7-12-2019

# Population Demographics of Golden Tilefish *Lopholatilus chamaeleonticeps* in the Gulf of Mexico

Greta J. Helmueller
*University of South Florida*, gjhelmueller@gmail.com

## Scholar Commons Citation

Helmueller, Greta J., "Population Demographics of Golden Tilefish *Lopholatilus chamaeleonticeps* in the Gulf of Mexico" (2019). *USF Tampa Graduate Theses and Dissertations.*
https://digitalcommons.usf.edu/etd/8370

# Population Demographics of Golden Tilefish *Lopholatilus chamaeleonticeps* in the Gulf of Mexico

by

Greta J. Helmueller

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
with a concentration in Marine Resource Assessment
College of Marine Science
University of South Florida

Major Professor: Steven Murawski, Ph.D.
Christopher Stallings, Ph.D.
Linda Lombardi, Ph.D.

Date of Approval:
July 12, 2019

Keywords: Growth, otolith, oil spill, mortality

# Acknowledgments

Funding was provided by BP/The Gulf of Mexico Research Initiative, C-IMAGE II/III, and the William T. Hogarth Fellowship in Marine Mammals.

I would like to thank my committee members, Dr. Steve Murawski, Dr. Chris Stallings, and Dr. Linda Lombardi for their support and guidance in finishing my thesis. A special thank you is due to Dr. Linda Lombardi for taking the time to teach me how to estimate Golden Tilefish ages, providing age validation, as well as traveling across the state for my defense.

I would also like to thank Dr. Liz Herdter and Jessica Carroll at Florida Fish and Wildlife Research Institute for assistance with otolith processing techniques. Thanks are also due to the "Lopholatilus Ladies", Susan Snyder, Kristina Deak, and Dr. Shannon O'Leary, for their professional guidance and help with everything Golden Tilefish related. I would also like to thank the rest of the Murawski Lab and the greater CMS community for your support and friendship throughout my graduate career. Thank you to the crew of the R/V Weatherbird II and everybody who assisted in sample collection.

Special thanks are due to Jessie Koehle for being a great mentor and providing moral support when graduate school was difficult. Finally, I would like to thank my parents for always encouraging my scientific interests and being there for me.

# Table of Contents

# List of Tables

## List of Figures

# Abstract

The *Deepwater Horizon* (DWH) oil spill had catastrophic impacts on aquatic organisms in the Northern Gulf of Mexico (GoM). Longline gear was used to sample demersal fish species at 344 locations distributed throughout the GoM in the seven years following DWH. Sampling was accomplished deploying 450-500 baited hooks per station in depths ranging from 20-600 m. Using data from these surveys, I analyzed the length and age frequency, condition, growth, and mortality rates of Golden Tilefish (*Lopholatilus chamaeleonticeps*) throughout the GoM. Demersal habitat use and apparent high contaminant levels in Golden Tilefish makes them potentially vulnerable to oil spills such as DWH. Therefore, comparing population resiliency by analyzing rates of growth and mortality is an obvious methodology for understanding the effects of anthropogenic perturbations and how vital rates vary spatially. Comparisons were also made by country of origin in order to establish a baseline dataset for the southern GoM. Although there is spatial and temporal variation in some length distribution, condition, and growth metrics, other metrics show no difference among Golden Tilefish by country of origin, site location relative to the DWH spill perimeter, and in pre- and post-spill comparisons. Golden Tilefish grow slightly faster off Mexico than in the Northern GoM, however the total mortality rate (Z), determined via catch curve analysis, was higher off Mexico than in the United States. Growth curves fit to length-at-age data from the DWH spill site and all other US sites post-spill showed slight differences, although those differences decreased in pre- and post-DWH spill site comparisons. Although the total mortality rate was much higher in fish from the DWH spill perimeter compared to all other US sites, there was no discernable difference in Z occurred pre- vs. post-spill. Thus, any differences in growth and mortality observed in post-spill fish from the DWH spill perimeter compared to post-spill fish from elsewhere in the US appear to be endemic to the northeastern Gulf of Mexico. While further study is needed to analyze the impacts from oil exposure on eggs and larvae on population demographics, Adult Golden Tilefish appeared to be resilient against DWH oil exposure.

# Introduction

## *Golden Tilefish Life History*

Golden Tilefish (*Lopholatilus chamaeleonticeps*) are demersal, nonmigratory fish residing throughout the Gulf of Mexico (GoM) and the Western Atlantic from Nova Scotia down to Venezuela (Aiken et al. 2015). They are typically slow growing and long lived, with an estimated maximum longevity of 40 years (Palmer et al. 2004; Lombardi et al. 2010; Lombardi-Carlson and Andrews 2015). Adult Golden Tilefish maintain burrows in soft-bottom habitats up to 500 meters water depth (NOAA 2019a). They use these burrows to avoid predation (Able et al. 1982) and are considered ecosystem engineers where abundant due to their modification of habitat (Grimes et al. 1986). Although the burrows are typically only inhabited by one Golden Tilefish at a time (Able et al. 1982), small crustaceans also co-inhabit the burrows. Golden Tilefish have high site fidelity; individuals may not move any more that 2 km in a year (Grimes et al. 1983). Little is known about the feeding habits of larval Golden Tilefish, but adults eat crustaceans, mollusks, echinoderms, eels, hagfish, and anthropogenic materials (Freeman and Turner 1977). The reproductive strategy of Golden Tilefish is largely unknown, although they have been estimated most recently to be protogynous hermaphrodites in the northern Gulf of Mexico (Lombardi-Carlson 2012). Golden Tilefish are serial spawners. The reproductive season is from March – November with a peak from May – September in the Atlantic, whereas in the GoM spawning season lasts from January – June with a peak in April (Erickson et al. 1985; Lombardi-Carlson 2012).

Golden Tilefish are fished commercially in the GoM and the North Atlantic (NOAA Fisheries 2018; Ortega-Ortiz et al. 2020; Figure 1). When the Gulf of Mexico Fishery Management Council established its Fishery Management Plan for Reef Fish in 1981, Golden Tilefish were listed as a part of the fishery but not actively managed as they were not actively targeted (Aska et al. 1981). Golden Tilefish were not added to the management unit until 1990 and even then, no specific management practices were put in place for them (GMFMC 1989). Today Golden Tilefish are managed commercially under the Grouper-Tilefish Individual Fishing Quota (IFQ) program with a quota set each year, which was established in 2010 in response to stricter deepwater grouper quotas and overfishing of the Gulf of Mexico Golden Tilefish stock (GMFMC 2008; SEDAR 2011). Recreationally, Golden Tilefish are considered part of the 20 reef fish aggregate bag limit for anglers. From 2010 to 2016 total commercial landings for Golden Tilefish were 1360 metric tons, worth $7.7 million (NOAA Fisheries 2018).

### *Oil Exposure*

The gap in information on the population demographics of Golden Tilefish and other demersal species throughout the GoM became especially apparent after the 2010 *Deepwater Horizon* oil spill (DWH). It was the largest marine oil spill ever to occur (outside of the Persian Gulf spill), releasing 4.9 million barrels of oil and causing widespread damage to nearby ecosystems (Machlis and McNutt 2010; Deepwater Horizon Natural Resource Damage Assessment Trustees 2017). Polycyclic aromatic hydrocarbons (PAHs), one of the components of crude oil, are particularly toxic to marine life and are associated with many adverse health conditions including DNA alteration, immune suppression, increased disease susceptibility, liver lesions, and reduced larval survival (Moore and Dwyer 1974). Oil contamination has been shown to effect the cardiovascular and musculature development of bluefin tuna, yellowfin tuna, and amberjack (Incardona et al. 2014). While previous studies have shown variable effects of the spill on the population dynamics of other species, e.g. red snapper and various nearshore fish assemblages (Fodrie and Heck 2011; Schaefer et al. 2016; Herdter et al. 2017), Golden Tilefish are particularly susceptible to PAH exposure due to their demersal life history strategies and had much higher levels of naphthalene metabolites after the spill than other GoM reef fish (Snyder et al. 2015; Pulster et al. 2020). Since much of the DWH oil eventually was sequestered in the sediment (Brooks et al. 2015; Romero et al. 2015), it is possible that Golden Tilefish continue to be exposed to oil through burrow digging as opposed to other modes of exposure to other demersal fish. Additionally, because Golden Tilefish tend not to stray far from their burrows (Grimes et al. 1983), they may have been more susceptible to oil contamination than other reef fish species that are more mobile and thus able to avoid high oil contamination.

Despite the prevalence of Golden Tilefish in the GoM as a commercially important species, little is known about their geographic and depth distribution in the southern GoM, let alone the existence of any spatial differences in sub-populations. Additionally, the DWH oil spill made apparent the need for widespread population demographic data, as it is more difficult to analyze the impact of a large anthropogenic perturbation without accurate pre-event estimates. Differences in population demographics were examined by country captured to establish a baseline in the southern GoM and investigate any detectible impacts from differences in fishing pressure and fishery management practices on those demographics.

To evaluate the potential effects of DWH on population dynamics of Golden Tilefish, I investigated aspects of age and growth, mortality, and length-weight relationships, as well as condition factors of fish caught within the oil exposure zone for DWH. I compared these metrics with population data collected before the spill (Lombardi et al. 2010). Furthermore, additional population demographics data were compared between fish collected from the spill zone with fish collected from the parts of the GoM not directly exposed to DWH oil (e.g. other regions within the USA).

My thesis established a baseline dataset for the Golden Tilefish population across the entirety of the GoM and examined any population-level effects from DWH by evaluating the following questions:

1. Are there differences in adult Golden Tilefish demographics by country?
2. Are there differences in the demographics of Golden Tilefish caught from the area of the spatial extent of the DWH oil spill compared to fish caught elsewhere in the northern GoM?
3. Are there differences in the demographics of Golden Tilefish caught before and after DWH oil spill?

*Tables and Figures*

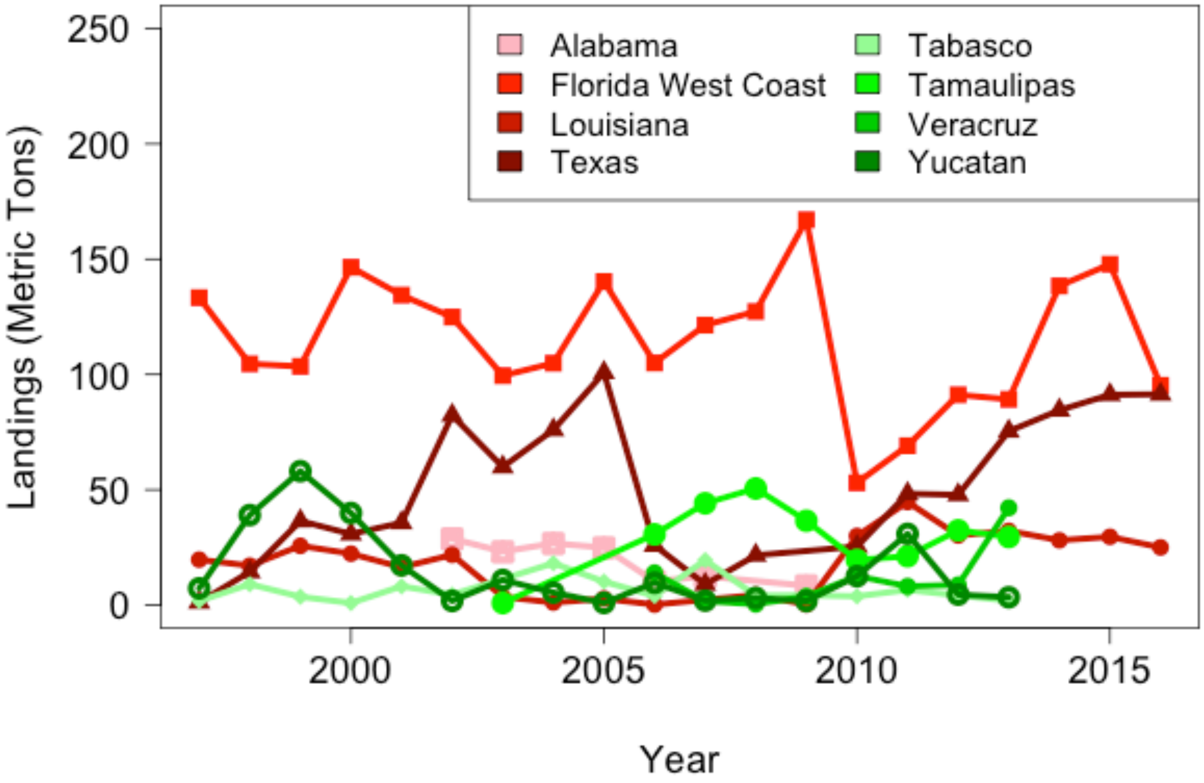

**Figure 1.** Golden Tilefish landings (metric tons) by state caught within the USA's EEZ from 1997 - 2016 (red; NOAA Fisheries 2018) and within Mexico's EEZ from 1997 - 2013 (green; Arreguín-Sánchez and Arcos-Huitrón 2007; Ortega-Ortiz et al. 2020). 2016 and 2013 were the last years that data were available from the US and Mexico, respectively. Data from Mexico also include all tilefish species and are self-reported.

## Methods

### *Sample Collection*

Demersal longline sampling occurred from 2011-2017 on the shelf and shelf edge around the GoM (Figure 2). Transects were selected around the Gulf, and six stations were chosen along each transect to sample a range of depths (Murawski et al. 2018). In 2011, samples were collected onboard chartered commercial fishing vessels and ranged from the Mississippi River Delta through the West Florida Shelf and the Florida Keys. Most of the sampling in 2012 was also done onboard chartered commercial fishing vessels; these samples were from the shelf south of Vermillion Bay, LA to the Tampa Bay area (Murawski et al. 2018). Some samples were also collected onboard the R/V *Weatherbird II* in 2012 from the Mississippi Delta area to the De Soto Canyon. The R/V *Weatherbird II* was the sole research vessel used in subsequent years. In 2013 and 2014, many of the same sites from the previous two years around the Mississippi River delta were resampled due to their proximity to the DWH spill site, as well as a few new sites around the De Soto Canyon area. The edge of Mexico's continental shelf was sampled in 2015, from the western Yucatan Peninsula to Heroica Veracruz. Resampling also occurred in the northern GoM from the Mississippi River delta area to the De Soto Canyon. In 2016 the entire western GoM was sampled from the shelf south of Houston to the northeastern edge of the Yucatan Peninsula. Sites around the Mississippi River delta in the northern GoM were re-sampled in 2017 as were locations on the northwestern shelf of Cuba. The main line was approximately five nautical miles long, and 400-500 2.4 m long leaders with size-13/0 circle hooks were set (Murawski et al. 2018).

Fish collected were identified to species, when possible. Total wet weight (kg), fork length (to the nearest cm), and total length (to the nearest cm) were measured. Livers, gastrointestinal tracts, and gonads were extracted from each Golden Tilefish and weighed (to the nearest g). Sex was determined (when possible) macroscopically for each Golden Tilefish by examining gonads. The sagittal otoliths were also collected from each Golden Tilefish. If both otoliths were excised intact, they were both extracted.

### *Otolith Analysis*

One otolith from each Golden Tilefish was sectioned using a Buehler Isomet Low – Speed Saw (Vanderkooy and Guindon-Tisdel 2003). Four blades were used to extract three sections approximately 0.3 mm in width. For consistency, the left otolith was sectioned if available, or if not the right otolith was used. The otolith cross-sections were then mounted on a microscope slide, using FloTexx® epoxy and aged under a microscope using transmitted light at 10x power.

Annual growth banding in Golden Tilefish has been validated using lead-radium dating (Lombardi-Carlson and Andrews 2015). Annuli (consistent of pairs of opaque and translucent bands) were counted from the primordial core either along the ventral axis edge or the ventral sulcus edge depending on readability (Figure 3). After age was determined, age and corresponding length can be used to estimate growth parameters (e.g. von Bertalanffy 1938) and to determine mortality rate from catch curves using numbers sampled at age (e.g. Hilborn and Walters 1992)

### *Reader Precision*

Two indices of precision, percent agreement and Average Percent Error (APE) were used to determine age accuracy according to methods outlined in Campana (2001). Dr. Linda Lombardi, who also provided training for visually estimating the age of Golden Tilefish otoliths, also served as a second reader to help estimate reader precision for 100 samples. Age precision estimates were calculated between primary reader and secondary reader determined ages, as well as first and second readings of all samples by the primary reader. An age bias plot comparing the mean and standard deviation of the first and second age estimations was also created.

### *Group Determination*

In order to determine if population demographics differed by country, group membership of Golden Tilefish was determined by country of origin. If a fish was caught within the USA EEZ it was deemed a “USA” fish. If a fish was caught within Mexico’s EEZ, it was deemed a “Mexico” fish.

To determine if population demographics differed by potential exposure to DWH oil, DWH-affected fish were determined by whether or not the station was within the geographic distribution of the spill (Murawski et al. 2014). From 2011 - 2017, sediment cores were also taken at some of the stations where fish were also sampled. Golden Tilefish from transects where oil was found are referred to as “DWH” fish, since they had the potential to be exposed to oil (Brooks et al. 2015; Romero et al. 2015). Fish from those sites were also found to have declining condition factors in the years since the DWH oil spill, corresponding to an increase in PAH exposure (Snyder et al. in review).

All other Golden Tilefish collected from transects within the United States of America's EEZ were considered to be from "All Other US sites".

To determine if Golden Tilefish population demographics differed before and after the DWH spill, Golden Tilefish that were determined to be a part of the "DWH" group as detailed above comprise the post-spill exposure group. The pre-spill group consisted of Golden Tilefish caught between 2000 - 2009 in the Northern GoM by various NOAA Fisheries fishery-independent (NMFS Pascagoula, NMFS Panama City, SERO Cooperative Research Proposal) and fishery-dependent (NMFS Galveston Observer Program, NMFS Panama City Shark Bottom Longline Observer Program, and Trip Interview Program) sources (for further detail see, Lombardi et al. 2010). For consistency, only Golden Tilefish previously collected using longline gear were used in this analysis. Additionally, only sites in the general vicinity of the "DWH" sites as detailed above were used. Most of the fishery-dependent sites did not record specific coordinates of collection, so all sites north of 28°N latitude and east of 90°W longitude were included. Methodologies, including standardization procedures and age validation for that particular set of samples, are detailed in Lombardi et al. (2010).

### *Data Analysis*

In order to detect any difference in population demographics corresponding to my research questions, I used each of the following analyses for each research question. "Groupings" refer to the differentiation of Golden Tilefish as described earlier relating to each research question (e.g. USA and Mexico).

Length frequencies were tested using a Kolmogorov-Smirnoff test with 1000 bootstrap iterations to test for differences in size structure between groupings (Neumann and Allen 2007). I tested the following hypothesis for each question:

Ho: There were no difference in the size structure between groupings of Golden Tilefish

Ha: There were a significant difference in the size structure between groupings of Golden Tilefish

Differences in the length-weight relationship between each grouping were analyzed, as differing length-weight relationship parameters are often an indication of a difference in life history characteristics between two groups of fish (Fonseca and Cabral 2007). The following equation was used to generate estimations for length-weight relationship parameters:

$W = \alpha L^{\beta}$
$W$ = total weight (kg)
$L$ = fork length (cm)
$\alpha, \beta$ = parameters

To determine statistical significance in differences among the parameters between groups, the above equation was log-transformed to generate the following linear relationship:

$\log(W) = \log(\alpha) + \beta \log(L)$

After calculating the above linear regression for each grouping, Analysis of Covariance (ANCOVA) was used to test for differences in slope (β) between pairs of regression equations. The following null hypotheses were analyzed for each question:

Ho: There were no statistical difference in β between groupings of Golden Tilefish

Ha: There were a statistically significant difference in β between groupings of Golden Tilefish

Length and weight measurements were also used to calculate indicators of Golden Tilefish overall body condition. The most commonly used measure of condition is Fulton's condition factor (Bolger and Connolly 1989). It is expanded as:

$Kf = (W/L^3) * 100$
W = Weight (in grams)
L = Fork length (in cm)

I also used the Le Cren (1951) index, known as Relative Condition Factor (Kn). It compares the predicted weight at the given length of the fish to its actual weight, although it can only be used to compare groups of fish when β in the length-weight relationships are not significantly different (Bolger and Connolly 1989). It is considered more reliable than Fulton's condition factor but is not as commonly used, so I analyzed both. It is defined as:

$Kn = W/\widehat{W}$
W = actual weight
$\widehat{W}$ = predicted weight

Hepatosomatic Index (HSI) was used specifically to analyze liver condition. It is calculated as:

$HSI = (LW/W) * 100$
LW = liver weight (g)
W = total body weight (kg)

Values of Fulton's condition factor, relative condition factor, and HSI were calculated for all sampled Golden Tilefish. HSI in Golden Tilefish has been found to be independent of month (Fitzhugh et al. 2010), but mean monthly values of HSI were compared using an ANOVA to verify that the difference in sampling months would not impact results. Mean condition factors were compared between each grouping using a Welch's t-test for significant differences between the groupings. The following null hypotheses were tested:

Ho: There were no difference in condition factors between fish length, month, and groupings of Golden Tilefish

Ha: There were a significant difference in condition factors between fish length, month, and groupings of Golden Tilefish

Growth curves for each grouping of Golden Tilefish were also calculated, using the methods in the von Bertalanffy (1938) equation:

$L_t = L_\infty * (1 - e^{-K * (t - t_0)})$
$L_t$ = length at time t
$L_\infty$ = asymptote of the von Bertalanffy equation
K = growth parameter
t = time of measurement
$t_0$ = time at which length is calculated to be 0

Growth curves were calculated for each grouping, and 95% confidence intervals from the bootstrapped (n = 1000) data were determined. Growth curves for each grouping were then compared using a Likelihood Ratio Test to determine which parameters significantly differ between groupings (Kimura 1980). Model selections using Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) then determined the best model fits (Burnham and Anderson 2002). The following null and alternate hypotheses were tested:

Ho: There were no difference in growth parameters between groupings of Golden Tilefish

Ha: There were a difference in growth parameters between groupings of Golden Tilefish

Estimations of instantaneous total mortality rate (Z) and annual total mortality rate (A) were also calculated for each fish grouping. Catch-at-age frequency was determined for both groupings, log transformed, and plotted. The slope of the descending limb of the catch curve, weighted with the natural log of the frequency of each age, was calculated to determine Z (Maceina and Bettoli 1998). Age ranges used in catch-at-age analyses were kept consistent between the two groupings. Total Mortality (A) was determined using the following formula:

$A = 1-e^{-Z}$
A = Annual total mortality rate
Z = Instantaneous total mortality rate

An ANCOVA was performed on the regression of each descending limb of the catch curves for each grouping to determine significant differences in Z. The following null and alternate hypotheses were tested:

> Ho: There were no difference in total mortality between groupings of Golden Tilefish
>
> Ha: There were a significant difference in total mortality between groupings of Golden Tilefish

All statistical analyses and graphics were conducted in R (R Core Team 2019). Most bootstrapping, growth model parameterization, and hypothesis testing were performed using the “FSA” package (Ogle et al. 2018).

*Tables and Figures*

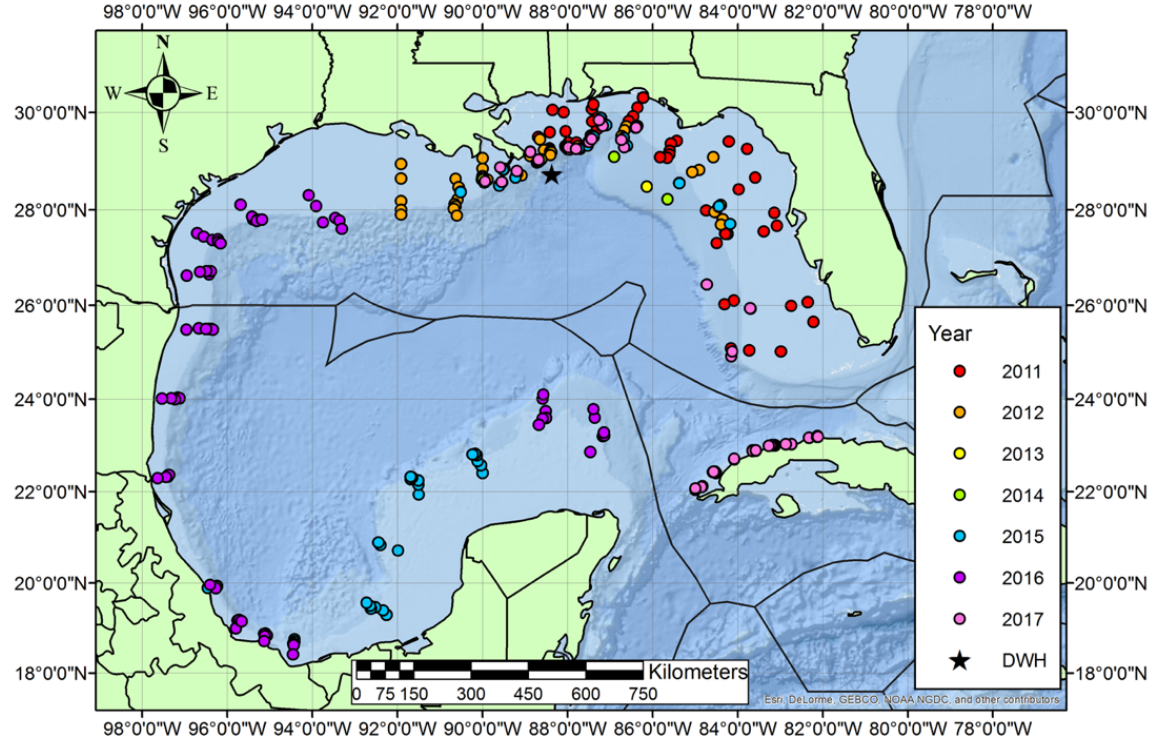

**Figure 2.** Map of sites sampled in the Gulf of Mexico from 2011 - 2017, as well as the site of the *Deepwater Horizon* (DWH) rig explosion (star).

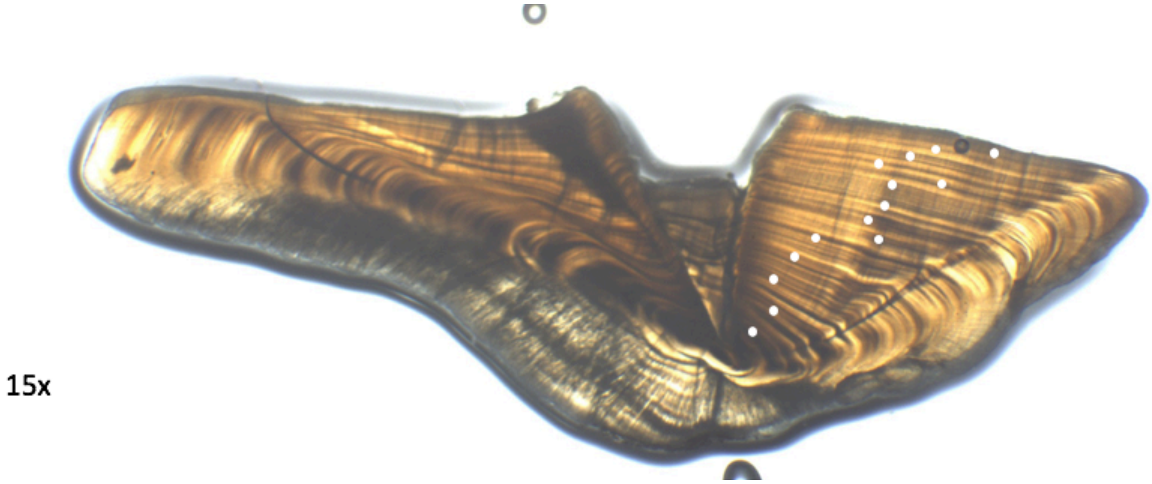

**Figure 3.** Sagittal otolith section (15x magnification). White dots represent annuli locations as determined by myself and Linda Lombardi. The fish was determined to be 14 years old and caught in 2013. Photo courtesy of Linda Lombardi

## Results

### *Samples Collected*

A total of 1353 Golden Tilefish were caught over the seven years of sampling, with 955 otoliths used in otolith-based age determination (Table 1). The remaining Golden Tilefish were not aged either because the otoliths were never extracted in the first place (e.g. station and size-specific sampling quotas were met), or because the otoliths cracked and became unusable during the extracting and sectioning processes. Catch per 1000 hook hours was highest in the De Soto canyon region (Figure 4). USA sampling yielded 1293 fish, and 140 fish were caught in Mexico (Table 1). Of the USA fish, 1025 were determined to belong to the "DWH" grouping, while 268 fish were sampled from all other US sites (Table 2; Figure 5).

### *Age Determination*

Reader precision and percent agreement estimations were calculated between the primary readings and primary and secondary readers. My Average Percent Error (APE) between first and second readings was 8.4%. APE between my readings and Dr. Lombardi's readings was 11%. Age uncertainty was highest in fish older than 15 years of age, although only a small number of fish were aged by two different readers for that age class (Figure 6). Percent agreement was 89% ± 3 bands between my readings, and 78% ± 3 bands between my readings and Dr. Lombardi's readings.

*Country of Capture*

Temperatures and depths at which Golden Tilefish were caught were similar among sites in the USA and Mexico (Figure 7). Both the native Kolmogorov-Smirnov test and the bootstrapped Kolmogorov-Smirnov test with 1000 bootstrap iterations indicated a difference in length distributions between the USA and Mexican samples (native p-value = 0.046*, bootstrap p-value = 0.028*, full sample statistic = 0.132). The dominant size group of Golden Tilefish from both countries was the 50 cm length class (Figure 8). There were relatively fewer older Golden Tilefish found in Mexico than in the USA (Figure 9). The Empirical Cumulative Distribution Function of Golden Tilefish from the USA and Mexico also illustrates the larger mean and median size of Golden Tilefish caught off Mexico (Figure 10). Therefore, I reject the null hypothesis; there is evidence that the length distributions were significantly different between Golden Tilefish from the USA and Golden Tilefish from Mexico.

Calculated parameters for the length-weight relationship were similar for Golden Tilefish between the USA and Mexico (ANCOVA of $\beta$ parameter: p value = 0.166 n.s., F = 1.921; Table 3). Predicted length-weight curves plotted on the raw data illustrate the lack of statistical difference in the length-weight relationship of Golden Tilefish from the USA and from Mexico (Figure 11). Therefore, I fail to reject the null hypothesis of no difference in the $\beta$ parameter between Golden Tilefish from the USA and Mexico.

Despite the similarity in length-weight relationship parameters, there is evidence that condition estimates significantly differ between fish caught from the USA and Mexico. Mean, median, and quartile estimates for both Fulton's condition factor and relative condition factor are predicted to be higher for fish from the USA than for fish from Mexico (Figure 12-13). Additionally, the mean estimates for both Fulton's condition factor and relative condition factor were found via a Welch's t-test to significantly differ between fish from the USA and Mexico ($p < 0.001$*** for both tests). However, HSI does not significantly differ ($p = 0.852$ n.s.). Although samples were collected in different months, there is no statistically significant difference in HSI by month of capture ($p = 0.503$ n.s.; Figure 14). I reject the null hypothesis for differences by country in both Fulton's condition factor and relative condition factor, but fail to reject the null hypothesis for differences by country in HSI.

However, von Bertalanffy growth curve parameters are consistent between the two countries (Table 4). Predicted growth curves for Golden Tilefish from both the USA and Mexico were plotted with each other along with bootstrapped 95% confidence intervals, however, there is not much overlap (Figure 15). Results from Kimura's likelihood ratio test model selection technique indicated only a significant difference in the K model parameters between USA and Mexico (Table 5). AIC and BIC model selections, however, suggested that the best model was the one where only $L_\infty$ differed between parameterizations (Table 6). Therefore, I fail to reject the null hypothesis of no difference in groups, as there was evidence that at least one von Bertalanffy parameter differed between the growth curves.

The total instantaneous mortality rate (Z) for Golden Tilefish from the USA (0.26 ± 0.03), calculated as the slope of the descending limb of the catch curve, was lower than for fish from Mexico (0.39 ± 0.05; Table 7; Figure 16). The age range used was 10 - 18 years. An ANCOVA comparing the slopes of the descending limbs revealed that the difference in Z between the USA and Mexico is statistically significant ($p = 0.017$*). Therefore, I reject the null hypothesis; the total instantaneous mortality rate was significantly different between Golden Tilefish caught in the USA and in Mexico.

### *DWH Spill Perimeter*

Both the native Kolmogorov-Smirnov test between length distributions from Golden Tilefish caught in the vicinity of the DWH site and Golden Tilefish caught elsewhere in the USA and the bootstrapped K-S test indicated no statistically significant difference (p-value = 0.496 n.s. and p-value = 0.379 n.s., respectively). Again, the most prevalent length class was 50 cm for both groupings (Figure 17). Age distribution was relatively consistent between Golden Tilefish caught in the DWH-affected area and fish caught elsewhere in the USA (Figure 18). Similarities in the length distribution according to DWH site membership is also apparent by examining the ECDF of both groupings (Figure 19). Since the bootstrapped p-value was greater than 0.05 for the K-S test, I fail to reject the null hypothesis of no difference in length distributions.

Additionally, the length-weight relationships were similar between groupings (Figure 20; Table 8). The ANCOVA for the linear regressions of ln(weight) on ln(length) for Golden Tilefish from DWH sites and all other US sites was not statistically significant (p = 0.691 n.s.), therefore I fail to reject the null hypothesis of no difference in the length-weight parameters between groupings.

Both Fulton's condition factor and relative condition factor were marginally larger at DWH sites than all other sites (Figure 21-22). The t-tests on both the Fulton's condition factor mean and the relative condition factor mean were statistically significant ($p < 0.001$*** for both tests). However, mean values of HSI do not significantly differ (p = 0.896 n.s.). Therefore, I reject the null of no difference in measures of condition for Fulton's condition factor and relative condition factor, but fail to reject the null for differences in HSI.

The predicted von Bertalanffy growth curves, with bootstrapped 95% confidence intervals, overlap when plotted, although the estimated parameters differed (Table 9; Figure 23). The likelihood ratio test suggested that the difference in parameters between DWH Golden Tilefish and all other US fish is in both $L_\infty$ and K (Table 10). AIC and BIC model selection both confirmed the model where both $L_\infty$ and K differ between groupings as the best model (Table 11). I fail to reject the null hypothesis; there was a statistically significant difference in some of the von Bertalanffy parameters between groupings.

The estimated mean total instantaneous mortality rate for fish from the DWH site was approximately 50% higher than elsewhere in the USA (0.32 ± 0.02 & 0.21 ± 0.03, respectively; Table 12; Figure 24). The age range used was 10 - 25 years. Subsequently, an ANCOVA testing difference between the slopes of the descending limbs was statistically significant at $\alpha = 0.05$ (p-value = 0.030*). Therefore, I reject the null hypothesis that there was a statistically significant difference in total instantaneous mortality rate between Golden Tilefish caught around the DWH site and Golden Tilefish caught elsewhere.

### *Before and After DWH Spill*

The pre-spill group consisted of 1776 fish, with 1732 ages analyzed (Table 13; Figure 25). The dominant length class was 50 cm for both Golden Tilefish caught before and after the DWH oil spill (Figure 26). The age frequency of Golden Tilefish caught pre-spill is also consistent with the age frequency of fish caught post-spill (Figure 27). Although the length distributions analyzed by a bootstrapped K-S test were significantly different (p-value = 0.012*), the ECDF shows little difference in the cumulative distributions between groupings of fish (Figure 28). However, since the K-S test p-value is significant, I reject the null hypothesis of no difference in size distribution between Golden Tilefish caught before the DWH spill and after.

Length and weight distributions were similar between the two groupings, as evidenced by the estimated parameters and the plotted regression curves (Table 14; Figure 29). As indicated by an ANCOVA of the log(length)-log(weight) relationships, there was no significant difference in $\beta$ between Golden Tilefish caught before the DWH oil spill and after ($p = 0.904$ n.s.). I fail to reject the null hypothesis of no difference in the length-weight relationship between groupings.

While the 95% confidence intervals for both condition factors are wider for Golden Tilefish caught after the DWH spill, the mean condition factors are higher (Figure 30-31). Welch's t-tests confirm that there are significant differences in the mean condition factor values between both groupings of fish ($p < 0.001$*** for both tests). I therefore reject the null hypothesis of no difference in condition factors pre- and post-spill.

Estimates of the von Bertalanffy growth parameters for fish caught before the DWH oil spill and after are also similar (Table 15). The predicted von Bertalanffy growth curves and bootstrapped 95% confidence intervals overlap when plotted, but the likelihood ratio test suggested that that the statistically significant difference in parameters was in $L_\infty$ and $t_0$ (Table 16; Figure 32). AIC model selection process also selected the model where $L_\infty$ and $t_0$ differ as the best model, but BIC model selection process selected the model where only $t_0$ differs as a parameter as the best model (Table 17). However, since BIC model selection is not a hypothesis test, I reject the null hypothesis of no difference in $L_\infty$ and $t_0$ between Golden Tilefish caught before and after the DWH oil spill. However, I fail to reject the null hypotheses for differences in K.

The total instantaneous mortality rates for Golden Tilefish caught before the DWH oil spill and after the spill were similar (before $Z = 0.31 \pm 0.02$, after $Z = 0.32 \pm 0.02$; Table 18; Figure 33). The age range used was 10 - 18 years. Additionally, an ANCOVA on the descending limbs suggested no statistically significant difference exists in slopes ($p = 0.759$ n.s.). Therefore, I fail to reject the null hypothesis of a significant difference in total instantaneous mortality rate between Golden Tilefish caught before and after the DWH spill.

*Tables and Figures*

**Table 1.** Number of Golden Tilefish sampled and otoliths collected by country caught and year.

| | **USA** | | **Mexico** | |
|---|---|---|---|---|
| **Year** | Fish Sampled | Total Ages Determined | Fish Sampled | Total Ages Determined |
| **2011** | 82 | 73 | - | - |
| **2012** | 431 | 172 | - | - |
| **2013** | 165 | 97 | - | - |
| **2014** | 160 | 58 | - | - |
| **2015** | 180 | 168 | 44 | 39 |
| **2016** | 142 | 134 | 96 | 91 |
| **2017** | 133 | 123 | - | - |
| **Total** | 1293 | 825 | 140 | 130 |

**Table 2.** Summary of fish sampled and ages determined by whether or not the fish was captured from the area of the DWH surface oil spill, 2011 - 2017.

| | **DWH** | | **All Other US Sites** | |
|---|---|---|---|---|
| **Year** | Fish Sampled | Total Ages Determined | Fish Sampled | Total Ages Determined |
| **2011** | 49 | 44 | 33 | 29 |
| **2012** | 372 | 161 | 59 | 11 |
| **2013** | 165 | 97 | - | - |
| **2014** | 130 | 47 | 30 | 11 |
| **2015** | 180 | 168 | - | - |
| **2016** | - | - | 142 | 134 |
| **2017** | 129 | 119 | 4 | 4 |
| **Total** | 1025 | 636 | 268 | 189 |

**Table 3**. Summary of fish sampled using longline fishing gear and number of ages determined, 1997 - 2009 (Lombardi et al. 2010). Data aggregated from fishery-dependent and fishery-independent sources by NMFS, and were used to compare growth curves pre- and post-DWH.

| | **All Data** | | **Used as Pre-DWH Estimates** | |
|---|---|---|---|---|
| **Year** | Fish Sampled | Ages Determined | Fish Sampled | Ages Determined |
| **1997** | 43 | 43 | - | - |
| **1998** | 4 | 4 | - | - |
| **1999** | - | - | - | - |
| **2000** | 17 | 17 | 17 | 17 |
| **2001** | 91 | 91 | 52 | 52 |
| **2002** | 122 | 119 | 67 | 66 |
| **2003** | 282 | 273 | 230 | 222 |
| **2004** | 557 | 544 | 396 | 385 |
| **2005** | 601 | 570 | 266 | 254 |
| **2006** | 286 | 268 | 121 | 117 |
| **2007** | 422 | 395 | 76 | 74 |
| **2008** | 739 | 720 | 30 | 29 |
| **2009** | 1393 | 1367 | 521 | 516 |
| **Total** | 4557 | 4411 | 1776 | 1732 |

**Table 4.** Estimates for weight-length relationship parameters ($\alpha$ and $\beta$) for Golden Tilefish caught within the USA's EEZ (n = 1154; length range = 34-106 cm; weight range = 0.350-15.800 kg) and Mexico's EEZ (n = 140; length range = 36-97 cm; weight range = 0.302-11.548 kg), 2011 - 2017.

| | | **Estimate** | **SE** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **USA** | $\alpha$ | 6.196e-03 | 0.032 | 158.1 | <0.001*** | 5.817e-03 | 6.600e-03 |
| | $\beta$ | 3.075 | 0.018 | 167.1 | <0.001*** | 3.039 | 3.111 |
| **Mexico** | $\alpha$ | 5.143e-03 | 0.099 | 53.19 | <0.001*** | 4.228e-03 | 6.257e-03 |
| | $\beta$ | 3.160 | 0.056 | 56.74 | <0.001*** | 3.050 | 3.270 |

**Table 5.** Estimated von Bertalanffy growth function parameters ($L_\infty$, K, and $t_0$) with bootstrapped (n = 1000) 95% confidence intervals for Golden Tilefish caught within the USA's EEZ (n = 816) and Mexico's EEZ (n = 125), 2011 - 2017.

| | | Estimate | Standard Error | t value | p-value | LCI | UCI |
|---|---|---|---|---|---|---|---|
| **USA** | $L_\infty$ | 83.822 | 4.330 | 19.356 | <0.001*** | 77.075 | 94.702 |
| | K | 0.090 | 0.015 | 5.813 | <0.001*** | 0.062 | 0.122 |
| | $t_0$ | -2.838 | 0.957 | -2.967 | 0.003** | -4.957 | -1.227 |
| **Mexico** | $L_\infty$ | 87.382 | 7.678 | 11.381 | <0.001*** | 76.405 | 112.993 |
| | K | 0.116 | 0.035 | 3.303 | 0.001** | 0.051 | 0.199 |
| | $t_0$ | -1.380 | 1.412 | -0.978 | 0.330 | -5.473 | 0.839 |

**Table 6.** Likelihood ratio test for similarities of von Bertalanffy parameters ($L_\infty$, K, and $t_0$; Kimura 1980) for Golden Tilefish caught within the USA's EEZ and Mexico's EEZ, 2011 - 2017.

| | df | Chi sq | p-value |
|---|---|---|---|
| **All parameters same vs All parameters differ** | 3 | 39.543 | <0.001*** |
| **$L_\infty$ and K differ vs All parameters differ** | 1 | 0.714 | 0.398 |
| **$L_\infty$ and $t_0$ differ vs All parameters differ** | 1 | 0.587 | 0.444 |
| **K and $t_0$ differ vs All parameters differ** | 1 | 0.203 | 0.653 |
| **K differs vs K and $t_0$ differ** | 1 | 2.558 | 0.110 |
| **$t_0$ differs vs K and $t_0$ differ** | 1 | 8.609 | 0.003** |
| **All parameters same vs K differs** | 1 | 36.782 | <0.001*** |

**Table 7.** Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) selection for von Bertalanffy growth curve models from Golden Tilefish caught within the USA's EEZ and Mexico's EEZ, 2011 - 2017.

| | df | AIC | df | BIC |
|---|---|---|---|---|
| **All parameters differ** | 7 | 6974.393 | 7 | 7008.322 |
| **$L_\infty$ and K differ** | 6 | 6973.107 | 6 | 7002.189 |
| **$L_\infty$ and $t_0$ differ** | 6 | 6972.980 | 6 | 7002.062 |
| **K and $t_0$ differ** | 6 | 6972.596 | 6 | 7001.678 |
| **$L_\infty$ differs** | 5 | 6971.107 | 5 | 6995.342 |
| **K differs** | 5 | 6973.154 | 5 | 6997.389 |
| **$t_0$ differs** | 5 | 6979.205 | 5 | 7003.440 |
| **All parameters same** | 4 | 7007.937 | 4 | 7027.324 |

**Table 8.** Total instantaneous mortality rate (Z) and annual mortality rate (A) estimates for Golden Tilefish caught within the USA's EEZ and Mexico's EEZ, 2011 - 2017.

| | | **Estimate** | **Standard Error** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **USA** | Z | 0.26 | 0.03 | 8.86 | <0.001 *** | 0.19 | 0.33 |
| | A | 0.23 | - | - | - | 0.17 | 0.28 |
| **Mexico** | Z | 0.39 | 0.05 | 7.68 | <0.001 *** | 0.27 | 0.52 |
| | A | 0.32 | - | - | - | 0.24 | 0.41 |

**Table 9.** Estimates for length-weight relationship parameters ($\alpha$ and $\beta$) for Golden Tilefish caught from sites close to the DWH oil spill (n = 895; length range = 34-106 cm; weight range = 0.350-15.800 kg) and from all other sites in the USA's EEZ (n = 259; length range = 34-104 cm; weight range = 0.380-14.800 kg), 2011 - 2017.

| | | **Estimate** | **SE** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **DWH** | $\alpha$ | 6.280e-03 | 0.037 | 138.0 | <0.001*** | 5.843e-03 | 6.749e-03 |
| | $\beta$ | 3.070 | 0.021 | 146.1 | <0.001*** | 3.029 | 3.111 |
| **All Others** | $\alpha$ | 5.976e-03 | 0.064 | 80.0 | <0.001*** | 5.268e-03 | 6.779e-03 |
| | $\beta$ | 3.087 | 0.037 | 84.2 | <0.001*** | 3.015 | 3.160 |

**Table 10.** Estimates for von Bertalanffy growth curve parameters ($L_\infty$, K, and $t_0$) for Golden Tilefish caught from sites close to the DWH oil spill (n = 624) and from all other sites in the USA's EEZ (n = 192), 2011 - 2017.

| | | **Estimate** | **Standard Error** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **DWH** | $L_\infty$ | 92.960 | 6.955 | 13.366 | <0.001*** | 82.353 | 114.161 |
| | K | 0.073 | 0.015 | 4.824 | <0.001*** | 0.044 | 0.104 |
| | $t_0$ | -3.229 | 1.081 | -2.988 | 0.003** | -6.039 | -1.461 |
| **All Other Sites** | $L_\infty$ | 70.431 | 4.383 | 16.069 | <0.001*** | 64.513 | 88.680 |
| | K | 0.135 | 0.044 | 3.060 | 0.002** | 0.053 | 0.228 |
| | $t_0$ | -1.987 | 1.968 | -1.009 | 0.314 | -9.110 | 0.596 |

**Table 11.** Likelihood ratio test ($L_\infty$, K, and $t_0$; Kimura 1980) for similarities of von Bertalanffy growth curve parameters for Golden Tilefish caught from sites close to the DWH oil spill and from all other sites in the USA's EEZ, 2011 - 2017.

| | **df** | **Chi sq** | **p-value** |
|---|---|---|---|
| **All parameters same vs All parameters differ** | 3 | 22.200 | <0.001*** |
| **$L_\infty$ and K differ vs All parameters differ** | 1 | 0.358 | 0.550 |
| **$L_\infty$ and $t_0$ differ vs All parameters differ** | 1 | 2.740 | 0.098 |
| **K and $t_0$ differ vs All parameters differ** | 1 | 6.220 | 0.013* |
| **$L_\infty$ differs vs $L_\infty$ and K differ** | 1 | 11.543 | <0.001*** |
| **K differs vs $L_\infty$ and K differ** | 1 | 16.031 | <0.001*** |

**Table 12.** Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC )model selection for von Bertalanffy growth curve parameters for Golden Tilefish caught from sites close to the DWH oil spill and from all other sites in the USA's EEZ, 2011 - 2017.

| | df | AIC | df | BIC |
|---|---|---|---|---|
| **All parameters differ** | 7 | 6055.388 | 7 | 6088.319 |
| **$L_\infty$ and K differ** | 6 | 6053.746 | 6 | 6081.973 |
| **$L_\infty$ and $t_0$ differ** | 6 | 6056.128 | 6 | 6084.354 |
| **K and $t_0$ differ** | 6 | 6059.608 | 6 | 6087.835 |
| **$L_\infty$ differs** | 5 | 6063.290 | 5 | 6086.812 |
| **K differs** | 5 | 6067.777 | 5 | 6091.300 |
| **$t_0$ differs** | 5 | 6071.408 | 5 | 6094.930 |
| **All parameters same** | 4 | 6071.588 | 4 | 6090.406 |

**Table 13.** Total instantaneous mortality rate (Z) and annual mortality rate (A) estimates for Golden Tilefish caught from sites close to the DWH oil spill and from all other sites in the USA's EEZ, 2011 - 2017.

| | | Estimate | Standard Error | t value | p-value | LCI | UCI |
|---|---|---|---|---|---|---|---|
| **DWH** | Z | 0.32 | 0.02 | 18.62 | <0.001*** | 0.29 | 0.36 |
| | A | 0.28 | - | - | - | 0.25 | 0.30 |
| **All Others** | Z | 0.21 | 0.03 | 6.58 | <0.001*** | 0.14 | 0.28 |
| | A | 0.19 | - | - | - | 0.13 | 0.24 |

**Table 14.** Estimates for weight-length relationship parameters ($\alpha$ and $\beta$) for Golden Tilefish caught from sites in the USA's EEZ before the DWH oil spill (2000 - 2009; n = 438; length range = 29-104 cm; weight range = 0.264-14.000 kg) and after the DWH oil spill (2011 - 2017; n = 895; length range = 34-106 cm; weight range = 0.350-15.800 kg).

| | | Estimate | SE | t value | p-value | LCI | UCI |
|---|---|---|---|---|---|---|---|
| **Before DWH** | $\alpha$ | 6.396e-03 | 0.052 | 97.97 | <0.001*** | 5.780e-03 | 7.079e-03 |
| | $\beta$ | 3.075 | 0.030 | 103.18 | <0.001*** | 3.016 | 3.133 |
| **After DWH** | $\alpha$ | 6.280e-03 | 0.037 | 138.0 | <0.001*** | 5.843e-03 | 6.749e-03 |
| | $\beta$ | 3.070 | 0.021 | 146.1 | <0.001*** | 3.029 | 3.111 |

**Table 15.** Estimates for von Bertalanffy growth curve parameters ($L_\infty$, K, and $t_0$) for Golden Tilefish caught from sites in the USA's EEZ before the DWH oil spill (2000 - 2009; n = 1732) and after the DWH oil spill (2011 - 2017; n = 624) with bootstrapped (n = 1000) 95% confidence intervals.

| | | **Estimate** | **Standard Error** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **Before DWH** | $L_\infty$ | 85.147 | 3.568 | 23.867 | <0.001*** | 79.911 | 94.612 |
| | K | 0.084 | 0.013 | 6.704 | <0.001*** | 0.060 | 0.108 |
| | $t_0$ | -4.485 | 0.985 | -4.552 | <0.001*** | -6.869 | -2.882 |
| **After DWH** | $L_\infty$ | 92.960 | 6.955 | 13.366 | <0.001*** | 82.353 | 114.161 |
| | K | 0.073 | 0.015 | 4.824 | <0.001*** | 0.044 | 0.104 |
| | $t_0$ | -3.229 | 1.081 | -2.988 | 0.003** | -6.039 | -1.461 |

**Table 16.** Likelihood ratio ($L_\infty$, K, and $t_0$; Kimura 1980) test for similarities of Von Bertalanffy growth curve parameters for Golden Tilefish caught from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017).

| | **df** | **Chi sq** | **p-value** |
|---|---|---|---|
| **No parameters differ vs all parameters differ** | 3 | 34.890 | <0.001 *** |
| **$L_\infty$ and K differ vs all parameters differ** | 1 | 0.793 | 0.373 |
| **$L_\infty$ and $t_0$ differ vs all parameters differ** | 1 | 0.366 | 0.545 |
| **K and $t_0$ differ vs all parameters differ** | 1 | 1.345 | 0.246 |
| **$L_\infty$ differs vs $L_\infty$ and $t_0$ differ** | 1 | 16.264 | <0.001 *** |
| **$t_0$ differs vs $L_\infty$ and $t_0$ differ** | 1 | 4.072 | 0.044* |
| **$t_0$ differs vs no parameters differ** | 1 | 30.452 | <0.001 *** |

**Table 17.** Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) model selection for von Bertalanffy growth curve parameters for Golden Tilefish caught from sites in the USA's EEZ before the DWH oil spill (1997 - 2009) and after the DWH oil spill (2011 - 2017).

| | **df** | **AIC** | **df** | **BIC** |
|---|---|---|---|---|
| **All parameters differ** | 7 | 17735.99 | 7 | 17776.35 |
| **L∞ and K differ** | 6 | 17734.79 | 6 | 17769.37 |
| **L∞ and to differ** | 6 | 17734.36 | 6 | 17768.95 |
| **K and to differ** | 6 | 17735.34 | 6 | 17769.93 |
| **L∞ differs** | 5 | 17748.62 | 5 | 17777.45 |
| **K differs** | 5 | 17742.43 | 5 | 17771.26 |
| **to differs** | 5 | 17736.43 | 5 | 17765.25 |
| **All parameters same** | 4 | 17764.88 | 4 | 17787.94 |

**Table 18.** Total instantaneous mortality rate (Z) and annual mortality rate (A) estimates for Golden Tilefish caught from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017).

| | | **Estimate** | **Standard Error** | **t value** | **p-value** | **LCI** | **UCI** |
|---|---|---|---|---|---|---|---|
| **Before DWH** | Z | 0.31 | 0.02 | 13.29 | <0.001*** | 0.26 | 0.36 |
| | A | 0.27 | - | - | - | 0.23 | 0.31 |
| **After DWH** | Z | 0.32 | 0.02 | 18.62 | <0.001*** | 0.29 | 0.36 |
| | A | 0.28 | - | - | - | 0.25 | 0.30 |

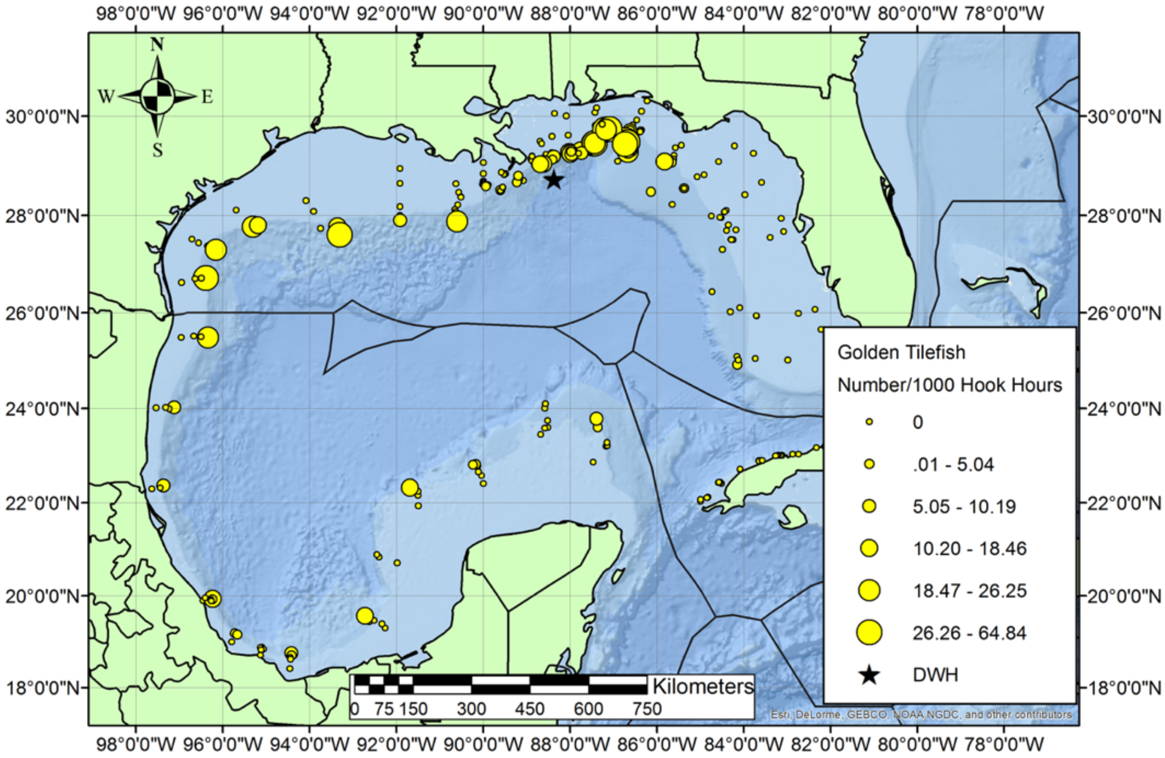

**Figure 4.** Map of Golden Tilefish catch per 1000 hook hours from 2011 - 2017, as well as the site of the *Deepwater Horizon* (DWH) rig explosion (star).

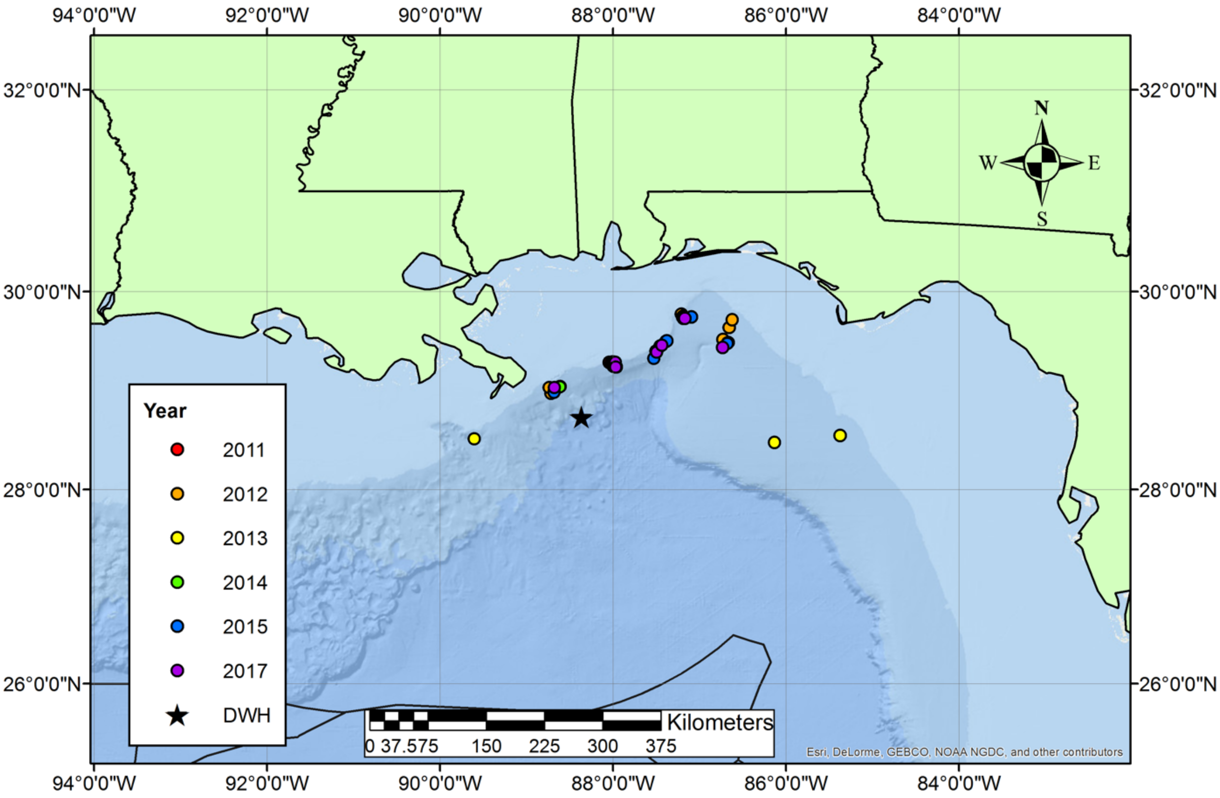

**Figure 5.** Map of sites sampled from 2011 - 2017 used as the DWH grouping, as well as the site of the *Deepwater Horizon* (DWH) rig explosion (star). The area around the DWH oil spill was not sampled in 2016.

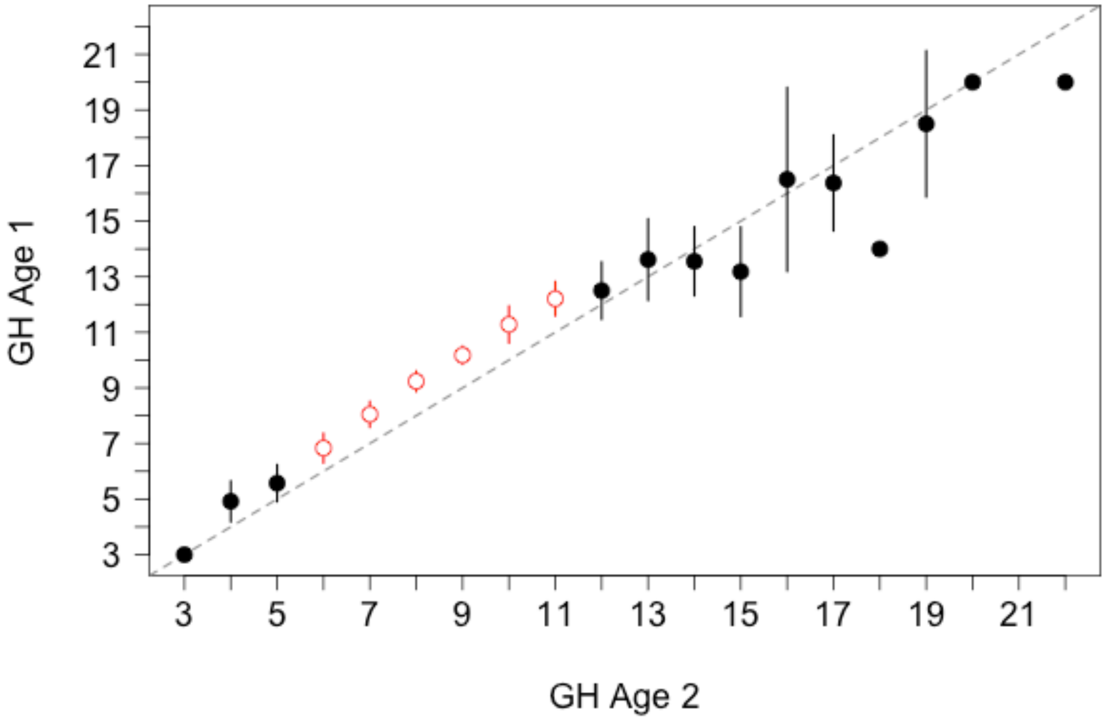

**Figure 6.** Age bias plot between first and second otolith readings by the primary reader (GH). Dots indicate the mean determined age, and solid vertical lines indicate the standard deviation of ageing estimates. The dotted line is the 1:1 reference line.

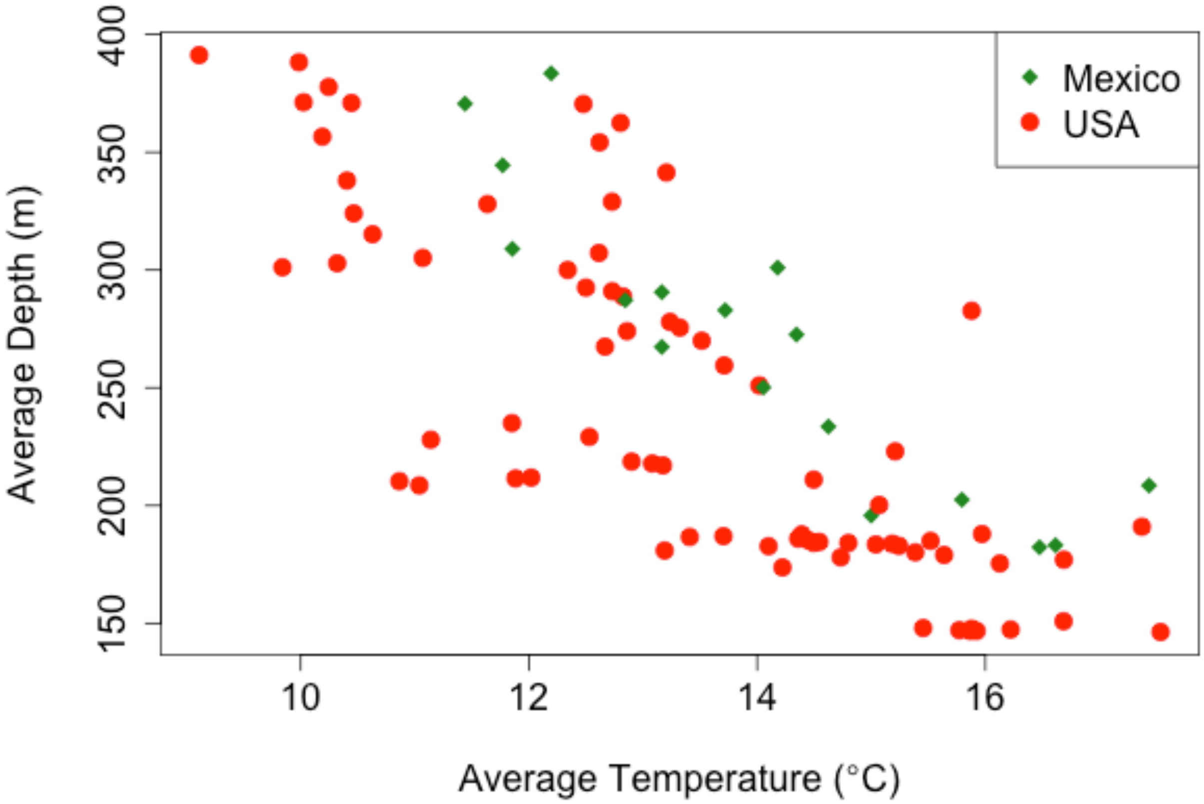

**Figure 7.** Temperature (°C) and depth (m) frequency for sites where Golden Tilefish were caught in the USA and Mexico, 2011 - 2017.

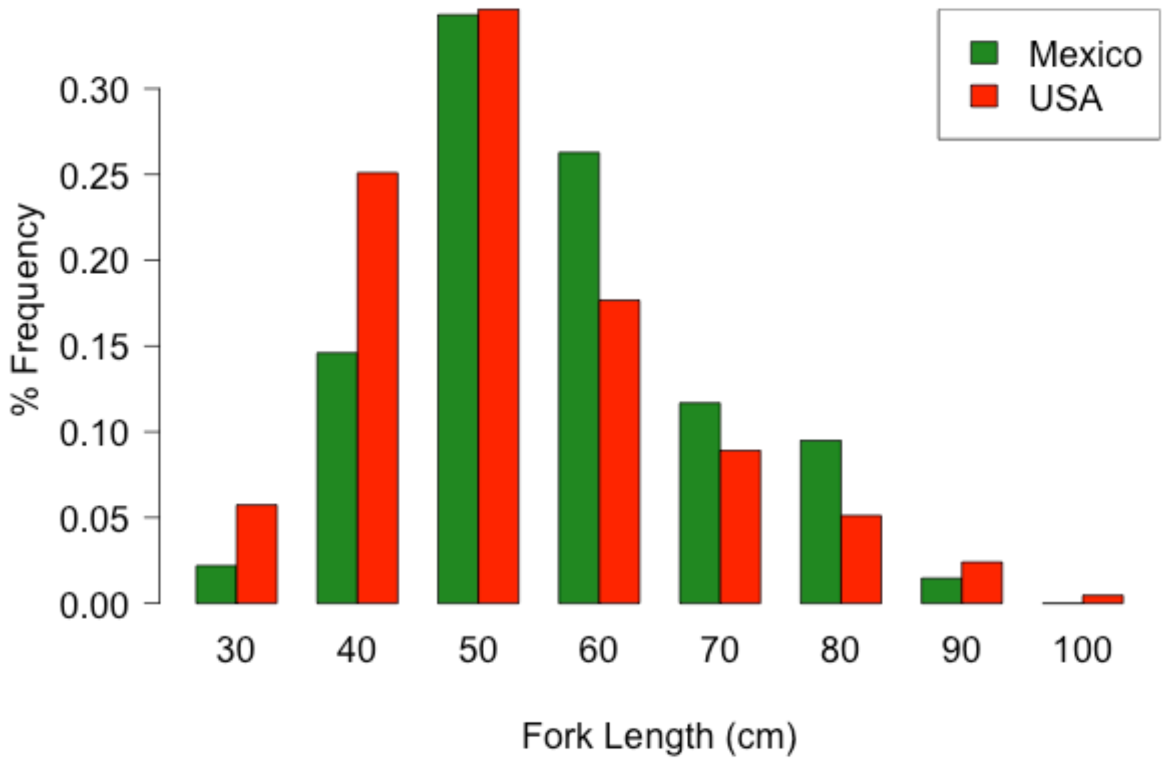

**Figure 8.** Fork length (cm) frequency distribution of Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017.

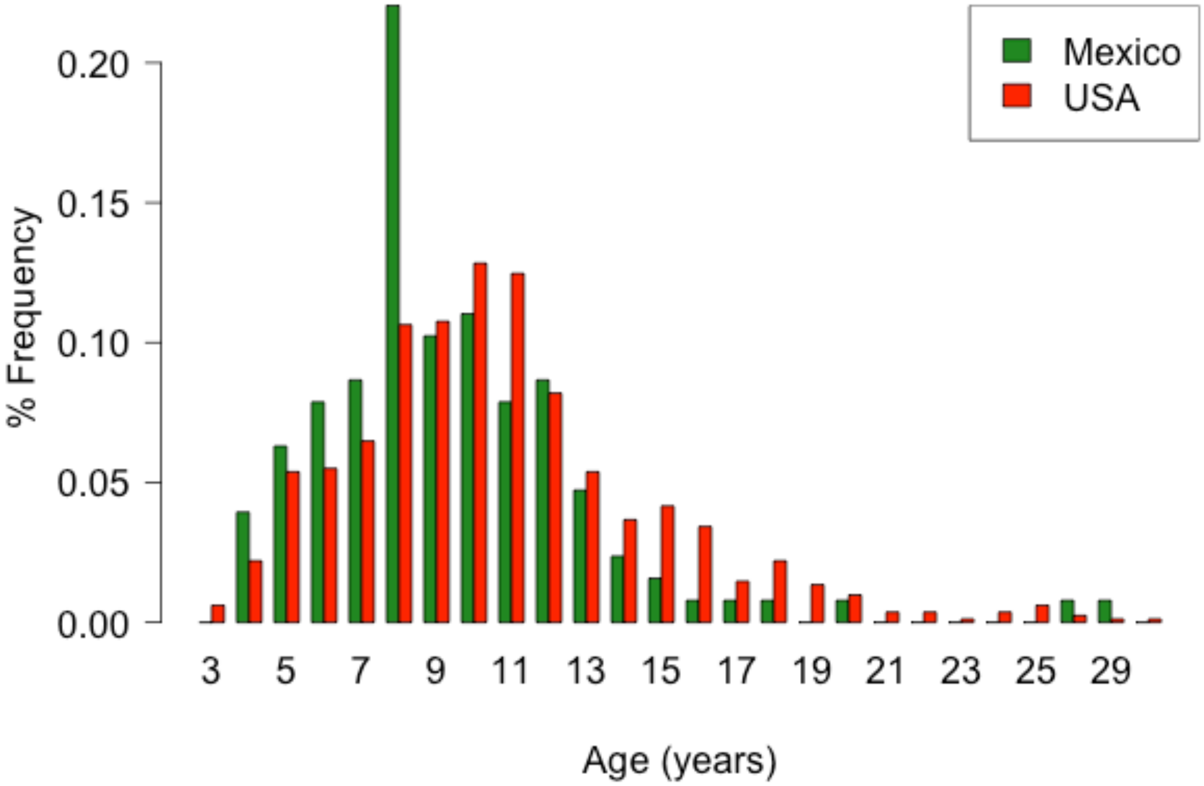

**Figure 9.** Age frequency distribution of Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017.

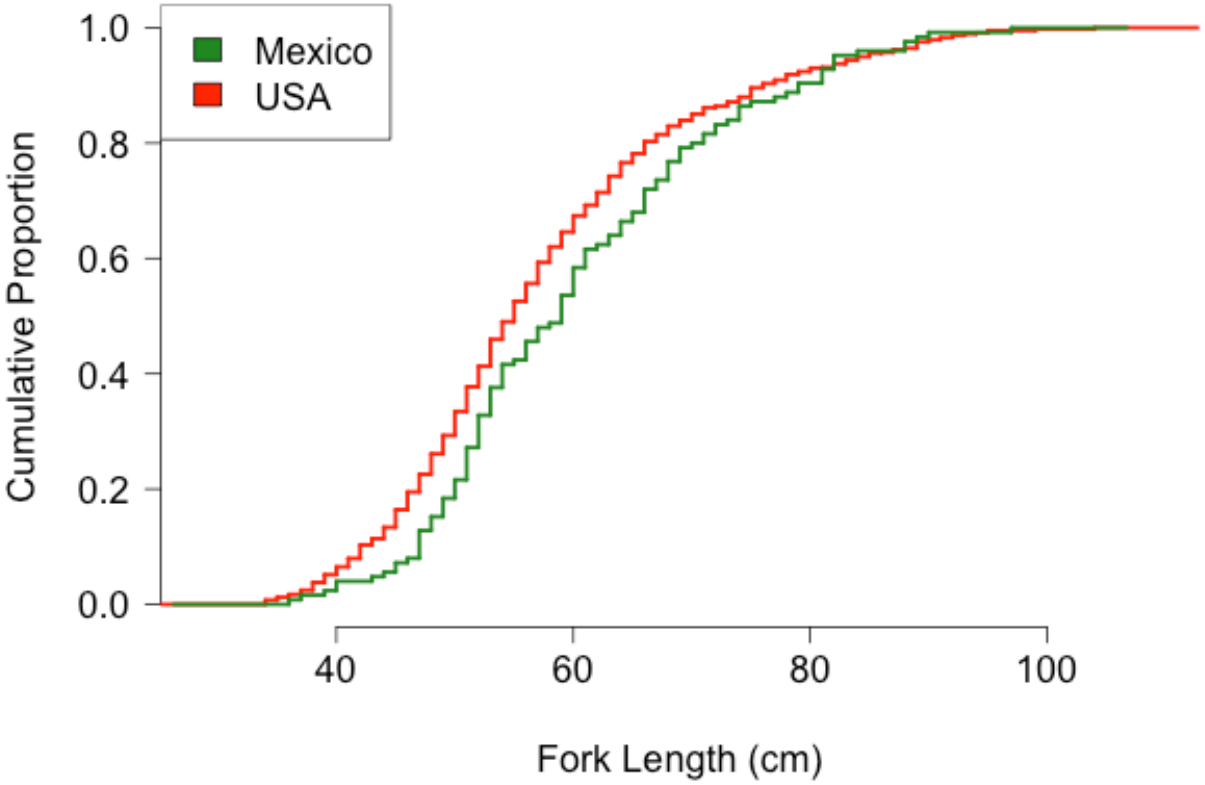

**Figure 10.** Empirical cumulative distribution (ECDF) function of Golden Tilefish, ages 4 - 18 sampled within the USA and Mexican EEZs, 2011 - 2017. The y-axis is the proportion of Golden Tilefish with fork lengths that correspond to the values on the x-axis.

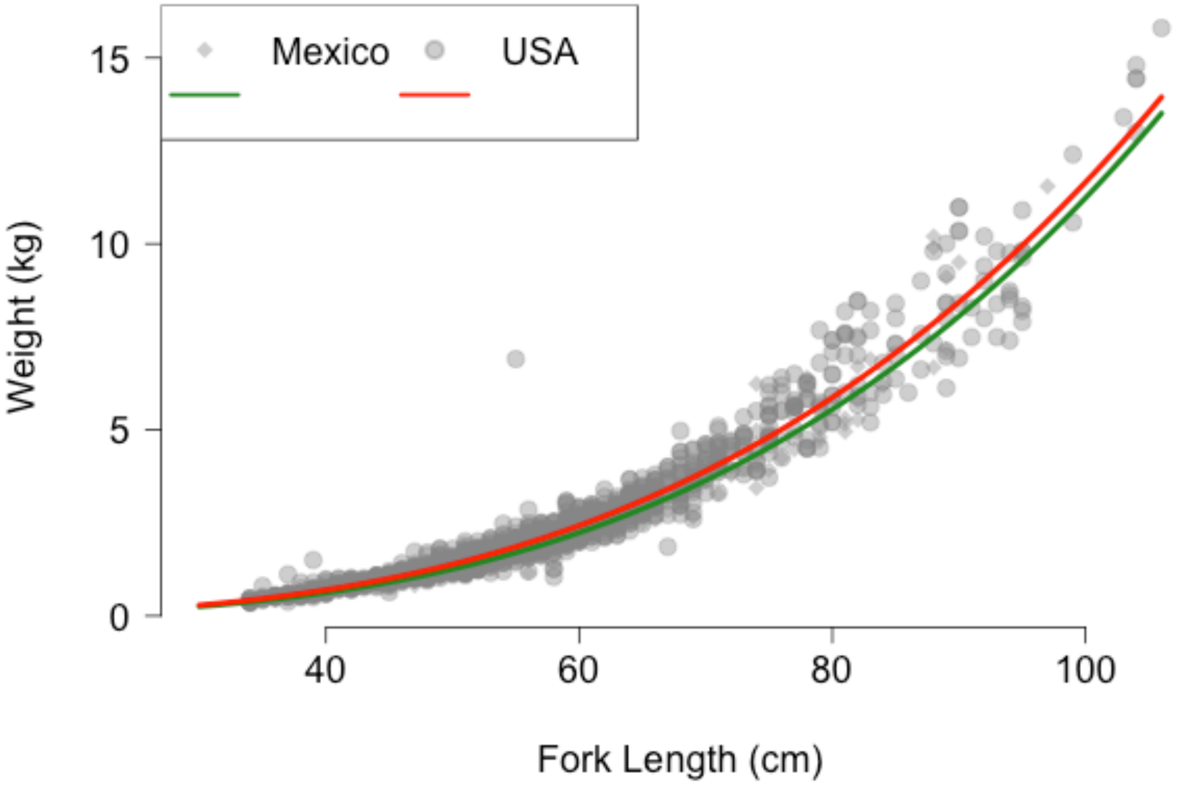

**Figure 11.** Fork length (cm) versus total weight (kg) for Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017. Length-weight regression equations are plotted by country.

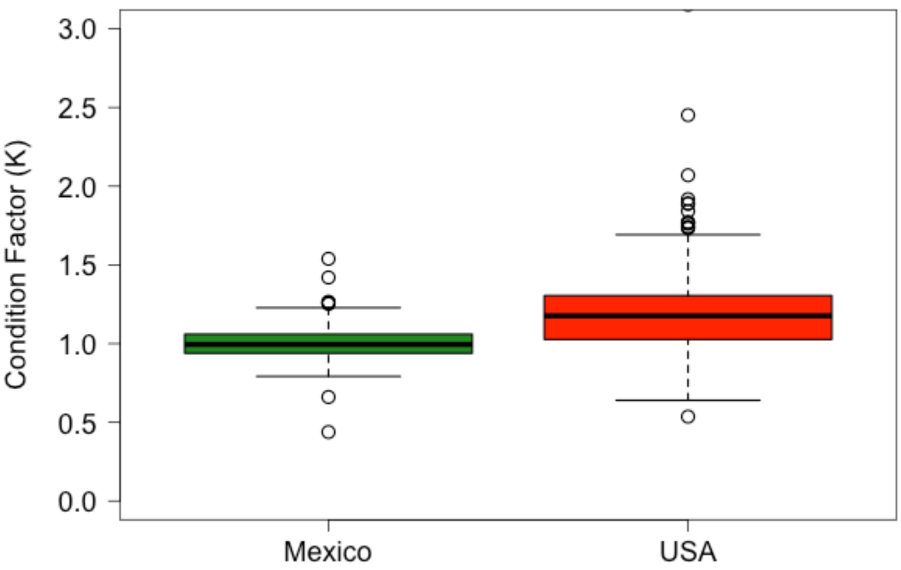

**Figure 12.** Boxplot of Fulton's condition factor (Kf) means, quartiles, and extremes for Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017. The average Fulton's condition factor was 1.187 ± 0.228 for fish from the USA (range = 0.536 - 4.544), whereas the average for fish from Mexico was 1.007 ± 0.127 (range = 0.438 - 1.539).

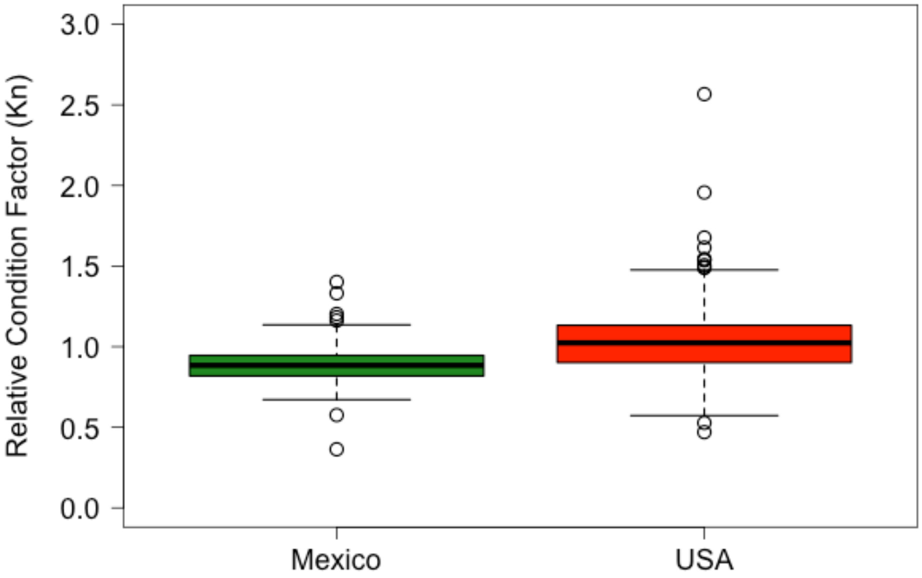

**Figure 13.** Boxplot of relative condition factor (Kn) means, quartiles, and extremes for Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017. The average relative condition factor was 1.030 ± 0.191 for fish from the USA (range = 0.470 - 3.932), whereas the average for fish from Mexico was 0.892 ± 0.126 (range = 0.365 - 1.403).

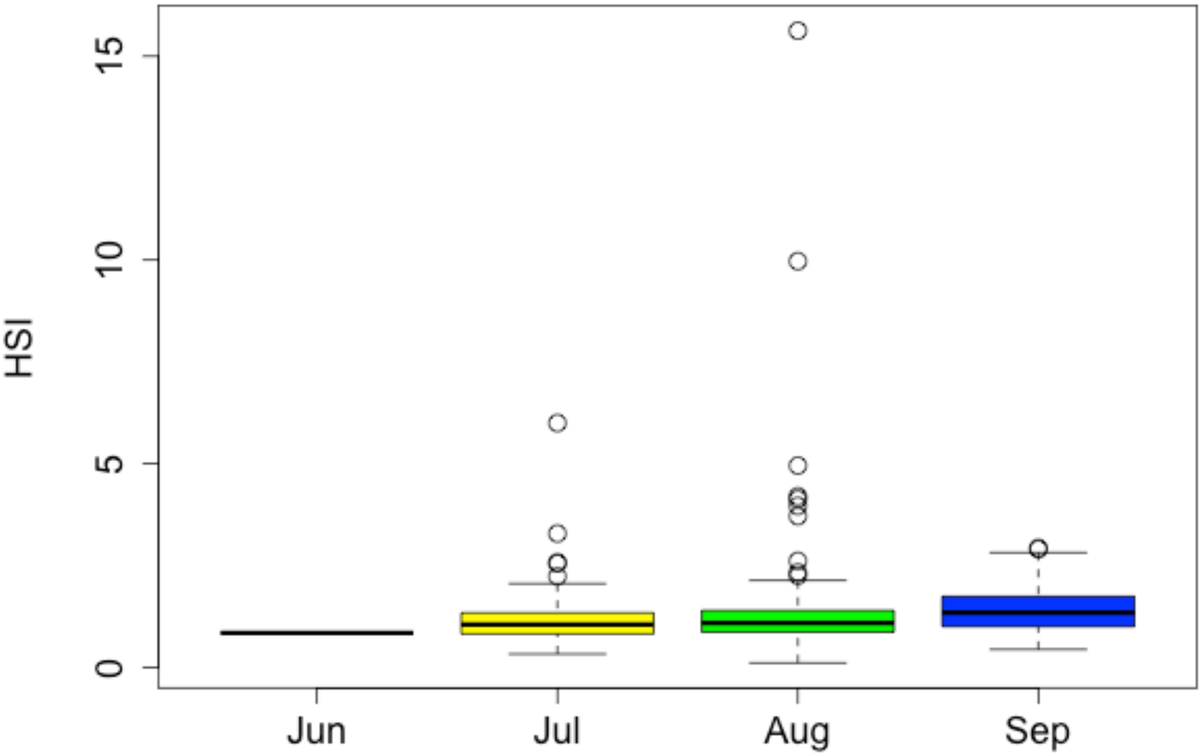

**Figure 14.** Boxplot of all Golden Tilefish HSI means, quartiles, and extremes by month of capture, 2011 - 2017.

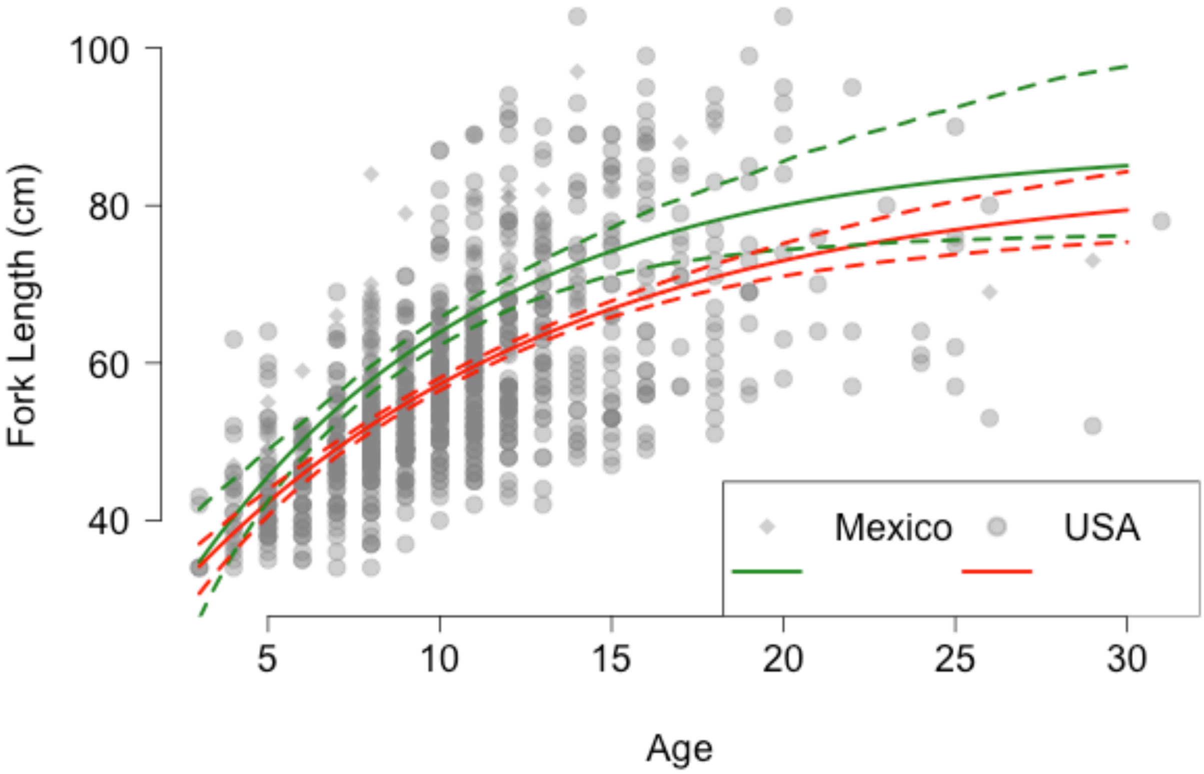

**Figure 15.** Von Bertalanffy growth curves (solid lines) for Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017. Dashed lines represent the bootstrapped 95% confidence intervals, and gray dots represent the observed age at length data for fish from the USA (circles) and Mexico (diamonds).

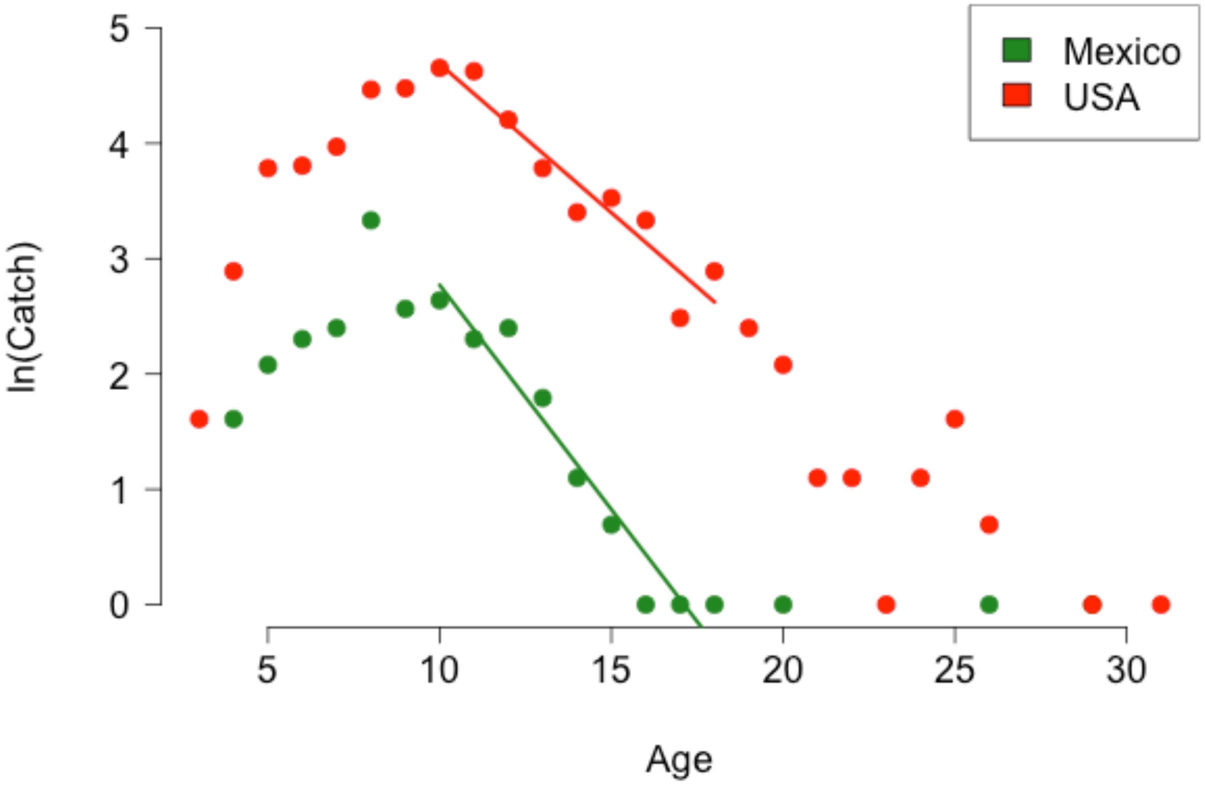

**Figure 16.** Catch curve for Golden Tilefish sampled within the USA and Mexican EEZs, 2011 - 2017. Lines indicate the sample ages (10 - 18 years) used to compute slopes of the descending limbs for estimates of total mortality rate.

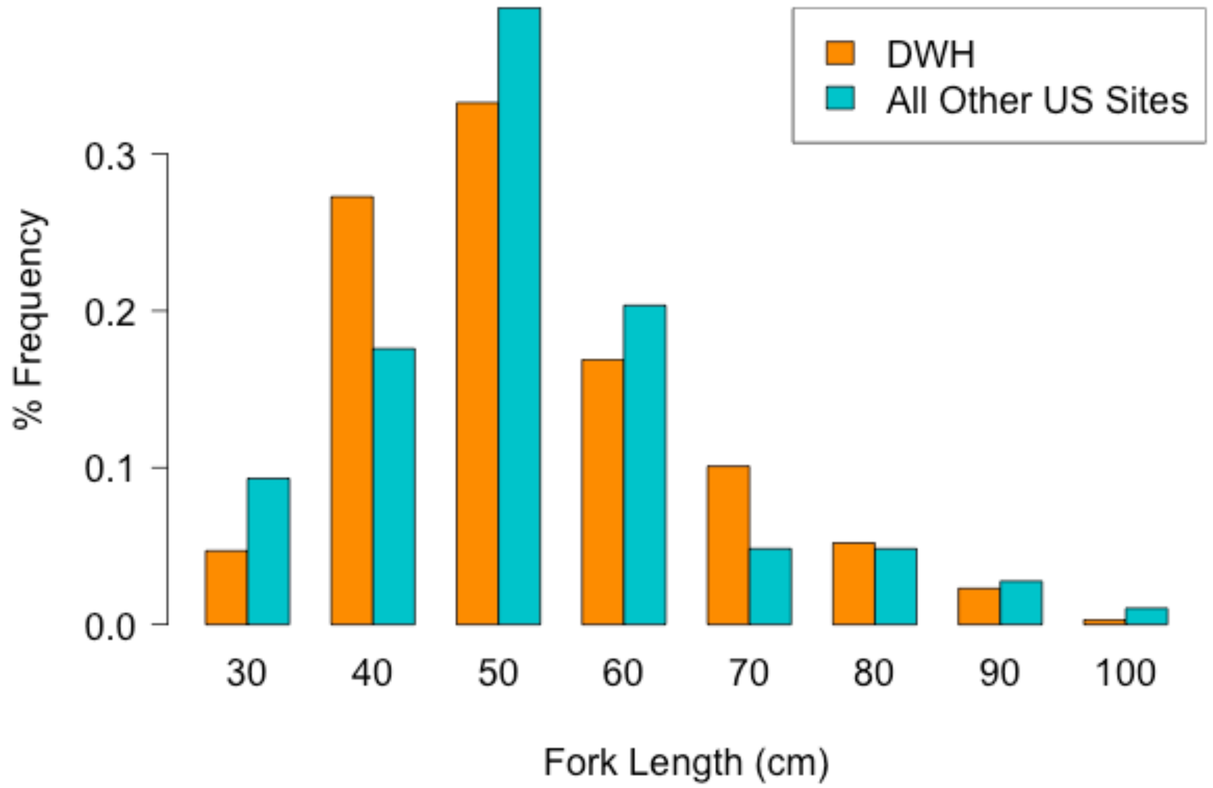

**Figure 17.** Fork length (cm) distribution frequency of Golden Tilefish sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017.

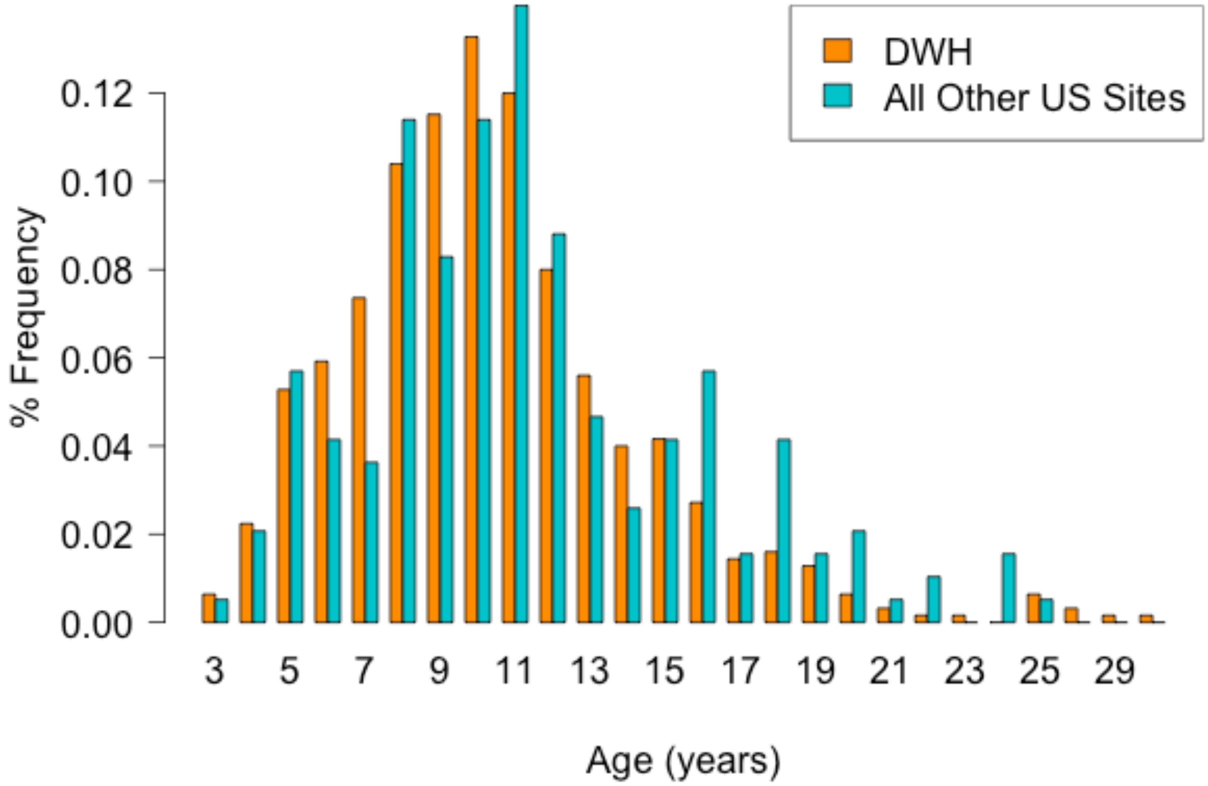

**Figure 18.** Age distribution frequency of Golden Tilefish sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017.

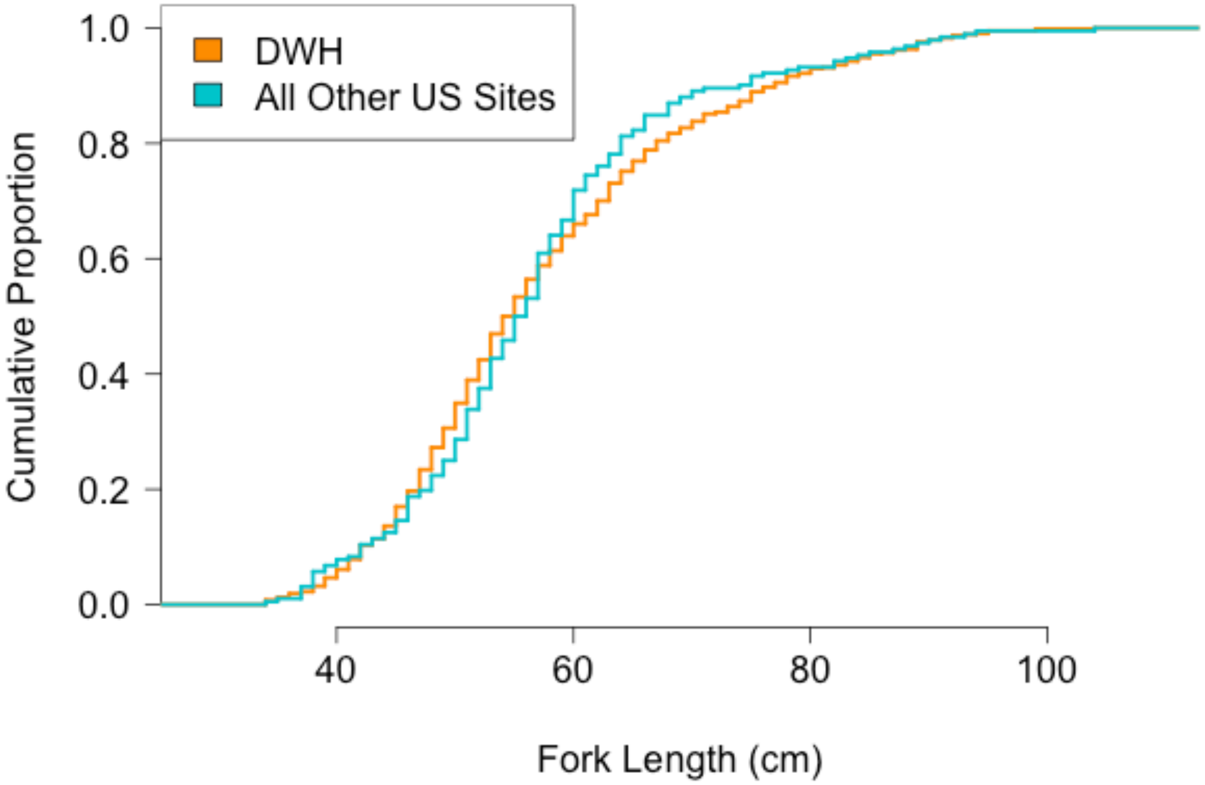

**Figure 19.** Empirical Cumulative Distribution Function (ECDF) of Golden Tilefish from ages 3 - 25 sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017. The y-axis represents the proportion of Golden Tilefish with fork lengths at or less than the values on the x-axis.

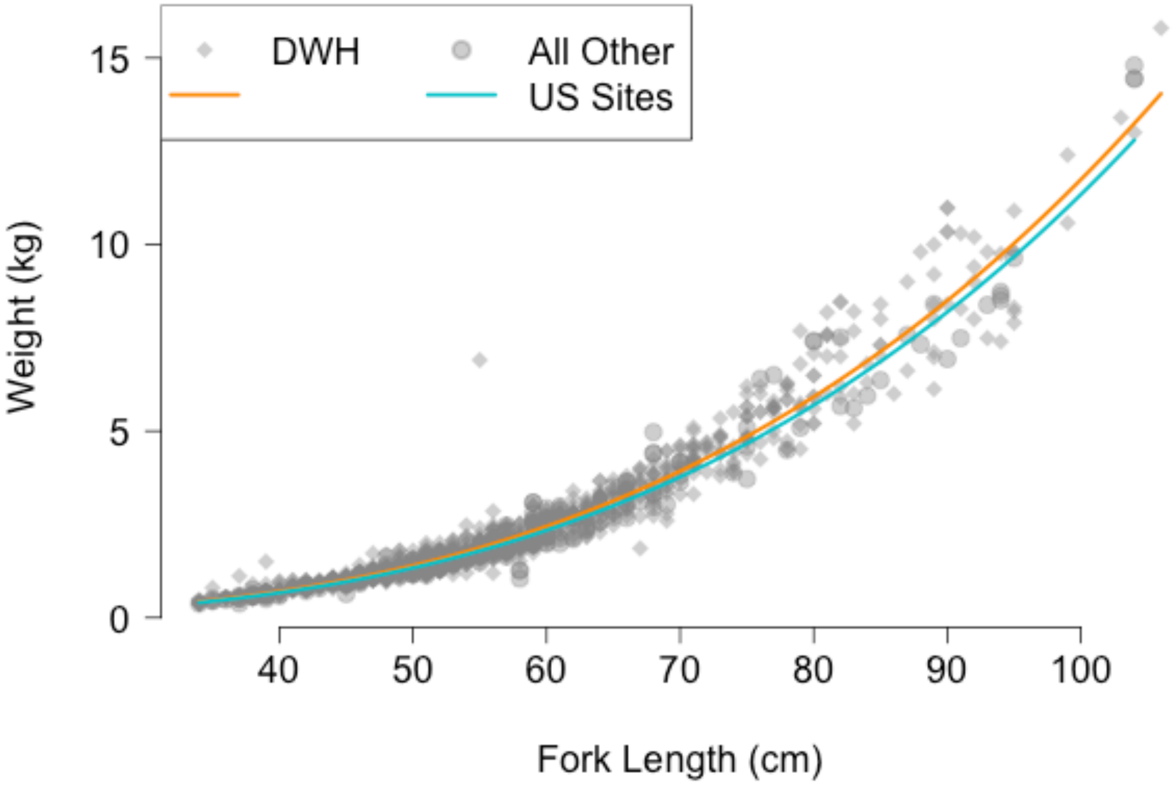

**Figure 20.** Fork length (cm) versus total weight (kg) of Golden Tilefish sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017. Length-weight regression lines are plotted by grouping.

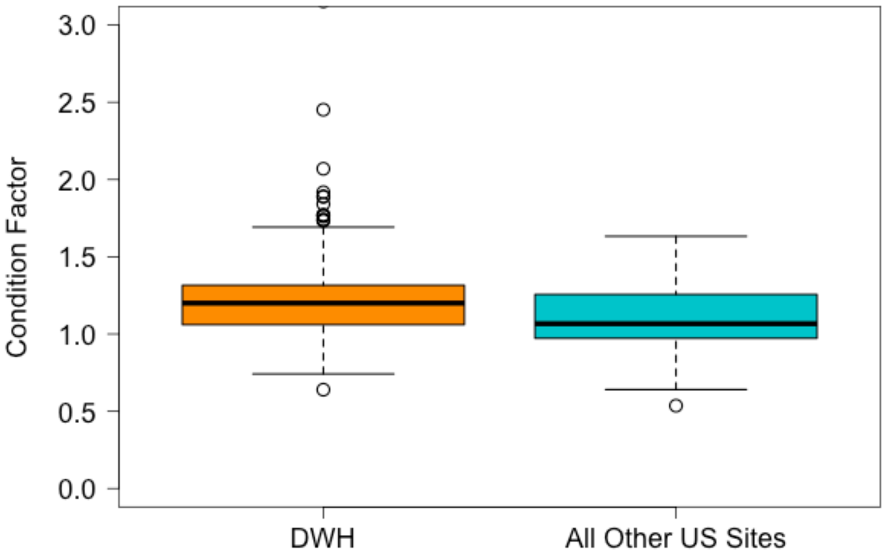

**Figure 21.** Boxplot of Fulton's Condition Factor (Kf) means, quartiles, and extremes of Golden Tilefish sampled from the DWH spill affected area and from all other sites in the USA's EEZ, 2011 - 2017. The average Fulton's condition factor was 1.210 ± 0.233 for fish from the DWH spill affected area (range = 0.640 - 4.544), whereas the average for fish from all other USA sites was 1.113 ± 0.187 (range = 0.536 - 1.633).

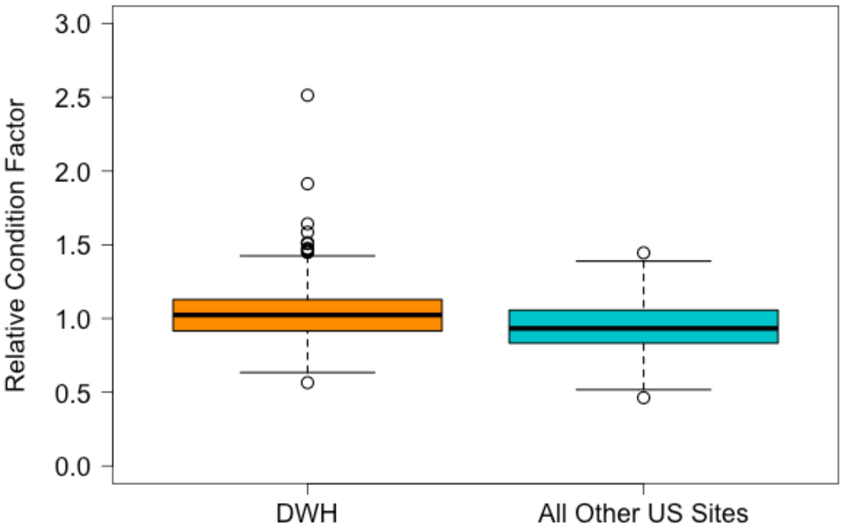

**Figure 22.** Boxplot of the Relative Condition Factor (Kn) means, quartiles, and extremes of Golden Tilefish sampled from the DWH spill affected area from all other sites in the USA's EEZ, 2011 - 2017. The average relative condition factor was 1.033 ± 0.191 for fish from the DWH spill affected area (range = 0.565 - 3.868), whereas the average for fish from all other USA sites was 0.951 ± 0.158 (range = 0.463 - 1.445).

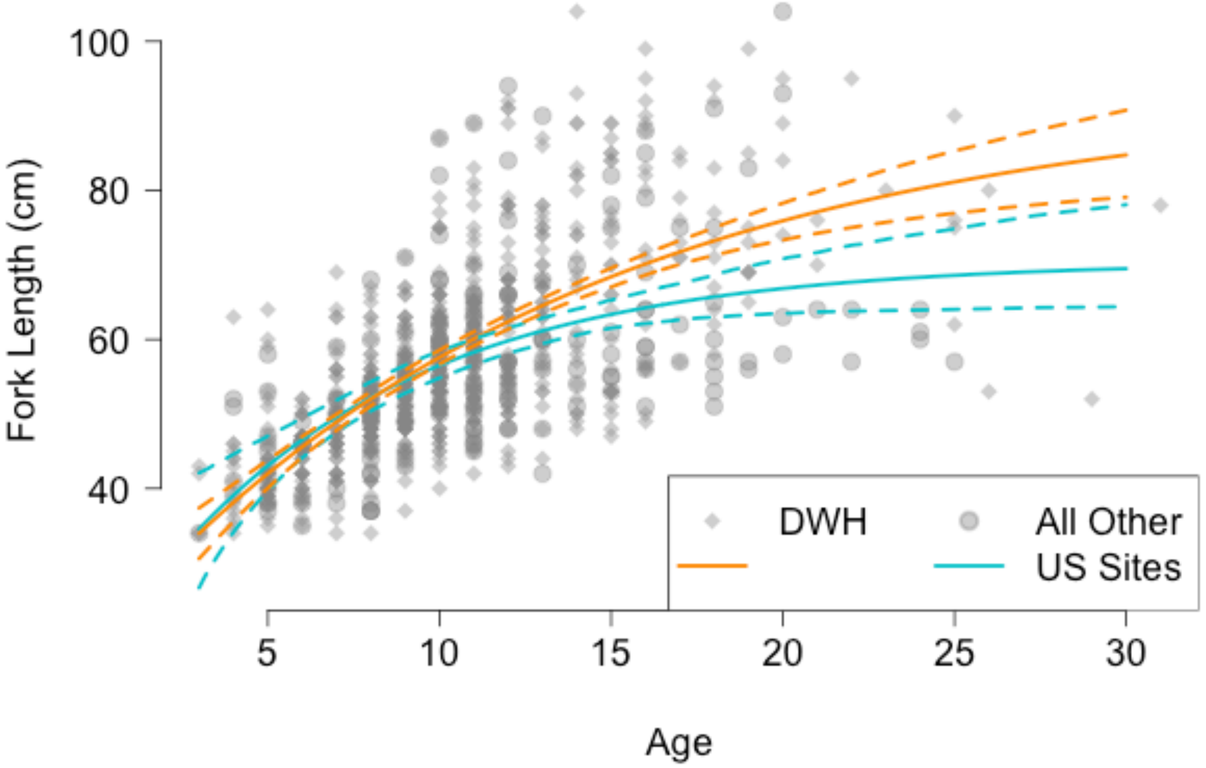

**Figure 23.** Von Bertalanffy growth curves (solid lines) for Golden Tilefish sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017. Dashed lines represent the bootstrapped 95% confidence intervals, and gray dots represent the observed age at length data for fish from the DWH sites (diamonds) and all other US sites (circles).

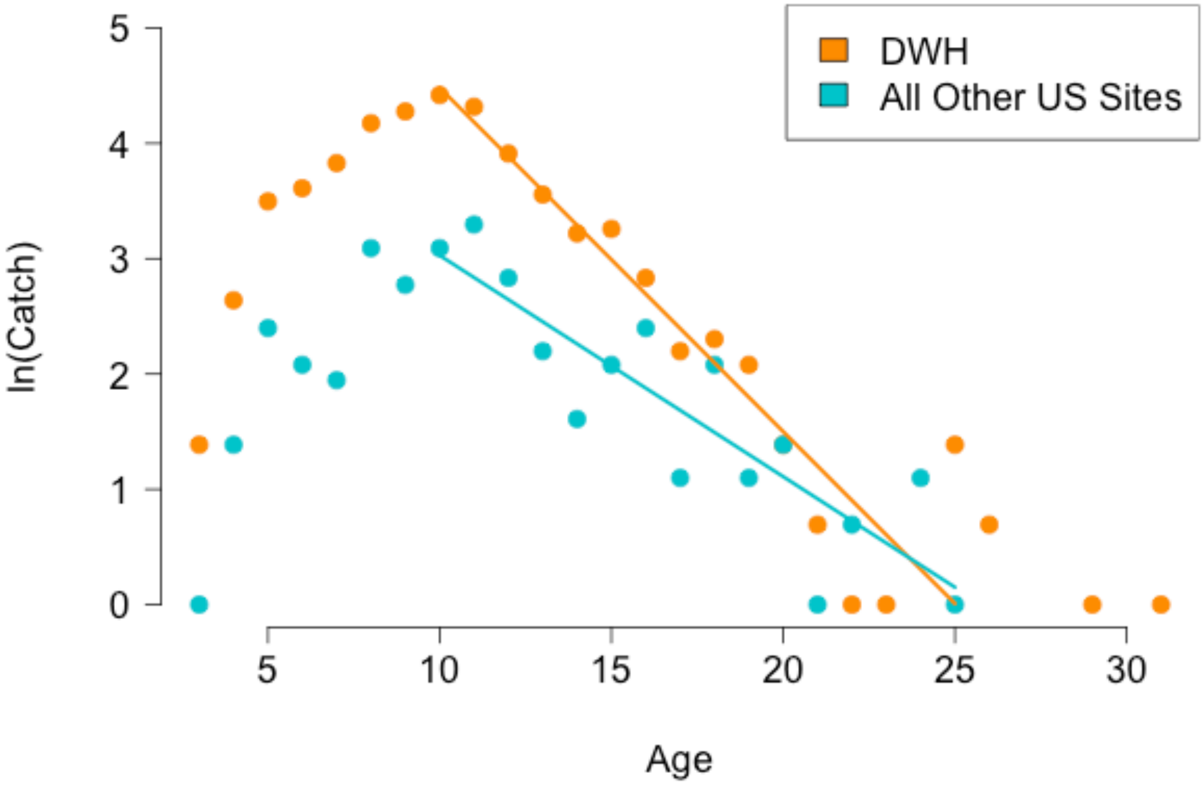

**Figure 24.** Catch curves for Golden Tilefish sampled from sites close to the DWH oil spill site and from all other sites in the USA's EEZ, 2011 - 2017. Lines indicate the sample ages (10 - 25) used to compute slopes of the descending limbs for estimates of total mortality rate.

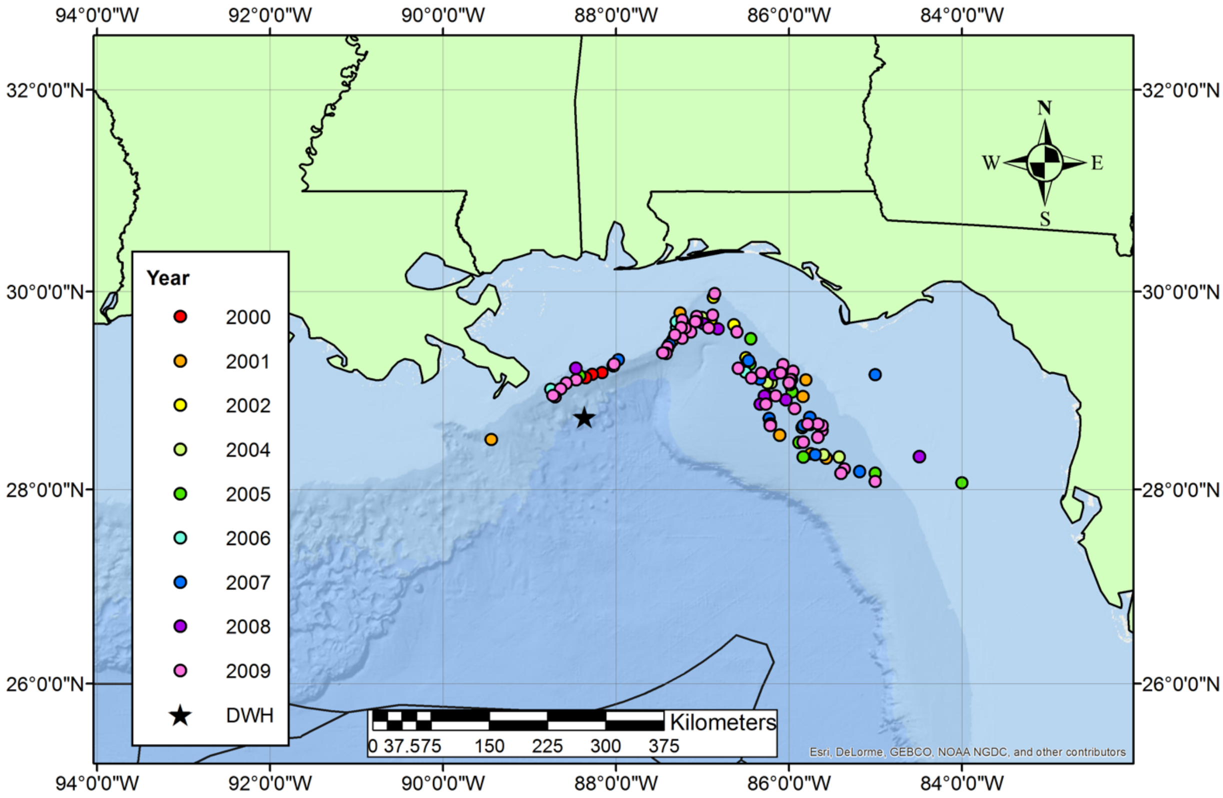

**Figure 25.** Map of sites sampled from 2000-2009, as well as the site of the *Deepwater Horizon* (DWH) rig explosion (star).

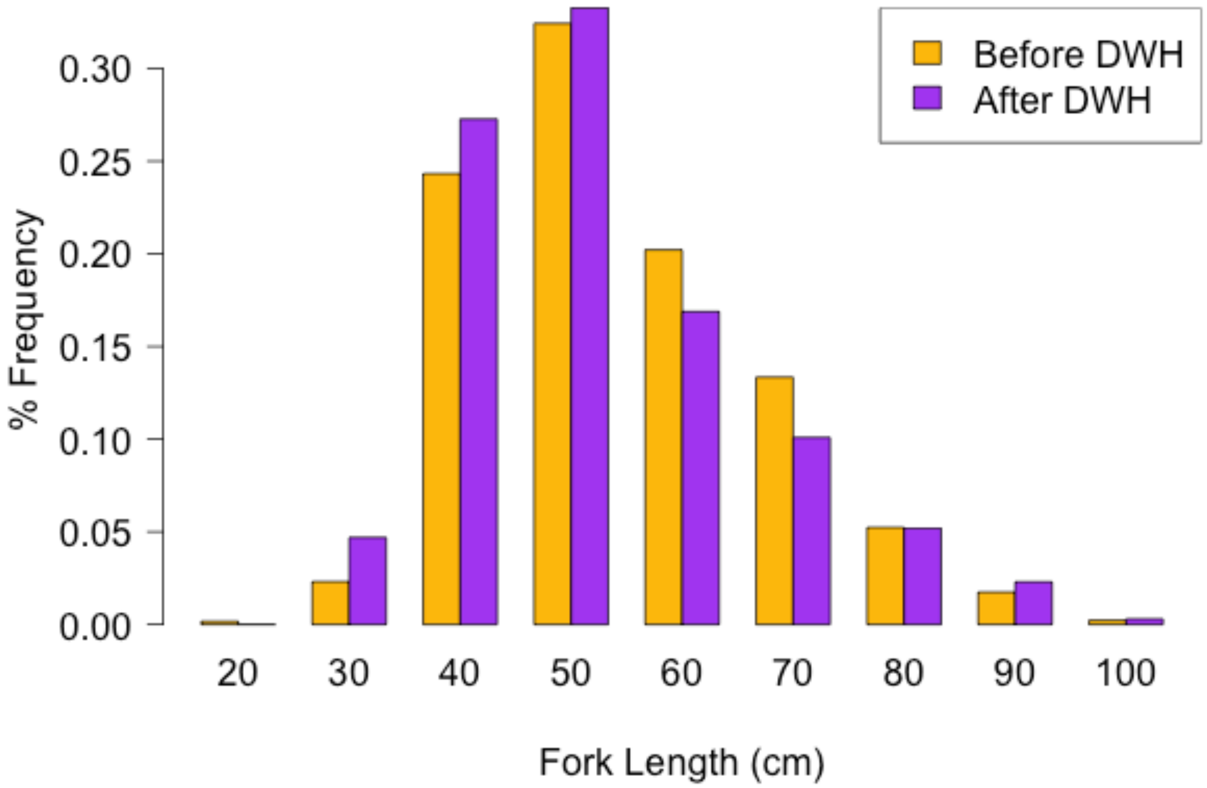

**Figure 26.** Fork length (cm) frequency of Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017).

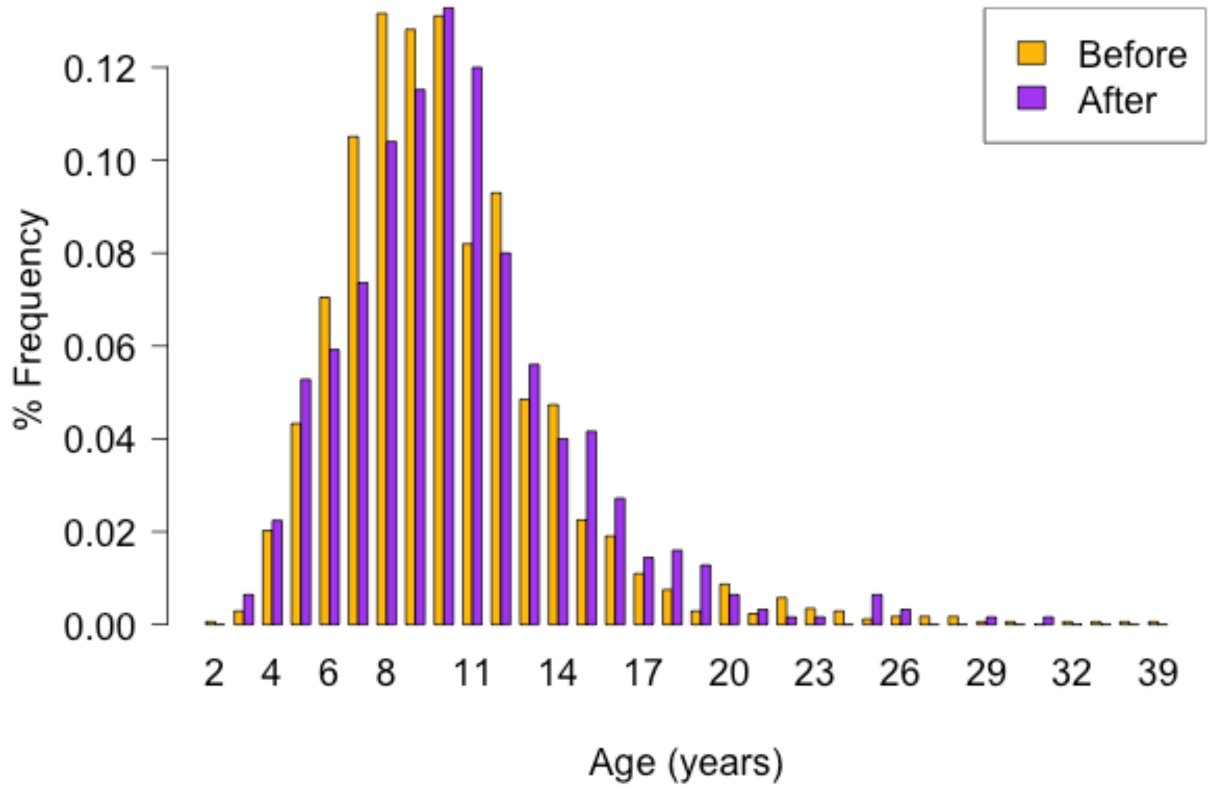

**Figure 27.** Age frequency of Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017).

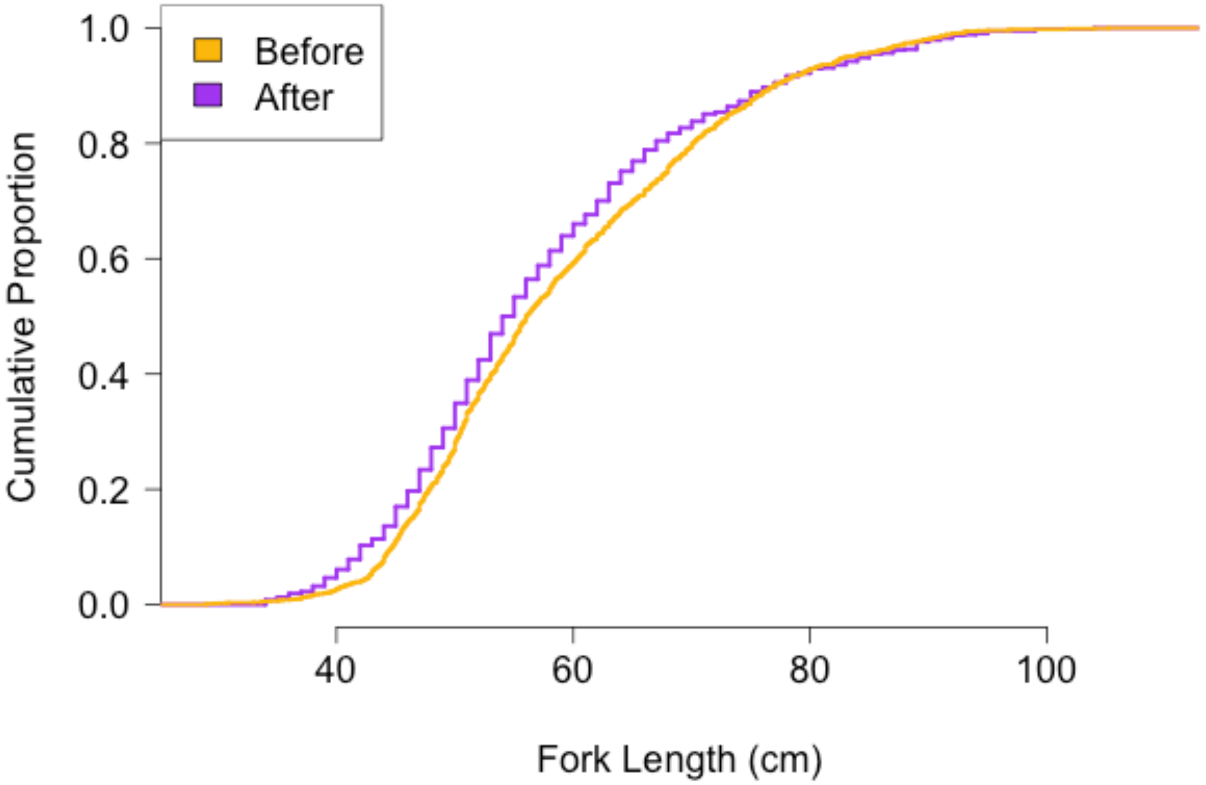

**Figure 28.** Empirical Cumulative Distribution Function (ECDF) of Golden Tilefish, ages 3 - 26, sampled from US sites before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017). The y-axis represents the proportion of Golden Tilefish with fork lengths at or less than the values on the x-axis.

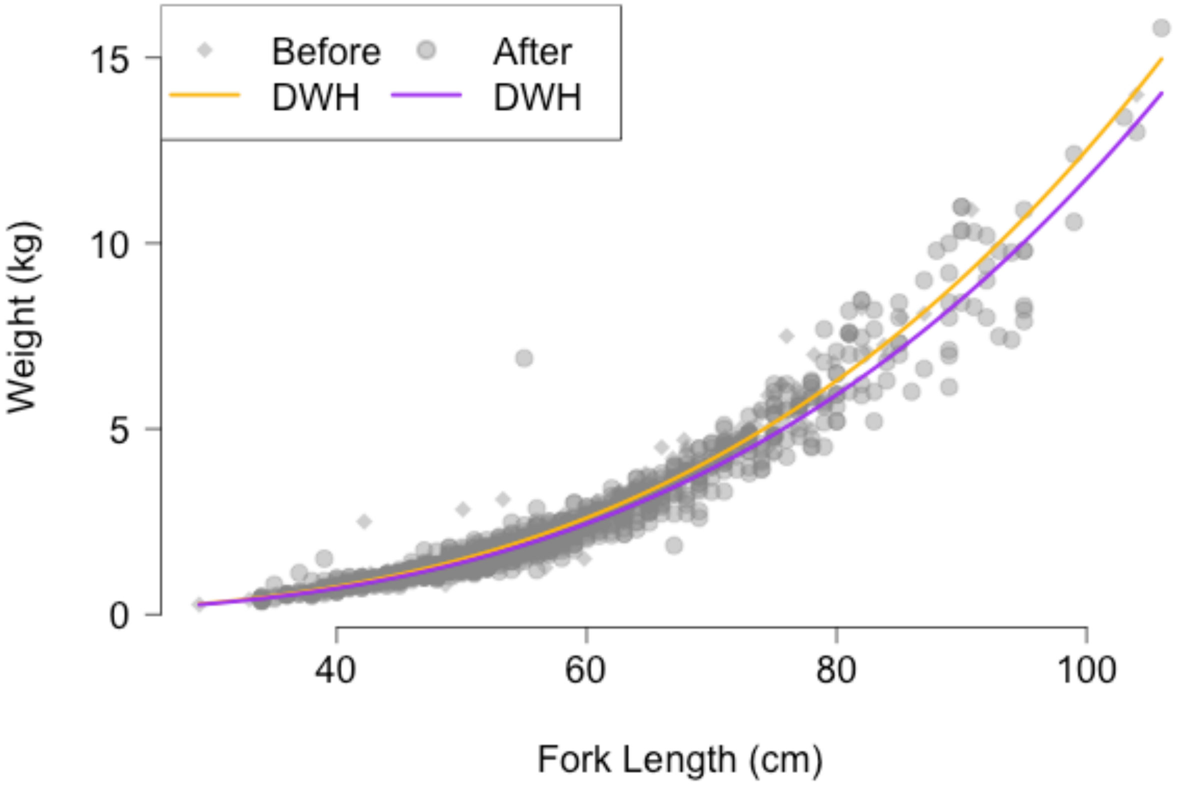

**Figure 29.** Fork length (cm) versus total weight (kg) of Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017). Length-weight regression lines are plotted by grouping.

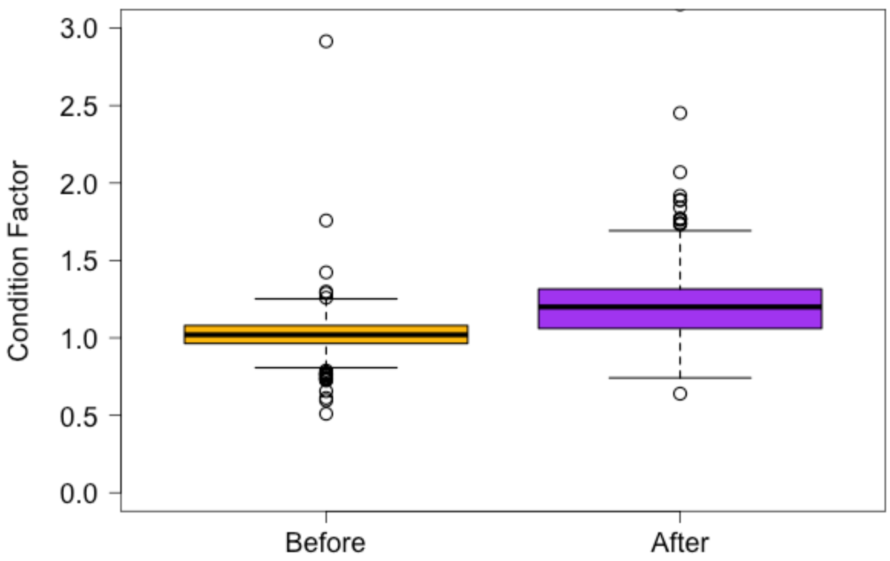

**Figure 30.** Boxplot of Fulton's Condition Factor (Kf) means, quartiles, and extremes of Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017). The average relative condition factor was 1.020 ± 0.145 for fish caught before the DWH spill (range = 0.510 - 2.915), whereas the average for fish from all other USA sites was 1.217 ± 0.233 (range = 0.640 - 4.544).

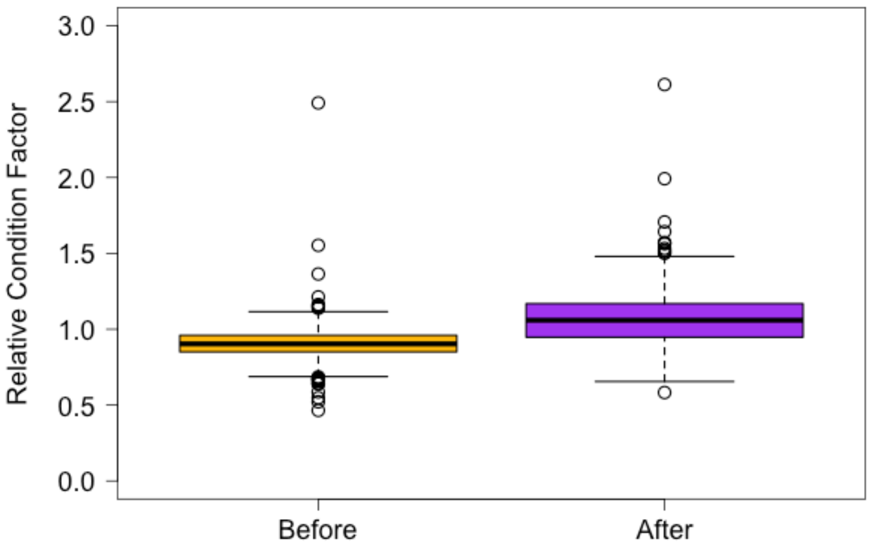

**Figure 31.** Boxplot of the Relative Condition Factor (Kn) means, quartiles, and extremes of Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017). The average relative condition factor was 0.906 ± 0.131 for fish caught before the DWH spill (range = 0.464 - 2.490), whereas the average for fish from all other USA sites was 1.068 ± 0.197 (range = 0.565 - 3.868).

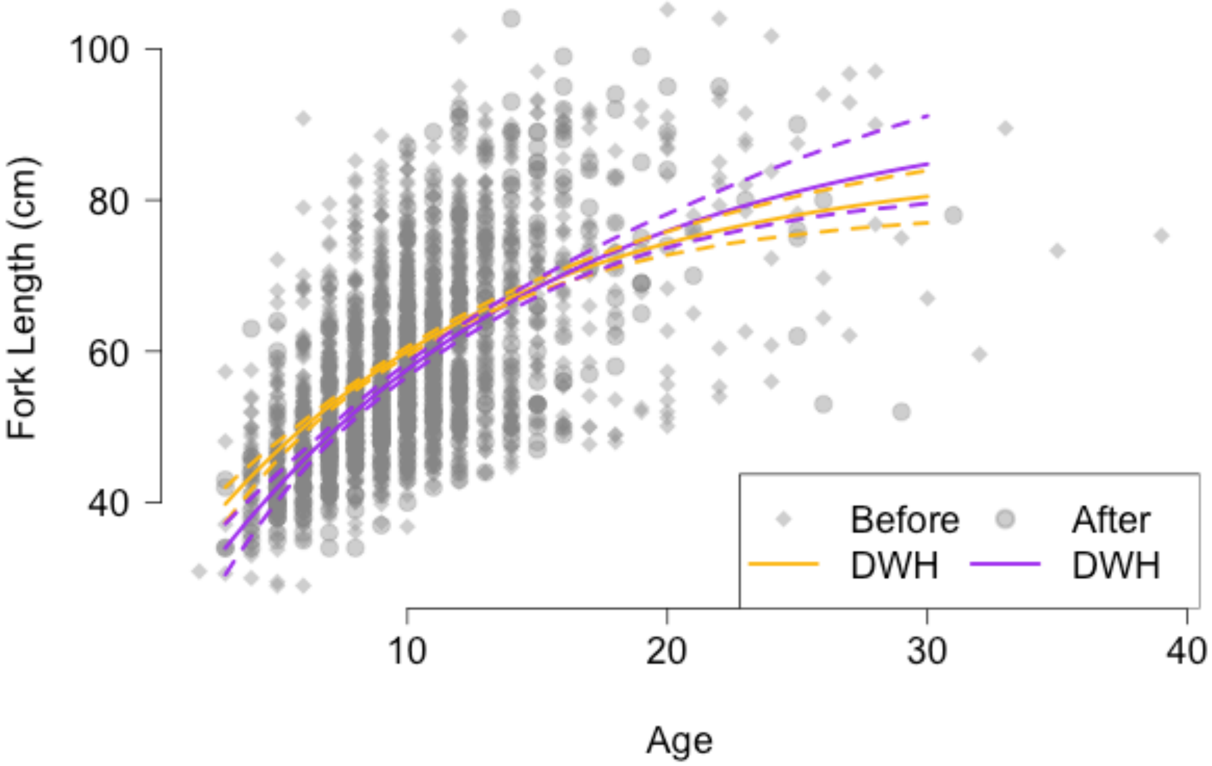

**Figure 32.** Von Bertalanffy growth curves (solid lines) for Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000-2009) and after the DWH oil spill (2011 - 2017). Dashed lines represent the bootstrapped 95% confidence intervals, and gray dots represent the observed age at length data for fish caught pre-spill (diamonds) and post-spill (circles).

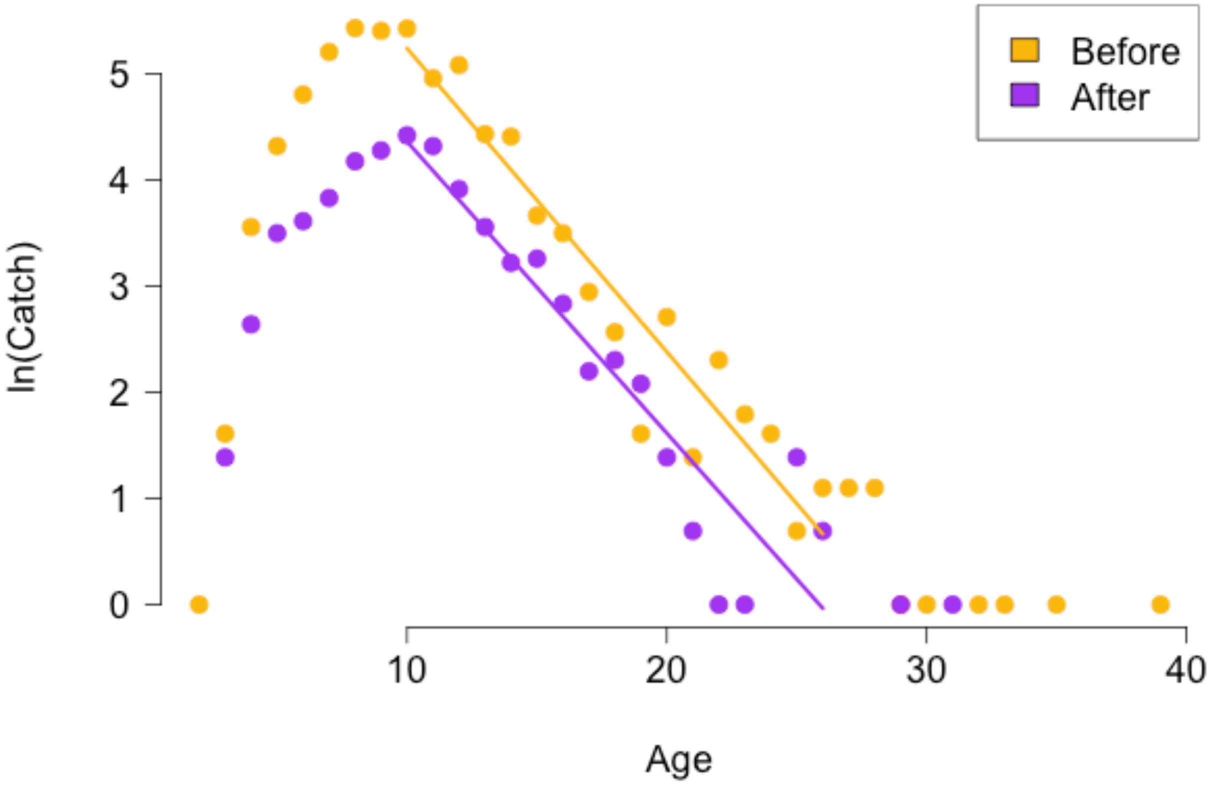

**Figure 33.** Catch curves for Golden Tilefish sampled from sites in the USA's EEZ before the DWH oil spill (2000 - 2009) and after the DWH oil spill (2011 - 2017). Lines indicate the sample ages (10 - 25) used to compute slopes of the descending limbs for estimates of total mortality rate.

## Discussion

I analyzed the population demographics of Golden Tilefish in the GoM to establish a baseline in the southern GoM and investigate any impacts from the DWH oil spill. Golden Tilefish are an important candidate with which to assess site-specific environmental perturbations because of the high degree of site fidelity they exhibit as adults (Grimes et al. 1983). The effect of the DWH spill on Golden Tilefish is particularly of interest due to their burrow-digging behavior and high association with sediment (NOAA 2019a), where much of the DWH oil was sequestered (Brooks et al. 2015; Romero et al. 2015). Measures of condition, growth, and mortality were used to analyze differences in population demographics based on country of origin and detect any impacts from the DWH spill. Although there were minor differences in condition and growth, it appears that Golden Tilefish were overall resilient to DWH oil exposure.

Golden Tilefish were a major target species during longline sampling throughout the GoM from 2011 – 2017 (Murawski et al. 2018). Data from those surveys were used to determine the presence of oil biomarkers and immune response of Golden Tilefish due to oil exposure, but there has not been a comprehensive study of DWH oil impacts on population demographics (Deak 2014; Snyder 2014). Other studies on population demographics of fish in the Northern GoM after the DWH oil spill showed growth resiliency on a large scale, but a decline in age-specific growth for Red Snapper (e.g., Herdter et al. 2017). Golden Tilefish, however, are more sediment-associated than Red

Snapper and were thought to be more likely to exhibit differences in growth due to higher potential for oil contamination.

Hard structures in fishes, including otoliths and fin rays, can be used for age determination from most temperate fish (Jackson 2007). Otoliths, which are small ear bones consisting of calcium carbonite, accrue daily layers with thicknesses that are correlated with the fish's growth. During the winter, when growth is slower, the layers tend to be thinner and closer together, forming an opaque band when cross-sectioned and viewed under a microscope (Pannella 1971; Cailliet et al. 2001). Opaque bands may correspond to days, weeks, or months depending on the species of fish. Temperatures are relatively stable year-round in the depth range where Golden Tilefish live (9-14°C, Grimes et al. 1986); they do not experience the same seasonal fluctuations in temperature that shallower water species experience. As a result, differences in growth between the seasons are not as pronounced, resulting in a weaker visible band in the otolith cross-sections (Cailliet et al. 2001).

Age estimates were highly variable, especially for the older fish. Golden Tilefish are a difficult species of fish to age through traditional age estimation methods, given the various patterns of growth zones (Lombardi-Carlson and Andrews 2015). However, my estimates of precision, as well as precision estimates between myself and Dr. Linda Lombardi, were well within the range of estimates from among multiple Golden Tilefish readers (APE: 6-11%; percent agreement: 77% ± 3 bands; SEDAR 2011) for ages used in previous assessments (SEDAR 2011). The calculated measures of growth that did not include age as a factor (i.e. length-weight relationships) yielded similar results to the measures of growth that did include age (i.e. von Bertalanffy growth curves), suggesting that age determination was relatively accurate. While age estimates are inherently more variable for deepwater fish, indices of reader precision were consistent between my study and other previously published Golden Tilefish population demographic studies.

### *Country of Capture*

My data provides the first description of Golden Tilefish from Mexican waters. Length distribution of Golden Tilefish sampled from Mexican waters was significantly larger than for samples collected off the USA, but both Fulton's condition factor and relative condition factor were significantly higher off the USA. Differences in growth were not large between USA and Mexico fish, but total instantaneous mortality was 10% higher in Mexico. While observed differences in demographics may be due to productivity or fishing pressure differences between the two countries, more information is needed.

Differences in size composition among areas can result from differential recruitment, total and fishing mortality rates, and the size selectivity of fisheries and sampling gear (Neumann and Allen 2007). Grimes (1980) attributed a truncation in size distribution to an increase in fishing pressure on Golden Tilefish in the Mid-Atlantic Bight. Large fish are selected by the fishery, which drives down mean size structure (Grimes et al. 1980). Gear type can also affect observed size composition; in a study on Golden Tilefish in the Mid-Atlantic, Turner (1983) showed that trawling gear yielded smaller fish than longline gear. I can eliminate differences in gear selectivity, habitat type, and otolith interpretation as areas of potential bias. In both areas, the same sample techniques and gear sizes were used and the predominant sediment type at both sites in Mexico and sites sampled in USA waters was mud (NOAA 2019b). I interpreted all otoliths using the same methodologies, too. Thus, size composition differences were likely due to recruitment and/or mortality variations among regions. Importantly, the lower predicted and observed weights and condition factors may have reflected differences in productivity of ecosystems in the two areas (White and Fletcher 1985; Bolger and Connolly 1989). Weighted mean temperatures at capture were virtually identical, so the differences in condition were likely not due to temperature-dependent metabolic differences. The most likely contributing factor to the lower weights-at-length was the level of primary productivity, which has been calculated to be about 40% lower off Mexico compared with the Northern GoM (Benway and Coble 2014). However, although differences in mean condition were statistically significant between fish from the USA and Mexico, the differences themselves were not large (16-18%).

Although the values of K and $L_\infty$ for Golden Tilefish from the USA and Mexico were significantly different according to the likelihood ratio test and information criterion tests, respectively, the values themselves are within each other's 95% bootstrapped confidence intervals. Due to the low sample size of Golden Tilefish from Mexico and the highly uncertain ageing of Golden Tilefish by otolith annuli (Lombardi-Carlson 2012), there may not have been sufficient age data to definitively estimate differences in growth rates at length among countries.

There is a possibility that fishing pressure could affect growth and mortality (Grimes et al. 1980; Turner et al. 1983). While fishing pressure has been higher in the USA than in Mexico for Golden Tilefish over the past 20 years, the fishery data from Mexico were self-reported and Golden Tilefish catch was indexed with other tilefish species (Arreguín-Sánchez and Arcos-Huitrón 2007; NOAA Fisheries 2018; Ortega-Ortiz et al. 2020). Therefore, the insufficiency of accurate landings and fishing effort data from Mexico makes it difficult to properly compare to the USA fishery.

### *DWH Spill Perimeter*

Differences in population demographics between Golden Tilefish caught from the area of the DWH spill and Golden Tilefish caught elsewhere in the US EEZ were not as predicted. Condition and total instantaneous mortality rate were higher in fish caught from the DWH spill perimeter, which could indicate negative impacts from oil exposure. However, contrary to what would be expected from oil exposure, growth and size distribution were also higher for DWH-area fish.

Condition factors, which measure the general well-being of fish by assuming that fish that are heavier for their weight are better off, do not respond uniformly to oil exposure. Some studies have found lower condition factors in response to oil, whereas other studies have shown that condition factors are unaffected by oil (Kiceniuk and Khan 1987; Tollefsen et al. 2011; Sundt et al. 2012; Brown-Peterson et al. 2016). Kicenuik and Khan (1987) found that condition factors decreased in Atlantic Cod (*Gadus morhua*) in response to oil exposure due to a significant reduction in food consumption in oil exposed fish. However, condition factors have been shown to increase in Southern Flounder (*Paralichthys lethostigma*), a benthic species with high sediment association like Golden Tilefish, after exposure to DWH oil-contaminated sediments. It was likely due to an increase in liver weight from PAH stress and not a positive response as length and weight both decreased (Brown-Peterson et al. 2016). Both Fulton's condition factor and relative condition factor were similarly higher in Golden Tilefish caught from the DWH spill site. However, since there was no difference in HSI between spill site and non-spill site fish, it is unlikely that the impact on Golden Tilefish condition from potential oil exposure was the same as the results observed in Southern Flounder. I did not, however, explore temporal trends in condition factors for the DWH fish, which may in fact have shown different trends due to cumulative impacts. Additionally, since condition was measured using methods that are not sensitive to monthly variation (i.e. Fulton's condition factor, relative condition factor, and HSI), there may be additional variation in fish condition by month not detected by this analysis (Fitzhugh et al. 2010).

Oil exposure can depress growth and raise mortality in fish, whether through direct exposure or indirectly through predation on oil-affected species (Christiansen and George 1995; Heintz et al. 2000). While the decreased mortality for Golden Tilefish caught from the site of the DWH spill was consistent with the expected effect from oil exposure, no subsequent decrease in growth compared to fish from outside the oil spill perimeter was observed. However, it is possible that differences in growth were misrepresented due to the difficulty of assigning accurate ages to Golden Tilefish (Lombardi-Carlson 2012).

Our samples did not cover every individual age in the catch curve. Although the age range used adequately described the descending limb of each catch curve (10 - 25 years old), there were a couple specific ages in each grouping that were not represented in our samples due to the wide range of ages present. The resulting regression line on the descending limb of the catch curve has high variability and may not accurately describe the data. Either the effect from oil exposure on the fish caught from the perimeter of the DWH spill was not as expected, which was further explored by comparing pre- and post-spill fish, or the differences observed in growth and mortality are inherent to the areas and unrelated to the DWH spill. Likewise, the use of catch curves for mortality estimation is predicated on the assumption of near constant recruitment, which could not be independently verified with the data at hand, although consistent descending limbs of the curves were apparent from all samples examined.

### *Before and After DWH Spill*

Comparisons of Golden Tilefish population demographics from the perimeter of the DWH oil spill pre- and post- spill were completed to investigate if differences observed in demographics from the DWH spill area and all other US sites post-spill were endemic to the area or potentially caused by oil exposure. Length distributions did not vary much, although condition was higher for the post-spill Golden Tilefish. However, differences in growth were minimal and total instantaneous mortality rates were identical, suggesting that there were no major detectible impacts from the DWH spill on the demographics of Golden Tilefish from the spill area.

Both Fulton's condition factor and relative condition factor were higher for Golden Tilefish caught after the oil spill than for fish caught before the spill. Again, a similar response was seen in Southern Flounder as a result of DWH sediment exposure (Brown-Peterson et al. 2016). Since both HSI values and length-weight relationships were similar between pre- and post- DWH Golden Tilefish, it's unlikely that oil exposure was causing the discrepancy in condition factors in the same manner. Additionally, as with the difference in condition between Golden Tilefish caught from the spill site and elsewhere in the northern GoM, there may be some monthly changes in condition not captured by the metrics I used (Fitzhugh et al. 2010).

Age frequency did not appear to differ much between Golden Tilefish caught before the DWH spill and after the spill, although it appeared that the highest frequency ages were slightly older after the spill than before, suggesting age progression. While the von Bertalanffy parameters $L_\infty$ and $t_0$ differed significantly between the two groupings, the predicted curves overlapped substantially when plotted, especially in the older ages where there was more aging uncertainty. Total instantaneous mortalities also did not differ significantly, suggesting there was no impact from oil exposure on the growth or mortality of Golden Tilefish as a whole in the Northcentral GoM. Thus, Golden Tilefish present a paradox. Their PAH body burdens are the highest observed among demersal fishes sampled in the northern Gulf of Mexico post-DWH (Pulster et al. 2020). Yet usual metrics of population dynamics were largely unchanged post-spill. Perhaps the Golden Tilefish population has become conditioned to a high PAH environment, or longer-term studies may yet reveal population-level consequences of DWH exposure.

### *Impact of DWH Oil Spill*

Although there were some minor differences in population demographics between Golden Tilefish caught from sites around the DWH oil spill and those caught elsewhere within US EEZ waters, the population demographics from our samples were consistent with those of the Golden Tilefish sampled before the DWH oil spill from the same area of the Gulf of Mexico. For example, the total instantaneous mortality estimate for fish from our study caught near the DWH spill was much higher than the estimate for fish caught elsewhere in the USA (0.32 vs. 0.21). However, the estimate for fish caught near the DWH spill post-2010 was indistinguishable from the total instantaneous mortality estimate for fish caught near the DWH spill pre-2010 (0.31). Additionally, the von Bertalanffy parameter estimates for fish caught near the DWH spill post-2010 were more similar to estimates from the same area pre-2010 than they were to estimates from elsewhere in the northern GoM post-2010. This suggests that any differences in growth and mortality between fish sampled from the oil-affected sites and other USA sites in our study were inherent to that area of the GoM and were not caused by oil exposure.

### *Future Research*

This study provides a baseline for Golden Tilefish population demographics over a period of 7 years but does not cover changes at finer scale resolutions, such as by sub-area of the GoM or by year. Sample sizes were too small for a robust analysis of population dynamics across sub-area or year, but a future study with a larger sample size could be able to analyze those changes. Some sites were re-sampled in subsequent years due to their proximity to the DWH oil spill, whereas other sites were only sampled over one year. There might have been some bias in the data due to the larger sample sizes from DWH-affected sites, and a future study might expend equal sampling effort across all sites. Since data were combined over all sampling years for each research question, it is possible that annual differences in population demographics were obscured in my analysis. Additionally, data collection might have been too soon after the DWH spill to capture the full impacts of oil exposure on Golden Tilefish due to their longevity. A majority (89.6%) of the fish examined in this study were hatched prior to the DWH spill as evidenced by the dominance of ages 7-20 in longline samples. This is because of the size selectivity of #13/0 circle hooks and the bait used. Thus, it is not possible to conclude from these data that recruitment dynamics were not impacted by oil exposure from DWH. Oil exposure has a more detrimental effect on fish larvae and eggs (Moore and Dwyer 1974), so there may be impacts from the DWH spill on Golden Tilefish population demographics as the fish are exposed to oil as eggs and larvae eventually comprise a greater proportion of the adult population. Modelling size-at-age over time would also be an effective way to analyze changes in growth for the cohorts spawned after the DWH oil spill, but the sample sizes at each age class for fish spawned post-spill were too small to conduct such an analysis for this study.

## Conclusions

The aftermath of the DWH oil spill revealed a substantial and important gap in baseline information data for many species of fish in the Gulf of Mexico, especially demersal, sedentary species including Golden Tilefish. This study provides a comprehensive baseline of population demographics for Golden Tilefish, not only within the area subject to DWH but across the GoM. Golden Tilefish from Mexico exhibited lower overall condition and experienced higher total instantaneous mortality rates than Golden Tilefish from the USA, although the rates of natural vs. fishing induced mortality could not be assessed using my data. Golden Tilefish caught from the vicinity of the DWH spill site appeared to differ substantially in growth and mortality from fish caught elsewhere in the USA. However, by examining the pre-spill data from the DWH-area I determined that factors other than oil exposure most likely play a greater role in explaining those differences. With anthropogenic perturbations, such as oil spills, there is no singular response of fish communities to contaminant exposure; some are unaffected on a population level while others are more vulnerable (Johnson et al. 2008; Herdter et al. 2017). Although Golden Tilefish exhibited high levels of petroleum by-products in tissue samples (Pulster et al. 2020), rates of growth and condition appeared to be robust.

## References

Able, K. W., C. B. Grimes, R. A. Cooper, and J. R. Uzmann. 1982. Burrow construction and behavior of tilefish, *Lopholatilus chamaeleonticeps*, in Hudson Submarine Canyon. Environmental Biology of Fishes 7(3):199–205. Kluwer Academic Publishers.

Aiken, K. A., B. Collette, J. Dooley, R. Kishore, J. Marechal, F. Pina Amargos, and S. Singh-Renton. 2015. *Lopholatilus chamaeleonticeps*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T16545046A16546277.en.

Arreguín-Sánchez, F., and E. Arcos-Huitrón. 2007. Fisheries catch statistics for Mexico. Pages 81–103 *in* D. Zeller and D. Pauly, editors. Reconstruction of marine fisheries catches for key countries and regions (1950-2005)15(2). Fisheries Centre Research Reports, Fisheries Centre, University of British Columbia.

Aska, D. Y., V. J. Blomo, S. Bortone, J. Cato, R. Dalton, C. Davis, G. Goltennan, J. Oglesby, C. R. O’Connor, F. J. Prochaska, R. Raulerson, W. E. Swingle, B. Turner, K. Walby, and J. Zuboy. 1981. Environmental Impact Statement and Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico. Tampa, FL.

Benway, H., and P. Coble. 2014. Report of the Gulf of Mexico Coastal Carbon Synthesis Workshop. St. Petersburg, FL.

Bolger, T., and P. L. Connolly. 1989. The selection of suitable indices for the measurement and analysis of fish condition. Journal of Fish Biology 34(2):171–182.

Brooks, G. R., R. A. Larson, P. T. Schwing, I. Romero, C. Moore, G.-J. Reichart, T. Jilbert, J. P. Chanton, D. W. Hastings, W. A. Overholt, K. P. Marks, J. E. Kostka, C. W. Holmes, and D. Hollander. 2015. Sedimentation Pulse in the NE Gulf of Mexico following the 2010 DWH Blowout. PLOS ONE 10(7).

Brown-Peterson, N. J., M. O. Krasnec, C. R. Lay, J. M. Morris, and R. J. Griffitt. 2016. Responses of juvenile southern flounder exposed to Deepwater Horizon oil-contaminated sediments. Environmental Toxicology and Chemistry 36(4):1067–1076.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference : a practical information-theoretic approach, 2nd edition. Springer, Verlag, New York.

Cailliet, G. ., A. . Andrews, E. . Burton, D. . Watters, D. . Kline, and L. . Ferry-Graham. 2001. Age determination and validation studies of marine fishes: do deep-dwellers live longer? Experimental Gerontology 36(4–6):739–764. Pergamon.

Christiansen, J. S., and S. G. George. 1995. Contamination of food by crude oil affects food selection and growth performance, but not appetite, in an Arctic fish, the polar cod (*Boreogadus saida*). Polar Biology 15(4):277–281. Springer-Verlag.

Deak, K. L. 2014. Cloning and Characterization of IL-1β, IL-8, IL-10, and TNFα from Golden Tilefish (*Lopholatilus chamaeleonticeps*) and Red Snapper (*Lutjanus campechanus*). Graduate Theses and Dissertations. University of South Florida.

Erickson, D. L., M. J. Harris, and G. D. Grossman. 1985. Ovarian cycling of tilefish, *Lopholatilus chamaeleonticeps* Goode and Bean, from the South Atlantic Bight, U.S.A. Journal of Fish Biology 27(2):131–146. Wiley/Blackwell (10.1111).

Fitzhugh, G. R., M. J. Wuenschel, and R. S. McBride. 2010. Evaluation of bioelectrical impedance analysis (BIA) to measure condition and energy allocated to reproduction in marine fishes. Journal of Physics: Conference Series 224.

Fodrie, F. J., and K. L. Heck. 2011. Response of coastal fishes to the Gulf of Mexico oil disaster. PLoS ONE 6(7).

Fonseca, V. F., and H. N. Cabral. 2007. Are fish early growth and condition patterns related to life-history strategies? Reviews in Fish Biology and Fisheries 17(4):545–564. Springer Netherlands.

Freeman, B. L., and S. C. Turner. 1977. Biological and fisheries data on tilefish, *Lopholatilus chamaeleonticeps* (Goode and Bean). Sandy Hook, New Jersey.

GMFMC. 1989. Amendment Number 1 to the Reef Fish Fishery Management Plan. Tampa, FL.

GMFMC. 2008. Amendment 29 to the Reef Fish Fishery Management Plan (Including Draft Environmental Impact Statement and Regulatory Impact Review): Effort Management in the Commercial Grouper and Tilefish Fisheries.

Grimes, C., K. Able, and R. Jones. 1986. Tilefish, *Lopholatilus chamaeleonticeps*, habitat, behavior and community structure in Mid-Atlantic and southern New England waters. Environmental biology of fishes 15(4):273.

Grimes, C. B., K. W. Able, and S. C. Turner. 1980. A Preliminary Analysis of the Tilefish, *Lopholatilus chamaeleonticeps*, Fishery in the Mid-Atlantic Bight. Marine Fisheries Review 42(11):13–18.

Grimes, C. B., S. C. Turner, and K. W. Able. 1983. A technique for tagging deep-water fish. Fishery Bulletin 81(3):663–666.

Heintz, R. A., S. D. Rice, A. C. Wertheimer, R. F. Bradshaw, F. P. Thrower, J. E. Joyce, and J. W. Short. 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205–216.

Herdter, E. S., D. P. Chambers, C. D. Stallings, and S. A. Murawski. 2017. Did the Deepwater Horizon oil spill affect growth of Red Snapper in the Gulf of Mexico? Fisheries Research 191:60–68.

Hilborn, R., and C. J. Walters. 1992. Statistical Catch-at-Age Methods. Pages 369–390 Quantitative Fisheries Stock Assessment. Springer US, Boston, MA.

Incardona, J. P., L. D. Gardner, T. L. Linbo, T. L. Brown, A. J. Esbaugh, E. M. Mager, J. D. Stieglitz, B. L. French, J. S. Labenia, C. A. Laetz, M. Tagal, C. A. Sloan, A. Elizur, D. D. Benetti, M. Grosell, B. A. Block, and N. L. Scholz. 2014. Deepwater Horizon crude oil impacts the developing hearts of large predatory pelagic fish. Proceedings of the National Academy of Sciences of the United States of America 111(15):E1510-8. National Academy of Sciences.

Jackson, J. R. 2007. Earliest References to Age Determination of Fishes and Their Early Application to the Study of Fisheries. Fisheries 32(7):321–328.

Johnson, L. J., M. R. Arkoosh, C. F. Bravo, T. K. Collier, M. M. Krahn, J. P. Meador, M. S. Myers, W. L. Reichert, and J. E. Stein. 2008. The effects of polycyclic aromatic hydrocarbons in fish from Puget Sound, Washington. The Toxicology of Fishes:877–923.

Kiceniuk, J. W., and R. A. Khan. 1987. Effect of petroleum hydrocarbons on Atlantic cod, *Gadus morhua*, following chronic exposure. Canadian Journal of Zoology 65(3):490–494. NRC Research Press Ottawa, Canada.

Kimura, D. K. 1980. Likelihood methods for the von Bertalanffy growth curve. Fishery Bulletin 77(4):765–776.

Le Cren, E. D. 1951. The Length-Weight Relationship and Seasonal Cycle in Gonad Weight and Condition in the Perch (*Perca fluviatilis*). The Journal of Animal Ecology 20(2):201.

Lombardi-Carlson, L. A. 2012. Life history, population dynamics, and fishery management of the golden tilefish, *Lopholatilus chamaeleonticeps*, from the southeast Atlantic and Gulf of Mexico. Dissertation. University of Florida.

Lombardi-Carlson, L. A., and A. H. Andrews. 2015. Age estimation and lead-radium dating of golden tilefish, *Lopholatilus chamaeleonticeps*. Environmental Biology of Fishes 98(7):1787–1801. Springer Netherlands.

Lombardi, L., G. Fitzhugh, and H. Lyon. 2010. Golden tilefish (*Lopholatilus chamaleonticeps*) age, growth, and reproduction from the northeastern Gulf of Mexico: 1985, 1997-2009. Panama City, FL.

Maceina, M. J., and P. W. Bettoli. 1998. Variation in Largemouth Bass Recruitment in Four Mainstream Impoundments of the Tennessee River. North American Journal of Fisheries Management 18(4):998–1003. John Wiley & Sons, Ltd.

Machlis, G. E., and M. K. McNutt. 2010. Disasters. Scenario-building for the Deepwater Horizon oil spill. Science (New York, N.Y.) 329(5995):1018–9. American Association for the Advancement of Science.

Moore, S. ., and R. . Dwyer. 1974. Effects of oil on marine organisms: A critical assessment of published data. Water Research 8(10):819–827. Pergamon.

Murawski, S. A., W. T. Hogarth, E. B. Peebles, L. Barbeiri, and S. A. Murawski. 2014. Prevalence of External Skin Lesions and Polycyclic Aromatic Hydrocarbon Concentrations in Gulf of Mexico Fishes, Post-Deepwater Horizon. Transactions of the American Fisheries Society 143(4):1084–1097.

Murawski, S. A., E. B. Peebles, A. Gracia, J. W. Tunnell Jr, M. Armenteros, and P. J. Sullivan. 2018. Comparative Abundance, Species Composition, and Demographics of Continental Shelf Fish Assemblages throughout the Gulf of Mexico. Marine and Coastal Fisheries 10(3):325–346.

Neumann, R. M., and M. S. Allen. 2007. Size Structure. Page 375 *in* Analysis and interpretation of freshwater fisheries data. Bethesda, Maryland.

NOAA. 2019a. Tilefish | FishWatch. https://www.fishwatch.gov/profiles/tilefish.

NOAA. 2019b. Gulf of Mexico Data Atlas. https://gulfatlas.noaa.gov/.

NOAA Fisheries. 2018. Annual Commercial Landings Statistics. https://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html.

Ogle, D., P. Wheeler, and A. Dinno. 2018. FSA: Fisheries Stock Analysis.

Ortega-Ortiz, J., C. Ainsworth, and A. Gracia. 2020. Comparing ecosystem model outcomes between Ixtoc 1 and Deepwater Horizon oil spills using ecosystem modeling. *In* S. A. Murawski, C. H. Ainsworth, S. Gilbert, D. J. Hollander, C. B. Paris, M. Schluter, and D. L. Wetzel, editors. Deep Oil Spills: Facts, Fate and Effects. Springer Nature: Switzerland AG.

Palmer, S., P. Harris, and P. Powers. 2004. Age, growth, and reproduction of Tilefish, Lopholatilus chamaeleonticeps, along the southeast Atlantic coast of the United States, 1980–87 and 1996–98. Marine Resource Research Institute, South Carolina Department of Natural Resources. SEDAR4-DW-18. Charleston, South Carolina.

Pannella, G. 1971. Fish Otoliths: Daily Growth Layers and Periodical Patterns. Science 173(4002):1124–1127. American Association for the Advancement of Science.

Pulster, E. L., A. Gracia, S. Snyder, I. C. Romero, B. Carr, G. A. Toro-Farmer, and S. A. Murawski. 2020. Polycyclic Aromatic Hydrocarbon Baselines in Gulf of Mexico Fishes. *In* S. A. Murawski, C. H. Ainsworth, S. Gilbert, D. J. Hollander, C. B. Paris, M. Shluter, and D. L. Wetzel, editors. Scenarios and Responses to Future Deep Oil Spills: Fighting the Next War. Springer Nature: Switzerland AG.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Romero, I. C., P. T. Schwing, G. R. Brooks, R. A. Larson, D. W. Hastings, G. Ellis, E. A. Goddard, and D. J. Hollander. 2015. Hydrocarbons in Deep-Sea Sediments following the 2010 Deepwater Horizon Blowout in the Northeast Gulf of Mexico. PLOS ONE 10(5):e0128371. Public Library of Science.

Schaefer, J., N. Frazier, and J. Barr. 2016. Dynamics of Near-Coastal Fish Assemblages following the Deepwater Horizon Oil Spill in the Northern Gulf of Mexico. Transactions of the American Fisheries Society 145(1):108–119.

SEDAR. 2011. SEDAR 22. Gulf of Mexico Tilefish Stock Assessment Report. SEDAR, North Charleston, SC. Available online at: https://sedarweb.org/sedar-22

Snyder, S. 2014. Polycyclic Aromatic Hydrocarbon Metabolites as a Biomarker of Exposure to Oil in Demersal Fishes Following the Deepwater Horizon Blowout. Graduate Theses and Dissertations. University of South Florida.

Snyder, S. M., E. L. Pulster, D. L. Wetzel, and S. A. Murawski. 2015. PAH Exposure in Gulf of Mexico Demersal Fishes, Post- Deepwater Horizon. Environmental Science and Technology 49(14):8786–8795.

Snyder, S., E. L. Pulster, and S. A. Murawski. (n.d.). Chronic PAH exposure and effects in Tilefish. Environmental Toxicology and Chemistry.

Sundt, R. C., A. Ruus, H. Jonsson, H. Skarphéðinsdóttir, S. Meier, M. Grung, J. Beyer, and D. M. Pampanin. 2012. Biomarker responses in Atlantic cod (*Gadus morhua*) exposed to produced water from a North Sea oil field: Laboratory and field assessments. Marine Pollution Bulletin 64(1):144–152.

Tollefsen, K. E., R. C. Sundt, J. Beyer, S. Meier, and K. Hylland. 2011. Endocrine Modulation in Atlantic Cod (*Gadus morhua L.*) Exposed to Alkylphenols, Polyaromatic Hydrocarbons, Produced Water, and Dispersed Oil. Journal of Toxicology and Environmental Health, Part A 74(7–9):529–542. Taylor & Francis Group.

Trustees. 2017. Trustees. 2016. Deepwater Horizon oil spill: final programmatic damage assessment and restoration plan and final programmatic environmental impact statement. Page Injury to Natural Resources.

Turner, S. C., C. B. Grimes, and K. W. Able. 1983. Growth, mortality, and age/size structure of the fisheries for Tilefish, *Lopholatilus chamaeleonticeps*, in the Middle Atlantic-Southern New England region. Fishery Bulletin 81(4):751–763.

Vanderkooy, S., and K. Guindon-Tisdel. 2003. A Practical Handbook for Determining the Ages of Gulf of Mexico Fishes. Ocean Springs, MS.

von Bertalanffy, L. 1938. A Quantitative Theory of Organic Growth (Inquiries on Growth Laws II). Human Biology 10(2):181–213.

White, A., and T. C. Fletcher. 1985. Seasonal changes in serum glucose and condition of the plaice, Pleuronectes platessa L. Journal of Fish Biology 26(6):755–764.