0.0001,0.0001,0.0001), upper=c(5,5,5),maxiter=1000)
```

Appendix 2: Raw results

```
$statistics
                    Value
Log-Likelihood      -879.008
K                      6.000
AIC                 1770.020
AICc                1770.080
Eff. Sample Size    1410.000
Unpooled Chi-square    0.000
Unpooled df            3.000
Unpooled c-hat         0.000
Pooled Chi-square      0.000
Pooled df             -1.000
Pooled c-hat           0.000

$model_convergence
[1] "Successful."

$parameter_correlation_matrix
          F1        F2       FA1       FA2       FA3        M1
F1  1.0000000 0.4000233 0.4408743 0.6926330 0.5008218 0.7238192
F2  0.4000233 1.0000000 0.2630173 0.4521112 0.3438866 0.4959382
FA1 0.4408743 0.2630173 1.0000000 0.4594656 0.3292928 0.4691409
FA2 0.6926330 0.4521112 0.4594656 1.0000000 0.5660348 0.8279898
FA3 0.5008218 0.3438866 0.3292928 0.5660348 1.0000000 0.6209055
M1  0.7238192 0.4959382 0.4691409 0.8279898 0.6209055 1.0000000

$fishing_mortality
          F       VAR        SE Year
```

```
1 0.23701794 0.001497816 0.03870162 2014
2 0.23701794 0.001497816 0.03870162 2015
3 0.03269444 0.001470959 0.03835309 2016

$tag_mortality
         FA          VAR         SE Year
1 0.1989479 0.0008513991 0.02917874 2014
2 0.3710872 0.0171438619 0.13093457 2015
3 0.0652855 0.0037405551 0.06116008 2016

$natural_mortality
          M       VAR        SE Year
1 0.7547687 0.0241294 0.1553364 2014
2 0.7547687 0.0241294 0.1553364 2015
3 0.7547687 0.0241294 0.1553364 2016

$total_mortality
         Z        VAR        SE Year
1 1.007702 0.03436912 0.1853891 2014
2 1.021474 0.03470029 0.1862801 2015
3 0.792686 0.03161936 0.1778183 2016

$survival
          S         VAR         SE Year
1 0.3650568 0.004580251 0.06767755 2014
2 0.3600640 0.004498756 0.06707276 2015
3 0.4526274 0.006477909 0.08048546 2016

$obs_recoveries_harvested
     2014 2015 2016
2014   81   23    1
2015   -1    0    0
2016   -1   -1    0

$pred_recoveries_harvested
         2014     2015     2016
2014 81.02792 23.00759 1.000971
2015       NA  0.00000 0.000000
2016       NA       NA 0.000000

$obs_recoveries_released
     2014 2015 2016
2014   68   36    2
2015   -1    0    0
2016   -1   -1    0
```

```
$pred_recoveries_released
         2014     2015     2016
2014 68.01313 36.02184 1.998778
2015       NA  0.00000 0.000000
2016       NA       NA 0.000000

$pred_number_notseen
[1] 1198.93    0.00    0.00

$unpooled_cell_chisquare_harvested
             2014         2015         2016
2014 9.620982e-06 2.505116e-06 9.427537e-07
2015 0.000000e+00 0.000000e+00 0.000000e+00
2016 0.000000e+00 0.000000e+00 0.000000e+00

$unpooled_cell_chisquare_released
             2014         2015         2016
2014 2.533034e-06 1.324642e-05 7.474469e-07
2015 0.000000e+00 0.000000e+00 0.000000e+00
2016 0.000000e+00 0.000000e+00 0.000000e+00

$unpooled_cell_chisquare_notseen
[1] 4.114033e-06          NaN          NaN

$unpooled_cell_Pearson_harvested
             2014         2015         2016
2014 -0.003101771 -0.001582756 -0.000970955
2015  0.000000000  0.000000000  0.000000000
2016  0.000000000  0.000000000  0.000000000

$unpooled_cell_Pearson_released
             2014         2015         2016
2014 -0.001591551 -0.003639563 0.0008645501
2015  0.000000000  0.000000000 0.0000000000
2016  0.000000000  0.000000000 0.0000000000

$unpooled_cell_Pearson_notseen
[1] 0.002028308         NaN         NaN

$type
[1] "cr"
```