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Growth Rates in Gulf of Mexico Red Snapper, *Lutjanus campechanus*, Before and After the *Deepwater Horizon* Blowout

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Growth Rates in Gulf of Mexico Red Snapper, *Lutjanus campechanus*,

Before and After the *Deepwater Horizon* Blowout

by

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DEDICATION

For my mother and father who have made many sacrifices to see me succeed.

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Disclaimer: Data presented here may be subject to additional analysis and interpretation, which may include interpretation in the context of additional data not presented here.

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ABSTRACT

The *Deepwater Horizon* blowout occurred on April 20th, 2010 and released nearly 5 million barrels of crude oil into the northern Gulf of Mexico causing pollution of the water and sediment inhabited by many fishes for at least 87 days while the wellhead went uncapped. Populations of the Gulf of Mexico Red snapper, *Lutjanus campechanus*, an important fish to the ecology and economy in the region, exhibit affinity to shallow water oil infrastructure such as the *Deepwater Horizon* making them especially vulnerable to crude oil contamination. The objective of this study is to determine growth of Red snapper before, during and after the *DWH* spill and to assess factors potentially explaining such growth variation. Sagittal otoliths were collected from individuals sampled in 2011 - 2013 from scientific, demersal long-line surveys in the northern Gulf of Mexico (GoM) and West Florida Shelf (WFS). Age and otolith increment width analyses were performed. No annual variation in von Bertalanffy growth parameters was determined among the three catch years. The L_∞ , K and t_0 estimated from the complete data set (2011-2013) were 82.91, 0.20 and 0.43, respectively. However, significant differences in otolith increment width-at-age were observed in increment numbers three - seven in years following the *DWH* event, with declines of 13%, 15% and 22% occurring in the fourth -sixth increments. To asses the potential significance of exogenous environmental variables to observed yearly growth variation I evaluated five parameters – meridional (V) winds, zonal (U) winds, wind stress curl which is a measure of upwelling, Mississippi River discharge, and mean sea level anomaly – using a linear mixed effects model. Hypothesis testing via reduced maximum likelihood estimates indicated that variation in U

winds and River discharge could significantly explain the variation in increment width. However, further work must be done in order to determine the natural, inter-annual variability in age specific growth before the results from model fitting can be considered conclusive. Mean back-calculated weight-at-age measurements were obtained in order to assess potential variation in productivity changes. Results from forward difference and reverse helmert contrast-coding indicated that weight at age three+, four+ and five+ declined by 16%, 15% and 11% in 2010, respectively. These analyses indicate a significant decline in fish growth in 2010 coincident with the *DWH* event, followed by a return to pre-spill rates.

CHAPTER ONE:

INTRODUCTION

On April 20th, 2010 an explosion occurring on the *Deepwater Horizon* (*DWH*) ultra deep-water drilling rig lead to the eventual release of an estimated 4.9 million barrels of crude oil into the waters of the northern Gulf of Mexico (GoM) over the 87 days the wellhead went uncapped[1]. Elevated levels of the toxic, volatile hydrocarbon complex BTEX (benzene, toluene, ethylbenzene and xylene) as well as polycyclic aromatic hydrocarbons (PAHs)- the second most abundant group of toxic compounds in oil- were detected in the upper 100 meters of the water column during the 87 day event[2]. BTEX (as well as n-alkane) concentrations persisted in the upper water column and were detected into the month of August- nearly a month after the wellhead was finally capped. Due to their high site fidelity and an affinity to shallow water oil infrastructure, northern Gulf of Mexico Red snapper, *Lutjanus campechanus*, were potentially vulnerable to the chemical contamination of surrounding shallow water and food items resulting from the release of these carcinogenic, crude oil constituents during the *DWH* event.

Red snapper Life History

Red snapper is an economically important, relatively long-lived reef fish. Two populations of Red snapper exist in USA waters: one residing on the continental shelf of the GoM and the other along the continental shelf of the Atlantic Ocean[3]. Adult Red snapper are highly fecund; mature individuals can produce over 55.5 million eggs in their lifetime[4]. Spawning is prolonged; in some cases lasting nearly six months during April to October, with maximum egg deposition occurring in July[5]. Eggs are spawned in many depths from mid-shelf to the continental slope and spend roughly 26 days in the planktonic phase before larvae settle to the benthos[5,6]. Juveniles associate with low relief, protective habitats when young[5]. Mature Red snapper seek more structured habitat including natural rock outcroppings and oil and gas infrastructure primarily for feeding and protection[5]. Male and females mature at age two; at age three-five they enter the directed hook and line fishery[6]. Between the ages of 2-10, individuals show high site fidelity to artificial reefs, reef pinnacles, rock ledges, shelf banks and, in the western GoM, seem to have a preference for shallow water oil infrastructure[5]. Gallaway and Szeldmayer[5] estimated that nearly 80% of the age two Red snapper resided near oil and gas structures in 1997. As adults, Red snapper are opportunistic feeders and consume primarily fish, shrimp and crabs[5,7]. Red snapper aged 10+ rely less upon shallow water infrastructure and expand their forage range as predation poses less of a threat to them due to their size[8].

Red snapper is a management priority in the GoM[9] and great efforts have been expended towards age based stock assessment including routine age composition and growth analysis. Nelson and Manooch[10] were some of the first to validate the use of opaque rings in sagittal otoliths of Red snapper as age criteria for Red snapper population in the GoM. Though their initial estimates for Red snapper maximum age was conservative (13 years), they provided the basis for Red snapper age research[11]. Since then, numerous studies have been undertaken to better understand the age structure and growth pattern of this fish. These data are important to stock assessment as Red snapper had been overfished in years past and rebuilding strategies are based on projection of the equilibrium age structure and maximum age[11]. Most recent estimates of Red snapper maximum age from various parts of the northern GoM are 53 years[12], 50 years[13] and 34 years[3].

Otolith Formation and Growth

Hard parts (scales, fin rays, otoliths) of fish are commonly used to age fish because they provide accurate information about daily and annual growth rates[14]. Sagittal otoliths, used primarily in age validation studies such as those previously described, are the most reliable hard-part used in the determination of annual age and growth in teleost fishes[15]. Otoliths are calcium carbonate structures which are nestled inside the endolymphatic sac of the inner ear[16]. They grow via daily deposition of aragonitic calcium carbonate yielding a two-part ring composed of a layer of aragonite crystals and a protein matrix[17]. Otolith growth and the pattern of ring formation can vary among many fishes. Validation procedures such as marginal increment analysis, a method that describes the amount of opaque band on the edge of the otolith over a certain time period, have indicated that spawning seasons and times of slow growth are coincident with daily rings spaced closely together[3]. These form opaque bands, commonly referred to as annuli, which appear dark when viewed under transmitted light and white under reflected light[18]. Alternatively, during times of increased growth, the daily rings bio-mineralize farther apart creating a zone which appears translucent when viewed under transmitted light[3,13,19,20]. There is no reabsorption of these layers and this process of bio-mineralization takes place even in calcium-deficient times[21]. All Red snapper hatch with a primordial core, the centermost part of otoliths, and the first annulus forms during the winter and spring after hatching[22]. As such, opaque zones can begin appearing in December and form until June, with some slight variation[3]. Opaque ring formation completes as spawning events occur, at which point the translucent zone becomes apparent (June-July). This zone can last into late November or December when the process of opaque zone formation begins again[3]. The pairing of one opaque zone and one translucent zone is considered one complete growth increment- and, in the case for Red snapper, representative of one complete year of growth[3,13]

Otoliths are a unique tool in the field of fisheries science because they can serve as a proxy for evaluating somatic growth of a fish much like the rings of trees provide information about tree growth. The constant bio-mineralization and growth of otoliths is a function of both somatic growth and metabolism[23]. Previously, it was suggested that otolith growth was completely independent of somatic growth but, rather, controlled solely by metabolic activity and regulated by environmental conditions[15,17]. However, Wilson et al., among others[24–26], have observed a significant relationship between otolith and somatic growth. So, otolith growth is most likely "coupled" with fish growth and thus, otoliths are a helpful tool for estimating Red snapper growth rate and determining fish length at any age[24].

Otoliths as Investigative Tools

Because they record and maintain information about fish growth, otoliths have been used in many ways to understand the complex interactions occurring between fishes and their environments. In the past, otoliths have been used for species identification and stock discrimination[27], understanding connectivity between natal spawning habitats and geographical regions[28], identifying site of origin by documenting elemental comosition[29], and correlating climate variability with individual fish growth[18,30–32]. Black at al.[18] used sclerochronology techniques (the study of periodic features in marine hard parts- the marine equivalent to tree-ring analysis[33]) to develop growth chronologies of Gulf of Mexico Red and Gray snapper (*Lutjanus* *spp.)*. They used these growth chronologies to correlate with several environmental variables. They found the Red snapper growth chronology correlated significantly with March winds and sea surface temperatures. Highest rates of growth occurred during warm years in March and April with strong onshore winds. This same technique was used by Matta et al.[30] and Black et al.[31] with Bering Sea flatfish species and a long-living rockfish, *Sebastes diploproa*. The time-series obtained from the otolith growth increments was correlated to climatic variations in the Pacific Ocean and Bering Sea to estimate the impact of climate variability on fish growth[30]. The principle concept employed by these authors is that otoliths provide a record of yearly growth for the life of individual fish. So, environmental disturbances that may cause growth variation will also be reflected by variable annual growth increments in the otolith. Because they continually record growth, otoliths are particularly useful for estimating the effects of an irregular or catastrophic environmental event.

Effects of Oil on Fish Growth and Condition

Following the *Exxon Valdez* spill in Prince William Sound, Alaska, in early spring of 1989, researchers have attempted to estimate the effects of crude oil on developing larvae and fishes[34]. Resulting evidence from these studies indicates that such contamination from the *DWH* event could similarly lead to physiological abnormalities, growth declines and, in some cases, increased mortality in GoM fishes like Red snapper[34]. Studies have shown that metabolism and somatic fish growth are highly sensitive to chemical contamination as a result of oil exposure[23]. For example, Kerambrun et al.[35] exposed juvenile sea bass ***(****Dicentrarchus labrax****)*** to an Arabian light crude oil for 48 and 96 hours to assess consequences of exposure to fish health. After a decontamination period of up to 28 days, they found significant decreases in growth rate, otolith margin growth and Fulton's K condition index in fish exposed to crude oil for 96 hours[35]. It was noted that such inhibition of growth might lead to increased susceptibility to predation and decreased ability to find food and resources, highlighting the importance of understanding the impact of pollution and contamination on fish populations [35,36]. Similarly, Moles and Norcross[37] exposed juvenile yellowfin sole (*Limanda aspera),* rock sole *(Lepidopsetta bilineata)* and Pacific halibut *(Hippoglossus stenolepis)* to sediments contaminated with Alaska North Slope crude oil. After 30-90 days of exposure, growth had decreased by 34-56%[37]. Also, in 2007, Morales-Nin et al.[23] investigated the effects of oil ingestion on the growth of juvenile turbot otoliths by exposing fish to five different concentrations of fuel oil via contaminated food pellets. Both somatic and otolith growth were negatively affected and growth changes were inversely correlated with contaminant level[23].

Objectives and Hypotheses

As Red snapper is one of the most important fish in the Gulf of Mexico supporting both commercial and recreational fisheries[38] it is important to estimate whether exposure and contamination from *DWH* crude oil lead to growth declines; such growth declines could have important implications for overall population productivity. Because much of the past research has focused on larval and developing fishes, it is unclear if and how contamination will affect adult, long-living demersal fish like Red snapper. Since somatic growth rate is both a key variable in determining productivity of fish populations and is sensitive to chemical contamination, otolith increment analysis, a method used to estimate annual growth rate, is necessary to understand the potential impacts of crude oil contamination on population level growth of important finfish species[17,21].

The main objective of this study is to estimate the effects that potential contamination from the *DWH* event had on growth of the Gulf of Mexico Red snapper. I will accomplish this main objective in four steps.

1. Estimate the age structure and growth rate of Gulf of Mexico Red snapper following the *DWH* event by performing age analysis on sagittal otoliths.
2. Evaluate year-specific growth before and after the *DWH* event by performing increment-width analysis on sagittal otoliths.
3. Explore the alternative environmental drivers of potential year-specific variation by performing model fitting analysis with relevant environmental data sets.
4. Estimate changes in productivity by back-calculating somatic growth to estimate age-specific length and weight in years before and after the *DWH* event.

I propose several testable hypotheses:

H_{a1}: There will be a difference in the annual von Bertlanffy growth parameter estimates of Red snapper.

H_{01}: There will be no difference between the annual growth parameter estimates.

H_{a2}: Variation in environmental variables through years can explain variation observed in otolith increment widths.

H_{03}: Variation in environmental variables through years does not explain any variation observed in the otolith increment widths.

H_{a3}: There will be a significant decline in increment width at age in years during and following the *DWH* event.

H_{02}: There will be no difference in increment width at age following during and following blowout event.

CHAPTER TWO:

METHODOLOGY

Field Sampling

Scientific, demersal long-line sampling was conducted during the summers of 2011- 2013 along pre-defined transects on the shelf and shelf edge of the northern GoM and the West Florida Shelf (WFS) (Figure 1). Sampling in 2011 occurred from June through August aboard commercial fishing vessels. Transects were composed of sampling sites ranging in nominal depths of 18, 36, 73, 109, 146 and 182 meters following shelf edge bathymetry. The distribution of sampling stations ranged from Terrebonne Bay, Louisiana, along the northern GoM and southward along the WFS to the Dry Tortugas Islands following the continental shelf curvature. Sampling in 2012 consisted of two sampling cruises, one occurring from June-July aboard a commercial, long-line fishing vessel C/V *Pisces* and the other in August aboard the R/V *Weatherbird II.* Of the stations sampled in 2011, 34 were re-sampled in 2012. Additional sites west of the Mississippi River less likely to have surface contamination were also sampled. Sampling in 2013 occurred in August aboard R/V *Weatherbird II.* Sites visited aboard this vessel during the August 2012 sampling event were re-visited in 2013.

Suitable hard bottom habitat to target reef -fish was located at all stations visited. If no suitable habitat was present at the pre-defined coordinate, the vessel was allowed to range up to a 9 km radius in search of hard bottom. Latitude, longitude, time, bottom depth and cloud cover were recorded at the beginning and end of each long-line set. Eight kilometers of steel ground line (2011,2012) and 1200 pound mono-filament (2013) with 350-500 #13 circle hooks alternatingly baited with a combination of squid wings and mackerel were deployed. A Star: Oddi CDST Centi© temperature - time - depth recorders were attached at the beginning and end of each set. The line was allowed an average soak time of 2 hours and 1 min during which time the vessel returned to the starting point to retrieve it.

During gear retrieval each animal was identified to the species level, if possible. Sharks larger than 2 meters were photographed and released from the line for safety reasons. Morphometric data including fork length and standard length, to the nearest centimeter (cm), as well as mass measurements, to nearest gram (cg), were obtained from all captured samples. Mass measurements were obtained using a Marel motion-compensated scale or a hand scale for animals larger than the measurement range of the Marel (6 kg). If animals exhibited any gross external abnormalities including skin conditions or apparent lesions, the animal was photographed and a sample of the abnormality was collected and stored in 10% buffered formalin.

The gastrointestinal tract, liver and gonads were dissected from the first five Red snapper captured and from all those with apparent external abnormalities. They were weighed separately using the Marel scale. Sex was determined if possible. However, due to the temporal overlap of sampling and Red snapper spawning season, the sex of some fish was not macroscopically evident if they had completed spawning. In this case the sex was marked as U for "unidentified". Left and right sagittal otoliths were excised from all Red snapper caught. Otoliths were cleaned of the endolymphatic fluid and placed in a scale envelope listing their identification number, catch date, length, weight, station number and sampler.

Otolith Processing and Age Analysis

Left otoliths were thinly sectioned (0.4mm) along the transverse plane using a Buehler Isomet© low speed saw equipped with three, 4-inch impregnated diamond cutting blades according to methods described by the Gulf States Marine Fisheries Commission[19]. Right otoliths were substituted if left otoliths were incomplete, unavailable or deformed. The three resulting cross sections were mounted to glass slides with Flo-Texx©, a permanent toluene-based mounting medium and viewed under transmitted light at 10X magnification with a SZ61 Olympus dissection microscope.

Age analyses were performed on the cross-sections containing the primordial core by counting the number of annuli along the dorsal axis from the primordial core to the proximal surface (Figure 2). If the presence of annuli was unclear along any part of the otolith cross-section, it was viewed under reflected light (where annuli appear white) because some annuli appeared more distinct under different light conditions. The size of the marginal increment, which is the translucent zone at the proximal surface of the otolith, was defined following a coding system described in Table 1[19]. The final age of the otolith was assigned based on the number of observed annuli, the code assigned to the marginal increment and the catch date per methods described in GSFMC[19], (Table 1). If samples had a catch date between January 1 and June 30th and also assigned a "4" margin code, the age (in years) of the otolith was calculated as the number of observed annuli plus 1. If samples had a margin code of "3" or less, the age of the otolith was calculated solely based on the number of observed annuli. For example, an otolith collected between January 1 and June 30th with six observable annuli and a "4" margin code would be assigned an age of seven. This was done in order to keep individuals in their true age class[19]. For all samples collected after June 30th, the age was determined based only on the number of observed annuli along the described axis regardless of the observed margin code. Quality assurance and control were performed on the data by the Age and Growth Lab at Florida Fish and Wildlife Research Institute in St. Petersburg, FL. A seasoned reader viewed the otoliths independently under the same light conditions and assigned ages. If the reader assigned an age that disagreed with the previously determined age, a conference was held to discuss discrepancies. Most of the discrepancies in age occurred when determining the presence of an annulus on the edge and timing of the first annulus. If the readers did not agree after conference, the age assigned by the seasoned reader was accepted as the true age.

Increment Width Analysis

Otoliths ranging in age from three to nine were chosen for this analysis because of the clarity of their observed annuli banding patterns. Only otoliths with clearly defined annuli and margins along the dorsal axis of the sulcal groove were used for this procedure. Samples were excluded from this analysis if the annuli were unreadable along any point of the axis. The annual growth increments were measured continuously from the dorsal distal margin to the primordial core along the sulcal groove following an axis perpendicular to increment growth using a microscope-mounted camera and the Lumenera Infinity Analyze© software. Annual growth increments were measured from the proximal side of one opaque zone to the proximal side of the previous years opaque zone (Figure 2-4). This measurement procedure was conducted three times on each otolith. The measurements were then averaged and individual increment widths were summed to obtain an average “chord” length per otolith. The measured increments were categorized by increment number and corresponding year of growth in order to make yearly comparisons of average increment width at age. Because ontogenetic changes during the first and second year of life distort the geometry of the increments along the sulcal grove making it difficult to obtain increment width measurements perpendicular to growth[30], we excluded the first and second increments from the analysis. Also, sample size of increments eight and nine were very limited so only increment numbers three through seven were used for further analysis.

Data Analysis

Age and Length

All data analyses were performed using R version 3.0.3[39]. Data exploration was performed to identify outliers. Only two fork length data points were removed due to recording errors in the field. Parameters of the Von Bertalanffy growth model were estimated (eq.1) using the length and age data from each catch year by performing a nonlinear least-squares estimate using the *stats* package in R.

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

L_t, length at time t;
L_∞, asymptotic length where fish growth is zero;
K, growth parameter; t, time of length measurement;
t_0, time when length equals zero

Non-parametric bootstrap resampling was performed using the *nlstools* package in R to obtain bootstrap estimates and the 95 percent confidence intervals[40] of the three parameters. A likelihood ratio test using the *vblrt* function in the *fish methods*[41] package was performed following methods described in Kimura 1980[42] to test for differences between the estimated von Bertalanffy growth curves calculated for each catch year and by sex. Parameters describing weight at length curves (eq. 2) were also estimated using the length and weight data from each catch year and by sex. Both total weight and somatic weight were used when available. Somatic weight was obtained by subtracting total gut and gonad weight from the total weight.

$$W = aFL^b \qquad [2]$$

W, weight;
FL, fork length;
a,*b*, parameters describing the relationship between length and weight

Parameter estimation was performed using nonlinear least squares methods with non-parametric bootstrap resampling for variance estimates. Sex- specific von Bertalanffy curves as well as length at weight curves were estimated. Finally, when appropriate, the data from all catch years were combined to create a composite von Bertalanffy and length-weight curve.

Model fitting with Increment Width Data

Increment width data from the third through seventh increment were transformed following Box-Cox methods in the *MASS* package[43] before determining the optimal model which best described the observed variation. Several parameters were evaluated in the model including increment number, increment width, fish identification - which accounted for individual variability - as well five environmental parameters which served as covariates to explore the potential explanatory, exogenous factors accounting for variability in increment width[18]. Black et al.[18] used chronology techniques to examine the multi-decadal otolith growth histories of Gulf of Mexico Red snapper. To determine climate relationships with Red and Gray snapper growth chronologies, they included monthly averages of sea surface temperatures, meridional and zonal winds, as well as Mississippi River discharge. As such, meridional or north-south winds, also referred to as V winds, and zonal or east-west winds, also referred to as U winds, were included in this study due to their potential influence on currents and upwelling along shelf edges[18,44]. Wind stress curl, (derived from the spatial gradients of U and V), the physical forcing that causes Ekman Transport and the downwelling/upwelling of water masses causing potential biological consequences along shelf edges, was also included[45]. Mississippi River discharge measured at Tarbert Landing, MS was included as an indicator of nutrient input[18] as well as sea level anomaly because it is an indicator of heat storage in the upper ocean[46]

Vector U and V wind data were obtained from the NCEP/NCAR Reanalysis: http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.pressure.html, available at a 2.5 x 2.5 ° grid and a pressure level of 1000 mb. River discharge at Tarbert Landing, MS (gage 01100) were obtained through the United States Army Corp of Engineers: http://www2.mvn.usace.army.mil/eng/edhd/wcontrol/miss.asp. Monthly sea level anomaly (MSLA) data were obtained from the daily Ssalto/Duacs- Delayed Time MSLA data set http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/msla-mean-climatology.html#c10358, available at a 0.25° x 0.25° grid. Wind stress curl was a derived quantity obtained following methods described in Chambers 2011[47] from wind stress data set described in Atlas 2011[48] and available at: http://podaac.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L4_OW_L3_5A_MONTHLY_WIND_VECTORS_FLK. All environmental data were extracted from coordinate locations on a grid closest to the catch locations of otoliths used for increment width analysis at the highest spatial resolution available. An overall average of each variable was obtained for the months of June through December (Red snapper growing season) of every year of increment formation. These data were then zero centered and no outliers were identified (Figure 5, 6).

With the resulting variance structure determined, the optimal model was identified through a process of variable elimination and likelihood ratio testing. The likelihood ratio testing was done following the preferred method[49] of refitting the model following maximum likelihood ratio techniques (ML) and subsequently dropping each of the five environmental parameters to create reduced models. For example, all five parameters were fitted to a complete model (eq. 3). Then, five reduced models, each of which had one environmental parameter eliminated, were defined.

$$\begin{aligned} \textit{Increment Width} = a_0 &+ a_1(\textit{Increment Number}) + \\ &a_2(\textit{Year of Formation}) + \\ &a_3(\textit{U winds}_{(x,\ YOF)}) + \\ &a_4(\textit{V winds}_{(x,\ YOF)}) + \\ &a_5(\textit{Wind Stress Curl}_{(x,\ YOF)}) + \\ &a_6(\textit{Mississippi River Discharge}_{(x,\ YOF)}) + \\ &a_7(\textit{Sea Level Anomaly}_{(x,\ YOF)}) + \\ &a_8(\textit{Fish Identification Number- Random}) \end{aligned} \qquad [3]$$

Where the subscript "x,YOF" denotes that values of the environmental variables are from the year that each measured otolith annual growth increment formed (YOF) and in the catch location of the fish (x). A coefficient for the random component "Fish Identification Number" was also estimated.

ANOVA compared each reduced model to the full model, which provided the significance of the dropped term and an Akaike Information Criterion (AIC) value. Parameters with non-significant L ratios were omitted from the model. This process continued until all that remained were significant environmental parameters. The final model was refit with REML and then model validation techniques were performed[49].

To assess age specific variation in increment width, forward difference contrast-coding, a method that compares the mean of the dependent variable for one level of a categorical variable to the mean of the next adjacent level, was performed using the final model[50]. Reverse helmert coding was also performed. This is a method that compares the mean of the dependent variable for one level of a categorical variable to the mean of all previous levels[50]. This was done to make a comparison of the mean value of each age specific increment formed during 2010 to the mean value of that same age specific increment in all years previous to 2010.

Back-calculated Length and Weight Calculations

Several studies have reviewed the efficacy of various back-calculation equations. Wilson et al.[24] compared the effectiveness of their Modified Fry back-calculation equation with the biological intercept method (eq. 4). By measuring length at capture (L_{cpt}) and radius at capture (R_{cpt}) from repeatedly internally and subcutaneously injected gobie species and performing regression analysis they found that the biological intercept method best approximated the growth relationship when the two variables were isometric[24]. Upon performing a regression analysis of L_{cpt} and R_{cpt} variables from the present study it was found the relationship between the two was indeed isometric (Figure 7). Furthermore, a study performed by Morita[25] also indicated that the biological intercept equation best modeled the relationship between the two variables as indicated by a high r^2 value from regression analysis on back-calculated fork length and observed fork length at age measurements[25]. Therefore, the Biological Intercept equation (eq. 4), which was proposed by Campana 1990[51,52] and is a modified version of the traditional Fraser-Lee model, was selected as our preferred method of back-calculation. Length at hatching and otolith radius at hatching were set to 0.2 cm and 0.001 cm, respectively[53]. The previously estimated a and b (eq. 2) parameters were applied to the back-calculated length at age data to obtain back-calculated weight at age data (eq. 2). Finally, to assess the variation in both back-calculated length at age and back-calculated weight at age, forward difference and reverse helmert contrast-coding techniques were applied to these measurements.

$$L_i = L_{cpt} + (L_{cpt} - L_{0p}) * ((R_i - R_{cpt})/(R_{cpt} - R_{0p})) \quad [4]$$

L_i, fish length at age; L_{cpt}, fish length at capture;
L_{0p}, fish length at biological intercept;
R_i, otolith radius at age;
R_{cpt}, otolith radius at capture;
R_{0p}, otolith radius at biological intercept

Tables and Figures

Table 1. Coding scheme for identifying marginal increment completion in Red snapper otoliths sampled in the northern Gulf of Mexico during 2011-2013[19]

Amount of Completed Translucent Zone	Margin Code
0 (opaque zone present on edge)	1
1/3 complete	2
1/3-2/3 complete	3
2/3 to fully complete	4

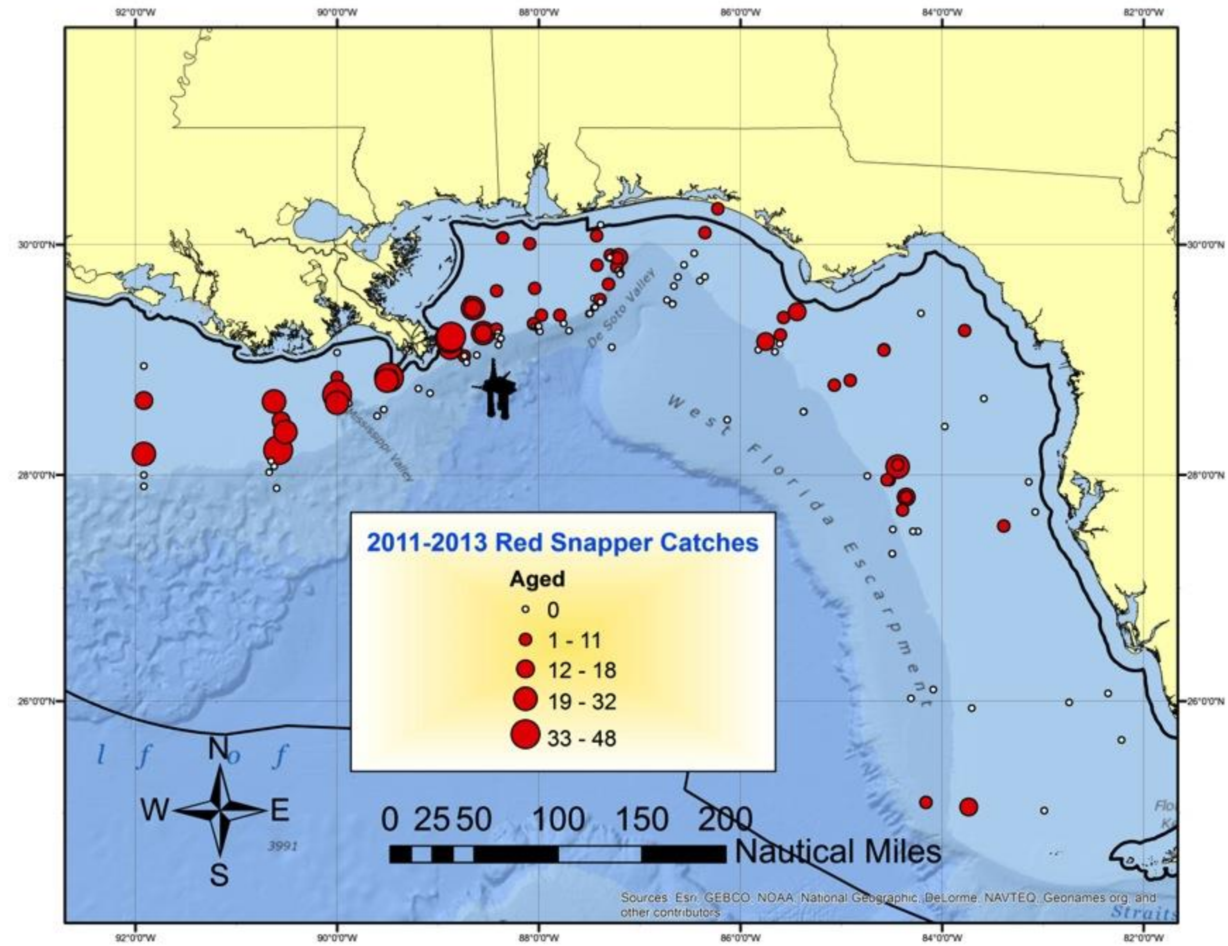

Figure 1. Sampling stations visited aboard commercial and research vessels along the West Florida Shelf and northern Gulf of Mexico during 2011-2013. Map courtesy of S.Murawski, 11/3/2014.

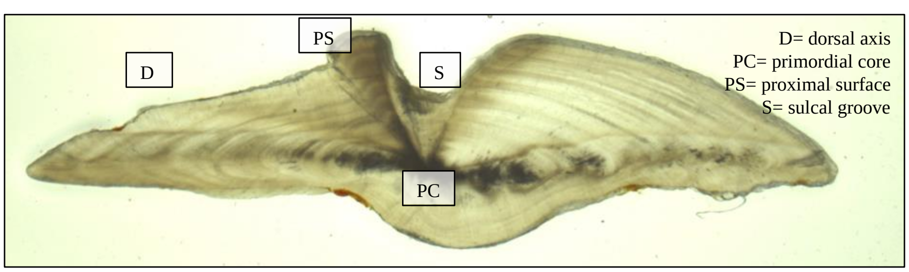

Figure 2. Photograph of a Red snapper otolith showing the sulcal groove (S), primordial core (PC), dorsal axis (D) and proximal surface (PS).

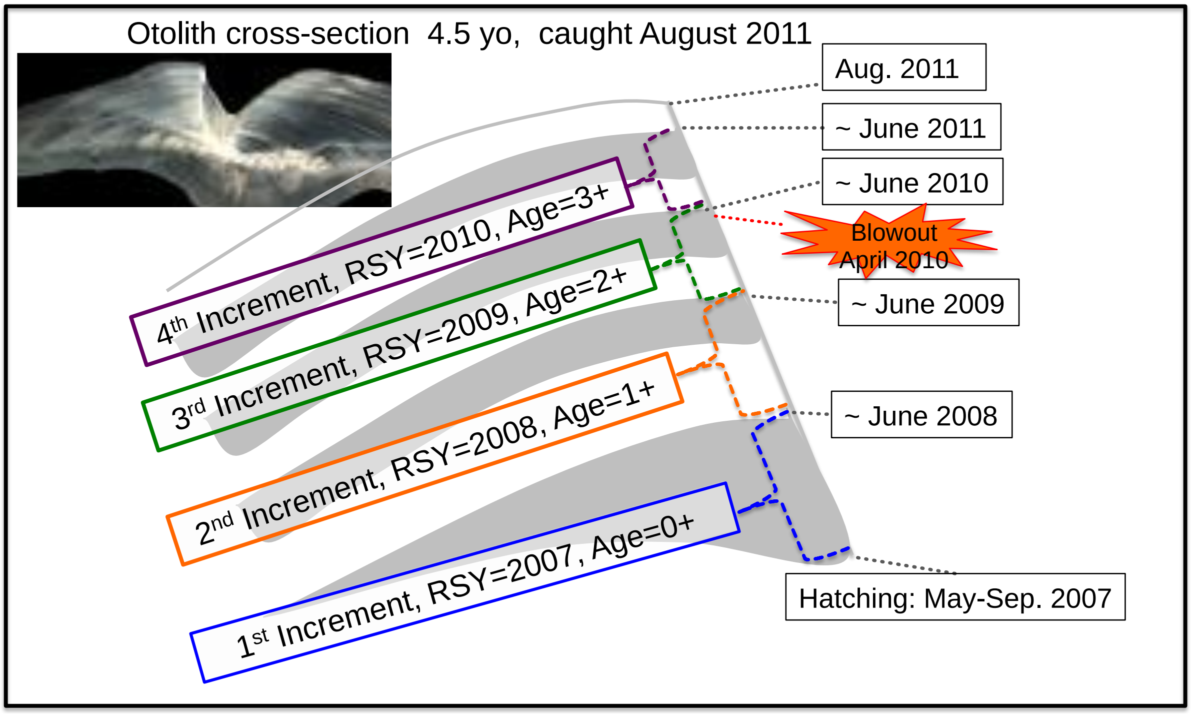

Figure 3. Schematic of an otolith cross-section from a 4.5 year-old Red snapper caught in August 2011. A photograph of an actual otolith cross-section in the top left corner is provided for reference. Brackets correspond to measurement location of increment widths; measurements were made along the dorsal axis of the sulcal groove. RSY = Red snapper year which is measured from June to June of the following year.

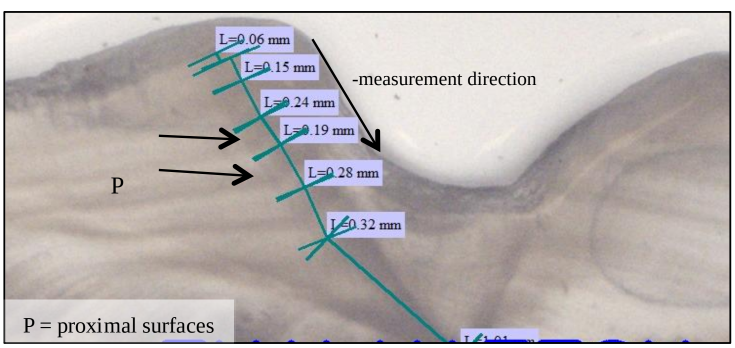

Figure 4. Photograph showing increment width measurements made on a cross-section of a Red snapper otolith. The “chord” length is the sum of each annual increment widths and can be directly measured from the primordial core to the edge of the otolith parallel to the sulcal groove.

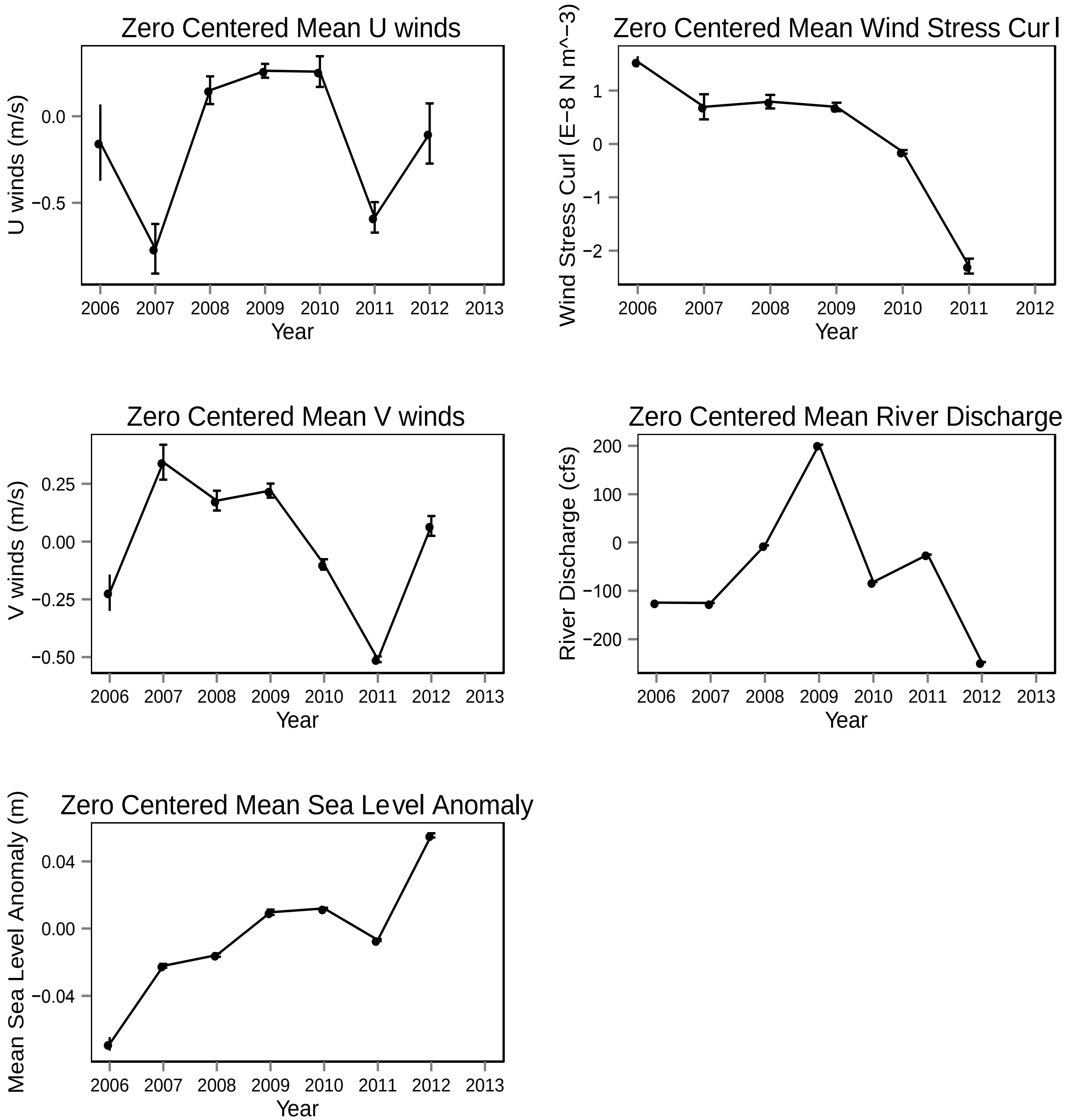

Figure 5. Zero centered mean values ± SE of meridional winds (V winds), zonal winds (U winds), wind stress curl, Mississippi River discharge and sea level anomaly in the Gulf of Mexico during the Red snapper growing season (June-December) in years 2006-2012.

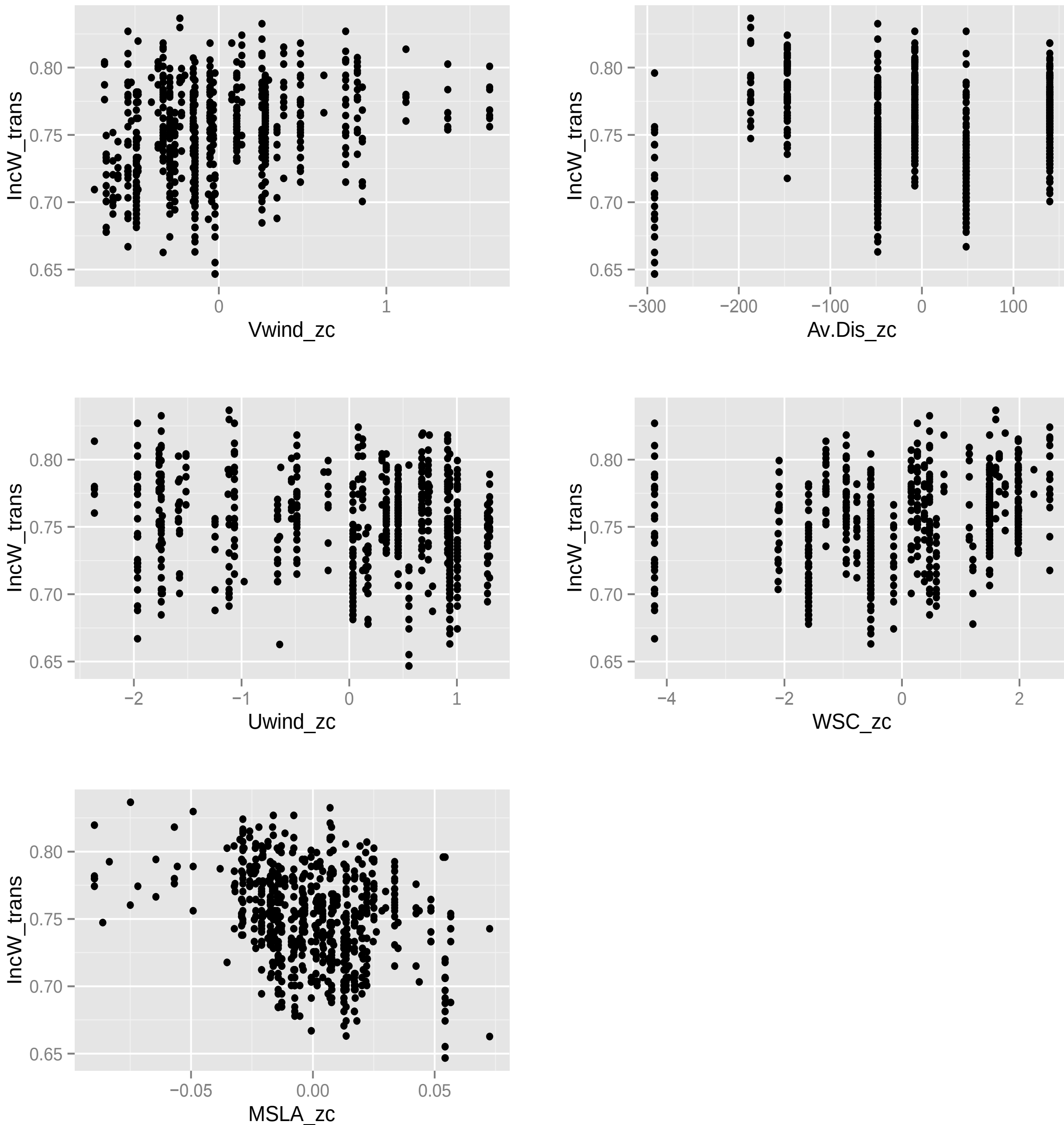

Figure 6. Zero centered mean values ± SE of meridional winds (V winds), zonal winds (U winds), wind stress curl, Mississippi River discharge and sea level anomaly in the Gulf of Mexico plotted against Box-Cox transformed increment width values from Red snapper otoliths caught in 2011-2013.

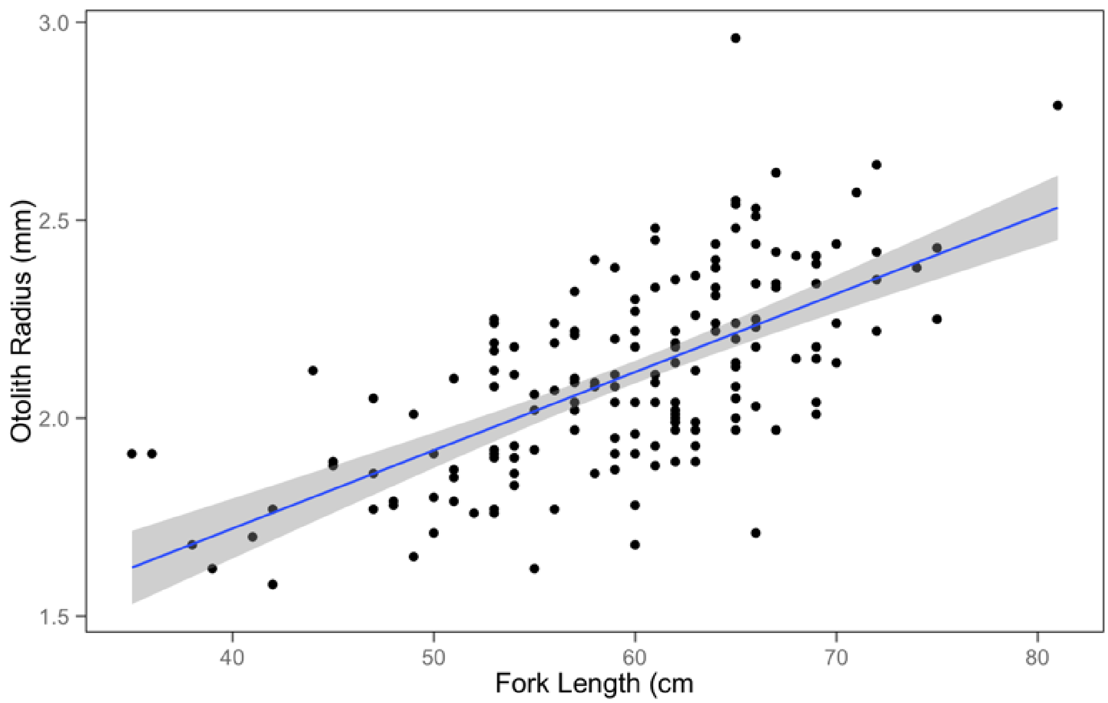

Figure 7. Fork length at capture (L_{cpt}) regressed against otolith radius at capture (R_{cpt}) for Gulf of Mexico Red snapper caught 2011-2013. The blue line indicates the model fit: adjusted r^2 = 0.41, $p < 0.0001$. The shaded gray area indicates the confidence region.

CHAPTER THREE:

RESULTS

Age and Growth

Sagittal otoliths sectioned for age determination were collected from 822 Red snapper. Of these, 327 were collected in 2011, 387 were collected in 2012 and 108 were collected in 2013 at sampling stations in the northern GoM and along the WFS (Figure 8, Table 2).

The longitude line coinciding with the Desoto Canyon, 87.000° W, was considered the boundary between the northern GoM and the WFS. Any sample collected east of 87.000° W was considered to be from the WFS; any sample collected west of 87.000° W was considered to be from the northern GoM. Ages ranged from 2-40 in 2011 with a mean of 5.76 ± 0.19 SE and median of 5, 3-24 in 2012 with a mean age of 6.43 ± 0.12 SE and median of 6, and 4-15 in 2013 with a mean age of 6.95 ± 0.15 SE and median of 7 (Figure 9, Table 3). Mean fork length ± SE of individuals caught in 2011 was 56.57± 0.59 cm, 59.60 ± 0.43 cm in 2012 and 61.71 ± 0.86 cm in 2013 (Figure 10, Table 4). The distributions of length at age for the complete data set (n = 799) range from a mean fork length of 32.66 ± 1.15 cm at age 2 to a mean fork length of 70.06 ± 1.24 cm at age 9 (Figure 11, Table 5). Sex was determined on 811 fish of which 415 were females and 396 were males. Mean fork length for males was 58.74 ± 0.44 cm and 58.07 ± 0.50 cm for females.

Von Bertalanffy growth parameters L_{∞}, K and t_0 were determined using data from each catch year. Bootstrapping procedures provided estimates of 84.93, 0.21 and 0.86 for 2011, 81.12, 0.203, 0.04 for 2012 and 80.11, 0.23 and 1.15 for 2013, respectively (Table 6, Figure 12). The first hypothesis, that annual variation in von Bertalanffy growth parameters exists among catch year data, was tested using Kimura's[42] likelihood method and visual inspection of bootstrapped values. The resulting p values indicated that we should reject this hypothesis and, therefore, we failed to reject the first null hypothesis (Table 7-9). Because we detected no annual variation, all data were combined and one von Bertalanffy growth equation was determined for the complete set (Figure 13).

The von Bertalanffy equation modeled for all fish was: $FL = 82.8(1\text{-}e^{-0.204(t-0.43)})$ (Table 6, Figure 13). Bootstrap 2.5% and 97.5% confidence estimates were 80.13 and 86.14, 0.17 and 0.23, and -0.007 and 0.81, respectively (Table 10). Males and females were also modeled separately (Table 6, Figure 14). The L_{∞} was significantly different ($p = 0.013$, $\alpha = 0.05$) between the two however the K and t_0 were not (Table 11). Nonlinear regression models of total weight - fork length relationships estimated for each catch year were: 2011: $\textit{Total Weight} = 1.08e\text{-}05FL^{3.12}$, 2012: $\textit{Total Weight} = 1.70e\text{-}05FL^{2.99}$, 2013: $\textit{Total Weight} = 9.73e\text{-}05FL^{2.56}$ (Figure 15, Table 12). Bootstrap resampling showed no annual variation in parameters (Figure 16). Therefore, a fork length-total weight relationship was estimated from the complete data set as: $\textit{Total Weight} = 1.85e\text{-}05L^{2.97}$(Table 12). Fork length – total weight regression models were also estimated for each sex where Female $\textit{Total Weight} = 1.96e\text{-}05FL^{2.96}$ and Male $\textit{Total Weight} = 1.55e\text{-}05FL^{3.02}$ (Figure 17, Table 12). Bootstrap resampling showed no variation in *a* and *b* parameters by (Figure 18).

Model Selection with Environmental Covariates

A total of 189 otoliths were selected for increment width analysis; 74 from sampling in 2011, 88 from 2012 and 27 from 2013. A total of 175 of them were from the northern Gulf of Mexico and 15 of them were from the WFS. A total of 619 increment width measurements were made from those collected in the northern Gulf of Mexico and 59 were made from those collected on the WFS (Figure 19, Table 2). The 74 otoliths from 2011 ranged in age from 3-7, the 88 otoliths from 2012 ranged from 3-8 and the 28 from 2013 ranged in age from 4-8. These otoliths represented a subset of those used for the age and growth analysis and were selected based on the clarity of their annuli banding patterns along the measurement axis.

Following measurement procedure described in Figure 3, mean values of the third increment width were obtained for Red snapper Years of Formation (RSYoF) 2006-2011. Mean values of the fourth increment width were obtained for RSYoF 2007-2012. Mean values of the fifth increment were obtained for RSYoF 2008-2012. Mean values of the sixth were obtained for RSYoF 2009-2012 and mean values from the seventh increment were obtained from 2010-2012 (Table 13). Most of the increment width measurements (27%) originated from width measurements made on increments formed in 2010. One quarter (25%) of width measurements were from increments formed in 2009, followed by 18% from increments formed in 2008, 16% from increments formed in 2011 and a combined 14% from increments formed in 2006, 2007 and 2012 (Table 14).

A likelihood ratio test indicated that a linear mixed effects model with fish identification number included as a random intercept was the best model $L = 140.6112$ ($df = 10$, $p < 0.0001$). An ANOVA comparing the full model to five reduced models to test the second hypothesis indicated that two variables proved to be significant in explaining the observed variation. The reduced model with the zero-centered U wind variable had a significant p value when compared to the full model ($p < 0.0001$, $\alpha = 0.05$) as well as Mississippi River discharge ($p < 0.0001$) (Table 15, 16).

Forward-difference contrast-coding was used to test the third hypothesis that there is significant variation in increment widths-at-age among years. The contrasting scheme was applied to the data presented in Figure 20. There was a significant decline (13%) in increment width of the third increment between RSYoF 2007 and 2008 ($p < 0.0001$), and a significant increase (10%) between 2009-2010 ($p = 0.0242$, $\alpha = 0.05$)(Table 17). Reverse helmert coding identified that there was no significant difference ($p = 0.2919$, $\alpha = 0.05$) in the mean of third increments, which had formed in 2010 to the mean of all those third increments that had formed in years previous (2006-2009) (Table 18). There were also significant declines in the fourth and fifth increment widths in RSYoF 2009 and 2010 (13%, $p < 0.0001$, 15%, $p < 0.0001$), respectively, as well as the sixth increment width which not only had a significant decline from 2009 to 2010 (22%, $p = 0.0002$) but also from 2011 to 2012 (14%, $p = 0.0252$)(Table 19,21,23). Reverse helmert results indicated a significant difference between the mean value of fourth increments formed in 2010 to all fourth increments formed in years previous (2007-2009) ($p < 0.0001$) (Table 20). Similarly, the mean value of fifth and sixth increments formed in 2010 are significantly different than all fifth and sixth increments formed in years previous (2008-2009) ($p < 0.0001$, $p = 0.0001$) (Table 22, 24). The results of model validation show that the linear mixed effects model appropriately modeled the observed variation and reduced residuals (Figure 21).

Back-Calculated Length and Weight Estimates

Back-calculated length estimates were obtained from the otolith increment measurements. Likelihood testing indicated that the linear mixed effects model with the random intercept (fish identification number) was best, L= 1127.478 (df = 10, p < 0.0001), at modeling the variation in back-calculated length. Forward difference contrast-coding was applied to the data summarized in Figure 22. Significant differences in back-calculated fork length (BCFL) at age two+, which corresponds to the to third increment (Figure 3), occurred between years 2006 and 2007 (p = 0.0250) and between 2008 and 2009 (p = 0.0069)(Table 26). Significant differences also occurred at age three+ between years 2009 and 2010 (p = 0.0003) and 2011 and 2012 (p = 0.0197), at age four+ between 2008 and 2009 (p = 0.0247), 2010 and 2011 (p = 0.0037), and at five+ between 2010 and 2011 (p = 0.0376) (Figure 22, Table 27-29).

Back-calculated weight estimates were obtained by applying the previously obtained *a* and *b* values to the back-calculated fork length measurements. As with the previous models, likelihood testing indicated that the linear mixed effects model with the random intercept (fish identification number) was best: L= 1133.364 (df = 10, p < 0.0001). Forward difference contrast-coding and reverse helmert coding were applied to these data as well (Figure 23). A 17% increase and 12% decrease in weight occurred between years 2006-2007 and 2008-2009 for Red snapper age two+ (p = 0.0248, 0.0121) (Table 31), a 16% decrease in weight occurred between years 2009-2010 for age three+ (p = 0.0006) (Table 33), a 17% increase, 9% decrease, 15% decrease in weight occurred between years 2008-2009, 2009-2010 and 2010-2011, respectively, for age four+ (p = 0.0176, 0.0456, 0.0045) (Table 35) and an 11% decrease in weight occurred between years 2010-2011 for age five+ (p = 0.0265) (Table 37). Reverse helmert contrast-coding results indicate that there is a significant difference in the mean back-calculated weight at age two+ in 2011 compared to the mean value of back-calculated length at age two+ in all years previous (2006-2010) ($p = 0.0031$) (Table 32). However, there was no significant difference between the mean back-calculated weight at age two+ in 2010 and the mean of all previous years (2006-2009) ($p = 0.1427$) (Table 32). Also, significant differences in weight at age three+ existed between 2010 and mean values of age three+ occurring in all years previous (2007-2009) ($p = 0.0007$) as well as 2012 and all previous years (2007-2011) ($p = 0.0056$) (Table 34). Significant differences existed between mean values of back-calculated weight at age four+ in years 2011 and all previous (2008-2010) ($p = 0.0013$) however not between 2010 and all previous (2008-2009) (Table 36). Finally, significant differences existed between mean values of back-calculated weight at age five+ in years 2012 and all previous (2009-2011) ($p = 0.046$) (Table 38).

Tables and Figures

Table 2. Numbers of Red snapper otoliths collected in the northern Gulf of Mexico and West Florida Shelf during 2011-2013 used for age, growth and increment width analyses.

Region	Year	Used for Age/Length Analysis	Used for Length/Weight Analysis	Female	Male	Used for Increment Width Analysis	Number of Total Increment Measurements Made by Region
Northern Gulf of Mexico	2011	254	237	136	117	68	619
	2012	348	349	185	164	81	
	2013	105	103	42	59	25	
West Florida Shelf	2011	73	71	24	45	6	59
	2012	39	39	29	10	7	
	2013	3	3	1	2	2	
Σ		822	802	415	396	190	678

Table 3. Summary of age frequency data of Gulf of Mexico Red snapper collected in 2011-2013.

Year	Mean Age (yrs)	Standard Error	5% CI	95% CI	Range	N
2011	5.76	0.19	5.39	6.14	38	327
2012	6.43	0.13	6.18	6.68	21	387
2013	6.95	0.15	6.65	7.25	11	108

Table 4. Summary of fork length frequency data of Gulf of Mexico Red snapper collected in 2011-2013.

Year	Median FL (cm)	Standard Error	5% CI	95% CI	Range	N
2011	56.57	0.59	55.41	57.73	60	325
2012	59.60	0.43	58.75	60.45	58	389
2013	61.71	0.87	60.02	63.41	51	108

Table 5. Mean fork length at age of Red snapper collected in the Gulf of Mexico during 2011-2013 (n=799).

Age	Mean FL (cm)	Range	Standard Error	N
2	32.67	7	1.15	6
3	41.68	20	0.94	25
4	45.88	26	0.59	77
5	53.92	32	0.45	201
6	60.43	41	0.37	235
7	64.23	37	0.46	164
8	66.34	27	0.57	76
9	70.07	18	1.24	15

Table 6. Estimated parameters from modeled von Bertalanffy growth functions of Gulf of Mexico Red snapper collected in 2011(n = 327), 2012(n = 387) and 2013(n = 108). The data were also combined to estimate one complete growth curve (n = 822) and separated by sex: female (n = 415) and male(n = 396) data sets.

Grouping	Parameter	Estimate	Standard Error	t-value	Pr(>$\lvert t \rvert$)
2011	L_∞	84.933	2.485	34.169	<2e-16***
	K	0.216	0.020	10.780	<2e-16***
	t_0	0.868	0.246	3.522	0.000491*
2012	L_∞	81.125	2.173	37.323	<2e-16***
	K	0.203	0.020	9.710	<2e-16***
	t_0	0.040	0.347	0.117	0.907
2013	L_∞	80.116	7.132	11.233	<2e-16***
	K	0.234	0.087	2.667	0.00888**
	t_0	1.151	1.124	1.024	0.308
Female	L_∞	86.459	2.254	38.354	<2e-16***
	K	0.183	0.015	11.775	<2e-16***
	t_0	0.255	0.265	0.962	0.337
Male	L_∞	78.426	2.081	37.676	<2e-16***
	K	0.238	0.024	9.581	<2e-16***
	t_0	0.691	0.304	2.267	0.0239*
All	L_∞	82.913	1.599	51.841	<2e-16***
	K	0.204	0.013	14.789	<2e-16***
	t_0	0.433	0.203	2.125	0.0339*

Note: *p<0.1; **p<0.05; ***p<0.01

Table 7. Kimura likelihood ratio tests comparing the parameter estimates of von Bertalanffy growth curves estimated from Gulf of Mexico Red snapper collected in 2011 and 2012.

Tests	Hypothesis	Chisq	Df	p
H_0 vs. H_1	$L_{\infty1} = L_{\infty2}$	1.29	1	0.26
H_0 vs. H_2	$K_1 = K_2$	0.20	1	0.66
H_0 vs. H_3	$t_{01} = t_{02}$	3.69	1	0.06
H_0 vs. H_4	$L_{\infty1} = L_{\infty2}, K_1 = K_2, t_{01} = t_{02}$	12.08	3	0.01

Table 8. Kimura likelihood ratio tests comparing the parameter estimates of von Bertalanffy growth curves estimated from Gulf of Mexico Red snapper collected in 2012 and 2013.

Tests	Hypothesis	Chisq	Df	p
H_0 vs. H_1	$L_{\infty 1} = L_{\infty 2}$	0.02	1	0.89
H_0 vs. H_2	$K_1 = K_2$	0.18	1	0.67
H_0 vs. H_3	$t_{01} = t_{02}$	0.98	1	0.32
H_0 vs. H_4	$L_{\infty 1} = L_{\infty 2}$, $K_1 = K_2$, $t_{01} = t_{02}$	8.63	3	0.04

Table 9. Kimura likelihood ratio tests comparing the parameter estimates of von Bertalanffy growth curves estimated from Gulf of Mexico Red snapper collected in 2011 and 2013.

Tests	Hypothesis	Chisq	Df	p
H_0 vs. H_1	$L_{\infty 1} = L_{\infty 2}$	0.35	1	0.55
H_0 vs. H_2	$K_1 = K_2$	0.04	1	0.84
H_0 vs. H_3	$t_{01} = t_{02}$	0.06	1	0.81
H_0 vs. H_4	$L_{\infty 1} = L_{\infty 2}$, $K_1 = K_2$, $t_{01} = t_{02}$	12.52	3	0.01

Table 10. Bootstrap parameter estimates of von Bertalanffy growth curves estimated for Gulf of Mexico Red snapper collected in 2011-2013.

Parameter	Grouping	Median	2.5%	97.5%
L_∞	2011	85.0	80.2	89.5
	2012	81.2	77.1	85.4
	2013	79.9	69.8	107.3
	Female	86.4	81.9	90.6
	Male	78.4	74.5	82.7
	All	82.8	80.0	85.9
K	2011	0.21	0.17	0.26
	2012	0.20	0.16	0.24
	2013	0.23	0.08	0.46
	Female	0.18	0.15	0.21
	Male	0.23	0.19	0.29
	All	0.20	0.17	0.23
t_0	2011	0.87	0.26	1.32
	2012	0.02	-0.77	0.64
	2013	1.25	-2.35	2.77
	Female	0.25	-0.30	0.75
	Male	0.70	0.009	1.24
	All	0.42	0.002	0.79

Table 11. Kimura likelihood ratio tests comparing the parameter estimates of von Bertalanffy growth curves estimated from male and female Gulf of Mexico Red snapper collected in 2011-2013.

Tests	Hypothesis	Chisq	Df	p
H_0 vs. H_1	$L_{\infty 1} = L_{\infty 2}$	6.20	1	**0.013**
H_0 vs. H_2	$K_1 = K_2$	3.29	1	0.07
H_0 vs. H_3	$t_{01} = t_{02}$	0.88	1	0.34
H_0 vs. H_4	$L_{\infty 1} = L_{\infty 2}$, $K_1 = K_2$, $t_{01} = t_{02}$	7.75	3	0.05

Table 12. Estimated parameters for total weight - fork length regression models for Gulf of Mexico Red snapper collected in 2011 (n = 308), 2012 (n = 388), and 2013 (n =105). Total weight-fork length and somatic weight-fork length regression models were also estimated from the complete set of data (2011-2013).

Grouping	Parameter	Estimate	Standard Error	t value	Pr (>|*t*|)
2011	*a*	1.08e-05	2.07e-06	5.21	3.29e-07***
	b	3.12	4.56e-02	68.36	<2e-16***
2012	*a*	1.70e-05	2.49e-06	6.80	3.91e-07***
	b	2.99	3.50e-02	85.41	<2e-16***
2013	*a*	9.73e-05	4.01e-05	2.426	0.017*
	b	2.56	9.79e-02	26.22	<2e-16***
Female	*a*	1.96e-05	3.11e-06	6.31	7.21e-10***
	b	2.96	3.76e-02	78.75	<2e-16***
Male	*a*	1.55e-05	3.32e-06	4.69	3.77e-06***
	b	3.02	5.10e-02	59.25	<2e-16***
All-TW	*a*	1.85e-05	2.36e-06	7.85	1.28e-14***
	b	2.97	3.03e-02	98.152	<2e-16***
All-SW	*a*	1.55e-05	2.99e-06	5.192	3.66e-07***
	b	3.01	4.55e-02	66.05	<2e-16***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 13. Sample numbers of Red snapper otoliths used for increment width analysis. Age at catch, timing of annual growth increments and total number of increment width measurements made are also included. Samples were collected in the northern Gulf ofMexico and West Florida Shelf in 2011-2013.

Age at Catch	Catch Year	N	Annual Growth Increment Number					Total Number of Increment Measurements Taken
			3	4	5	6	7	
3.5	2011	5	2010					5
	2012	3	2011					3
4.5	2011	12	2009	2010				24
	2012	10	2010	2011				20
	2013	3	2011	2012				6
5.5	2011	28	2008	2009	2010			84
	2012	21	2009	2010	2011			63
	2013	2	2010	2011	2012			6
6.5	2011	15	2007	2008	2009	2010		60
	2012	33	2008	2009	2010	2011		132
	2013	10	2009	2010	2011	2012		40
7.5	2011	14	2006	2007	2008	2009	2010	70
	2012	16	2007	2008	2009	2010	2011	80
	2013	10	2008	2009	2010	2011	2012	50
8.5	2012	5	2006	2007	2008	2009	2010	25
	2013	1	2007	2008	2009	2010	2011	5
9.5	2013	1	2006	2007	2008	2009	2010	5
Σ		189						678

Table 14. Sample sizes for age specific, otolith annual growth increment width measurements from Red snapper otoliths collected in 2011-2013. Year represents "Year of Formation" which was measured from June to June of the following year.

Year	3	4	5	6	7	∑
2006	20					20
2007	32	20				52
2008	71	32	20			123
2009	43	71	32	20		166
2010	17	43	71	32	20	183
2011	6	12	31	43	17	109
2012		3	2	10	10	25

Table 15. Significance of five environmental terms – Mississippi River discharge, zonal winds (U winds), meridional winds (V winds), sea level anomaly (MSLA) and wind stress curl- in modeling variation in Gulf of Mexico Red snapper age specific, otolith annual growth increment widths. These values were determined from a variable elimination process and analysis of variance.

Model	df	AIC	BIC	logLik	Test	L Ratio	p-value
1. Full Model	10	-3099.50	-3054.89	1559.75			
2. River Discharge	9	3087.71	3047.55	1552.85	1 vs 2	22.78	**<0.0001**
3. U winds	9	3076.87	3036.72	1547.43	1 vs 3	33.61	**<0.0001**
4. V winds	9	3110.31	-3070.16	1564.15	1 vs 4	0.17	0.6727
5. MSLA	9	3108.98	-3068.83	1563.49	1 vs 5	1.50	0.2193
6. Wind Stress Curl	9	3110.46	3070.30	1564.23	1 vs 6	0.03	0.8624

Table 16. Summary of a linear-mixed-effects model fit with restricted maximum likelihood methods to estimate the significance of zonal winds (U winds) and Mississippi River discharge in modeling variation in Gulf of Mexico Red snapper age-specific, otolith annual growth increment widths.

	Value	Std.Error	DF	t-value	p-value
(Intercept)	8.23	2.30	485	3.57	0.0004
IncNum	-0.017	0.001	485	-14.50	0.0000
Yr.Inc.Form	-0.0036	0.001	485	-3.20	0.0014
U winds	-0.0061	0.001	485	-5.48	0.0000
River Discharge	0.0000	0.000006	485	4.50	0.0000

Table 17. Results from a forward difference contrast-coding scheme to assess the significance between Gulf of Mexico Red snapper mean third annual otolith growth increment widths formed during years 2006-2011.

3rd increment	Value	Std. Error	df	t-value	p-value	Change (%)
2006-2007	-0.010	0.011	183	-0.924	0.3564	
2007-2008	0.037	0.008	183	4.376	**0.0000**	**-13%**
2008-2009	-0.001	0.007	183	-0.146	0.8839	
2009-2010	-0.025	0.011	183	-2.272	**0.0242**	**10%**
2010-2011	-0.018	0.018	183	-0.962	0.3369	

Table 18. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean third annual otolith growth increments formed in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	0.005	0.010	183	0.47	0.2919

Table 19. Results from a forward difference contrast-coding scheme to assess the significance between Gulf of Mexico Red snapper mean fourth annual otolith growth increments formed during years 2007-2012.

4th increment	Value	Std. Error	df	t-value	p-value	Change (%)
2007-2008	0.013	0.010	175	1.31	0.1912	
2008-2009	-0.007	0.007	175	-0.94	0.3450	
2009-2010	0.031	0.007	175	4.41	**0.0000**	**-13%**
2010-2011	-0.018	0.012	175	-1.56	0.1199	
2011-2012	-0.017	0.024	175	-0.72	0.4717	

Table 20. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean fourth annual otolith growth increments formed in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	-0.031	0.006	175	-4.58	**0.0000**

Table 21. Results from a forward difference contrast-coding scheme to assess the significance between Gulf of Mexico Red snapper mean fifth annual otolith growth increments formed during years 2008-2012.

5th increment	Value	Std. Error	df	t-value	p-value	Change (%)
2008-2009	-0.016	0.009	151	-1.70	0.0930	
2009-2010	0.032	0.007	151	4.61	**0.0000**	**-15%**
2010-2011	0.0006	0.007	151	0.09	0.9282	
2011-2012	-0.023	0.024	151	-0.94	0.3455	

Table 22. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean fifth annual otolith growth increments formed in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	-0.024	0.006	151	-3.98	**0.0001**

Table 23. Results from a forward difference contrast-coding scheme to assess the significance between Gulf of Mexico Red snapper mean sixth annual otolith growth increments formed during years 2009-2012.

6th increment	Value	Std. Error	df	t-value	p-value	Change (%)
2009-2010	0.030	0.003	101	3.82	**0.0002**	**-22%**
2010-2011	0.003	0.008	101	0.50	0.6178	
2011-2012	-0.022	0.006	101	2.27	**0.0252**	**-14%**

Table 24. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean sixth annual otolith growth increments formed in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2009 to mean of all subsequent	0.040	0.007	101	5.53	**0.0000**

Table 25. Results from a forward difference contrast-coding scheme to assess the significance between Gulf of Mexico Red snapper mean seventh annual otolith growth increments formed during years 2010-2012.

7th increment	Value	Std. Error	df	t-value	p-value
2010-2011	0.010	0.010	44	1.04	0.3014
2011-2012	-0.000	0.012	44	-0.006	0.9947

Table 26. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated fork length at age two+ between years 2006-2011.

Age 2+	Value	Std. Error	df	t-value	p-value
2006-2007	-2.402	1.062	183	-2.26	**0.025**
2007-2008	0.964	0.793	183	1.21	0.2261
2008-2009	1.969	0.720	183	2.73	**0.0069**
2009-2010	1.336	1.068	183	1.25	0.2124
2010-2011	3.240	1.770	183	1.83	0.0688

Table 27. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated fork length at age three+ between years 2007-2012.

Age 3+	Value	Std. Error	df	t-value	p-value
2007-2008	-2.259	1.241	175	-1.82	0.0705
2008-2009	0.795	0.927	175	0.85	0.3923
2009-2010	3.131	0.841	175	3.72	**0.0003**
2010-2011	0.250	1.421	175	0.17	0.8605
2011-2012	6.615	2.811	175	2.35	**0.0197**

Table 28. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated fork length at age four+ between years 2008-2012.

Age 4+	Value	Std. Error	df	t-value	p-value
2008-2009	-2.967	1.307	151	-2.26	**0.0247**
2009-2010	1.794	0.976	151	1.83	0.0681
2010-2011	2.912	0.987	151	2.94	**0.0037**
2011-2012	-3.723	3.346	151	-1.11	0.2676

Table 29. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated fork length at age five+ between years 2009-2012.

Age 5+	Value	Std. Error	df	t-value	p-value
2009-2010	-2.291	1.321	101	-1.73	0.0859
2010-2011	2.279	1.082	101	2.10	**0.0376**
2011-2012	2.422	1.627	101	1.48	0.1397

Table 30. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated fork length at age six+ between years 2010-2012.

Age 6+	Value	Std. Error	df	t-value	p-value
2010-2011	-0.471	1.752	44	-0.26	0.7891
2011-2012	0.374	2.117	44	0.17	0.8605

Table 31. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age two+ between years 2006-2011.

Age 2+	Value	Std. Error	df	t-value	p-value	Change in Weight (%)
2006-2007	-0.233	0.103	183	-2.26	**0.0248**	**16.96**
2007-2008	0.101	0.077	183	1.30	0.1923	
2008-2009	0.177	0.070	183	2.53	**0.0121**	**-11.77**
2009-2010	0.116	0.103	183	1.12	0.263	
2010-2011	0.259	0.172	183	1.50	0.1329	

Table 32. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age two+ in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	-0.1473693	0.10010294	183	-1.47218	0.1427
2011 to mean of all previous	-0.472	0.157	183	-2.99	**0.0031**

Table 33. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age three+ between years 2007-2012.

Age 3+	Value	Std. Error	df	t-value	p-value	Change in Weight (%)
2007-2008	-0.294	0.155	175	-1.89	0.0595	
2008-2009	0.115	0.115	175	0.99	0.3212	
2009-2010	0.367	0.105	175	3.49	**0.0006**	**-16.19**
2010-2011	0.028	0.177	175	0.16	0.8725	
2011-2012	0.662	0.351	175	1.88	0.0612	

Table 34. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age three+ in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	-0.346	0.100	175	-3.45	**0.0007**
2011 to mean of all previous	-0.2884245	0.1640995	175	-1.75762	0.0806
2012 to mean of all previous	-0.893	0.318	175	-2.80	**0.0056**

Table 35. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age four+ between years 2008-2012.

Age 4+	Value	Std. Error	df	t-value	p-value	Change in Weight (%)
2008-2009	-0.498	0.207	151	-2.40	**0.0176**	**17.19**
2009-2010	0.312	0.154	151	2.01	**0.0456**	**-9.28**
2010-2011	0.451	0.156	151	2.88	**0.0045**	**-14.85**
2011-2012	-0.729	0.530	151	-1.37	0.1712	

Table 36. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red mean back-calculated weight at age four+ in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2010 to mean of all previous	-0.0632707	0.1349538	151	-0.468832	0.6399
2011 to mean of all previous	-0.123	0.037	151	-3.27	**0.0013**

Table 37. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age five+ between years 2009-2012.

Age 5+	Value	Std. Error	df	t-value	p-value	Change in Weight (%)
2009-2010	-0.461	0.251	101	-1.83	0.07	
2010-2011	0.464	0.206	101	2.25	**0.0265**	**-11.13**
2011-2012	0.439	0.310	101	1.41	0.1594	

Table 38. Results from a reverse helmert contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age five+ in years before and after 2010.

Comparisons	Value	Std. Error	df	t-value	p-value
2011 to mean of all previous	-0.233958	0.1843886	101	-1.26883	0.2074
2012 to mean of all previous	-0.595	0.295	101	-2.01	**0.0462**

Table 39. Results from a forward difference contrast-coding scheme to assess the significance of Gulf of Mexico Red snapper mean back-calculated weight at age six+ in years 2006-2011.

Age 6+	Value	Std. Error	df	t-value	p-value
2010-2011	-0.136	0.380	44	-0.35	0.7215
2011-2012	0.104	0.460	44	0.22	0.822

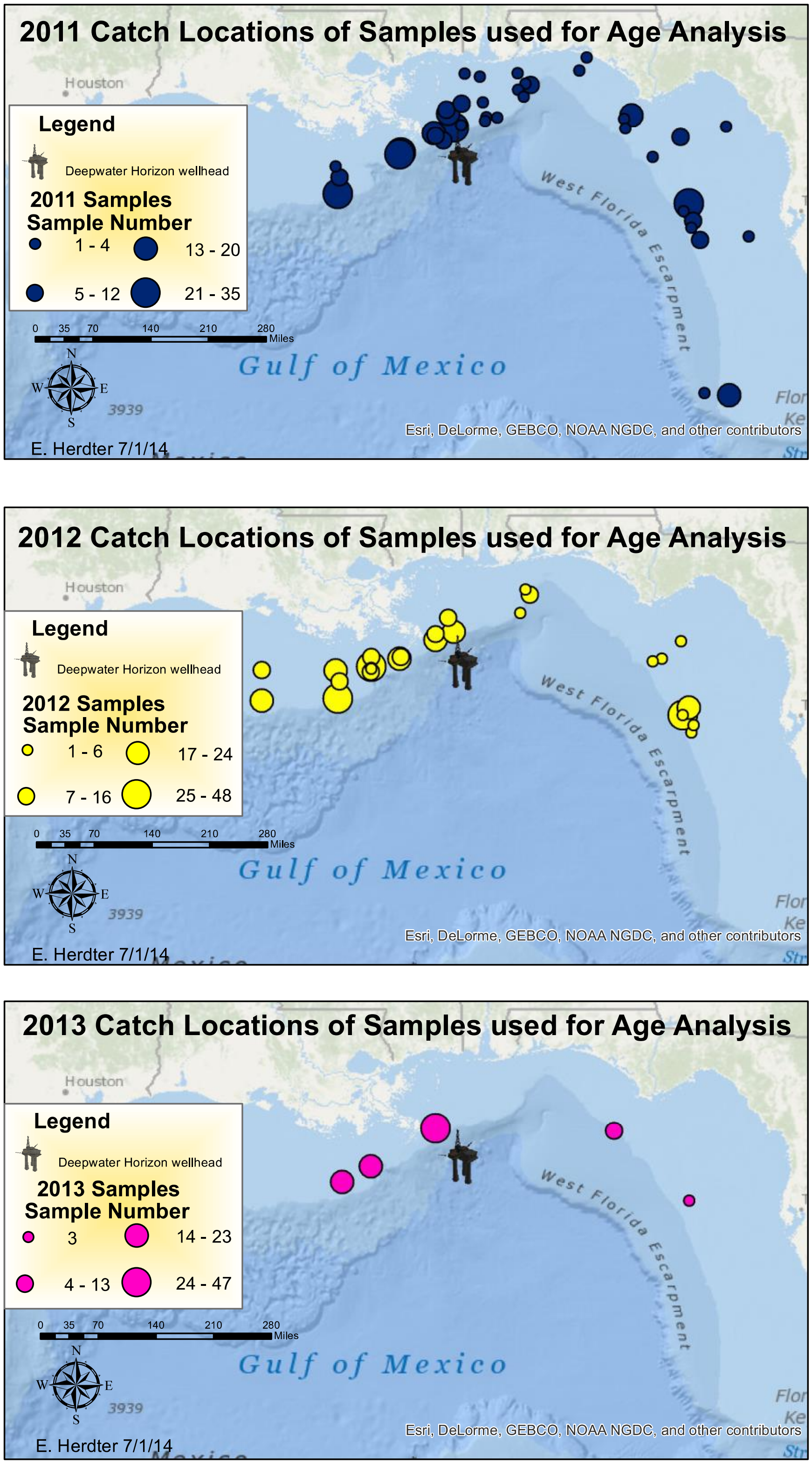

Figure 8. Catch locations of Red snapper otoliths collected in the northern Gulf of Mexico and West Florida Shelf during 2011-2013.

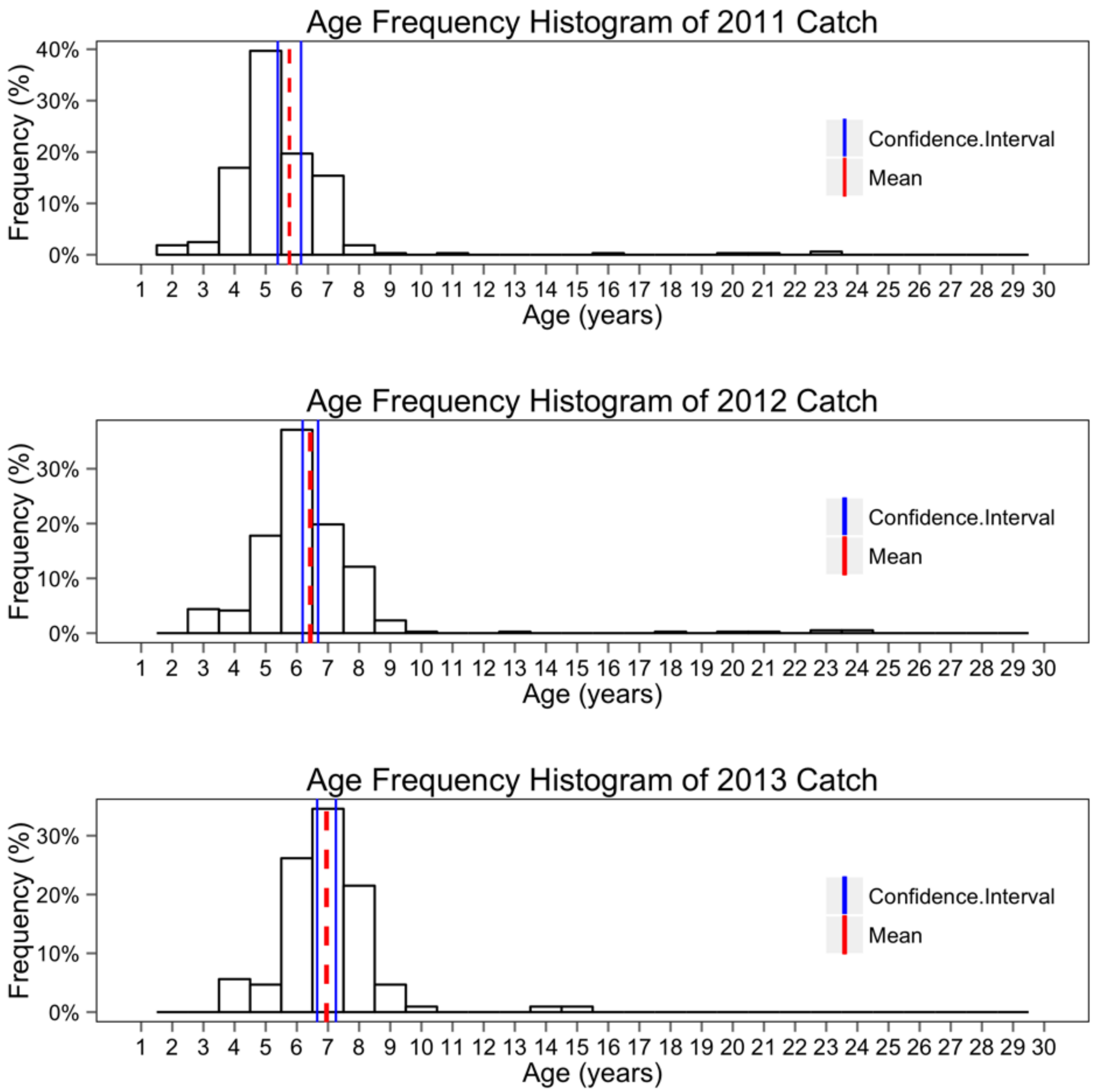

Figure 9. Age frequency histograms of Gulf of Mexico Red snapper collected in 2011 (n = 327), 2012 (n = 387) and 2013 (n = 108). Mean age and upper 95% and lower 5% confidence intervals are presented as red dashes and blue lines, respectively.

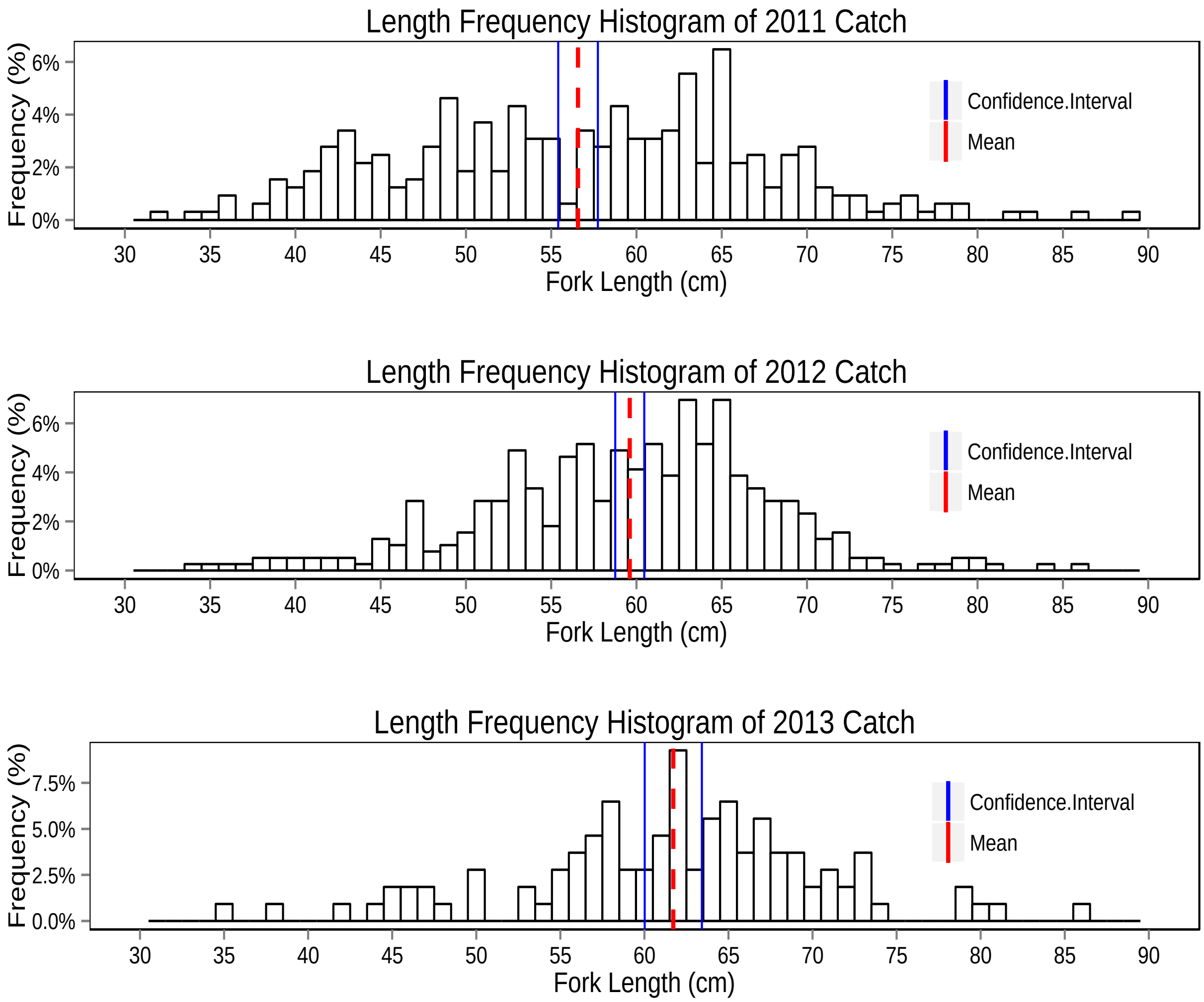

Figure 10. Fork length frequency histograms of Gulf of Mexico Red snapper collected in 2011 (n = 325), 2012 (n = 389) and 2013 (n = 108). Mean age and upper 95% and lower 5% confidence intervals are presented as red dashes and blue lines, respectively.

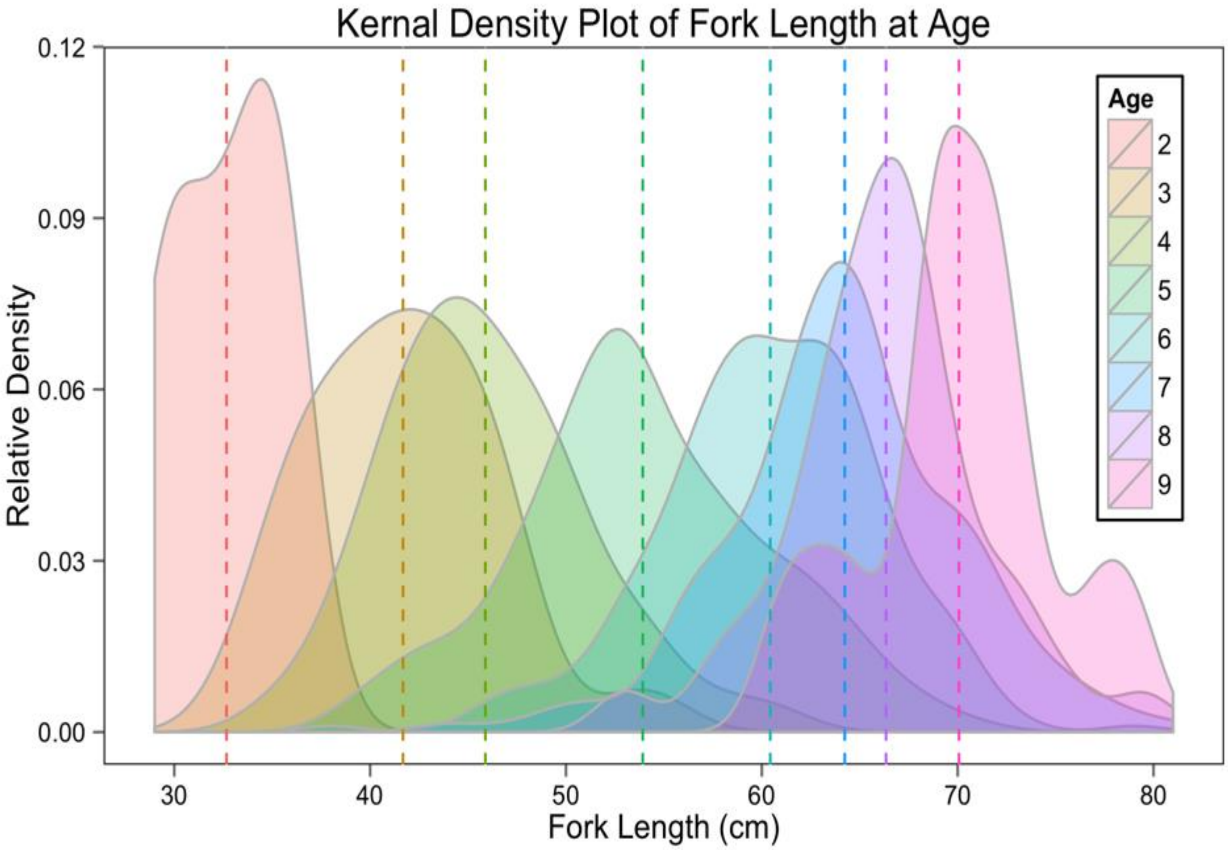

Figure 11. Kernal density plot of fork length-at-age from Gulf of Mexico Red snapper collected during 2011-2013 (n = 799). Dashed lines correspond to mean fork length-at-age.

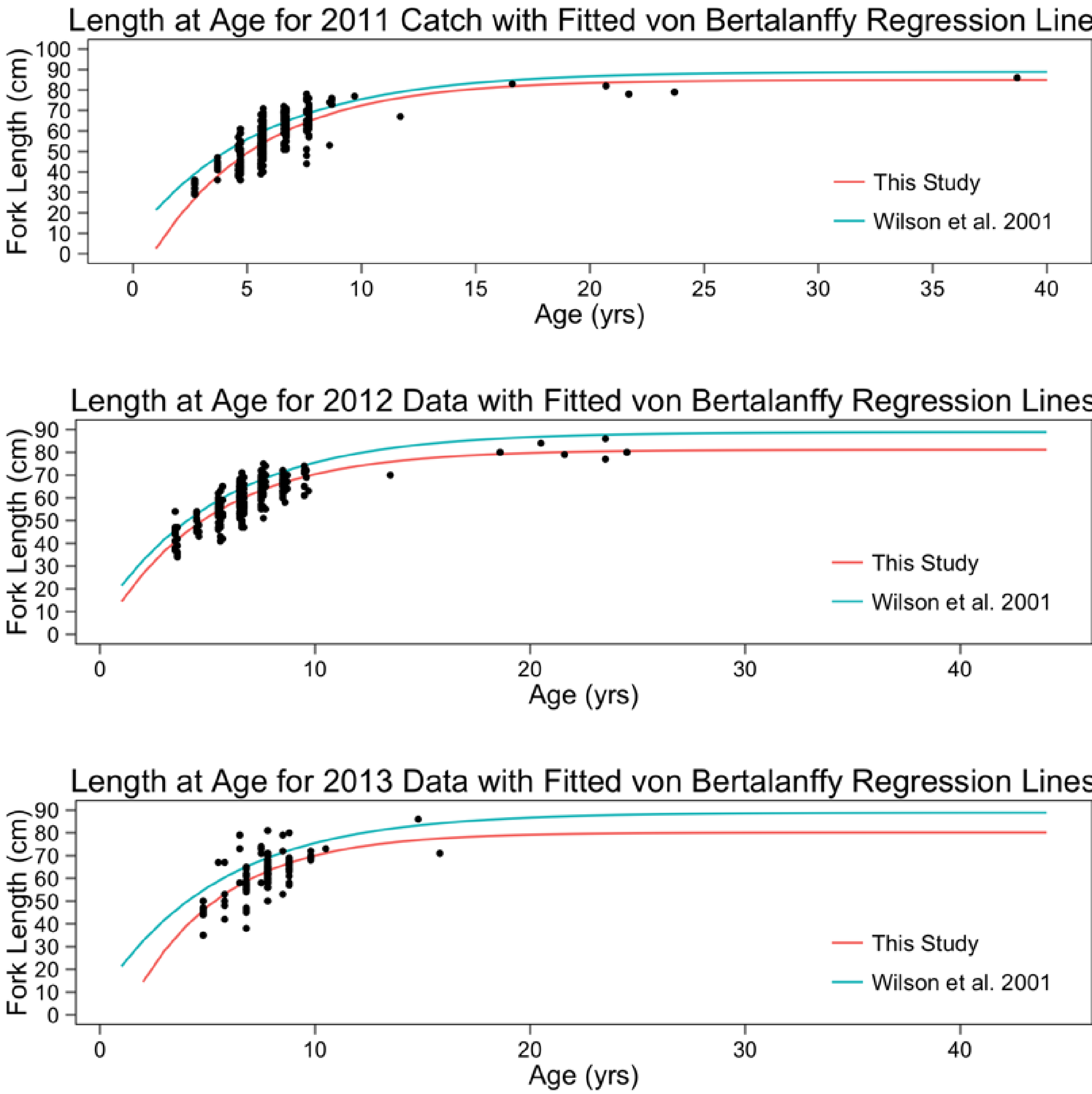

Figure 12. Estimated von Bertalanffy growth curves for Gulf of Mexico Red snapper collected in 2011 (n= 327), 2012 (n= 387) and 2013 (n =108). The plotted red line represents the von Bertalanffy growth function fitted to the raw data presented as black circles. The plotted blue line is a Red snapper von Bertalanffy growth function estimated by Wilson and Nieland in 2001, which is provided on the plot for comparison. Because the authors estimated L_∞ using total length (TL), their fitted total length data set was adjusted to fork length (FL) using the relationship $TL=1.058FL + 0.386$[54]. This conversion was necessary in order to display it on this plot.

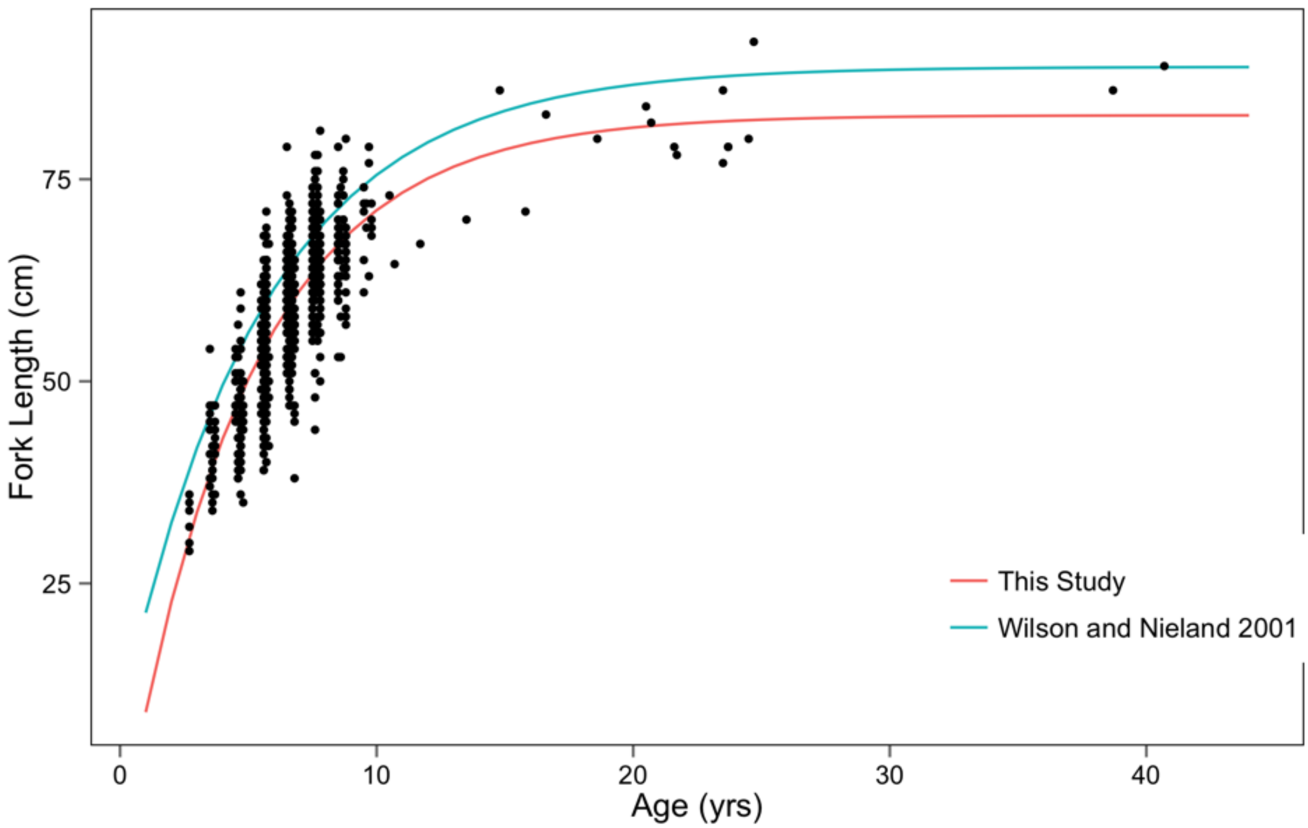

Figure 13. Estimated von Bertalanffy growth curve for Gulf of Mexico Red snapper collected in 2011-2013 (n=822). The plotted red line represents the von Bertalanffy growth function fitted to the raw data presented as black circles. The plotted blue line is a Red snapper von Bertalanffy growth curve estimated by Wilson and Nieland in 2001, which is provided on the plot for comparison. Because the authors estimated L_∞ using total length (TL), their fitted total length data set was adjusted to fork length (FL) using the relationship $TL=1.058FL + 0.386$[54]. This conversion was necessary in order to display it on this plot.

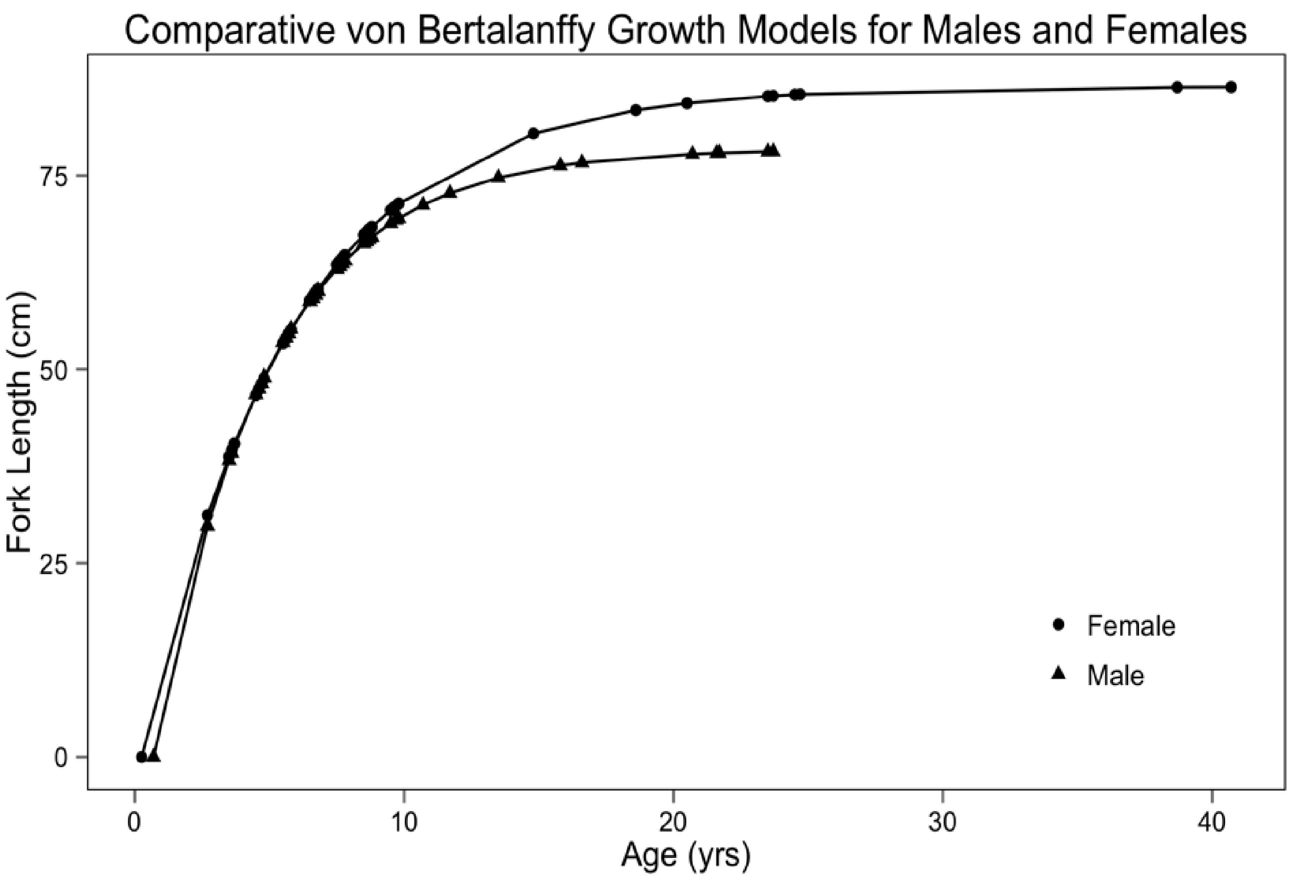

Figure 14. Von Bertalanffy growth curves estimated for male (n = 396) and female (n = 415) Gulf of Mexico Red snapper collected in 2011-2013.

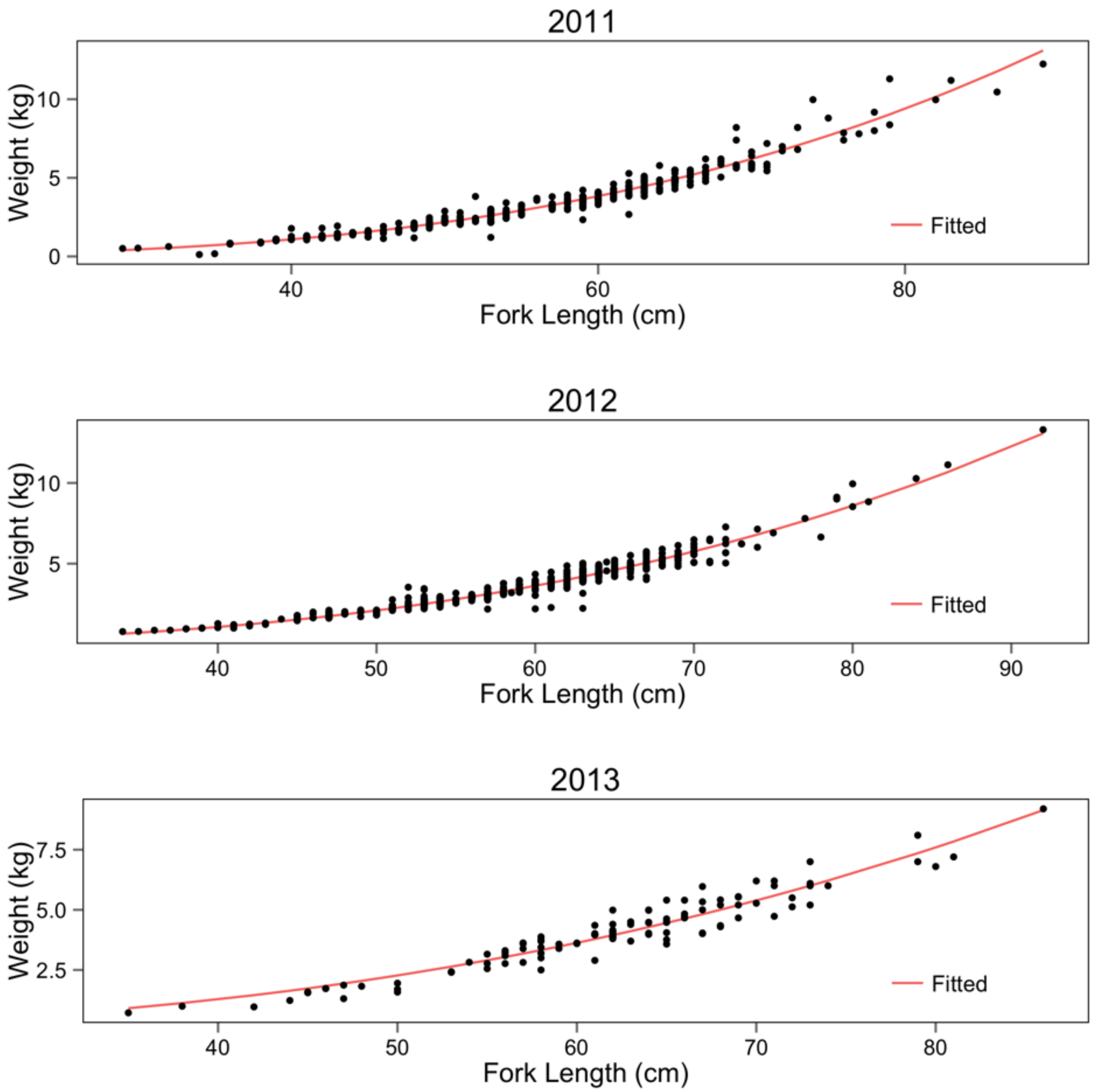

Figure 15. Total weight – fork length regression models estimated for Gulf of Mexico Red snapper collected in 2011 (n = 308), 2012 (n = 388), and 2013 (n =105).

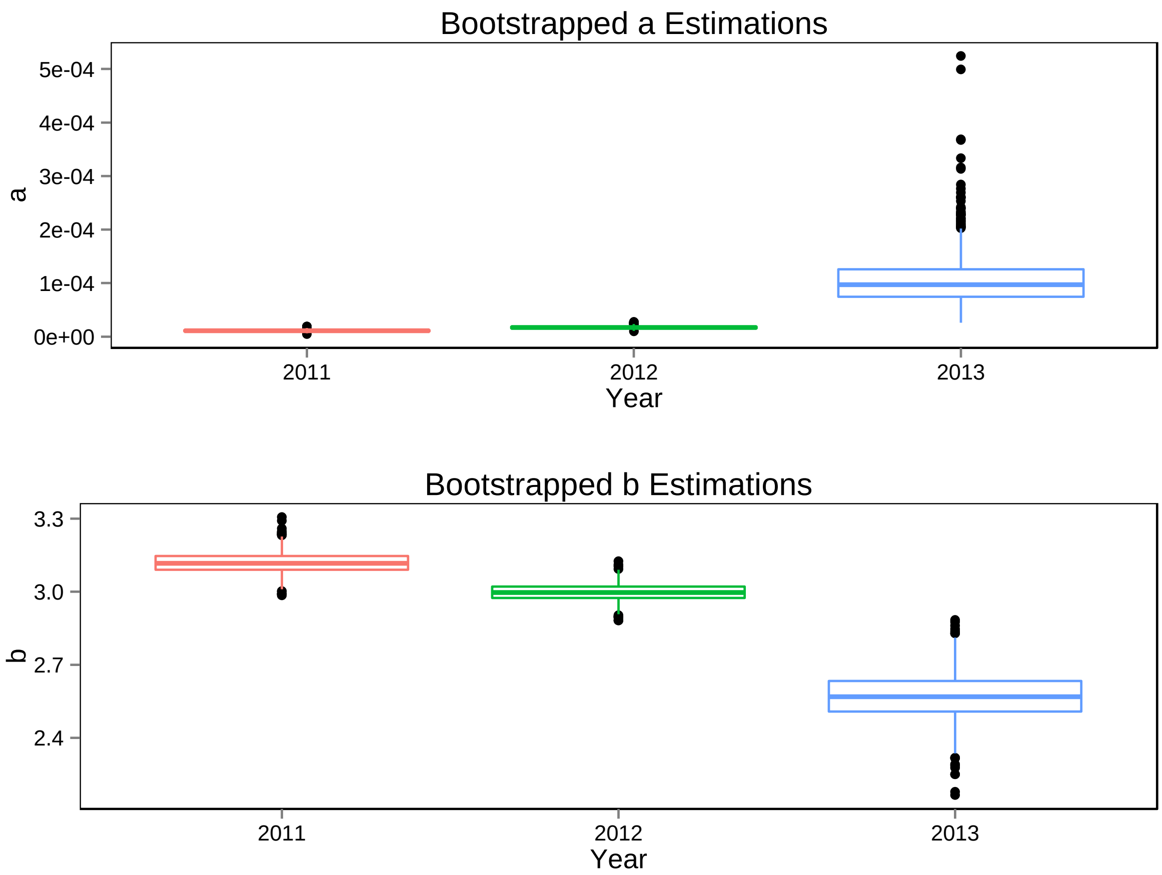

Figure 16. Bootstrap estimates of the parameters *a* and *b* from total weight – fork length regressions from Gulf of Mexico Red snapper collected in 2011 - 2013.

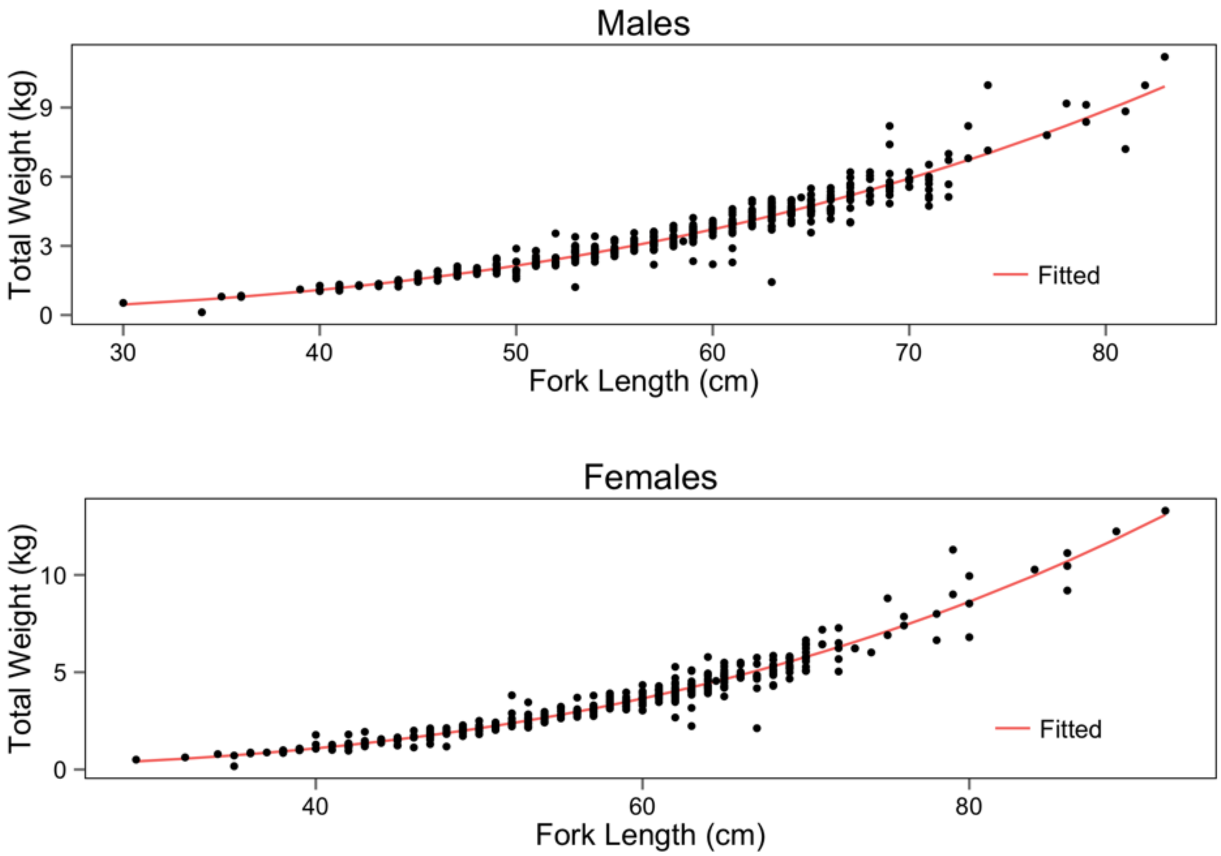

Figure 17. Total weight - fork length regression estimates from male (n = 383) and female (n = 399) Gulf of Mexico Red snapper collected in 2011-2013.

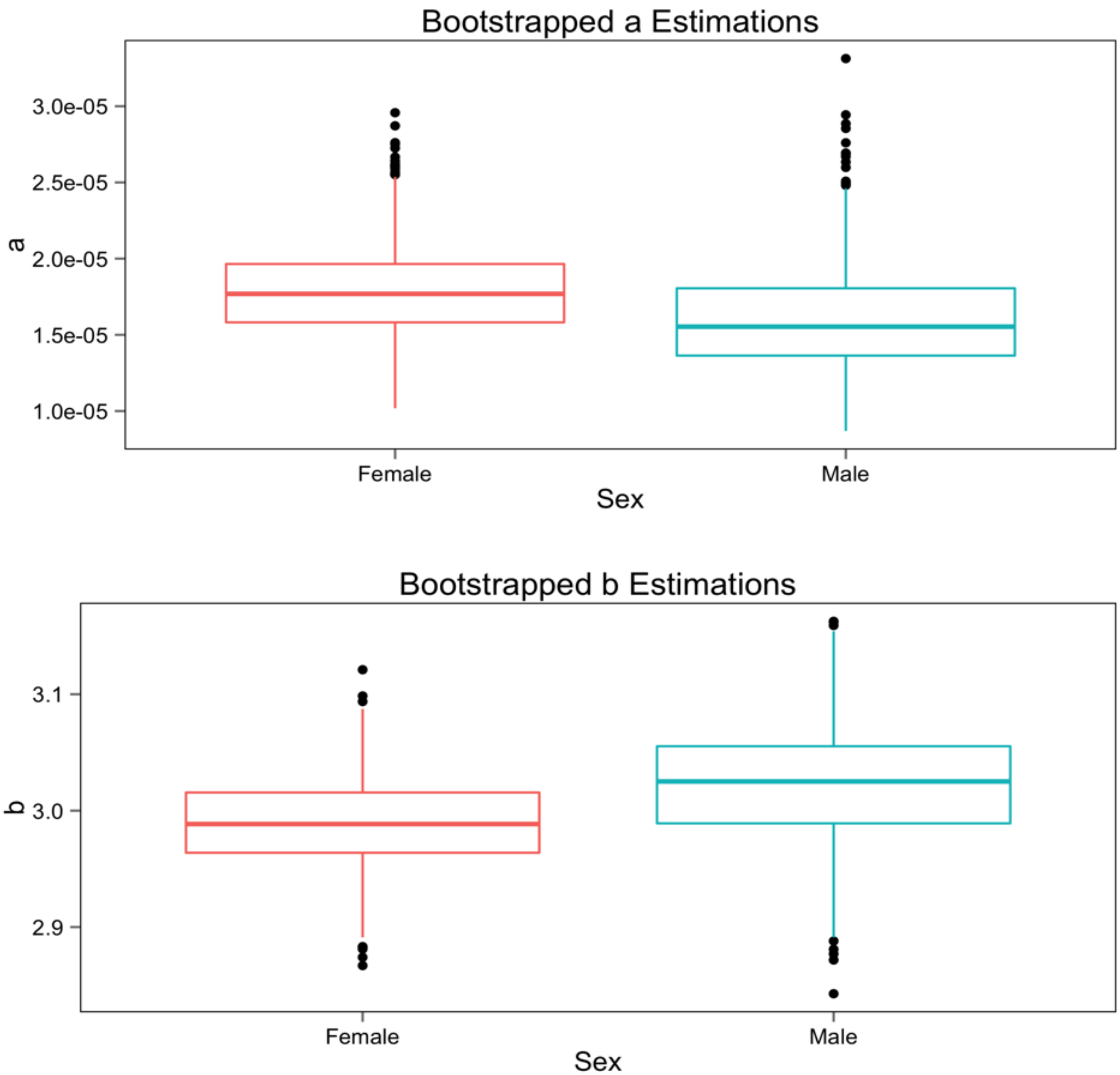

Figure 18. Bootstrap estimates of the parameters *a* and *b* from total weight – fork length regressions from male and female Gulf of Mexico Red snapper collected in 2011-2013.

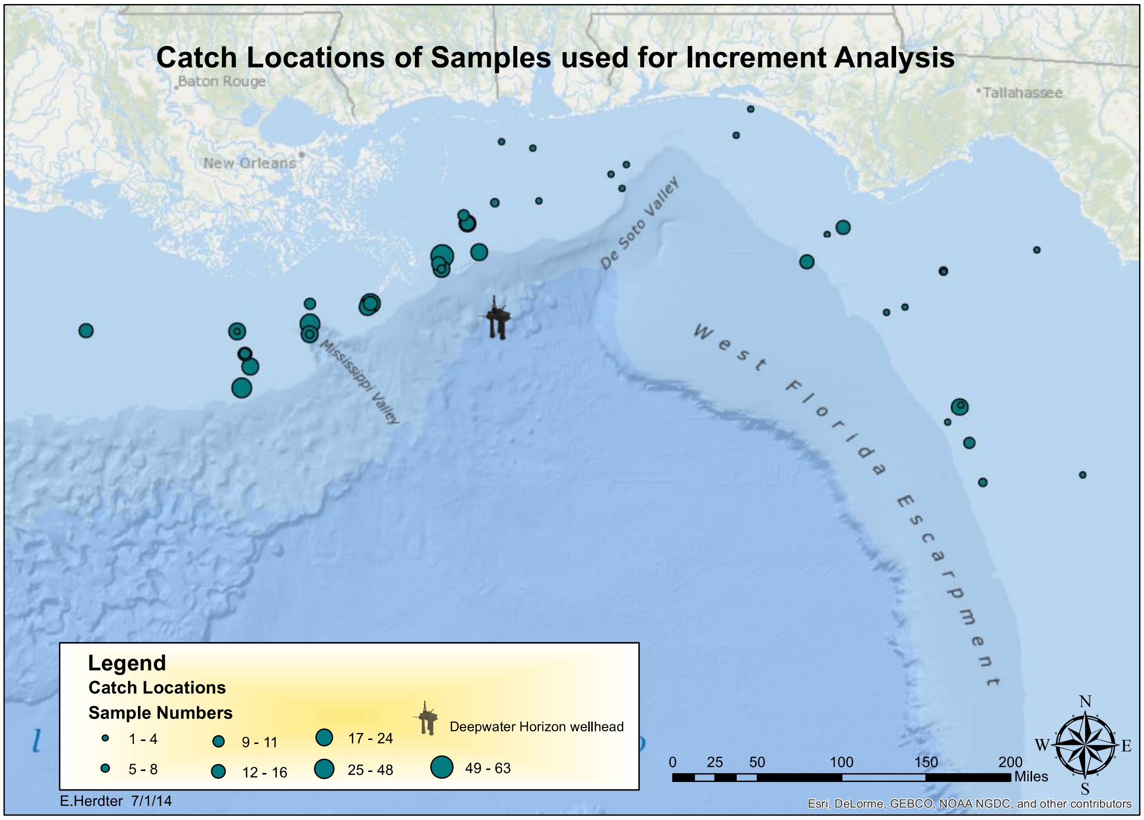

Figure 19. Catch locations of Red snapper otoliths used for increment width analysis. The size of the turquoise circle indicates the number of increment width measurements made on otoliths collected from the sampling sites in 2011-2013.

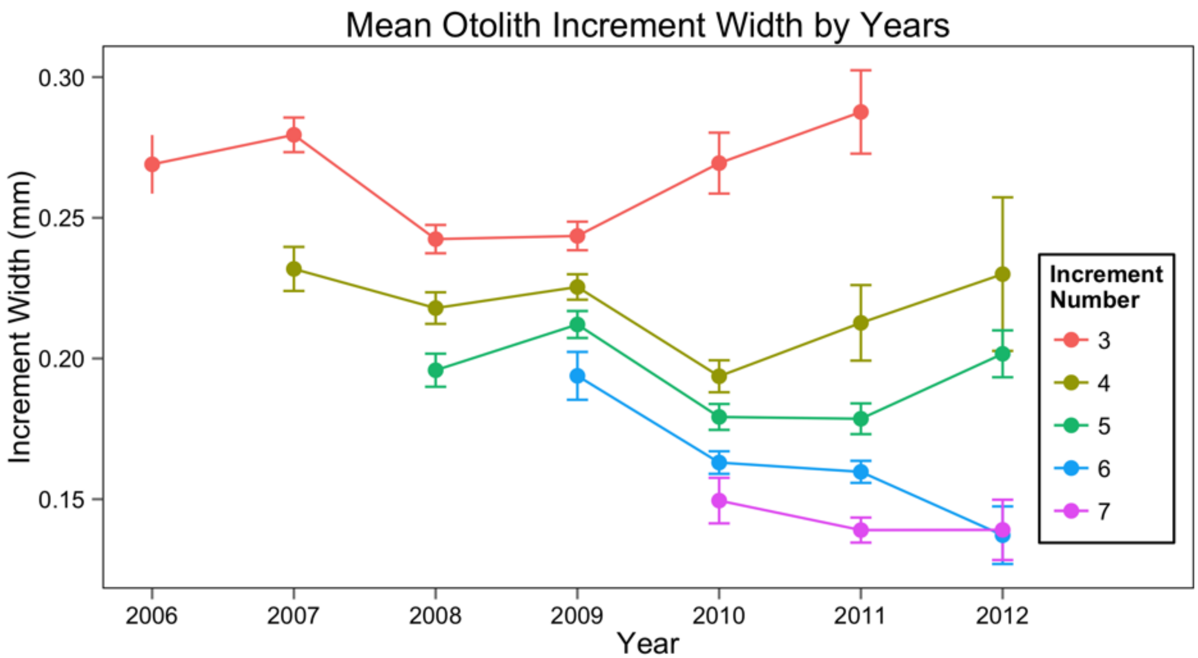

Figure 20. Mean annual otolith growth increment widths ± SE observed during years 2006-2012 for the Gulf of Mexico Red snapper third – seventh annual growth increments. Year is measured from June to June of the following year ("RSY").

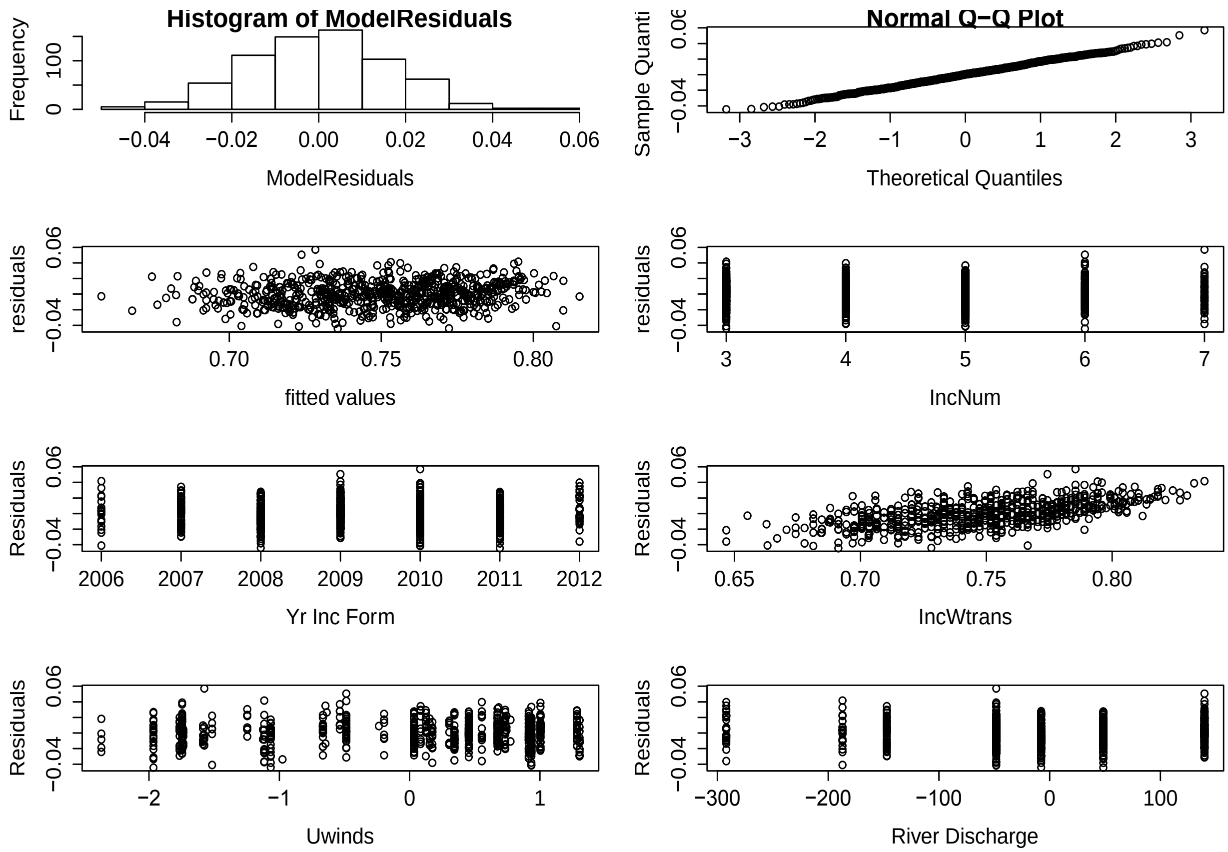

Figure 21. Model validation graphs for the random intercept linear-mixed-effects model with plots showing residual values fitted against variables Yr Inc Form (Year of Increment Formation), IncWtrans (transformed Increment Width), Uwinds (U winds) and Mississippi River Discharge.

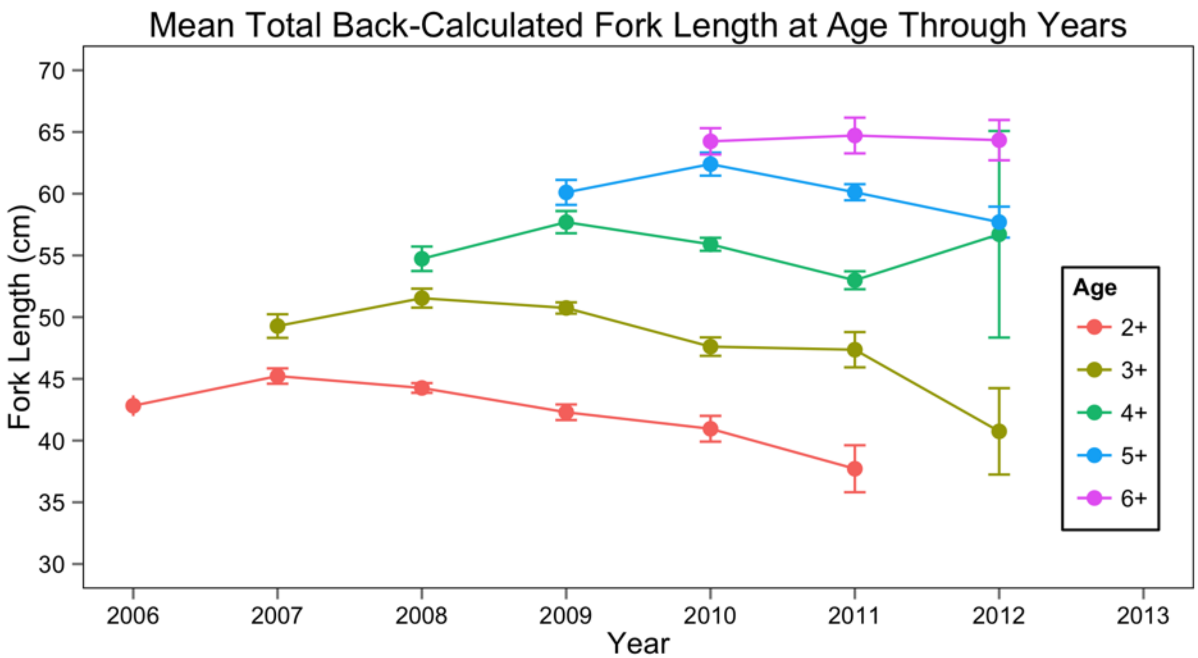

Figure 22. Mean back-calculated fork length ± SE estimated during years 2006-2012 for Gulf of Mexico Red snapper ages two+ to six+; ages 2+ to 6+ correspond to otolith increment numbers three-seven, respectively.

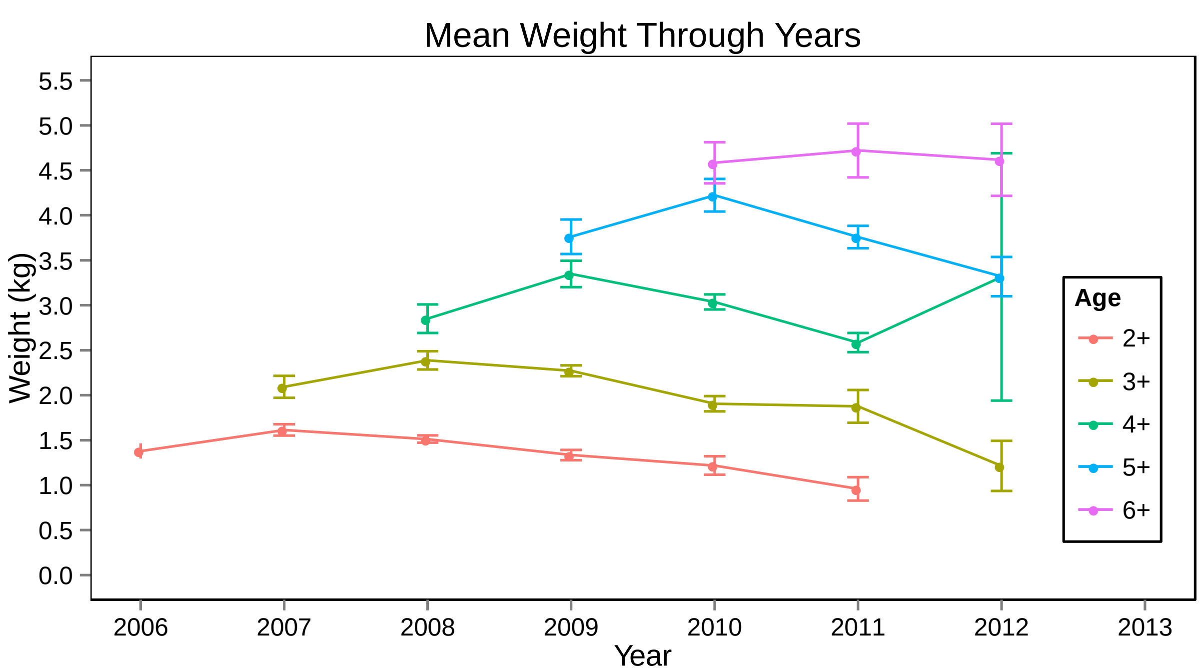

Figure 23. Mean back-calculated weight ± SE estimated during years 2006-2012 for Gulf of Mexico Red snapper ages 2+ to 6+.

CHAPTER FOUR:

DISCUSSION

The objective of this study was to estimate the effects of potential crude oil contamination from the *Deepwater Horizon* on age specific growth rates in the ecologically and economically important reef-fish Red snapper. Otoliths were obtained from captured Red snapper and were used to evaluate age structure and, because they are a proxy for somatic growth, variation in growth before, during and after the *DWH* event. The findings of this study provide strong evidence for annual growth variation in Red snapper and have identified significant declines in age specific growth following the blowout.

Red snapper Age Structure

To test the first hypothesis that there is annual variation in growth in Red snapper living in areas subjected to oil contamination from the *DWH* blowout, age and growth analyses were performed using the collected otoliths. The otoliths used for age, growth and increment width analyses were collected during the months of June through August. Because I did not have year-round collection of otoliths we could not re-validate the yearly pattern of opaque zone formation. However, numerous other validation studies have been performed on Red snapper otoliths from the north-central and north-western Gulf of Mexico as well as otoliths from several sub-tropical and tropical Lutjanid species and all indicate annual formation of opaque zones from January to

May with some mild variation in start and stop time[3,13,52,55–57]. Thus, I am confident that each annulus represents one year of growth and that the age estimates obtained from these otoliths are accurate representations of the true age of the fish.

The age distribution of fish from 2011-2013 (Figure 9) had a predominance of ages four - six and a smaller numbers of individuals aged seven and greater. Age zero and one Red snapper were not observed in any sampling efforts primarily because they inhabit mainly shallow areas and inshore nursery habitats not included in the sampling regime. They also recruit mostly to ground trawling, not hook and line, because of their size[13,58]. The oldest Red snapper I aged was 40 years old and caught in 2011 however Red snapper older than 10 years represented only 2.4% of my samples. Low numbers of fish older than 7 are most likely due to natural and fishing mortalities and long-term recovery from overfishing[13]. Although we only landed marginal amounts of individuals greater than age 10 in all three catch years, my findings of a maximum observed age of 40 are consistent with several other earlier studies where maximum observed ages were 52 years[13], 42 years[59] and 31 years[60].

Variation in year class strength is evident by a strong 2006 cohort which progresses through all three catch years: age five in 2011, age six in 2012 and age seven in 2013 (Figure 9). I also detected this strong year class as a dominant mode in the length frequency histograms (Figure 10). The median fork length of the 2011 catch was 57 cm (Figure 11) and the median fork length of all age 5 fish from that sampling year was nearly the same at 54 cm. This was also observed with the age 6 fish sampled in 2012. The median fork length of age six fish was 60 cm: exactly the same as the median fork length of all fish sampled during that year. Again, this same pattern was observed in 2013 with the age seven fish, though not as strong as what was observed in 2012. The median fork length of age seven fish sampled in 2013 was 64 cm and the median fork length of all fish sampled in 2013 was 61.17 cm (Table 3). This variation in year class strength (YCS) is thought to be caused by a fluctuation in stock size, which results in varied year - to- year age structures[61]. Variation in YCS in Red snapper has been previously observed in the 1989 and 1995 year-classes where it was evident by a progression of age two to age four Red snapper in 1991 to 1993 and 1997 to 1999, respectively[62]. Importantly, we note that in 2005 the back-calculated fork length of individuals at age was larger than all others for years 2004 to 2009 (Figure 22). Stock productivity is highly dependent on size of the female spawners; larger females produce a greater quantity of eggs as well as eggs of greater quality and larger average radius compared to smaller individuals[63]. The occurrence of larger individuals at age in 2005 may attempt to explain increased recruitment and survival of the 2006 cohort. Of course, this is just one hypothesis: the causes of recruitment variability are complex and an ongoing field of research in marine and fisheries science[64].

Also notable is that age two Red snapper were missing from the 2012 catch and age two and age three Red snapper were again missing from the 2013 catch. These age classes represent the 2010 and 2011 cohorts; those that would have been spawned just following the *DWH* event. I postulate two hypotheses that may explain the missing 2010 and 2011 year classes in 2012 and 2013 catch data: *1*) Sampling locations that yielded high catches of age two and three year olds in 2011 were not visited in 2012 and 2013; *2*) Year class strength of post *DWH* cohorts was very weak, potentially due to the lethal effects that oil can have on larval fish. Upon exploring hypothesis 1 and parsing the catch data by age and year, it does not seem to be a feasible explanation as the stations that yielded age 2 and age 3 Red snapper were visited again in 2012 and 2013 (Figure 24).

In fact, there was a very large sampling effort in 2012 and 2013 in areas north-west of the *Deepwater Horizon* wellhead (Figure 8) which, in the previous year (2011) produced six age twos and eight age threes. Hypothesis *2,* that oil contamination causes adverse effects, including mortality, to fish larvae and embryos, has been observed many times in laboratory studies investigating effects of oil on fish embryo and larvae following the *Exxon Valdez* spill as well as the *DWH*[23,35,65–67]. So, we consider this one plausible hypothesis that may explain the missing 2010 and 2011 year-classes as adults.

Red snapper Growth

The overall growth model estimated using data from all catch years is quite similar to von Bertalanffy growth curves presented in the literature within the last 15 years[3,10,13,55,59](Figure 25). However, the growth model presented here has a slightly smaller estimated L_{∞}. It is difficult to determine whether significant differences exist among these growth curves because confidence intervals were not presented alongside the parameter estimates in previous studies. Also, the age and length data used to estimate previous curves were collected from various sources including independent and dependent fishing methods each with different age and size limits. It is apparent, however, that the same steep growth is observed in early years of growth (age one-ten) followed by a decline in growth reaching an estimated maximum fork length of between 82.8 cm (current study) and 96.7 cm (S&S 94) (Figure 25). Also, the previously estimated parameters fell within my range of confidence intervals.

I observed a statistically significant difference in L_{∞} by sex: females displayed a larger maximum fork length compared to males. This occurrence of large females has been observed in many fishes[68,69]. Many believe that the role of large, older, female fish is to produce high quality eggs to support and maintain the stock[70,71]. However, some authors note that sexual dimorphism in Gulf of Mexico Red snapper is discordant with growth studies of Lutjanid species in the Southern Hemisphere[72] and emphasize that it is still unclear what length differences mean for ecological processes in these fishes[13].

Variation in Age Specific Growth

To test the second hypothesis that age specific growth declines occurred in Red snapper collected in areas contaminated by *DWH* oil, increment width analysis was performed on a select group of otoliths with clearly marked banding patterns. Accretion of the fourth, fifth and sixth increments declined coincident with the DWH event in 2010 and are significantly different than the mean accretion rates of these increments over several years prior to the spill. However the third increment displayed an increased accretion rate following the event and there was no significant difference in accretion rate of this increment in RSY 2010 compared to the mean of years prior (Figure 20). It is unclear exactly why the third increment growth would be different as age three Red snapper have been found occupying similar habitat as age four, five, and six Red snapper and thus potentially would be exposed to the same toxic constituents present in the water column[5,73]. However, it is possible that during the time of the third increment formation, between the ages of two and three, there is still rapid growth that distorts this increment along the sulcal groove. In fact, it seems that the largest difference in mean size at age in our data existed between age two and three perhaps representing the rapid growth that could cause such distortion (Figure 11). Distortion among early increments has been observed in past studies. Specifically, in a study examining otolith growth increment chronologies and associated climate synchrony on long-living Bering Sea flatfish, Matta[30] found the first three – five increments so distorted along the measurement axis that they were excluded from their study[30]. Because sample number constraints resulted in few samples that would have provided information about increments greater than seven in years before the *DWH* event, we were limited to assessing increments no greater than seven in the present study. Therefore, to increase overall sample size we chose to include the third increment into this analysis. However, if the third increment were excluded in future studies and more focus was placed on increments four and greater, mean increment width might look more uniform among increment numbers across years.

Significance of Environmental Variables

To test my third set of hypotheses, that environmental variables explain the significant variation in these increment widths, five environmental variables were included in a linear mixed- effects model and then sequentially removed to determine their significance to the overall fit. Of the 5 parameters, U winds and River Discharge were the only parameters to significantly describe any of the variation suggesting that environmental variables play a significant role in annual variation among age-specific growth rates. Though suggestive, these results are still not conclusive until we are able to determine the long-term variability among age-specific growth rates. Furthermore, although U winds appeared significant, the p value of the true component driving upwelling, wind stress curl[44], indicated that we should reject the hypothesis that variation in related upwelling can explain the variation observed in age specific increment widths. So, the exact mechanism between U winds and growth changes in this study remains unclear. Currently, we are still unable to reject the hypothesis that crude oil contamination from the *DWH* event caused the significant declines observed in increment width at age in 2010.

Estimating Productivity Changes

The last objective of this study was to estimate changes in productivity by obtaining back-calculated fork length at age from the increment width measurements. Although otolith growth is a proxy for fish growth, the relationship between total radius at age (Figure 26) and BCFL at age appears not entirely proportional which was un-expected. Potentially, this may be due to the intercept included in the biological intercept equation which accounts for "systematic variation in the fish length – otolith size ratio with somatic growth rate"[26]. This may also be a result of a phenomenon called decoupling where otolith growth becomes out of phase with somatic growth. This has only been observed in laboratory studies with juvenile fish, however, where growth was observed at much higher resolution using daily increments[26] so it is unlikely to have caused the annual differences in increment width and back-calculated length.

Otolith radius at age appeared relatively consistent throughout years especially at age three (Figure 26). Because otolith radius-at-age is dependent upon all prior increment widths, the large differences observed in the third increment width through years are less present. A similar theme exists for otolith radius at age four and five but we note a decline in otolith radius at age in 2010, which matches the similar decline observed in both the widths of the fourth and fifth increments. It is hard to tell how much this is due to the significant decline in width of the fourth and fifth increment in 2010 or the increments before these. Importantly, it appears that most significant declines in BCFL seemed to lag behind the significant declines in otolith increment width, occurring between years 2010 and 2011. Perhaps because BCFL is a function of otolith radius at age (R_i) more so than of increment width, the signal observed from the individual increment widths is dampened. However, it does appear that significant declines in mean back-calculated fork length at age did occur following the *DWH* event, if not exactly matching those of the increment widths.

Weight-at-age is an important metric used to understand population productivity because egg production is proportional to female weight and thus fecundity; larger females produce a greater quantity of eggs as well as eggs of greater quality and larger average egg diameter compared to smaller individuals[63]. The observed declines in total back-calculated weight-at-age may indicate that fewer eggs were produced that may have been of lower quality and smaller in size. On average, there were significant declines in weight at age two+, three+ , four+ and five+ in years following the *DWH* blowout compared to the mean weight of these ages in years prior which can correspond to a significant decline in egg production. Furthermore, the eggs spawned during the *DWH* may have experienced higher than normal mortality rates or were of low condition due to skeletal and physiological abnormalities [34]. Not only do we estimate a reduction in egg production, it is also possible that the delayed effect of oil could continue to hamper production of new individuals. Such delayed effects of oil were observed by Heintz[74] when he exposed pink salmon embryos to declining concentrations of PAHs during development. The individuals were tagged and released to the north Pacific Ocean and upon their return as adults 16 months later, they displayed obvious physical abnormalities and, most noticeably, were in much fewer numbers that the control groups. There was a 40% reduction in survival from embryos to adulthood[74] which means there were far fewer adults participating in spawning events. These kind of delayed effects can have a tremendous impact on the success of the stock as a whole. When populations are dependent upon large quantities of healthy adults to create viable embryos, it is almost certain that the productivity of the stock will suffer if adults are either not present[61] or are smaller in size and condition. However, it does appear that variation in age specific increment width, back-calculated fork length and back-calculated weight at age occurred in years before the event as well. Therefore, the results of this study are suggestive of the possible effects contamination had on age specific growth but not yet conclusive until we are able to identify the long-term variability in Red snapper annual growth.

Figures

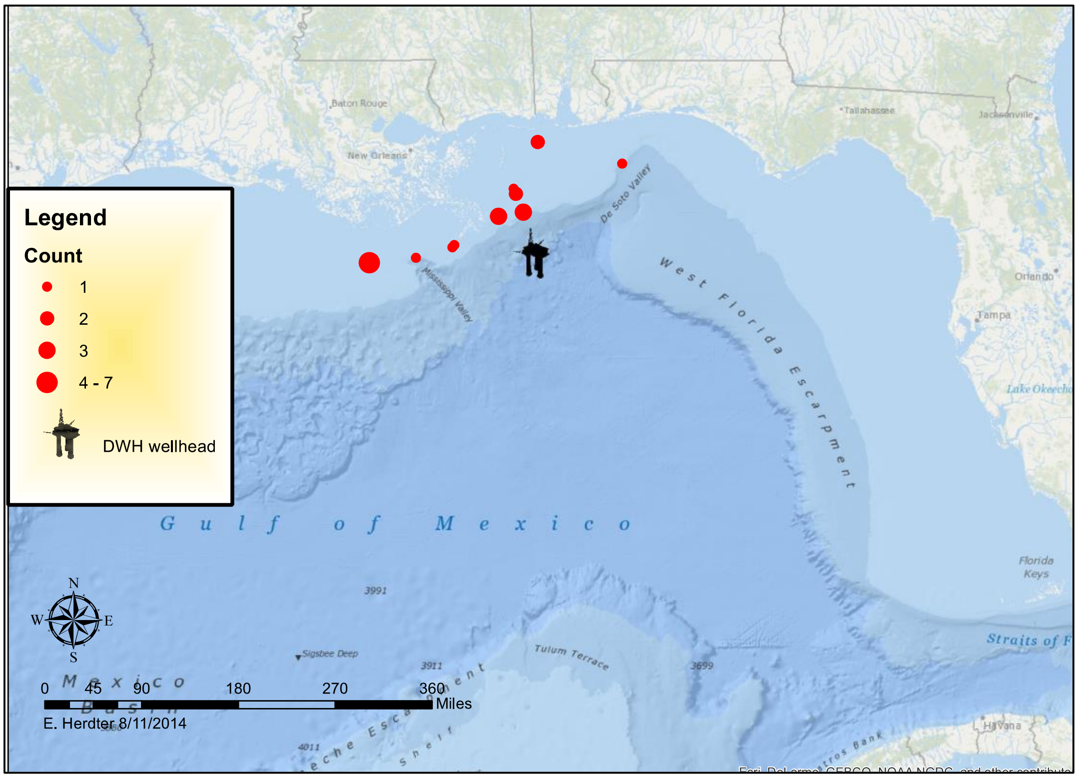

Figure 24. Catch locations of age two and three Gulf of Mexico Red snapper during the 2011 sampling effort (n = 14). Dot size indicates number of Red snapper caught per station.

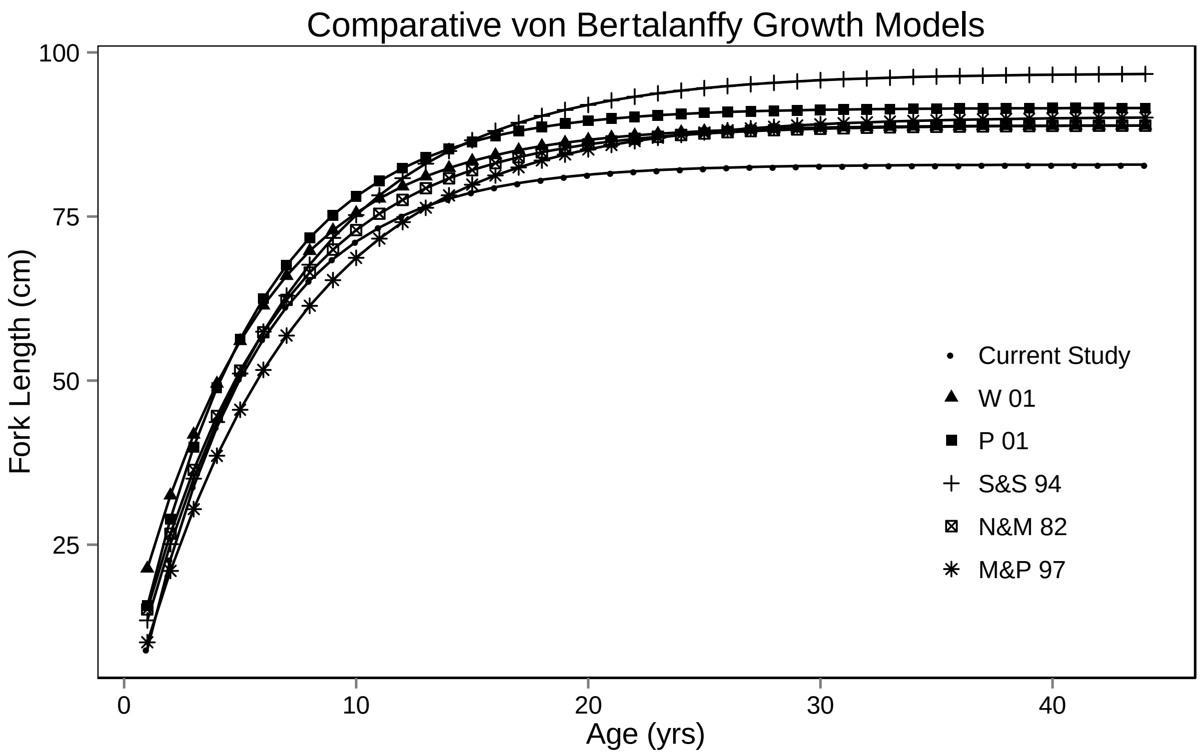

Figure 25. Comparative von Bertalanffy growth models for Red snapper from the northern Atlantic Ocean and Gulf of Mexico. Current study is presented in circles: W 01 = Wilson (2001), P 01 = Patterson (2001), S&S 94 = Szedlmayer and Ship (1994), N&M 82 = Nelson and Manooch (1982), M&P = Manooch and Potts (1997). Because the authors estimated L_∞ using total length (TL), their fitted total length data set was adjusted to fork length (FL) using the relationship $TL=1.058FL + 0.386$[54]. This conversion was necessary in order to display it on this plot.

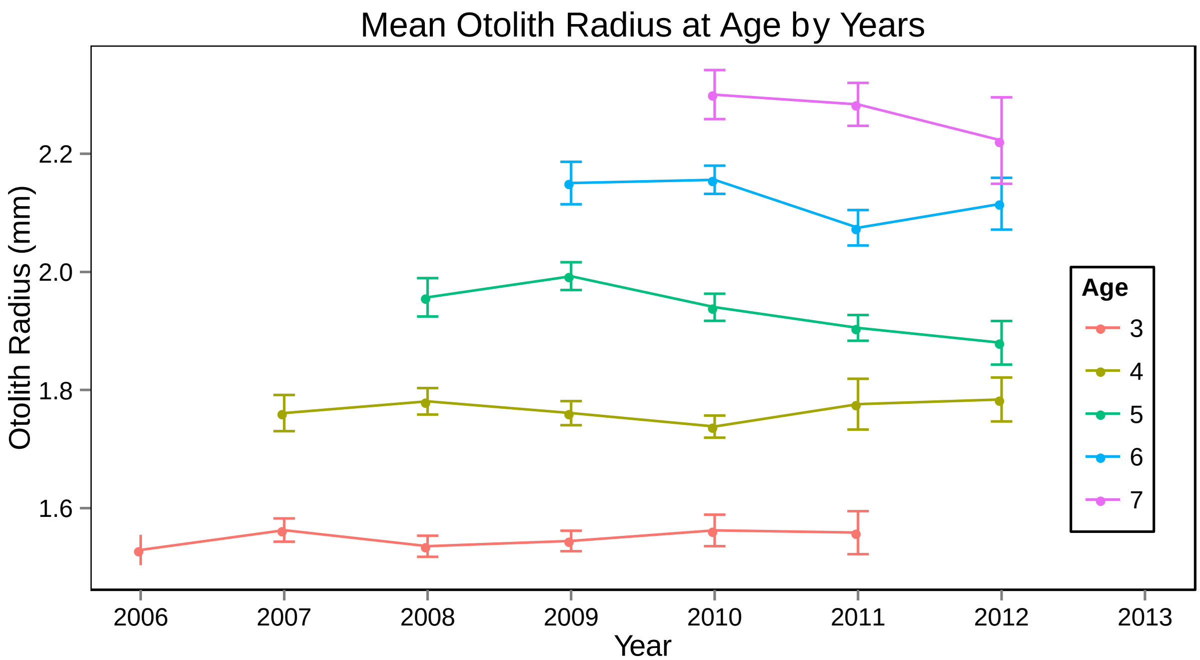

Figure 26. Mean otolith radius ± SE at age observed for years 2006-2012 for Gulf of Mexico Red snapper third-seven annual growth increments. Year is measured from June to June of the following year ("RSY").

CHAPTER FIVE:

CONCLUSIONS

The main objective of this study was to estimate the effects that the *DWH* event had on growth of an ecologically and economically important finfish in the Gulf of Mexico. This study is novel because it is one of the first to use otoliths collected from specific locations in the field following the *DWH* event. Also, it is one of the first studies to focus on the threat that contamination may pose to long-living, adult fish. Although we did not find any difference in growth estimates in the recovery years following the *DWH*, there were significant declines in increment width at age compared to the mean of those in years previous. From these increment width measurements we estimated declines weight at age in years following the event. Such declines in weight at age have implications for overall stock productivity, as it is healthy, large adults who ensure future stock success. However, because of our limited time series, our results cannot be considered conclusive until we can define the actual inter-annual variability in increment width and weight at age. Further work must be done to expand our time series and explore other environmental parameters that may potentially contribute to growth variation in Red snapper. Considering the ever expanding frontier of oil exploration in our oceans it is necessary that we conduct *in vitro* work via exposure studies to fully quantify the effects of oil on growth in adult fishes. If an event such as the *DWH* were to happen again, a comprehensive understanding of how oil affects fish of all ages will prove to be invaluable to processes of remediation and restoration.

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APPENDIX

Table A1. Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	7/27/11	25.061	-83.734	SF-01-40-13	6	63	4.53	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-14	7	71	5.872	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-15	5	68	5.044	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-16	6	64	5.782	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-17	7	70	5.912	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-18	9	77	7.8	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-23	6	70	6.4	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-24	8	76	7.4	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-25	7	64	4.601	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-26	5	67	6.2	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-27	6	71	5.442	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-38	8	75	8.8	F	-
2011	7/27/11	25.061	-83.734	SF-01-40-41	8	73	6.8	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-42	8	73	8.2	M	-
2011	7/27/11	25.061	-83.734	SF-01-40-43	6	65	5.298	F	-
2011	7/26/11	25.095	-84.165	SF-01-80-18	6	51	2.068	U	-
2011	7/11/11	27.561	-83.387	BR-03-20-47	5	53	2.156	F	Y
2011	7/8/11	27.504	-84.241	BR-03-40-2	6	63	4.25	M	-
2011	7/8/11	27.504	-84.241	BR-03-40-8	6	70	5.896	M	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	7/8/11	27.504	-84.241	BR-03-40-17	6	69	8.2	M	-
2011	7/8/11	27.504	-84.241	BR-03-40-28	5	44	1.39	M	-
2011	7/8/11	27.504	-84.241	BR-03-40-46	4	57	3.3	F	-
2011	7/8/11	27.504	-84.241	BR-03-40-57	5	48	1.95	M	-
2011	7/8/11	27.504	-84.241	BR-03-40-74	6	61	3.8	F	-
2011	7/17/11	27.801	-84.359	BR-34-40-3	4	53	2.75	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-4	7	69	5.78	M	Y
2011	7/17/11	27.801	-84.359	BR-34-40-20	7	63	5.062	F	-
2011	7/17/11	27.801	-84.359	BR-34-40-23	7	65	5.492	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-31	5	55	3.266	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-38	5	54	2.446	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-39	5	52	2.28	F	-
2011	7/17/11	27.801	-84.359	BR-34-40-40	6	59	4.216	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-53	5	51	2.272	M	-
2011	7/17/11	27.801	-84.359	BR-34-40-54	5	58	3.872	F	-
2011	7/16/11	27.692	-84.392	BR-34-50-7	7	61	3.75	F	-
2011	7/16/11	27.692	-84.392	BR-34-50-8	7	63	4.935	M	-
2011	7/16/11	27.692	-84.392	BR-34-50-9	8	74	9.972	M	-
2011	7/16/11	27.692	-84.392	BR-34-50-10	6	68	5.85	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-2	5	50	2.32	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-5	5	54	2.816	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-3	5	49	2.39	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-8	5	45	1.24	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-10	5	43	1.186	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-13	5	43	1.472	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-15	5	56	3.564	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	7/10/11	28.073	-84.440	BR-04-40-19	5	49	2.186	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-20	5	42	1.8	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-21	5	49	2.161	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-27	5	50	2.304	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-28	5	49	1.79	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-29	5	51	2.789	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-34	5	44	1.526	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-36	6	53	2.942	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-38	5	51	2.028	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-40	5	44	1.462	M	Y
2011	7/10/11	28.073	-84.440	BR-04-40-55	5	51	2.546	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-59	5	53	2.84	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-60	5	62	5.278	F	-
2011	7/10/11	28.073	-84.440	BR-04-40-77	5	-	-	U	-
2011	7/10/11	28.073	-84.440	BR-04-40-78	5	-	-	U	-
2011	7/10/11	28.073	-84.440	BR-04-40-42	5	57	3.36	M	-
2011	7/10/11	28.073	-84.440	BR-04-40-41	5	54	3.414	M	-
2011	7/10/11	27.950	-84.526	BR-04-60-5	6	59	3.614	F	-
2011	7/10/11	27.950	-84.526	BR-04-60-9	5	48	2.13	F	-
2011	7/10/11	27.950	-84.526	BR-04-60-4	6	59	3.802	M	-
2011	8/7/11	29.251	-83.781	BR-4/5-10-16	5	59	3.332	M	Y
2011	8/6/11	29.094	-84.582	BR-05-20-2	4	42	1.162	F	Y
2011	8/6/11	29.094	-84.582	BR-05-20-3	7	73	8.2	U	-
2011	8/6/11	29.094	-84.582	BR-05-20-9	4	41	1.322	M	-
2011	8/6/11	29.094	-84.582	BR-05-20-10	5	49	1.92	M	-
2011	8/6/11	29.094	-84.582	BR-05-20-11	7	69	7.4	M	-
2011	8/6/11	29.094	-84.582	BR-05-20-19	4	48	1.926	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/6/11	29.094	-84.582	BR-05-20-20	4	46	1.912	M	-
2011	8/5/11	28.784	-85.067	BR-05-60-14	4	49	2.464	M	-
2011	8/5/11	28.784	-85.067	BR-05-60-15	5	55	3.168	M	-
2011	7/13/11	29.424	-85.440	PC-06-10-1	5	65	-	F	-
2011	7/13/11	29.424	-85.440	PC-06-10-2	6	66	-	M	Y
2011	7/13/11	29.424	-85.440	PC-06-10-3	6	69	-	M	-
2011	7/13/11	29.424	-85.440	PC-06-10-4	6	67	-	M	Y
2011	7/13/11	29.424	-85.440	PC-06-10-5	7	76	-	M	-
2011	7/13/11	29.424	-85.440	PC-06-10-6	7	70	-	F	Y
2011	7/13/11	29.424	-85.440	PC-06-10-7	6	69	-	M	Y
2011	7/13/11	29.424	-85.440	PC-06-10-8	5	53	-	F	-
2011	7/13/11	29.424	-85.440	PC-06-10-9	7	75	-	F	Y
2011	7/13/11	29.424	-85.440	PC-06-10-10	6	65	-	M	-
2011	7/13/11	29.424	-85.440	PC-06-10-11	4	51	-	F	Y
2011	7/13/11	29.424	-85.440	PC-06-10-12	6	72	-	M	Y
2011	7/13/11	29.424	-85.440	PC-06-10-13	5	61	-	F	Y
2011	7/13/11	29.424	-85.440	PC-06-10-14	5	53	-	F	Y
2011	7/13/11	29.424	-85.440	PC-06-10-15	4	43	-	F	-
2011	7/13/11	29.424	-85.440	PC-06-10-16	5	57	-	F	Y
2011	7/13/11	29.369	-85.574	PC-06-20-14	5	42	1.3	M	-
2011	7/13/11	29.369	-85.574	PC-06-20-15	7	65	4.5	F	Y
2011	7/14/11	29.224	-85.551	PC-06-40-3	5	46	1.64	F	-
2011	7/14/11	29.224	-85.551	PC-06-40-10	6	54	2.98	M	-
2011	7/18/11	30.303	-86.230	PC-07-10-2	5	60	4.1	M	Y
2011	7/18/11	30.303	-86.230	PC-07-10-9	5	57	3.8	F	-
2011	7/18/11	30.303	-86.230	PC-07-10-10	5	62	4.7	F	-
2011	7/18/11	30.105	-86.353	PC-07-20-6	4	38	0.85	F	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	7/19/11	30.067	-87.432	PC-08-10-30	7	78	8	F	-
2011	7/19/11	29.909	-87.295	PC-08-20-3	5	68	6.2	M	-
2011	7/19/11	29.909	-87.295	PC-08-20-6	16	83	11.2	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-1	5	39	0.988	F	-
2011	7/19/11	29.889	-87.206	PC-08-40-2	7	51	2.12	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-4	4	39	1.072	F	-
2011	7/19/11	29.889	-87.206	PC-08-40-5	5	39	1.01	F	-
2011	7/19/11	29.889	-87.206	PC-08-40-6	7	44	1.496	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-10	4	38	0.916	F	-
2011	7/19/11	29.889	-87.206	PC-08-40-11	6	51	2.17	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-12	7	60	3.602	F	-
2011	7/19/11	29.889	-87.206	PC-08-40-13	4	41	1.22	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-27	8	53	2.736	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-37	7	48	1.77	M	-
2011	7/19/11	29.889	-87.206	PC-08-40-38	4	41	1.054	M	-
2011	8/2/11	30.009	-88.095	PC-09-10-2	6	67	5.426	F	Y
2011	8/2/11	30.009	-88.095	PC-09-10-3	6	67	5.685	M	-
2011	8/2/11	30.009	-88.095	PC-09-10-4	5	53	2.602	F	Y
2011	8/2/11	29.620	-88.043	PC-09-20-12	4	36	0.782	M	Y
2011	8/1/11	29.397	-87.980	PC-09-40-4	6	67	4.98	M	-
2011	8/1/11	29.338	-88.005	PC-09-60-41	4	43	1.352	M	-
2011	8/17/11	29.512	-88.687	PC-10-10-5	2	32	0.624	F	-
2011	8/17/11	29.512	-88.687	PC-10-10-6	2	34	0.118	M	-
2011	8/17/11	29.512	-88.687	PC-10-10-7	2	36	0.84	M	-
2011	8/17/11	29.512	-88.687	PC-10-10-10	4	54	2.852	F	Y
2011	8/17/11	29.512	-88.687	PC-10-10-11	4	61	3.64	M	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/17/11	29.512	-88.687	PC-10-10-18	2	35	0.17	F	-
2011	8/17/11	29.512	-88.687	PC-10-10-19	4	51	2.302	F	Y
2011	8/17/11	29.512	-88.687	PC-10-10-20	3	45	1.538	F	Y
2011	8/17/11	29.512	-88.687	PC-10-10-21	4	55	3.228	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-37	5	65	4.868	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-44	5	62	4.228	M	Y
2011	8/17/11	29.453	-88.653	PC-10-20-45	5	62	4.489	M	Y
2011	8/17/11	29.453	-88.653	PC-10-20-46	5	64	4.866	F	-
2011	8/17/11	29.453	-88.653	PC-10-20-47	5	71	5.695	M	-
2011	8/17/11	29.453	-88.653	PC-10-20-48	5	62	4.098	F	-
2011	8/17/11	29.453	-88.653	PC-10-20-49	5	63	1.428	M	Y
2011	8/17/11	29.453	-88.653	PC-10-20-50	5	58	3.914	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-51	5	64	4.645	F	-
2011	8/17/11	29.453	-88.653	PC-10-20-52	5	61	4.288	F	-
2011	8/17/11	29.453	-88.653	PC-10-20-53	5	65	4.29	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-54	5	57	2.982	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-55	5	53	1.21	M	-
2011	8/17/11	29.453	-88.653	PC-10-20-57	5	58	3.684	M	-
2011	8/17/11	29.453	-88.653	PC-10-20-58	4	50	2.258	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-59	3	36	0.826	F	Y
2011	8/17/11	29.453	-88.653	PC-10-20-60	3	42	1.274	F	-
2011	8/17/11	29.453	-88.653	PC-10-20-61	5	62	3.97	M	Y
2011	8/17/11	29.453	-88.653	PC-10-20-62	5	65	4.76	M	-
2011	8/17/11	29.453	-88.653	PC-10-20-63	6	66	4.768	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-2	6	60	4.012	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-3	7	67	5.292	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/17/11	29.236	-88.552	PC-10-40-4	5	47	1.76	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-5	4	45	1.232	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-7	5	53	2.168	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-9	5	52	2.212	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-30	5	54	2.416	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-31	7	63	4.708	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-32	3	44	1.508	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-33	7	66	5.21	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-34	4	43	1.326	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-35	5	53	2.508	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-36	4	40	1.274	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-37	5	48	1.824	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-38	4	44	1.364	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-39	7	76	7.86	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-40	4	42	1.25	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-42	6	70	6.65	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-43	4	43	1.246	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-45	3	47	1.53	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-46	4	42	1.17	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-47	4	42	1.23	F	-
2011	8/17/11	29.236	-88.552	PC-10-40-49	4	45	1.44	M	-
2011	8/17/11	29.236	-88.552	PC-10-40-50	4	42	1.348	F	-
2011	8/16/11	29.150	-88.900	PC-11-20-136	7	65	4.846	F	-
2011	8/16/11	29.150	-88.900	PC-11-20-137	6	63	4.828	M	Y
2011	8/16/11	29.150	-88.900	PC-11-20-139	7	61	4.6	M	-
2011	8/16/11	29.150	-88.900	PC-11-20-140	6	66	5.048	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/16/11	29.150	-88.900	PC-11-20-145	7	65	4.68	F	Y
2011	8/16/11	29.150	-88.900	PC-11-20-146	7	63	5.104	F	Y
2011	8/16/11	29.150	-88.900	PC-11-20-147	5	55	2.754	M	-
2011	8/16/11	29.150	-88.900	PC-11-20-148	5	53	3.012	M	-
2011	8/16/11	29.150	-88.900	PC-11-20-149	7	64	4.338	M	Y
2011	8/16/11	29.150	-88.900	PC-11-20-151	5	50	2.126	F	-
2011	8/16/11	29.150	-88.900	PC-11-20-152	4	51	2.458	M	-
2011	8/16/11	29.150	-88.900	PC-11-20-153	5	61	4.256	F	-
2011	8/16/11	29.150	-88.900	PC-11-20-154	5	49	2.102	F	Y
2011	8/16/11	29.150	-88.900	PC-11-20-156	5	49	2.162	F	-
2011	8/16/11	29.150	-88.900	PC-11-20-159	7	66	5.502	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-73	7	63	4.836	M	-
2011	8/16/11	29.109	-88.876	PC-11-40-110	5	69	5.818	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-111	7	71	7.185	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-112	7	63	4.335	M	-
2011	8/16/11	29.109	-88.876	PC-11-40-113	23	79	11.296	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-114	6	65	4.655	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-115	7	65	4.8	F	-
2011	8/16/11	29.109	-88.876	PC-11-40-117	7	72	6.715	M	Y
2011	8/16/11	29.037	-88.737	PC-11-100-21	5	48	2.046	M	-
2011	8/16/11	29.037	-88.737	PC-11-100-22	7	66	5.358	M	-
2011	8/16/11	29.037	-88.737	PC-11-100-25	5	46	1.134	F	-
2011	8/16/11	29.037	-88.737	PC-11-100-26	6	59	3.61	F	-
2011	8/16/11	29.037	-88.737	PC-11-100-27	5	50	2.502	F	-
2011	8/16/11	29.037	-88.737	PC-11-100-28	6	62	4.316	M	-
2011	8/16/11	29.037	-88.737	PC-11-100-29	6	58	3.026	M	-
2011	8/16/11	29.037	-88.737	PC-11-100-30	5	49	2.22	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/16/11	29.037	-88.737	PC-11-100-31	5	52	2.43	F	-
2011	8/16/11	29.037	-88.737	PC-11-100-32	5	47	1.674	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-7	5	56	3.696	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-8	5	65	4.96	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-9	7	57	3.092	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-10	4	49	2.026	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-18	6	60	3.44	M	Y
2011	8/15/11	28.851	-89.485	PC-12-20-20	5	63	4.14	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-21	4	48	1.902	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-22	5	59	3.818	M	Y
2011	8/15/11	28.851	-89.485	PC-12-20-23	5	59	2.334	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-24	5	55	2.69	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-25	5	57	3.12	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-69	4	49	2.276	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-70	5	47	2.118	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-71	4	59	3.428	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-72	5	49	1.946	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-73	5	58	3.36	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-74	5	55	2.628	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-76	4	45	1.562	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-77	6	59	3.828	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-78	4	45	1.562	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-79	5	60	3.686	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-80	4	48	1.914	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-81	4	48	1.18	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-91	5	57	3.218	M	Y
2011	8/15/11	28.851	-89.485	PC-12-20-109	5	54	2.644	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/15/11	28.851	-89.485	PC-12-20-110	5	64	4.262	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-111	5	55	3.278	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-112	4	49	1.912	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-113	5	61	3.92	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-116	6	70	5.772	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-126	4	39	1.112	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-142	3	41	1.28	F	Y
2011	8/15/11	28.851	-89.485	PC-12-20-143	2	30	0.526	M	-
2011	8/15/11	28.851	-89.485	PC-12-20-151	2	29	0.506	F	-
2011	8/15/11	28.851	-89.485	PC-12-20-197	6	65	5.482	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-179	6	59	3.082	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-180	7	58	3.596	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-181	6	63	3.84	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-183	7	63	4.368	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-184	4	46	1.482	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-185	4	43	1.302	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-186	4	44	1.486	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-187	5	40	1.066	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-188	21	78	9.175	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-189	4	45	1.442	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-190	5	47	1.736	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-191	4	45	1.652	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-194	5	43	1.344	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-195	5	55	2.994	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-196	4	43	1.938	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-197	5	60	3.298	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-198	4	41	1.162	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/15/11	28.824	-89.507	PC-12-40-199	4	41	1.282	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-200	5	51	2.276	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-201	7	65	5.492	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-203	5	52	2.27	F	-
2011	8/15/11	28.824	-89.507	PC-12-40-204	4	43	1.342	M	-
2011	8/15/11	28.824	-89.507	PC-12-40-205	5	54	2.44	F	-
2011	8/14/11	28.643	-90.626	PC-13-10-63	5	61	4.076	F	Y
2011	8/14/11	28.474	-90.557	PC-13-20-17	7	72	6.995	M	Y
2011	8/14/11	28.474	-90.557	PC-13-20-19	7	65	4.974	F--	-
2011	8/14/11	28.474	-90.557	PC-13-20-20	6	69	5.618	M	Y
2011	8/14/11	28.474	-90.557	PC-13-20-21	6	70	5.812	M	-
2011	8/14/11	28.474	-90.557	PC-13-20-75	4	49	1.876	F	-
2011	8/14/11	28.474	-90.557	PC-13-20-76	7	65	4.788	M	Y
2011	8/14/11	28.474	-90.557	PC-13-20-77	6	65	4.978	M	Y
2011	8/14/11	28.474	-90.557	PC-13-20-78	7	66	4.528	M	-
2011	8/14/11	28.474	-90.557	PC-13-20-79	7	68	6.04	M	-
2011	8/14/11	28.474	-90.557	PC-13-20-80	5	65	4.92	F	Y
2011	8/14/11	28.474	-90.557	PC-13-20-84	7	65	4.998	M	Y
2011	8/14/11	28.218	-90.585	PC-13-40-30	38	86	10.46	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-46	5	57	3.094	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-48	6	61	4.042	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-49	7	70	5.564	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-50	5	53	2.234	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-51	5	53	2.36	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-53	5	59	3.456	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-62	5	57	3.272	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-63	6	64	4.138	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/14/11	28.218	-90.585	PC-13-40-64	6	63	4.06	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-65	5	58	2.974	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-66	6	59	3.15	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-67	20	82	9.965	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-68	5	55	2.668	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-72	6	57	3.124	F	Y
2011	8/14/11	28.218	-90.585	PC-13-40-73	5	52	2.284	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-74	6	60	3.748	M	Y
2011	8/14/11	28.218	-90.585	PC-13-40-75	6	60	3.598	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-76	6	59	3.514	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-78	6	60	3.988	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-79	7	63	4.698	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-80	6	62	4.468	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-81	6	58	3.42	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-82	7	63	3.832	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-83	6	65	4.804	F	Y
2011	8/14/11	28.218	-90.585	PC-13-40-84	6	52	3.814	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-85	6	58	3.118	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-87	6	63	4.146	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-88	6	67	4.772	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-89	5	50	2.88	M	-
2011	8/14/11	28.218	-90.585	PC-13-40-90	5	54	2.582	F	-
2011	8/14/11	28.218	-90.585	PC-13-40-91	6	55	2.928	M	-
2011	7/29/11	29.817	-87.424	PC-14-20-6	5	51	2.224	F	-
2011	7/29/11	29.817	-87.424	PC-14-20-7	5	59	3.234	F	Y
2011	8/3/11	30.056	-88.363	PC-15-10-1	3	43	1.356	F	Y
2011	8/3/11	30.056	-88.363	PC-15-10-2	3	42	1.228	F	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2011	8/3/11	30.056	-88.363	PC-15-10-3	4	54	2.826	M	Y
2011	8/3/11	29.605	-88.419	PC-15-20-4	4	39	1.076	F	Y
2011	8/3/11	29.605	-88.419	PC-15-20-5	5	60	3.978	M	Y
2011	8/3/11	29.605	-88.419	PC-15-20-6	5	49	1.984	F	Y
2011	8/3/11	29.605	-88.419	PC-15-20-7	6	70	5.722	F	Y
2011	8/3/11	29.605	-88.419	PC-15-20-11	6	63	4.024	F	-
2011	8/3/11	29.605	-88.419	PC-15-20-16	6	62	3.886	M	Y
2011	8/3/11	29.605	-88.419	PC-15-20-17	7	62	3.84	M	Y
2011	8/3/11	29.271	-88.422	PC-15-40-16	5	62	2.672	F	-
2011	8/3/11	29.271	-88.422	PC-15-40-23	11	67	5.2	M	-
2011	8/3/11	29.271	-88.422	PC-15-40-24	4	40	1.088	M	-
2011	8/19/11	29.710	-87.329	PC-814-60-38	7	69	5.724	F	Y
2011	8/18/11	29.389	-87.796	PC-914-40-10	5	40	1.779	F	-
2011	8/18/11	29.389	-87.796	PC-914-40-11	40	89	12.24	F	-
2011	8/18/11	29.389	-87.796	PC-914-40-19	23	79	8.375	M	-
2012	7/22/12	28.073	-84.440	14-1	6	58	3.076	M	-
2012	7/22/12	28.073	-84.440	14-3	5	52	2.346	F	-
2012	7/22/12	28.073	-84.440	14-4	6	56	2.7	F	-
2012	7/22/12	28.073	-84.440	14-5	6	66	4.864	F	-
2012	7/22/12	28.073	-84.440	14-6	6	58	3.18	M	-
2012	7/22/12	28.073	-84.440	14-7	6	47	1.644	F	-
2012	7/22/12	28.073	-84.440	14-8	6	56	2.818	M	-
2012	7/22/12	28.073	-84.440	14-9	6	62	3.724	F	Y
2012	7/22/12	28.073	-84.440	14-10	6	60	3.884	F	-
2012	7/22/12	28.073	-84.440	14-11	8	70	5.748	F	-
2012	7/22/12	28.073	-84.440	14-12	8	70	5.09	F	-
2012	7/22/12	28.073	-84.440	14-13	6	53	2.446	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/22/12	28.073	-84.440	14-15	9	63	4.042	F	-
2012	7/22/12	28.073	-84.440	14-16	5	65	4.35	M	-
2012	7/22/12	28.073	-84.440	14-17	6	55	2.81	M	-
2012	7/22/12	28.073	-84.440	14-18	7	65	4.468	F	-
2012	7/22/12	28.073	-84.440	14-19	6	64	4.41	M	-
2012	7/22/12	28.073	-84.440	14-20	6	54	2.55	F	-
2012	7/22/12	28.073	-84.440	14-21	8	64	3.916	F	Y
2012	7/22/12	28.073	-84.440	14-22	6	56	2.867	F	-
2012	7/22/12	28.073	-84.440	14-22	6	56	2.867	F	-
2012	7/22/12	28.073	-84.440	14-23	7	55	2.732	M	-
2012	7/22/12	28.073	-84.440	14-24	6	60	3.69	F	Y
2012	7/22/12	28.073	-84.440	14-25	6	57	3.134	F	-
2012	7/23/12	28.826	-84.909	15-18	7	74	6.015	F	Y
2012	7/23/12	28.826	-84.909	15-20	5	42	1.138	F	-
2012	7/23/12	28.826	-84.909	15-19	5	53	3.39	M	Y
2012	7/23/12	28.784	-85.067	16-8	6	57	2.184	M	-
2012	7/23/12	28.784	-85.067	16-9	5	59	3.226	M	Y
2012	7/13/12	29.809	-87.225	21-5	6	50	1.812	F	-
2012	7/13/12	29.809	-87.225	21-7	5	41	1.22	F	-
2012	7/13/12	29.809	-87.225	21-8	6	49	1.716	F	-
2012	7/13/12	29.809	-87.225	21-12	6	48	1.93	M	-
2012	7/13/12	29.809	-87.225	21-13	4	45	1.554	F	-
2012	7/13/12	29.809	-87.225	21-14	7	51	2.254	M	-
2012	7/13/12	29.809	-87.225	21-24	8	68	5.898	M	-
2012	7/13/12	29.809	-87.225	21-27	3	34	0.792	F	-
2012	7/9/12	29.453	-88.653	27-9	5	63	4.022	F	-
2012	7/9/12	29.453	-88.653	27-11	7	69	5.342	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/9/12	29.453	-88.653	27-12	6	71	6.525	M	-
2012	7/9/12	29.453	-88.653	27-13	5	56	2.91	F	-
2012	7/9/12	29.453	-88.653	27-15	-	73	6.225	F	-
2012	7/9/12	29.453	-88.653	27-18	6	69	5.37	M	Y
2012	7/9/12	29.453	-88.653	27-20	6	64	4.404	M	Y
2012	7/9/12	29.453	-88.653	27-21	6	68	4.928	F	-
2012	7/9/12	29.453	-88.653	27-23	6	64	4.398	M	Y
2012	7/9/12	29.453	-88.653	27-26	6	62	3.934	M	-
2012	7/9/12	29.453	-88.653	27-28	6	56	2.932	F	-
2012	7/9/12	29.453	-88.653	27-30	5	63	3.165	F	Y
2012	7/9/12	29.453	-88.653	27-31	5	53	2.525	M	Y
2012	7/9/12	29.453	-88.653	27-32	6	66	4.905	F	Y
2012	7/9/12	29.453	-88.653	27-33	6	62	3.985	F	Y
2012	7/9/12	29.236	-88.552	28-8	5	47	1.862	F	-
2012	7/9/12	29.236	-88.552	28-13	7	66	4.705	F	Y
2012	7/9/12	29.236	-88.552	28-21	5	50	2.125	F	-
2012	7/9/12	29.236	-88.552	28-27	7	75	6.905	F	Y
2012	7/9/12	29.236	-88.552	28-31	6	59	3.365	M	-
2012	7/9/12	29.236	-88.552	28-35	7	56	2.905	M	-
2012	7/9/12	29.236	-88.552	28-47	6	55	2.8	F	-
2012	7/9/12	29.236	-88.552	28-49	5	51	2.185	M	-
2012	7/9/12	29.236	-88.552	28-52	5	43	1.32	F	-
2012	7/9/12	29.236	-88.552	28-56	5	51	2.095	F	-
2012	7/9/12	29.236	-88.552	28-66	4	43	1.235	F	-
2012	7/9/12	29.236	-88.552	28-76	5	48	1.87	F	-
2012	7/9/12	29.236	-88.552	28-81	3	35	0.8	M	-
2012	7/9/12	29.236	-88.552	28-82	6	47	1.765	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/9/12	29.236	-88.552	28-83	5	50	2	F	-
2012	7/9/12	29.236	-88.552	28-84	6	53	2.705	M	-
2012	7/9/12	29.236	-88.552	28-85	6	54	2.845	M	-
2012	7/9/12	29.236	-88.552	28-88	6	69	5.535	M	Y
2012	7/9/12	29.236	-88.552	28-93	7	66	4.615	M	Y
2012	7/9/12	29.109	-88.876	30-5	6	61	3.93	M	-
2012	7/9/12	29.109	-88.876	30-17	6	63	4.148	M	-
2012	7/9/12	29.109	-88.876	30-22	18	80	9.945	F	-
2012	7/9/12	29.109	-88.876	30-72	-	81	8.835	M	-
2012	7/9/12	29.109	-88.876	30-82	21	79	9.12	M	-
2012	7/9/12	29.109	-88.876	30-83	8	69	5.75	F	-
2012	7/9/12	29.109	-88.876	30-84	7	71	6.44	F	Y
2012	7/9/12	29.109	-88.876	30-85	8	68	5.645	F	-
2012	7/9/12	29.109	-88.876	30-86	6	58	3.255	F	-
2012	7/9/12	29.109	-88.876	30-87	7	65	4.53	M	-
2012	7/9/12	29.109	-88.876	30-88	8	65	4.46	M	-
2012	7/9/12	29.109	-88.876	30-89	7	64	4.825	F	-
2012	7/9/12	29.109	-88.876	30-90	7	66	4.55	M	-
2012	7/9/12	29.109	-88.876	30-91	9	69	5.19	F	-
2012	7/9/12	29.109	-88.876	30-92	6	57	3.435	M	-
2012	7/9/12	29.109	-88.876	30-93	6	59	3.92	M	-
2012	7/9/12	29.109	-88.876	30-94	7	64	4.21	F	-
2012	7/9/12	29.109	-88.876	30-95	8	63	4.44	M	-
2012	7/9/12	29.109	-88.876	30-96	9	72	7.275	F	-
2012	7/9/12	29.109	-88.876	30-97	6	57	3.065	M	-
2012	7/9/12	29.109	-88.876	30-98	6	65	4.54	M	-
2012	7/9/12	29.109	-88.876	30-100	7	62	4.195	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/23/12	28.851	-89.485	33-4	5	52	2.614	F	-
2012	6/23/12	28.851	-89.485	33-6	5	57	2.868	M	-
2012	6/23/12	28.851	-89.485	33-8	3	39	1.016	F	-
2012	6/23/12	28.851	-89.485	33-9	5	57	3.006	F	-
2012	6/23/12	28.851	-89.485	33-11	3	42	1.256	M	-
2012	6/23/12	28.851	-89.485	33-12	4	45	1.465	F	Y
2012	6/23/12	28.851	-89.485	33-13	5	59	3.68	M	Y
2012	6/23/12	28.851	-89.485	33-15	5	54	2.904	M	-
2012	6/23/12	28.851	-89.485	33-17	4	48	2.028	F	Y
2012	6/23/12	28.851	-89.485	33-19	5	52	2.31	M	-
2012	6/23/12	28.851	-89.485	33-26	5	53	2.655	F	Y
2012	6/23/12	28.851	-89.485	33-27	5	53	2.65	F	Y
2012	6/23/12	28.851	-89.485	33-28	3	36	0.872	F	-
2012	6/23/12	28.824	-89.507	34-5	5	58	3.342	M	Y
2012	6/23/12	28.824	-89.507	34-15	5	57	3.052	F	-
2012	6/23/12	28.824	-89.507	34-34	6	59	3.24	F	Y
2012	6/23/12	28.824	-89.507	34-37	7	64	4.726	M	-
2012	6/23/12	28.824	-89.507	34-45	7	61	3.906	F	-
2012	6/23/12	28.824	-89.507	34-48	7	64	4.545	F	-
2012	6/23/12	28.824	-89.507	34-53	6	59	3.464	F	Y
2012	6/23/12	28.824	-89.507	34-55	6	61	4.122	F	-
2012	6/23/12	28.824	-89.507	34-57	6	59	3.512	F	-
2012	6/23/12	28.824	-89.507	34-59	5	54	2.51	M	-
2012	6/23/12	28.824	-89.507	34-62	3	47	1.846	F	-
2012	6/23/12	28.824	-89.507	34-65	8	58	3.528	F	-
2012	6/23/12	28.824	-89.507	34-67	8	65	5.102	F	-
2012	6/23/12	28.824	-89.507	34-70	6	61	3.742	F	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/23/12	28.824	-89.507	34-71	7	66	5.114	M	-
2012	6/23/12	28.824	-89.507	34-73	6	61	4.039	F	-
2012	6/23/12	28.824	-89.507	34-74	6	56	2.856	F	Y
2012	6/23/12	28.824	-89.507	34-75	6	61	3.862	F	-
2012	6/23/12	28.824	-89.507	34-78	5	51	2.42	F	-
2012	6/23/12	28.824	-89.507	34-80	6	57	3.514	M	-
2012	6/23/12	28.824	-89.507	34-82	6	58	3.775	F	-
2012	6/23/12	28.824	-89.507	34-84	6	53	2.978	M	-
2012	6/23/12	28.824	-89.507	34-85	5	51	2.158	F	-
2012	6/23/12	28.824	-89.507	34-87	5	46	1.884	M	-
2012	6/18/12	28.643	-90.626	36-15	4	53	2.625	F	Y
2012	6/18/12	28.643	-90.626	36-18	8	65	4.654	M	-
2012	6/18/12	28.643	-90.626	36-23	8	67	5.75	F	Y
2012	6/18/12	28.643	-90.626	36-24	6	57	2.818	M	Y
2012	6/18/12	28.643	-90.626	36-27	3	46	1.648	M	-
2012	6/18/12	28.643	-90.626	36-31	3	38	0.962	F	Y
2012	6/18/12	28.643	-90.626	36-32	7	66	4.73	F	Y
2012	6/18/12	28.643	-90.626	36-33	3	47	1.618	F	-
2012	6/18/12	28.643	-90.626	36-35	5	54	2.752	F	Y
2012	6/18/12	28.643	-90.626	36-36	3	54	2.446	F	-
2012	6/18/12	28.643	-90.626	36-37	4	47	1.806	F	-
2012	6/18/12	28.643	-90.626	36-39	6	64	4.868	M	Y
2012	6/18/12	28.643	-90.626	36-41	4	47	2.112	M	Y
2012	6/18/12	28.643	-90.626	36-42	6	67	5.525	M	Y
2012	6/18/12	28.643	-90.626	36-43	3	44	1.566	F	Y
2012	6/18/12	28.643	-90.626	36-44	4	54	2.964	F	Y
2012	6/18/12	28.643	-90.626	36-45	3	45	1.798	M	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/18/12	28.643	-90.626	36-46	4	45	1.524	F	-
2012	6/18/12	28.643	-90.626	36-47	4	51	2.768	M	Y
2012	6/18/12	28.643	-90.626	36-48	3	37	0.876	F	-
2012	6/15/12	28.473	-90.557	37-1	6	58	3.415	F	Y
2012	6/15/12	28.473	-90.557	37-2	6	64	4.102	M	-
2012	6/15/12	28.473	-90.557	37-3	6	62	3.528	F	Y
2012	6/15/12	28.473	-90.557	37-4	6	64	4.368	M	-
2012	6/15/12	28.473	-90.557	37-5	6	64	4.656	M	-
2012	6/15/12	28.473	-90.557	37-7	5	59	3.702	M	-
2012	6/15/12	28.473	-90.557	37-8	5	56	2.964	M	-
2012	6/15/12	28.473	-90.557	37-9	6	57	3.244	M	-
2012	6/15/12	28.473	-90.557	37-11	6	57	3.01	F	-
2012	6/15/12	28.473	-90.557	37-12	6	63	4.23	M	-
2012	6/15/12	28.473	-90.557	37-13	6	56	2.774	M	-
2012	6/15/12	28.473	-90.557	37-15	6	60	3.444	F	Y
2012	6/15/12	28.473	-90.557	37-16	5	62	3.95	F	-
2012	6/15/12	28.473	-90.557	37-17	6	60	3.848	M	-
2012	6/15/12	28.473	-90.557	37-18	5	55	2.678	M	-
2012	6/15/12	28.473	-90.557	37-20	6	65	4.262	F	-
2012	6/15/12	28.218	-90.585	38-5	7	69	5	F	-
2012	6/15/12	28.218	-90.585	38-6	8	66	5.514	M	-
2012	6/15/12	28.218	-90.585	38-7	20	84	10.275	F	-
2012	6/15/12	28.218	-90.585	38-8	8	62	4.39	F	-
2012	6/15/12	28.218	-90.585	38-11	8	68	5.33	0	-
2012	6/15/12	28.218	-90.585	38-13	6	63	4.1	M	-
2012	6/15/12	28.218	-90.585	38-14	6	60	3.984	M	-
2012	6/15/12	28.218	-90.585	38-16	8	68	5.376	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/15/12	28.218	-90.585	38-17	7	57	3.262	F	-
2012	6/15/12	28.218	-90.585	38-18	7	56	3.098	F	-
2012	6/15/12	28.218	-90.585	38-19	8	61	3.786	M	-
2012	6/15/12	28.218	-90.585	38-20	6	63	4.616	M	-
2012	6/15/12	28.218	-90.585	38-21	8	63	4.498	M	-
2012	6/15/12	28.218	-90.585	38-22	8	65	5.214	M	-
2012	6/15/12	28.218	-90.585	38-23	7	66	4.984	M	-
2012	6/15/12	28.218	-90.585	38-24	7	64	4.324	F	-
2012	6/15/12	28.218	-90.585	38-25	6	63	5.028	M	-
2012	6/15/12	28.218	-90.585	38-26	8	67	4.752	F	-
2012	6/15/12	28.218	-90.585	38-27	8	62	4.566	M	-
2012	6/15/12	28.218	-90.585	38-28	8	65	4.4	M	-
2012	6/15/12	28.218	-90.585	38-29	8	67	5.179	M	-
2012	6/15/12	28.218	-90.585	38-30	8	63	4.08	F	-
2012	6/15/12	28.218	-90.585	38-89	7	65	4.5	M	-
2012	6/15/12	28.218	-90.585	38-90	8	66	4.43	M	Y
2012	6/15/12	28.218	-90.585	38-92	9	71	5.058	M	-
2012	6/15/12	28.218	-90.585	38-93	7	64	4.218	F	Y
2012	6/15/12	28.218	-90.585	38-94	7	68	5.154	M	-
2012	6/15/12	28.218	-90.585	38-96	6	57	2.846	M	-
2012	6/15/12	28.218	-90.585	38-97	5	52	2.138	M	-
2012	6/15/12	28.218	-90.585	38-98	5	56	3.012	F	-
2012	6/15/12	28.218	-90.585	38-99	9	65	4.784	F	-
2012	6/15/12	28.218	-90.585	38-100	8	65	4.79	F	-
2012	6/15/12	28.218	-90.585	38-102	6	66	4.164	M	-
2012	6/15/12	28.218	-90.585	38-103	6	60	3.032	F	-
2012	6/15/12	28.218	-90.585	38-104	7	61	2.282	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/15/12	28.218	-90.585	38-105	7	67	5.024	M	-
2012	6/15/12	28.218	-90.585	38-106	7	63	4.106	F	-
2012	6/15/12	28.218	-90.585	38-107	8	68	5.302	F	-
2012	6/15/12	28.218	-90.585	38-108	6	54	2.468	F	-
2012	6/15/12	28.218	-90.585	38-109	7	63	4.034	F	-
2012	6/15/12	28.218	-90.585	38-110	7	70	5.06	F	-
2012	6/15/12	28.218	-90.585	38-111	7	61	3.654	F	Y
2012	6/15/12	28.218	-90.585	38-112	7	62	3.582	F	-
2012	6/15/12	28.218	-90.585	38-113	6	53	3.454	F	-
2012	6/15/12	28.218	-90.585	38-115	6	63	3.854	M	-
2012	6/15/12	28.218	-90.585	38-131	8	70	5.565	F	-
2012	6/15/12	28.218	-90.585	38-156	7	72	5.038	F	-
2012	6/15/12	28.218	-90.585	38-202	7	64	4.358	M	-
2012	7/12/12	29.526	-87.393	43-2	7	71	6.425	F	-
2012	7/12/12	29.526	-87.393	43-20	7	71	5.152	M	-
2012	6/20/12	28.850	-90.000	51-1	6	67	5.64	M	-
2012	6/20/12	28.850	-90.000	51-21	8	72	6.235	F	-
2012	6/20/12	28.850	-90.000	51-22	7	69	6.13	M	-
2012	6/20/12	28.850	-90.000	51-23	7	69	5.724	F	-
2012	6/20/12	28.850	-90.000	51-25	6	63	4.001	F	-
2012	6/20/12	28.850	-90.000	51-26	6	61	3.8	F	-
2012	6/20/12	28.850	-90.000	51-28	6	68	4.892	M	-
2012	6/20/12	28.850	-90.000	51-30	7	62	4.866	M	Y
2012	6/20/12	28.850	-90.000	51-32	6	63	4.092	F	Y
2012	6/20/12	28.700	-90.000	52-23	6	63	3.99	F	-
2012	6/20/12	28.700	-90.000	52-27	8	67	5.35	U	-
2012	6/20/12	28.700	-90.000	52-30	6	67	4.64	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/20/12	28.700	-90.000	52-31	7	63	4.32	F	-
2012	6/20/12	28.700	-90.000	52-32	5	53	2.478	M	-
2012	6/20/12	28.700	-90.000	52-33	5	47	1.84	M	-
2012	6/20/12	28.700	-90.000	52-34	7	59	3.716	F	-
2012	6/20/12	28.700	-90.000	52-35	5	52	3.54	M	-
2012	6/20/12	28.700	-90.000	52-36	6	60	4.344	F	-
2012	6/20/12	28.700	-90.000	52-37	6	63	2.232	F	-
2012	6/20/12	28.700	-90.000	52-38	6	64	4.366	M	-
2012	6/20/12	28.700	-90.000	52-39	6	65	4.244	F	-
2012	6/20/12	28.700	-90.000	52-40	6	61	4.056	F	-
2012	6/20/12	28.700	-90.000	52-41	6	53	2.812	F	-
2012	6/20/12	28.700	-90.000	52-42	4	50	1.984	F	-
2012	6/20/12	28.700	-90.000	52-43	7	64	4.516	M	-
2012	6/20/12	28.700	-90.000	52-45	6	65	4.694	M	-
2012	6/20/12	28.700	-90.000	52-46	7	61	3.636	F	-
2012	6/20/12	28.700	-90.000	52-47	7	60	3.72	M	-
2012	6/20/12	28.700	-90.000	52-48	6	53	2.204	F	-
2012	6/20/12	28.700	-90.000	52-49	6	61	3.822	F	-
2012	6/20/12	28.700	-90.000	52-50	6	59	3.964	F	-
2012	6/20/12	28.700	-90.000	52-51	8	60	3.958	F	-
2012	6/20/12	28.700	-90.000	52-52	4	46	1.646	F	Y
2012	6/20/12	28.700	-90.000	52-53	6	60	3.72	F	Y
2012	6/20/12	28.700	-90.000	52-54	6	63	4.078	F	-
2012	6/20/12	28.700	-90.000	52-55	7	61	4.092	F	-
2012	6/20/12	28.700	-90.000	52-56	6	51	2.172	F	-
2012	6/20/12	28.700	-90.000	52-57	5	52	2.49	M	-
2012	6/20/12	28.700	-90.000	52-58	6	59	3.37	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/20/12	28.700	-90.000	52-59	5	60	3.042	F	-
2012	6/20/12	28.700	-90.000	52-60	6	61	4.476	M	-
2012	6/20/12	28.700	-90.000	52-61	6	60	3.438	F	-
2012	6/20/12	28.700	-90.000	52-62	3	41	1.006	F	-
2012	6/20/12	28.700	-90.000	52-63	4	50	1.832	M	Y
2012	6/20/12	28.700	-90.000	52-64	5	52	2.414	F	-
2012	6/20/12	28.700	-90.000	52-66	5	57	2.946	F	-
2012	6/20/12	28.700	-90.000	52-67	6	65	4.538	M	-
2012	6/20/12	28.700	-90.000	52-68	6	61	3.464	F	-
2012	6/20/12	28.700	-90.000	52-69	6	65	4.212	F	-
2012	6/20/12	28.700	-90.000	52-70	6	65	5.225	M	Y
2012	6/19/12	28.683	-90.000	53-8	8	63	4.58	M	-
2012	6/19/12	28.683	-90.000	53-24	6	65	4.938	M	-
2012	6/19/12	28.667	-90.000	54-16	8	72	6.505	F	-
2012	6/16/12	28.650	-91.917	58-6	7	68	4.85	F	Y
2012	6/16/12	28.650	-91.917	58-7	6	66	4.868	F	Y
2012	6/16/12	28.650	-91.917	58-8	6	52	2.218	M	--
2012	6/16/12	28.650	-91.917	58-9	8	66	5.012	F	Y
2012	6/16/12	28.650	-91.917	58-10	8	63	4.648	M	-
2012	6/16/12	28.650	-91.917	58-11	6	65	4.532	M	Y
2012	6/16/12	28.650	-91.917	58-14	5	62	3.47	F	Y
2012	6/16/12	28.650	-91.917	58-20	7	72	5.67	M	Y
2012	6/16/12	28.650	-91.917	58-21	8	65	4.624	M	Y
2012	6/16/12	28.650	-91.917	58-24	9	61	4.13	F	-
2012	6/16/12	28.650	-91.917	58-25	7	69	5.486	M	Y
2012	6/16/12	28.650	-91.917	58-26	23	86	11.125	F	-
2012	6/16/12	28.650	-91.917	58-27	9	74	7.14	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	6/17/12	28.183	-91.917	59-13	7	59	3.458	F	-
2012	6/17/12	28.183	-91.917	59-14	24	80	8.53	F	-
2012	6/17/12	28.183	-91.917	59-19	8	70	6.482	F	-
2012	6/17/12	28.183	-91.917	59-23	7	67	4.849	F	-
2012	6/17/12	28.183	-91.917	59-26	5	49	2.066	F	-
2012	6/17/12	28.183	-91.917	59-28	8	66	4.652	M	-
2012	6/17/12	28.183	-91.917	59-31	7	62	4.445	M	-
2012	6/17/12	28.183	-91.917	59-33	6	56	2.805	M	-
2012	6/17/12	28.183	-91.917	59-35	7	57	3.112	M	-
2012	6/17/12	28.183	-91.917	59-37	8	60	3.668	F	-
2012	6/17/12	28.183	-91.917	59-39	9	72	5.678	F	-
2012	6/17/12	28.183	-91.917	59-44	8	67	4.176	F	-
2012	6/17/12	28.183	-91.917	59-45	13	70	5.554	M	-
2012	6/17/12	28.183	-91.917	59-46	6	59	3.27	F	-
2012	6/17/12	28.183	-91.917	59-48	7	60	3.34	F	-
2012	6/17/12	28.183	-91.917	59-49	8	68	4.928	M	-
2012	6/17/12	28.183	-91.917	59-50	23	77	7.8	M	-
2012	6/17/12	28.183	-91.917	59-51	8	69	4.835	M	-
2012	6/17/12	28.183	-91.917	59-52	7	55	2.548	M	-
2012	6/17/12	28.183	-91.917	59-53	8	67	4.014	M	-
2012	6/17/12	28.183	-91.917	59-54	7	56	2.884	F	-
2012	6/17/12	28.183	-91.917	59-55	7	59	3.408	M	-
2012	6/17/12	28.183	-91.917	59-56	8	63	4.004	F	-
2012	7/21/12	27.805	-84.355	69-14	5	52	2.406	F	-
2012	7/21/12	27.805	-84.355	69-18	6		4.616	F	-
2012	7/21/12	27.692	-84.392	70-2	7	70	6.225	F	-
2012	7/21/12	27.692	-84.392	70-3	8	67	4.802	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/21/12	27.692	-84.392	70-7	6	69	5.24	F	-
2012	7/21/12	27.692	-84.392	70-8	7	70	6.02	F	-
2012	7/21/12	27.692	-84.392	70-13	7	67	4.655	F	-
2012	7/21/12	27.692	-84.392	70-16	7	73	6.225	F	-
2012	7/8/12	29.188	-88.886	80-1	6	59	3.712	M	-
2012	7/8/12	29.188	-88.886	80-2	5	54	2.68	M	Y
2012	7/8/12	29.188	-88.886	80-3	7	61	4.13	M	-
2012	7/8/12	29.188	-88.886	80-4	5	51	2.284	M	Y
2012	7/8/12	29.188	-88.886	80-5	6	65	4.535	F	-
2012	7/8/12	29.188	-88.886	80-6	6	64	4.94	F	-
2012	7/8/12	29.188	-88.886	80-7	6	63	3.894	F	-
2012	7/8/12	29.188	-88.886	80-8	5	51	2.145	M	-
2012	7/8/12	29.188	-88.886	80-9	6	63	4.904	M	-
2012	7/8/12	29.188	-88.886	80-10	6	59	3.618	M	-
2012	7/8/12	29.188	-88.886	80-11	5	53	2.362	F	Y
2012	7/8/12	29.188	-88.886	80-12	6	57	2.81	M	Y
2012	7/8/12	29.188	-88.886	80-13	6	62	3.672	F	-
2012	7/8/12	29.188	-88.886	80-14	6	61	3.546	M	-
2012	7/8/12	29.188	-88.886	80-15	6	59	3.408	M	Y
2012	7/8/12	29.188	-88.886	80-16	5	53	2.394	F	Y
2012	7/8/12	29.188	-88.886	80-17	6	63	4.412	F	-
2012	7/8/12	29.188	-88.886	80-18	6	64	4.364	M	Y
2012	7/8/12	29.188	-88.886	80-19	6	62	3.814	F	Y
2012	7/8/12	29.188	-88.886	80-20	7	57	2.996	M	-
2012	7/8/12	29.188	-88.886	80-21	5	54	2.546	M	Y
2012	7/8/12	29.188	-88.886	80-22	5	58	3.778	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/8/12	29.188	-88.886	80-23	6	58	3.44	F	-
2012	7/8/12	29.188	-88.886	80-24	6	63	4.736	M	Y
2012	7/8/12	29.188	-88.886	80-25	6	55	3.176	F	Y
2012	7/8/12	29.188	-88.886	80-26	5	53	2.684	M	-
2012	7/8/12	29.188	-88.886	80-27	6	58	3.168	F	-
2012	7/8/12	29.188	-88.886	80-28	3	40	1.034	M	-
2012	7/8/12	29.188	-88.886	80-34	3	38	0.962	F	-
2012	7/8/12	29.188	-88.886	80-35	6	49	2.13	M	-
2012	7/8/12	29.188	-88.886	80-36	6	49	1.98	M	-
2012	7/8/12	29.188	-88.886	80-37	5	53	2.834	F	Y
2012	7/8/12	29.188	-88.886	80-38	4	47	1.676	M	Y
2012	7/8/12	29.188	-88.886	80-39	5	56	2.948	F	-
2012	7/8/12	29.188	-88.886	80-40	5	52	2.486	M	-
2012	7/8/12	29.188	-88.886	80-41	6	60	3.772	M	-
2012	7/8/12	29.188	-88.886	80-42	6	56	3.062	F	-
2012	7/8/12	29.188	-88.886	80-44	3	39	1	F	-
2012	7/8/12	29.188	-88.886	80-45	6	52	2.8914	F	Y
2012	7/8/12	29.188	-88.886	80-46	5	54	2.652	M	Y
2012	7/8/12	29.188	-88.886	80-48	4	40	1.284	F	-
2012	7/8/12	29.188	-88.886	80-50	5	57	3.06	M	-
2012	7/8/12	29.188	-88.886	80-51	6	53	2.392	M	-
2012	7/21/12	27.958	-84.544	82-5	7	78	6.645	F	-
2012	7/21/12	27.958	-84.544	82-7	7	68	5.13	F	Y
2012	7/21/12	27.958	-84.544	82-19	9	79	9	F	-
2012	7/21/12	27.958	-84.544	82-21	24	92	13.3	F	-
2012	7/23/12	29.089	-84.576	83-4	6	54	2.304	M	Y
2012	8/16/12	29.205	-88.870	WBSL1040-16	6	54	2.866	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	7/21/12	27.958	-84.544	82-19	9	79	9	F	-
2012	7/21/12	27.958	-84.544	82-21	24	92	13.3	F	-
2012	7/23/12	29.089	-84.576	83-4	6	54	2.304	M	Y
2012	8/16/12	29.205	-88.870	WBSL1040-16	6	54	2.866	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-14	5	50	1.94	M	Y
2012	8/16/12	29.205	-88.870	WBSL1040-19	7	65.5	-	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-21	6	58.5	3.2	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-23	5	51	2.2	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-24	5	46	2	F	-
2012	8/16/12	29.205	-88.870	WBSL1040-30	6	62	4.2	F	-
2012	8/16/12	29.205	-88.870	WBSL1040-31	5	53	2.8	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-32	5	51	2.4	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-48	7	65	5	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-73	10	64.5	5.1	M	-
2012	8/16/12	29.205	-88.870	WBSL1040-74	4	47	2	F	Y
2012	8/16/12	29.205	-88.870	WBSL1040-77	6	60	2.2	M	Y
2012	8/16/12	29.205	-88.870	WBSL1040-78	6	57	3	M	Y
2012	8/16/12	29.205	-88.870	WBSL1040-80	8	70	5.8	F	-
2012	8/16/12	29.205	-88.870	WBSL1040-101	6	64.5	4.554	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-32	7	65	4.2	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-33	7	65	4.238	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-37	7	56	3.002	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-38	7	53	2.282	M	Y
2012	8/23/12	28.621	-90.005	WBSL16150-39	6	56	2.86	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-40	7	58	3.124	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-41	6	57	2.744	F	-
2012	8/23/12	28.621	-90.005	WBSL16150-42	8	59	3.42	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2012	8/19/12	29.888	-87.294	WBSL840-9	7	56	3	F	Y
2012	8/19/12	29.888	-87.294	WBSL840-10	5	47	2	M	Y
2012	8/19/12	29.888	-87.294	WBSL840-11	5	45	1.7	M	Y
2013	8/26/13	28.621	-90.005	WBSL16150-113	8	57	3.386	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-102	8	66	4.724	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-103	8	68	4.344	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-104	8	61	4.012	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-105	9	68	5.2	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-106	9	69	5.548	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-107	8	63	4.502	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-109	6	57	2.813	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-110	6	55	2.77	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-111	5	48	1.822	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-112	5	53	2.425	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-114	7	58	3.878	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-115	4	35	0.718	F	Y
2013	8/26/13	28.621	-90.005	WBSL16150-116	6	45	1.583	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-117	8	66	5.4	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-118	8	67	5.968	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-119	7	56	2.766	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-120	6	38	0.992	F	-
2013	8/26/13	28.621	-90.005	WBSL16150-121	7	59	3.572	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-122	8	64	3.978	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-123	7	50	1.948	M	-
2013	8/26/13	28.621	-90.005	WBSL16150-124	6	54	2.82	F	Y
2013	8/26/13	28.621	-90.005	WBSL16150-125	6	46	1.724	F	-
2013	6/17/13	29.163	-85.748	BS1-2	8	73	5.2	F	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2013	6/17/13	29.163	-85.748	BS1-3	6	73	6.1	F	-
2013	6/17/13	29.163	-85.748	BS1-4	8	53	2.4	F	-
2013	6/17/13	29.163	-85.748	BS1-5	8	72	5.5	M	-
2013	6/17/13	29.163	-85.748	BS1-6	7	74	6	F	-
2013	6/17/13	29.163	-85.748	BS1-7	8	79	8.1	F	-
2013	6/17/13	29.163	-85.748	BS1-8	7	71	6.2	M	-
2013	6/17/13	29.163	-85.748	BS1-9	7	73	6	F	Y
2013	6/17/13	29.163	-85.748	BS1-12	6	67	5	M	Y
2013	6/17/13	29.163	-85.748	BS1-13	10	73	7	M	-
2013	6/17/13	29.163	-85.748	BS1-14	7	58	2.5	M	-
2013	6/17/13	29.163	-85.748	BS1-15	6	79	7	F	-
2013	6/17/13	29.163	-85.748	BS1-16	7	58	3	F	-
2013	8/25/13	28.377	-90.511	He 265-1	15	71	6	M	-
2013	8/25/13	28.377	-90.511	He 265-2	8	68	5.414	M	-
2013	8/25/13	28.377	-90.511	He 265-3	8	69	5.2	M	-
2013	8/25/13	28.377	-90.511	He 265-4	6	62	4.4	F	-
2013	8/25/13	28.377	-90.511	He 265-5	7	65	3.756	F	Y
2013	8/25/13	28.377	-90.511	He 265-6	6	61	2.896	M	Y
2013	8/25/13	28.377	-90.511	He 265-7	7	68	4.296	F	-
2013	8/25/13	28.377	-90.511	He 265-8	8	67	4.008	M	-
2013	8/25/13	28.377	-90.511	He 265-10	7	71	4.73	M	-
2013	8/25/13	28.377	-90.511	He 265-11	5	67	2.122	F	Y
2013	8/25/13	28.377	-90.511	He 265-12	8	80	6.8	F	-
2013	8/25/13	28.377	-90.511	He 265-13	7	81	7.2	M	Y
2013	8/25/13	28.377	-90.511	He 265-14	4	47	1.306	F	Y
2013	8/25/13	28.377	-90.511	He 265-15	8	65	4.05	M	-
2013	8/25/13	28.377	-90.511	He 265-17	9	72	5.123	M	-

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2013	8/25/13	28.377	-90.511	He 265-18	9	69	4.664	F	-
2013	8/25/13	28.377	-90.511	He 265-19	7	67	4.035	M	-
2013	8/25/13	28.377	-90.511	He 265-21	5	42	0.964	F	-
2013	8/25/13	28.377	-90.511	He 265-22	4	44	1.23	M	-
2013	8/25/13	28.377	-90.511	He 265-23	5	50	1.695	M	Y
2013	8/25/13	28.377	-90.511	He 265-24	6	65	3.576	M	-
2013	8/25/13	28.377	-90.511	He 265-26	4	50	1.578	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-1	7	63	4.39	F	Y
2013	8/21/13	29.205	-88.870	WBSL1040-25	7	64	4.994	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-42	6	61	3.964	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-43	6	62	4.082	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-54	7	66	4.662	U	Y
2013	8/21/13	29.205	-88.870	WBSL1040-55	7	60	3.594	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-57	8	69	5.528	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-60	8	67	5.333	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-61	9	70	6.2	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-62	8	66	4.828	F	Y
2013	8/21/13	29.205	-88.870	WBSL1040-70	7	65	5.402	U	-
2013	8/21/13	29.205	-88.870	WBSL1040-115	7	65	4.624	U	-
2013	8/21/13	29.205	-88.870	WBSL1040-117	7	61	3.956	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-118	6	65	4.476	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-126	7	58	3.694	F	Y
2013	8/21/13	29.205	-88.870	WBSL1040-136	14	86	9.2	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-140	7	59	3.392	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-141	6	57	3.623	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-142	4	45	1.551	M	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013.

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2013	8/21/13	29.205	-88.870	WBSL1040-143	8	64	4.46	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-144	7	62	3.884	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-145	6	55	3.156	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-146	7	63	3.698	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-147	7	62	4.058	U	-
2013	8/21/13	29.205	-88.870	WBSL1040-148	7	62	3.892	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-149	4	46	1.728	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-150	8	64	4.028	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-151	7	62	3.958	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-152	7	62	3.8	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-153	7	60	-	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-154	7	62	3.84	F	Y
2013	8/21/13	29.205	-88.870	WBSL1040-155	6	56	3.208	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-156	8	58	3.194	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-157	7	56	3.092	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-158	7	62	4.15	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-159	6	56	3.302	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-160	6	57	3.598	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-161	6	47	1.868	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-162	6	55	2.553	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-163	7	62	4.988	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-164	6	59	-	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-165	6	61	4.354	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-166	_	60	3.62	F	-
2013	8/21/13	29.205	-88.870	WBSL1040-167	6	57	3.598	M	-
2013	8/21/13	29.205	-88.870	WBSL1040-168	6	58	3.438	M	Y
2013	8/21/13	29.205	-88.870	WBSL1040-169	6	58	3.758	M	Y

Table A1(continued). Raw catch data from Gulf of Mexico Red snapper caught in 2011-2013

Year	Catch Date	Station Latitude	Station Longitude	Fish Identification Number	Age	Fork Length (cm)	Weight (kg)	Sex	Used for Increment Analysis
2013	8/21/13	29.205	-88.870	WBSL1040-170	7	64	4.98	M	-
2013	8/29/13	28.089	-84.432	WBSL440-6	7	65	4.508	M	Y
2013	8/29/13	28.089	-84.432	WBSL440-7	7	70	5.274	F	-
2013	8/29/13	28.089	-84.432	WBSL440-29	6	64	4.484	M	Y