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## Reassessment of the Red Drum Stock in Mississippi Coastal Waters: The Role of Ages 3-5 Year-Class Fish

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REASSESSMENT OF THE RED DRUM STOCK IN MISSISSIPPI COASTAL  
WATERS: THE ROLE OF AGES 3-5 YEAR-CLASS FISH

by

Emily Satterfield

A Thesis

Submitted to the Graduate School,  
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and the School of Ocean Science and Technology  
at The University of Southern Mississippi  
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for the Degree of Master of Science

December 2017

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WATERS: THE ROLE OF AGES 3-5 YEAR-CLASS FISH

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## ABSTRACT

### REASSESSMENT OF THE RED DRUM STOCK IN MISSISSIPPI COASTAL WATERS: THE ROLE OF AGES 3-5 YEAR-CLASS FISH

by Emily Satterfield

December 2017

Red Drum, *Sciaenops ocellatus*, are highly sought after by sport fishermen in Mississippi coastal waters. In 2016, Mississippi anglers made over 180,000 fishing trips targeting Red Drum, making it the second most targeted marine species. The current Fishery Management Plan of the Gulf of Mexico Fishery Management Council, prohibits harvest of Red Drum in federal waters. Monitoring of the stock in Mississippi state waters occurs at sites that are almost exclusively estuarine, using gear types selective for juvenile fish. Additional samples come from the for-hire-industry that typically targets larger Red Drum. This project's goal was to target age three to five-year-old Red Drum to investigate any bias in some precautionary reference point estimates potentially introduced by relatively small numbers of samples in that age range. A sensitivity analysis was conducted to determine if estimates of Spawning Stock Biomass Per Recruit (SSBPR) and Escapement Rate (ER) were impacted by the addition of length-at-age data for Red Drum collected by additional methods. Estimates of SSBPR and ER made with model parameters determined from previously collected data were compared to these estimates that include the additional data. I found that the mean SSBPR estimates were significantly lower ( $p < 0.05$ ) prior to the inclusion of the additional data, while the ER estimates from the existing

data were significantly greater ( $p < 0.05$ ) than the new estimates. These findings attest to the value of resampling techniques and sensitivity analysis when choosing appropriate precautionary reference points and investigating the integrity of data collection methods.

## ACKNOWLEDGMENTS

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## DEDICATION

This thesis is dedicated to the memory of my father, Paul Satterfield, without whom I would not have developed a passion for fisheries and life on the water; also to my mother, Marilyn Satterfield, for her tireless support, cheerleading, counsel, and prayer. I could have done this without her, but I'm glad I didn't have to.



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## CHAPTER I - INTRODUCTION

This project is a sensitivity analysis to investigate potential bias in estimates of life history parameters of Red Drum in Mississippi coastal waters caused by sampling error. Length-at-age is the basis of calculations fisheries scientists use to develop stock metrics (Kirkwood 1983, Coggins et al. 2013), and thus making reliable estimates of life-history parameters critical. Inaccurate estimates of growth model parameters that describe length-at-age can occur when gear selectivity and/or sampling location cause bias within data (Taylor et al. 2005, Rudstam et al. 1984).

Fisheries scientists consider life history of Red Drum when developing an assessment strategy and choosing appropriate precautionary reference points. In the Gulf of Mexico (GOM), adults first enter reproductive stages between one to five years. Males become sexually mature at one to three years, and females mature at three to five years (Mercer 1984, Beckman et al. 1989, Goodyear 1989 and 1996, Murphy and Taylor 1990, Wilson and Neiland 1994). Red Drum exhibit a relatively narrow seasonal spawning window and typically begin spawning in early September, peak in October, and continue into November (Reagan and Parsons 1985). Red Drum are an estuarine dependent species. In contrast to fully anadromous fish, mature adults do not return to the estuary to spawn. Rather, they spawn offshore near the mouths of rivers and estuaries (Pearson 1928, Simmons and Breuer 1962, Johnson 1978, Perret et al. 1980, Reagan and Parsons 1985). Red Drum eggs float in higher salinities of 30 ppt or higher and sink when

the salinity drops below 20 ppt. This allows the nektonic eggs to be carried on high salinity currents into coastal habitats (Marley 1983, Reagan and Parsons 1985) where the eggs sink to the bottom as the salinity drops (Holt et al. 1983, Reagan and Parsons 1985). Red Drum larvae occupy seagrass and marsh-edge habitats (Baltz et al. 1998, Rooker and Holt 1997, Murphy 1994, Peters and McMichael 1987) where post-larvae and juveniles find shelter, feed, and grow into mobile nekton (Pearson 1928, Miles 1950, Bass and Avault 1975, Perret et al. 1980, Holt et al. 1983, Mercer 1984, Reagan and Parsons 1985). Periods of changing salinity and temperature appear to trigger the movements of juveniles between primary and secondary bays and marshes; sub-adults may even venture briefly into offshore waters (Simmons and Breuer 1962, Pearson 1928, Reagan and Parsons 1985). After reaching full adulthood, fish remain offshore year-round in the GOM (Simmons and Breuer 1962, Reagan and Parsons 1985). Red Drum can live to approximately 40 years (Murphy and Munyandorero 2009, Murphy and Taylor 1990), and have been known to reach up to 60 years in Mid-Atlantic waters (Murphy and Munyandorero 2009, Ross et al. 1995).

In addition to life-history data, the magnitude of fishing effort and harvest by recreational and commercial sectors must also be incorporated into assessment of stock metrics. Red Drum is highly sought by sport fishermen in Mississippi coastal waters. The species is the second most targeted marine finfish by recreational anglers in Mississippi (National Marine Fisheries Service 2017) and is primarily harvested as sub-adults

(one to two years). As of 1988, harvest is prohibited in federal waters where adult fish live (Gulf of Mexico Fishery Management Council 1987). The Fisheries Management Plan (FMP) prohibits all harvest of Red Drum from the Economic Exclusive Zone (EEZ). Following an increase in demand for Red Drum and drastically increased commercial harvest in the late 1980s, stricter fishing regulations for Red Drum within the EEZ were enacted by the Gulf of Mexico Fisheries Management Council (GMFMC). Regulations were based on the finding that the estimated Escapement Rate (ER) was less than 2%. This was well below the recommended 20% minimum escapement (Gulf of Mexico Fishery Management Council 1987). ER is defined as the ratio of the biomass of ages one through four fish undergoing fishing mortality to the biomass of ages one through four fish in an unfished population.

In addition to federal management, the state of Mississippi has imposed regulations on size and bag limits. The daily bag limit in 1987 for recreational anglers was 10 Red Drum per person. After the federal moratorium, the bag limit was reduced to three fish per person in 1990 and the length restrictions fluctuated until 1995 when the minimum length was set at 18 inches with one fish over 30 inches allowed per person (Hill 2014). A commercial fishery for Red Drum does remain within Mississippi state waters, albeit with restrictions limiting fishermen to degradable (cotton or linen) nets and/or hook-and-line harvest. The commercial fishery is also

regulated by a quota which limits the catch to 60,000 pounds per year with the same length restrictions as the recreational sector.

Although offshore sampling of the Red Drum stock has been limited, inshore sampling has been conducted regularly since the implementation of the Monitoring and Assessment of Mississippi's Inter-Jurisdictional Marine Resources project (IJ) in 1982 (Mississippi Department of Marine Resources and Gulf Coast Research Laboratory 2009). Current monitoring in Mississippi state waters utilizes gill nets with multiple panels of mesh sizes: 2.0", 2.5", 2.75", 3.0", 3.5", 4.0", and 5". The sampling station locations are almost exclusively estuarine, and the gill nets are composed of mesh sizes selective for juvenile fish (Porch et al. 2002). Large individuals (> 500 TL, mm) within the current Mississippi Department of Marine Resources (MDMR) Red Drum data were obtained from the for-hire industry, mainly as carcasses contributed to MDMR by for-hire vessel captains.

Given the current interest in the potential commercial value of Red Drum, it is vital that the most appropriate data collection methods be used to provide robust biological data to be incorporated by fisheries scientists estimating growth model parameters for this species. The combination of the harvest moratorium in federal waters, the fact that these fish move offshore at maturity, and the lack of data from fish at the life stage in which this major habitat shift occurs necessitates investigation into the validity of

current data collection methods and the potential bias of resulting growth parameter estimates.

To evaluate the implications of potentially inadequately sampling 20” to 30” TL Red Drum (approximately three to five-year-old fish) additional samples were collected and incorporated an Age-at-Length Key (ALK). Because the paucity of data for the age three to five-year-old Red Drum nearing or undergoing maturation may impact our understanding of stock dynamics, I developed Spawning Stock Biomass Per Recruit (SSBPR) estimates using the data collected via pre-existing methods as a base model against which SSBPR derived from this study would be evaluated. Furthermore, if the SSBPR estimates are biased, it follows that the ER estimates might also be impacted. Red Drum are considered to have “escaped” at four years of age in the northern GOM (National Marine Fisheries Service 1988 and 1992, Porch 2000, Blanchet 2005, Florida Fish and Wildlife Conservation Commission 2005, Murphy 2005, Alabama Marine Resources Division 2008, Mississippi Department of Marine Resources 2010, Powers and Burns 2010), the approximate age of maturity and the estimated age at which they leave the estuary to join the offshore adult spawning population. I hypothesize that an inaccurate estimate of length-at-age would yield an inaccurate biomass and introduce bias to the SSBPR and ER.

In this work, I address the following objectives:



1) Investigate potential differences in observed mean length-at-age between the existing data collected via traditional methods and the data collected for this study.

2) Explore the precision of the estimated Spawning Stock Biomass Per Recruit (SSBPR), and interpret the implications of any differences in mean estimates of SSBPR between data.

3) Determine escapement rates from each data set and evaluate potential differences in estimates of escapement rate between data.

## CHAPTER II - METHODS

To aid in determining “unbiased” length-at-age estimates, I employed multiple alternative gear types and sampled additional sites to target sub-adult Red Drum. Inland marsh sites were selected from across coastal Mississippi within St. Louis Bay, Biloxi Bay, the Pascagoula River, and in the surrounding waters of Ship Island and Horn Island (Figure 1). Site selection was based on knowledge of historically successful collections of Red Drum in conjunction with sightings reported by the for-hire industry, commercial, and recreational fishermen.

During the sampling period, May 2014 through Jan 2016, three sites were sampled each month for a total of 60 sampling events. The fishery-independent portion of sampling was conducted in conjunction with sampling events for the IJ project. Each sampling event for this study included deployment of four nets of mesh sizes chosen to be selective for larger fish than the sampling methods already in use by the IJ program. Four gill nets, each 300 feet long and six feet deep constructed of 0.5 mm or 0.75 mm monofilament with a mesh size of 5.5”, 6.0”, 6.5”, or 7.0” were concurrently set for one hour, with 50 m between each net. The four nets were set in a “J” shape, extending from the shore toward open water, to target the desired habitat (Figure 2). All captured Red Drum were immediately euthanized via decapitation/pithing, put on ice, and returned to the laboratory for processing and otolith removal. All non-target species

were returned to the water while at the sample site.

In addition to the routine fishery-independent collections, fish were obtained from the for-hire industry and by dockside interceptions of recreational anglers fishing inshore marshes as well as near Ship and Horn Islands (Figure 1). Anglers and researchers made coordinated efforts to obtain Red Drum carcasses and/or whole fish for processing or to obtain pertinent biological data and extract otoliths while the angler remained in possession of the fish.

At the laboratory Red Drum were assessed for total length (TL, mm), fork length (FL, mm), standard length (SL, mm), and total weight (g). Otoliths were removed using a saw to make a cut from the rear of the skull downward and forward to a point behind the eye sockets, exposing the sagittal otoliths. Forceps were used to remove the otoliths, which were then rinsed with tap water, allowed to air dry, and placed in a labeled envelope until processing. One otolith was then embedded in a 5:1 mixture of Araldite resin and hardener in a mold and positioned with the long axis of the otolith parallel to the sides of the mold. Embedded otoliths were allowed to dry for approximately 30 minutes before being removed from the mold. The core was located before the otolith was placed in the chuck of a low speed wafering saw for sectioning. The arm of the saw was set to 25 microns, plus an additional 6 microns to allow for blade width. Multiple cuts were made until a cross-section of the core was obtained. The core section was then

mounted to a glass slide using Flowtexx and allowed to dry overnight (VanderKooy 2009).

Age assignment was accomplished by counting the number of opaque annular increments using a trinocular compound microscope with I-Solution Lite imaging software. Two readers examined each otolith. There was one percent discrepancy in ring counts between readers. Red Drum typically deposit the first opaque annual increment at 14 to 18 months of age, and each successive increment is deposited approximately every 12 months. Using the generally accepted birthdate of October 1 for Red Drum in the northern GOM (VanderKooy 2009), fish showing no annuli were considered to be from zero to 18 months in age, in accordance with the date of capture. Fish with only one annual increment were assumed to be at least 18 months old, and each annular increment thereafter was considered to reflect 12 additional months of growth. This method of age determination, in conjunction with the date of capture, allows fish ages to be estimated to the month.

The three sets of data (Directed, Non-directed, and Combined) to be used in all comparisons made within the scope of this project are defined as follows: “Directed” which refers to the data collected by the methods described in this project, “Non-directed” which is comprised of the existing data collected by traditional methods, and “Combined” which is the combination of the previous two data sets.

The best fit growth model was determined using a candidate set of four growth models commonly used by fisheries managers to describe length-at-age. The candidate growth models included:

Two-parameter vonBertalanffy:

$$L_t = L_\infty(1 - e^{-Kt}),$$

Three-parameter vonBertalanffy:

$$L_t = L_\infty(1 - e^{-K(t-t_0)}),$$

Three-parameter logistic:

$$L_t = L_\infty(1 - \beta e^{-kt})^{-1},$$

and the Gompertz Function:

$$L_t = L_\infty e^{-e^{-g_i(t-t_i)}}.$$

To choose the best fit of these growth models, the Akaike Information Criterion ( $AIC_c$ ) corrected for small sample size was determined for each of the models.  $AIC_c$  scores and AIC weights ( $W_i$ ) were determined for all four models of each data set.  $AIC_c$  scores were calculated as (Burnham & Anderson 2002):

$$AIC_c = -2\log L + 2K + \frac{2K(K+1)}{n-K-1},$$

where  $L$  is the maximum log likelihood,  $K$  is the number of free parameters, and  $n$  is the sample size.  $W_i$  is the  $AIC_c$  weight which is an expression of the

probability that a model is most parsimonious compared to the other three models (Burnham & Anderson 2004) and was then calculated as:

$$W_i = \frac{e^{\frac{1}{2}\Delta AIC_{c,i}}}{\sum_{i=1}^R e^{\frac{1}{2}\Delta AIC_{c,i}}},$$

where  $\Delta AIC_c$  is the difference between the lowest  $AIC_c$  score and the  $AIC_c$  score of each of the four models tested and  $R$  is the number of candidate models. The model with the largest  $W_i$  indicates the best supported growth model of the four growth models tested. The best supported growth model was used for all further calculations within this project.

To determine significant differences among mean length-at-age for the three, four, and five-year-old samples from the Non-directed data and the Combined data, bootstrap resampling was used to simulate 1,000 growth curves for each the Non-directed and Combined data. The length-at-ages were compared based on 95% confidence intervals.

To explore the precision of the estimated SSBPR, a sensitivity analysis was performed to understand the impact of alternative growth parameter estimates on SSBPR estimates. Parameter estimates of each realization of the simulated growth curves for both Non-directed and

Combined data were then applied to the SSBPR to get a distribution of SSBPR estimates with 95% confidence intervals (CI). The formula for SSBPR is:

$$SSBPR = \sum_{t_0}^{t_{\max}} N_t * W_t * P_t,$$

where  $N_t$  is the number of individuals remaining at age ( $t$ ),  $W_t$  is the weight of an individual at age, and  $P_t$  is the percent maturity-at-age. In this equation  $N_t$  was calculated by:

$$N_t = N_{(t-1)} e^{-Zt}.$$

$N$  is the number of individuals and  $t$  is age (yrs).  $Z$  ( $y^{-1}$ ) is the total mortality calculated as the sum of fishing mortality ( $F$ ) and natural mortality ( $M$ ). For  $F$ , a range of feasible values from  $0.1 y^{-1}$  to  $1.4 y^{-1}$  was used. The 1,000 simulations of growth curves for each data set already generated were used to estimate an accompanying distribution of Lorenzen (2000) age-specific instantaneous natural mortality rates ( $M_l$ ) using the formula:

$$M_l = M_r \left( \frac{l}{l_r} \right)^c.$$

$M_l$  is the estimated natural mortality rate at each ( $l$ ) length-at-age (yrs). The reference natural mortality ( $M_r$ ) =  $15 y^{-1}$  when the reference length ( $l_r$ ) = 1 cm and the exponent of the mortality-length relationship ( $c$ ) = -1. This is an allometric relationship of body size to  $M$  used by Lorenzen in his method of determining age-specific natural mortality (Lorenzen 2000, 2005). One thousand iterations of this equation were computed for each estimated

length-at-age from zero through 38 years (38 years being the oldest aged fish in the data sets).

$W_t$  was estimated by a power function, where  $a$  and  $b$  are parameters estimated via non-linear least squares from observed length-at-age and weight-at-age relationships:

$$W_t = a(L_t)^b.$$

$P_t$  is the percent maturity at age ( $t$ ) in the SSBPR equation. In the GOM males become sexually mature between the ages of one to three years, and females mature between the ages of three and five years (Murphy and Taylor 1990). Assuming a 1:1 ratio of males and females (Wilson and Nieland 1994), the ages of two and three were assigned 25% and 50% maturity respectively. All ages prior to two years were assumed to have zero percent maturity and all ages four years and older were considered 100% mature.

The distributions of both sets of three growth parameter estimates from the SSBPR model for each value of  $F$  and both data sets were examined to understand the impact of including fish from directed sampling. To assess potential bias in the SSBPR model predictions, the extent to which the 95% CI of the distributions of SSBPR estimates differed and/or overlapped between data sets was determined.

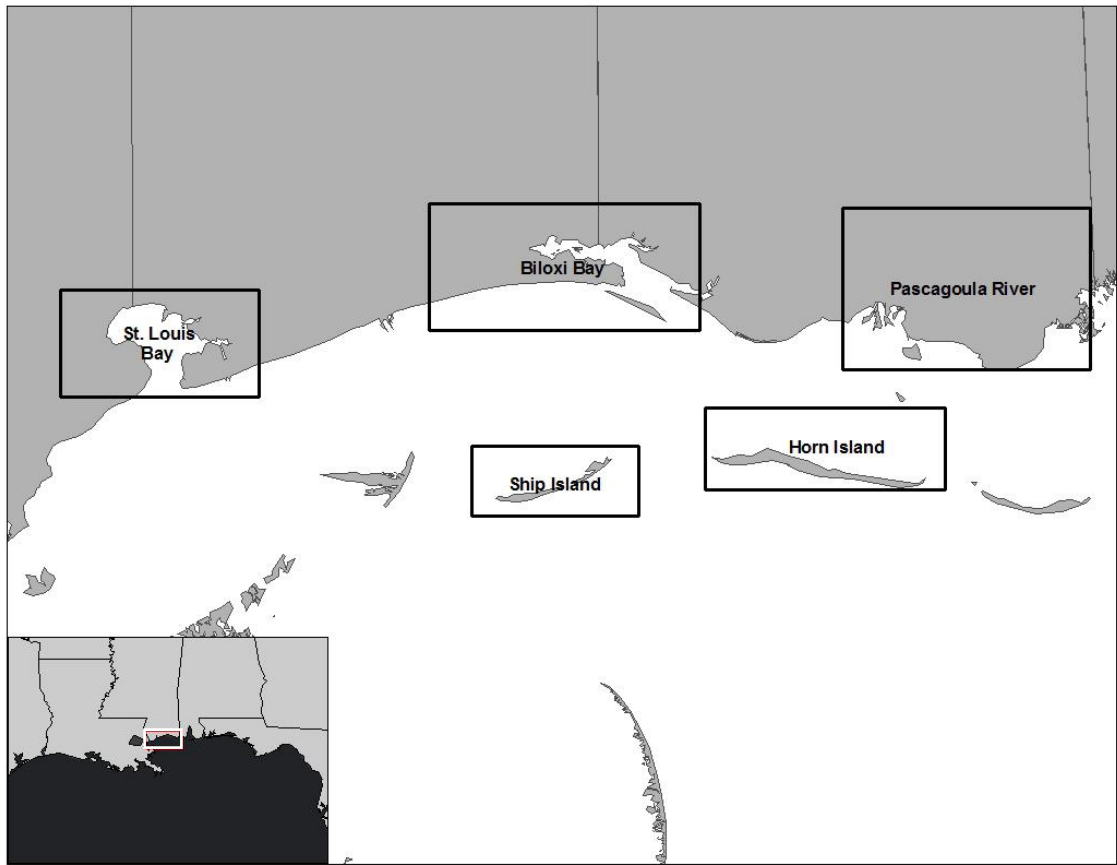
Estimates of ER were evaluated for potential differences stemming



from the addition of data collected for this project using the formula:

$$E = \frac{e^{\sum_{t=0}^4 -Zt}}{e^{\sum_{t=0}^4 -M_t t}}.$$

To look for a difference in estimated escapement rates between the data sets, the 95% Confidence intervals of each ER estimate over the range of  $F$  values were compared for each distribution.



*Figure 1.* Map of sample area.

Boxes represent areas from which samples were collected by the methods presented for this study.

## CHAPTER III – RESULTS

Sampling efforts were successful in obtaining additional Red Drum to compare the mean length-at-age for the targeted age groups between data sets. The Non-directed data consisted of a total of 1,010 Red Drum collected between 2006 to 2012, of which only 72 fish were age three, four, or five (Table 1, Figure 3). The Combined data included the Non-directed data with the addition of 263 samples collected by Directed sampling, yielding a total of 1,273 Red Drum samples, 142 of which were determined to be between the ages of three and five years (Table 1, Figure 4).

The observed mean length-at-age of all three age groups was greater in the data collected by the Directed methods and the Combined data than the Non-directed data (Table 2), though the variance between data sets was not equal. In order to investigate whether these differences were significant, parameters were estimated for each of the four alternative growth models (Figures 5 and 6), and  $AIC_c$  analysis indicated the logistic growth curve was the most supported for both data sets. Although the AIC scores for the Gompertz model were the next closest to those for the logistic growth curve, AIC weights indicated that the logistic model had a much higher probability of being the best fit for both data sets (Tables 4 and 5). When the logistic growth curve was fitted to observed data in both the Non-directed and Combined data, the length-at-age for all three ages of concern was larger when predicted by parameters estimated from the Combined data than from

the Non-directed (Figure 7).

The differences in length-at-age estimates prompted further investigation, so resampling was used to simulate a distribution of 1,000 sets of logistic growth curve parameters (Figure 8) for each data set. The simulated logistic growth curve estimates for ages three, four, and five-year-old fish (Figure 9) also indicated a significant difference ( $p < 0.001$ ) in the mean length-at-age between the Non-directed data and the Combined data. To further investigate potential bias, the growth curve distributions were then applied to the SSBPR. First, the Lorenzen age-specific natural mortality rates ( $M y^{-1}$ ) were estimated (Table 6) and used to estimate  $N_t$ . Then a power function was applied to estimate  $W_t$ . Finally, the estimates of  $N_t$ ,  $W_t$ , and  $P_t$  were input into the SSBPR over a feasible range of fishing mortality ( $F y^{-1}$ ). The mean SSBPR estimates for both data sets decreased as the simulated  $F$  increased. For every  $F$ , SSBPR estimates were significantly ( $p < 0.05$ ) larger when the Combined data was used for the estimates (Figure 10).

Finally, the simulated distributions of growth parameters were applied to the ER function for the Non-Directed and Combined data. The mean ERs calculated were significantly different ( $p < 0.05$ ) (Figure 11) between data sets for all simulations of  $F$ ; however, they were never more than two percentage points different, which is not likely to be meaningful. The estimated ER did fall below the recommended 20% at  $F = 0.8 y^{-1}$ .

Table 1

*Observed data*

	Non-directed	Directed	Combined
Total	1,010	263	1,273
Age 0-2	793	58	851
Age 3-5	72	70	142
Age 6+	145	135	280

Summary of observed data composition by number of samples (n)

Table 2

*Observed data: Age 3-5*

	Age-3 Years			Age-4 Years			Age-5 Years		
	(n)	Mean	sd	(n)	Mean	sd	(n)	Mean	sd
Non-directed	42	590	96	19	71	56	12	769	41
Directed	31	647	78	27	721	111	12	830	36
Combined	73	614	93	46	718	92	24	800	49

Summary of observed data composition of 3-5 year old fish by number of samples (n) and data set

Table 3

*AIC scores: Non-directed*

Model	Number of parameters	AIC <sub>c</sub>	Δ AIC	Evidence ratio	AIC weight
Logistic	3	11,489	0	1.00	1
Gompertz	3	11,518	29	0.00	0
Three parameter von Bertalanffy	3	11,568	79	0.00	0
Two parameter von Bertalanffy	2	13,108	1,619	0.00	0

AIC<sub>c</sub> Results of the four alternative growth models when applying the Non-directed data. Scores inversely reflect the degree of support for four alternative growth models; the lowest value representing the most supported model in relation to the others tested. The highest AIC weight indicates the model must supported by the data.

Table 4

*AIC scores: Combined*

Model	Number of parameters	AIC <sub>c</sub>	Δ AIC	Evidence ratio	AIC weight
Logistic	3	14,597	0	1.00	1
Gompertz	3	14,641	44	0.00	0
Three parameter von Bertalanffy	3	14,726	129	0.00	0
Two parameter von Bertalanffy	2	16,337	1,740	0.00	0

AIC<sub>c</sub> Results of the four alternative growth models when applying the Non-directed data. Scores inversely reflect the degree of support for four alternative growth models; the lowest value representing the most supported model in relation to the others tested. The highest AIC weight indicates the model must supported by the data.

Table 5

*Predicted length-at-age*

Age (yrs)	Non-Directed			Combined		
	$L_t$ (mm)	2.5% (mm)	97.5% (mm)	$L_t$ (mm)	2.5% (mm)	97.5% (mm)
3	582	572	592	610	600	620
4	657	644	668	692	681	702
5	716	704	727	755	745	765

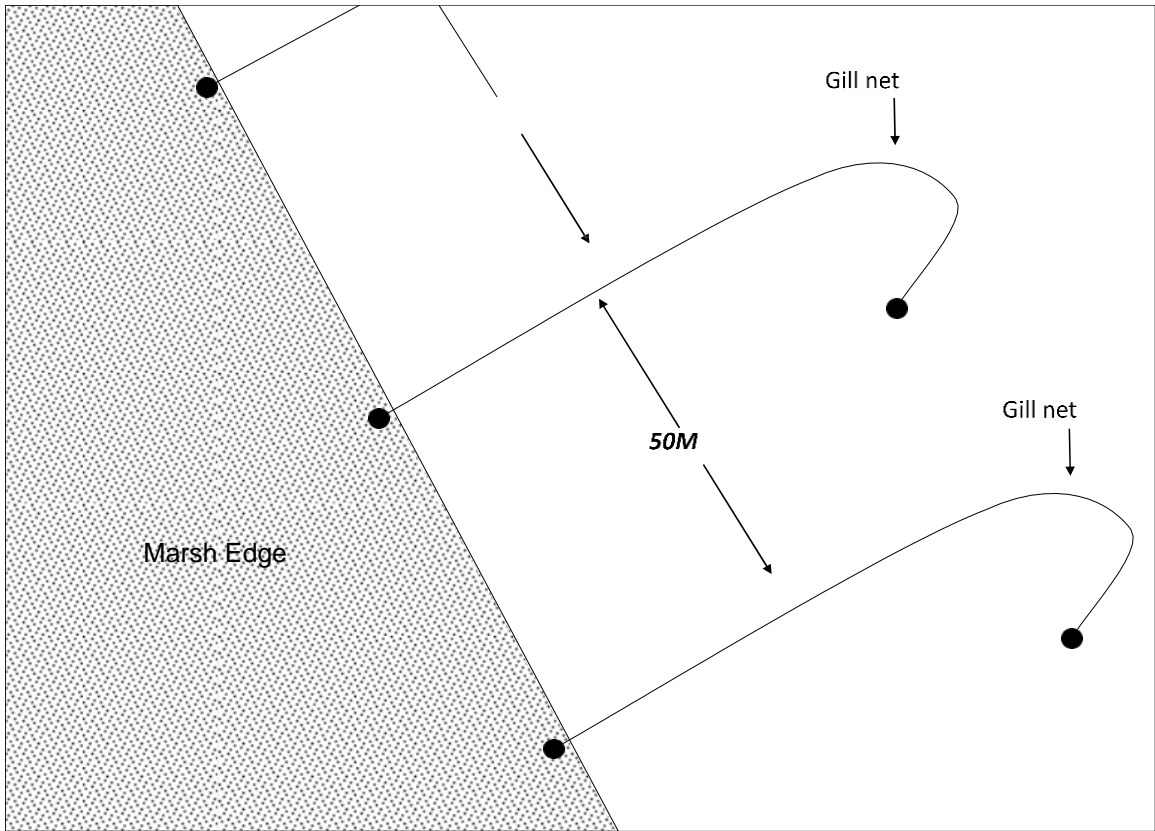
Mean length-at-age ( $L_t$ ) estimates predicted by the logistic growth curve for Non-directed and Combined data and 95% confidence intervals. 2.5% is the lower bound of the confidence interval, and 97.5 is the upper bound of the confidence interval

Table 6

*Lorenzen mortality estimates*

t	0	1	2	3	4	5	6	7	8	9	10+
Non-directed	0.48	0.37	0.30	0.26	0.23	0.21	0.20	0.19	0.18	0.18	0.18
Combined	0.49	0.37	0.29	0.25	0.22	0.20	.019	0.18	0.18	0.18	0.17

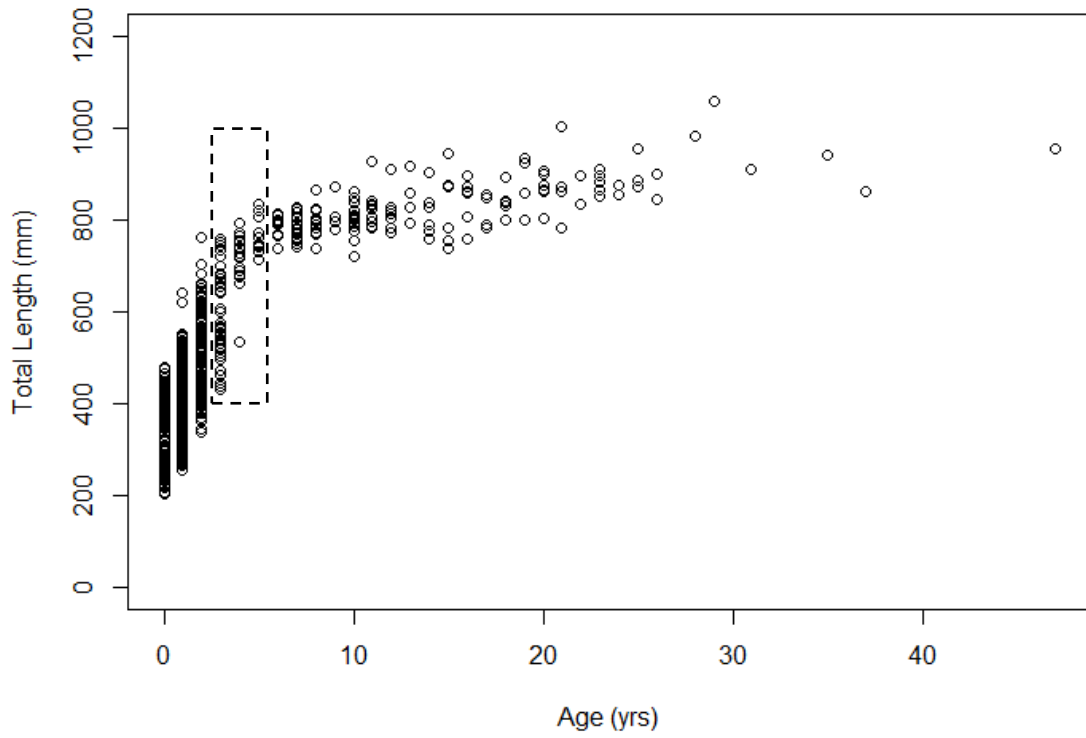
Mean estimates of Lorenzen natural mortality ( $y^{-1}$ ) listed by age (t) and separated by data set



*Figure 2.* Deployment diagram.

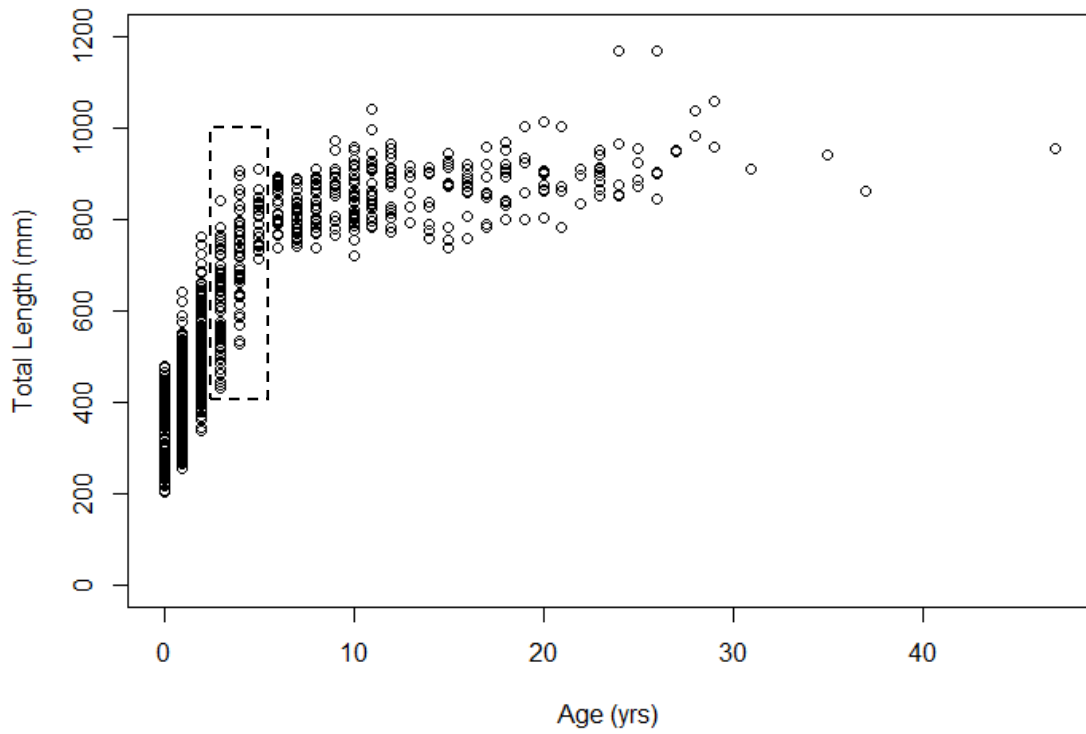
Depiction of gill net deployment method to target Red Drum. Gill nets are set 50 m apart, extending from the marsh edge out into the water, in a J-shape.





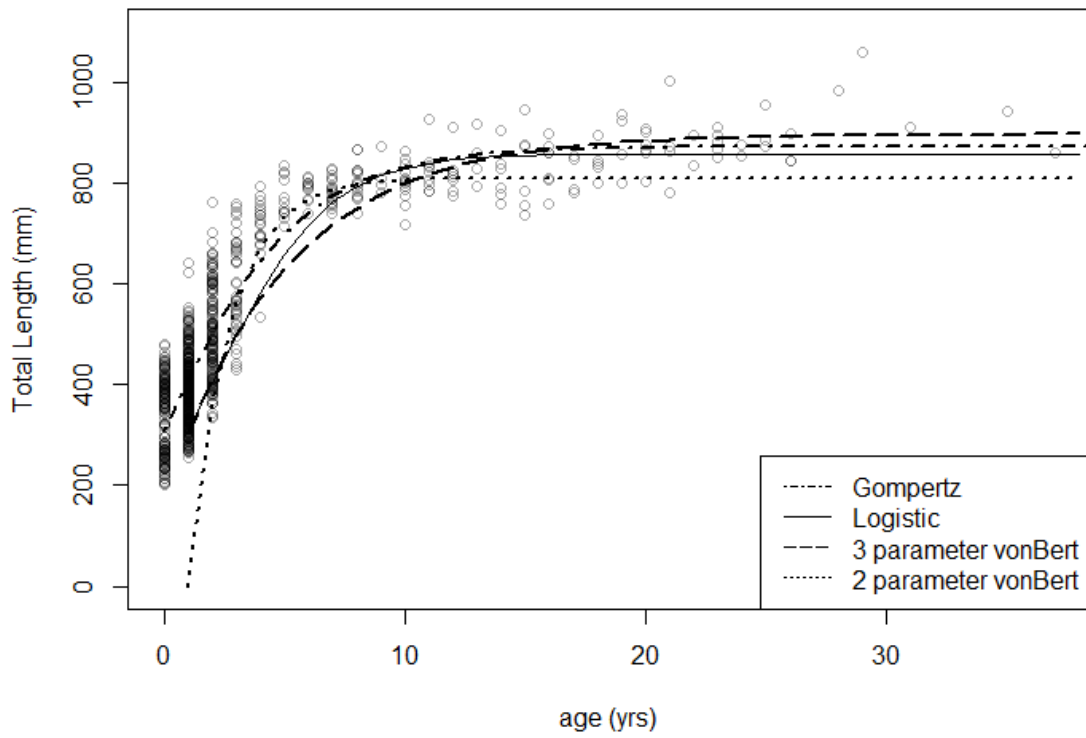
*Figure 3.* Length-at-age: Non-directed.

Observed length-at-age for Non-directed data. The area within the dashed outline denotes the ages of interest in this study (3-5 years). Area within the dashed box represents the observed age 3-5 fish.



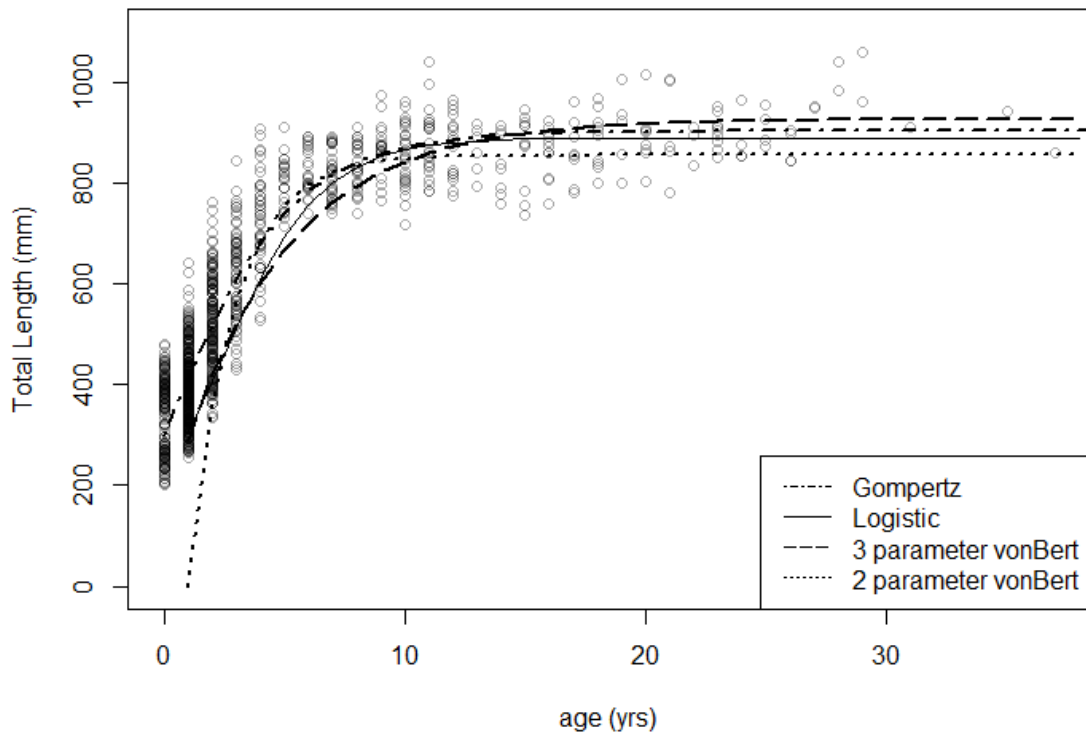
*Figure 4.* Length-at-age: Non-directed.

Observed length-at-age for Non-directed data. The area within the dashed outline denotes the ages of interest in this study (3-5 years). Area within the dashed box represents the observed age 3-5 fish.



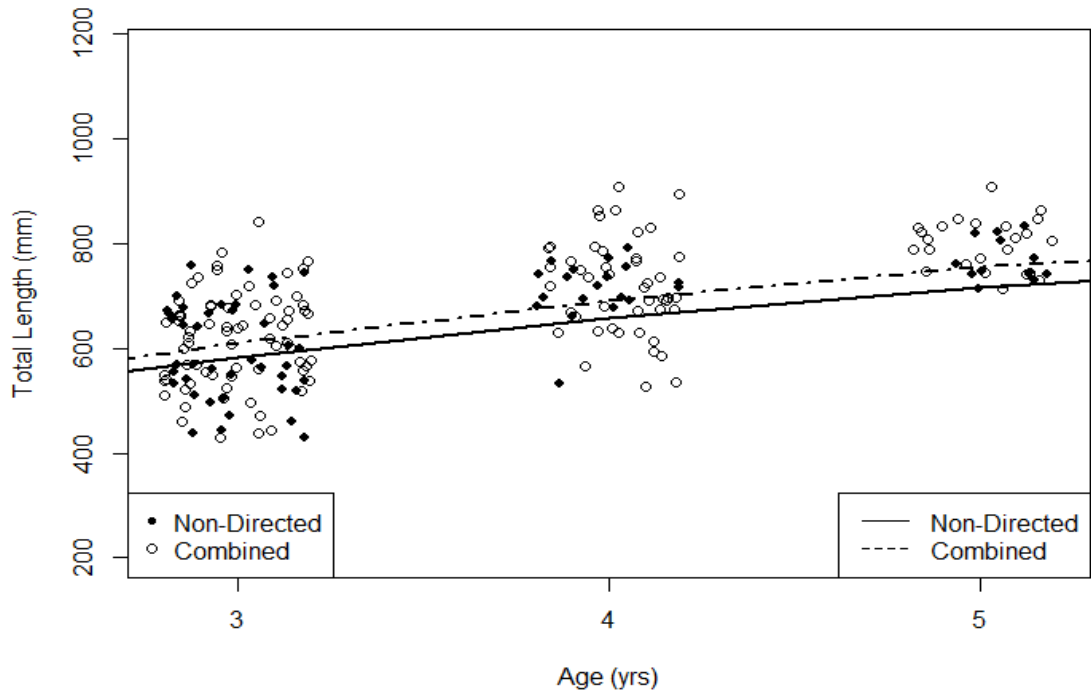
*Figure 5.* Alternative growth models: Non-directed.

Lines represent the fit of each of the four alternative growth models when fit to the observed Non-directed data.



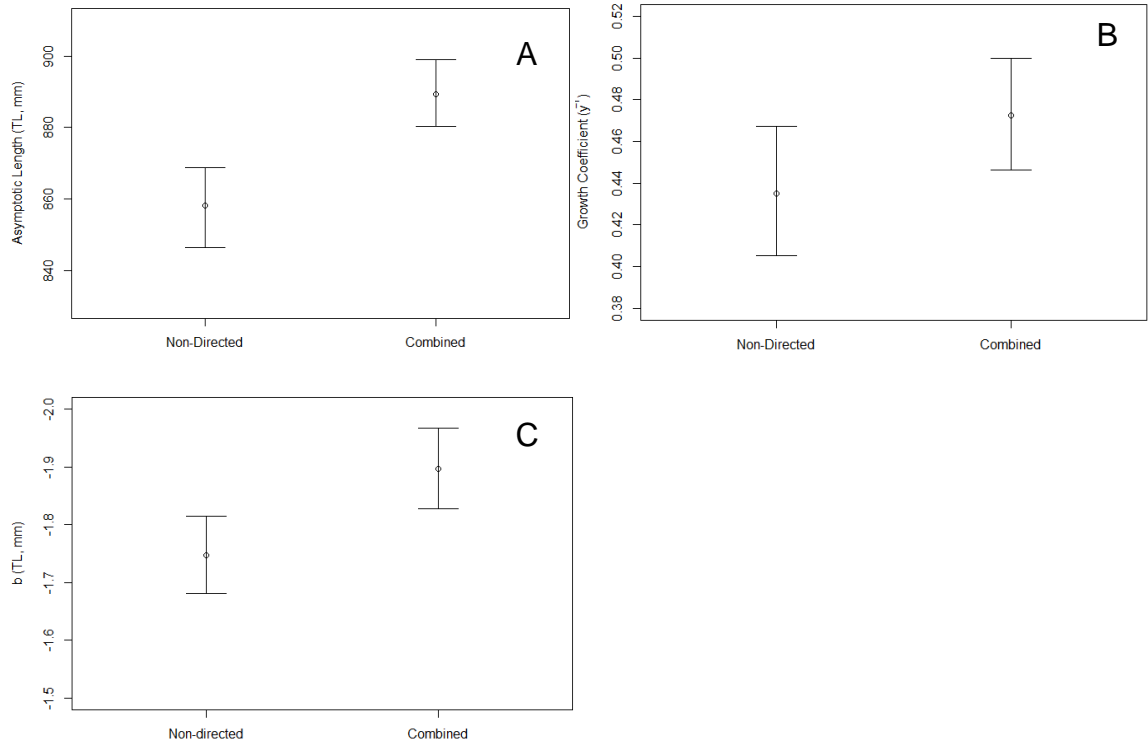
*Figure 6.* Alternative growth models: Combined.

Lines represent the fit of each of the four alternative growth models when fit to the observed Combined data.



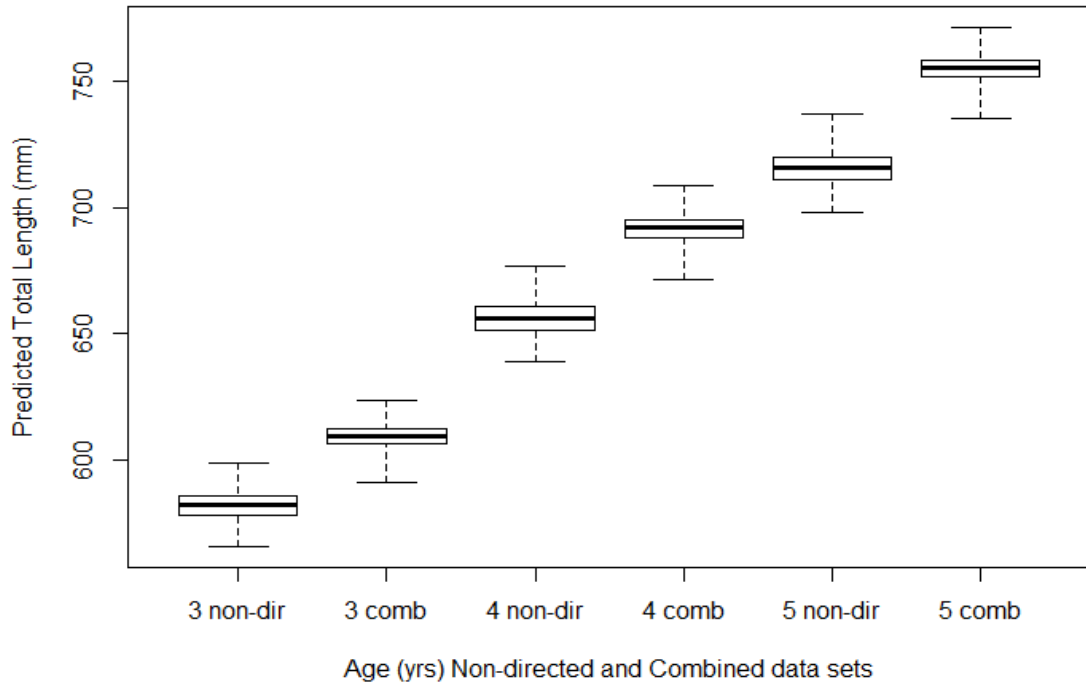
*Figure 7.* Logistic growth curve: Ages 3-5.

Section of the Logistic growth curves for ages 3-5 fish when fit to each observed data set.



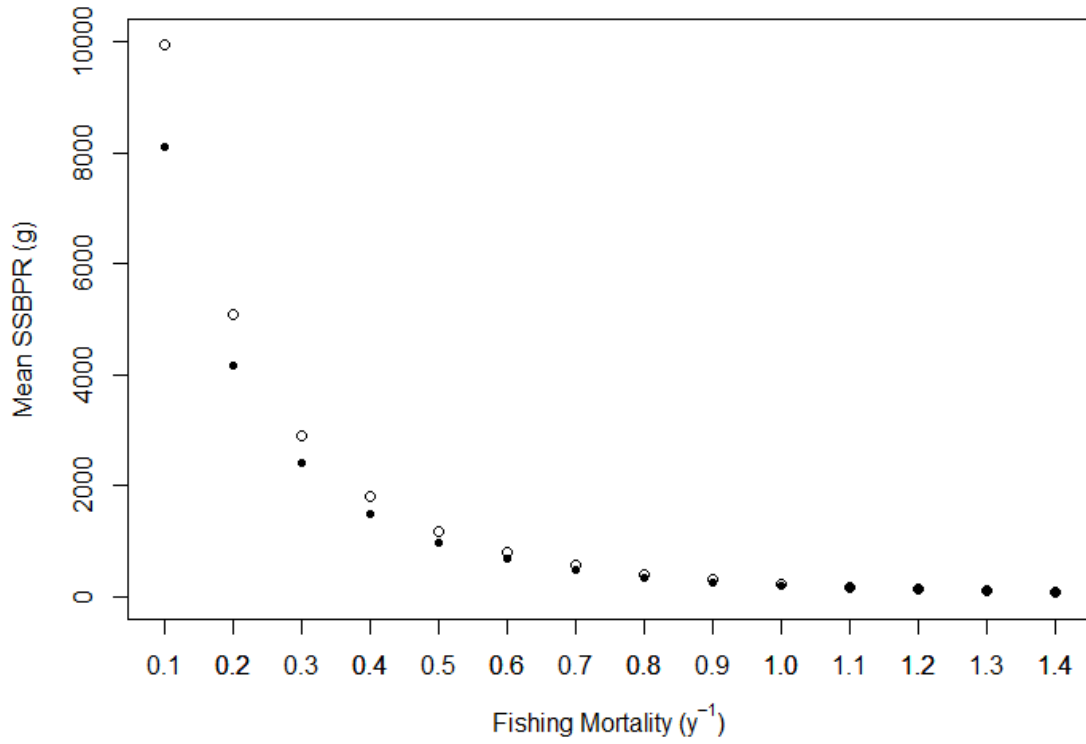
**Figure 8.** Parameter distributions.

Point plot of logistic growth curve estimated parameter distributions from both Non-directed and Combined data with whiskers at 95% CI. A) The asymptotic length (mm). B) Growth coefficient. (C) Inflection point of the logistic growth curve (mm).



*Figure 9.* Distribution of predicted mean length-at-age.

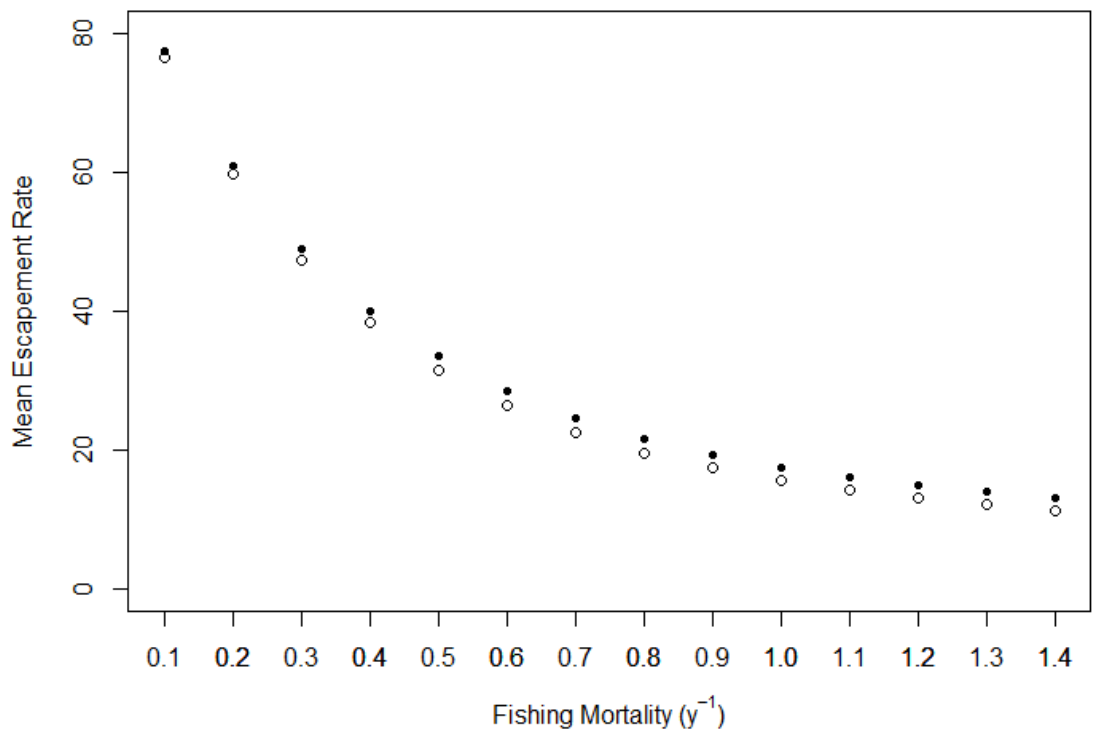
Predicted distributions of mean length-at-age using the logistic growth curve fit to simulated data; comb denotes the predictions generated by the Combined data, non-dir denotes the predictions generated by the Non-directed data. Dark line is the median, the box contains 50% of the predicted means, and the whiskers are the extremes of the predicted distribution of mean.



*Figure 10.* Mean SSBPR.

Mean Spawning Stock Biomass Per Recruit predictions related to a range of fishing mortality. Closed circles denote the use of Non-directed data simulations in the predictions and the open circles denote the Combined data was used.





*Figure 11.* Mean ER.

Mean Spawning Stock Biomass Per Recruit predictions related to a range of fishing mortality. Closed circles denote the use of Non-directed data simulations in the predictions and the open circles denote the Combined data was used.

## CHAPTER IV – DISCUSSION

In this sensitivity analysis, it was imperative that the model of best fit be used (Katsanevakis and Maravelias 2008, Roth 1980). The four growth curves tested are among the most commonly used, with the 3-parameter von Bertalanffy being the most common among fisheries managers and researchers. The widely recognized and easily implemented formula for the von Bertalanffy growth curve is often chosen when using a growth model to investigate changes in growth of a single population over time, in which case, it is not as crucial to use the best-fit model (Murphy 1994 and 2005, Murphy and Munyandorero 2009, Murphy and Taylor 1990, Goodyear 1989, Roth 1980, National Marine Fisheries Service 1986, Porch 2000). In such cases, the model parameter estimates are treated as an index of comparison rather than as reliable estimates from which to derive age and growth estimates. This analysis is concerned with potential bias in the estimates, rather than changes over time. The results of the  $AIC_c$  analysis showed that in the case of Red Drum, there are at least two growth curves that are better supported than the von Bertalanffy: Gompertz and logistic. The logistic, having scored the highest was used for the remainder of this study.

The three to five-year-old mean lengths-at-age predicted by the simulated growth curves fitted to the Non-directed and Combined data were significantly different. The mean length-at-age for the Non-directed data was

lower than that of the Combined data collected by the additional gear; thus pointing to effects of gear selectivity found to introduce bias when estimating growth parameters (Taylor et al. 2005, Rudstam et al. 1984). These findings support the need to continue sampling by both Non-directed methods as well as by the Directed methods used in this study. The results of the comparison validate the need for further investigation into the presence of potential bias arising from inadequately represented year classes in the data.

The results of this study predicted significantly different SSBPR when using the Non-directed vs. Combined data to estimate growth. Bootstrap simulations were beneficial for providing confidence intervals of the SSBPR estimate distributions. While the mean estimates were significantly different and showed an increase from the Non-directed estimate to the Combined estimate for every simulation of  $F$ , the differences were larger and therefore more concerning with lower levels of  $F$ . These results have implications for management. Lower estimates of SSBPR might imply that a stock is overfished or undergoing overfishing, while inflated estimates of biomass production might induce managers to draw the opposite conclusions. In either case, the presence of biased results may lead management officials to adjust creel limits, and/or size limits when adjustments are unnecessary or in a manner too conservatively or liberally based on the true status of the stock.

Studies using simulation methodology comparable to what was used in this analysis have been conducted to examine the effects of error in age assignment on growth parameter estimates and subsequent choice of management practices (Dippold et al. 2015, Lai and Gunderson 1987, Reeves, 2003, and Tyler et al. 1989). Such studies have shown the potential for biased results and possible inappropriate classification of a stock (overpopulated, overfished, or stable) when applying those results. Alternatively, this study did not address the error in aging practices, but rather addresses how insufficient data for certain age classes might bias parameters. While the cause of such bias is different from that shown in other studies, the effects are the same. As errors in age interpretation can affect most inputs of stock assessments (Reeves 2003), it is clear from the results of this sensitivity analysis that inaccurate length-at-age estimates caused by inadequate sampling techniques can have analogous management implications. It follows that if the mean predicted biomass per recruit is incorrect, the ratio of predicted change in biomass, as the result of a management shift, could be grossly inaccurate; as indicated in this project by the inverse relationship of  $F$  to discrepancy between estimates of production. The difference in SSPBR estimates was due to the growth curve parameter estimates based on the Non-directed data leading to under-estimation of size-at-age and is cause for concern for managers. These findings validate the need for more thorough sampling to ensure more

robust data going forward.

In addition to the frequently utilized SSBPR in fisheries management, ER is an often relied upon metric for this species. In the time since the implementation of the original FMP, the GMFMC has repeatedly called for updated ER estimates when revisiting the status of Red Drum in the GOM (Mareska 2004, Porche 2004, Blanchet 2005, Florida Fish and Wildlife Conservation Commission 2005, Murphy 2005, Alabama Marine Resources Division 2008, Mississippi Department of Marine Resources 2010, Powers and Burns 2010). The FMP uses ER as the precautionary index, suggesting that a minimum 20% escapement be maintained to prevent stock collapse (Gulf of Mexico Fisheries Management Council 1987). Mean ER estimates from both data sets, though statistically different, both remained above the 20% recommended by the FMP until  $F$  reached  $0.80 \text{ y}^{-1}$ . Using a range of  $F$  when estimating ER helps to identify a precautionary index point. In this example, management strategies should be implemented such that  $F$  is maintained above  $0.80 \text{ y}^{-1}$ .

The escapement rate was not substantively affected by the addition of the Directed data because the growth coefficient ( $k$ ) from the logistic growth curve was not significantly different when incorporating the Directed data. If the steepness of the growth curve had increased between data sets, the ER would likely have been affected to a greater degree. In this case, predicted lengths were greater, thus driving mortality rates lower; but the

rate at which those values changed was proportionate between data sets. Lorenzen mortality is based on the predicted lengths and is inversely proportionate to length, where increasing length translates to lower  $M$  (Lorenzen 2000, 2005). Longer estimated lengths and lower mortality render greater estimated biomass “escaping” to the spawning stock. However, ER is not a measure of biomass that survives to join the spawning stock; rather it is a ratio of biomass that survives fishing and natural mortalities to biomass that would have survived without fishing mortality. In this study, while the estimated SSBPR increased when the Directed data was incorporated, the ER estimates remained stable because the rate at which biomass increased as a function of age was not statistically different.

Recall the method of field collection required targeting a particular size range that bracketed fish between the ages of three and five years and that the actual ages of specimens were unknown until after laboratory analysis. In retrospect, some of the specimens collected using this protocol proved to be outside the three to five-year age range that was hypothesized to be lacking, and thereby, biasing recruitment model estimates. While the number of samples for the age group in question increased considerably with the addition of the targeted fish, this addition also accounted for a moderate increase for the six-year-plus age group (Table 1). These additional six-year-plus adult fish could have affected the revised SSBPR and ER estimates.

To investigate the possibility that the new six-year-plus fish definitively influenced the revised estimates, the process of estimating an SSBPR distribution and ER distribution was retroactively repeated for the Combined data excluding any specimen that was not three to five years old or between 500 and 800 mm. This analysis also revealed significant difference in estimates of SSBPR ( $p < 0.05$ ) between data sets, however, the magnitude of difference was nearly half that of the estimates that included all specimens collected by the Directed methods. The estimated ER was not affected by the removal of non-targeted ages from the data. The targeted ages, hypothesized to be a source of bias, were not the only contributing factor to the findings of this study.

## CHAPTER V – SUMMARY

While the originally hypothesized age range within the augmented Combined sample was not the sole determinant of the significant differences in estimates, it remains that the sensitivity analysis demonstrated that the addition of supplementary fish collected according to the protocol followed in this study significantly affected the revised estimated SSBPR and ER values. The exposed discrepancy between estimates based on Non-directed versus Combined data thus still raises concern, notwithstanding the original hypothesis regarding lack of ages three to five years. In light of these findings, this study demonstrates that resampling techniques and sensitivity analysis comprise valuable fishery modeling tools when choosing appropriate precautionary reference points and data collection methods.



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