# Standardized Catch Rates Of Great Hammerheads (Sphyrna Mokarran) Collected During Bottom Longline Surveys In Coastal Waters Of The Northern Gulf Of Mexico, 2006-2019

Eric Hoffmayer, Adam Pollack, Jill Hendon, Marcus Drymon, and Sean Powers

SEDAR77-DW25

Received: 12/10/2021
*Revised: 3/17/2022*

Please cite this document as:

Hoffmayer, Eric, Adam Pollack, Jill Hendon, Marcus Drymon, and Sean Powers. 2021. Standardized Catch Rates Of Great Hammerheads (Sphyrna Mokarran) Collected During Bottom Longline Surveys In Coastal Waters Of The Northern Gulf Of Mexico, 2006-2019 . SEDAR77-DW25. SEDAR, North Charleston, SC. 19 pp.

# STANDARDIZED CATCH RATES OF GREAT HAMMERHEADS (*SPHYRNA MOKARRAN*) COLLECTED DURING BOTTOM LONGLINE SURVEYS IN COASTAL WATERS OF THE NORTHERN GULF OF MEXICO FROM 2006 TO 2019.

Eric Hoffmayer[1], Adam Pollack[1], Jill Hendon[2], Marcus Drymon[3], and Sean Powers[4]

*A combined index of great hammerhead abundance from fishery independent bottom longline surveys conducted in coastal waters of the northern Gulf of Mexico was generated using Southeast Area Monitoring and Assessment Program bottom longline (SEAMAP BLL) data (AL-TX, 2008-2019) and Dauphin Island Sea Lab bottom longline data (2006-2019). Both bottom longline surveys use the same gear, bait, and identical deployment protocols. Due to a change in survey design of the SEAMAP BLL survey, which started sampling exclusively in waters between 3-10m in 2015 to complement the NMFS bottom longline survey and the fact that the majority of the great hammerhead sharks were caught in shallow waters (<15m), the datasets were truncated to include only stations that occurred in less than 15 m of water. The index extends from 2006 to 2019, and resulted in 85 great hammerheads captured during 1,279 BLL sets. Standardized catch rates were estimated using a delta-lognormal modeling method. Nominal and standardized great hammerhead catch rates remained relatively stable throughout the survey period.*

[1]NOAA, National Marine Fisheries Service, Southeast Fisheries Science Center, Mississippi Laboratories, Pascagoula, Mississippi 39567; [2]Center for Fisheries Research and Development, The University of Southern Mississippi. Gulf Coast Research Laboratory, 703 East Beach Drive, Ocean Springs, MS 39564; [3]Mississippi State University Extension, Coastal Research & Extension Center, 1815 Popps Ferry Rd., Biloxi, Mississippi, 39532; [4]Dauphin Island Sea Lab, Center for Ecosystem Based Fishery Management, 101 Bienville Blvd, Dauphin Island, Alabama 36528.

## INTRODUCTION

The National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center (SEFSC) fishery-independent bottom longline (BLL) survey was established in 1995 and covers continental shelf waters ranging in water depth from 9 to 366 meters. Complementary fishery-independent inshore BLLs of coastal shark populations in the northcentral Gulf of Mexico using the same gear was initiated in 2006. Since 2006, the Dauphin Island Sea Laboratory (DISL) has been conducting an annual shark BLL survey. In 2008, the NMFS Southeast Area Monitor and Assessment Program (SEAMAP) developed a coastal BLL in Alabama, Mississippi, Louisiana, and Texas state waters. The SEAMAP state partners that conduct this survey work include DISL, Gulf Coast Research Laboratory, Louisiana Department of Wildlife and Fisheries, and Texas Parks and Wildlife Department. Since 2015, a change in the SEAMAP BLL survey design was implemented to sample exclusively in waters less than 10 meters. Due to this change and the fact that the majority of the great hammerheads were caught in shallow waters (<15m), we truncated the data to only include stations that occurred in less than 15 meters of water. Data from both surveys were combined in an attempt to provide a combined single relative index of abundance for great hammerheads for the northern Gulf of Mexico.

## MATERIALS AND METHODS

### *DISL BLL Survey*

The sampling protocol and equipment follows the procedures established by the NOAA Fisheries Mississippi Laboratories bottom longline survey (Grace and Henwood 1997, Driggers et al. 2008). The longline gear consisted of a 1.6 km (426 kg test) monofilament mainline and 100, 3.7 m gangions (332 kg test monofilament) outfitted with a 15/0 circle hooks and baited with Atlantic mackerel (*Scomber scombrus*). The longline fished for one hour from the time of last high-flier deployment to the time of first high-flier retrieval. Bottom longline sampling for the Alabama nearshore survey began in May 2006 and employed a random stratified block design. Blocks were established both in the Mississippi Sound/Mobile Bay and waters south of Dauphin Island. Each month (January to December), stations were randomly selected within the blocks, and effort was allocated across three depth strata (0-5m, 5-10m, and 10-20m). For additional details, see Drymon and Powers (2012).

### *SEAMAP BLL Survey*

The sampling protocol and equipment follows the procedures established by the NOAA Fisheries Mississippi Laboratories bottom longline survey (Grace and Henwood 1997, Driggers et al. 2008). The longline gear consisted of a 1.6 km (426 kg test) monofilament mainline and 100, 3.7 m gangions (332 kg test monofilament) outfitted with a 15/0 circle hooks and baited with Atlantic mackerel, (*Scomber scombrus*). The longline fished for one hour from the time of last high-flier deployment to the time of first high-flier retrieval. Initially, the bottom longline sampling employed a random stratified block design within each state with effort within each block allocated across three depth strata (0-5m, 5-10m, and 10-20m). The study area was broken into three regions: Mississippi Sound, South of barrier islands, and Chandeleur Sound. Each month from March to October, three stations were sampled from each region. Beginning in 2015 the Gulf SEAMAP coastal bottom longline survey switched from a state to a gulf-wide design and monthly sampling was switched to seasonal sampling (e.g. spring, summer, and fall). For additional details, see Hendon *et al.* (2012).

***Data***

SEAMAP BLL data were obtained from the Gulf States Marine Fisheries Commission (GSMFC) database, which contains data collected by state agencies/partners from Alabama, Florida, Louisiana, Mississippi and Texas. Additional bottom longline data was obtained from Marcus Drymon that represents the DISL BLL sampling done by AL. A total of 2,742 stations were sampled from 2006-2019 during the SEAMAP and DISL BLL surveys. All young-of-the-year great hammerheads were excluded from the analysis (fork length < 800 mm). The final analytical dataset included 1,279 stations sampled between SEAMAP and DISL (Table 1), which included captures of 85 great hammerheads (Table 2).

***Data Exclusions***

We used the time series of data between 2006 and 2019 to develop great hammerhead abundance indices. As previously mentioned, the data was limited to only those stations sampled in less than 15 m of water due to the change in sample design and the lack of any deeper sampling later in the time series. All sampling done in January, February, and December was excluded due to the inconsistent sampling over the time series (Table 3). In addition, sampling done in March, April, October, and November was excluded due to the lack of significant catches of great hammerhead (Table 4).

***Index Development***

Delta-lognormal modeling methods were used to estimate relative abundance indices for vermilion snapper (Pennington 1983, Bradu and Mundlak 1970). The main advantage of using this method is allowance for the probability of zero catch (Ortiz *et al.* 2000). The index computed by this method is a mathematical combination of yearly abundance estimates from two distinct generalized linear models: a binomial (logistic) model which describes proportion of positive abundance values (i.e. presence/absence) and a lognormal model which describes variability in only the nonzero abundance data (*cf.* Lo *et al*. 1992).

The delta-lognormal index of relative abundance ($I_y$) was estimated as:

(1) $$I_y = c_y p_y,$$

where $c_y$ is the estimate of mean CPUE for positive catches only for year $y$, and $p_y$ is the estimate of mean probability of occurrence during year $y$. Both $c_y$ and $p_y$ were estimated using generalized linear models. Data used to estimate abundance for positive catches ($c$) and probability of occurrence ($p$) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $\ln(c) = X\beta + \varepsilon$

and

(3) $p = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}}$,

respectively, where $c$ is a vector of the positive catch data, $p$ is a vector of the presence/absence data, $X$ is the design matrix for main effects, $\beta$ is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance $\sigma^2$. Therefore, $c_y$ and $p_y$ were estimated as least-squares means for each year along with their corresponding standard errors, SE ($c_y$) and SE ($p_y$), respectively. From these estimates, $I_y$ was calculated, as in equation (1), and its variance calculated using the delta method approximation

(4) $V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y)$.

A covariance term is not included in the variance estimator since there is no correlation between the estimator of the proportion positive and the mean CPUE given presence. The two estimators are derived independently and have been shown to not covary for a given year (Christman, unpublished).

The submodels of the delta-lognormal model were built using a backward selection procedure based on type 3 analyses with an inclusion level of significance of $\alpha = 0.05$. Binomial submodel performance was evaluated using AIC, while the performance of the lognormal submodel was evaluated based on analyses of residual scatter and QQ plots in addition to AIC. Variables that could be included in the submodels were:

**Submodel Variables**

Year: 2006 – 2019
Depth: 3.7 – 15.0 m (continuous)
Bottom Temperature: 19.8 – 31.7°C (continuous)
Bottom Salinity: 5.7 – 38.7 ppt (continuous)
Bottom Dissolved Oxygen: 0.02 – 12.16 mg/L (continuous)
Longitude: 97.52°W – 87.29°W (continuous)

## RESULTS AND DISCUSSION

### *Distribution, Size and Age*

Of the 85 great hammerheads captured during the surveys, 70 were measured with a mean fork length of 1513 mm. The length frequency distribution of great hammerheads captured is shown in Figure 1. The distribution of great hammerheads from the SEAMAP and DISL BLL surveys is presented in Figure 2, with seasonal/annual abundance and distribution presented in the Appendix Figure 1. The annual number of great hammerheads captured annually ranged from 2 to 12 (Table 5).

***Index of Abundance***

For the SEAMAP and DISL BLL surveys (2006-2019) abundance index of great hammerheads in the GOM, year, bottom salinity, and bottom DO were retained in the binomial submodel, while year was retained in the lognormal submodel. A summary of the factors used in the analysis is presented in Appendix Table 1. Table 6 summarizes the final set of variables used in the submodels and their significance. The AIC for the binomial and lognormal submodels were 5279.5 and 29.4, respectively. The diagnostic plots for the lognormal submodel are shown in Figure 3. Annual abundance indices are presented in Table 7 and Figure 4.

**REFERENCES**


Bradu, D. & Mundlak, Y. 1970. Estimation in Lognormal Linear Models, Journal of the American Statistical Association, 65, 198-211.

Driggers III, W.B., Ingram Jr., G.W., Grace, M.A., Gledhill, C.T., Henwood, T.A., Horton, C.N., and Jones, C.M. 2008. Pupping areas and mortality rates of young tiger sharks *Galeocerdo cuvier* in the western North Atlantic Ocean. Aquatic Biology 2:161-170.

Drymon, M.J. and S. Powers. 2012. Catch rates and size distribution of blacktip shark *Carcharhinus limbatus* in the northern Gulf of Mexico, 2006-2010. SEDAR29-WP-11. SEDAR, North Charleston, SC. 13p.

Grace, M.A. and T. Henwood. 1997. Assessment of the distribution and abundance of coastal sharks in the U.S. Gulf of Mexico and Eastern Seaboard, 1995 and 1996. Mar. Fish Rev. 59: 23–32.

Hendon, J.M., E.R. Hoffmayer, and A.G. Pollack. 2012. Standardized catch rates of blacktip sharks (*Carcharhinus limbatus*) collected during a SEAMAP bottom longline survey in Mississippi/Louisiana coastal waters from 2008-2011. SEDAR 29-WP-15. SEDAR, North Charleston, SC. 49p.

Hoffmayer, E., J. Hendon, and A. Pollack. 2012a. Standardized catch rates of blacktip sharks (*Carcharhinus limbatus*) collected during a bottom longline survey in Mississippi coastal waters, 2004-2011. SEDAR29-WP-14. SEDAR, North Charleston, SC. 30p.

Hoffmayer E., J. Hendon, M. Drymon, S. Powers, A. Pollack, and J. Carlson. 2012b. Standardized catch rates of blacktip sharks (Carcharhinus limbatus) collected during bottom longline surveys in Mississippi, Louisiana, and Alabama coastal waters from 2004 to 2010. SEDAR29-WP-21. SEDAR, North Charleston, SC.

Lo, N.C., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

Ortiz, M. 2006. Standardized catch rates for gag grouper (*Mycteroperca microlepis*) from the marine recreational fisheries statistical survey (MRFSS). Southeast Data Assessment and Review (SEDAR) Working Document S10 DW-09.

Ortiz, M., C.M Legault and N.M. Ehrhardt. 2000. An alternative method for estimating bycatch from the U.S. shrimp trawl fishery in the Gulf of Mexico, 1972-1995. *Fishery Bulletin* 98:583-599.

Pennington, M. 1983. Efficient Estimators of Abundance, for Fish and Plankton Surveys. Biometrics, 39, 281-286.

SAS Institute Inc. 2018. SAS Online Help Documentation. Available: http://documentation.sas.com/?cdcId=pgmsascdc&cdcVersion=9.4_3.2&docsetId=proc&docsetTarget=titlepage.htm&locale=en. Last Accessed: May 2018.

Table 1. Breakdown of stations sampled by SEAMAP partners and DISL during annual bottom longline surveys.

| Year | DISL | SEAMAP | | | | Total |
|---|---|---|---|---|---|---|
| | | AL | LA | MS | TX | |
| 2006 | 69 | | | | | *69* |
| 2007 | 111 | | | | | *111* |
| 2008 | 93 | | | 60 | | *153* |
| 2009 | 4 | | | 64 | | *68* |
| 2010 | | 3 | | 58 | 20 | *81* |
| 2011 | 10 | 2 | 5 | 46 | 12 | *75* |
| 2012 | 4 | 8 | 4 | 37 | 14 | *67* |
| 2013 | | 6 | 9 | 31 | 12 | *58* |
| 2014 | | 9 | 7 | 39 | 14 | *69* |
| 2015 | 15 | 7 | 52 | 22 | 14 | *110* |
| 2016 | 27 | 10 | 49 | 24 | 18 | *128* |
| 2017 | 14 | 9 | 58 | 11 | 16 | *108* |
| 2018 | | 5 | 65 | | 21 | *91* |
| 2019 | | 5 | 53 | 20 | 13 | *91* |
| *Total* | *347* | *64* | *302* | *412* | *154* | *1279* |

Table 2. Breakdown of numbers of great hammerhead caught by SEAMAP partners and DISL during annual bottom longline surveys.

| Year | DISL | SEAMAP | | | | SEAMAP Total | Total |
|---|---|---|---|---|---|---|---|
| | | AL | LA | MS | TX | | |
| 2006 | 6 | | | | | | *6* |
| 2007 | 4 | | | | | | *4* |
| 2008 | 8 | | | 3 | | 3 | *11* |
| 2009 | 0 | | | 3 | | 3 | *3* |
| 2010 | | 0 | | 1 | 1 | 2 | *2* |
| 2011 | 0 | 3 | 0 | 0 | 0 | 3 | *3* |
| 2012 | 0 | 1 | 0 | 2 | 1 | 4 | *4* |
| 2013 | | 4 | 0 | 1 | 3 | 8 | *8* |
| 2014 | | 3 | 2 | 5 | 2 | 12 | *12* |
| 2015 | 0 | 1 | 5 | 0 | 0 | 6 | *6* |
| 2016 | 4 | 0 | 2 | 1 | 2 | 5 | *9* |
| 2017 | 1 | 2 | 1 | 1 | 2 | 6 | *7* |
| 2018 | | 0 | 3 | | 1 | 4 | *4* |
| 2019 | | 2 | 3 | 1 | 0 | 6 | *6* |
| *Total* | *23* | *16* | *16* | *18* | *12* | *62* | *85* |

Table 3. Number of stations sampled by month during SEAMAP and DISL bottom longline surveys.

| Year | Month | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 2006 | | | | | 9 | 10 | 12 | 7 | 10 | 19 | | 2 | *69* |
| 2007 | 3 | 1 | 7 | 12 | 12 | 12 | 14 | 13 | 14 | 13 | 10 | | *111* |
| 2008 | | | 15 | 23 | 4 | 17 | 27 | 24 | 13 | 16 | 14 | | *153* |
| 2009 | | | 8 | 5 | 5 | 8 | 11 | 12 | 12 | 7 | | | *68* |
| 2010 | | | 12 | 8 | 10 | 9 | 10 | 12 | 11 | 9 | | | *81* |
| 2011 | | 1 | 6 | 4 | 4 | 9 | 10 | 16 | 15 | 9 | 1 | | *75* |
| 2012 | | 1 | 9 | 2 | 7 | 10 | 12 | 11 | 5 | 9 | 1 | | *67* |
| 2013 | | | 5 | 6 | 4 | 11 | 7 | 11 | 9 | 5 | | | *58* |
| 2014 | | | 6 | 4 | 3 | 4 | 16 | 17 | 12 | 7 | | | *69* |
| 2015 | | | | 5 | 20 | 18 | 22 | 14 | 19 | 12 | | | *110* |
| 2016 | | | 2 | 14 | 18 | 12 | 24 | 24 | 34 | | | | *128* |
| 2017 | | | | 18 | 23 | 8 | 22 | 19 | 14 | 4 | | | *108* |
| 2018 | | | | 12 | 7 | 24 | 9 | 29 | 10 | | | | *91* |
| 2019 | | | | 13 | 12 | 19 | 17 | 18 | 12 | | | | *91* |
| *Total* | *3* | *3* | *70* | *126* | *138* | *171* | *213* | *227* | *190* | *110* | *26* | *2* | *1279* |

Table 4. Number of great hammerheads caught by month during SEAMAP and DISL bottom longline surveys.

| Year | Month | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 2006 | | | | | 0 | 2 | 4 | 0 | 0 | 0 | | 0 | *6* |
| 2007 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | | *4* |
| 2008 | | | 0 | 0 | 2 | 0 | 3 | 5 | 1 | 0 | 0 | | *11* |
| 2009 | | | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | | | *3* |
| 2010 | | | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | | | *2* |
| 2011 | | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | | *3* |
| 2012 | | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 | | *4* |
| 2013 | | | 0 | 0 | 5 | 1 | 1 | 0 | 1 | 0 | | | *8* |
| 2014 | | | 0 | 0 | 0 | 2 | 2 | 6 | 1 | 1 | | | *12* |
| 2015 | | | | 0 | 0 | 3 | 0 | 1 | 2 | 0 | | | *6* |
| 2016 | | | 0 | 0 | 0 | 1 | 1 | 1 | 6 | | | | *9* |
| 2017 | | | | 1 | 2 | 0 | 3 | 0 | 1 | 0 | | | *7* |
| 2018 | | | | 0 | 1 | 0 | 0 | 3 | 0 | | | | *4* |
| 2019 | | | | 0 | 0 | 2 | 2 | 2 | 0 | | | | *6* |
| *Total* | *0* | *0* | *0* | *1* | *13* | *12* | *21* | *20* | *16* | *2* | *0* | *0* | *85* |

Table 5. Summary of the great hammerhead data from the combine SEAMAP and DISL BLL surveys between 2006 and 2019. Note that all YOY great hammerheads have been removed.

| Survey Year | Number of Stations | Number Collected | Number Measured | Minimum Fork Length (mm) | Maximum Fork Length (mm) | Mean Fork Length (mm) | Standard Deviation |
|---|---|---|---|---|---|---|---|
| 2006 | 69 | 6 | 1 | 1297 | 1297 | 1297 | - |
| 2007 | 111 | 4 | 2 | 1227 | 1515 | 1371 | 203 |
| 2008 | 153 | 11 | 10 | 1367 | 1725 | 1482 | 104 |
| 2009 | 68 | 3 | 3 | 1019 | 1625 | 1356 | 309 |
| 2010 | 81 | 2 | 0 | - | - | - | - |
| 2011 | 75 | 3 | 3 | 1310 | 1723 | 1565 | 223 |
| 2012 | 67 | 4 | 3 | 1455 | 1890 | 1635 | 227 |
| 2013 | 58 | 8 | 5 | 1290 | 1810 | 1584 | 203 |
| 2014 | 69 | 12 | 10 | 855 | 1865 | 1491 | 342 |
| 2015 | 110 | 6 | 6 | 1275 | 2052 | 1562 | 291 |
| 2016 | 128 | 9 | 9 | 905 | 2085 | 1504 | 299 |
| 2017 | 108 | 7 | 7 | 1000 | 2025 | 1462 | 359 |
| 2018 | 91 | 4 | 4 | 1260 | 1860 | 1439 | 282 |
| 2019 | 91 | 6 | 5 | 1286 | 2440 | 1793 | 513 |

| Total Number of Years | Total Number of Stations | Total Number Collected | Total Number Measured | Overall Mean Fork Length (mm) |
|---|---|---|---|---|
| 14 | 1,279 | 85 | 70 | 1513 |

Table 6. Summary of backward selection procedure for building delta-lognormal submodels for great hammerhead SEAMAP and DISL BLL surveys index of relative abundance from 2009 to 2019 in the Gulf of Mexico.

| ***Model Run #1*** | *Binomial Submodel Type 3 Tests (AIC 5395.3)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 60.3)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 901 | 17.41 | 1.34 | 0.1814 | 0.1840 | 13 | 48 | 1.71 | 0.0904 |
| *Depth* | 1 | 901 | 2.14 | 2.14 | 0.1436 | 0.1439 | 1 | 48 | 0.17 | 0.6844 |
| *Bottom Temperature* | 1 | 901 | 3.32 | 3.32 | 0.0684 | 0.0687 | 1 | 48 | 0.22 | 0.6399 |
| *Bottom Salinity* | 1 | 901 | 4.89 | 4.89 | 0.0271 | 0.0273 | 1 | 48 | 1.70 | 0.1987 |
| *Bottom Dissolved Oxygen* | 1 | 901 | 8.73 | 8.73 | 0.0031 | 0.0032 | 1 | 48 | 2.09 | 0.1550 |
| *Longitude* | 1 | 901 | 4.55 | 4.55 | 0.0328 | 0.0331 | 1 | 48 | 0.67 | 0.4167 |
| ***Model Run #2*** | *Binomial Submodel Type 3 Tests (AIC 5366.5)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 54.2)* | | | |
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 902 | 19.04 | 1.46 | 0.1217 | 0.1243 | 13 | 49 | 1.74 | 0.0818 |
| *Depth* | | | | Dropped | | | | Dropped | | |
| *Bottom Temperature* | 1 | 902 | 2.86 | 2.86 | 0.0906 | 0.0909 | 1 | 49 | 0.18 | 0.6760 |
| *Bottom Salinity* | 1 | 902 | 8.88 | 8.88 | 0.0029 | 0.0030 | 1 | 49 | 1.58 | 0.2148 |
| *Bottom Dissolved Oxygen* | 1 | 902 | 8.62 | 8.62 | 0.0033 | 0.0034 | 1 | 49 | 2.11 | 0.1525 |
| *Longitude* | 1 | 902 | 4.33 | 4.33 | 0.0374 | 0.0377 | 1 | 49 | 0.63 | 0.4323 |
| ***Model Run #3*** | *Binomial Submodel Type 3 Tests (AIC 5319.1)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 48.0)* | | | |
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 903 | 18.18 | 1.40 | 0.1506 | 0.1533 | 13 | 50 | 1.76 | 0.0772 |
| *Depth* | | | | Dropped | | | | Dropped | | |
| *Bottom Temperature* | | | | Dropped | | | | Dropped | | |
| *Bottom Salinity* | 1 | 903 | 7.53 | 7.53 | 0.0061 | 0.0062 | 1 | 50 | 1.67 | 0.2017 |
| *Bottom Dissolved Oxygen* | 1 | 903 | 10.45 | 10.45 | 0.0012 | 0.0013 | 1 | 50 | 2.00 | 0.1638 |
| *Longitude* | 1 | 903 | 2.68 | 2.68 | 0.1014 | 0.1018 | 1 | 50 | 1.18 | 0.2833 |
| ***Model Run #4*** | *Binomial Submodel Type 3 Tests (AIC 5297.5)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 42.3)* | | | |
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 905 | 16.52 | 1.27 | 0.2221 | 0.2246 | 13 | 51 | 1.78 | 0.0715 |
| *Depth* | | | | Dropped | | | | Dropped | | |
| *Bottom Temperature* | | | | Dropped | | | | Dropped | | |
| *Bottom Salinity* | 1 | 905 | 5.92 | 5.92 | 0.0150 | 0.0151 | 1 | 51 | 1.38 | 0.2463 |
| *Bottom Dissolved Oxygen* | 1 | 905 | 8.68 | 8.68 | 0.0032 | 0.0033 | 1 | 51 | 1.49 | 0.2275 |
| *Longitude* | | | | Dropped | | | | Dropped | | |

Table 6. Continued

| **Model Run #5** | *Binomial Submodel Type 3 Tests (AIC 5297.5)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 36.7)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 905 | 16.52 | 1.27 | 0.2221 | 0.2246 | 13 | 52 | 1.79 | 0.0704 |
| *Depth* | | | | Dropped | | | | Dropped | | |
| *Bottom Temperature* | | | | Dropped | | | | Dropped | | |
| *Bottom Salinity* | 1 | 905 | 5.92 | 5.92 | 0.0150 | 0.0151 | | Dropped | | |
| *Bottom Dissolved Oxygen* | 1 | 905 | 8.68 | 8.68 | 0.0032 | 0.0033 | 1 | 52 | 0.93 | 0.3394 |
| *Longitude* | | | | Dropped | | | | Dropped | | |
| **Model Run #6** | *Binomial Submodel Type 3 Tests (AIC 5297.5)* | | | | | | *Lognormal Submodel Type 3 Tests (AIC 29.4)* | | | |
| *Effect* | *Num DF* | *Den DF* | *Chi-Square* | *F Value* | *Pr > ChiSq* | *Pr > F* | *Num DF* | *Den DF* | *F Value* | *Pr > F* |
| *Year* | 13 | 905 | 16.52 | 1.27 | 0.2221 | 0.2246 | 13 | 58 | 1.91 | 0.0478 |
| *Depth* | | | | Dropped | | | | Dropped | | |
| *Bottom Temperature* | | | | Dropped | | | | Dropped | | |
| *Bottom Salinity* | 1 | 905 | 5.92 | 5.92 | 0.0150 | 0.0151 | | Dropped | | |
| *Bottom Dissolved Oxygen* | 1 | 905 | 8.68 | 8.68 | 0.0032 | 0.0033 | | Dropped | | |
| *Longitude* | | | | Dropped | | | | Dropped | | |

Table 7. Indices of great hammerhead abundance developed using the delta-lognormal (DL) model for SEAMAP and DISL BLL surveys from 2006-2019 in the northern Gulf of Mexico. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the DL indices scaled to a mean of one for the time series, the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

| Survey Year | Frequency | *N* | DL Index | Scaled Index | CV | LCL | UCL |
|---|---|---|---|---|---|---|---|
| 2006 | 0.12500 | 48 | 0.01297 | 0.17076 | 1.06211 | 0.03003 | 0.97098 |
| 2007 | 0.06154 | 65 | 0.04521 | 0.59519 | 0.52501 | 0.22187 | 1.59666 |
| 2008 | 0.10588 | 85 | 0.10894 | 1.43429 | 0.34383 | 0.73501 | 2.79885 |
| 2009 | 0.04167 | 48 | 0.03930 | 0.51737 | 0.72751 | 0.14051 | 1.90508 |
| 2010 | 0.03846 | 52 | 0.05039 | 0.66340 | 0.71590 | 0.18325 | 2.40159 |
| 2011 | 0.01852 | 54 | . | . | . | . | . |
| 2012 | 0.08889 | 45 | 0.06389 | 0.84125 | 0.53152 | 0.31021 | 2.28135 |
| 2013 | 0.11905 | 42 | 0.14153 | 1.86349 | 0.45556 | 0.78187 | 4.44138 |
| 2014 | 0.19231 | 52 | 0.17258 | 2.27221 | 0.32306 | 1.20998 | 4.26696 |
| 2015 | 0.06452 | 93 | 0.05105 | 0.67211 | 0.42085 | 0.29970 | 1.50726 |
| 2016 | 0.08036 | 112 | 0.08925 | 1.17515 | 0.33477 | 0.61236 | 2.25518 |
| 2017 | 0.05814 | 86 | 0.08050 | 1.05989 | 0.45064 | 0.44852 | 2.50459 |
| 2018 | 0.05063 | 79 | 0.04343 | 0.57179 | 0.52057 | 0.21473 | 1.52257 |
| 2019 | 0.06410 | 78 | 0.08834 | 1.16312 | 0.44890 | 0.49370 | 2.74019 |

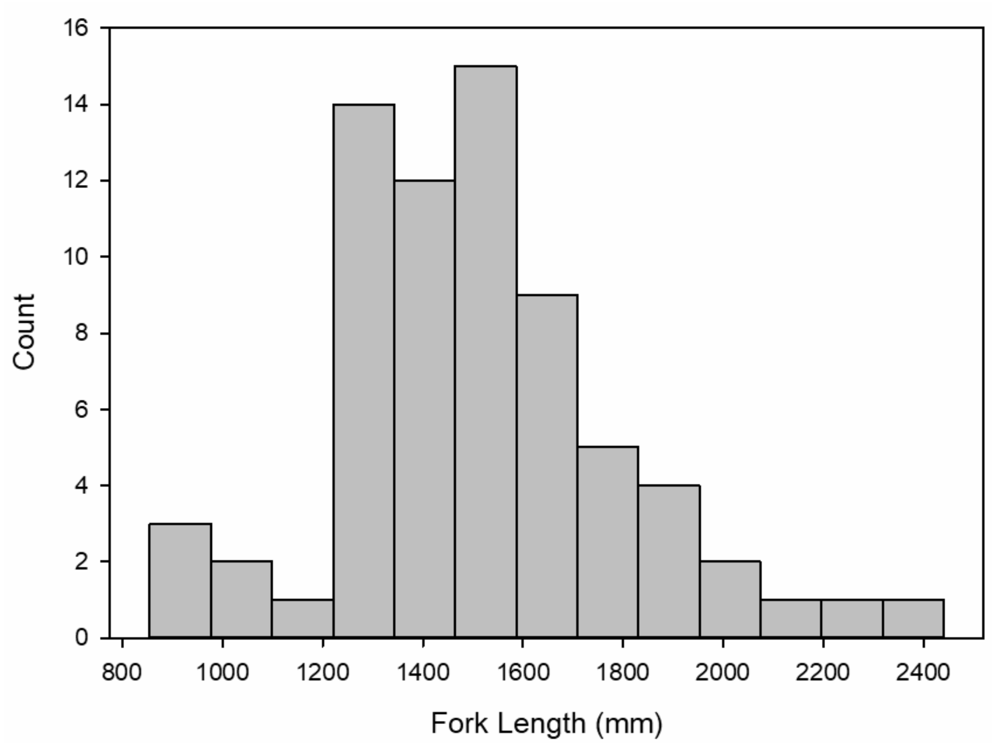



Figure 1. Length frequency of Great hammerhead, *Sphyrna mokarran*, caught in the combined SEAMAP and DISL BLL surveys. Note that all YOY great hammerheads have been removed.

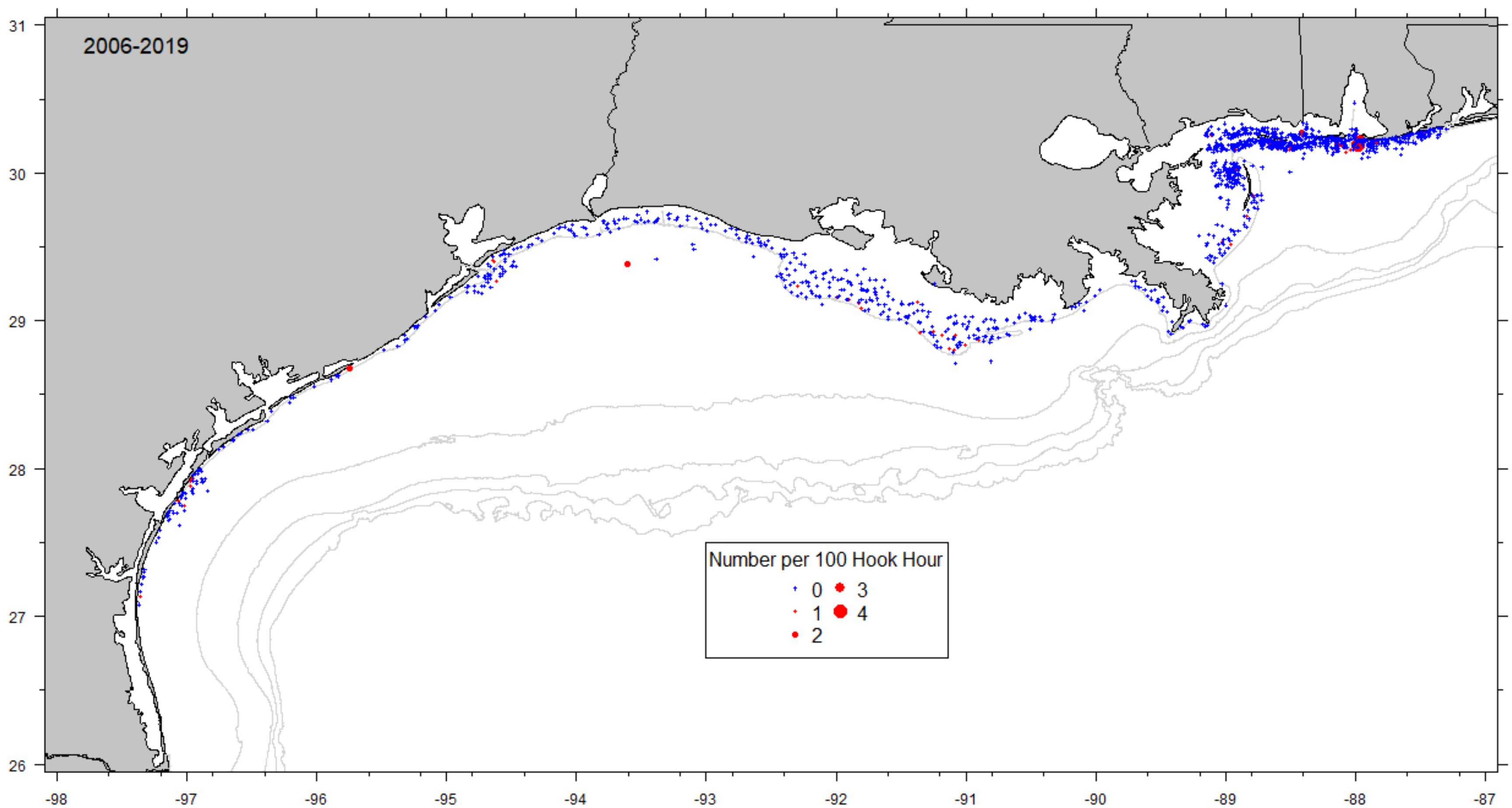



Figure 2. Stations sampled from 2006 to 2019 during the SEAMAP and DISL BLL surveys with CPUE for great hammerheads.

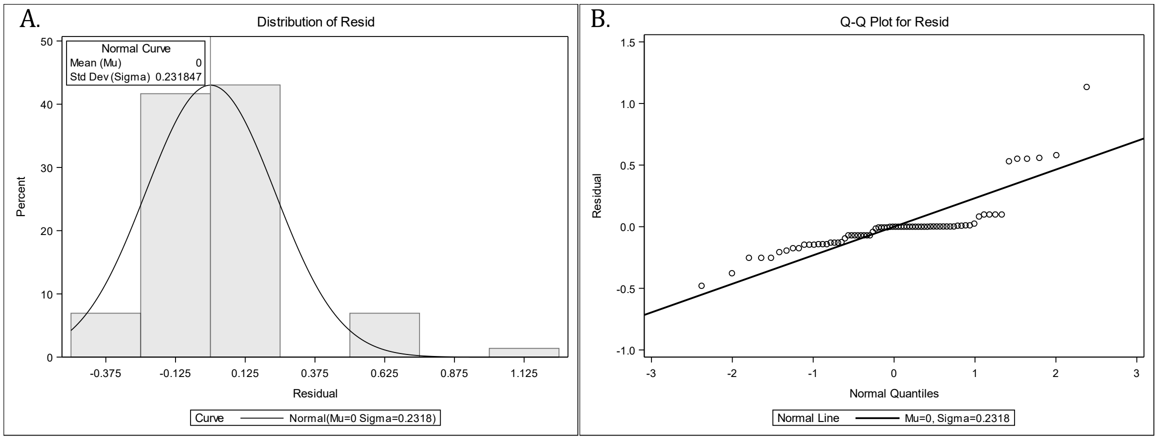



Figure 5. Diagnostic plots for lognormal component of the great hammerhead NMFS Bottom Longline Surveys model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

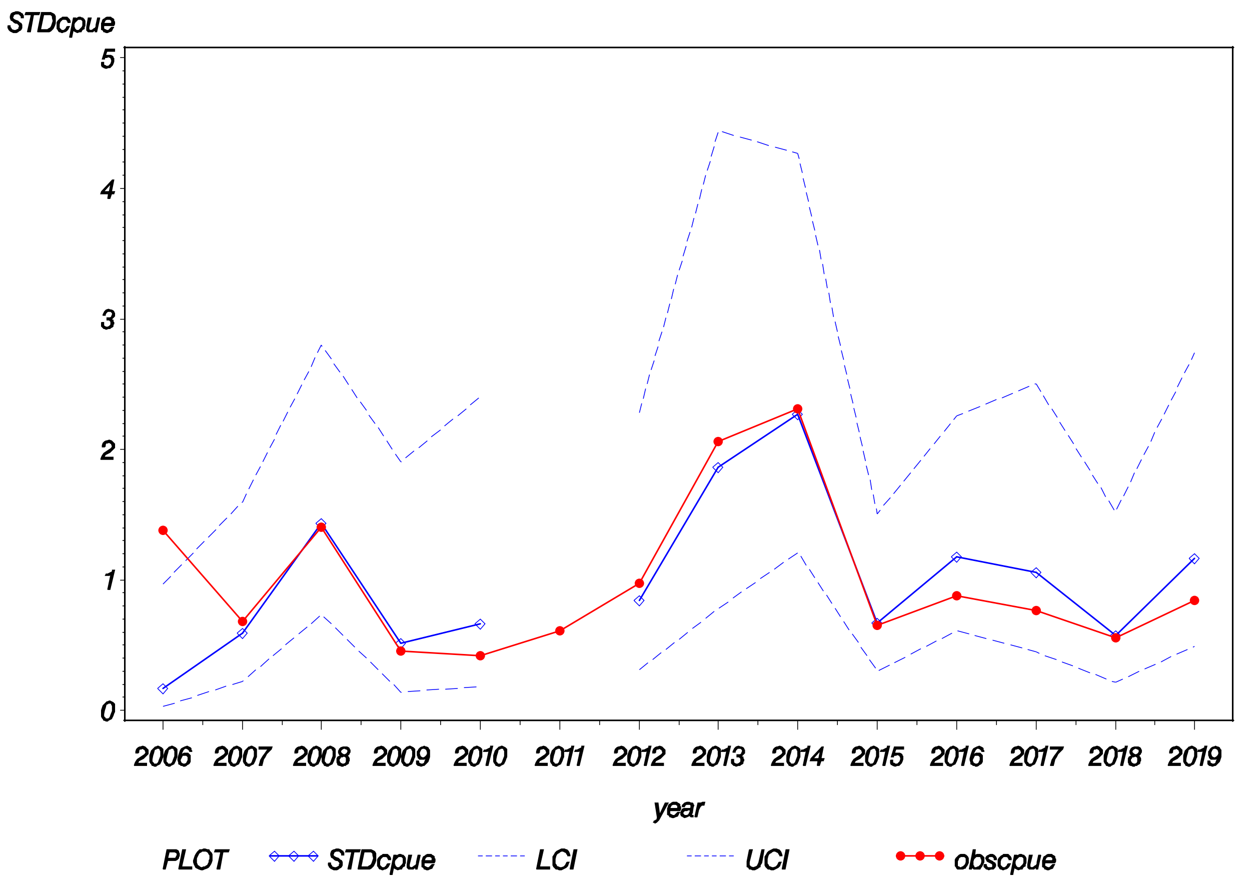


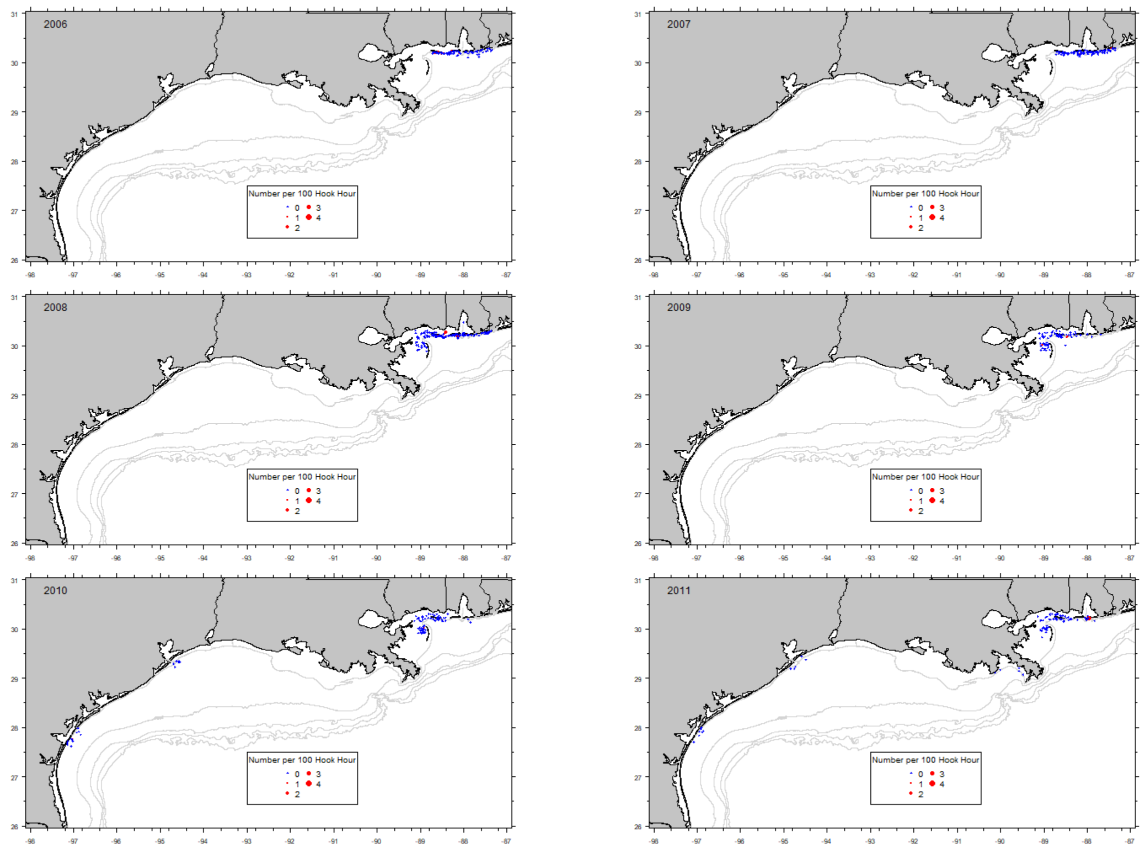

Figure 4. Annual index of abundance for great hammerheads from the SEAMAP and DISL BLL surveys from 2006 – 2019.

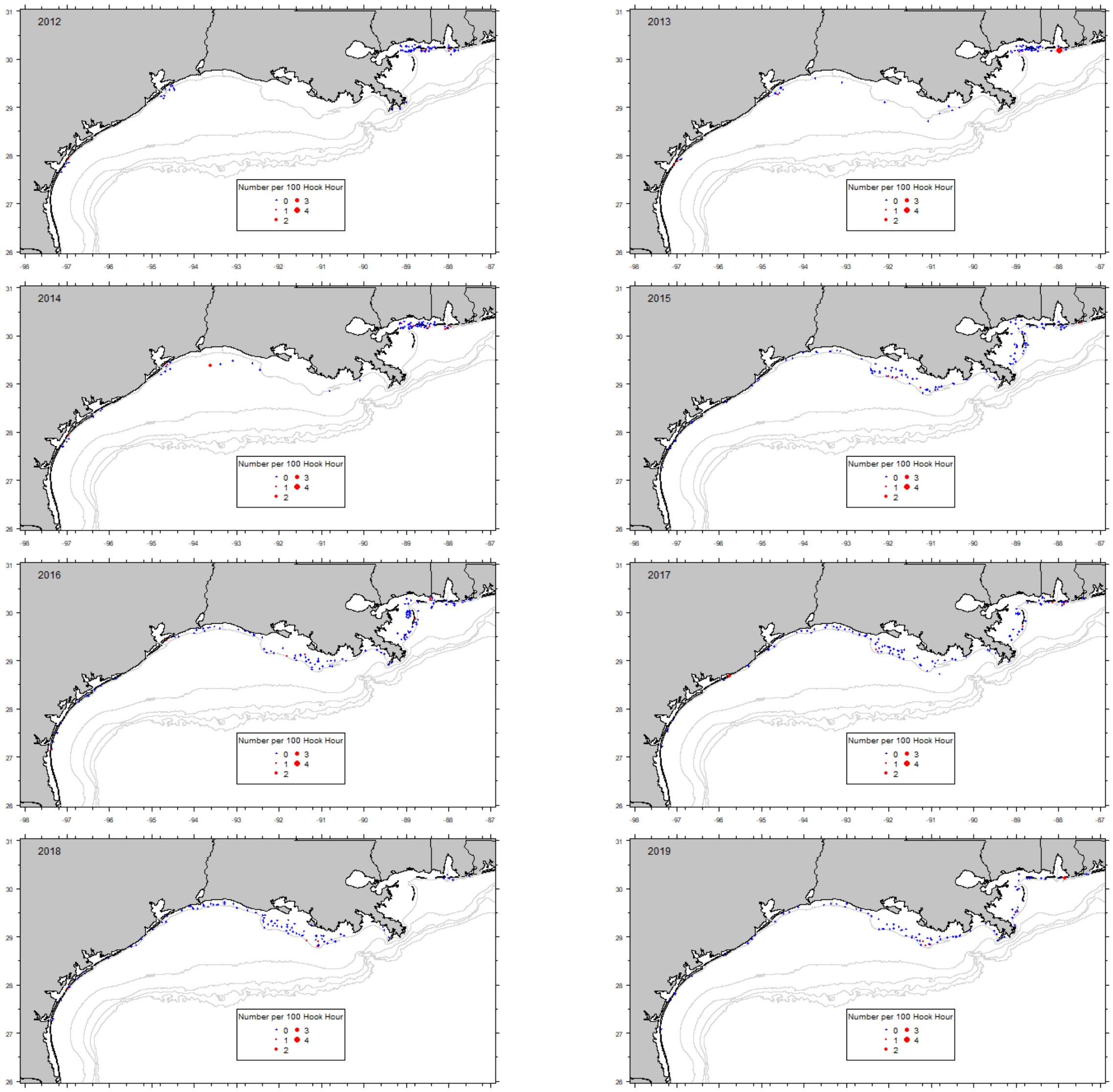
# Appendix

Appendix Table 1. Summary of the factors used in constructing the great hammerhead abundance index from the updated SEAMAP and DISL bottom longline surveys.

| Factor | Level | Number of Observations | Number of Positive Observations | Proportion Positive | Mean CPUE |
|---|---|---|---|---|---|
| Year | 2006 | 48 | 6 | 0.12500 | 0.12500 |
| Year | 2007 | 65 | 4 | 0.06154 | 0.06154 |
| Year | 2008 | 85 | 9 | 0.10588 | 0.12941 |
| Year | 2009 | 48 | 2 | 0.04167 | 0.04167 |
| Year | 2010 | 52 | 2 | 0.03846 | 0.03846 |
| Year | 2011 | 54 | 1 | 0.01852 | 0.05556 |
| Year | 2012 | 45 | 4 | 0.08889 | 0.08889 |
| Year | 2013 | 42 | 5 | 0.11905 | 0.19048 |
| Year | 2014 | 52 | 10 | 0.19231 | 0.21154 |
| Year | 2015 | 93 | 6 | 0.06452 | 0.06452 |
| Year | 2016 | 112 | 9 | 0.08036 | 0.08036 |
| Year | 2017 | 86 | 5 | 0.05814 | 0.06977 |
| Year | 2018 | 79 | 4 | 0.05063 | 0.05063 |
| Year | 2019 | 78 | 5 | 0.06410 | 0.07692 |

Appendix Figure 1. Annual survey effort and catch of great hammerhead from the SEAMAP and DISL bottom longline surveys (2006-2019).




2012
2013
2014
2015
2016
2017
2018
2019
Number per 100 Hook Hour
0
1
2
3
4