Evaluating the current status of red drum (*Sciaenops ocellatus*) in offshore waters of the North Central Gulf of Mexico: age and growth, abundance, and mercury concentration

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EVALUATING THE CURRENT STATUS OF RED DRUM (*SCIAENOPS OCELLATUS*) IN OFFSHORE WATERS OF THE NORTH CENTRAL GULF OF MEXICO: AGE AND GROWTH, ABUNDANCE, AND MERCURY CONCENTRATION

BY

Crystal LouAllen Hightower

A Thesis

Submitted to the Graduate Faculty of the
University of South Alabama
in partial fulfillment of the
requirements for the degree of

Master of Science

in

Marine Sciences

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ABSTRACT

LouAllen Hightower, Crystal, M.S., University of South Alabama, July 2013. Evaluating the Current Status of Red Drum (*Sciaenops ocellatus*) in Offshore Waters of the North Central Gulf of Mexico: Age and Growth, Abundance, and Mercury Concentration. Chair of Committee: Sean P. Powers, Ph.D.

Red Drum is a demersal sciaenid that occurs throughout the Gulf of Mexico (GOM). Over the last two decades, GOM Red Drum has been overfished, and a harvest ban has existed in federal waters since 1987. As a result, there is a lack of quantitative data to describe the current status of the adult spawning stock. Here, I addressed several issues relevant to evaluating the current status of the stock. Specifically, I: 1) examined age composition, growth, and mortality in adult Red Drum in offshore waters of the north central GOM from 2010-2012 using otoliths from fishery-independent and -dependent sources, 2) developed an index of relative abundance for Red Drum in the north central GOM with fishery-independent catch data from 2006-2012, and 3) determined the relationship between total mercury (Hg) concentration and Red Drum size and age. Recreational catch has increased over the past 26 years. Age composition and growth rates showed an increase in average age during the current moratorium, but an absence of 5-10 year old fish. The abundance index showed a declining trend. My results suggest that the public should limit consumption of Red Drum > 660 mm total length due to high total Hg concentrations. My results provide clear indication of success immediately following the moratorium, but also point out increased fishing mortality in state waters and a potential human health risk of allowing anglers to keep large Red Drum.

GENERAL INTRODUCTION

The life history of GOM Red Drum (*Sciaenops ocellatus*) has been studied extensively. At early ages (0-6 years), Red Drum is primarily characterized as a demersal fish, feeding on bottom dwelling fish and invertebrates; however, as they age they exhibit traits of a coastal pelagic, such as long (up to 700km) migrations across the GOM and a more piscivorous diet (Overstreet, 1983; Peters and McMichael, 1987; Scharf and Schlicht, 2000). Red Drum is an estuarine-dependent fish with estuarine residence occurring at the larval and juvenile stages and offshore residence after reaching maturity (3-6 years) occupying the continental shelf (Pearson, 1929; Beckman et al., 1988; Davis, 1990; Murphy and Taylor, 1990). Their spawning season is light and temperature-dependent and occurs mostly during the fall from August to November in the GOM. Red Drum are batch spawners and form large spawning aggregations near bay and Gulf passes making them vulnerable to fishing in state waters (Pearson, 1929; Overstreet, 1983; Holt et al., 1985).

Results from early GOM Red Drum studies indicated no real trend in landings from the 1890s to the 1920s (Higgins and Lord, 1927); however, Pearson (1929) highlighted that data were lacking to conduct appropriate statistical analyses and argued that fishing effort had probably increased in the early 1900s. With increased fishing efficiency and introduction of a purse seine fishery in the 1980s due to the popularity of the dish “blackened redfish,” the commercial catch of Red Drum increased from 2.5 million pounds in the early 1980s to over 14 million pounds per year by 1986 (NMFS, 2011), which led to its overfished status (Figure 1). Since 1987, federal waters have been closed to recreational and commercial fishing due to stock depletion.

The current management strategy for Red Drum, as prescribed by the GOM Red Drum Fishery Management Plan, includes a harvest moratorium in federal waters and management via escapement rates calculated by state agencies in state waters (Gulf of Mexico Fishery Management Council, 1987). Escapement is estimated as the ratio of the observed cumulative survival of a group of Red Drum through age 4 to that group’s potential cumulative survival through age 4 if it hadn’t been fished (Murphy, 2005; Powers and Burns, 2010). These values are estimated using yearly fishing mortality for ages 0-4, calculated based on age distributions of fish caught using fishery-independent surveys and fishery-dependent recreational creel surveys. The current escapement rate for managing Red Drum in GOM States is set at a minimum of 30% (40% in Florida); however, there is some fishing mortality of older Red Drum in the population (Murphy, 2005). Fishing mortality of older Red Drum in state waters must be considered for an accurate assessment of the species. Recent data are sparse for older Red Drum, precluding an understanding of the current status of the spawning population.

The most recent extensive sampling for GOM Red Drum was completed during the 1980s in conjunction with the purse seine fishery, and in the 1990s based on a National Marine Fisheries Service (NMFS) tag-and-recapture program and scientific collections off the west coast of Florida and discussed the relevance of nearshore recreational fishing pressure on the status of the stock (Beckman et al., 1988; Wilson and

Nieland, 1994; Murphy and Crabtree, 2001; Porch et al., 2002). Declining escapement rates were estimated in the latest Gulf-wide stock assessment in 2000; although, rates were high enough that the species was estimated to no longer be subjected to overfishing and was thought to have recovered from its overfished status (Porch, 2000; Hogarth, 2004). According to the federal status of marine fisheries, the GOM Red Drum stock status is now listed as “undefined,” largely due to uncertainty regarding age structure and population estimates (Hogarth, 2004).

Recent evidence indicates the recovery of older age classes of Red Drum in offshore waters of the GOM. Two Marine Fisheries Initiative (MARFIN) studies provided estimates of age structure and population size of the Red Drum stock and both studies indicated recovery of older age classes off Tampa Bay, FL and Alabama, respectively. Winner et al. (2009) conducted purse seine sampling of Red Drum schools off Tampa Bay, Florida in a study designed to repeat earlier methods of Murphy and Crabtree (2001). Older Red Drum were encountered in higher frequencies, mean size was significantly larger, and there was a significant shift in the length frequency towards larger sizes of fish a decade after the first Tampa Bay, FL study in the late 1990s (Winner, 2009; Murphy and Crabtree, 2001). Powers et al. (2012) aged 428 Red Drum collected with bottom longline in coastal Alabama from 2006-2010 and also found high frequencies of older (>10 years) age class Red Drum. Interestingly, Red Drum older than 24 years had a lower frequency of occurrence; these older Red Drum represented pre-moratorium fish (i.e. fish born before 1986) and provide an indication of the effectiveness of the current management scheme.

Despite the apparent success of the harvest moratorium in rebuilding GOM Red Drum spawning biomass, the abundance of adult Red Drum in federal waters has been difficult to assess without catch data. Powers et al. (2012) attempted to estimate adult Red Drum abundance with spotter planes. Aerial surveys were useful for distribution and presence/absence data but too costly and inaccurate for estimating abundance. Powers et al. (2012) suggested fishery-independent bottom longline sampling as an efficient method for obtaining an abundance index for Red Drum. While such an index should be a valuable tool for assessing Red Drum stock status, the limited time series of sampling (2006-2010) prevents the inclusion of the Alabama data in any formal stock assessment. I continued this time series through 2012 for these data to be available for the next stock assessment.

In February 2010, the Gulf of Mexico Fishery Management Council (Gulf Council) met to discuss the status of GOM Red Drum. The Gulf Council recommended that the overfishing limit remain at near zero for GOM federal waters based on the lack of current data on offshore adult populations, and that a small quota (20,000 Red Drum) be set and devoted to scientific study. The second recommendation was to conduct a stock assessment in state and federal waters at the earliest opportunity. This stock assessment would include age composition of Red Drum in offshore waters and include all applicable inshore data collected within state waters. The working group also recommended that mercury (Hg) concentrations in various age and size groups of Red Drum be collected (Powers and Burns, 2010).

Although not part of most stock assessments, Hg is important to investigate when considering the management of a consumed fish. Mercury is a toxic metal that bioaccumulates in tissues of long-lived fishes and can pose health risks to humans when consumed in large quantities, with monomethylmercury (MeHg) being the most toxic form of Hg (NRC, 2000). While the accumulation of Hg in marine fishes in the GOM has been well established (Ache et al., 2000), Hg concentrations above the United States Food and Drug Administration (FDA) action limit (1.0 ppm) and the Florida action limit (0.5-1.5 ppm) have only recently been reported for Red Drum (Adams and Onorato, 2005; Winner, 2009; Stunz and Robillard, 2011). Red Drum are likely candidates for bioaccumulation of Hg because they spend their early years in coastal estuaries, forage on the benthos, are long lived, and grow to large sizes (Pearson, 1929; Beckman et al., 1988; Murphy and Taylor, 1990). Management of this species should include this aspect of public health to limit human exposure to fish with elevated Hg concentrations.

Management of Red Drum is difficult due to their life history and movement across state and federal boundaries. Assessment has further been delayed due to a lack of up-to-date data from all areas of the GOM. This assessment included typical measurements of age and growth, abundance, and mortality coupled with a current ecotoxicological assessment of Red Drum in state and federal waters. This study will contribute these valuable data from the north central region of the GOM to this assessment. The Red Drum continues to be one of the more popular sportfish in the GOM and proper management will ensure it continues to be abundant for generations to come.

OBJECTIVES AND HYPOTHESES

The overall objective of this study was to examine the population ecology of Red Drum in the northern Gulf of Mexico south of Alabama, an area that is considered Red Drum essential fish habitat. Data from this study will be made available to managers to conduct a current stock assessment.

The specific objectives were:

Objective 1: Examine age composition, growth, and mortality in adult Red Drum in offshore waters of the north central Gulf of Mexico from 2010-2012

Objective 2: Develop a bottom longline abundance index for Red Drum in offshore waters of the north central Gulf of Mexico.

Objective 3: Determine the relationship between total mercury concentrations, age, and size of Red Drum.

$H_{0,1}$: There is no relationship between total mercury concentration and size of Red Drum.

$H_{A,1}$: There is a positive relationship between total mercury concentration and size of Red Drum

$H_{0,2}$: There is no relationship between total mercury concentration and age of Red Drum.

$H_{A,2}$: There is a positive relationship between total mercury concentration and age of Red Drum

CHAPTER 1: AGE AND GROWTH, MORTALITY ESTIMATES, AND ABUNDANCE

Introduction

Red Drum in the Gulf of Mexico (GOM) have been overfished since the late 1980s. In an effort to stop overfishing, a recreational and commercial harvest moratorium was established in 1987 for the federal waters of the GOM (Gulf of Mexico Fishery Management Council, 1987). This species continues to be one of the more popular sportfish in state waters. Due to the apparent return of large spawning aggregations in the northern GOM over the past decade, managers are being urged by fishermen to open federal waters to recreational fishing (Powers and Burns, 2010). The official status of the stock was characterized as undefined in the latest assessment in the early 2000s (Porch, 2000). Over a decade later, the status of the stock remains unknown (Hogarth, 2004).

Management of Red Drum is difficult due to several factors, including movements across state and federal boundaries. Although the recreational fishery in state waters is mostly limited to the removal of juveniles, the current management plans for four out of five GOM states include opportunities to keep large, sexually mature fish (Table 1). Data needed to define the current status of the stock include samples of adult Red Drum historically collected through fishery-dependent methods. The absence of a federal fishery has limited the amount of fishery-dependent sampling that can be conducted. Consequently, research has moved to collection using fishery-independent methods and recreational catch from state waters to gain data for age, growth, mortality and abundance estimates.

Powers et al. (2012) conducted a fishery-independent longline survey in the northern GOM from 2006-2010. They discussed the circular issue of needing a current Red Drum stock assessment but lacking long-term standardized studies of offshore adults to conduct such an assessment. They concluded that increased fishery-independent longline effort could potentially sample the amount of Red Drum needed from offshore waters to examine the current status of the stock. This, coupled with inshore collections available from state agencies, could address the lack of available data.

The 2006 reauthorization of the Magnusun-Stevens Fishery Conservation and Management Act included a congressionally-mandated deadline to end overfishing by setting annual catch limits (ACL) for species with fisheries management plans by the year 2011 (MSFCMA, 2006). In July 2010, the Gulf of Mexico Fishery Management Council set an acceptable biological catch (ABC) to determine the ACL. They set the ABC at 20,000 Red Drum for scientific study until a stock assessment could be conducted. Using fishery-independent gillnets and longline surveys, a shore-based sampling opportunity during a 2012 fish kill, and fishery-dependent samples from the Alabama Deep Sea Fishing Rodeo (ADSFR), I collected traditional data to investigate age and growth, abundance, and mortality of Red Drum from the north central GOM needed to evaluate population dynamics and vital rates to inform managers of the current status of the stock.

Methods

Since May 2006, Red Drum were collected using fishery-independent longline surveys and were sampled through November 2012. All longline set locations were randomly selected within the study area. From May 2006 through November 2008, sampling was stratified in blocks along the continental shelf (east to west; Figure 2A) as well as across the shelf (north to south; Figure 2B) with a depth range of approximately 2-20 m. In 2009, transect sampling was conducted between 88°30′ and 87°30′W (the longitudinal boundaries of Alabama) extending sampling southward to approximately 200 m depth (Figure 2C). In 2010, the Fisheries Ecology Lab at the University of South Alabama in conjunction with the Alabama Department of Conservation and Natural Resources conducted Southeastern Monitoring and Assessment Program (SEAMAP) bottom longline sets in nearshore waters of coastal Alabama. Four stations were sampled monthly (March-October) from inside Mobile Bay and Mississippi Sound as well as offshore (Figure 2D). From 2010-2012, targeted longline sets at the inlets near Mississippi Sound and Mobile Bay were also conducted (March-November) to increase catch of Red Drum for age, growth, and mortality estimation.

For all longline sets, a commercial-style bottom longline gear setup was used. A monofilament mainline (1000 lb. test, 1 nautical mile length) was deployed through a block off the stern of the research vessel. High flier buoys were used at the start and end of each set. Five kg weights (start, mid-set, end set), and 3.66 m monofilament gangions (318 kg test) with 15/0 Mustad 39960D circle hooks were clipped to the mainline during deployment. Bottom longline effort was 100 hooks fished for one hour soak time. Soak time was determined from the time the last high flier buoy was deployed until the first high flier buoy was retrieved to begin the haul back (Driggers et al., 2008). For all surveys, except the targeted effort sets, hooks were baited with dead Atlantic Mackerel (*Scomber scombrus*). For the targeted sampling effort, whole live Atlantic Croaker (*Micropogonias undulatus*) alternated on every other hook with Atlantic Mackerel. All fish were boated, measured to the nearest mm, and weighed to the nearest 0.1 kg. Haul back speed was approximately 3.5 - 4 knots. In addition, a hydrolab cast was made during the soak time to measure surface and bottom temperature, salinity, and dissolved oxygen. A paired t-test was used to test the effect of bait type on CPUE.

For all Red Drum captured on the longline, standard morphometrics, otoliths, gonads and intraperitoneal fat were sampled from each fish. Standard length (SL), fork length (FL) natural total length (NTL) and stretch total length (STL) to the nearest mm and mass to the nearest 0.1 kg were recorded. Sagittal otoliths were removed and stored dry for future processing. Gonads and any intraperitoneal fat were removed and weighed to the nearest gram and gonadosomatic (GSI) and intraperitoneal fat (IPF) indices were calculated. Gonadosomatic and IPF indices are measures of condition where gonad mass or intraperitoneal fat mass is divided by total body mass then multiplied by 100 (Wilson and Nieland, 1994; Craig et al., 1995). The GSI and IPF provide information on the relative investment of energy used for reproduction and growth (McGoogan and Gatlin, 1988; Wilson and Nieland, 1994). A Fulton condition index was also calculated by dividing the mass of the fish by TL^3 and multiplying by 100,000 (Ricker, 1975).

Additional fishery-independent data including standard morphometrics and ages were collected by the Alabama Marine Resources Division (AMRD) using experimental gillnets in Alabama state waters. These age and length data were collected during monthly gillnet sampling from 2006 to 2009. These data were not included in the abundance index but were used to increase the number of smaller individuals to improve estimates of parameters in Red Drum growth models.

Red Drum were also sampled for standard morphometrics, otoliths, gonads and fat through a fishery-dependent source, the Alabama Deep Sea Fishing Rodeo (ADSFR). The ADSFR was held in July 2009 and 2011, and fish were caught within territorial waters of the ADSFR. The ADSFR was cancelled in 2010 because of the Deepwater Horizon Oil Spill. The coordinates for the ADSFR territorial waters are: north: all bays and inlets of the GOM; east: 85°W longitude; south: 28°N latitude; and, west: 91°W longitude (Figure 3). Anglers who brought in a Red Drum above the slot limit size (660 mm TL) were entered into a random drawing for prizes. Alabama state law allows one Red Drum above 26 inches total length per day, and all fishing was conducted in accordance with state regulations.

Sagittal otoliths were used to estimate ages of Red Drum in this study. Sagittal otoliths for age determination of GOM Red Drum were first used by Beckman et al. in 1988. Otolith processing techniques for this study were conducted according to the methods for thin sectioning described in the Gulf of Mexico Marine Fisheries Commission otolith manual (VanderKooy and Guidon-Tisdel, 2003) and Beckman et al. (1988). The left otolith was processed, leaving the right otolith for use when the left was not available or when there was a disagreement between otolith readers (Beckman et al., 1988). Otoliths were cut along the transverse plane as close to the core as possible with a Model 1010 Hillquist Thin-Sectioning Petrographic Saw. Sectioned otoliths were polished with a Crystal Master 6 Plus polishing wheel affixed with a Buehler microfiber polishing cloth treated with 0.3 µm aluminum oxide powder and water. Polished sections were placed sectioned side down on a glass microscope slide and secured using Loctite 349™ ultraviolet adhesive. The slides were placed under a blacklight overnight to cure. The remaining otolith section was trimmed with the cut-off saw followed by the precision grinder to grind the otolith until it reached approximately 50 µm. The slide was then polished on the Crystal Master 6 Plus with aluminum oxide and water, cleaned, and covered with Flo-Texx liquid cover slip to remove scratches. All otoliths were aged independently by two readers. Average percent error (APE) was calculated to ensure correct integer ages using the following equation:

$$\text{APE} = 100\% \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

where, R was the number of readings of individual j, X_{ij} was the age i, determined for individual j, and X_j was the mean age among readers. Integer age was determined by counting number of opaque zones. Year at birth was estimated for all Red Drum by subtracting opaque zone count from year of capture with the assumption that the initial annulus was deposited during the winter of year two (Beckman et al., 1988).

To estimate growth parameters for Red Drum in this study, von Bertalanffy and double von Bertalanffy growth curves were fit to both males and females for the complete data set, fishery-independent (gillnet and longline) data and fishery-dependent (ADSFR). The von Bertalanffy growth curve was calculated using the following equation:

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

where L_t is total length at time t, L_∞ is the asymptotic length, e is the base of natural logarithms, K is the von Bertalanffy growth coefficient, t is age, and t_0 is the theoretical age at which total length equals zero (von Bertalanffy, 1938). The ‘double von Bertalanffy’ growth parameters as described by Condrey et al. (1988) were calculated with the following equation:

$$L_t = \begin{cases} L_\infty [1 - e^{-K(t-t_1)}] \text{ if } t < t_p \\ L_\infty [1 - e^{-K(t-t_2)}] \text{ if } t > t_p \end{cases}$$

$$t_p = (k_2 t_2 - k_1 t_1)/(k_2 - k_1)$$

where t is age, L_∞ is the asymptotic length, k_1, k_2 describe instantaneous growth coefficients, and t_1, t_2 are the age intercept parameters. The models were fit using Excel and the R (2.10.1) statistical software package with the FSA add-in (Koenker and Ng, 2012). Differences in growth curves between males and females were tested with a likelihood ratio test (Kimura, 1980; Haddon, 2000). The growth model with the most parsimonious fit was selected based on the Akaike information criterion (AIC) calculated using the following equation:

$$\text{AIC} = 2k\text{-}2\ln(L)$$

where k is the number of parameters in the model and L is the maximized value of the likelihood function for the model. The results from these growth models were compared to similar equations calculated previously for Red Drum in the GOM (Tables 2 and 3).

These growth parameters were compared with those of previous studies by using the following conversion provided by Goodyear (1996): total length = 1.092(fork length)-1.01.

A catch curve was computed to estimate total mortality (Z) by fitting a linear regression to the fully-recruited ages in a scatterplot of the natural log of numbers versus age. Two methods were employed to estimate natural mortality (M) from the maximum observed longevity. Hoenig's (1983) regression equation was used to predict M from t_{max} (maximum age observed) using the equation:

$$\ln(M) = 1.44 - 0.982 * \ln(t_{max}).$$

A simpler rule-of-thumb approach evaluated by Hewitt and Hoenig (2005) using $P = 0.05$ (the proportion of the population that survives to the t_{max}) was also used.

$$M = \frac{-\ln(P)}{t_{max}}$$

Because $Z = M + F$, F can be estimated if you have accurate estimates of Z and M. These three estimates were calculated using the entire 2008-2012 data set including that from Powers et al. (2012). The estimates were then compared to those of previous studies.

Spatial analysis of the fishery-independent longline Red Drum data was conducted to elucidate the age distribution and abundance of Red Drum in state and federal waters of the GOM. This was done by plotting the state/federal boundary and a selection process using ArcGIS v10.1. I examined age versus distance from shore to verify the age distribution of Red Drum available to recreational fishermen in state waters and those protected in federal waters. Red Drum abundance, using the fishery-independent longline survey from 2006-2012, was examined by location in state or federal boundary waters. A one-way ANOVA was used to test for differences in CPUE between state and federal waters.

Powers et al. (2012) concluded that an abundance index could be calculated using standardized bottom longline catch data. In their approach, all fishery-independent longline catch data were converted to nominal CPUE, expressed as fish caught/100 hooks/hour. Differences in nominal CPUE by month and year were tested using one-way ANOVAs. If significance was detected by the model, Tukey's HSD post hoc analysis was performed. To standardize CPUE for an abundance index, the delta-lognormal index (dGLM) of relative abundance (I_y) as described by Lo *et al*. (1992) and Ingram *et al*. (2010) was estimated as

$$I_y = c_y p_y,$$

where c_y is the estimate of mean CPUE for positive catches only for year y, and p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y are estimated using generalized linear models. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) are assumed to have lognormal and binomial distributions, respectively. The final index was the product of the back-transformed year effects from the two above mentioned general linear models (GLMs). All GLMs were computed with year and month as factors. The standard error and coefficient of variation of index values were estimated using a jackknife routine on factors with greater than two positive observations. These models were estimated using code provided by E.J. Dick using the R (2.10.1) statistical software package.

Results

Fishery-independent samples from the longline (adults) and gillnets (juveniles) provided a robust data set to examine age based metrics of population status. One hundred eighty-six fish were collected during all fishery-independent longline surveys from May 2010 to November 2012 (Figure 4.). Fishing effort for the standardized fishery-independent longline survey was 87, 87, and 82 sets in 2010, 2011, and 2012, respectively and caught 50 Red Drum. An additional 37 targeted longline sets were conducted to supplement the age data and captured 136 Red Drum. A paired t-test was used to test the effect of live versus dead bait on Red Drum CPUE. The t-test indicated a significantly higher CPUE for Red Drum caught using live versus dead bait ($t=4.530$, $d.f.=12$, $p<0.05$) (Figure 5). The AMRD conducted 851 gillnet sets and provided data for 208 Red Drum caught in Alabama state waters from 2006-2009. The fishery-dependent ADSFR provided 78 and 90 Red Drum in 2011 and 2012, respectively. In 2012, 23 Red Drum were collected during a fish kill event that occurred south of Dauphin Island, Alabama. The cause of the fish kill was not determined, but AMRD tests were negative for a bacterial cause and investigation of water samples collected during the event did not indicate a red tide.

Examination of condition indices demonstrated a strong period of pre-spawning, especially for females (Figure 6). Using the 2010-2012 fishery-independent longline and fishery-dependent ADSFR data, values for Fulton condition index (n=350) were consistent across months. There was a slight peak in GSI (n=341) and decline in IPF (n=341) signaling spawning in October but, the current data set did not contain fish collected during September (Figure 6A). The data were combined with Powers et al. (2012) to cover dates from 2008-2012 and the GSI and IPF reflected the fall spawning season (Figure 6B). There was no significant difference between males and females for the Fulton condition and IPF indices; however, GSI was significantly greater for females (0.688 ± 0.037) than males (0.323 ± 0.024) (Mann-Whitney U test, $U = 111141$, $p<0.0001$).

Differences in selectivity between fishery-independent bottom longlines and gillnets and fishery-dependent hook and line allowed a broad survey of Red Drum age structure. Five hundred and seventy two Red Drum were aged in this study. Age composition and length frequency were calculated for both fishery-independent and fishery-dependent samples (Figures 7A-B). The APE for all Red Drum in this study was 0.002 resulting in 99.998% agreement between two independent readers. The youngest fish in this study was 0 years old and collected in an AMRD gillnet and the oldest fish was 40 and collected during the 2011 ADSFR using hook and line (Figure 8). The highest proportion age class for the fishery-independent longline was age 20 and the size range was 759-1067 mm. The fishery-dependent ADSFR provided younger fish with 3 year olds being the highest proportion covering a size range of 446-1040 mm (Figure 9). The AMRD gillnet provided the most fish from 0-2 ages and 179-889 mm size classes. The length frequency of the samples collected during the 2012 fish kill indicated the affected fish were large with 75% of the fish collected greater than 900 mm. The age distribution for the fish kill Red Drum was evenly distributed with fish varying in age from 4-26 years old. Kolmogorov-Smirnov comparisons of two distributions were used to test for differences in age distribution and length frequencies between all fishery-independent and dependent samples. The K-S tests showed the distributions were significantly different for both age distribution (D = 0.503, p<0.0001) and length frequency (D = 0.467, p<0.0001). Fish caught during the fishery-independent longline were longer and older than those caught during the fishery-dependent ADSFR.

Growth parameters differed between sex and collection type. Length at age was plotted for all sampling gears and used to calculate growth parameters (Figure 10). Von Bertalanffy and double von Bertalanffy growth models were first fit using all Red Drum data with both sexes combined (von Bertalanffy, 1938; Porch et al., 2002) (Tables 2-4) (Figure 11). The double von Bertalanffy function resulted in higher values for k_2 than k_1 indicating faster growth after age five, which would not be accurate based on the length at age data. Also, because of relatively large sizes (approximately 200-400 mm) at age zero, t_2 was so small (-84.5) it was considered biologically meaningless. To investigate more meaningful parameters, the double von Bertalanffy function fit was forced through zero (making t_1, t_2=0). The L_∞ for the double von Bertalanffy forced through zero was slightly smaller (938) and k_1 (0.56) was greater than k_2 (0.40). The AIC calculated for the standard von Bertalanffy was slightly lower (6357) than the double von Bertalanffy growth function (6404) and much lower than the von Bertalanffy growth function forced through zero (7319); thus, the standard von Bertalanffy function was evaluated to be the most parsimonious fit. The the standard von Bertalanffy growth function for all gear types with both sexes combined and for males and females separately were fit to the data. Sex was determined for 427 Red Drum from fishery-dependent and -independent sources and had a 1:1.4 male to female ratio. A likelihood ratio test showed a difference in model fit between males and females ($\chi^2 = 18.26$, df = 1, $P<0.05$). The L_∞ was larger for females (953 mm) than it was for males (928 mm), growth coefficients were very similar between the sexes, and t_0 was identical for males vs. females for the main model. L_∞ was slightly larger for fishery-independent data versus fishery-dependent data. The k was larger and the t_0 was smaller for fishery-dependent data ($k = 0.27$, $t_0 = -2.6$) compared to fishery-independent data ($k = 0.24$, $t_0 = -1.6$).

Several methods used to calculate Red Drum mortality reflected differences in mortality estimates with collection type. Catch curve regressions were plotted starting with the ages fully selected for the fishery-independent longline (20 years old) and fishery-dependent hook and line (3 years old). Total mortality (Z) was estimated as 0.25 for fishery-independent catch and 0.08 for fishery-dependent catch (Figure 12). Hoenig's (1983) model and Hewitt and Hoenig's (2005) rule-of-thumb model to estimate M were calculated using a t_{max} of 40 years. Hoenig's (1983) model calculated M at 0.11 and the Hewitt and Hoenig (2005) rule-of-thumb model calculated M at 0.07. Fishing mortality was estimated between 0.14 to 0.18 for fishery-independent catch and 0 to 0.01 for fishery-dependent catch when using the Hoenig (1983) and Hewitt and Hoenig (2005) estimates for M, respectively.

Age and length distributions and abundance of fishery-independent longline Red Drum were examined spatially to examine any differences between state and federal waters. Since 2006, longline sets were evenly distributed in state versus federal waters with 57% and 43% effort in each boundary, respectively (Figure 4). Spatial analysis of the fishery-independent longline data showed that the age (D = 0.484, $p<0.0001$) and length distributions (D = 0.507, $p<0.0001$) were significantly different for Red Drum caught in state versus federal waters. Fish were older and larger in state waters. Average ages were 18 years in state and 13 years federal waters. Average length was 929 mm within state waters and 866 mm in federal waters. Further analysis of fishery-independent longline ages, as a function of distance from shore, showed there was a weak negative correlation with age and distance from shore (r = -0.414, $p<0.0001$) (Figure 13). Abundance of fishery-independent longline Red Drum also differed by location. Red Drum mean CPUE was significantly higher in state (0.954 ± 0.114) versus federal waters (0.343 ± 0.072) (one-way ANOVA, $F_{1, 732} = 17.707$, $p<0.0001$) (Figure 14).

Temporal analyses of Red Drum abundance resulted in differences in CPUE by month and year. The observed abundance of Red Drum displayed a seasonal catch trend with significantly different CPUE by month (one-way ANOVA, $F_{11, 732} = 7.131$, $p<0.0001$). The Tukey HSD post hoc analysis indicated significantly lower CPUE occurring in the summer (June-September) and the highest CPUE in January, March, April, and October (Figure 15). The observed index also revealed a slight significant difference in CPUE by year (one-way ANOVA, $F_{6, 732} = 2.276$, $p<0.05$); however, a Tukey HSD post-hoc test did not show significant differences (Figure 16). The dGLM calculated for abundance by year showed similar results with apparent non-significance between CPUE and year; although, there was a declining trend (Table 5) (Figure 17).

Discussion

Traditional stock assessment data, obtained by sampling commercial and recreational fisheries, are no longer available during harvest moratoriums and must be collected using alternative sampling strategies. Fishery-independent sampling can play a vital role in data collection needed to manage species during harvest bans (Powers et al., 2012). In the case of Red Drum, current fishery-independent longline sampling by the NMFS could provide data for abundance estimates; however, to be useful for determining age and growth, mortality, and condition of the entire population, the full range of sizes and ages of fish in that population must be included. A combination of fishery-independent gears can be used to collect the entire range of sizes and ages present in the population. A unique opportunity for data collection exists when fishes under federal harvest moratoriums have life histories that include movements in and out of separately managed state waters. Since recreational harvest is allowed in state waters, I had the opportunity to supplement my fishery-independent data with fishery-dependent collections at a recreational tournament.

Improvements made to fishery-independent longline sampling techniques as well as current information regarding seasonal CPUE trends (Powers et al., 2012) have increased numbers of Red Drum collected for an age and growth study. The use of live Atlantic Croaker as bait for targeted sets almost doubled Red Drum CPUE. The targeted inlet longline sets produced greater than twice the Red Drum than the random sets with less than 15% of the effort. Coordinating sampling at the inlets during the months of March through November as suggested by Powers et al. (2012) has been effective in collecting samples for age and growth but cannot be included in the standardized abundance index because it is not consistent with methods dating back to the original longline sets in 2006.

Condition indices were similar to previous studies; however, spawning condition of fish was not completely depicted in the two-year time frame of this study. Previously reported GSI values for Red Drum in the northern GOM range between approximately 0.5 and 8.5 for fish captured between May and November (Wilson and Nieland, 1994). Although the GSI was consistent with previous studies, I did not catch red drum in the 2010-2012 longline sampling during the important spawning month of September. When combined with Powers et al. (2012) condition data, the 2008-2012 GSI and IPF indices reflected changes in reproductive indices during spawning and accurately depicted the spawning season.

The age distribution in this study provided evidence for the initial effectiveness of the federal fishery closure with a distinct increase in the relative proportion of Red Drum from post-moratorium age classes. The length frequency and age distribution of Red Drum in this study reflects a bimodal distribution of ages and lengths. Fishery-dependent ADSFR and fishery-independent gillnet collections represented fish less than 5 years old and the fishery-independent longline represented a majority of those 15-25 years old (Figure 9). The age classes comprising 5-10 year olds were infrequent in the collections. The length range of these ages would be approximately 700-1000 mm. Although the entire size range of Red Drum in this study included these sizes, the range of sizes contributing significantly to the overall fishery-independent length frequency of Red Drum was approximately 300-500 mm for gillnet and 900-1000 mm for the longline.

Gear selectivity of the gillnet was shown to be a dome-shaped length distribution that is common for size selective gears such as gillnets (Figure 9). The longline represents a knife-edge, flat-topped distribution because the gear is highly selective for larger sizes based on the large hook size and the distribution would continue without overfishing and natural mortality (Figure 9). Low abundance of the 800-850 mm size class was also seen in the fishery-dependent length frequency. There is no evidence to suggest that recreational fishermen would choose gear to select against this size range; therefore, it is possible that the size and thus age class underrepresented in this study is due to absence in the population. Based on the fishery-independent and fishery-dependent collections, the absence of the 5-10 year olds may be due to sampling bias, but is more likely due to fishing mortality in state waters.

Spatial analysis of Red Drum age distribution for the fishery-independent longline in state versus federal waters actually showed significantly larger, older fish collected in state waters. Age as a function of distance from shore also showed a negative relationship (Figure 13). Authors suggest that Red Drum susceptible to recreational fishing in state waters are ages 0-4 (Murphy and Taylor, 1990; Murphy and Crabtree, 2001). Although the fishery-dependent (ADSFR) age distribution supports this, it also clearly shows that in states where oversize fish are allowed to be kept, older fish are available for harvest in state waters. A 2008 AMRD Red Drum assessment stated that large fish (>26 in/660 mm TL) comprised approximately 34% and 37% of the samples collected in Alabama by NMFS Marine Recreational Fishery Statistics Survey (MRFSS) and AMRD biological sampling (otolith) surveys, respectively (AMRD, 2008). Given this information and the age distribution, the federal harvest moratorium does not fully protect older age classes of Red Drum from harvest; it simply lessens overall fishing mortality.

Von Bertalanffy growth function parameters differed from previous studies mostly due to differing sample collection methods that leads to different length and age distributions. Because the fishery-independent longline selects for older fish, gillnet data were necessary for biologically meaningful growth parameter estimates. Previous studies that sampled larger, older fish (Beckman et al., 1988; Powers et al., 2012) had artificially large negative estimates for t_0 because they did not adequately sample young fish in the population. The t_0 in my study was similar to that of Murphy and Taylor (1990) because in both studies, several gears were employed to attempt collection of all sizes of Red Drum. Inclusion of the gillnet data also led to a smaller L_∞ than estimated in previous studies. This is also the area of the growth curve where the aforementioned age data are lacking, that could also lead to differing estimates of L_∞. Comparisons between my Alabama growth parameters with those from other states are further complicated by different collection methods. The relatively low L_∞ is most like that reported in Texas for a study that included smaller fish collected using gillnet surveys (Porch, 2000). Another possibility for low estimates of L_∞ could be due to the higher population density of Red Drum post-moratorium; previous studies were conducted within 10 years of the harvest moratorium and might not be representative of the current population.

Total, natural, and fishing mortality of Red Drum reflected the effect of increased fishing pressure in state waters. Natural mortality estimates for Red Drum in this study were low and similar to recent studies. Total mortality estimates for Red Drum in the fishery-independent collections were similar to those previously published between 0.1

and 0.3 y^{-1} (Porch, 2000). The catch curve *Z* estimates using fishery-independent and fishery-dependent methods highlight the importance of fishery-independent collection since the samples collected by fishermen at the ADSFR provided a 0.08 y^{-1} estimate of total mortality, much lower than any of the fishery-independent samples (0.25 y^{-1}) and those in previous studies. Hoenig (1983) and Hewitt and Hoenig (2005) methods of estimating *M* based on longevity and proportion of the population surviving to 40 years were 0.11 and 0.07 y^{-1}, respectively. These estimates were fairly consistent with those from other post-moratorium studies; although, the mortality estimates made by catch curve analysis were lower than those recently reported in a Florida stock assessment (Porch, 2000; Murphy, 2009). Fishing mortality also reflected the increase in state recreational fishing pressure, as *F* was more than twice as high as *M* for the fishery independent bottom longline catch.

The observed nominal abundance of Red Drum calculated by month in this survey continued to be consistent with that of the Powers et al. (2012). This was the primary reason the targeted sampling was conducted from March-November and proved to be successful in achieving a larger sample size than the previous study. Yearly nominal abundance data showed a declining trend in CPUE, as did the standardized dGLM index. These models, coupled with clear trends of increased catch in state waters, indicate that the recreational fishery existing in Alabama state waters could be a significant source of mortality for all Red Drum, especially the large adults thought to be protected by the moratorium in federal waters.

Gulf of Mexico Red Drum have undergone the strictest form of fisheries management and have clearly increased in abundance over the past two decades. This is a success story in terms of increasing older age classes; however, recreational fishing pressure in state waters remains high. This study provides the information needed as well as underscores the importance of spatial analysis of data to investigate current fishing mortality in state waters. State fisheries in Louisiana, Mississippi, and Alabama exhibit a great deal of fishing pressure on large adults that can negatively impact the spawning stock in protected federal waters. This is supported by the current recreational catch data and my fishery-independent and -dependent age, mortality and abundance data; however, gear selectivity is still an issue that complicates understanding the underrepresented size and age classes. Although escapement rates are high enough for this fishery to no longer be undergoing overfishing, according to my study as well as the 2000 stock assessment the abundance seems to be declining in recent years (Porch, 2000).

For fisheries undergoing harvest bans, such as Red Drum in the GOM, alternative collection strategies must be developed. Future studies are also needed that cover gear types selective for the entire range of sizes to determine if missing 5-10 year olds in this study were due to gear selectivity or recreational fishing mortality. Fishery-independent longlines are effective for collecting samples needed to examine population dynamics of Red Drum; however, smaller hook sizes may be necessary to deal with gear selectivity issues. Tournament sampling is cost-effective and can provide a snapshot of the population vulnerable to recreational fishing mortality in state waters. Proper management of this species will be dependent on these types of collections and analyses to determine if the status of GOM Red Drum continues to be overfished.

CHAPTER 2: MERCURY CONCENTRATIONS IN RED DRUM

<u>Introduction</u>

Gulf of Mexico (GOM) Red Drum have an interesting management history that includes a dichotomous management strategy with a state managed recreational fishery and a total federal harvest ban. In the late 1980s, the popularity of the blackened redfish recipe led to severe overfishing and a harvest moratorium was mandated for federal waters of the GOM. The moratorium has been in place for the past twenty six years, and signs of improvement have been seen in the form of large spawning schools returning to coastal waters and an increase in older age classes of fish. Although escapement rates have met the 30% goals, recreational fishing in state waters continues to have an impact (Porch, 2000). As pressure increases to reopen the fishery in federal waters, several issues need to be examined under current conditions.

In addition to the current population status of Red Drum (Chapter 1), human health issues may need to be addressed given the established relationship between long-lived marine fish and mercury (Hg) levels. Although Red Drum are not conventionally thought to contain high Hg concentrations, they are likely candidates for high Hg because they forage in the benthos, are long lived, and grow to large sizes (Pearson, 1929; Beckman et al., 1988; Murphy and Taylor, 1990). Red Drum also undergo an ontogenetic diet shift from invertebrates to fish that would also likely increase Hg bioaccumulation and biomagnification (Peters and McMichael, 1987; Scharf and Schlicht, 2000; Adams and Onorato, 2005). Authors of several GOM studies have reported total Hg concentrations above 1 ppm for Red Drum (Ache et al., 2000; Adams and Onorato, 2005; Winner et al., 2009; Stunz and Robillard, 2011; and Harris et al., 2012). As with any fish that is long lived and feeds at upper trophic levels, managers of Red Drum should not only examine traditional stock assessment data, but also include this aspect of public health to limit human exposure to fish with elevated Hg concentrations.

Mercury is a chemical element that comes from natural and anthropogenic sources (U.S. EPA, 1997; U.S. DHHS, 1999; NRC, 2000). Mercury can be introduced into the environment in small concentrations when rocks erode, volcanoes erupt, and when soil decomposes. Anthropogenic inputs such as burning fossil fuels, mining, and chlor-alkali production add to the amount of Hg in the atmosphere (Morel et al., 1998 and Fitzgerald, 2007). Mercury is introduced into the marine environment through atmospheric deposition via precipitation and wet deposition through riverine inputs. Once in the marine environment, inorganic Hg can become methylated, particularly by sulfate reducing bacteria, and then become bioavailable (Morel et al., 1998 and Fitzgerald, 2007). Monomethylmercury (MeHg) is the most toxic and bioavailable form of Hg in the environment. The MeHg form can bioaccumulate in fish tissues over time and biomagnify through the aquatic food web, leading to fish containing high concentrations of Hg in their tissues (U.S. DHHS, 1999; NRC, 2000). Currently, the Environmental Protection Agency (EPA) has a MeHg criterion at 0.3 ppm, and the United States Food and Drug Administration (FDA) action limit is 1.0 ppm. Because of the high consumption of marine sportfish by US Gulf Coast residents, public awareness pertaining to fishes with Hg concentrations greater than advisory limits is needed to maintain good public health (U.S. EPA, 2004).

Recent studies of Hg concentrations in Red Drum tissues conducted in Florida and Texas showed that larger size classes of Red Drum accumulated Hg above the acceptable limits (Adams and Onorato, 2005; Winner et al., 2009; and Stunz and Robillard, 2011). Adams and Onorato (2005) measured total Hg concentrations in Red Drum across several estuaries in Florida and found total Hg concentrations ranged from 0.020 to 3.6 ppm. Analysis of Hg-length relationships over the entire study area indicated a significant exponential relationship between total Hg and fish length (Adams and Onorato, 2005). Winner et al. (2009) also found a strong positive exponential relationship between total Hg and fish length in Tampa Bay, FL. Authors of both papers concluded that the maximum size limit in Florida waters (686 mm TL) effectively restricts access to Red Drum above the Florida advisory limits (0.5-1.5 ppm). Stunz and Robillard (2011) also reported a positive relationship between total Hg and Red Drum length off the Texas coast. Mean ± standard deviation total Hg for Red Drum in their study ranged from 0.090 ± 0.005 ppm in Aransas Bay to 1.024 ± 0.181 ppm in Surf near Port Aransas. These elevated Hg concentrations of Red Drum in Texas waters pose a particular problem in that the Texas slot size for Red Drum includes larger fish (508-711 mm TL) and two "over the slot" Red Drum per angler per year may be kept (Table 1). Given this allowance of larger fish to recreational anglers, human consumption of contaminated fish is likely.

While Hg concentrations for Red Drum have been studied in Florida and Texas, Red Drum Hg data are lacking from the central region of the GOM. To assess the breadth of Hg contamination of Red Drum in the GOM, more studies are needed in Alabama, Mississippi, and Louisiana. Currently, four out of the five Gulf States allow anglers to keep oversized Red Drum. Each state manages catch limits for Red Drum in their waters separately from that of the other Gulf States (Table 1). The allowable catch limits for all Gulf States except Florida present the possibility of human consumption of high total Hg concentrated Red Drum. Quantifying concentrations of Hg in GOM Red Drum is essential for effectively setting advisory and management limits to reduce the consumption of contaminated fish. In this study, I measured total Hg concentrations in GOM Red Drum and examined relationships between total Hg and size and age of Red Drum from fishery-independent longline surveys and fishery-dependent collections at the 2011 Alabama Deep Sea Fishing Rodeo (ADSFR). I also compared fishery-dependent collected Red Drum Hg concentrations to that of the fishery-dependent collected King Mackerel, a GOM fish with known elevated Hg concentrations (Adams and McMichael, 2007).

Methods

In 2010 and 2011, Red Drum were sampled in the northern GOM using a fishery-independent bottom longline (Figure 18). The Fisheries Ecology Lab at the University of South Alabama in conjunction with the Alabama Department of Conservation and Natural Resources conducted monthly Southeastern Monitoring and Assessment Program (SEAMAP) bottom longline sets in nearshore waters of coastal Alabama. Four stations were sampled monthly (March-October) from inside Mobile Bay and Mississippi Sound as well as offshore. Targeted sampling at fixed stations was also conducted to increase catch of Red Drum for age distribution and Hg analysis. For all longline sets, a commercial-style bottom longline gear setup was used. A monofilament mainline (1000 lb. test, 1 nautical mile length) was deployed through a block off the stern of the research vessel. High flier buoys were used at the start and end of each set. Five kg weights (start, mid-set, end set), and 3.66 m monofilament gangions (318 kg test) with 15/0 Mustad 39960D circle hooks were clipped to the mainline during deployment. Bottom longline effort was 100 hooks fished for one hour soak time. Soak time was determined from the time the last high flier buoy was deployed and until the first high flier buoy was retrieved to begin the haul back (Driggers et al., 2008). For the SEAMAP surveys, all 100 hooks were baited with Atlantic Mackerel (*Scomber scombrus*). For the targeted sampling effort, whole live Atlantic Croaker (*Micropogonias undulatus*) alternated on every other hook for a total of 50 Atlantic Mackerel and 50 Atlantic Croaker. All fish and sharks possible to lift were boated, measured to the nearest mm, and weighed to the nearest 0.1 kg. Haul back speed is approximately 3.5 - 4 knots. In addition, a hydrolab cast was made during the soak time where surface and bottom measurements of temperature, salinity, and dissolved oxygen were recorded.

To cover the sizes and ages of Red Drum landed by GOM recreational fishermen, I also conducted a fishery-dependent survey. Standard morphometrics, gonads, intraperitoneal fat, otoliths and muscle tissue samples were collected at the 2011 ADSFR for analysis. The ADSFR was held July 15-17 and fish were caught within territorial waters of the ADSFR. The coordinates for the ADSFR territorial waters are: north: all bays and inlets of the GOM; east: 85°W longitude; south: 28°N latitude; and, west: 91°W longitude (Figure 3). Anglers who collected a legal Red Drum including those above the slot limit size (660 mm TL) were entered into a random drawing for prizes. There was no award by weight for Red Drum, so anglers were not given incentive to bring in their largest fish. Alabama state law allows one Red Drum above 26 inches per day and all fishing was conducted in accordance with state regulations. In addition to Red Drum, tissue samples of each species sampled during the 2011 ADSFR (n=20, if possible) were analyzed to compare total Hg concentrations.

For both fishery-independent and fishery-dependent collections, standard morphometrics, otoliths, gonads, intraperitoneal fat, and muscle tissue were sampled from each fish. Standard length (SL), fork length (FL) natural total length (NTL; without the tail pinched) and stretch total length (STL; with the tail pinched) to the nearest mm and mass to the nearest 0.1 kg were recorded. Sagittal otoliths were removed and stored dry for future processing. For Red Drum only, gonads and any intraperitoneal fat were removed and weighed to the nearest gram and gonadosomatic (GSI) and intraperitoneal fat (IPF) indices were calculated. Gonadosomatic and IPF indices are measures of condition where gonad mass or intraperitoneal fat mass is divided by total body mass then multiplied by 100 (Wilson and Nieland, 1994; Craig et al., 1995). The GSI and IPF can elucidate the relative investment of energy used for reproduction and growth (McGoogan and Gatlin, 1988; Wilson and Nieland, 1994). A Fulton condition index was also calculated by dividing the mass of the fish by TL^3 and multiplying by 100,000 (Ricker, 1975).

Otolith processing techniques for Red Drum and King Mackerel in this study were conducted according to the methods for thin sectioning described in the Gulf of

Mexico Marine Fisheries Commission otolith manual (VanderKooy and Guidon-Tisdel, 2003) and Beckman et al. (1988). The left sagittal otolith was processed, leaving the right otolith for use when the left was not available or when there was a disagreement between otolith readers (Beckman et al., 1988). Otoliths were cut along the transverse plane as close to the core as possible with a Model 1010 Hillquist Thin-Sectioning Petrographic Saw. Sectioned otoliths were polished with a Crystal Master 6 Plus polishing wheel affixed with a Buehler microfiber polishing cloth treated with 0.3 µm aluminum oxide powder and water. Polished sections were placed sectioned side down on a glass microscope slide and secured using Loctite 349™ ultraviolet adhesive. The slides were placed under a blacklight overnight to cure. The remaining otolith section was trimmed with the cut-off saw followed by the precision grinder to grind the otolith until it reached approximately 50 µm. The slide was then polished on the Crystal Master 6 Plus with aluminum oxide and water, cleaned, and covered with Flo-Texx liquid cover slip to remove scratches. All otoliths were aged independently by two readers. Average percent error (APE) was calculated to ensure correct integer ages using the following equation:

$$\text{APE} = 100\% \text{ x } \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

where, R was the number of readings of individual j, X_{ij} was the age i, determined for individual j, and X_j was the mean age among readers. Integer age was determined by counting number of opaque zones.

Fish muscle tissue was collected to measure total Hg concentrations using a direct Hg analyzer. Muscle tissue for Hg and stable isotopes was excised from a fish's left dorsal area above the lateral line. This represents the area where fillets are obtained for human consumption (Adams and McMichael, 2001). A clean stainless steel knife was used to take small fillet samples (5 g) from each fish. Skin and scales were left intact to reduce possible freezer burn and changes in wet weight. Tissue samples were placed in clean scintillation tubes and frozen. Tissue samples were shipped frozen to the National Marine Fisheries Service's (NMFS) Laboratory in Beaufort, North Carolina to be analyzed for total Hg using a modified EPA method 7473: Hg in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry using a Milestone Direct Hg Analyzer-80. Because more than 95% of total Hg found in fish tissue is the monomethyl form, total Hg is an accurate proxy for MeHg in fish (Grieb et al., 1990; Bloom, 1992). Wet muscle tissue aliquots of 0.1 to 0.2 g were cut from fillets and analyzed directly against aqueous Hg standards prepared in 2% hydrochloric acid. Associated quality assurance samples included four reference materials, National Research Council of Canada (NRCC) TORT-2, DORM-2, DOLT-3, and a scallop sample prepared at the NMFS Beaufort laboratory. Method blanks, replicate samples, and spike recovery samples were also included. In terms of accuracy, mean measured concentrations of the certified reference materials (CRMs) TORT-2 and DORM-2 from the NRCC were within the certified confidence intervals. Precision estimated as the coefficient of variation (CV = 100% x standard deviation/mean) was about 4-5% for both CRMs and 6% for the two in-house reference materials of lower Hg concentration (NRCC tissue and scallop).

Total Hg in Red Drum and King Mackerel was analyzed by size and age using a series of univariate tests. Analysis of covariance (ANCOVA) was used to examine any significant difference between fishery-dependent Red Drum and King Mackerel total Hg concentrations to remove variance in total Hg associated with differences in size and age. The total Hg data were checked for normality and homogeneity of variances. A subset of the data that included only sizes that overlapped between Red Drum and King Mackerel was taken to compare total Hg between similar sizes of fish. The subset of overlapping lengths for Red Drum and King Mackerel total Hg data were also analyzed using ANCOVA.

Stable isotope analysis was conducted using muscle tissue samples for several fish in this study (n=20 each species). Samples for stable isotopes were taken from the same muscle tissue used for Hg analysis, freeze dried, and ground into a homogenous powder. The powder was weighed and packed into tin capsules for instrumental analysis at the University of California, Davis. The isotope ratios were measured with an isotope ratio mass spectrophotometer. The ratios were depicted using the standard δ notation as parts per mil (‰) differences from a standard:

$$\delta x = [(R_{sample}/ R_{standard})-1] \times 1000$$

where, x = ^{13}C and ^{15}N, R= ratio of $^{13}C/^{12}C$ and $^{15}N/^{14}N$, R standard = atmospheric diatomic nitrogen, VPDB, and Canyon Diablo troilite for C and N respectively. The δ values for C and N were used to describe the relative trophic positions of Red Drum and other species in the GOM sampled at the 2011 ADSFR. Trophic level was calculated for Red Drum and King Mackerel using the following equation:

$$TL=\lambda + (\delta^{15}N_c-\delta^{15}N_{base})/\Delta_n$$

where, λ is the trophic level of the base of the food web, $\delta^{15}Nc$ and $\delta^{15}Nbase$ are the nitrogen isotope values of the consumer and base, respectively, and Δn is the trophic fractionation factor for nitrogen. I set λ=1 (a primary producer) to reduce the propagation of error associated with the variability in Δn (Vander Zanden and Rassmussen, 2001). I used $\delta^{15}N$ values chosen from primary producers (POM) for values that were collected within my study area (Rooker, 2006). I chose a fish tissue specific Δn value of 2.5 for bulk fish tissue following the experimentally determined trophic fractionation factors for shark tissues (Wells et al., 2008). Values of $\delta^{15}N$ and trophic position estimates were used to examine biomagnification of Hg in Red Drum and King Mackerel using univariate tests.

Results

In 2010-2011, 71 Red Drum were sampled for traditional morphometrics, condition indices, age, total Hg concentrations, and the stable isotope ratios $\delta^{13}C$ and $\delta^{15}N$ by fishery-independent bottom longline in GOM waters south of Alabama (Figure 18). Approximately 91% of these fish were caught in state waters. The size distribution of these fish ranged from 776-1041 mm NTL (Figure 19). The ages ranged from 3-31 years old (Figure 20). Total Hg for these fish ranged from 0.22-1.1 ppm and mean total Hg was 0.67 ppm. Maximum total Hg was 1.1 ppm for an 894 mm, 17 year old fish. For fishery-independent Red Drum samples, there was no significant relationship between Hg and any of the condition indices (Hg vs. GSI, p=0.818; Hg vs. IPF, p=0.919; and Hg vs.

Fulton, p=0.406). There was a weak positive relationship between total Hg and NTL (R^2=0.081, p=0.016) (Figure 21) but, there was a strong positive relationship between total Hg and age (R^2= 0.381, p<0.0001) (Figure 22). Stable isotope $\delta^{15}N$ measurements ranged from 14.2-16.3 ‰, and resulted in a small trophic level range from 3.5-4.3. Mean trophic level calculated for the fishery-independent Red Drum was 3.9. There was no significant relationship between total Hg and $\delta^{15}N$ or total Hg and trophic level (p=0.877) (Figure 23).

Similar to fishery-independent analyses, traditional morphometrics, condition indices, age, total Hg concentrations, and stable isotope ratios for $\delta^{13}C$ and $\delta^{15}N$ were examined for 74 Red Drum at the 2011 ADSFR (Figure 3). All of these fish were caught within state waters. The length distribution of the fishery-dependent Red Drum ranged from 565-816 mm NTL (Figure 19). The age distribution ranged from 1-40 years old (Figure 20). Total Hg for the fishery-dependent Red Drum ranged from 0.12-1.2 ppm and mean total Hg was 0.47 ppm. Maximum total Hg for fishery-dependent Red Drum of 1.2 ppm was measured in a 1010 mm NTL, 26 year old fish. For fishery-dependent Red Drum there was no significant relationship between total Hg and IPF (p=0.309), but there was a significant weak positive relationship between total Hg and GSI (p<0.05) and total Hg and Fulton's condition index (p<0.05). There was a significant positive relationship between total Hg and length (R^2=0.611, p<0.0001) (Figure 24) and total Hg and age (R^2= 0.749, p<0.0001) (Figure 25). Stable isotope $\delta^{15}N$ measurements ranged from 11.5-15.4 ‰, and resulted in a trophic level range from 2.4-4.0. Mean trophic level calculated for the fishery-independent Red Drum was 3.5. There was a significant positive relationship between total Hg and $\delta^{15}N$ or total Hg and trophic level (R^2=0.347, p<0.01) (Figure 26).

To compare total Hg concentrations of fishery-dependent Red Drum to a species of known high Hg concentrations, I examined 49 King Mackerel for standard morphometrics, age, total Hg, and stable isotope ratios of $\delta^{13}C$ and $\delta^{15}N$ from the fishery-dependent ADSFR samples. King Mackerel length ranged from 810-1534 mm NTL and age from 1-16 years old (Figure 27). Total Hg ranged from 0.24-3.5 ppm and mean total Hg for King Mackerel was 1.3 ppm, the fifth highest mean Hg concentration of all species sampled at the 2011 ADSFR (Figure 28). The maximum total Hg for King Mackerel (3.5 ppm) was for a 1534 mm NTL, 16 year old fish, the largest and oldest King Mackerel in this study. There was a significant positive relationship between King Mackerel total Hg and length (R^2=0.507, p<0.0001) (Figure 29) and total Hg and age (R^2=0.321, p<0.0001) (Figure 30). Stable isotope $\delta^{15}N$ ranged from 14.4-16.4 ‰, and resulted in trophic level range from 3.6-4.3. Mean trophic level for King Mackerel was 4.0. Due to the small range of trophic levels in my King Mackerel data set, there was no significant relationship between total Hg and $\delta^{15}N$ or trophic level (p=0.966) (Figure 31).

Mercury level did not differ between Red Drum and King Mackerel when the effect of length was used as a covariate. The total Hg data were non-normal (Shapiro-Wilk test; W= 0.973, p<0.05) and variances were heterogeneous (Levene's test; F=47.086, p<0.0001); therefore the data were log transformed. There was a significant difference in mean total Hg between Red Drum and King Mackerel when all of the variance associated with length was considered, but the Type I Sum of Squares (SS) analysis showed no significant difference between species of fish but a significant difference in NTL; however, there was also significant interaction between species and length (Figure 32). Because one assumption of ANCOVA (homogeneity in regression coefficients) was violated with an interaction between length and species, data were used for a subset of samples with equal size range (810-1020 mm NTL). The subset was checked for normality and homogeneity of variances and were both normal (Shapiro-Wilk; $W=0.987$, $p>0.05$) and variances were homogeneous (Levene's test; $F=1.158$, $p>0.05$). An ANCOVA was run on the subset of data and there was a significant effect in the main model and the Type I SS showed that this significance was attributed to length only ($p<0.01$) and there was no significant difference between species and no interaction ($p>0.05$) (Figure 33). The Tukey's HSD post-hoc analysis also confirmed that when the covariate of NTL was considered, there was no significant difference in mean total Hg between Red Drum and King Mackerel. In another ANCOVA, with age as the covariate, there was a strong significant difference in total Hg between species when age is considered ($p<0.0001$) but there was no interaction between species and age ($p=0.213$) (Figure 34).

Discussion

Gulf of Mexico Red Drum are no longer undergoing overfishing due to aggressive management in federal waters; however, it is unknown if they are still overfished. The current status of the stock is still listed as undefined but will soon be assessed Gulfwide (Hogarth, 2004; Powers and Burns, 2010). If GOM Red Drum management strategies are reevaluated and regulations are relaxed on the harvest of large Red Drum, managers should consider how these new regulations could impact public health.

This study provides Hg concentrations for Red Drum from the central region of the northern GOM. Similar to previous studies in other areas of the GOM, large Red Drum in my study area had elevated total Hg concentrations in their tissues. Approximately 80% of all Red Drum in this study had tissues that contained concentrations greater than the 0.3 ppm EPA criterion and 5% were above the 1.0 ppm FDA action limit. Total Hg among both fishery-independent and fishery-dependent Red Drum ranged from 0.12 to 1.2 ppm. This is a smaller range than Adams and Onorato (2005) found in Florida and is closer to that reported by Stunz and Robillard (2011) in Texas (Table 6). Mean total Hg for large fishery-independent (0.64 ppm) and fishery-dependent Red Drum (0.47 ppm) samples in this study was comparable to the mean total Hg reported in Texas (0.46 ppm) and Florida studies, but was lower than Tampa Bay offshore samples (1.7 ppm; Adams and Onorato, 2005) and greater than the 686 mm TL size class in Tampa Bay (1.03 ppm; Winner, 2009). The length distribution was similar to Tampa Bay offshore but contained a number of fish smaller than the largest size class collected by Winner et al. (2009). However, when the data were sorted into lengths greater than 686 mm TL, my mean total Hg concentration was 0.60 ppm. This was still lower than the total Hg for Red Drum in Tampa Bay studies. These differences are likely due to differences in environmental Hg concentrations at each location; however, neither study made environmental measurements to elucidate this.

For species undergoing harvest moratoriums, fishery-independent data are useful to gather information that would normally be collected from the commercial fishery (Powers, 2012). I collaborated with an ongoing SEAMAP bottom longline to collect Red Drum samples for Hg analysis. Fishery-independent Red Drum total Hg was positively associated with NTL. This was statistically significant; however, the relationship was weak. Based on the length frequency distribution and current knowledge of the gear, the bottom longline gear is size selective for large Red Drum and produced a narrow range of sizes that resulted in this weak relationship. I would expect a stronger positive relationship if the gear were altered to include a larger size range of fish. The significant relationship does point out that even with size selective gear, Red Drum bioaccumulate Hg in their tissues as they grow. Fishery-independent Red Drum total Hg was also positively associated with age. This was a stronger relationship, compared to the total Hg vs. NTL, and showed that as Red Drum age they continue to bioaccumulate Hg in their tissues. Total Hg vs. age could provide a more precise method for comparisons. This is especially true for studies using different types of length measurements where data must be converted. It is well known that Red Drum are easily aged using otoliths and this type of analysis could be included in future studies (Beckman, 1988; VanderKooy and Guidon-Tisdel, 2003).

Because Red Drum migrate in and out of state waters throughout life, it is possible to supplement fishery-independent sampling in offshore waters with fishery-dependent collections in state waters. These fishery-dependent samples represent what is potentially available for human consumption. Sociological studies also support the popularity of consumption of this fish in the northern GOM (Nystrom, 2007). The fishery-dependent Red Drum in this study also had elevated total Hg in their tissues. There were strong positive relationships between total Hg and NTL and total Hg and age of fishery-dependent Red Drum, further supporting bioaccumulation of Hg as Red Drum grow larger and older. Total Hg for ADSFR Red Drum was also positively associated with $\delta^{15}N$ and trophic level suggesting biomagnification of Hg with ontogenetic diet shift.

King Mackerel total Hg concentrations in this study were comparable to previous measurements in Florida (Adams and McMichael, 2007). The mean size of King Mackerel in this study (1057 mm FL and 1139 mm NTL) was slightly larger that of the Florida study (1024 mm FL) but was inclusive of lengths > 750 mm FL in the Florida study. Despite this size difference, mean total Hg was slightly lower in this study (1.28 ppm) than in the Florida study (1.51 ppm); although, both studies mean total Hg concentrations were above the 1.0 ppm FDA action limit. Approximately 98% of King Mackerel in this study had total Hg concentrations greater than the 0.3 ppm EPA criterion and 57% of King Mackerel in this study had total Hg concentrations greater than or equal to the 1.0 ppm FDA limit. Similar to this study, Adams and McMichael (2007) also reported significant positive relationships between total Hg in King Mackerel tissues with size and age. This supports my conclusion of bioaccumulation of total Hg in King Mackerel as they grow.

Diet is the main source of Hg bioaccumulation in fish tissues. The life history of the Red Drum and their ontogenetic shift in diet from mostly invertebrates to fish as Red Drum reach adulthood lends itself to an increase in the rate of Hg bioaccumulation as Red Drum age (Peters and McMichael, 1987; Scharf and Schlicht, 2000; Adams and Onorato, 2005). In contrast, King Mackerel are continuous piscivores throughout their life history leading to an overall higher trophic level and faster rate of Hg bioaccumulation over time (Adams and McMichael, 2007). This difference in diet is likely the main reason there are differences in total Hg concentrations between the two species. According to their stable isotope ratios, King Mackerel were feeding at a higher trophic level than Red Drum (Figure 35).

Awareness among Gulf Coast residents concerning high-risk fish consumption varies. University of South Alabama sociologists conducted a 2004 telephone poll of Alabama and Mississippi Gulf Coast residents to evaluate fish consumption. Specifically, they were concerned with consumption of high-risk fish, or those with elevated concentrations of MeHg. They found that the average Gulf Coast resident was aware of the MeHg risk to health but only 63% of individuals in this study were aware of advisories concerning MeHg in fish. This study group consumed an average of 23.7 pounds of fish per year and 3.69 pounds of Red Drum per year, the eighth most consumed fish species reported in the study (Nystrom, 2007).

Consumption advisories for King Mackerel exist in every GOM state (U.S. EPA, 2012). The Hg status of this species is widely known because state and federal agencies have conducted public outreach concerning limiting consumption. This is important due to high concentrations of Hg in King Mackerel and potential for Hg poisoning especially in children and women of childbearing age. Based on my analyses, when the variance in mean total Hg due to differing sizes was accounted for, there was no significant difference in total Hg concentrations between similar sized Red Drum and King Mackerel. In other words, large Red Drum in this study had statistically similar Hg concentrations as smaller King Mackerel (Figure 33). This finding should create a simple and effective strategy for explaining elevated Hg concentrations in large Red Drum.

Management strategies may be reconsidered after the next GOM Red Drum stock assessment. All five of the GOM states have advisories regarding consumption of fish with elevated Hg concentrations. Some of these species include sharks, King Mackerel, and tilefish. Recently, Florida added Red Drum to their fish advisory list (FL DOH, 2013). I suggest that other GOM states consider adding large (>660 mm NTL) Red Drum to their list of species of concern. Cooperation from GOM states is needed for management plans that limit Hg exposure from marine fishes in their waters. Mean total Hg for large Red Drum in this study was less than the FDA action limit but greater than the EPA Criterion. All Red Drum with total Hg above 1.0 ppm were larger than the current Alabama slot size (660 mm NTL); thus, the current slot size can effectively limit Hg exposure to humans (Figure 24). Florida is also the only GOM state that does not allow over the slot sized Red Drum to be kept (Table 1). In addition to advisory lists, it would be prudent of the GOM state agencies to reevaluate the amount of over the slot size Red Drum to be kept based on Hg concentrations of Red Drum in their waters. Future studies are needed across the GOM to effectively assess and monitor the concentrations of Hg in Red Drum so this public health issue may be included in management strategies.

CONCLUSIONS AND RECOMMENDATIONS

A GOM Red Drum SEDAR stock assessment, utilizing the most up-to-date data available, is needed. Red Drum continues to be one of the most popular sportfish in the northern GOM and is widely considered good to eat. This creates a significant amount of recreational fishing mortality in state waters that is affecting the abundance of large offshore Red Drum. The age distribution, mortality, and abundance data reflects the need to decrease the amount of large Red Drum allowed to be kept in state waters. This will decrease the overall pounds of Red Drum harvested and should increase the number of teenage fish in the population. Alabama currently allows one oversized Red Drum to be kept per day. A more reasonable management strategy is seen in Texas where fishermen are allowed to keep one Red Drum per year with an opportunity to apply for another, resulting in only two oversized Red Drum collected per year. Florida has a strict management strategy of zero oversized Red Drum allowed to be kept. Alabama managers should consider the other GOM states management strategies and their effectiveness.

Similar to other GOM studies, large Red Drum in this study contained high concentrations of Hg in their tissues. It is important that this information be reported to public health agencies so they might make appropriate recommendations for consumption advisories. Currently, the slot limits in Alabama and Florida limit exposure to Red Drum with mean total Hg concentrations greater than EPA and FDA advisory limits. Managers across the GOM states should also consider this important public health issue when creating fishing limits for over the slot size fish.

Future studies are needed in Mississippi, Louisiana, and Texas to gain the most complete picture of Red Drum Hg concentrations across the northern GOM. Further fishery-independent longline surveys are needed in the northern GOM to compare to my standardized abundance index. For a fishery undergoing harvest moratorium in federal waters, fishery-independent studies coupled with fishery-dependent collections in state waters are necessary to collect these data.

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APPENDICES

Appendix A: Tables 1-6

Table 1. State allowable bag and size limits for Red Drum.

State	Bag (#) and Size Limit (TL in)		
AL	3	16-26” 1 can be > 26”/day	
FL	1	18-27”	
LA	5	16”	minimum 1 can be > 27”/day
MS	3	18”	minimum 1 can be > 30”/day
TX	3	20-28” 1 over slot size with RD tag/year	
			Plus 1 with Bonus RD tag/year

Table 2. Parameter estimates for standard von Bertalanffy growth equations. Data were analyzed by the following categories: combined sexes, males, and females for fishery-dependent and independent collections.

Hightower Thesis	L_∞ (NTL mm)	k	t_0
All Data			
Combined Sexes	946	0.32	-1.2
Males	928	0.31	-1.4
Females	953	0.32	-1.4
Fishery-Independent			
Combined Sexes	950	0.24	-1.6
Males	933	0.24	-1.9
Females	964	0.22	-2.1
Fishery-Dependent			
Combined Sexes	947	0.27	-2.6
Males	935	0.25	-2.9
Females	955	0.28	-2.4

Table 3. Literature parameter estimates for standard von Bertalanffy growth equation. Lengths were converted to natural total length if necessary using equations derived by Goodyear (1996).

Area, Study	L_∞ (NTL mm)	k	t_0
TX,LA,MS,AL			
Beckman et al., 1988			
Males	991	0.137	-7.74
Females	1105	0.088	-11.29
Alabama			
Powers et al., (2012)			
Males	1007	0.110	-10.00
Females	1052	0.109	-10.00
Hightower Thesis			
Combined Males and Females	946	0.320	-1.20
Males	928	0.310	-1.40
Females	953	0.320	-1.40
Florida			
Murphy and Taylor, 1990			
Combined Males and Females	1019	0.450	0.03

Table 4. Literature parameter estimates for 'double von Bertalanffy' growth equation. Total lengths reported by Porch (2000) were converted from inches to mm and compared to parameters estimated in this study.

Area, Study	L_∞ (NTL mm)	k_1	k_2	t_1	t_2
Texas **M. Fisher**	982	0.313	0.146	0.184	4.78
LA,MS,AL **Wilson and Nieland**	1017	0.402	0.195	0.038	3.06
Hightower Thesis	947	0.33	1.13	-1.2	-84.5
Florida **M. Murphy**	1019	0.413	0.114	-0.056	8.39

Table 5. Abundance index values for the 2006-2012 fishery-independent longline.

Year	n	Observed mean	Obs se	dGLM mean	dGLM se	dGLM cv	positive index	binomial index
2006	93	0.65	0.18	1.03	1.03	1.00	3.71	0.28
2007	148	1.00	0.22	0.98	0.89	0.91	3.26	0.30
2008	141	0.84	0.15	0.83	0.80	0.97	2.95	0.28
2009	94	0.86	0.27	0.55	0.70	1.27	2.94	0.19
2010	87	0.62	0.18	0.52	0.63	1.22	2.62	0.20
2011	87	0.30	0.10	0.21	0.33	1.58	2.02	0.10
2012	82	0.22	0.08	0.18	0.30	1.65	2.05	0.09

Table 6. Mean size and total Hg values for Red Drum in the Gulf of Mexico. Lengths from Adams and Onorato, 2005 were converted using the following equation from Porch, 2000: total length=1.184(standard length) + 0.420.

			Total Length (mm)			Total Hg (ppm)			
Study	Location	Number	Mean	Min.	Max.	Mean	s.e.	Min.	Max.
This Study									
Fishery-Independent	Dauphin Island, AL	71	935	776	1041	0.67	0.023	0.22	1.1
Fishery-Dependent	Dauphin Island, AL	74	816	565	1020	0.47	0.034	0.12	1.2
Adams and Onorato, 2005	Choctawhatchee Bay, FL	15	483	214	736	0.17	0.025	0.050	0.35
	Apalachicola, FL	86	534	410	732	0.20	0.011	0.057	0.69
	Cedar Key, FL	133	472	264	718	0.18	0.0067	0.061	0.55
	Tampa Bay Inshore, FL	98	608	237	906	0.26	0.022	0.042	1.8
	Tampa Bay Offshore, FL	139	901	665	1175	1.7	0.057	0.30	3.6
	Charlotte Harbor, FL	34	607	331	832	0.28	0.031	0.055	0.72
	Shark River Slough-Everglades,FL	20	478	324	663	0.25	0.016	0.097	0.4
	Florida Keys-Florida Bay, FL	42	538	273	744	0.50	0.068	0.11	2.7
	Indian River Lagoon, FL	145	615	292	1267	0.37	0.034	0.020	2.2
Stunz and Robillard, 2011	Aransas Bay, TX	4	570	527	611	0.090	0.005	0.083	0.104
	Corpus Christi Bay, TX	2	713	511	915	0.120	0.046	0.074	0.166
	Nueces Bay, TX	4	577	523	659	0.576	0.069	0.451	0.721
	Upper Laguna Madre, TX	4	597	558	654	0.193	0.055	0.122	0.358
	Surf	5	945	804	1018	1.024	0.181	0.498	1.542
Ache et al., 2000	Gulfwide	364	NA	NA	NA	0.31	0.020	0.005	2.7
	Gulfwide	442	NA	NA	NA	0.65	0.038	0.001	4.62

Appendix B: Figures 1-35

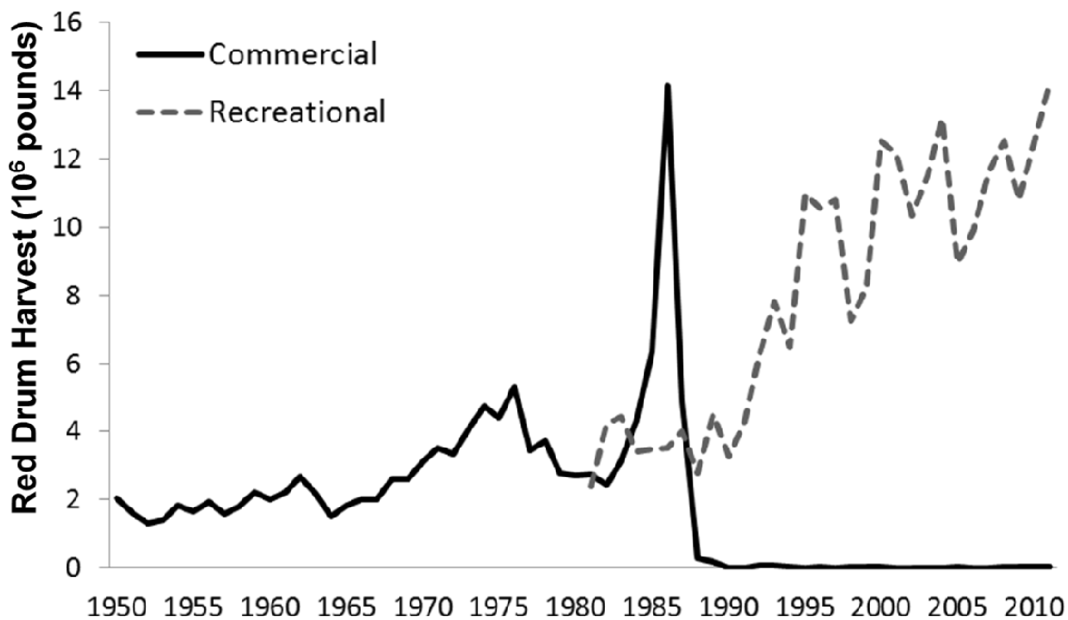


Figure 1. Catch data for Red Drum in the Gulf of Mexico (1950-2010). Data available from National Marine Fisheries Service, Fisheries One-Stop-Shop (FOSS) landings phase-https://www.st.nmfs.noaa.gov/apex/foss/f?p=114:9:882289119646183 (accessed March 2013).

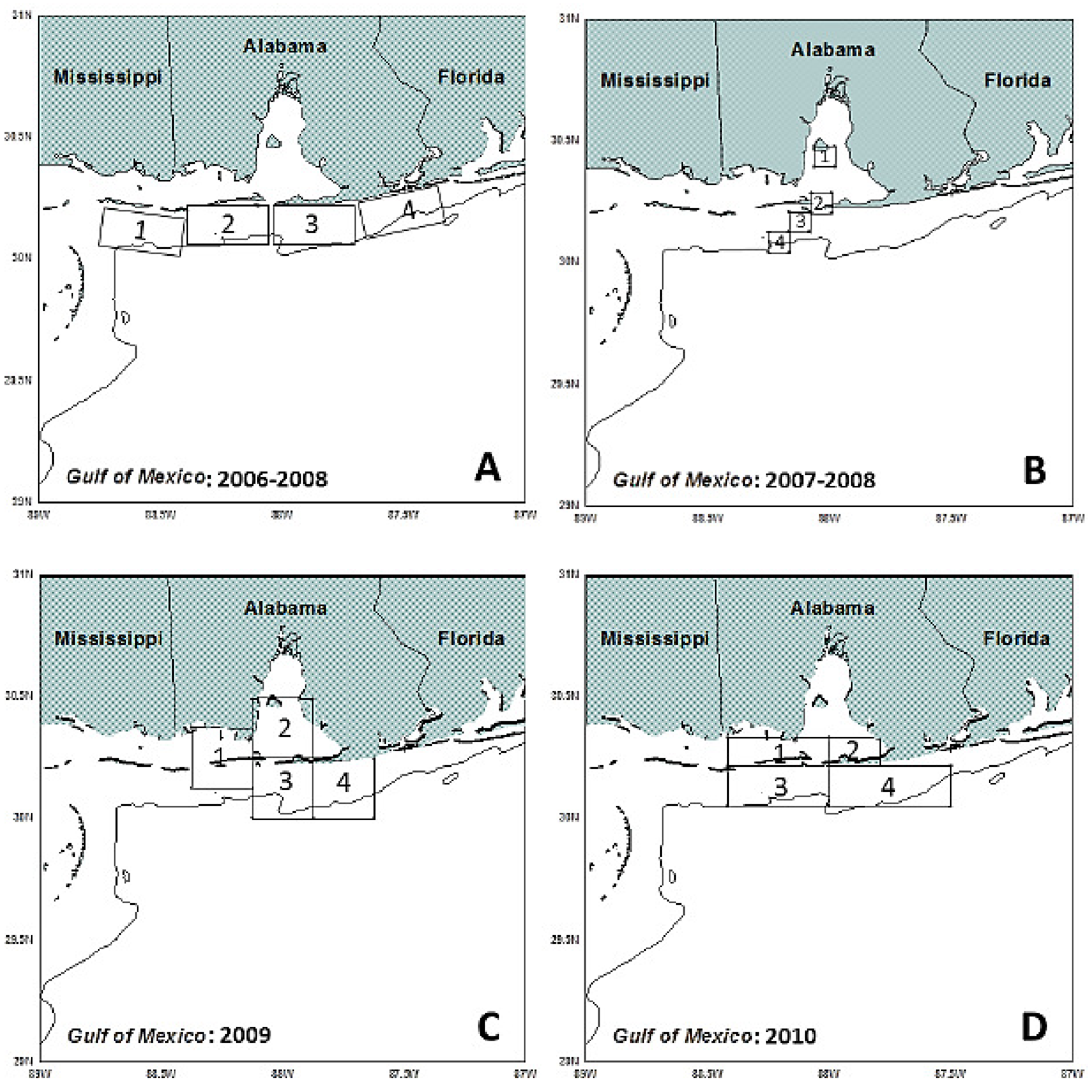


Figure 2. Locations of standardized fishery-independent surveys with starting and ending dates. A. DISL/NMFS Cooperative longline (2006-2008) B. DISL transect survey (2007-2008) C. DISL shark longline survey (2009 only) and D. SEAMAP survey (2010-2012). Randomized block surveys were supplemented with transect sampling along a randomly selected line of longitude.

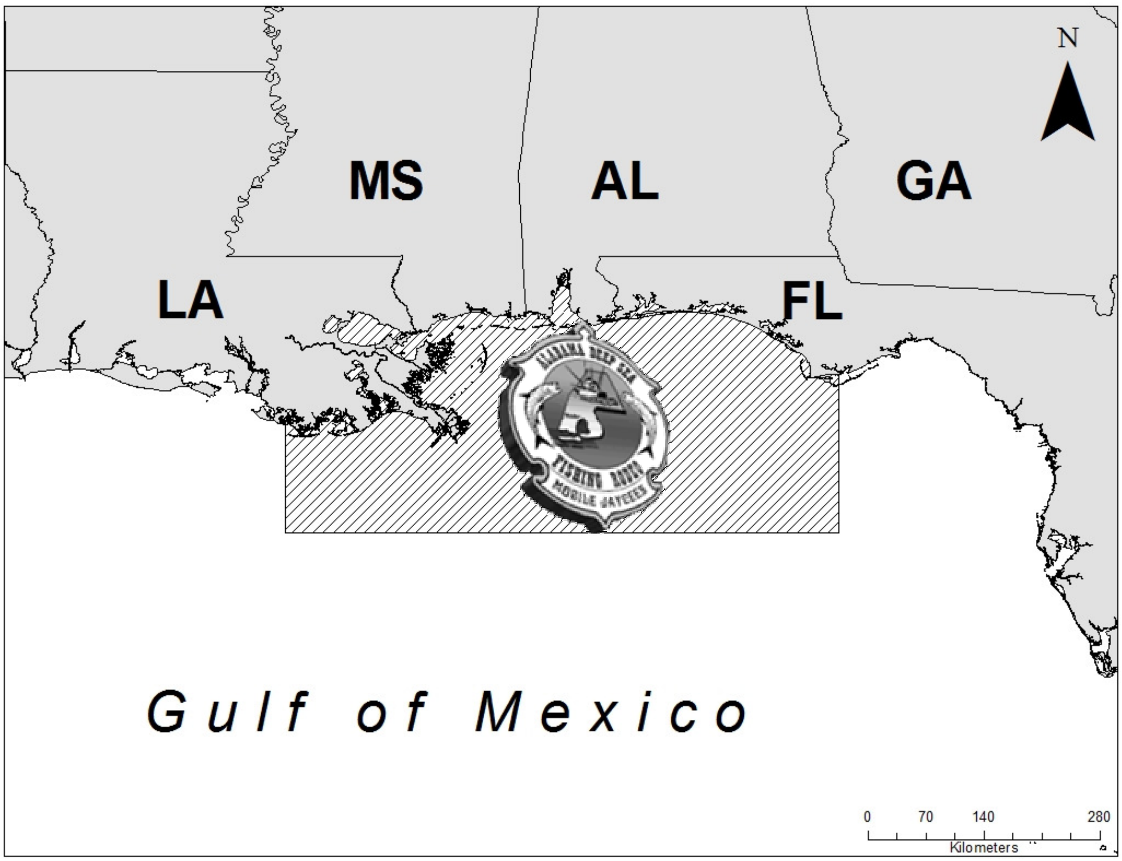


Figure 3. Location of the fishery-dependent Alabama Deep Sea Fishing Rodeo. Fish collection boundary is the shaded area: north: all bays and inlets of the GOM; east: 85°W longitude; south: 28°N latitude; and, west: 91°W longitude. All fish entered are brought in to the Alabama Deep Sea Fishing Rodeo weigh station in Dauphin Island, Alabama.

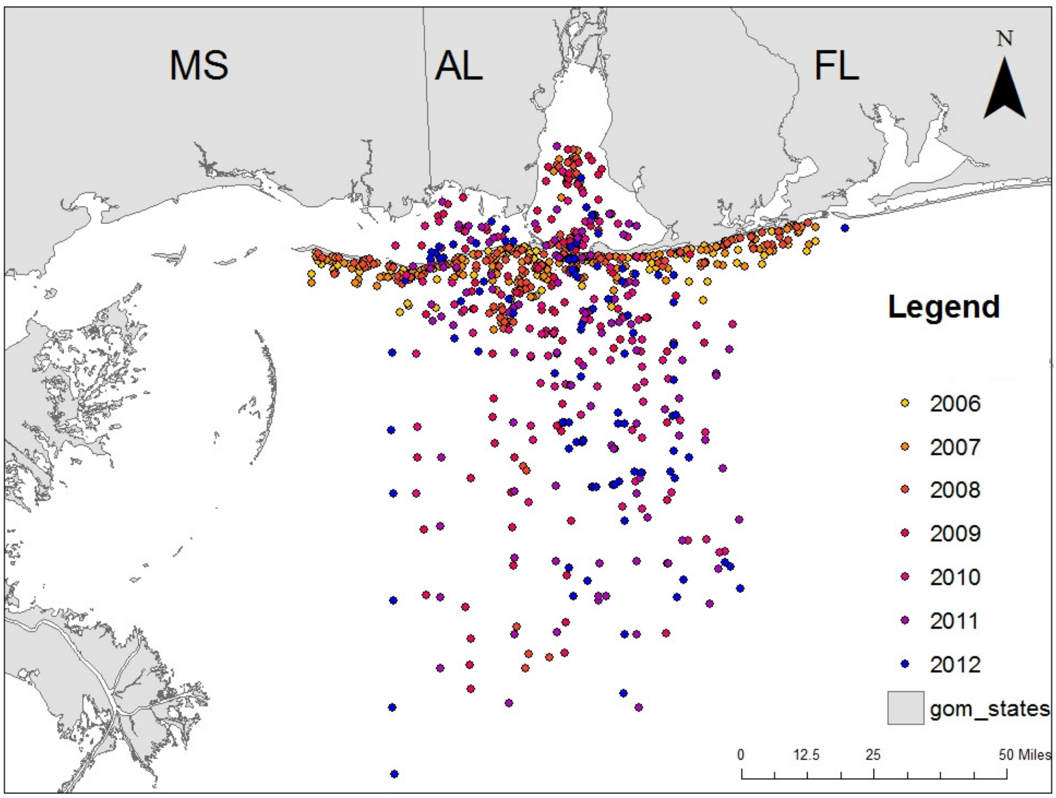


Figure 4. Sampling locations for all fishery-independent bottom longline surveys 2006-2012.

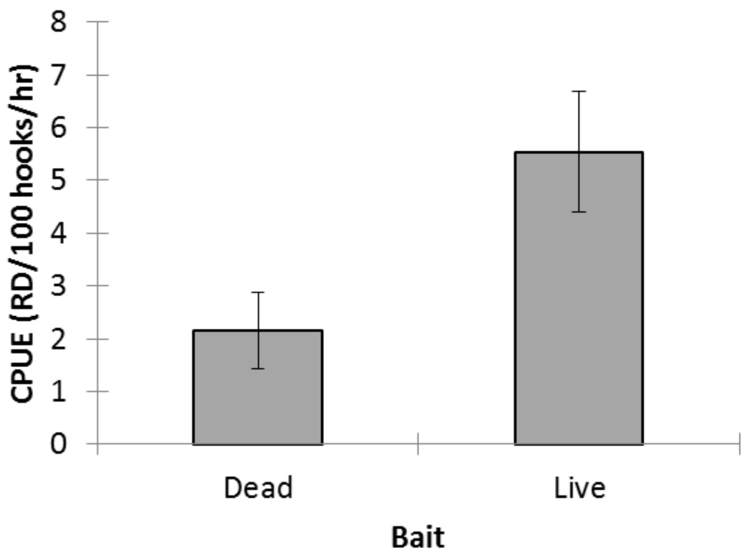


Figure 5. Average Red Drum CPUE (fish/100 hooks/hr) for fish caught on dead versus live bait.

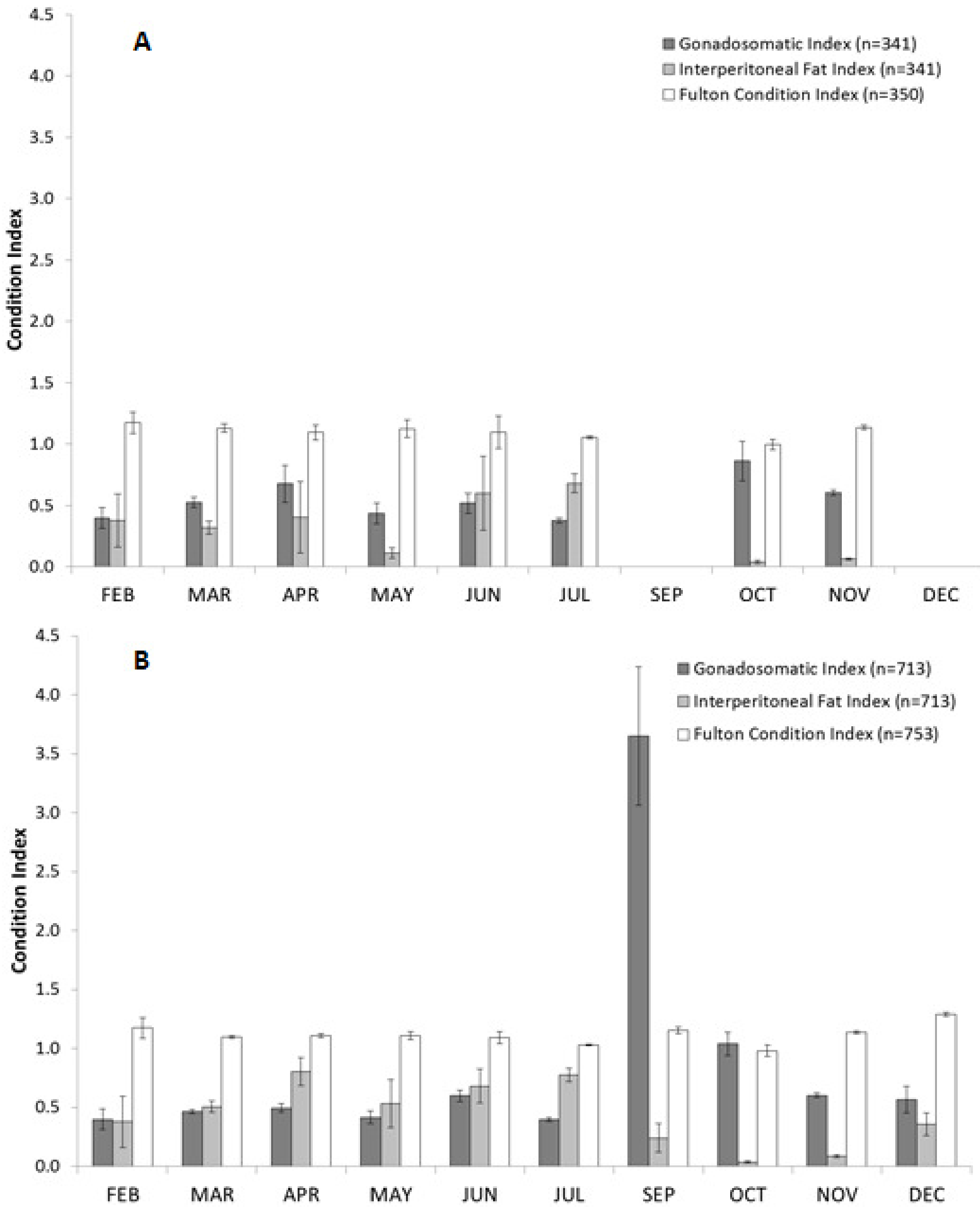


Figure 6. Condition Indices plotted by month for all Red Drum samples. A. Condition indices for this study (2010-2012) and B. Condition indices for this study combined with Powers et al. (2012) (2008-2012).

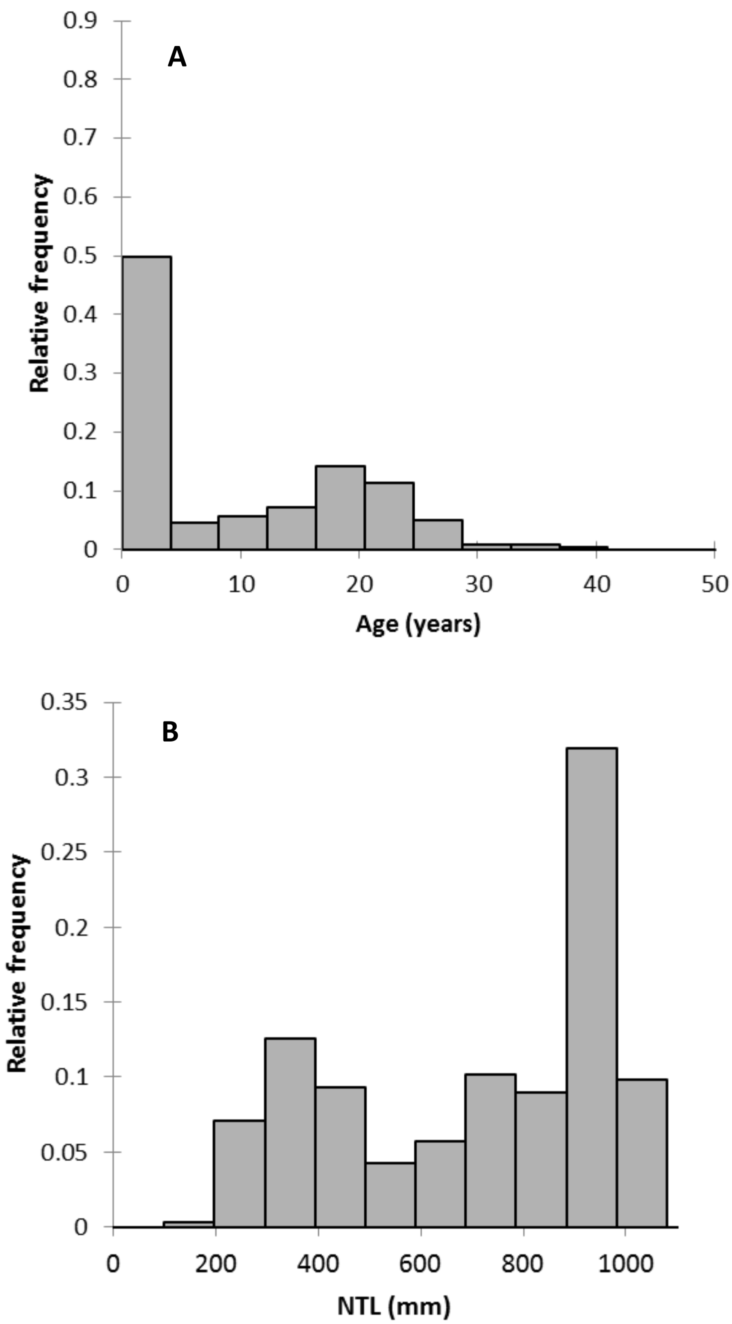


Figure 7. Age distribution (A) and length frequency (B) of all Red Drum in this study (2010-2012).

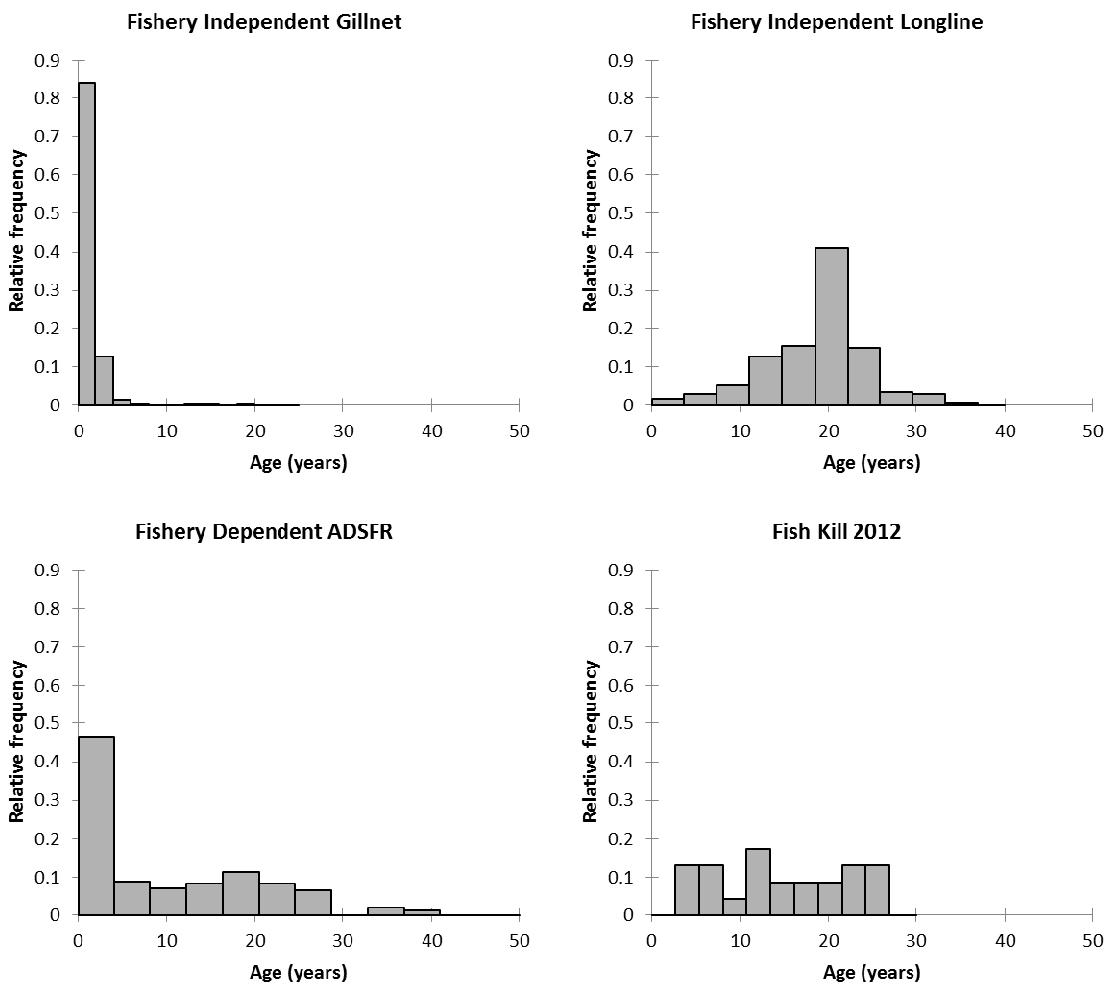


Figure 8. Age distributions of all Red Drum in this study by gear type (2010-2012).

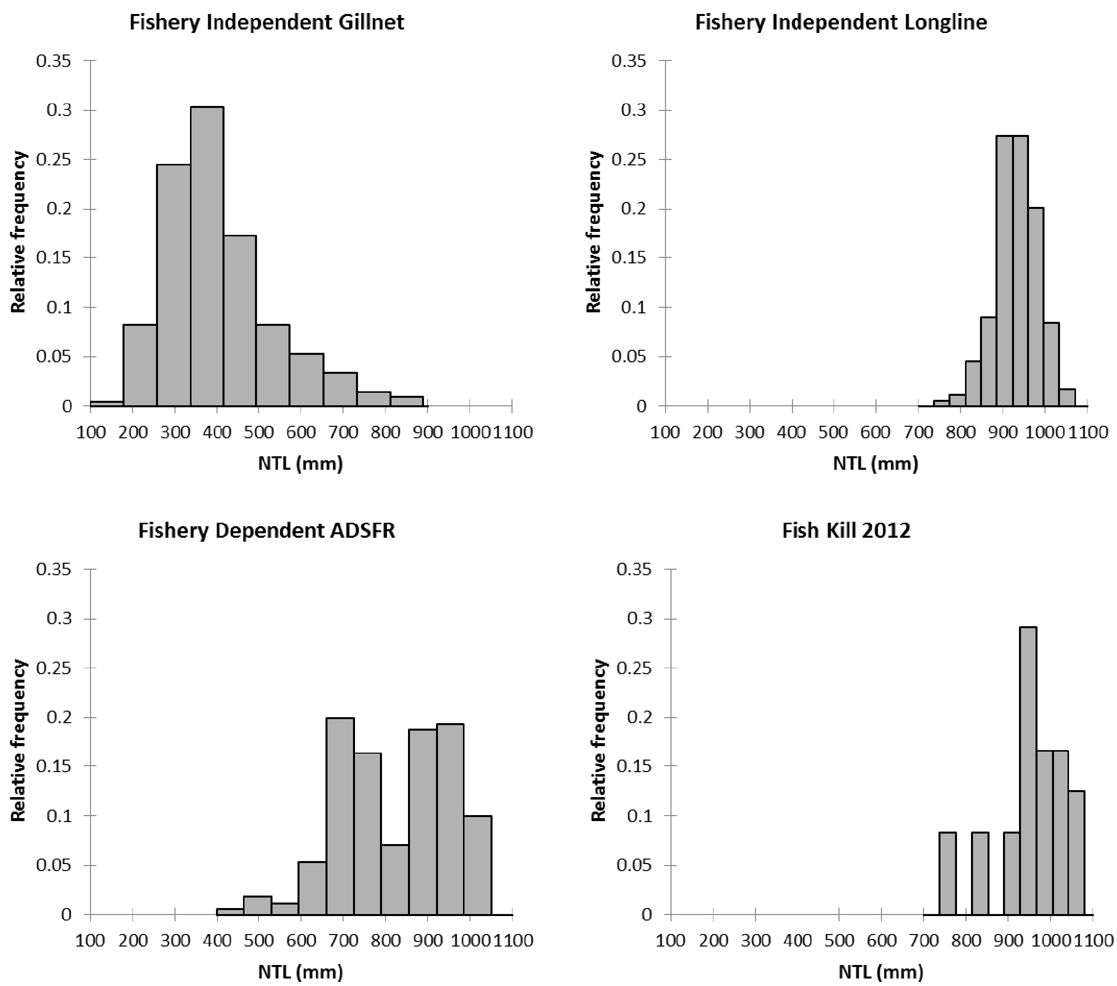


Figure 9. Length frequencies of all Red Drum in this study by gear type (2010-2012).

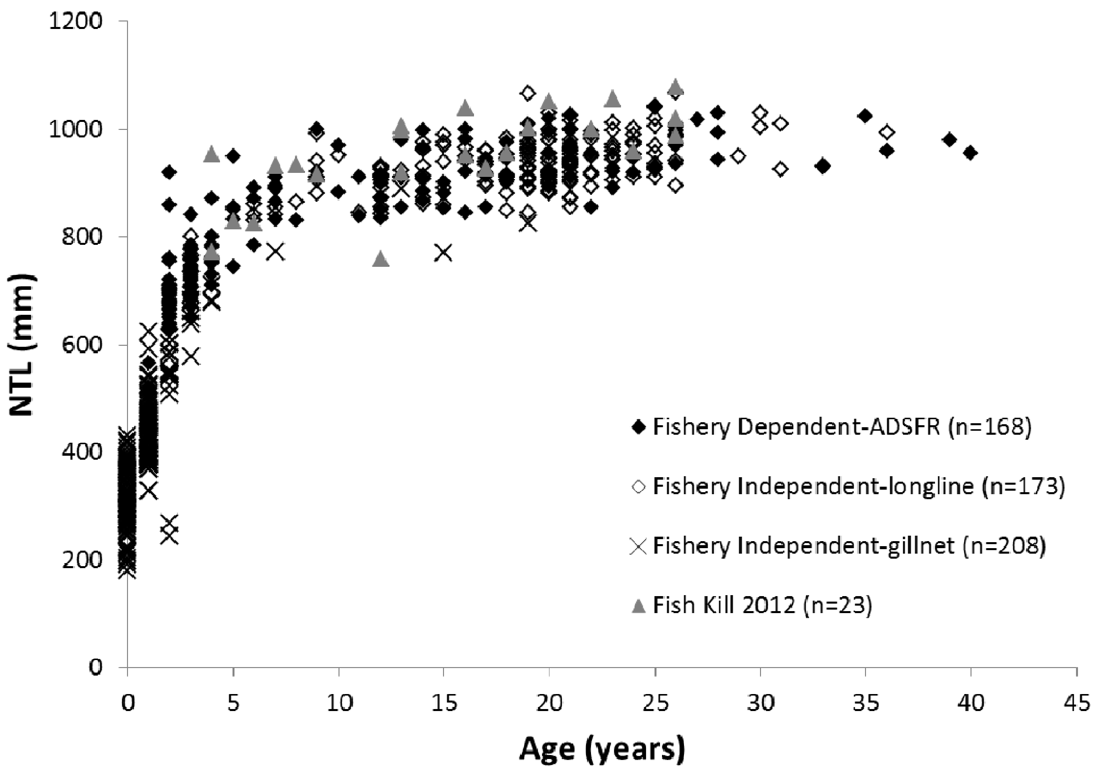


Figure 10. Length at age for all Red Drum in this study (2010-2012).

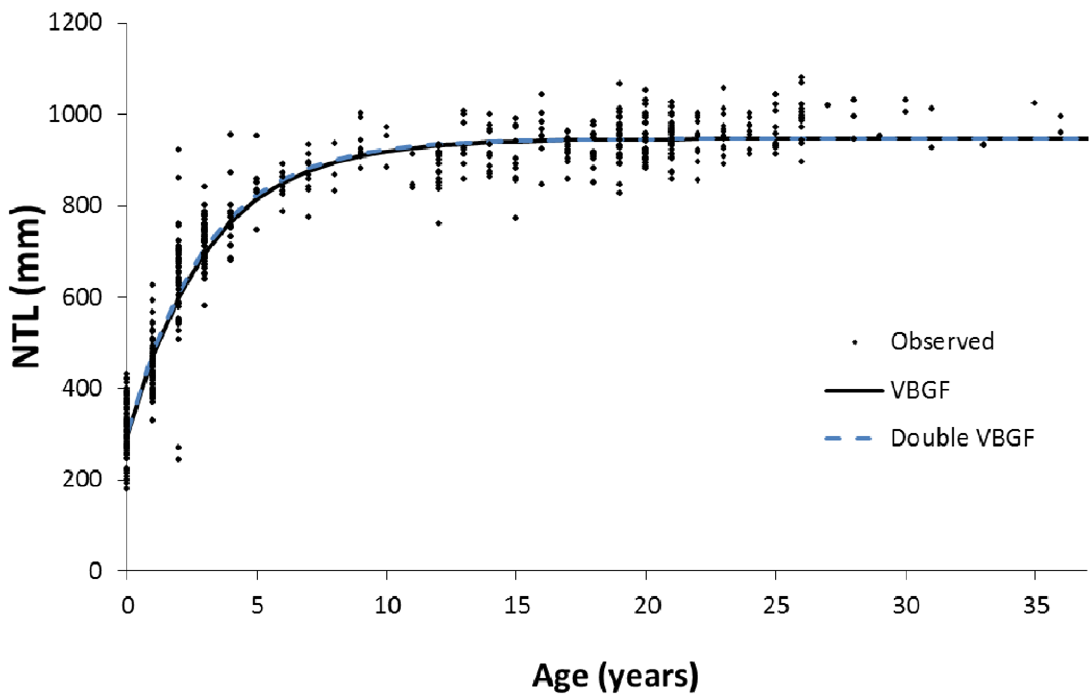
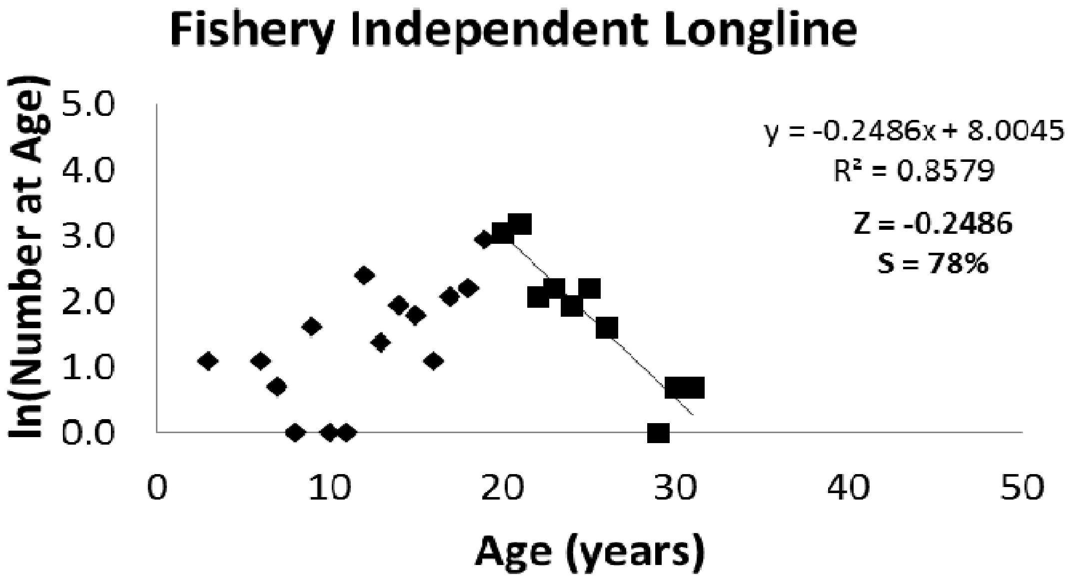


Figure 11. Von Bertalanffy growth function (solid line) and double von Bertalanffy growth function (dashed line) fit to the age at length data for all Red Drum in this study (2010-2012).



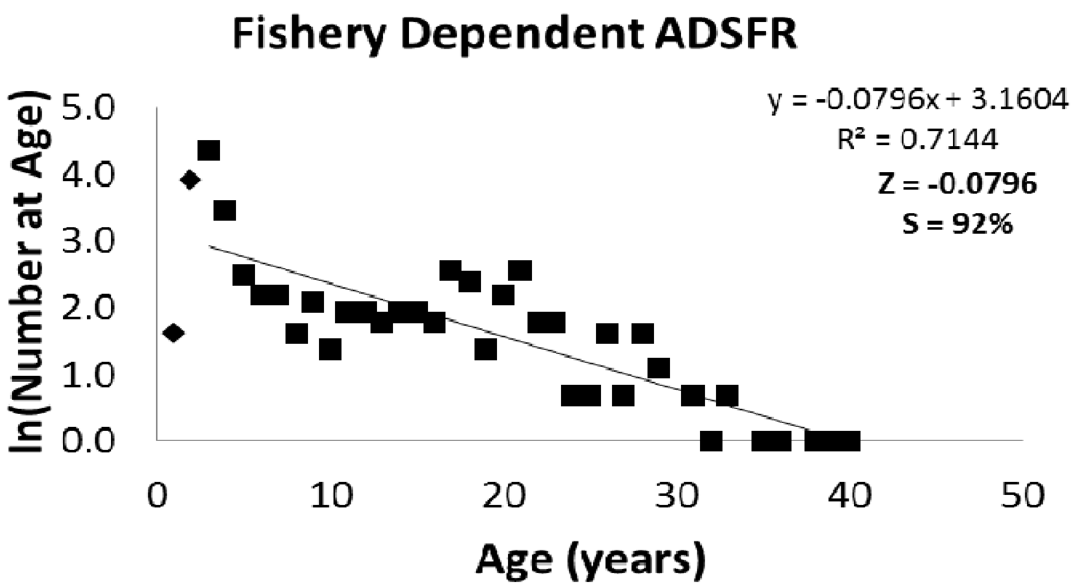


Figure 12. Catch curve regressions for the fishery-independent longline (n = 400) and fishery-dependent ADSFR (n = 344) (2008-2012). Total Mortality (*Z*) was estimated as the slope of the linear regression to the fully-recruited ages in a scatterplot of the natural log of numbers versus age. Annual survival (*S*) was calculated as the exponential of *Z*.

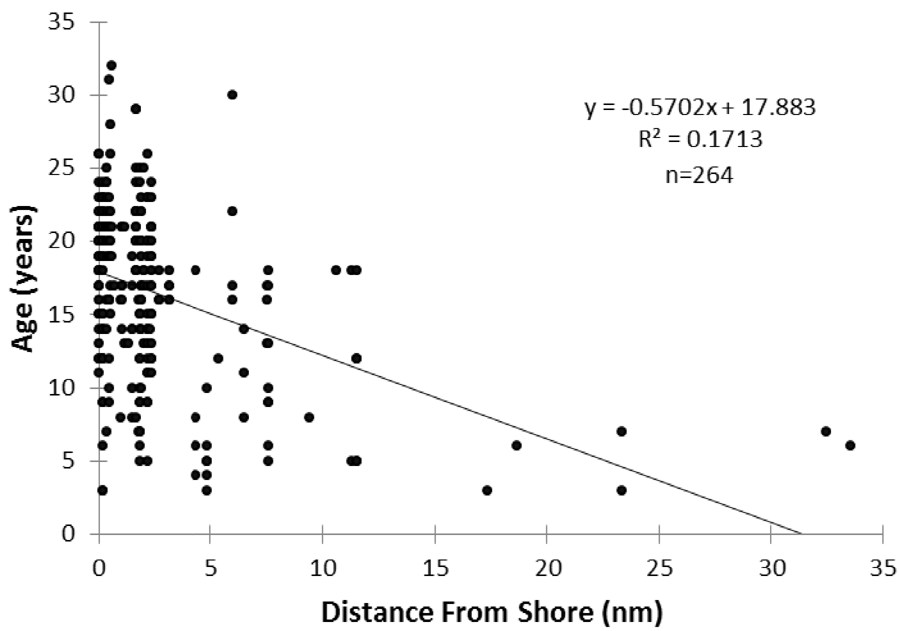


Figure 13. Age versus distance from shore for Red Drum caught using the 2010-2012 fishery-independent longline.

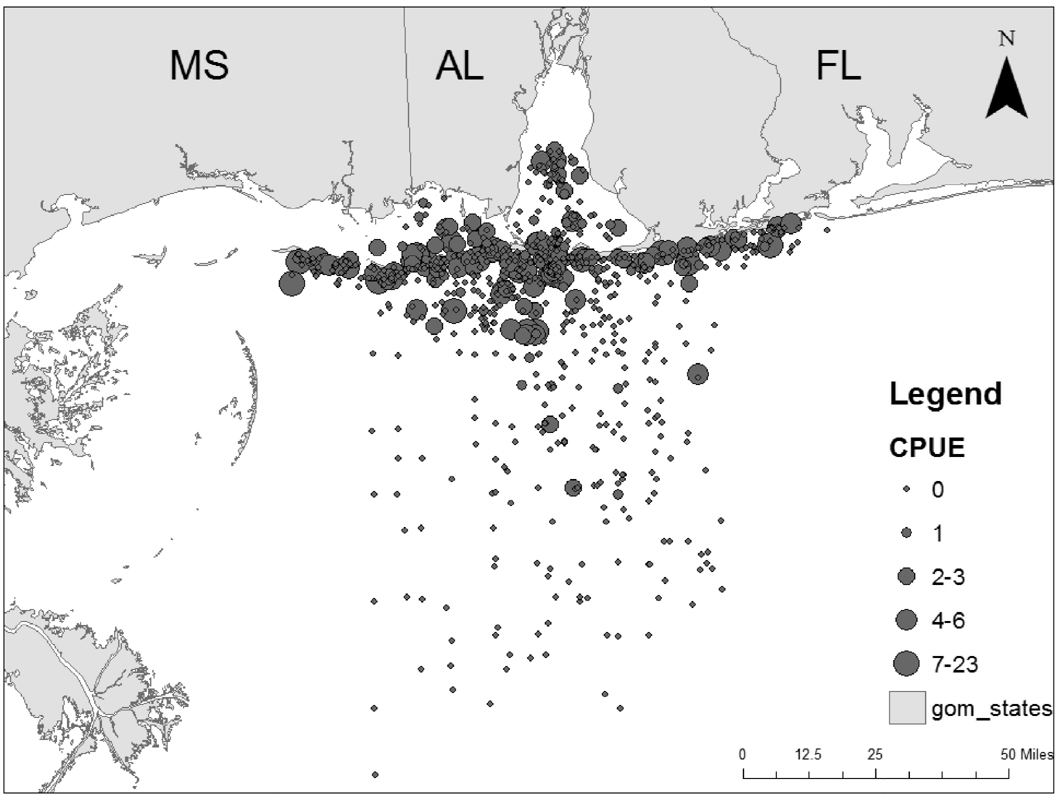


Figure 14. Catch per unit effort of Red Drum for all fishery-independent longline surveys (2006-2012).

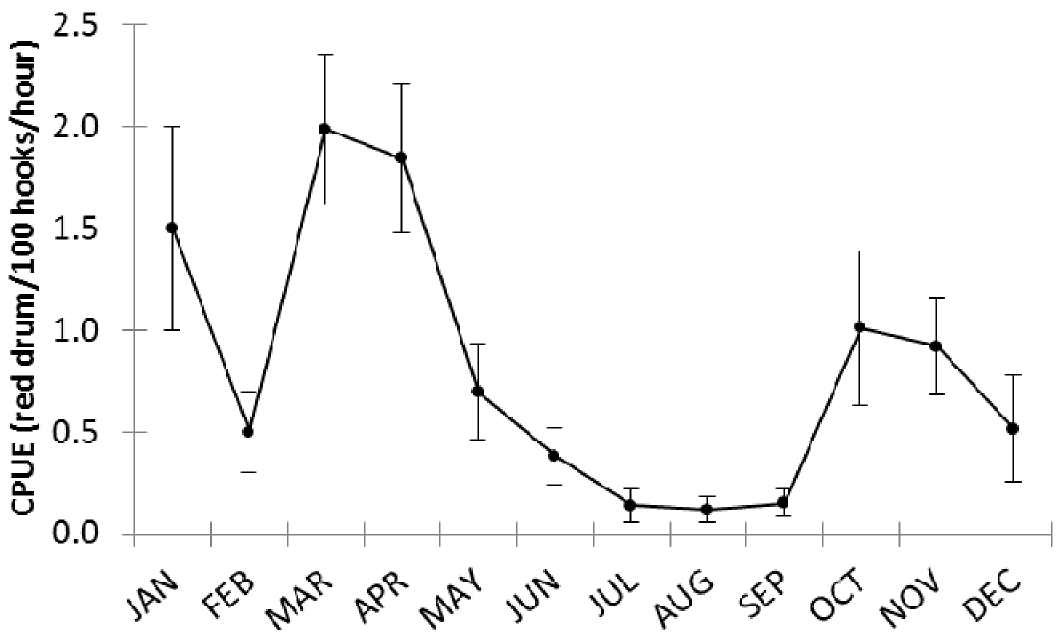


Figure 15. Observed fishery-independent longline CPUE index by month (2006-2012).

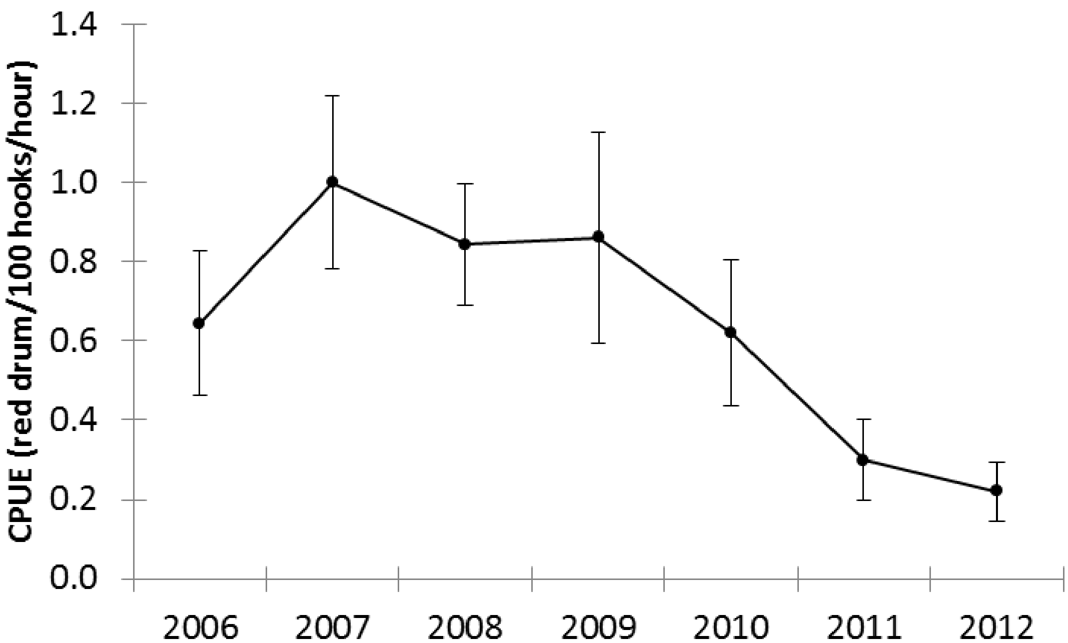


Figure 16. Nominal fishery-independent longline CPUE index by year (2006-2012). Error bars represent standard error of the mean.

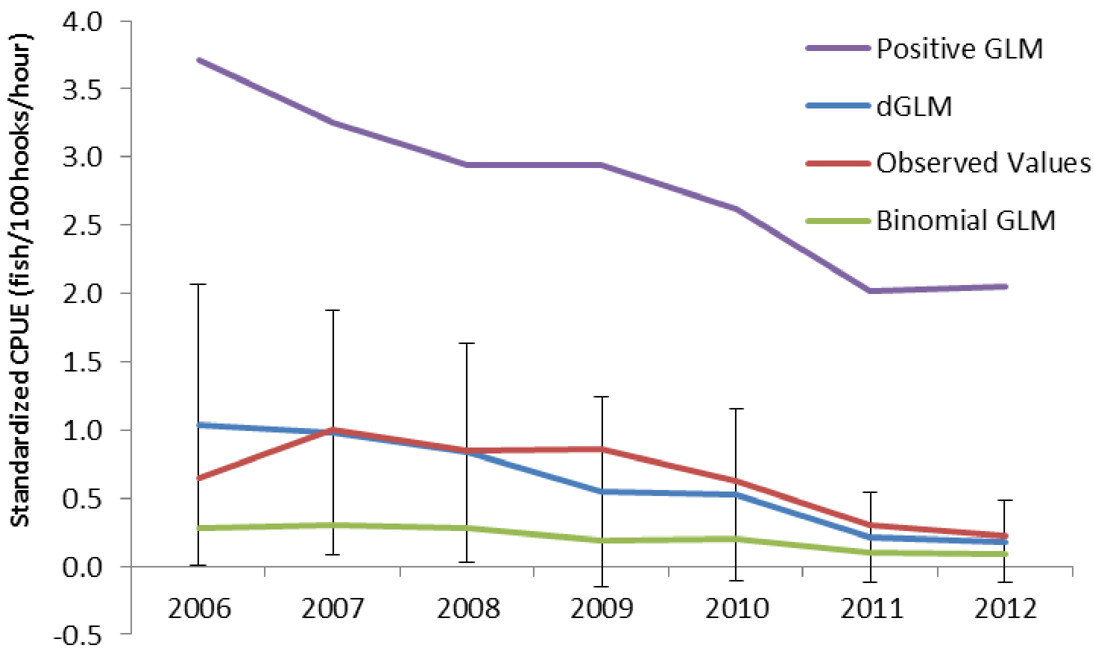


Figure 17. Fishery-independent longline abundance indices by year (2006-2012).

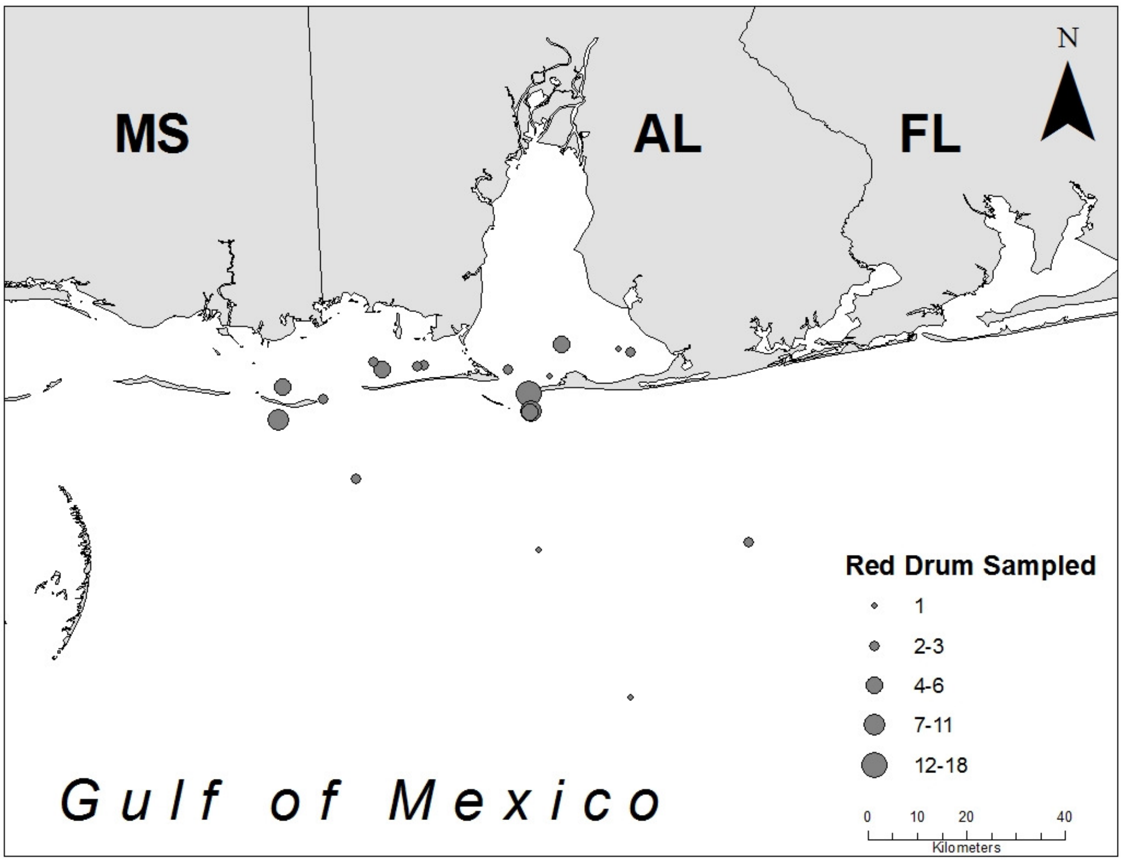


Figure 18. Locations of fishery-independent longline Red Drum sampled for mercury and stable isotope analysis.

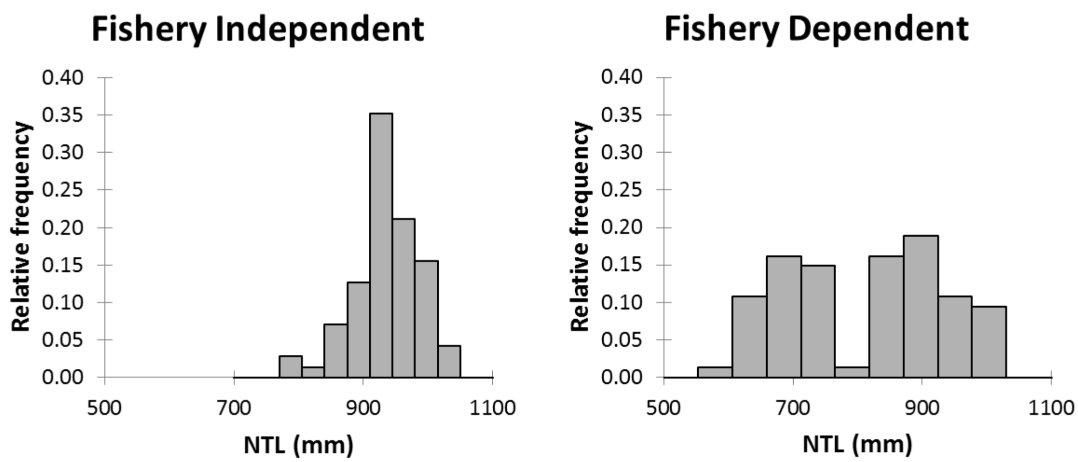


Figure 19. Fishery-independent and fishery-dependent length frequencies for Red Drum sampled for mercury and stable isotopes.

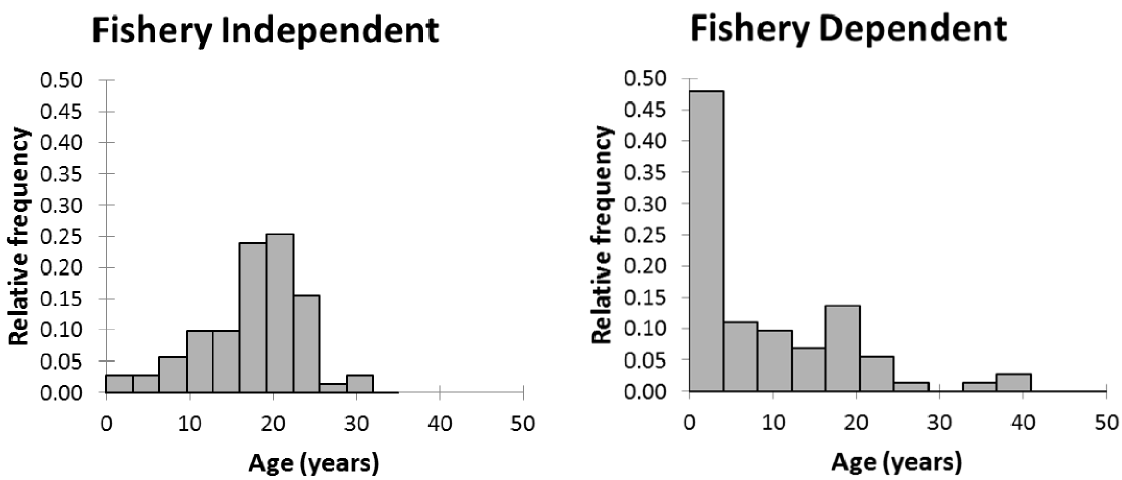


Figure 20. Fishery-independent and fishery-dependent age distributions for Red Drum sampled for mercury and stable isotopes.

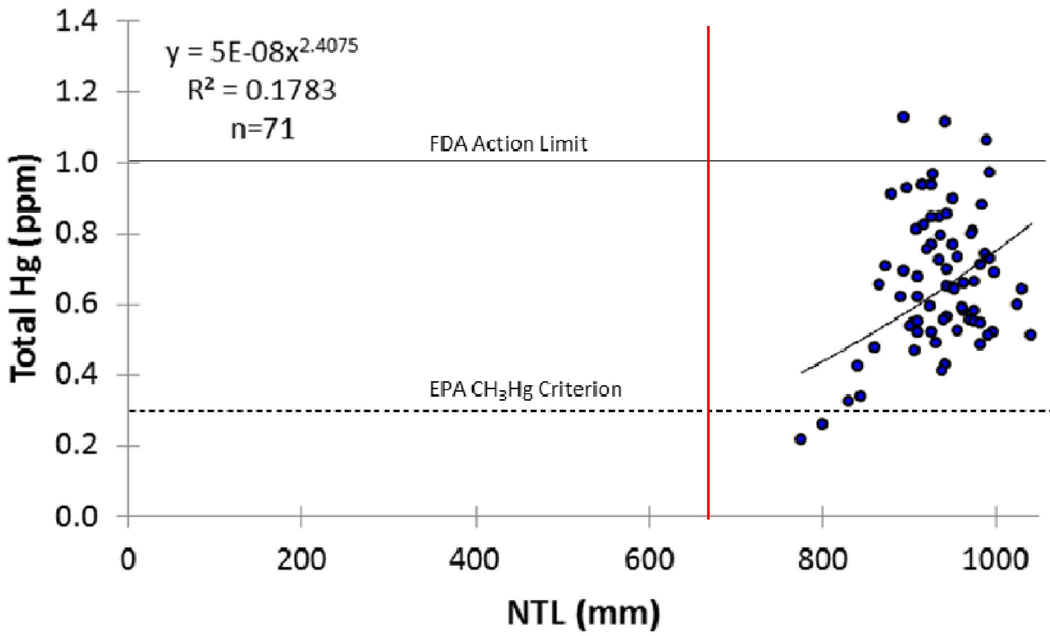


Figure 21. Fishery-independent Red Drum total Hg versus natural total length (NTL). Red line indicates the upper slot size for Alabama (660 mm NTL).

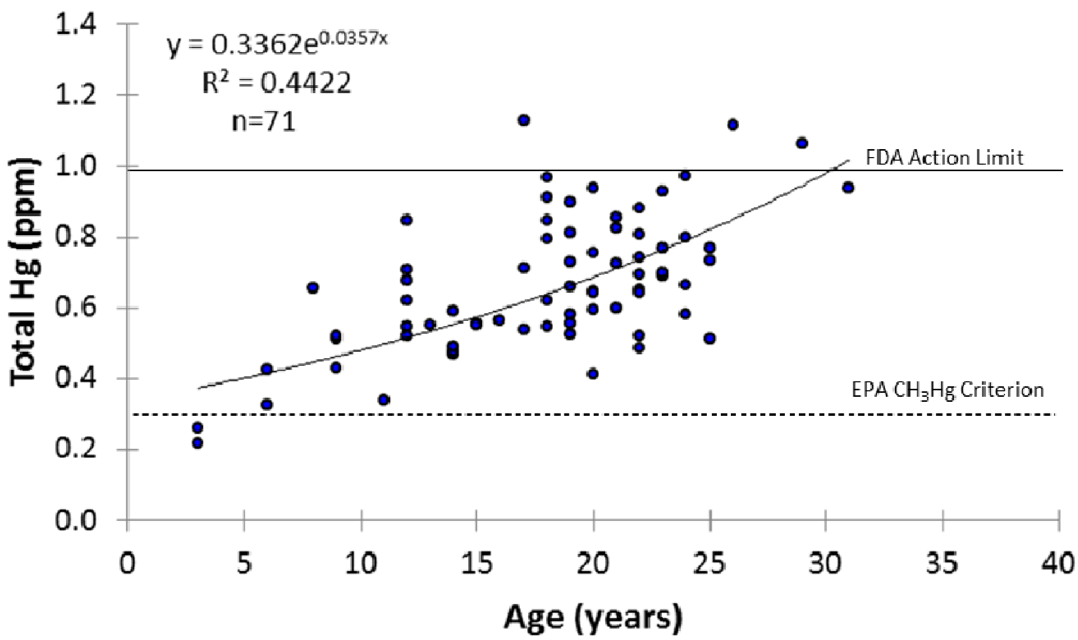


Figure 22. Fishery-independent Red Drum total Hg versus age.

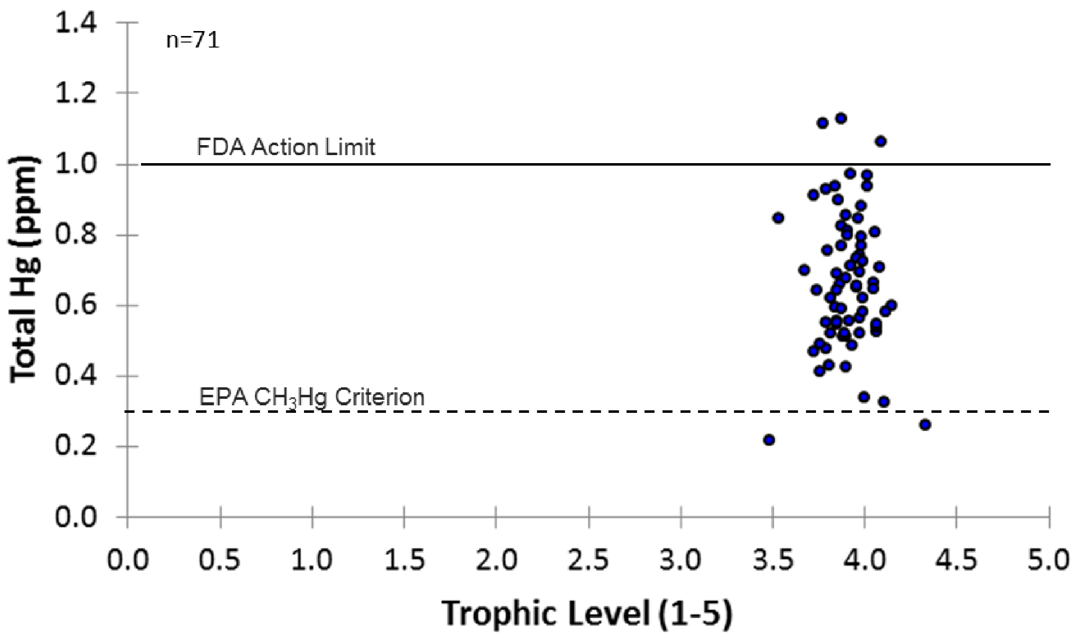


Figure 23. Fishery-independent Red Drum total Hg versus trophic level.

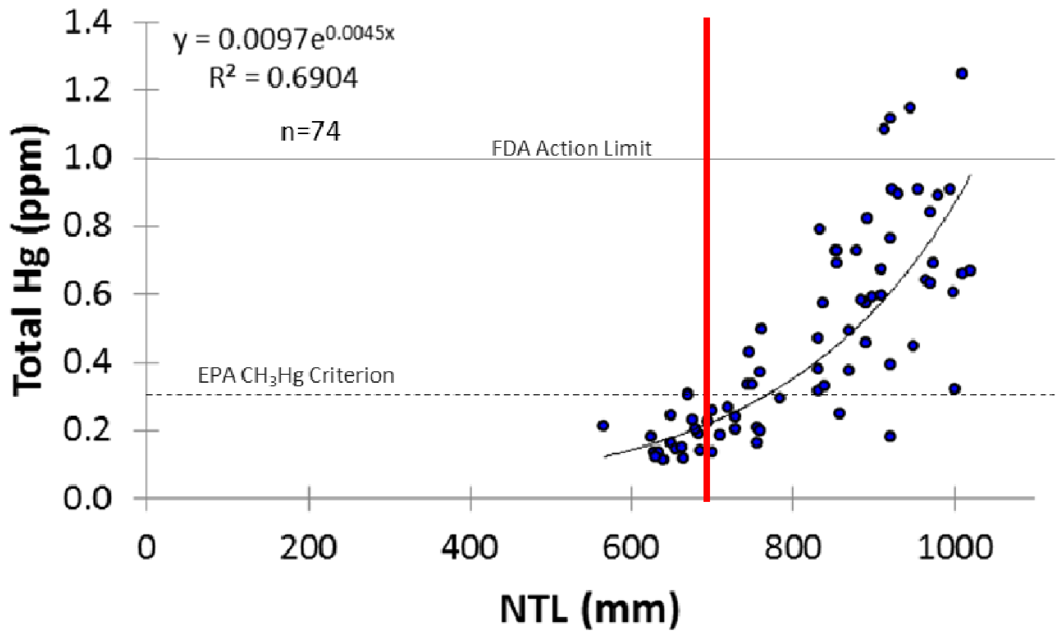


Figure 24. Fishery-dependent Red Drum total Hg versus natural total length (NTL). Red line indicates the upper slot size for Alabama (660 mm NTL).

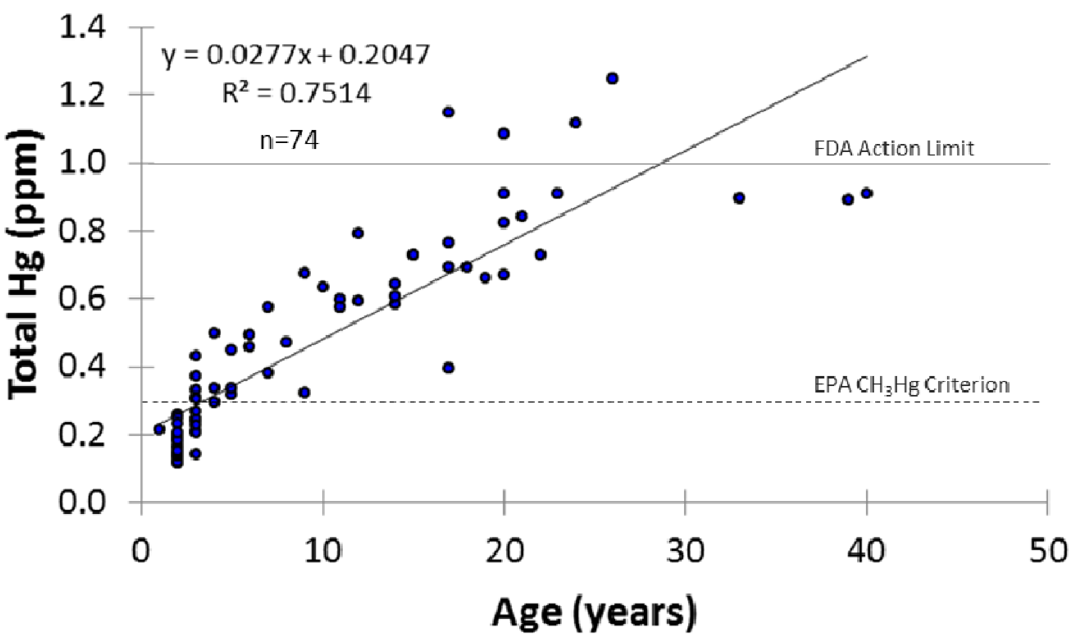


Figure 25. Fishery-dependent Red Drum total Hg versus age.

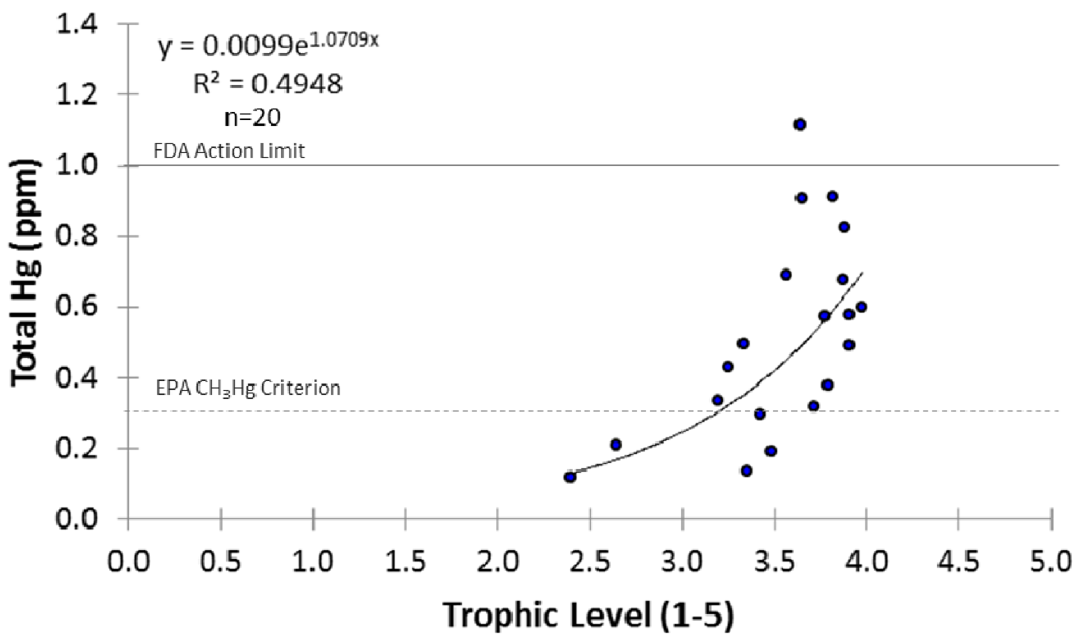


Figure 26. Fishery-dependent Red Drum total Hg versus trophic level.

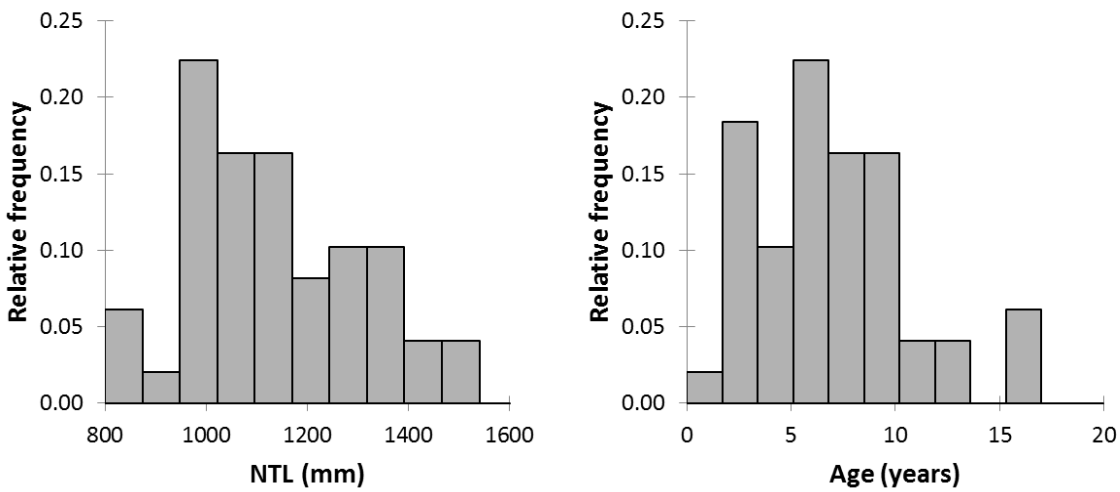


Figure 27. Fishery-independent and fishery-dependent length frequency and age distribution for King Mackerel sampled for mercury and stable isotopes.

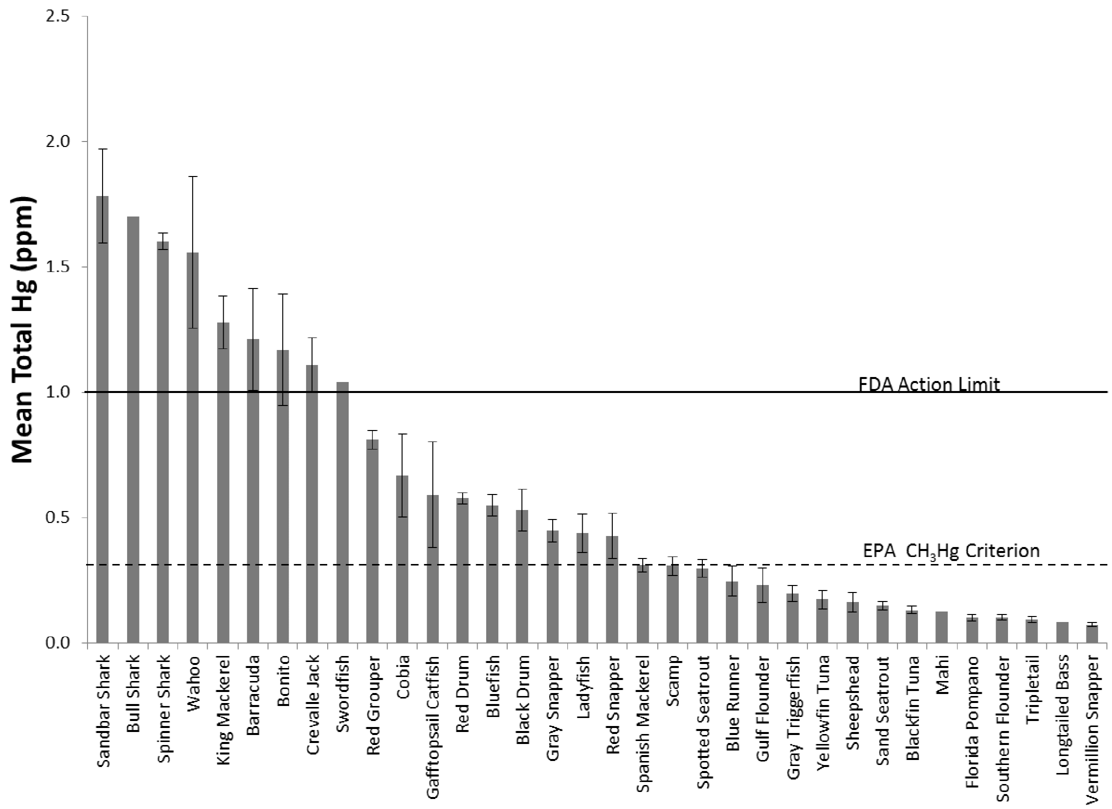


Figure 28. Mean total mercury for all species sampled at the 2011 Alabama Deep Sea Fishing Rodeo.

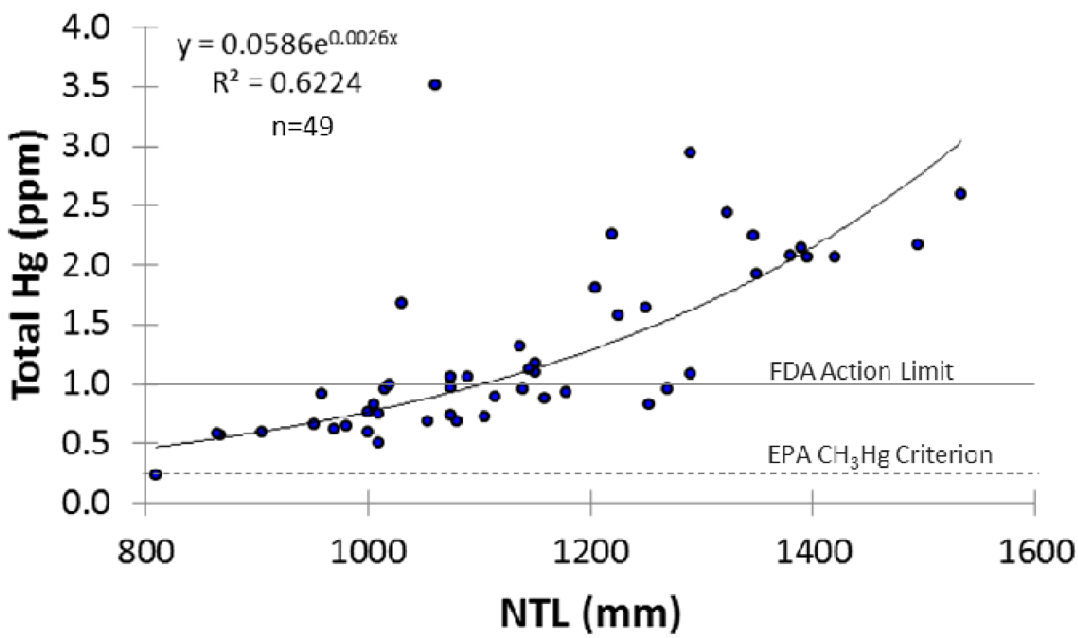


Figure 29. Fishery-dependent King Mackerel total Hg versus natural total length (NTL).

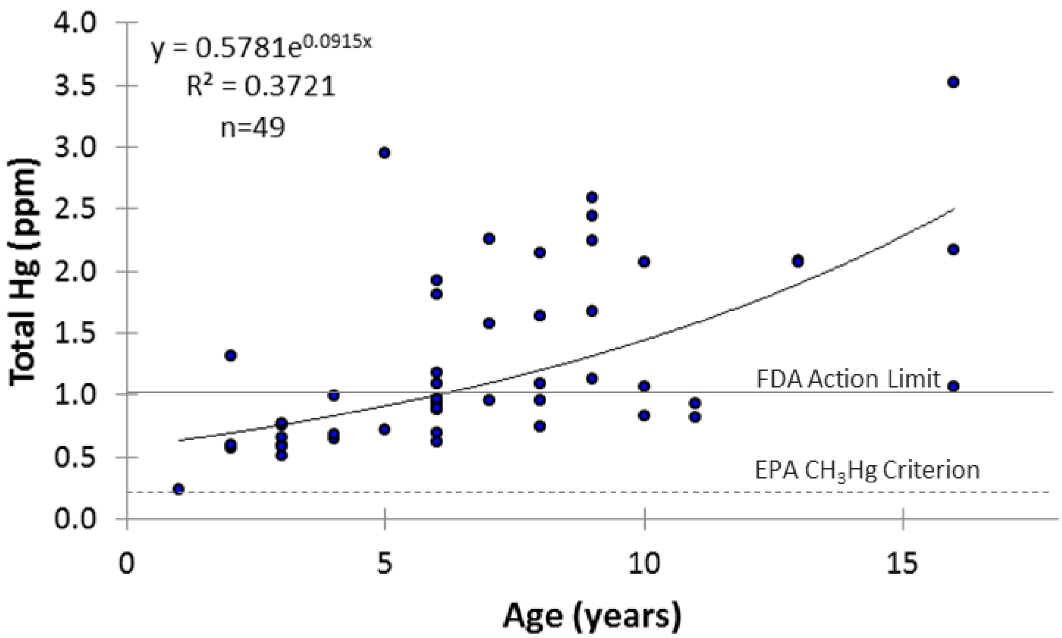


Figure 30. Fishery-dependent King Mackerel total Hg versus age.

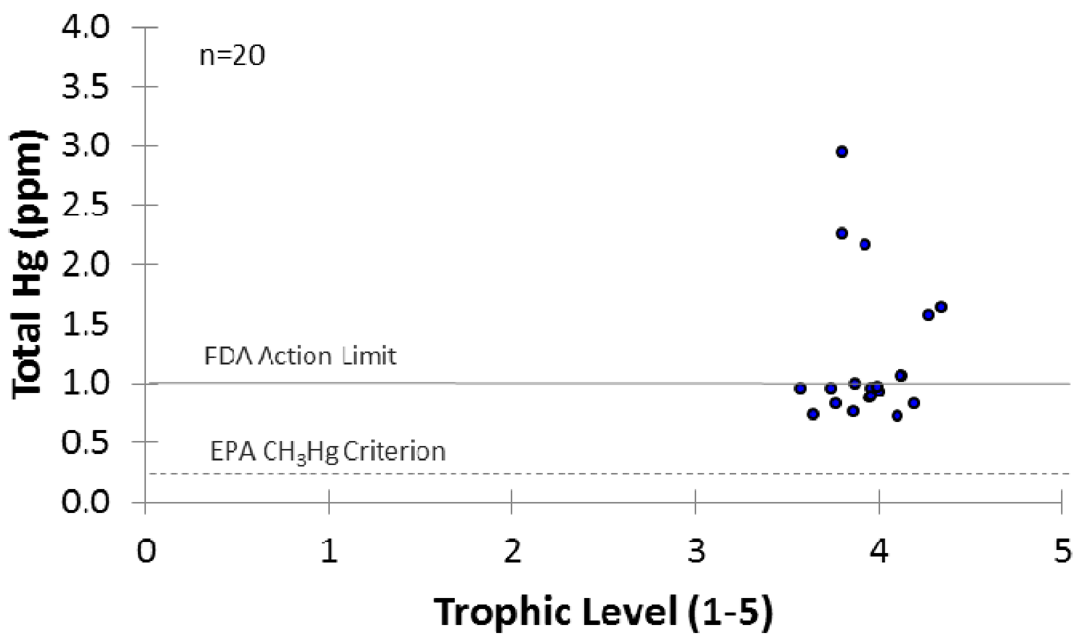


Figure 31. Fishery-dependent King Mackerel total Hg versus trophic level.

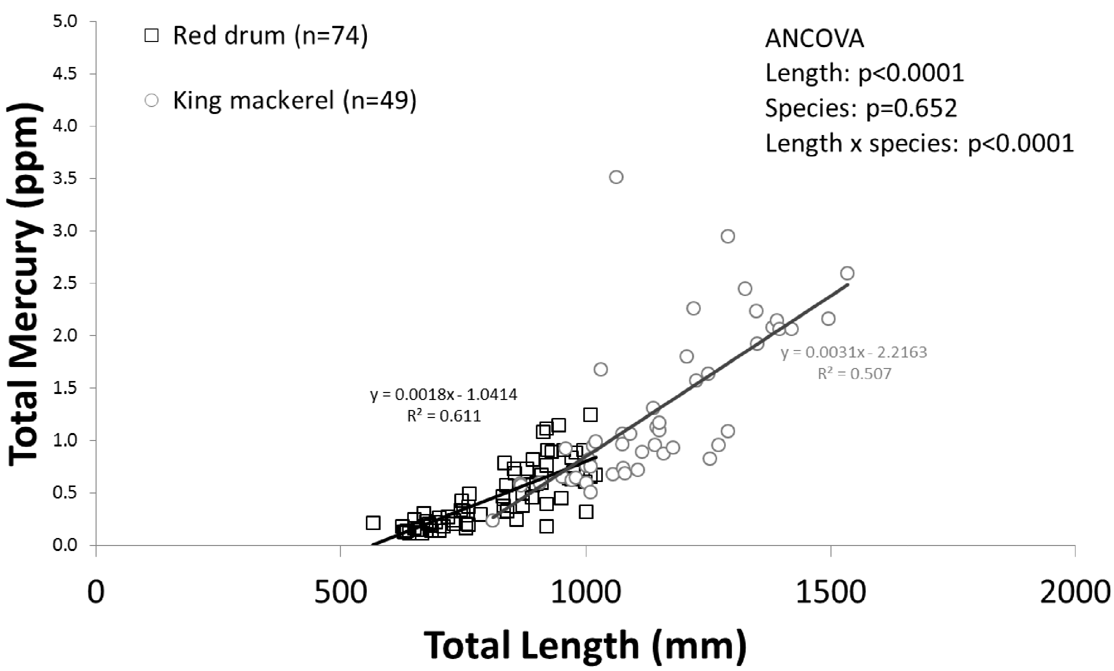


Figure 32. Fishery-dependent King Mackerel and Red Drum total Hg versus size and ANCOVA results.

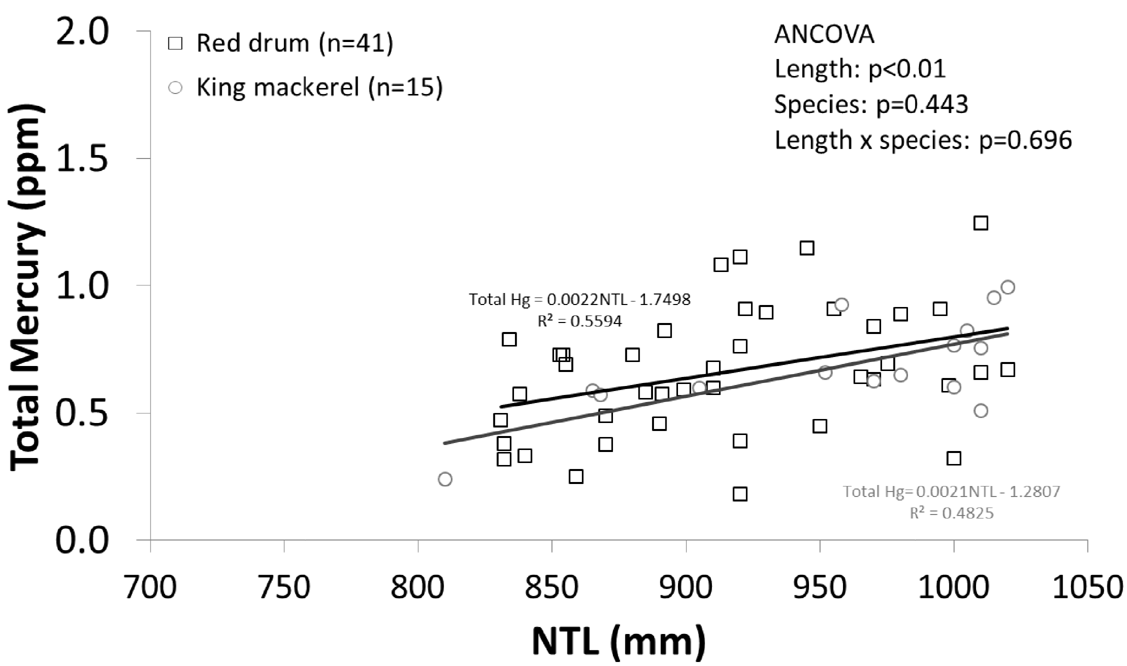


Figure 33. Fishery-dependent King Mackerel and Red Drum total Hg versus subset sizes and ANCOVA results.

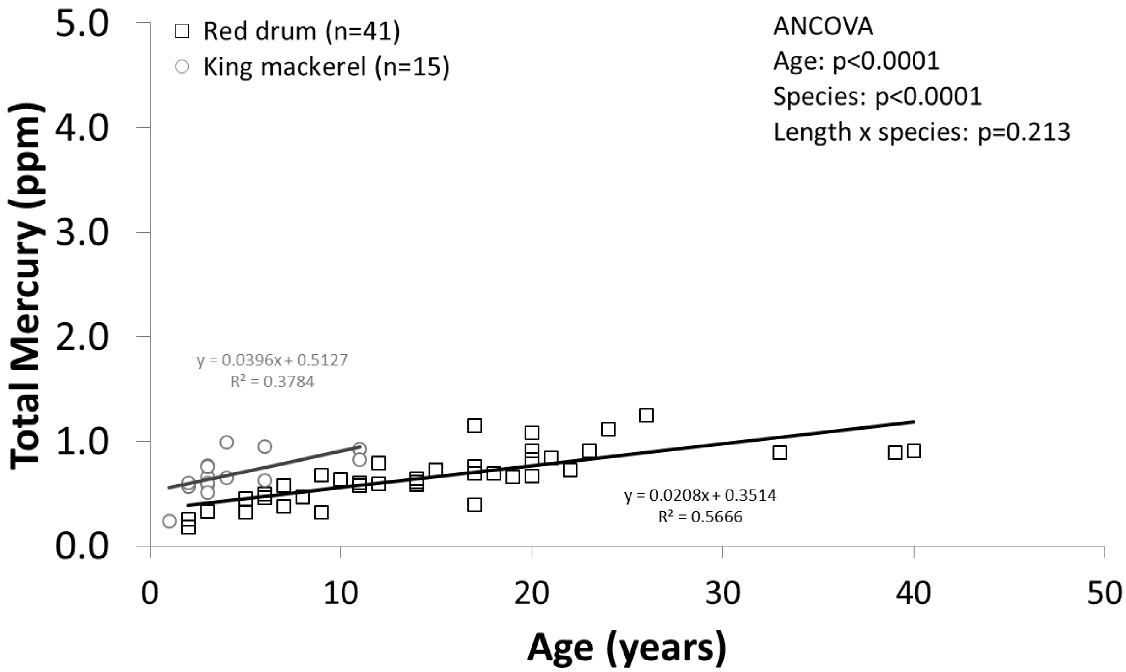


Figure 34. Fishery-dependent King Mackerel and Red Drum total Hg versus age and ANCOVA results for subset sizes.

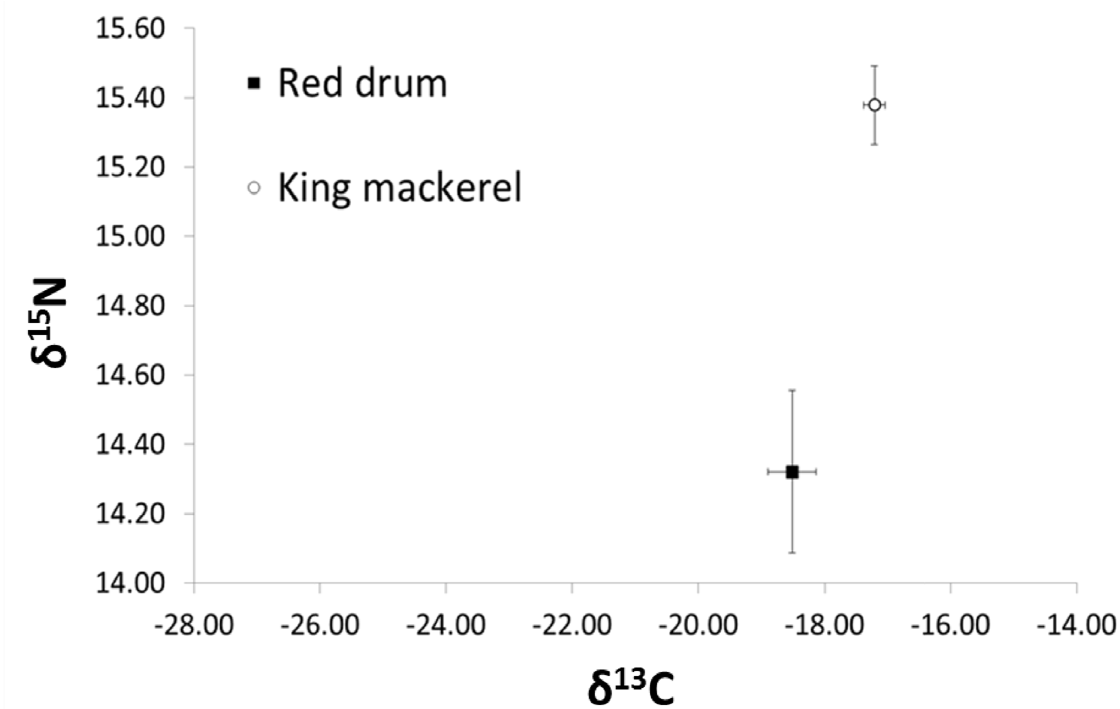


Figure 35. Fishery-dependent King Mackerel and Red Drum stable isotope biplot.

BIOGRAPHICAL SKETCH

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