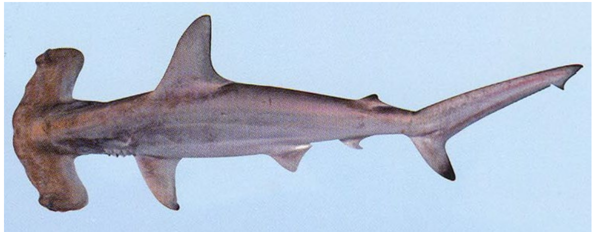
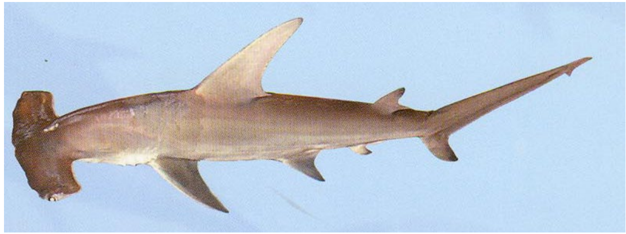
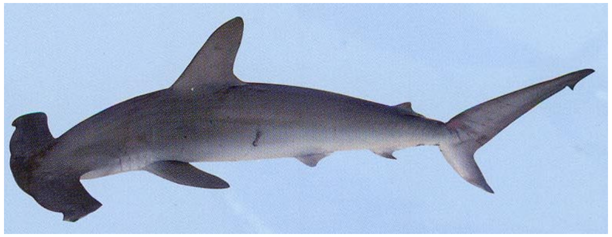
Simple Stock Synthesis (SSS) applied to the smooth hammerhead shark stock assessment

SEDAR 77 (Review Workshop)

November 13, 2023

SEDAR 77 Description

SEDAR 77 is a research track stock assessment for HMS Hammerhead Sharks with 4 major milestones.

- The Stock ID process was conducted through a series of Stock ID webinars before the Data process started.
- The Data process was conducted through a series of webinars and an online workshop.
- The Assessment Process was conducted through a series of webinars.
- The Review Workshop (in-person 8/28/23 then online now).

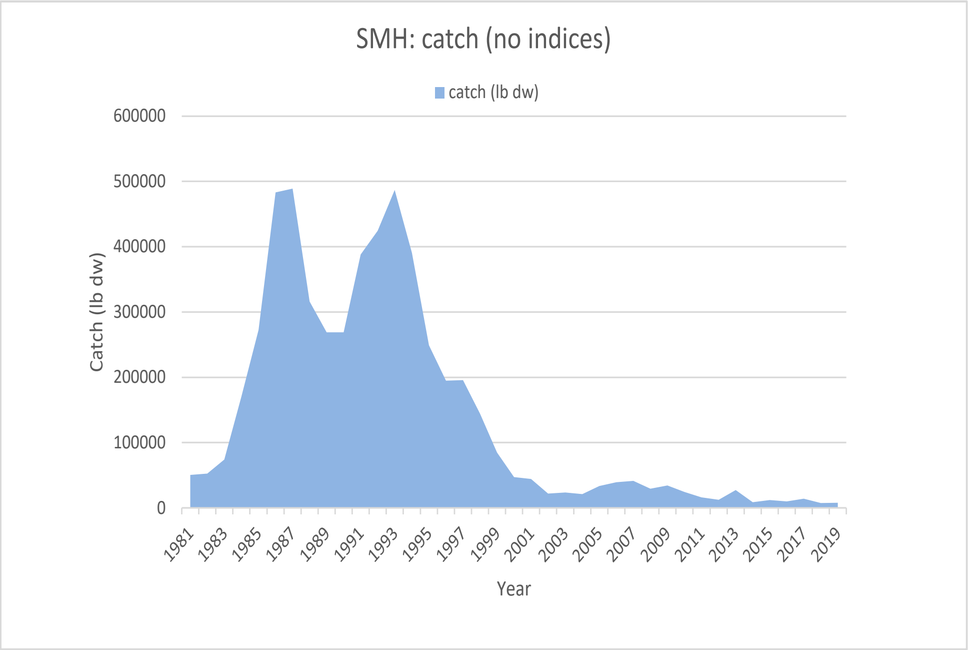
Stock ID Process Final Report (October 2021)

- The SEDAR 77 HMS Hammerheads Stock ID Process was conducted via a series of webinars, including a data scoping webinar (5/26/2021) and two webinars to discuss data analysis (7/20/2021, 8/10/2021).
- Regarding Smooth Hammerhead, there were limited data available for assessing the stock identification of Smooth Hammerhead. The Stock ID Workshop recommended that one stock assessment be conducted for Smooth Hammerhead.

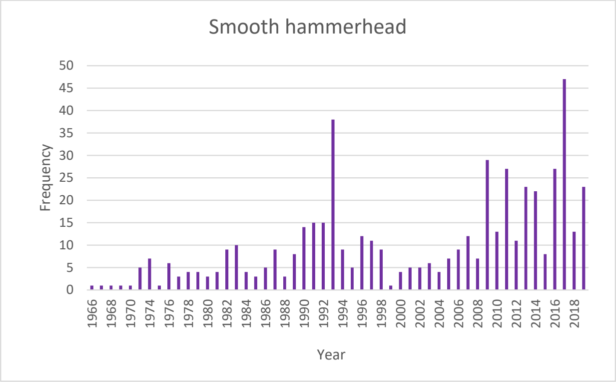
Data Workshop Final Report (April 2022)

- The SEDAR 77 Data Workshop meeting was held December 13-17, 2021 online. Three data webinars were held before the workshop on September 23, October 20, and November 9, 2021. Two additional webinars were held after the Data workshop on January 13 and January 31, 2022.

Data availability
Smooth hammerhead



- Catches
- No indices
- Life history (*borrowed from E equatorial and South Atlantic*)
- Length compositions (n=524)



Assessment Report: Smooth Hammerhead Shark (June 2023)

- The SEDAR 77 Assessment Workshop was conducted via 9 webinars from May 2022 – March 2023.
- There are 7 completed working papers and 6 reference document listed with this assessment report.

Working Papers			
SEDAR77-AW01	Exploratory analysis of U.S Atlantic and Gulf of Mexico scalloped hammerhead recruitment indices	Henning Winker	5/27/2022
SEDAR77-AW02	Hierarchical analyses of U.S. Atlantic and Gulf of Mexico scalloped hammerhead recruitment indices	Camilla T. McCandless and John K. Carlson	5/31/2022
SEDAR77-AW03		Cami McCandless	Not Received
SEDAR77-AW04	Estimates of vital rates and population dynamics parameters of interest for hammerhead sharks (*Sphyrna lewini, S. mokarran, and S. zygaena*) in the western North Atlantic Ocean	Enric Cortés	6/17/2022
SEDAR77-AW05	Reconciling age-0 indices of relative abundance of the U.S. Atlantic and Gulf of Mexico scalloped hammerhead (*Sphyrna lewini*)	Dean Courtney, Robert J. Latour, and Cassidy D. Peterson	6/20/2022
SEDAR77-AW06	Fishpath Questions	Enric Cortés	9/21/2022
SEDAR77-AW07	Selected FishPath Results for Smooth hammerhead shark, U.S. Atlantic and Gulf of Mexico	Enric Cortés	9/21/2022
SEDAR77-AW08	Selected FishPath Results for Smooth hammerhead shark, U.S. Atlantic and Gulf of Mexico: Narrowed	Enric Cortés	9/21/2022

Reference Documents			
SEDAR77-RD49	Stock Assessment of Scalloped Hammerheads in the Western North Atlantic Ocean and Gulf of Mexico	Christopher G. Hayes, Yan Jiao, and Enric Cortés	11/30/2020
SEDAR77-RD50	Poor-data and data-poor species stock assessment using a Bayesian hierarchical approach	Yan Jiao, Enric Cortés, Kate Andrews, And Feng Guo	11/30/2020
SEDAR77-RD51	Hierarchical Bayesian approach for population dynamics modelling of fish complexes without species-specific data	Yan Jiao, Christopher Hayes, and Enric Cortés	11/30/2020
SEDAR77-RD52	Highly migratory species predictive spatial modeling (PRiSM): an analytical framework for assessing the performance of spatial fisheries management	Daniel P. Crear, Tobey H. Curtis, Stephen J. Durkee, John K. Carlson	5/26/2022
SEDAR77-RD53	Dynamic factor analysis to reconcile conflicting survey indices of abundance	Cassidy D. Peterson, Michael J. Wilberg, Enric Cortés, and Robert J. Latour	5/26/2022
SEDAR77-RD54	SEDAR 65 - AW03: Reconciling indices of relative abundance of the Atlantic blacktip shark (*Carcharhinus limbatus*)	Robert J. Latour and Cassidy D. Peterson	5/31/2022

Exploring the FishPath tool for use with Smooth hammerhead

While there was a 40-year time series of catches for this smooth hammerhead stock, the life history information was extracted from a number of published sources, most based on studies conducted outside of the western North Atlantic Ocean, and the length-composition data were very limited and very likely unrepresentative of the real length-composition of the catches.

Given this data-poor situation, it was initially decided to explore FishPath (https://www.fishpath.org; Dowling et al., 2016), which is a decision support tool intended to justify and document the best way forward to find the right-fit models in data- and resource-limited situations.

Overview

- FishPath Tool is an online decision-support tool for data-limited fisheries management
- The primary goal of the FishPath Tool is to support users in understanding and refining options for the three major components of a harvest strategy:
  1) data collection,
  2) data-limited assessment, and
  3) management measures
- The FishPath Tool is not quantitative
- The FishPath Tool does aid in the process of identifying a short list of viable options, but it does not prescribe a single, preferred option for data collection, assessment, or management measures. It encourages <u>critical evaluation of an identified subset of options</u>
- The FishPath Tool is designed to be navigated by a trained fisheries scientist who facilitates the use of the tool in a group setting with fishery stakeholders. These stakeholders can be multi- (e.g., scientists, managers, universities, fishing industry) or single- (e.g., agency scientists) stakeholder groups

Overview

- The FishPath Tool is also intended to be used by individuals or groups without the support of a trained FishPath facilitator (also referred to as "desktop Users" or those who use the FishPath Tool on their own).
- Examples of individual users include: fisheries scientists, researchers, or students, who are interested in identifying appropriate data-limited assessment options for a data-limited fishery
- The Assessment section of the FishPath Tool allows the user to understand which data-limited stock assessment approaches are available and best suited to their fishery

FishPath tool questionnaire

Consists of 46 questions categorized in 6 main categories:

- 1. Biology/Life History
- 2. Data Availability
- 3. Governance
- 4. Management
- 5. Operational Characteristics
- 6. Socio-Economic

Initial conclusions/Recommendations

Use (a suite of) length-based methods:

- **Length-based Spawning Potential Ratio (LB-SPR):** provides overfished status
- **Length-based Bayesian Biomass Estimation (LBB):** estimates overfished stock status based on lengths
- **Length-Only Integrated Model:** provides overfished stock status
- **Mean length mortality estimators**: estimates Z (and F) that can be compared to externally derived Fmsy to provide overfishing status
- **Analysis of sustainability indicators based on length-based reference points (LBRP):** provides overfished status

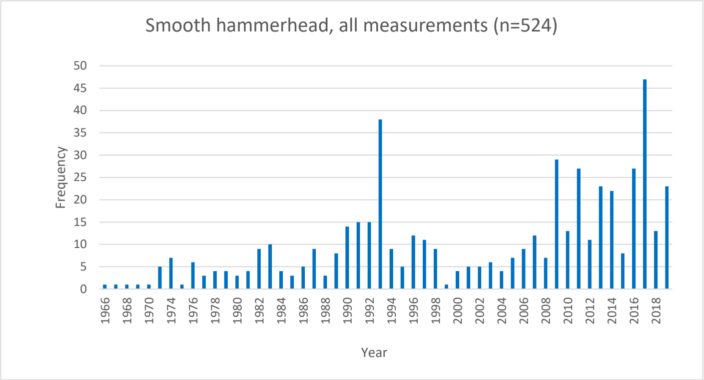
Use catch-only methods:

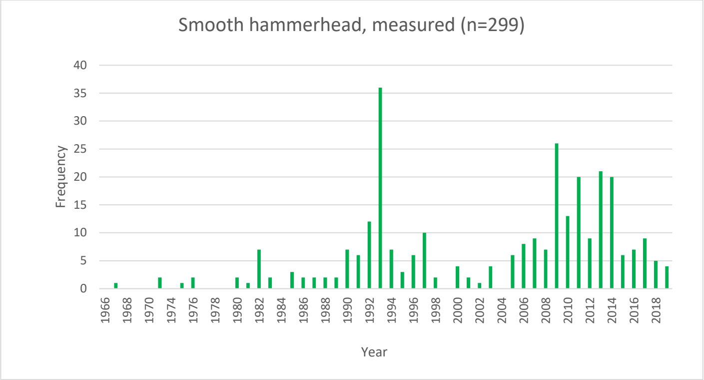
- **(Refined) Only Reliable Catch Stocks (ORCS):** provides catch limit (OFL and ABC)
- **Depletion-Corrected Average Catch (DCAC):** provides catch limit

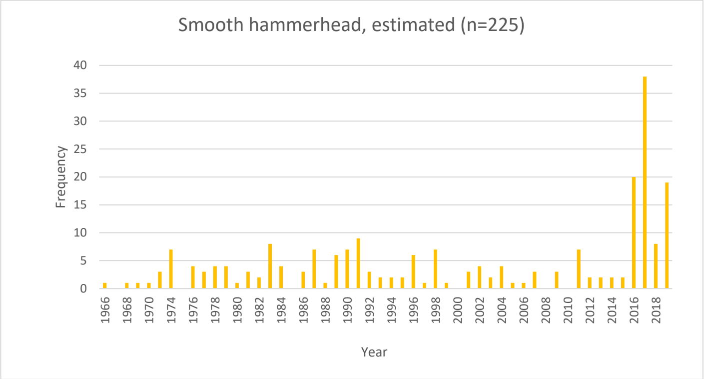
Use life-history-based method:

- **Yield-Per-Recruit:** provides Fmax

Annual length compositions of smooth hammerheads





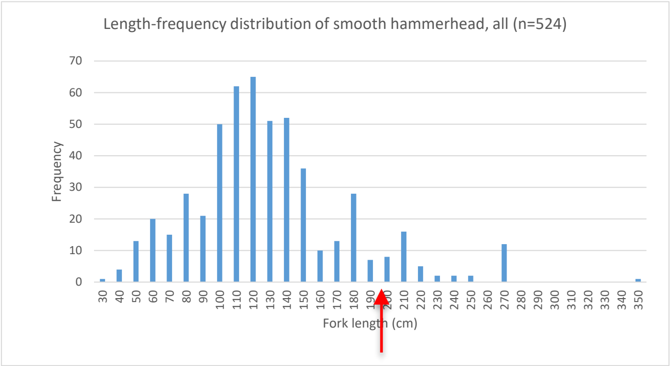


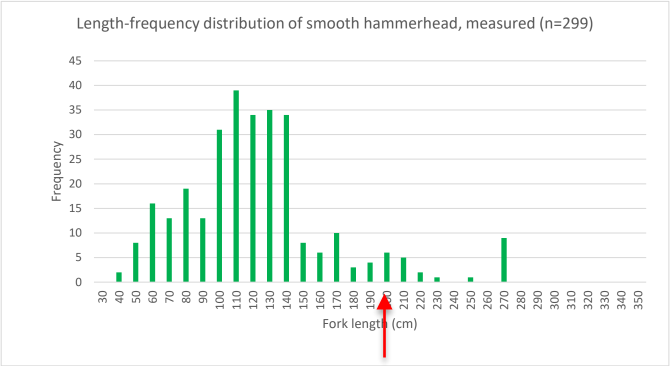
Data sources	Gear types	n	Percent
CSTP*	Rod and reel	284	0.54
GNOP	Gillnet	14	0.03
MRIP	Rod and reel	45	0.09
POP*	Pelagic longline	108	0.21
Sampson	Pelagic longline	58	0.11
SBLOP	Bottom longline	7	0.01
UF BLL	Bottom longline	8	0.02
Total		524	1

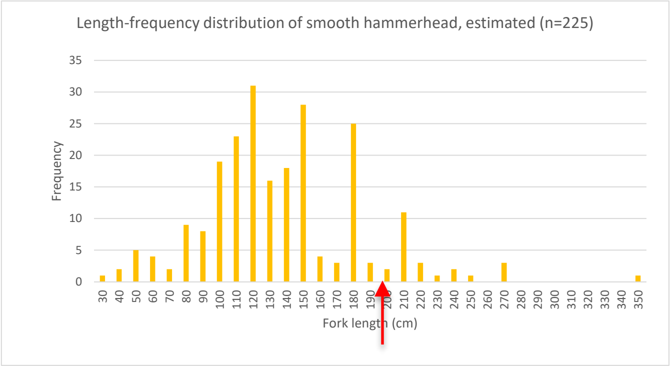
By gear	n	Percent
Rod and reel	329	0.63
Gillnet	14	0.03
Pelagic longline	166	0.32
Bottom longline	15	0.03
Total	524	1

Most years have less than 15-20 individuals.

Length-frequency distributions of smooth hammerheads







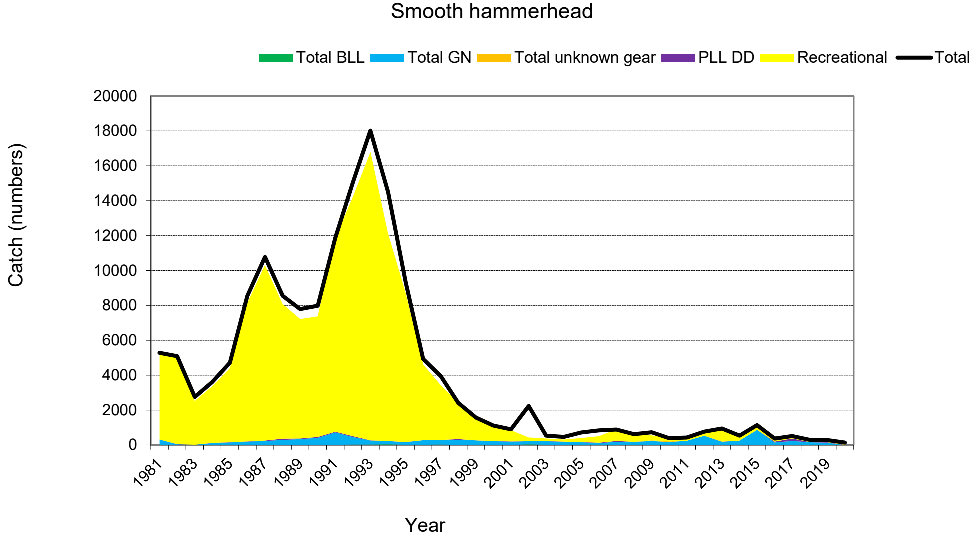
Male Lmat50=194 cm FL;

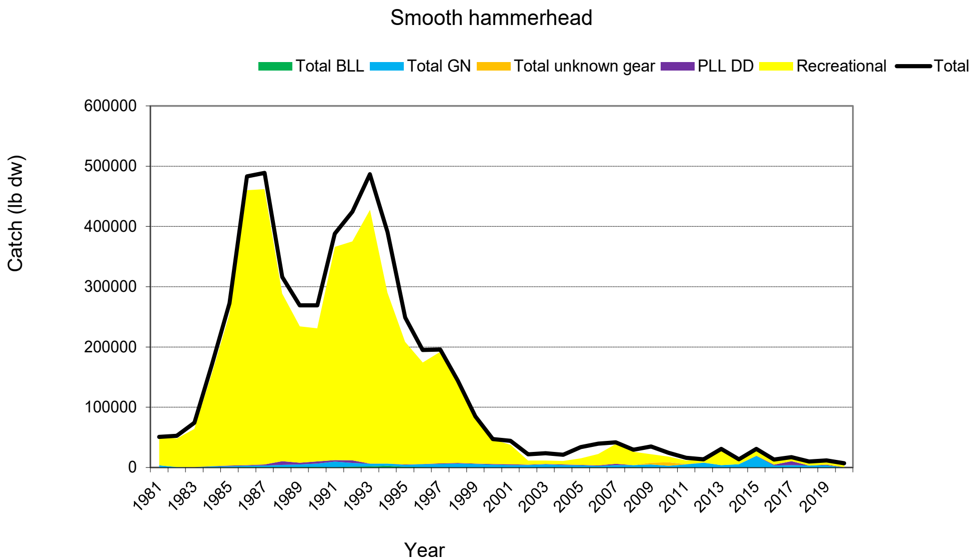
Female Lmat50=200 cm FL

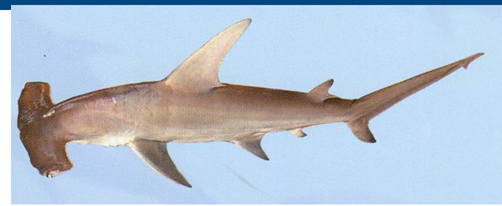
At least 90% of the sample is composed of immature individuals

The lack of representativeness of mature females probably prevents using the Length Based Spawning Potential Ratio (LBSPR), for example, to assess stock status since this model requires a representative size composition from the mature portion of the stock.

Catches of smooth hammerheads







The Panel recommended assessment model

- The Panel recommended to explore the use of SSS, which is one application of Stock Synthesis Data-limited Tool (Cope 2013) to assess the data-limited smooth hammerhead which only has *a 40-year time series of catch data, some life history information, and very limited length data that maybe unrepresentative*
- Stock Synthesis Data-limited Tool implements several common data-limited assessment methods all in one modeling framework. Under a unified modeling framework, additional data can be added as it becomes available.

2. DATA REVIEW AND UPDATE

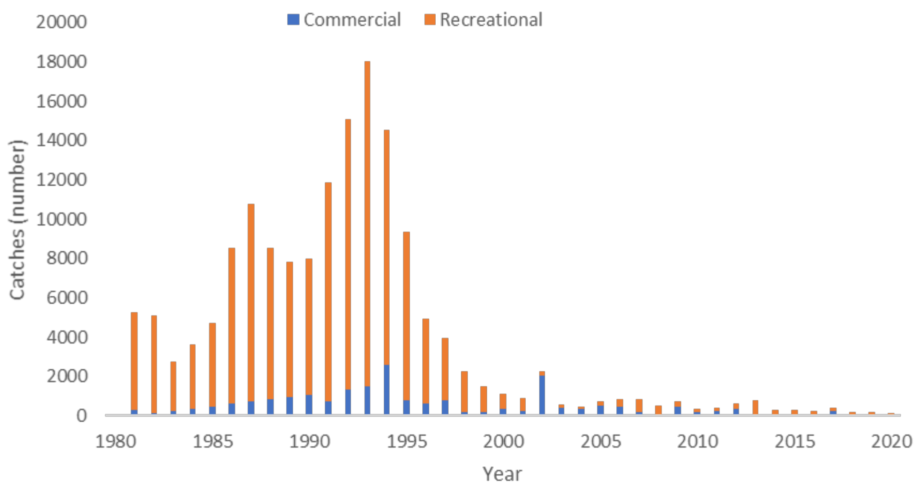
2.1 CATCHES

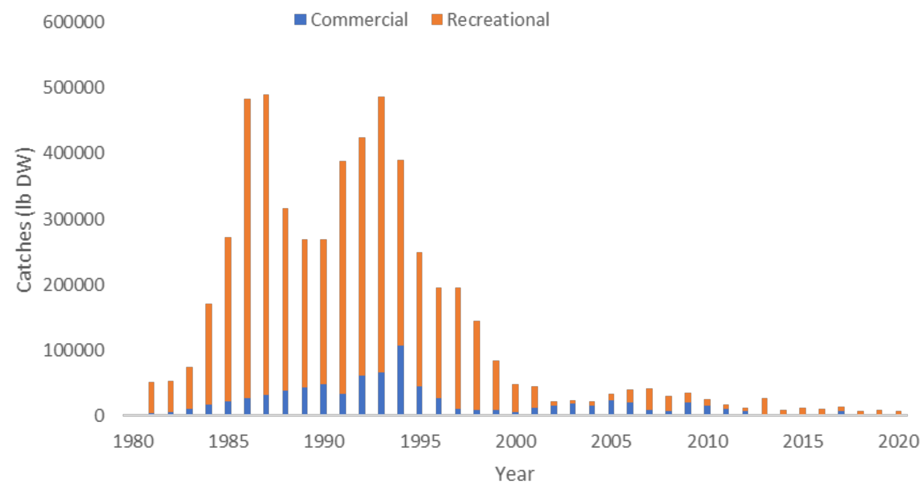
The SEDAR 77 DW Report approved total commercial catch and total recreational catch in pounds dressed weight (lb dw), which were converted to metric tons whole weight (mt ww) obtained using a conversion ratio for dressed weight (dw) to whole weight (ww) of dw=ww/1.39 (default used by NMFS, Pers. Comm. E. Cortés) and one lb=0.0004536 mt.

The vast majority of smooth hammerhead catches were from the recreational sector (**Tables 2.5.1** and **2.5.2**; **Figures 2.6.1** and **2.6.2**).

Fishing pressure showed an initial increasing trend from 1981 to high values during a period ranging from 1985 to 1995, followed by a decreasing trend to a low value in 2000, and very reduced values during the last 20 years (**Figure 2.6.2**).

Catches of smooth hammerhead





Recommended unit to be used in SSS

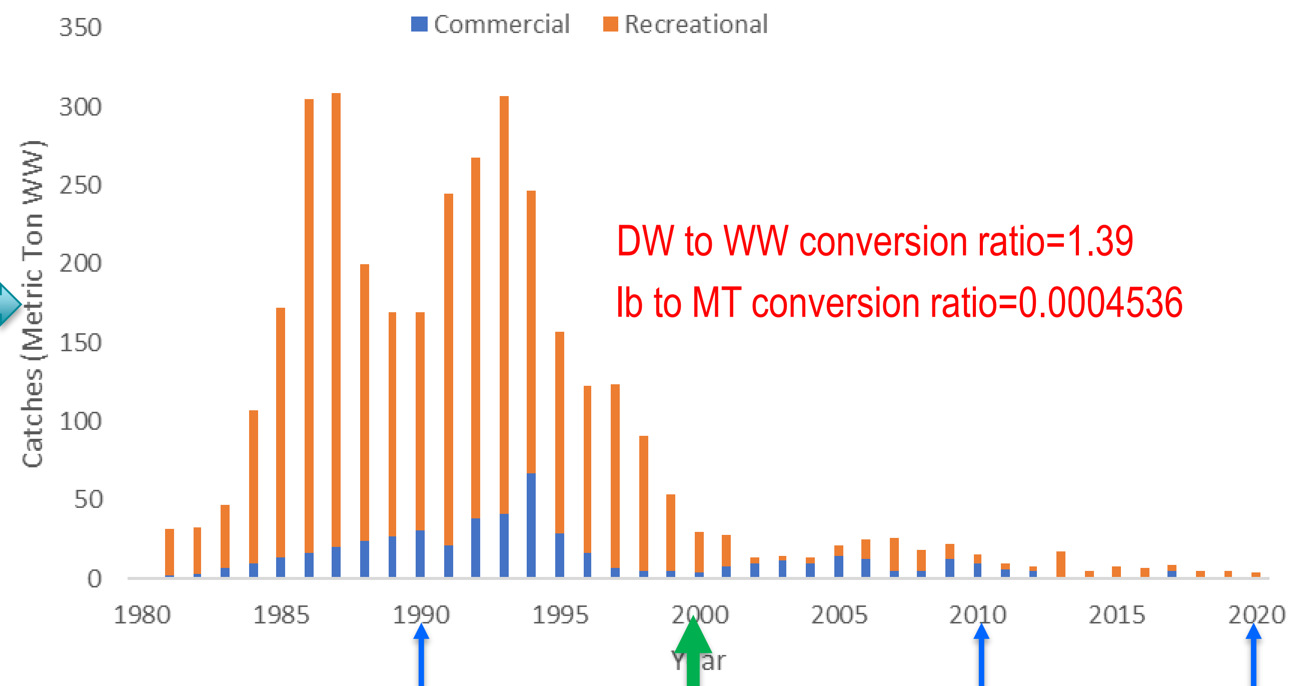


Table 2.5.2. Total commercial catch and total recreational catch of smooth hammerheads in weight (mt ww) used in SSS.

Year	Commercial	Recreational
1981	2.300	29.700
1982	3.400	29.700
1983	6.800	40.000
1984	10.100	97.200
1985	13.500	158.300
1986	16.900	287.800
1987	20.300	288.000
1988	23.700	175.700
1989	27.000	142.600
1990	30.400	139.300
1991	21.300	223.300
1992	38.600	229.100
1993	41.500	265.500
1994	67.500	178.800
1995	28.500	128.500
1996	16.800	106.100
1997	6.600	116.800
1998	5.300	85.700
1999	5.200	48.200
2000	3.800	25.900
2001	7.500	20.400
2002	9.500	4.300
2003	11.300	3.700
2004	9.600	3.800
2005	14.500	6.800
2006	13.000	11.900
2007	5.500	20.700
2008	4.700	13.900
2009	12.800	9.000
2010	9.400	6.000
2011	6.300	3.900
2012	4.600	3.300
2013	0.200	17.100
2014	0.400	5.100
2015	0.500	7.200
2016	1.000	5.500
2017	4.800	4.200
2018	0.500	4.200
2019	0.800	4.200
2020	0.200	4.200

2. DATA REVIEW AND UPDATE

2.2 LIFE HISTORY INPUTS

Biological input values for females used to compute maximum population growth rate (r_{max}), proportion of unfished recruits produced when the stock is at 20% of the unfished population size (steepness), and other parameters of interest for smooth hammerheads in **Table 2.5.3** are as reported in SEDAR77-AW04 (Cortés 2022).

Parameter	Definition	Value	Unit	References
L_∞	Theoretical maximum length	293.9	cm FL	DW report life history section
K	Brody growth coefficient	0.09	yr^{-1}	DW report life history section
t_0	Theoretical age at zero length	-2.195*	yr	DW report life history section
a	Intercept of maturity ogive	n/a	dimensionless	DW report life history section
b	Slope of maturity ogive	n/a	dimensionless	DW report life history section
c	Scalar coefficient of weight on length	2.000E-06	dimensionless	DW report life history section
d	Power coefficient of weight on length	3.329	dimensionless	DW report life history section
w	Observed lifespan	25	yr	DW report life history section
	Theoretical lifespan (99% of L inf)	49	yr	DW report life history section
	Sex ratio at birth	1:1	dimensionless	DW report life history section
	Reproductive cycle	biennial	yr	DW report life history section
mx	Constant litter size	33.5	pups per litter	DW report life history section
e	Intercept of maternal length vs. fecundity	n/a	dimensionless	DW report life history section
f	Slope of maternal length vs. fecundity	n/a	dimensionless	DW report life history section
GP	Gestation period	11	months	DW report life history section

* Obtained from an L_0 of 52.7 cm FL.

2.2 LIFE HISTORY INPUTS

For the computation of stochastic estimates of steepness and natural mortality rate at age were obtained through six alternative life history-invariant estimators (see **Appendix 1** of Cortés 2022 for details).

The median estimates of the average (age 1 to maximum age) natural mortality rate (M=0.129 yr^{-1}) and steepness (0.78) obtained in the Leslie matrix stochastic analyses were used as fixed inputs for SSS (see **Section 3.1.4** and SEDAR77-AW04 (Cortés 2022) for details). Life history inputs for SSS are summarized in **Table 2.5.4.**

2. DATA REVIEW AND UPDATE

2.3 LENGTH COMPOSITION DATA

There were 524 observations over an approximately 55-year period (1966-2016) (225 of those measurements were estimated; only 7 years had more than 20 observations) (**Table 2.5.5**) (presented at Assessment Webinar 8 on February 21, 2023 based on Length Composition Section of the DW report and Pers. Comm. E. Cortés). The sample size of these length composition data is very small and very likely unrepresentative of the real length composition of the catches. Therefore, it is not advisable to fully use them at this stage.

Table 2.5.5. Length composition data of smooth hammerheads in years 1966-2019.

Year	Sample Size	Year	Sample Size
1966	1	1994	9
1967	1	1995	5
1968	1	1996	12
1969	1	1997	11
1970	1	1998	9
1973	5	1999	1
1974	7	2000	4
1975	1	2001	5
1976	6	2002	5
1977	3	2003	6
1978	4	2004	4
1979	4	2005	7
1980	3	2006	9
1981	4	2007	12
1982	9	2008	7
1983	10	2009	29
1984	4	2010	13
1985	3	2011	27
1986	5	2012	11
1987	9	2013	23
1988	3	2014	22
1989	8	2015	8
1990	14	2016	27
1991	15	2017	47
1992	15	2018	13
1993	38	2019	23
Grand Total			**524**

only 8 years with more than 20 samples.
The sample size of these length composition data is very small and very likely unrepresentative of the real length-composition of the catches.

STOCK ASSESSMENT MODEL AND RESULTS

3.1 SSS ASSESEMENT MODEL

3.1.1 Overview

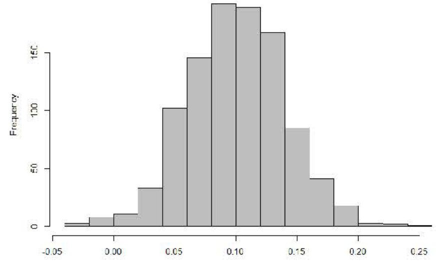
- The Stock Synthesis Data-limited tool (SS-DL tool) (Cope 2013) uses Stock Synthesis (Methot and Wetzel 2013) to implement several common data-limited assessment methods all in one modelling framework. Under a unified modelling framework, additional data can be added as they become available. The SS-DL tool builds Stock Synthesis files for provided data and life history information.
- The SS-DL tool is an open-source modelling framework and is available at github.com/shcaba/SS-DL-tool. SSS is one application of the SS-DL tool for use with data-limited stocks that estimates catch limits (i.e. *OFL*).
- SSS needs the stock status on the value of depletion in a given year (i.e. a proxy of overfished stock status) as an input, so SSS should not be used to determine if the stock is overfished.
- It is an age-structured version of other catch-only methods such as Depletion-Based Stock Reduction Analysis (DB-SRA)(Cope 2013). The underlying population dynamics in SSS are fully age-structured. Age and growth estimates are needed in SSS to define age structure and remove catch according to age/length-based selectivity patterns. Biomass (*B*) is measured as the sex-combined biomass of mature individuals.

Catch only method: Simple Stock Synthesis (SSS)

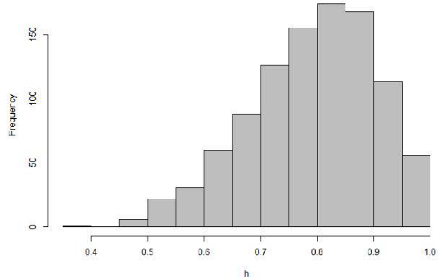
- **Data**
  - **Catch**
- **Explore uncertainty about:**
  - **Natural Mortality**
  - **Steepness**
  - **Depletion**
- **Fixed assumptions:**
  - **Growth**
  - **Weight length**
  - **Fecundity**
  - **Selectivity**

- **Solve for $\ln(R_0)$**

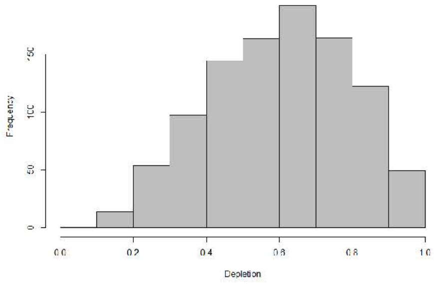
Natural Mortality



Steepness

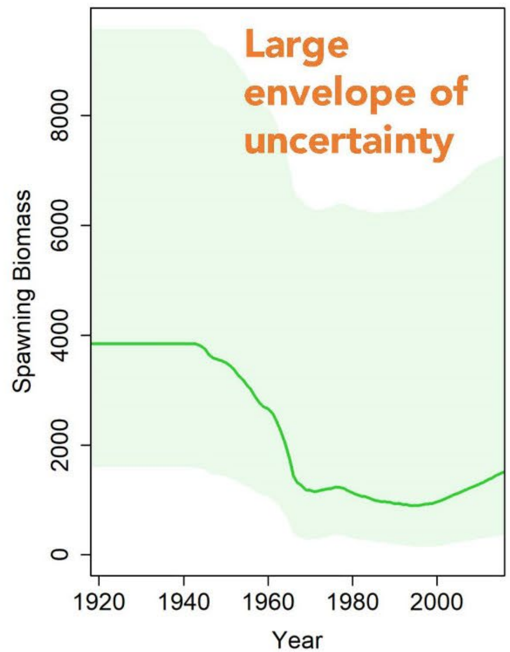


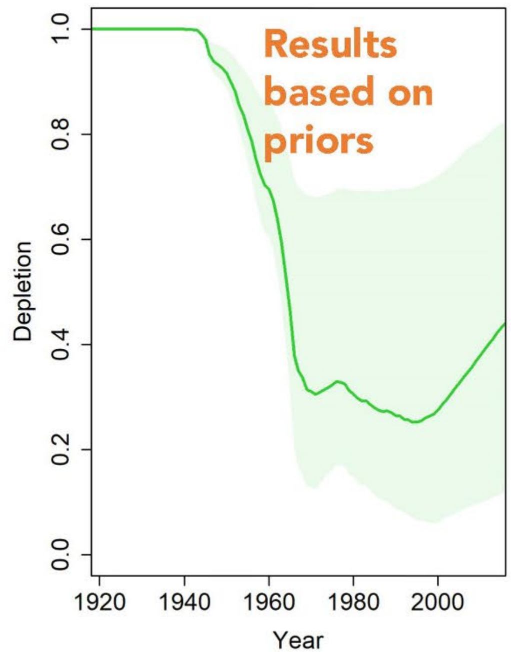
Depletion

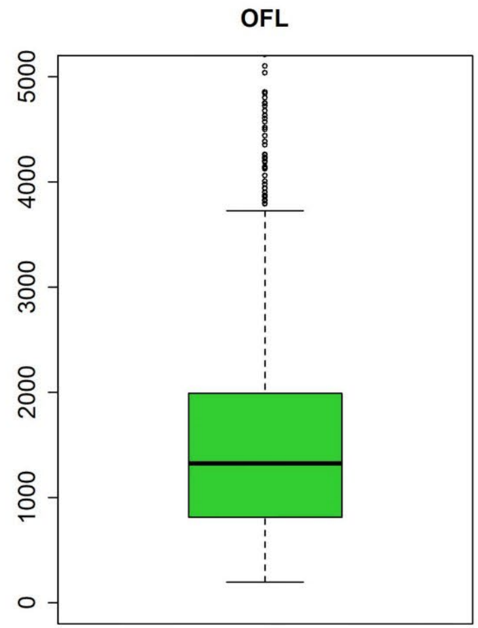


Cope, 2013. Fisheries Research 142: 3-14

SSS: stock size, status, and harvest







Able to harness harvest control rules and/or precautionary buffers

Courtesy of Cope

Scaling up with data: Stock Synthesis Example

Removals + **Abundance indices** + **Size & Age compositions**

Simple Stock Synthesis (SSS)

eXtended Simple Stock Synthesis (XSSS); Age structured production model (ASPM)

Stock Synthesis (SS)

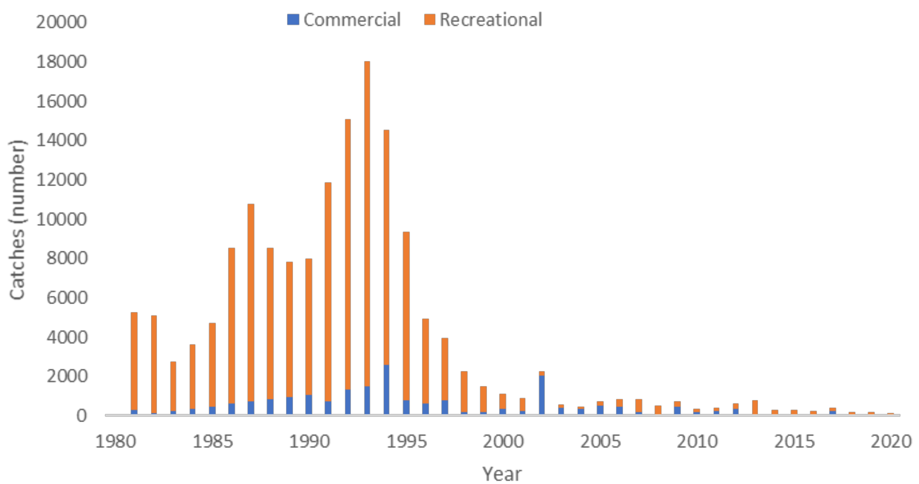
Stock Synthesis nesting doll

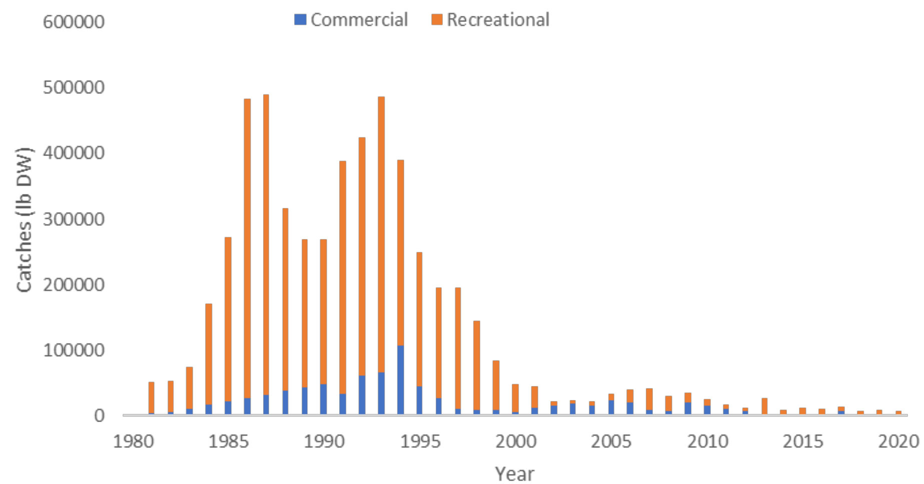
Courtesy of Cope

Data inputs and assumptions for SSS (smooth HH)

- Catch (in MT whole weight) without associated standard errors
  1. Commercial (1981 – 2020)
  2. Recreational (1981 – 2020)
- Life History (either fixed or assume a distribution)
  1. Natural mortality
  2. Growth curve
  3. Maturity-length relationship
  4. Fecundity-length relationship
  5. Steepness
  6. Weight-length relationship
- Assumed stock status on the value of depletion in a given year (i.e. a proxy of stock status on overfished)
- Selectivity is fixed and can be specified for multiple fleets and different shapes.
- LnR_0 is the only estimated parameter by the model with an assumed initial value

Catches of smooth hammerhead





Recommended unit to be used in SSS

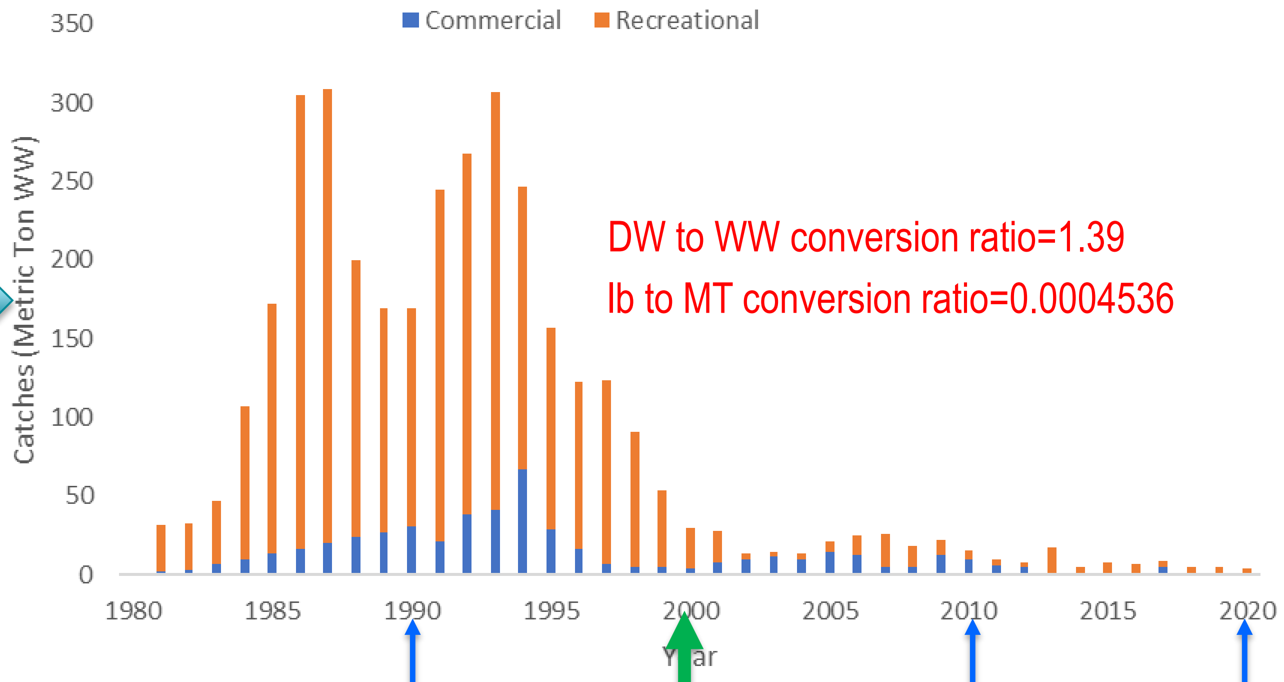
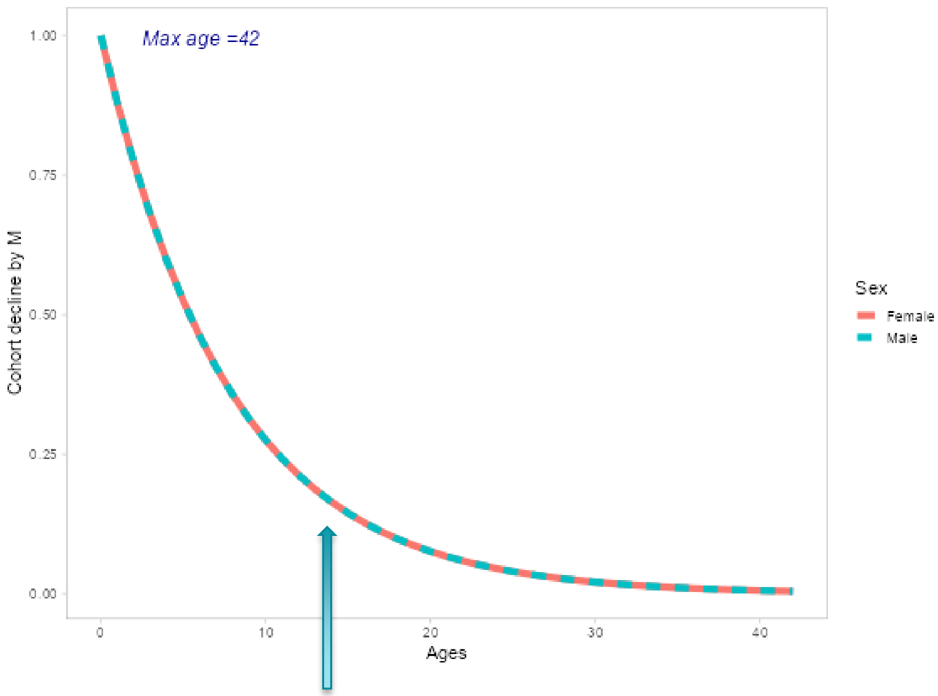
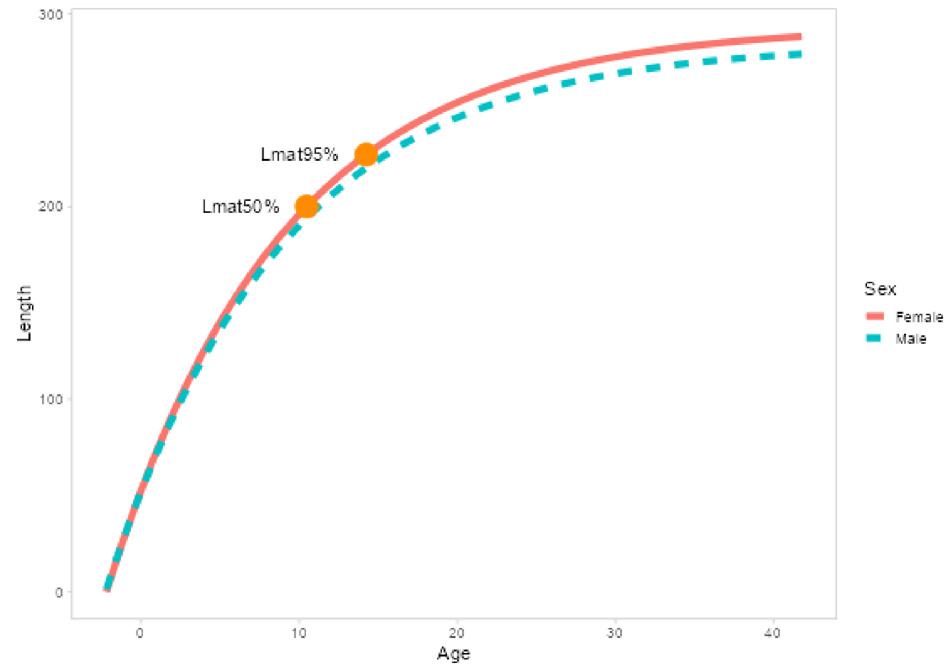


Table 2.5.4. Life history inputs for smooth hammerheads for SSS

Female	Mean	SD	Prior type
Natural Mortality (M)	0.129	0.024	Lognormal
Asymptotic size (Linf)	293.9	0	Fixed
Growth coefficient (k)	0.09	0	Fixed
Correlation between Linf and k	0.96		Fixed
Age at length 0 (t_0)	-2.195	0	Fixed
CV at length(young then old)	0.1,0.1	0,0	Fixed
Length at 50% maturity	200		Fixed
Length at 95% maturity	227		Fixed
Reproductive cycle	biennial		Fixed
Constant litter size	33.5 pups per litter		Fixed
Fecundity-length relationship: Coefficient a	16.75		Fixed
Fecundity-length relationship: Exponent b	1E-10		Fixed
Steepness	0.78	0.15	Symmeric Beta
Weight (kg)-Length (cm) relationship: Coefficient a	0.000002		Fixed
Weight (kg)-Length (cm) relationship: Exponent b	3.329		Fixed
Male			
Natural Mortality (M)	0.129	0.024	Lognormal
Asymptotic size (Linf)	284.6	0	Fixed
Growth coefficient (k)	0.09	0	Fixed
Age at length 0 (t_0)	-2.25	0	Fixed
CV at length(young then old)	0.1,0.1	0,0	Fixed
Weight (kg)-Length (cm) relationship: Coefficient a	0.000002		Fixed
Weight (kg)-Length (cm) relationship: Exponent b	3.329		Fixed

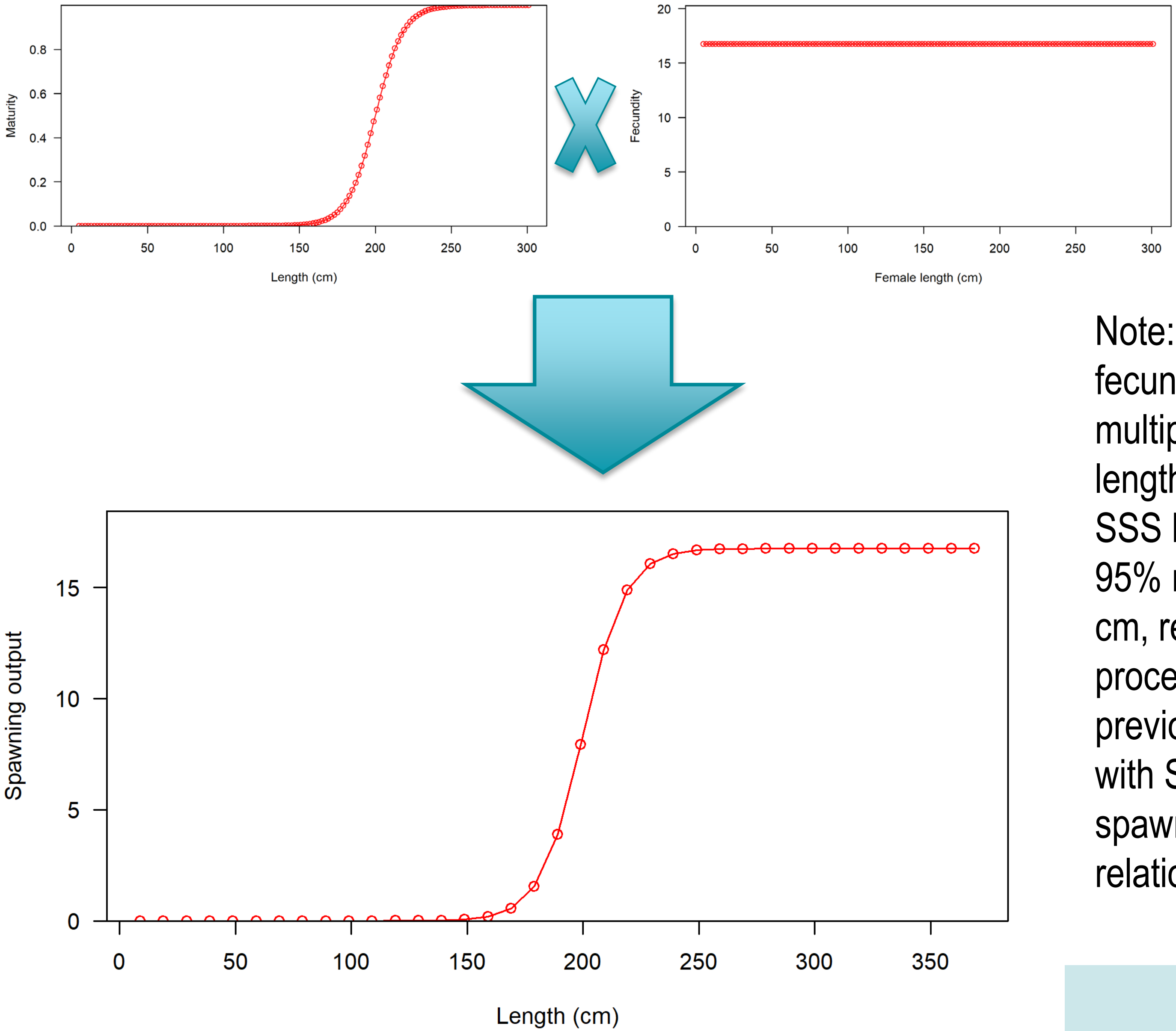
Natural mortality and growth curve





Note: the estimate of generation time is 13.0 years (SEDAR 77-AW-04)

Maturity, fecundity and spawning output



Note: This length invariant fecundity will be scaled (i.e. multiplied) with a logistic maturity-length relationship derived in the SSS based on length at 50% and 95% maturity being 200 and 227 cm, respectively. This scaling procedure has been used in previous HMS shark assessments with SSASPM and SS to derive spawning output-length relationship.

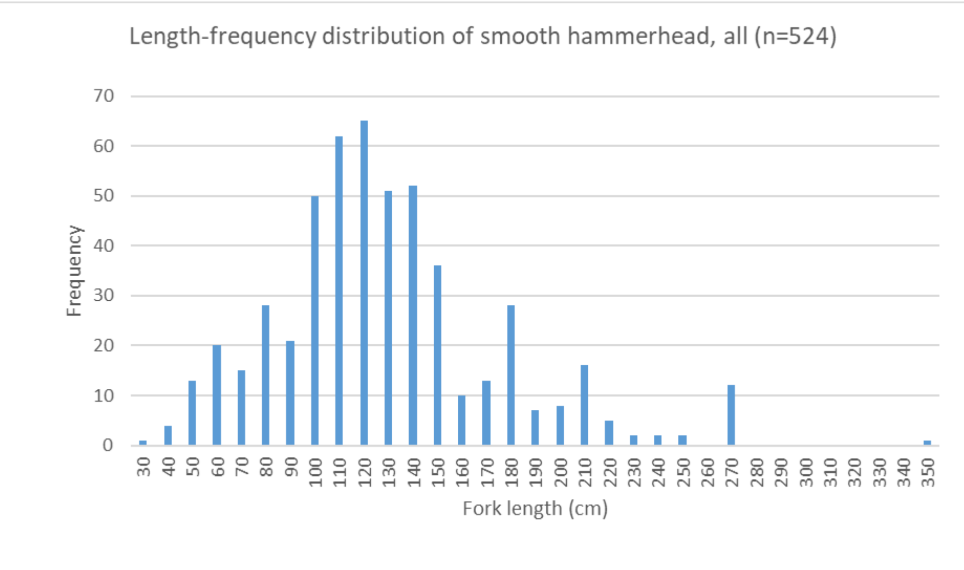
Weight-length relationship

The weight(W)-length (L) relationship was assumed to be same for both sexes and fixed (**Table 2.5.4**). A coefficient a=0.000002 and exponent b=3.329 were used to implement the weight-length relationship, $W=a*L^b$, in SSS.

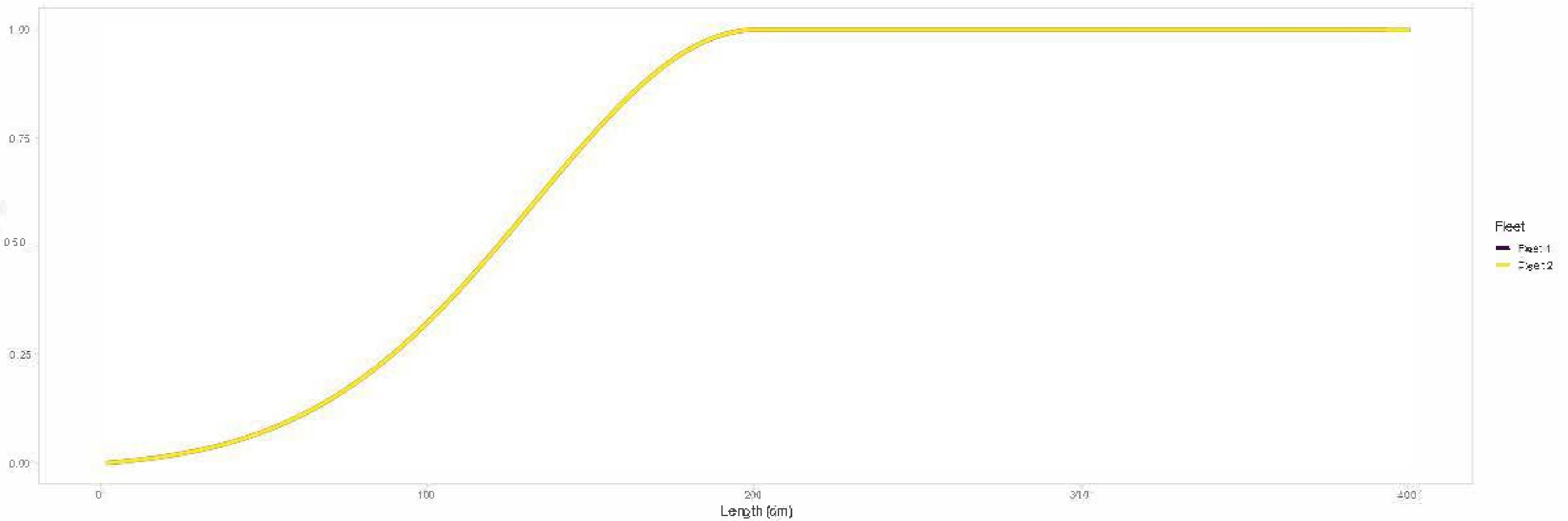
Steepness

Two values of steepness (0.78 and 0.58) were explored. The model results are not sensitive to the changes of steepness. The Panel recommended to use steepness=0.78 for the reference model run (**Table 2.5.4**).

Selectivity of smooth hammerhead



SSS requires to associate length selectivity to each catch series. Rather than assuming a selectivity pattern for each catch series, we examined the length-frequency distribution of the entire composition data and approximated by eye the lengths at 50% and 95% selectivity assuming a logistic pattern, being 120 and 200 cm fork length (FL), respectively



Relative stock status (stock depletion)

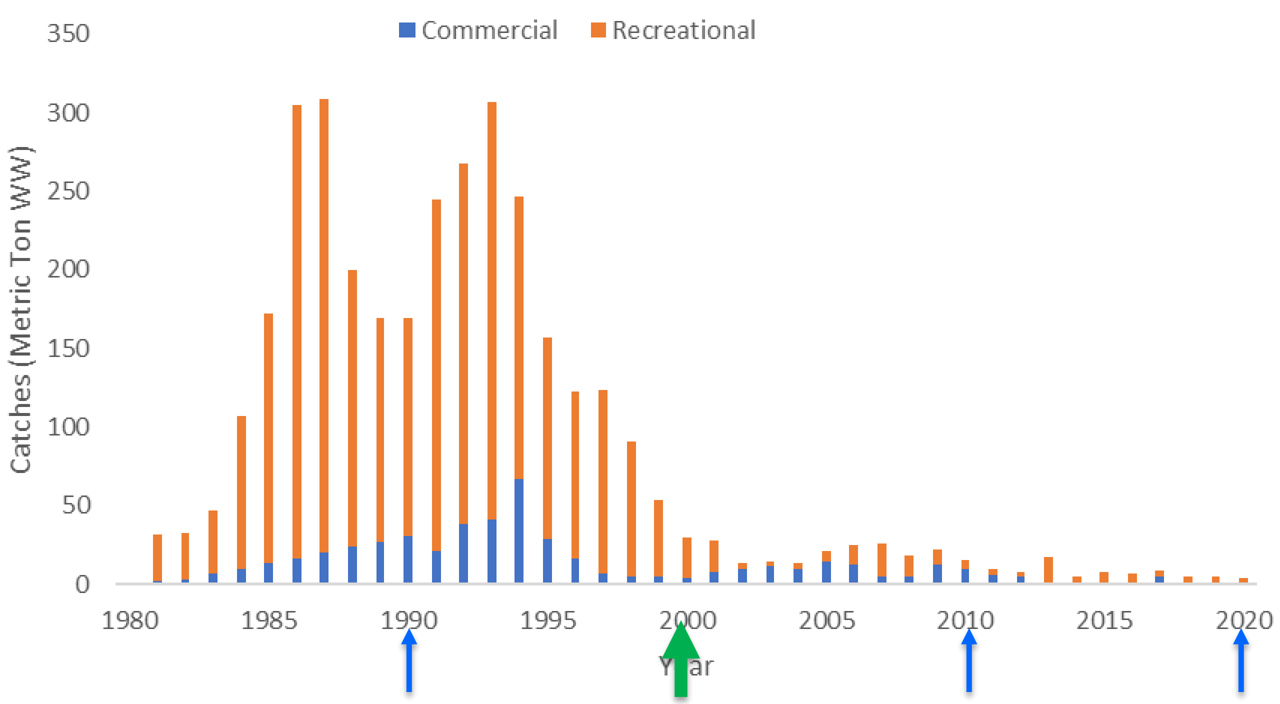
This input represents the prior belief on the status of the stock in a given year, measured as stock depletion. Fishing pressure showed an initial increasing trend from 1981 to high values during a period ranging from 1985 to 1995, followed by a decreasing trend to a low value in 2000, and very reduced values during the last 20 years.

The Panel recommended to use a relative stock status in 2000 (depletion mean=0.1 and beta standard deviation=0.2) as the best educated guess for the reference model run. This recommendation was mainly based on

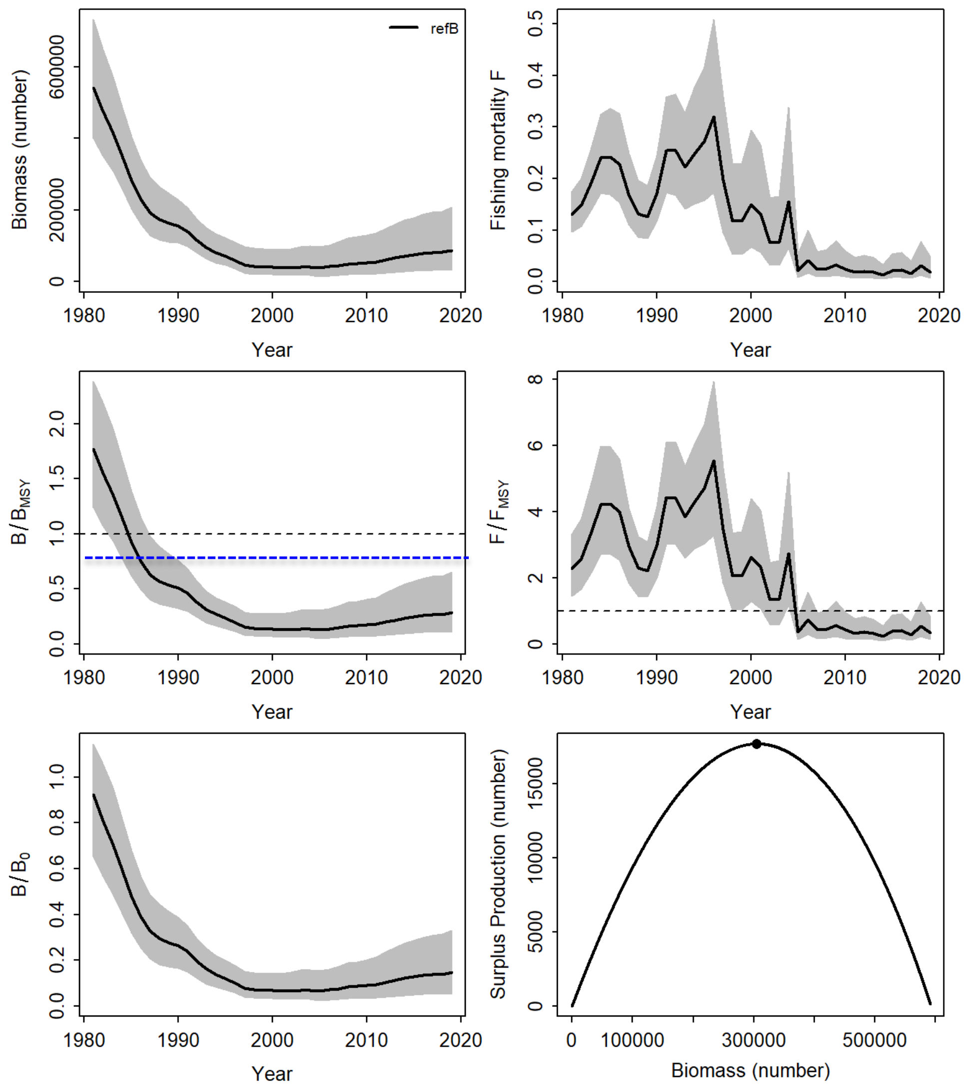
1) year 2000 is the starting point of low fishing pressure during the last 20 years, and
2) the preliminary assessment results of SEDAR 77 suggest that stock depletion is about 0.1 for great hammerheads in 2000 (i.e. the assumption about the relative stock status in 2000 (depletion mean=0.1) for the Panel-approved reference run was in line with results for the great hammerheads).

Due to the large uncertainty associated with this catch-only method and the assumed status of the stock in 2000, the Panel is only able to recommend a reference model instead of a base model.

Catches of smooth hammerhead



Great hammerhead (Base model)



Borrow from great hammerhead:

The preliminary assessment results of SEDAR 77 suggest that stock depletion is about 0.1 for great hammerheads in 2000

Log value of initial recruitment (lnR_0)

- The population model underlying SSS is sex- and age-structured with a Beverton-Holt stock-recruitment relationship, though recruitment is assumed deterministic.
- The only estimated parameter is lnR_0.
- Two values of lnR_0 (12 and 2) were explored. The model results are not sensitive to the changes of lnR_0. However, models run much faster with lnR_0=2. Therefore, the Panel recommended to use lnR_0=2 for the reference model run.

3.1.5. Parameter estimation

- Only one parameter, lnR_0, is estimated in SSS.
- SSS estimates a lnR_0 value which results in a population that meets the assumed depletion value, based on the other fixed model parameters.
- 1000 Monte Carlo draws were used for SSS to define the probability distributions.
- It takes 10-20 hours to complete each model run (laptop computer with a processor: 11th Gen Intel(R) Core (TM) i9-11950H@2.60GHz).

3.1.6. Sensitivity to stock depletion assumptions and steepness

- The Panel approved to use the relative stock status in 2000 (depletion mean=0.1 and beta standard deviation=0.2) as the best educated guess for the reference model run.
- The uncertainty in the assumed stock depletion was examined through the use of sensitivity scenarios with depletion mean=0.2, 0.3, 0.5, and 0.7.

Scenario runs
The Panel-approved reference run and sensitivity runs
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)

3.1.7. Projection methods

- SSS needs the stock status on the value of depletion in a given year (i.e. a proxy of overfished stock status) as an input, so SSS should not be used to determine if the stock is overfished.
- In accordance with Term of Reference 9(d) *If data limitations and/or model limitations preclude classic projections (i.e. a, b, and c above), explore alternate projection models.*
- OFL_{2021} was estimated with the SSS inbuilt terminal year plus one projection. Longer terms of catch-based and *F*-based projections were not carried out due to the limitations of this catch-only method.

3.1.8. ABC calculations

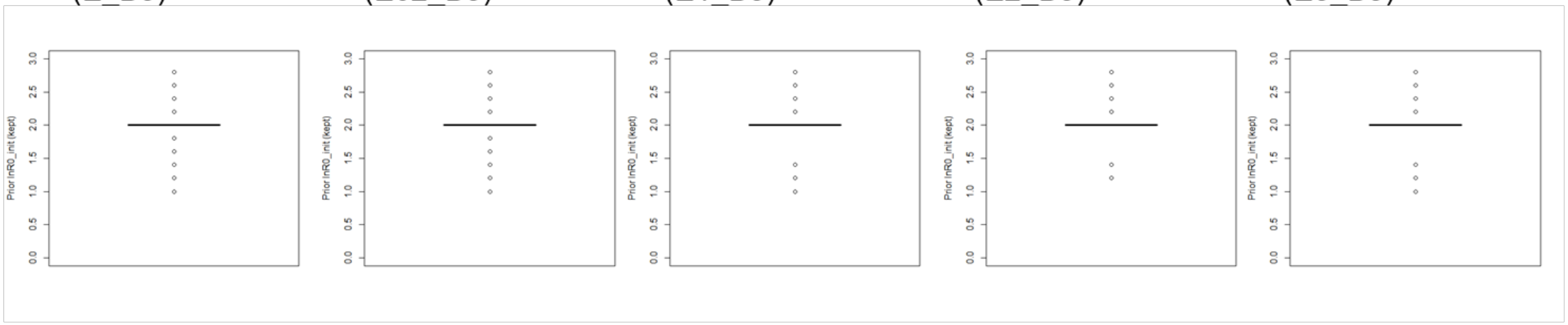
- This assessment can be considered data limited.
- Catch and life history data were available to be used in this stock assessment, but there were no time series data to develop indices of abundance or to fully parameterize catch-at-age or catch-at-length population dynamics.
- Therefore, this assessment falls under tier 3 of the *ABC* control rule in Final Amendment 14 to the 2006 Consolidated Atlantic Highly Migratory Species Fishery Management Plan (2023).
- In accordance with Term of Reference 10 *Provide ABCs in accordance with HMS management needs,* two approaches were used to calculate *ABC* from *OFL*.

1. Calculating *ABC* as 30th percentile of *OFL*
2. Calculating *ABC* by using an *ABC*/*OFL* ratio of 0.647 for tier 3 stocks with a *P**=0.3 following Courtney and Rice (2023)

Priors and posteriors of the estimated lnR_0

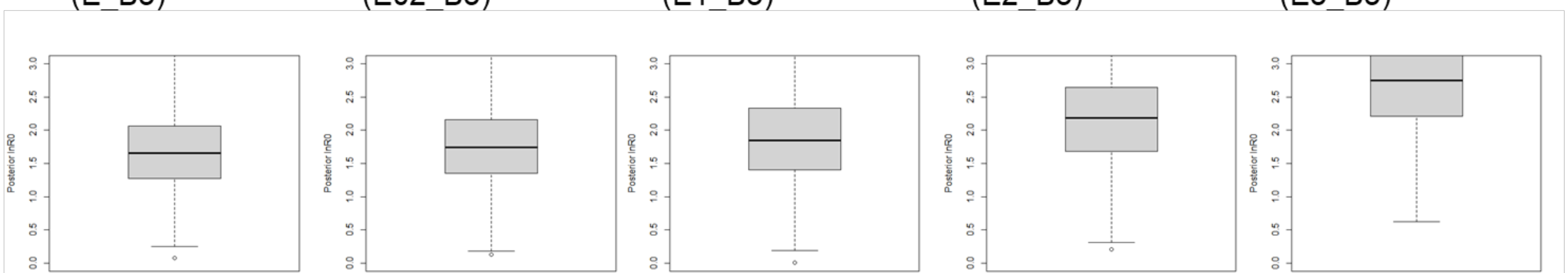
Prior

Dep=0.1 (E_B3) | Dep=0.2 (E02_B3) | Dep=0.3 (E1_B3) | Dep=0.5 (E2_B3) | Dep=0.7 (E3_B3)



Posterior

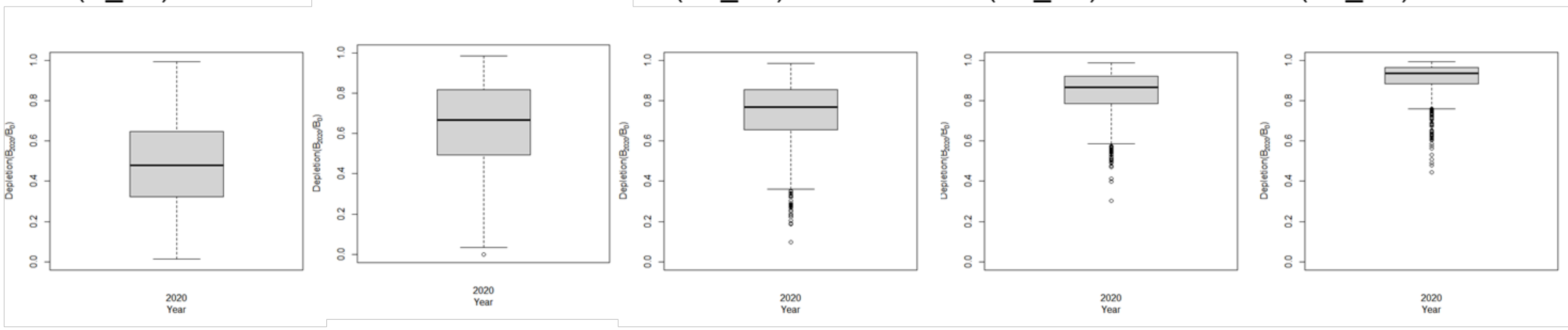
Dep=0.1 (E_B3) | Dep=0.2 (E02_B3) | Dep=0.3 (E1_B3) | Dep=0.5 (E2_B3) | Dep=0.7 (E3_B3)

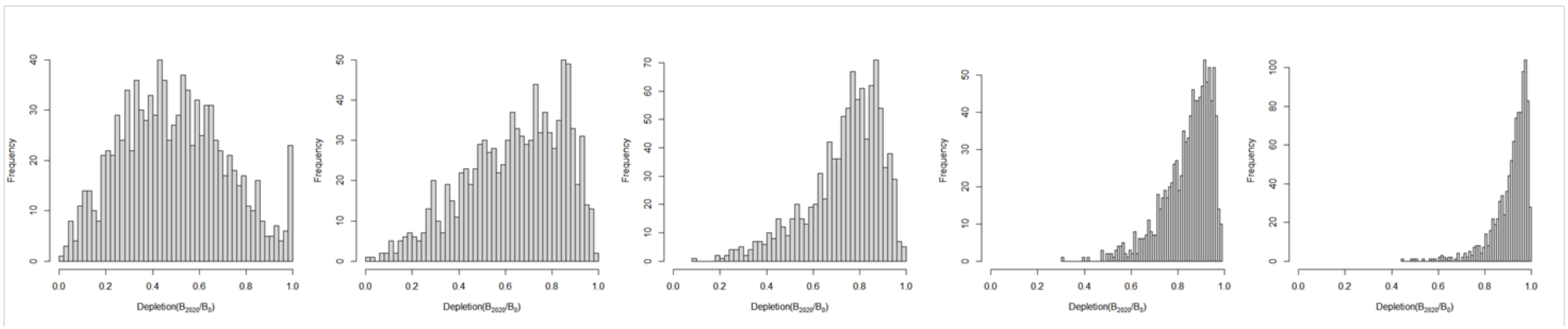


- Prior medians for lnR_0 were almost identical to the input value (lnR_0=2) as expected for all runs (i.e. no many rejected runs).
- The posterior medians for lnR_0 showed an increasing trend from the assumed input depletion=0.1 to depletion=0.7.
- The posterior medians for lnR_0 were slightly less than 2 for the runs with depletion=0.1, 0.2, and 0.3, whereas were slightly greater than 2 for the runs with depletion=0.5 and 0.7.

Terminal year (2020) depletion

Dep=0.1 (E_B3)	Dep=0.2 (E02_B3)	Dep=0.3 (E1_B3)	Dep=0.5 (E2_B3)	Dep=0.7 (E3_B3)





- The posterior medians for the terminal year depletion showed an increasing trend from the assumed input depletion=0.1 to depletion=0.7 in the year 2000.
- Among the 5 runs, the distribution of the terminal year depletion for the Panel-approved reference run is the most similar to a bell shape.

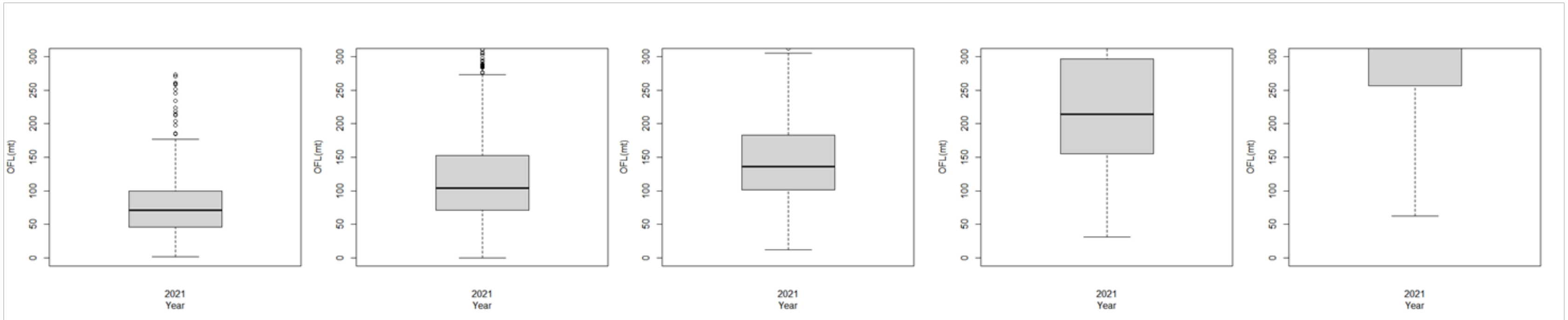
Terminal year (2020) depletion

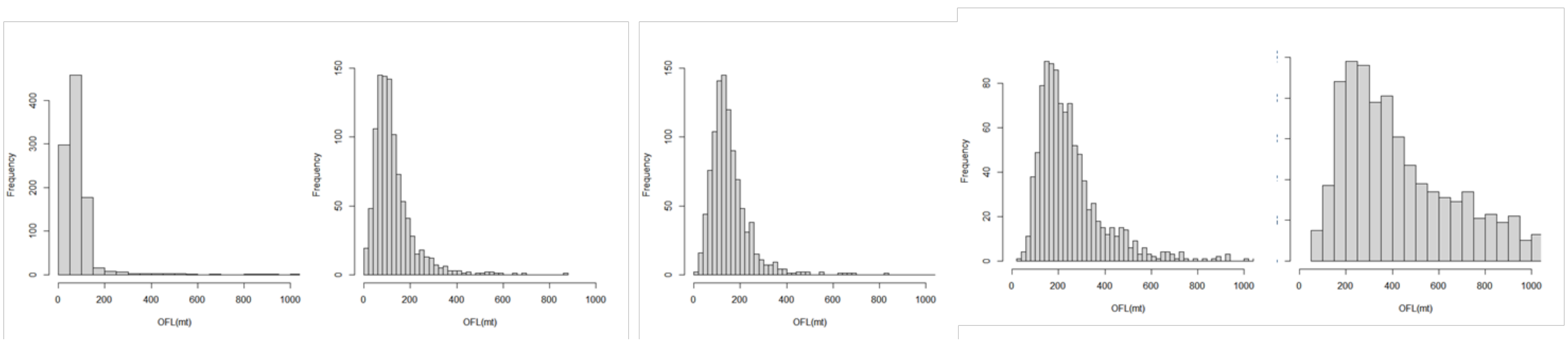
Scenario runs	Dep (median)	Dep (mean)
The Panel-approved reference run and sensitivity runs		
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)	0.48	0.49
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)	0.67	0.64
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)	0.77	0.73
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)	0.87	0.84
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)	0.94	0.91

- The median (0.48) and mean (0.49) of the terminal year depletion were very similar for the Panel-approved reference run.
- The medians of the terminal year depletion for the Panel-approved reference run and sensitivity runs were in a range between 0.48 and 0.94.
- The median of the terminal year depletion for each of the 5 Panel-approved reference run and sensitivity runs was larger than the assumed depletion in the year 2000 (i.e. 0.48 vs 0.1, 0.67 vs 0.2, 0.77 vs 0.3, 0.87 vs 0.5, 0.94 vs 0.7), which suggested the stock has been rebuilding since 2000.

Overfishing limits in the year 2021 (OFL_{2021})

Dep=0.1 (E_B3)	Dep=0.2 (E02_B3)	Dep=0.3 (E1_B3)	Dep=0.5 (E2_B3)	Dep=0.7 (E3_B3)





- The posterior medians for OFL_{2021} showed an increasing trend from the assumed input depletion=0.1 to depletion=0.7 in the year 2000.

Overfishing limits in the year 2021 (OFL_{2021})

Scenario runs	OFL (median)	OFL (mean)	SD	CV
Dep=0.1 in 2000 (E_B3)	71.208	126.307	309.533	2.451
Dep=0.2 in 2000 (E02_B3)	104.280	124.813	87.984	0.705
Dep=0.3 in 2000 (E1_B3)	136.120	156.070	110.623	0.709
Dep=0.5 in 2000 (E2_B3)	214.380	251.820	148.484	0.590
Dep=0.7 in 2000 (E3_B3)	406.480	556.360	428.517	0.770

- The medians of OFL_{2021} for the Panel-approved reference run and sensitivity runs were in a range between 71.208 and 406.480 mt ww (**Table 3.5**).
- SSS needs the stock status on the value of depletion in a given year (i.e. a proxy of stock status on overfished) as an input, so SSS should not be used to determine if the stock is overfished.
- As total catches (4.4 MT WW) in the terminal year is much less than the estimated OFL_{2021} for all scenario runs, overfishing most likely is not occurring.

Option 1: calculating ABCs as 30th percentile of OFLs

Scenario runs	OFL (median)	OFL (mean)	SD	CV	ABC (30th percentile of OFL)	ABC/OFL ratio
The Panel-approved reference run and sensitivity runs						
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)	71.208	126.307	309.533	2.451	50.178	0.705
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)	104.280	124.813	87.984	0.705	77.107	0.739
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)	136.120	156.070	110.623	0.709	109.147	0.802
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)	214.380	251.820	148.484	0.590	166.356	0.776
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)	406.480	556.360	428.517	0.770	287.747	0.708

ABC/OFL Map

TABLE 5. Examples of the tradeoffs between the buffer sizes (ABC/OFL ratios) and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*). Example ABC/OFL ratios were obtained for Tier 1 from meta-analysis of completed assessments for Tier 1 stocks ($\sigma_{min} = 0.4151$). Example ABC/OFL ratios were obtained for lower tiers from multiples equal to 1.5, 2.0, and 4.0 times σ_{min} for Tier 2, Tier 3, and Tier 4 stocks, respectively.

	ABC/OFL Ratios			
P*	Tier1 ($\sigma_{min} = 0.4151$)	Tier 2 ($1.5 \times \sigma_{min}$)	Tier 3 ($2.0 \times \sigma_{min}$)	Tier 4 ($4.0 \times \sigma_{min}$)
0.50	1.000	1.000	1.000	1.000
0.45	0.949	0.925	0.901	0.812
0.40	0.900	0.854	0.810	0.657
0.35	0.852	0.787	0.726	0.527
0.30	**0.804**	**0.721**	**0.647**	**0.419**
0.25	0.756	0.657	0.571	0.326
0.20	0.705	0.592	0.497	0.247
0.15	0.650	0.524	0.423	0.179
0.10	0.587	0.450	0.345	0.119
0.05	0.505	0.359	0.255	0.065

E.g., in MS Excel, 0.804 = LOGNORM.INV(0.3,0,0.415).
E.g., in MS Excel, 0.721 = LOGNORM.INV(0.3,0, 0.623).
E.g., in MS Excel, 0.647 = LOGNORM.INV(0.3,0, 0.830).

Courtney and Rice (2023)

Option 2: calculating ABCs following Courtney and Rice(2023)

Scenario runs	OFL (median)	OFL (mean)	SD	CV	ABC (median)	ABC/OFL ratio
The Panel-approved reference run and sensitivity runs						
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)	71.208	126.307	309.533	2.451	46.072	0.647
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)	104.280	124.813	87.984	0.705	67.469	0.647
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)	136.120	156.070	110.623	0.709	88.070	0.647
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)	214.380	251.820	148.484	0.590	138.704	0.647
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)	406.480	556.360	428.517	0.770	262.993	0.647

ABC/OFL ratio is 0.647 for P* = 0.3 and tier 3 stocks

ABCs: option 1 vs. option 2

					Option 1	Option 2
Scenario runs	OFL (median)	OFL (mean)	SD	CV	ABC (30th percentile OFL)	ABC (median)
Dep=0.1 in 2000 (E_B3)	71.208	126.307	309.533	2.451	50.178	46.072
Dep=0.2 in 2000 (E02_B3)	104.280	124.813	87.984	0.705	77.107	67.469
Dep=0.3 in 2000 (E1_B3)	136.120	156.070	110.623	0.709	109.147	88.070
Dep=0.5 in 2000 (E2_B3)	214.380	251.820	148.484	0.590	166.356	138.704
Dep=0.7 in 2000 (E3_B3)	406.480	556.360	428.517	0.770	287.747	262.993

ABCs of option 1 are a little larger than ABCs of option 2 in this case

Additional sensitivity to stock depletion assumptions and steepness

- In addition to the Panel-approved relative stock status in 2000, additional sensitivity scenarios were carried out assuming the relative stock status in 1990, 2010, and 2020 using the same levels of stock depletion (0.1, 0.2, 0.3 0.5, and 0.7).
- Sensitivity scenarios assuming the relative stock status in 2020 using the same levels of stock depletion (0.1, 0.2, 0.3 0.5, and 0.7) with a lower steepness (0.58 instead of 0.78) were also carried out.

Scenario runs
The Panel-approved reference run and sensitivity runs
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)
Additional sensitivity runs assuming a relative stock status in 1990
2-1) Dep=0.1 in 1990, lnR0=2, steepness=0.78 (F_B3)
2-2) Dep=0.2 in 1990, lnR0=2, steepness=0.78 (F02_B3)
2-3) Dep=0.3 in 1990, lnR0=2, steepness=0.78 (F1_B3)
2-4) Dep=0.5 in 1990, lnR0=2, steepness=0.78 (F2_B3)
2-5) Dep=0.7 in 1990, lnR0=2, steepness=0.78 (F3_B3)
Additional sensitivity runs assuming a relative stock status in 2010
3-1) Dep=0.1 in 2010, lnR0=2, steepness=0.78 (D_B3)
3-2) Dep=0.2 in 2010, lnR0=2, steepness=0.78 (D02_B3)
3-3) Dep=0.3 in 2010, lnR0=2, steepness=0.78 (D1_B3)
3-4) Dep=0.5 in 2010, lnR0=2, steepness=0.78 (D2_B3)
3-5) Dep=0.7 in 2010, lnR0=2, steepness=0.78 (D3_B3)
Additional sensitivity runs assuming a relative stock status in 2020
4-1) Dep=0.1 in 2020, lnR0=2, steepness=0.78 (C_B3)
4-2) Dep=0.2 in 2020, lnR0=2, steepness=0.78 (C02_B3)
4-3) Dep=0.3 in 2020, lnR0=2, steepness=0.78 (C1_B3)
4-4) Dep=0.5 in 2020, lnR0=2, steepness=0.78 (C2_B3)
4-5) Dep=0.7 in 2020, lnR0=2, steepness=0.78 (C3_B3)
Additional sensitivity runs assuming a relative stock status in 2020 with a lower steepness
5-1) Dep=0.1 in 2020, lnR0=2, steepness=0.58 (C_B3_C2)
5-2) Dep=0.2 in 2020, lnR0=2, steepness=0.58 (C02_B3_C2)
5-3) Dep=0.3 in 2020, lnR0=2, steepness=0.58 (C1_B3_C2)
5-4) Dep=0.5 in 2020, lnR0=2, steepness=0.58 (C2_B3_C2)
5-5) Dep=0.7 in 2020, lnR0=2, steepness=0.58 (C3_B3_C2)

Scenario runs	Dep (median)	Dep (mean)
The Panel-approved reference run and sensitivity runs		
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)	0.48	0.49
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)	0.67	0.64
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)	0.77	0.73
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)	0.87	0.84
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)	0.94	0.91
Additional sensitivity runs assuming a relative stock status in 1990		
2-1) Dep=0.1 in 1990, lnR0=2, steepness=0.78 (F_B3)	0.00	0.05
2-2) Dep=0.2 in 1990, lnR0=2, steepness=0.78 (F02_B3)	0.00	0.08
2-3) Dep=0.3 in 1990, lnR0=2, steepness=0.78 (F1_B3)	0.00	0.12
2-4) Dep=0.5 in 1990, lnR0=2, steepness=0.78 (F2_B3)	0.43	0.40
2-5) Dep=0.7 in 1990, lnR0=2, steepness=0.78 (F3_B3)	0.87	0.73
Additional sensitivity runs assuming a relative stock status in 2010		
3-1) Dep=0.1 in 2010, lnR0=2, steepness=0.78 (D_B3)	0.23	0.27
3-2) Dep=0.2 in 2010, lnR0=2, steepness=0.78 (D02_B3)	0.40	0.44
3-3) Dep=0.3 in 2010, lnR0=2, steepness=0.78 (D1_B3)	0.57	0.56
3-4) Dep=0.5 in 2010, lnR0=2, steepness=0.78 (D2_B3)	0.75	0.72
3-5) Dep=0.7 in 2010, lnR0=2, steepness=0.78 (D3_B3)	0.87	0.85
Additional sensitivity runs assuming a relative stock status in 2020		
4-1) Dep=0.1 in 2020, lnR0=2, steepness=0.78 (C_B3)	0.05	0.10
4-2) Dep=0.2 in 2020, lnR0=2, steepness=0.78 (C02_B3)	0.14	0.22
4-3) Dep=0.3 in 2020, lnR0=2, steepness=0.78 (C1_B3)	0.27	0.30
4-4) Dep=0.5 in 2020, lnR0=2, steepness=0.78 (C2_B3)	0.51	0.51
4-5) Dep=0.7 in 2020, lnR0=2, steepness=0.78 (C3_B3)	0.73	0.70
Additional sensitivity runs assuming a relative stock status in 2020 with a lower steepness		
5-1) Dep=0.1 in 2020, lnR0=2, steepness=0.58 (C_B3_C2)	0.05	0.10
5-2) Dep=0.2 in 2020, lnR0=2, steepness=0.58 (C02_B3_C2)	0.12	0.20
5-3) Dep=0.3 in 2020, lnR0=2, steepness=0.58 (C1_B3_C2)	0.27	0.31
5-4) Dep=0.5 in 2020, lnR0=2, steepness=0.58 (C2_B3_C2)	0.50	0.50
5-5) Dep=0.7 in 2020, lnR0=2, steepness=0.58 (C3_B3_C2)	0.73	0.85

- Posterior Dep values are very sensitive to the assumed value of depletion in a given year.
- 1990 runs: the stock would be completely depleted in the year 2020 with the assumed INPUT values of Dep=0.1, 0.2 and 0.3 in the year 1990. These three scenarios are UNREALISTIC.
- 2010 runs: the terminal year depletion was smaller than its counterpart run of the Panel-approved reference run and sensitivity runs.
- 2020 runs: the terminal year depletion was smaller than its counterpart run of the additional sensitivity runs assuming a relative stock status in 2010

Scenario runs	OFL (median)	OFL (mean)	SD	CV
The Panel-approved reference run and sensitivity runs				
1-1) Dep=0.1 in 2000, lnR0=2, steepness=0.78 (E_B3)	71.208	126.307	309.533	2.451
1-2) Dep=0.2 in 2000, lnR0=2, steepness=0.78 (E02_B3)	104.280	124.813	87.984	0.705
1-3) Dep=0.3 in 2000, lnR0=2, steepness=0.78 (E1_B3)	136.120	156.070	110.623	0.709
1-4) Dep=0.5 in 2000, lnR0=2, steepness=0.78 (E2_B3)	214.380	251.820	148.484	0.590
1-5) Dep=0.7 in 2000, lnR0=2, steepness=0.78 (E3_B3)	406.480	556.360	428.517	0.770
Additional sensitivity runs assuming a relative stock status in 1990				
2-1) Dep=0.1 in 1990, lnR0=2, steepness=0.78 (F_B3)	0.013	36.688	200.595	5.468
2-2) Dep=0.2 in 1990, lnR0=2, steepness=0.78 (F02_B3)	0.013	17.734	57.637	3.250
2-3) Dep=0.3 in 1990, lnR0=2, steepness=0.78 (F1_B3)	0.016	25.895	79.645	3.076
2-4) Dep=0.5 in 1990, lnR0=2, steepness=0.78 (F2_B3)	57.720	95.659	122.418	1.280
2-5) Dep=0.7 in 1990, lnR0=2, steepness=0.78 (F3_B3)	224.440	314.650	314.650	1.000
Additional sensitivity runs assuming a relative stock status in 2010				
3-1) Dep=0.1 in 2010, lnR0=2, steepness=0.78 (D_B3)	41.340	69.830	155.561	2.228
3-2) Dep=0.2 in 2010, lnR0=2, steepness=0.78 (D02_B3)	64.540	77.330	46.555	0.602
3-3) Dep=0.3 in 2010, lnR0=2, steepness=0.78 (D1_B3)	89.740	98.230	54.918	0.559
3-4) Dep=0.5 in 2010, lnR0=2, steepness=0.78 (D2_B3)	131.750	149.760	71.412	0.477
3-5) Dep=0.7 in 2010, lnR0=2, steepness=0.78 (D3_B3)	225.990	302.880	213.153	0.704
Additional sensitivity runs assuming a relative stock status in 2020				
4-1) Dep=0.1 in 2020, lnR0=2, steepness=0.78 (C_B3)	11.809	29.927	81.847	2.735
4-2) Dep=0.2 in 2020, lnR0=2, steepness=0.78 (C02_B3)	28.022	39.386	30.920	0.785
4-3) Dep=0.3 in 2020, lnR0=2, steepness=0.78 (C1_B3)	47.777	53.242	32.935	0.619
4-4) Dep=0.5 in 2020, lnR0=2, steepness=0.78 (C2_B3)	81.280	86.730	38.413	0.443
4-5) Dep=0.7 in 2020, lnR0=2, steepness=0.78 (C3_B3)	124.680	156.520	100.546	0.642
Additional sensitivity runs assuming a relative stock status in 2020 with a lower steepness				
5-1) Dep=0.1 in 2020, lnR0=2, steepness=0.58 (C_B3_C2)	9.536	32.039	109.602	3.421
5-2) Dep=0.2 in 2020, lnR0=2, steepness=0.58 (C02_B3_C2)	22.446	36.103	35.114	0.973
5-3) Dep=0.3 in 2020, lnR0=2, steepness=0.58 (C1_B3_C2)	46.515	56.243	40.703	0.724
5-4) Dep=0.5 in 2020, lnR0=2, steepness=0.58 (C2_B3_C2)	88.550	88.550	56.657	0.640
5-5) Dep=0.7 in 2020, lnR0=2, steepness=0.58 (C3_B3_C2)	158.020	214.170	214.170	1.000

Data inputs for SSS including length composition data
(Proof of concept)

- Catch (in MT whole weight) without associated standard errors
  1. Commercial (1981 – 2020)
  2. Recreational (1981 – 2020)
- Life History (either fixed or assume a distribution)
  1. Natural mortality
  2. Growth curve
  3. Maturity-length relationship
  4. Fecundity-length relationship
  5. Steepness
  6. Weight-length relationship
- ~~Assumed stock status on the value of depletion in a given year (i.e. a proxy of stock status on overfished)~~
- Super year (2019 or 2016) with aggregated years 2016-2019 length composition data
- Selectivity is fixed and can be specified for multiple fleets and different shapes.
- LnR_0 is estimated by the model with an assumed initial value (it is the only estimated parameter).

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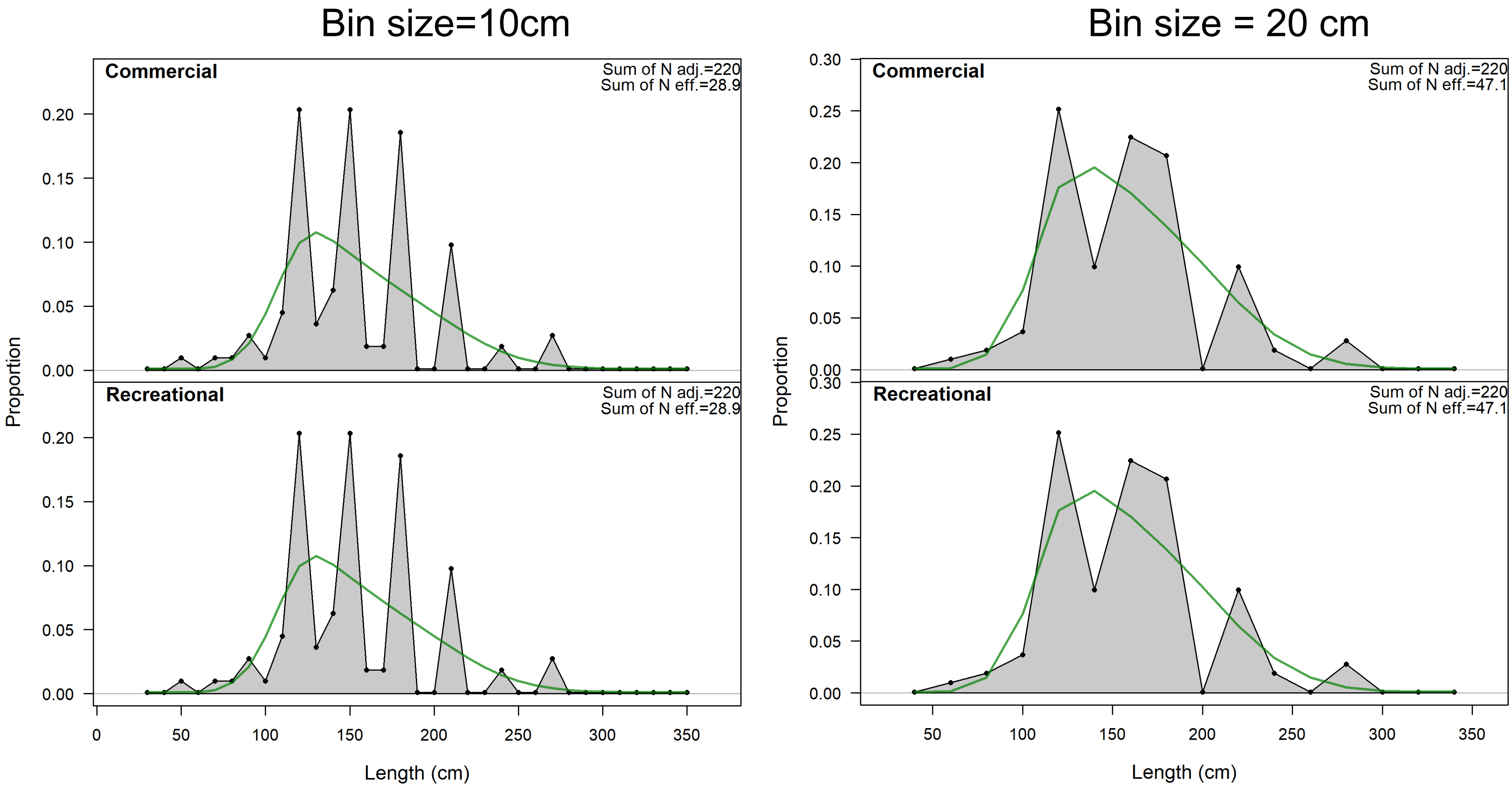
Table 2.5.5. Length composition data of smooth hammerheads in years 1966-2019.

Year	Sample Size	Year	Sample Size
1966	1	1994	9
1967	1	1995	5
1968	1	1996	12
1969	1	1997	11
1970	1	1998	9
1973	5	1999	1
1974	7	2000	4
1975	1	2001	5
1976	6	2002	5
1977	3	2003	6
1978	4	2004	4
1979	4	2005	7
1980	3	2006	9
1981	4	2007	12
1982	9	2008	7
1983	10	2009	29
1984	4	2010	13
1985	3	2011	27
1986	5	2012	11
1987	9	2013	23
1988	3	2014	22
1989	8	2015	8
1990	14	2016	27
1991	15	2017	47
1992	15	2018	13
1993	38	2019	23
Grand Total			**524**

only 8 years with more than 20 samples.
The sample size of these length composition data is very small and very likely unrepresentative of the real length-composition of the catches.

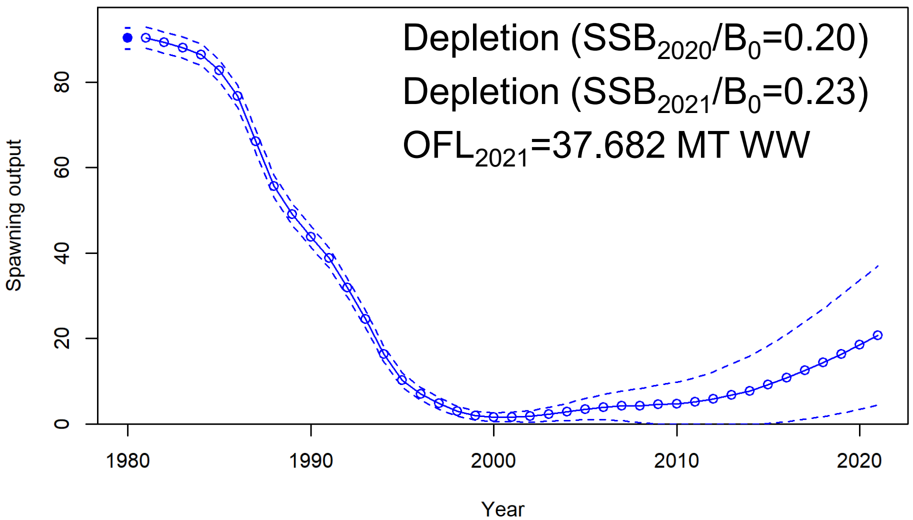
Fit of length composition data of super year 2019 based on aggregated 2016-2019 data



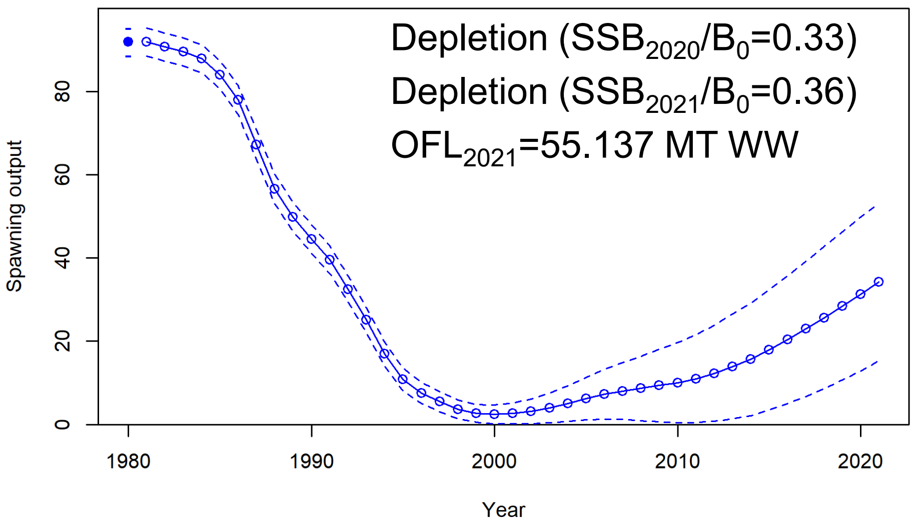
As the sample size is small, need to increase the bin size from 10 cm to 20 cm to smooth the distribution and get rid of some of the spikes

Depletion and OFL_{2021} estimated from SSS including super year 2019 based on aggregated 2016-2019 length composition data

Bin size=10cm



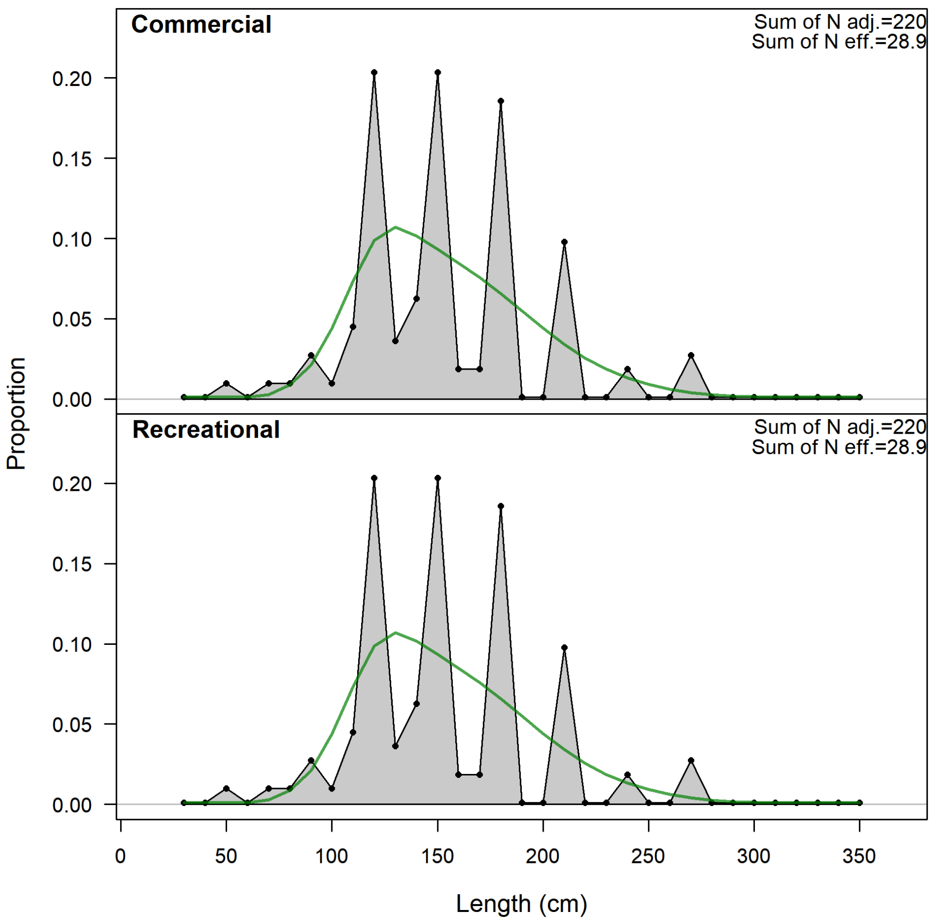
Bin size = 20 cm



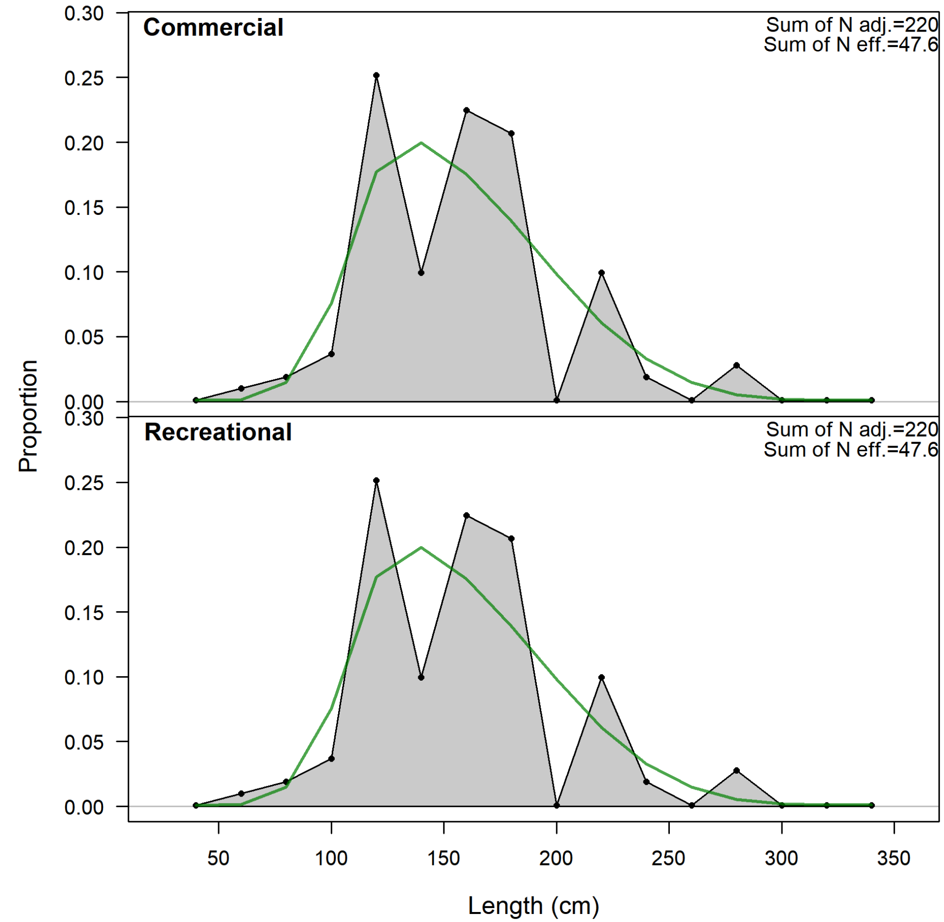
- The values of depletion and OFL_{2021} increase with the increase of the bin size
- The values of $depletion_{2020}$ and OFL_{2021} are in the same ballpark of the recommended reference model (0.48 and 71.208 MT WW).
- As these length data most likely are unrepresentative, these results should be interpreted with caution.

Fit of length composition data of super year 2016 based on aggregated 2016-2019 data

Bin size=10cm



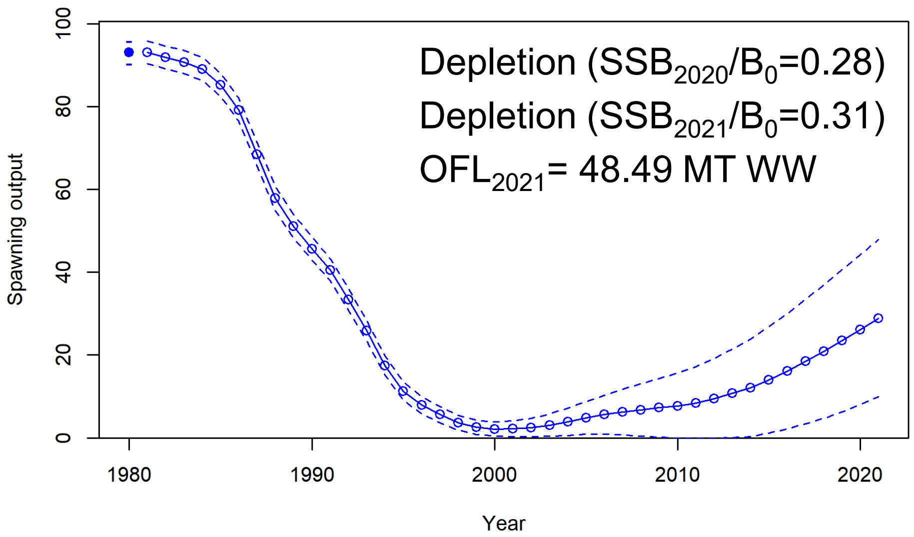
Bin size = 20 cm



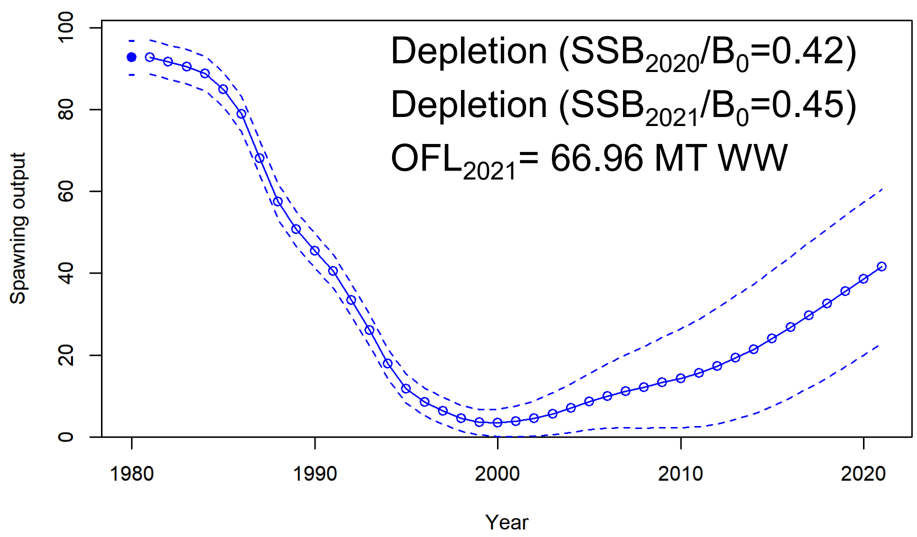
As the sample size is small, need to increase the bin size from 10 cm to 20 cm to smooth the distribution and get rid of some of the spikes

Depletion and OFL_{2021} estimated from SSS including super year 2016 based on aggregated 2016-2019 length composition data

Bin size=10cm



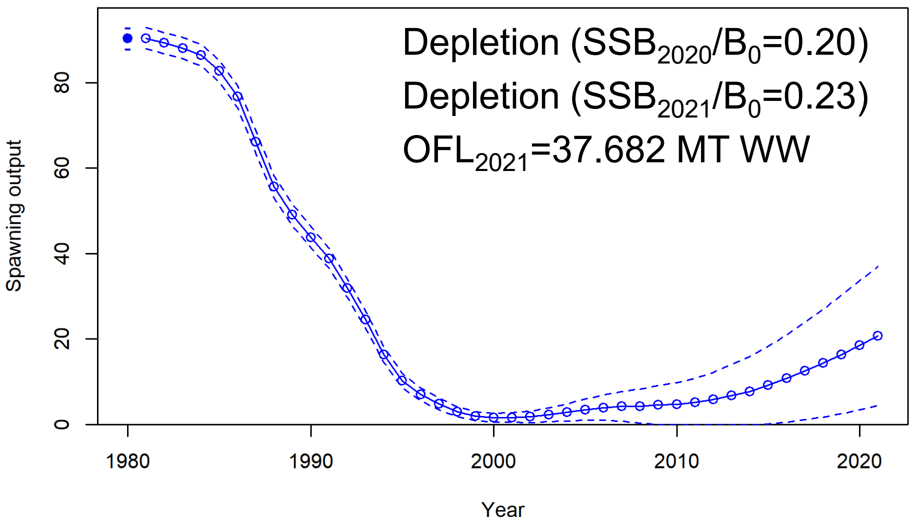
Bin size = 20 cm



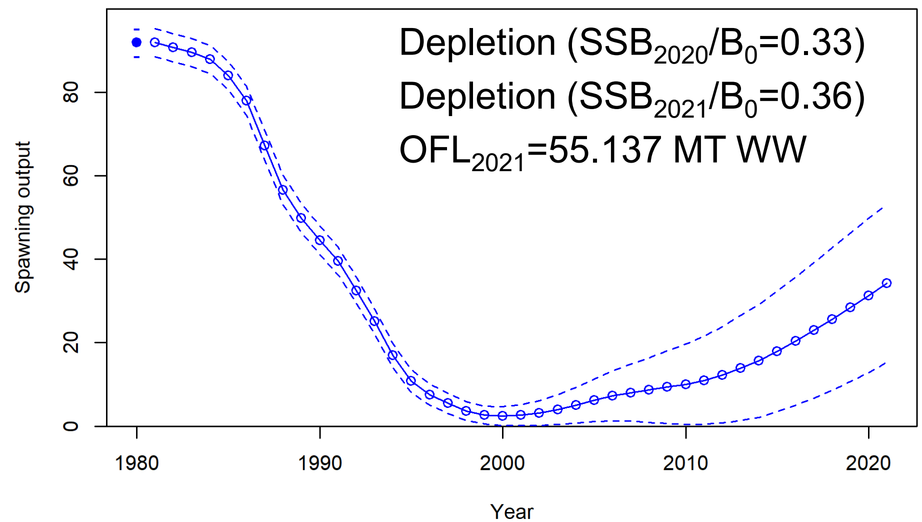
- The values of depletion and OFL_{2021} increase with the increase of the bin size
- The values of $depletion_{2020}$ and OFL_{2021} are in the same ballpark of the recommended reference model (0.48 and 71.208 MT WW).
- As these length data most likely are unrepresentative, these results should be interpreted with caution.

Depletion and OFL_{2021} estimated from SSS including a super year in either 2019 or 2016 based on aggregated length composition data

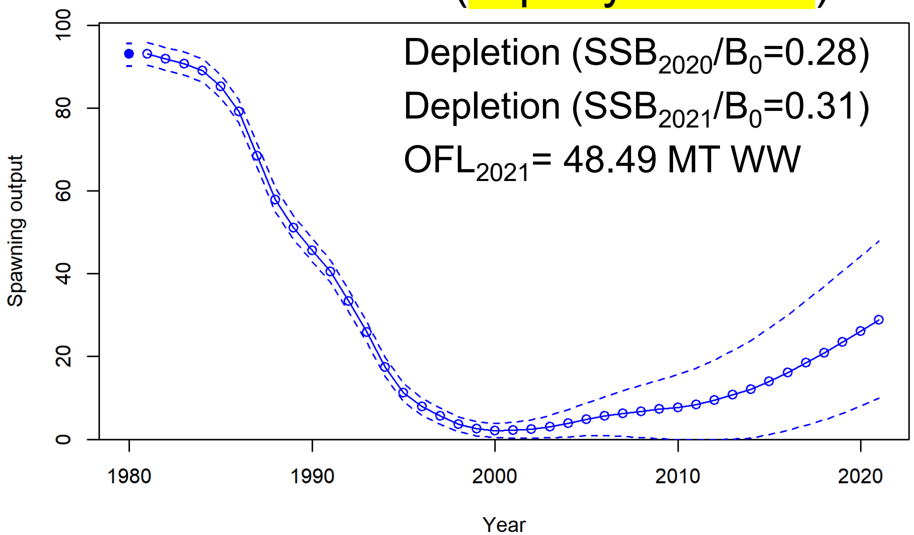
Bin size=10cm (super year 2019)



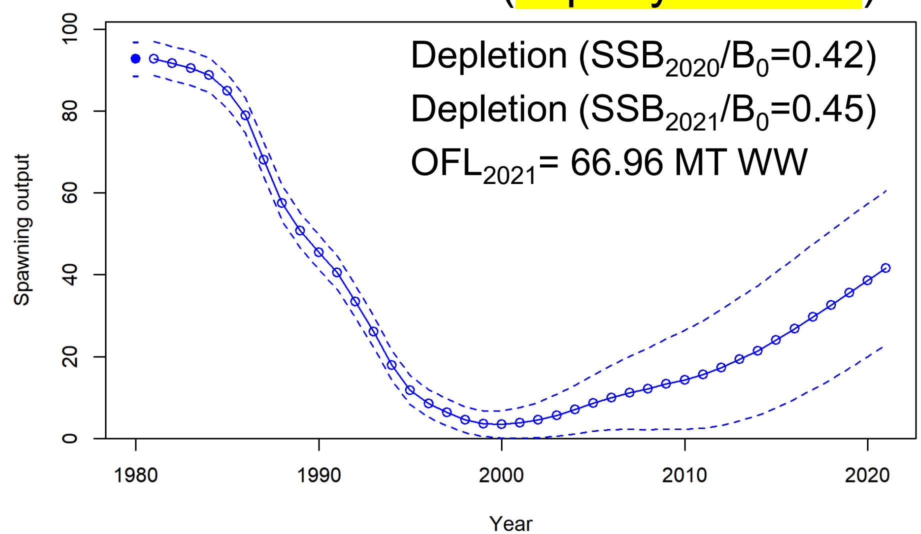
Bin size = 20 cm (super year 2019)



Bin size=10cm (super year 2016)



Bin size = 20 cm (super year 2016)



Summary of SSS including length composition data

- The values of depletion and OFL_{2021} increase with the increase of the bin size
- The values of depletion and OFL_{2021} increase when moving back the super year from 2019 to 2016
- The values of depletion and OFL_{2021} are in the same ballpark of the recommended reference model
- As these length data most likely are unrepresentative, these results should be interpreted with caution.

Jiao et al. (2011)

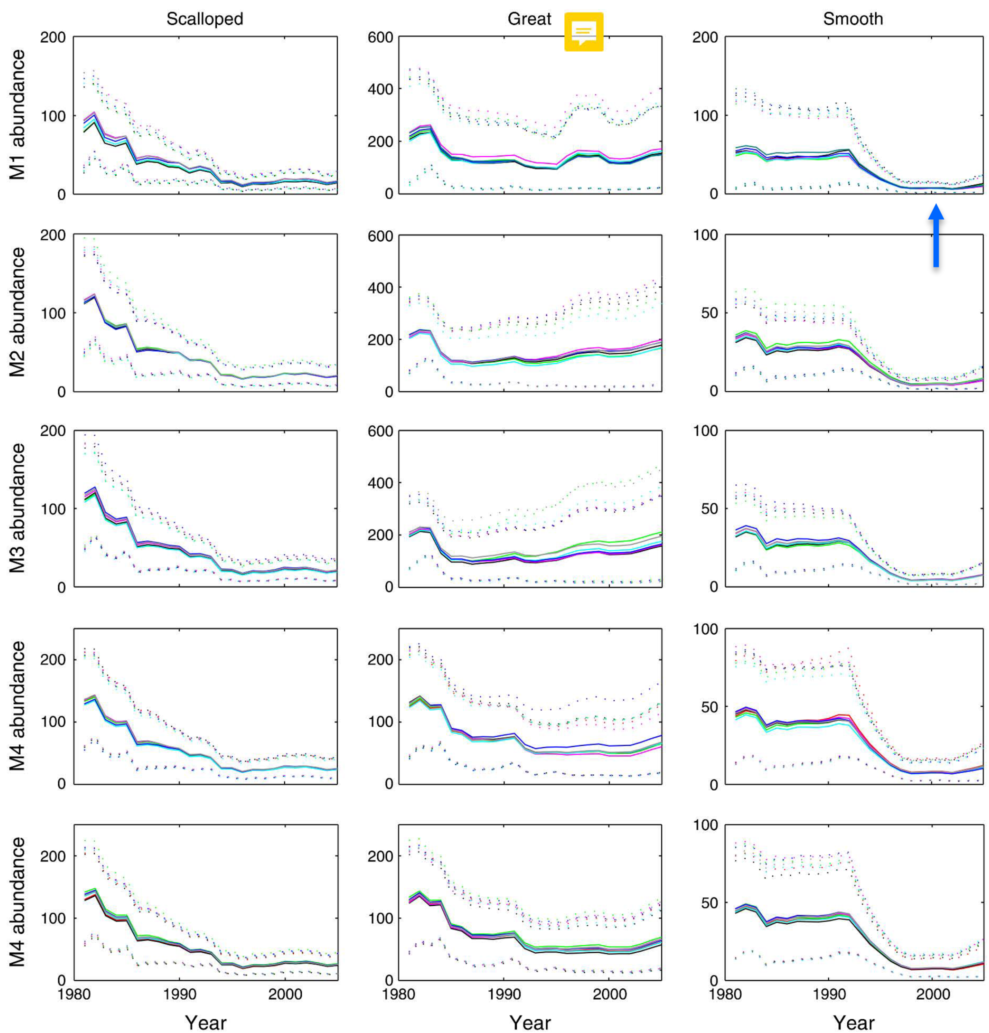


Fig. 4. Population abundance trajectories (in thousands of fish) for scalloped, great, and smooth hammerhead sharks. Solid lines denote the posterior mean of population abundance; dotted lines denote 95% credible intervals of population abundance. Different scenarios are denoted by different colors, which have the same meaning as in Fig. 3.

Depletion level in 2000 is in the ballpark of 10% which supports the AW Panel's depletion level recommendation (10% in 2000) used for the reference case.

M1: nonhierarchical priors

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Conclusions and management implications

- SSS needs the stock status on the value of depletion in a given year (i.e. a proxy of overfished stock status) as an input, so SSS should not be used to determine if the stock is overfished
- As total catch (4.400 mt ww) in the terminal year is much less than the estimated OFL_{2021}, overfishing most likely is not occurring
- Since SSS provides highly uncertain estimates of *OFL*, the catch recommendations should be interpreted with caution
- The median of the terminal year depletion was larger than the assumed depletion in the year 2000, which suggested the stock has been rebuilding since 2000 due to the low fishing pressure during the last 20 years or so. Therefore, the stock is very likely continuously rebuilding under the current management regulations.

RECOMMENDATIONS FOR DATA COLLECTION AND FUTURE RESEARCH

- Since catches are dominated by recreational catches, decreasing the uncertainty associated with the recreational catches will be critical for improvement of future stock assessments of this stock.
- Since representative length composition data can be added to SSS as they become available to free the input requirement of the stock status on the value of depletion in a given year (i.e. a proxy of overfished stock status), programs to collect length data to allow their incorporation into SSS in future assessments should be developed.
- Since there are insufficient time series data to develop indices of abundance, programs to collect relative abundance data to allow their incorporation into SSS in future assessments should also be developed.
- Since some of the life history data were borrowed from other stocks, programs to obtain representative biological information for this stock should also be developed.

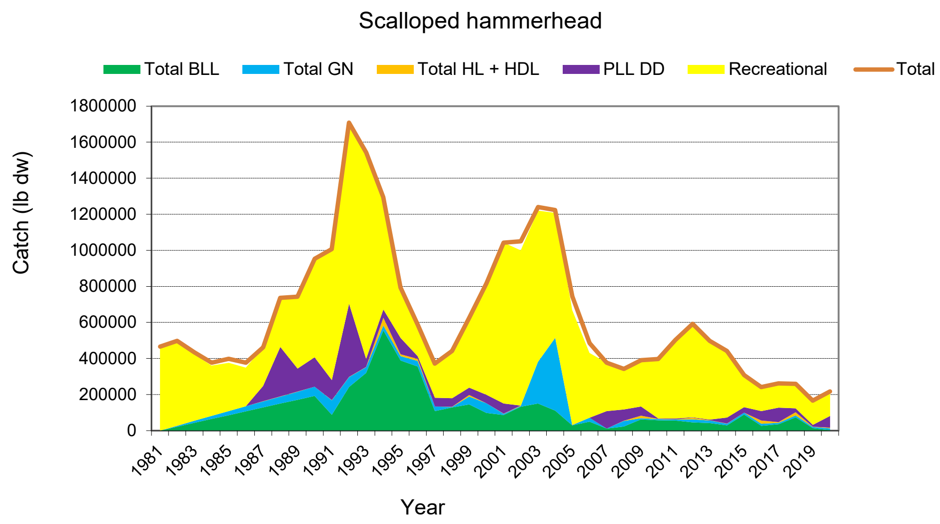
Questions?

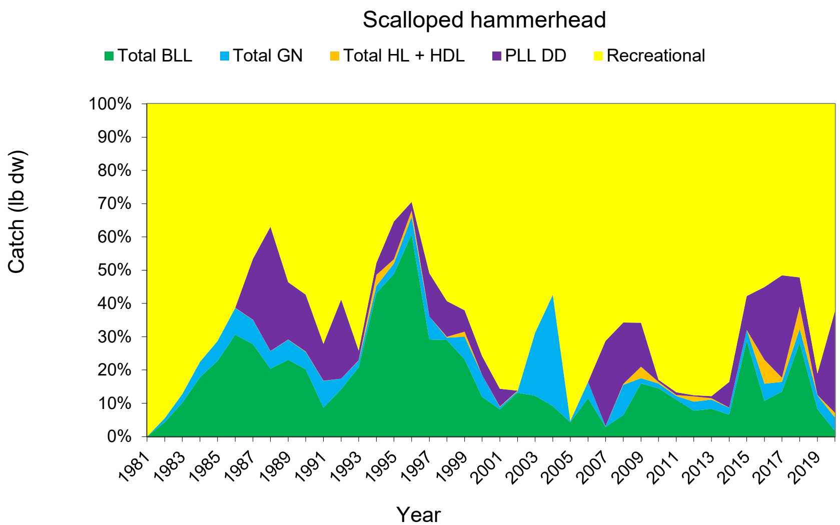
Additional slides

Catches: decisions made and implemented

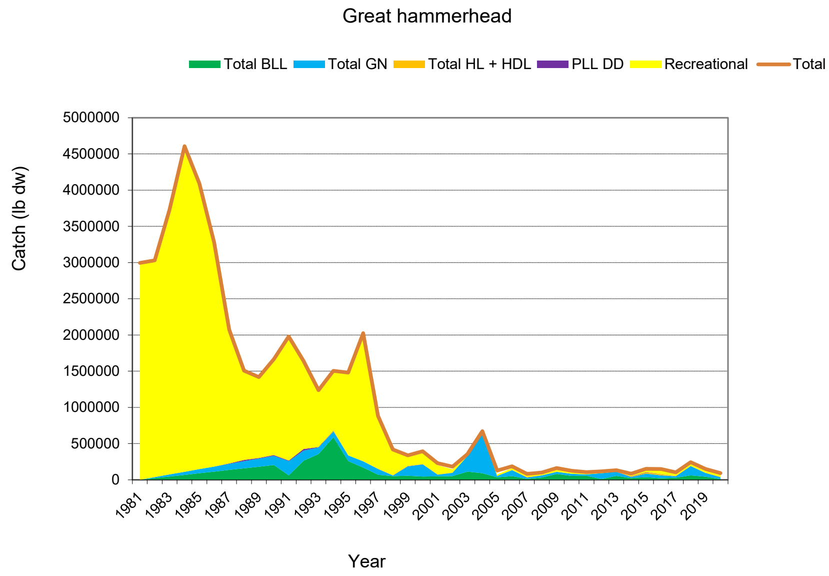
- ✓ Back-calculate commercial landings to 1981 to match recreational catches
- ✓ For back-calculations, assume linear increase starting from 0 in 1980 up to 90% of the average for the first 3 years of data (1991-1993) in 1990
- ✓ Back-calculate all discard series to 1981 as above but using mean of entire time series (as done in SEDAR 65) (for now just showing average of entire time series of values presented in bycatch papers pending ongoing work by bycatch ad-hoc working group)
- ✓ Use latest post-release mortality rates for bottom longline (for now SHH=80.52%; GHH=80.36%; SMH=80.44%), gillnet (same as for BLL), and hook and line (for now 27%)
- ✓ Do not include Mexican reconstructed landings from Castillo et al. (1998) or PR/USVI landings in the base run
- ✓ Use the published dead discard estimates from the pelagic longline fishery reported to the ICCAT Task 1 database in the base run
- ✓ Apportion the AB1 and B2 unclassified sphyrnid sharks as follows: 1) for 1981-2000, use annual proportions based on A catches (observed by interviewer) and 2) for 2001-2020, use average proportion during 1981-2000 based on the A catches to account for management measures implemented
- ✓ Smooth individual extreme peaks identified in recreational catches
- ✓ Smooth recreational series with three-year geometric moving average

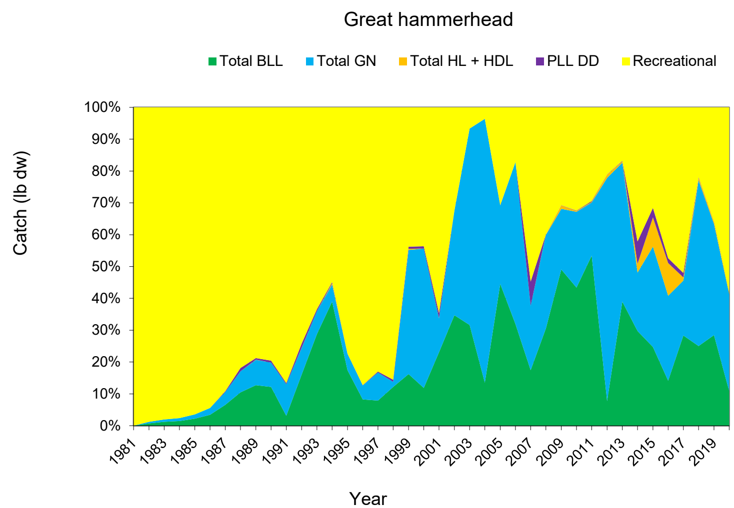
Preliminary catches by sector: Scalloped hammerhead



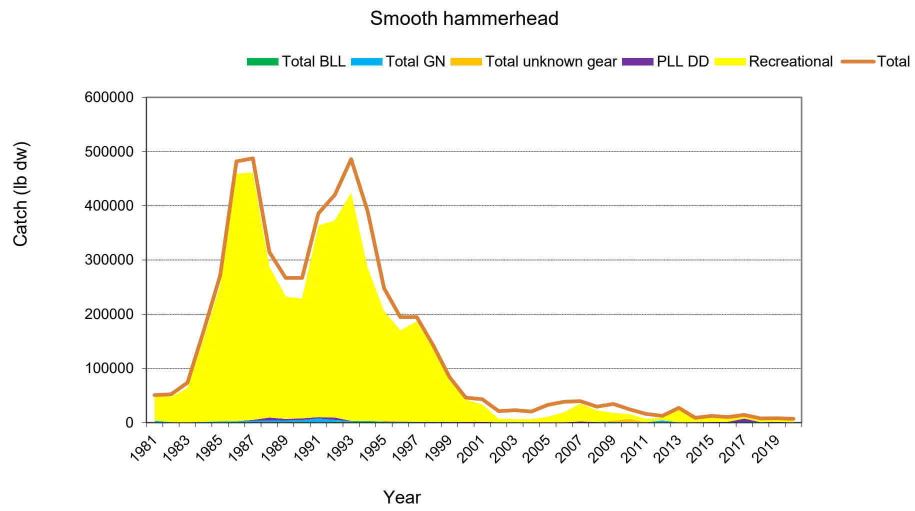


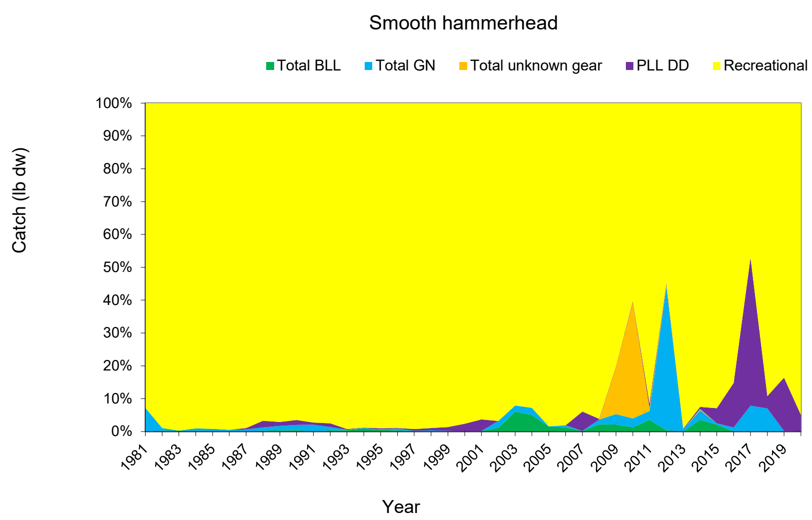
Preliminary catches by sector: Great hammerhead





<u>Preliminary</u> catches by sector: Smooth hammerhead

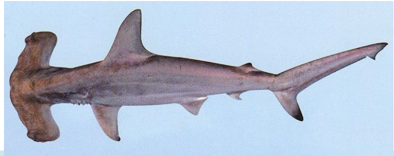




Biological input values (females) used to compute population dynamics parameter estimates for scalloped hammerheads (areas combined)

Parameter	Definition	Value	Unit	References
L_∞	Theoretical maximum length	229.2 (5.44)	cm FL	DW report life history section
K	Brody growth coefficient	0.086 (0.005)	yr^{-1}	DW report life history section
t_0	Theoretical age at zero length	-2.352 (0.11)	yr	DW report life history section
a	Intercept of maturity ogive	-11.979 (3.80)	dimensionless	DW report life history section
b	Slope of maturity ogive	0.744 (0.24)	dimensionless	DW report life history section
c	Scalar coefficient of weight on length	5.774E-06	dimensionless	DW report life history section
d	Power coefficient of weight on length	3.128	dimensionless	DW report life history section
w	Observed lifespan	29.5	yr	DW report life history section
	Theoretical lifespan (99% of L inf)	51.2	yr	DW report life history section
	Sex ratio at birth	1:1	dimensionless	DW report life history section
	Reproductive cycle	annual	yr	DW report life history section
mx	Constant litter size	18.0 (SD=7.67; 7-30)	pups per litter	DW report life history section
e	Intercept of maternal age vs. fecundity	n/a	dimensionless	DW report life history section
f	Slope of maternal age vs. fecundity	n/a	dimensionless	DW report life history section
GP	Gestation period	11	months	DW report life history section

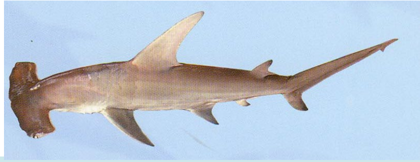
Values in parentheses are SEs.



Biological input values (females) used to compute population dynamics parameter estimates for great hammerheads

Parameter	Definition	Value	Unit	References
L_∞	Theoretical maximum length	323.9 (7.49)	cm FL	DW report life history section
K	Brody growth coefficient	0.11 (0.011)	yr^{-1}	DW report life history section
t_0	Theoretical age at zero length	-2.06 (0.20)	yr	DW report life history section
a	Intercept of maturity ogive	-7.569 (2.67)	dimensionless	DW report life history section
b	Slope of maturity ogive	0.937 (0.32)	dimensionless	DW report life history section
c	Scalar coefficient of weight on length	9.275E-06	dimensionless	DW report life history section
d	Power coefficient of weight on length	3.028	dimensionless	DW report life history section
w	Observed lifespan	35	yr	DW report life history section
	Theoretical lifespan (99% of L inf)	40	yr	DW report life history section
	Sex ratio at birth	1:1	dimensionless	DW report life history section
	Reproductive cycle	biennial	yr	DW report life history section
mx	Constant litter size	30.93 (SD=10.74; 13-56)	pups per litter	DW report life history section
e	Intercept of maternal length vs. fecundity	-67.9565	dimensionless	DW report life history section
f	Slope of maternal length vs. fecundity	0.3453	dimensionless	DW report life history section
GP	Gestation period	12	months	DW report life history section

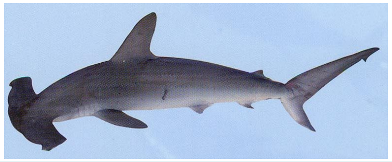
Values in parentheses are SEs.



Biological input values (females) used to compute population dynamics parameter estimates for smooth hammerheads

Parameter	Definition	Value	Unit	References
L_∞	Theoretical maximum length	293.9	cm FL	DW report life history section
K	Brody growth coefficient	0.09	yr^{-1}	DW report life history section
t_0	Theoretical age at zero length	-2.195*	yr	DW report life history section
a	Intercept of maturity ogive	n/a	dimensionless	DW report life history section
b	Slope of maturity ogive	n/a	dimensionless	DW report life history section
c	Scalar coefficient of weight on length	2.000E-06	dimensionless	DW report life history section
d	Power coefficient of weight on length	3.329	dimensionless	DW report life history section
w	Observed lifespan	25	yr	DW report life history section
	Theoretical lifespan (99% of L inf)	49	yr	DW report life history section
	Sex ratio at birth	1:1	dimensionless	DW report life history section
	Reproductive cycle	biennial	yr	DW report life history section
mx	Constant litter size	33.5	pups per litter	DW report life history section
e	Intercept of maternal length vs. fecundity	n/a	dimensionless	DW report life history section
f	Slope of maternal length vs. fecundity	n/a	dimensionless	DW report life history section
GP	Gestation period	11	months	DW report life history section

* Obtained from an L_0 of 52.7 cm FL.

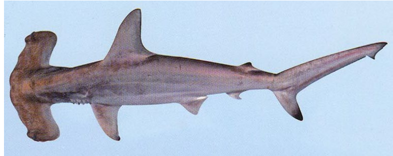


Deterministic estimates of r_{max} for hammerhead sharks obtained through seven methods

	Stock				
Method	Scalloped hammerhead (GOM +ATL)	Scalloped hammerhead (GOM)	Scalloped hammerhead (ATL)	Great hammerhead	Smooth hammerhead
Eberhardt et al. (1982)	0.099	0.120	0.096	0.177	0.149
Skalski et al. (2008)	0.099	0.120	0.096	0.177	0.149
Au et al. (2016)	0.048	0.052	0.048	0.080	0.063
Neil and Lebreton's (2005) DIM*	0.039	0.043	0.039	0.067	0.053
Euler-Lotka/Leslie matrix	0.098	0.114	0.095	0.131	0.154
Pardo et al. (2016)	0.099	0.122	0.095	0.186	0.154
Mean	0.080	0.095	0.078	0.136	0.120

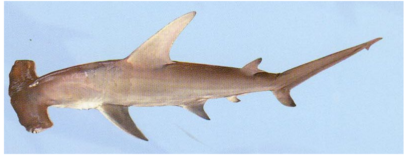
Estimates of population dynamics parameters obtained from Monte Carlo simulation of vital rates with a Leslie matrix approach: Scalloped hammerhead (combined areas)

	Median	LCL	UCL	Deterministic
r_{max}	0.104	0.039	0.189	0.098
Generation time	20.1	10.0	74.0	21.8
Net reproductive rate (R_0)	10.732	3.656	29.320	10.769
Age-0 survivorship (S_0)	0.88	0.68	0.92	0.70
Steepness (h)	0.69	0.44	0.87	0.65
SPR_{MER}	0.33	0.19	0.56	0.36
R (inflection point)	0.483	0.335	0.597	0.47
M	0.117	0.092	0.164	0.091



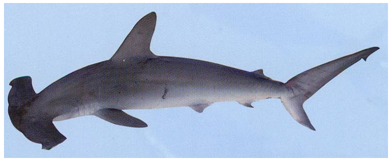
Estimates of population dynamics parameters obtained from Monte Carlo simulation of vital rates with a Leslie matrix approach: Great hammerhead

	Median	LCL	UCL	Deterministic
r_{max}	0.146	0.059	0.199	0.131
Generation time	14.5	12.7	60.7	14.8
Net reproductive rate (R_0)	11.193	4.053	33.844	9.553
Age-0 survivorship (S_0)	0.85	0.76	0.90	0.66
Steepness (h)	0.71	0.46	0.87	0.61
SPR_{MER}	0.32	0.20	0.53	0.40
R (inflection point)	0.476	0.296	0.571	0.48
M	0.156	0.080	0.206	0.117



Estimates of population dynamics parameters obtained from Monte Carlo simulation of vital rates with a Leslie matrix approach: Smooth hammerhead

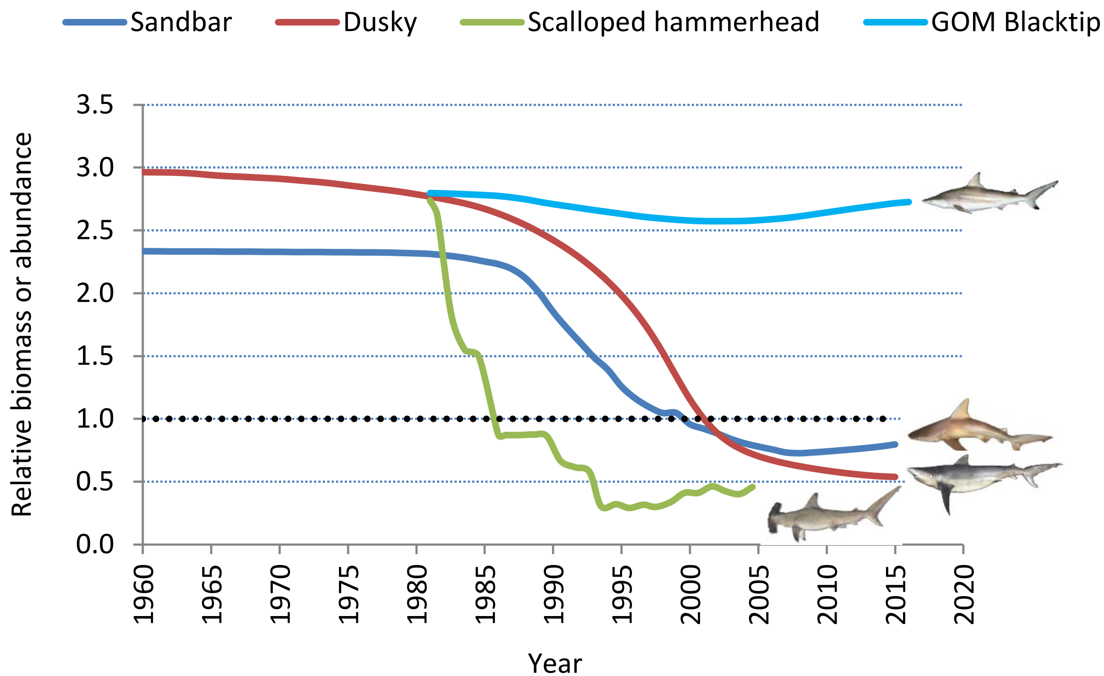
	Median	LCL	UCL	Deterministic
r_{max}	0.182	0.139	0.423	0.154
Generation time	13.0	3.4	35.5	14.1
Net reproductive rate (R_0)	15.850	9.209	34.783	13.940
Age-0 survivorship (S_0)	0.87	0.71	0.91	0.69
Steepness (h)	0.78	0.66	0.88	0.70
SPR_{MER}	0.27	0.19	0.36	0.32
R (inflection point)	0.476	0.327	0.559	0.45
M	0.129	0.081	0.138	0.095



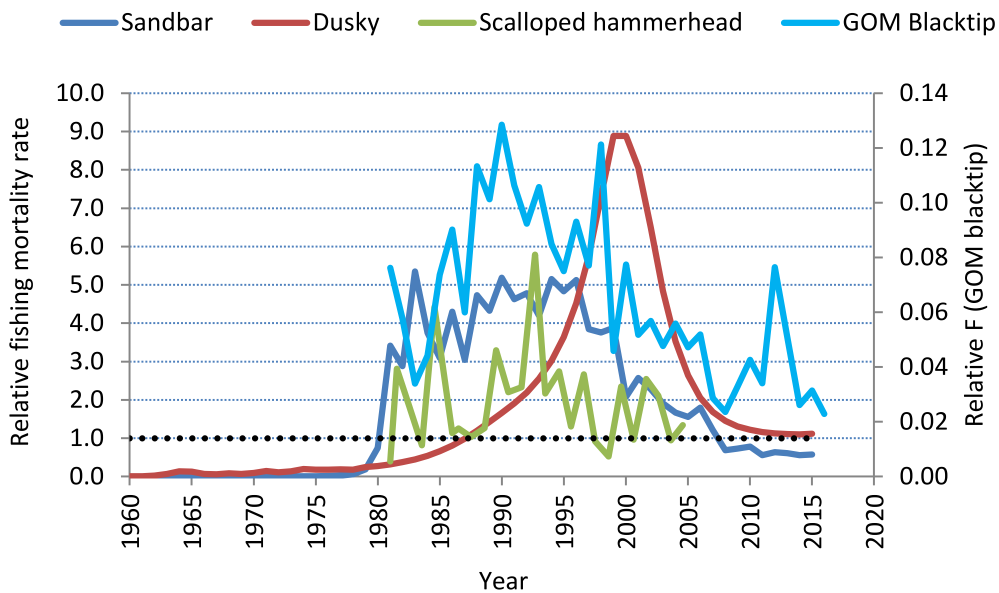
Stock status of large coastal sharks

Stock	Area	Previous assessment			Latest assessment			Improved status?	Projections / Comments
		SEDAR / Date	*Overfished? (B/Bmsy)*	*Overfishing? (F/Fmsy)*	*SEDAR / Date*	*Overfished? (B/Bmsy)*	*Overfishing? (F/Fmsy)*		
Sandbar	Atlantic + GOM	SEDAR 21 (2011; benchmark)	Yes (0.66)	No (0.62)	SEDAR 54 (2017; standard)	**Yes** (0.77)	**No** (0.58)	**YES** (overfished and overfishing)	TAC increased from 220 to 246 mt dw
Dusky	Atlantic + GOM	SEDAR 21 (2011; benchmark)	Yes (0.47)	Yes (1.59)	SEDAR 21 update (2016)	**Yes** (0.54)	**Yes** (1.12)	**YES** (overfished and overfishing)	Required reductions in F to achieve rebuilding by rebuilding year with a 70% probability decreased from 62% to 39%
Blacktip	GOM	SEDAR 29 (2012; standard)	No (2.62)	No (0.074)	SEDAR 29 update (2018)	**No** (2.73)	**No** (0.023)	**YES** (overfished and overfishing)	Could support total annual removals ranging from 200,000 to 1,200,000
Scalloped hammerhead	Atlantic + GOM	Hayes et al. (2009; external)	**Yes** (0.45)	**Yes** (1.29)	SEDAR 77 (Research Track)				Also includes GOM and SA scalloped hh stocks; great and smooth hammerheads
Spinner, Bull, Tiger	Atlantic + GOM	Not previously assessed			Planned for 2024 (Research track)				May also include GOM-specific stocks of these species

Relative biomass (abundance) of large coastal shark stocks



Relative fishing mortality rate of large coastal shark stocks



Summary of status and trends

- All large coastal shark stocks re-assessed have improved in status since the previous assessment (sandbar, dusky, GOM blacktip). Increasing trends in abundance detected in 3 of 4 cases and decreasing or stable F trends in all cases

Discussion

- Is there really a discrepancy between the results of stock assessments and on-water observations?
  - Almost all trends obtained from stock assessments lend support to the on-water observations of increasing shark populations, especially if considering abundance in numbers
  - Stock assessments use multiple sources of information. In addition to CPUEs, they also use Catch, Biology, and Length Compositions
  - CPUEs (indices of abundance) are supposed to reflect changes in (be proportional to) the relative abundance of the population
  - On-water observations may reflect effort concentrated on areas of higher abundance (hyperstability) whereas stock assessments theoretically reflect the abundance of the entire population

Atlantic Sharks: 30 Years of Successes and Lessons

https://www.fisheries.noaa.gov/podcast/atlantic-sharks-30-years-successes-and-lessons