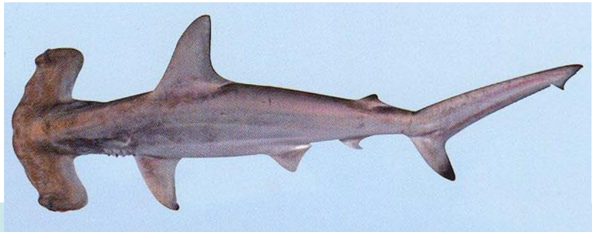
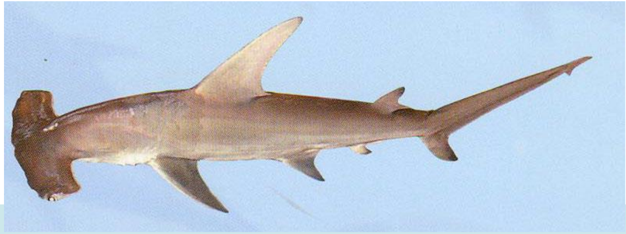
NOAA FISHERIES

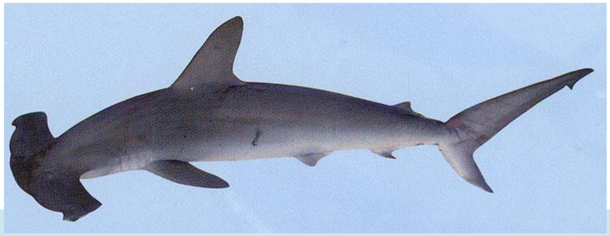
BAYESIAN SURPLUS PRODUCTION MODELS (JABBA) APPLIED TO THE GREAT HAMMERHEAD SHARK ASSESSMENT

SEDAR 77 (Review Workshop)

August, 2023







SEDAR 77 Description

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

- Hammerhead Stock ID process was conducted prior to the start of the SEDAR 77 Data process through a series of Stock ID webinars.
- The Data process was conducted through a series of webinars and an on-line workshop.
- The Assessment Process was conducted through a series of webinars.
- The Review Workshop (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 Great Hammerhead, the Life History WG determined it was not possible to conclude whether regional differences in life history exist. The Genetics WG found no significant genetic differentiation between the Gulf of Mexico and U.S. Atlantic, and the Spatial Distribution/Movement WG concluded Great Hammerhead comprise a single biological stock based on movements of individuals between regions.
- The Stock ID Process panel recommended that one stock assessment be conducted for Great Hammerhead.

Data Workshop Final Report (April 2022)

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

Life History Information Summary and Consensus

2.2.1 Age and Growth Datasets and Decisions

Decision: Use sex-specific growth model parameters from SEDAR77-DW-11 and a maximum age of 42 years from Passerotti et al. (2010).

2.2.2 Reproduction Datasets and Decisions

Decision: Use sex-specific age and size at maturity ogives reported for great hammerheads in SEDAR77-DW18 and summarized in Table 3 and maturity schedules listed in Tables 7 and 8.

Decision: Use reproductive characteristics summarized in Table 3.

The DW Panel recommended life history inputs used to compute productivity (i.e. maximum population growth rate r_{max}), natural mortality at age, generation time, and the inflection point of the surplus production curve (B_{MSY}/K) for great hammerheads (SEDAR77-AW04).

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 Linf)	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.

Data Review - Catch Statistics

3.1.2 Commercial Datasets and Decisions

Commercial landings

U.S. commercial landings in weight (lb dw) were available for the period 1991-2020. These data were gathered from two different sources over the time series. Commercial landings for 1991-2013 come from the FINS database, which includes Atlantic Coastal Cooperative Statistics Program (ACCSP) and Gulf Fisheries Information Network (GulfFIN) landings, from the Atlantic and Gulf of Mexico regions, respectively. Landings for 2014-2020 come from the NOAA Fisheries Highly Migratory Species commercial landings (eDealer) database.

Commercial landings in numbers were calculated by dividing annual landings in weight (lb dw) by average weights (lb dw) obtained from the Southeast Gillnet Observer Program (GNOP) and the Reef Fish and Shark Bottom Longline Observer Programs (collectively referred to as BLLOP henceforth) as appropriate. All weights from the GNOP and BLLOP were predicted from fork length measurements taken by observers in gillnet and longline fisheries, respectively, using weight-length regressions given in SEDAR77-DW03. Since there were no observations of sharks caught on hook and line/hand line fisheries, average weights for hook and line/hand line gears were assumed equal to those from the bottom longline fishery. Since the native form of commercial catches is weight (lb dw, with lb dw = lb whole weight/1.39) it is more appropriate to use catch in weight in models where catches can be entered either in numbers or in weight (e.g., Stock Synthesis).

Commercial landings* (reconstruct the commercial landings series from 1991 back to 1981*)

Although recreational catch statistics are available since 1981, commercial landings by species only start in 1991. Based on previous input from the commercial shark fishing industry provided for SEDAR 65, there was very little commercial shark fishing effort in the early 1980s so it was proposed that to reconstruct the commercial landings series back to 1981, a linear decrease from the average of the first three years of data (1991-1993) be assumed from 1990 back to 1981. This back-calculation methodology should also be applied to the discard series available.

Decision: Assume a linear increase of landings from 0 in 1981 to 90% of the mean of 1991-1993 in 1990 to represent growing market for shark products. Apply this increase to the three fleets considered for each stock (longlines, gillnets, and hook and line/unknown gear)

Commercial bottom longline and gillnet dead and live discards

Estimates of dead and live discards were generated for 1993-2019 for longlines and 1998-2019 for gillnets for the southeast region, and 1995-2019 for gillnets in the northeast region. *For consistency with the landings, which started in 1981, it was also proposed that the longline and gillnet dead and live discards be back-calculated to 1981*.

The Group discussed that the ratio method used to estimate discards in the three working papers was a reasonable approach, but that the estimated standard deviations (or CVs) obtained from bootstrapping were extremely high in working papers SEDAR77-DW20 and SEDAR77-DW21. It was decided to form a small bycatch working group to use an alternative discard estimation method based on the delta-lognormal approach (Pennington, 1983) using the same data sets with the expectation that this alternative method can provide reasonable estimated standard deviations (or CVs).

The discard estimates from the delta-lognormal method were presented in working papers SEDAR77-DW37 and SEDAR77-DW38 after the data workshop for the bottom longline fishery and the gillnet fishery for the southeast region, respectively. *SEDAR77-DW20 and SEDAR77-DW21 were replaced by SEDAR77-DW37 and SEDAR77-DW38 after the data workshop for the bottom longline fishery and the gillnet fishery for the southeast region, respectively.*

Commercial post-release live discard mortality

Decision: Use a PRLDM rate of 81.41% for great hammerheads released alive from commercial bottom longline gear.

Decision: Use PRLDM rates obtained for hammerheads captured with bottom longline gear as the best available estimates of PRLDM for hammerheads captured in commercial gillnet gear.

Pelagic longline dead discards and live post-release mortality

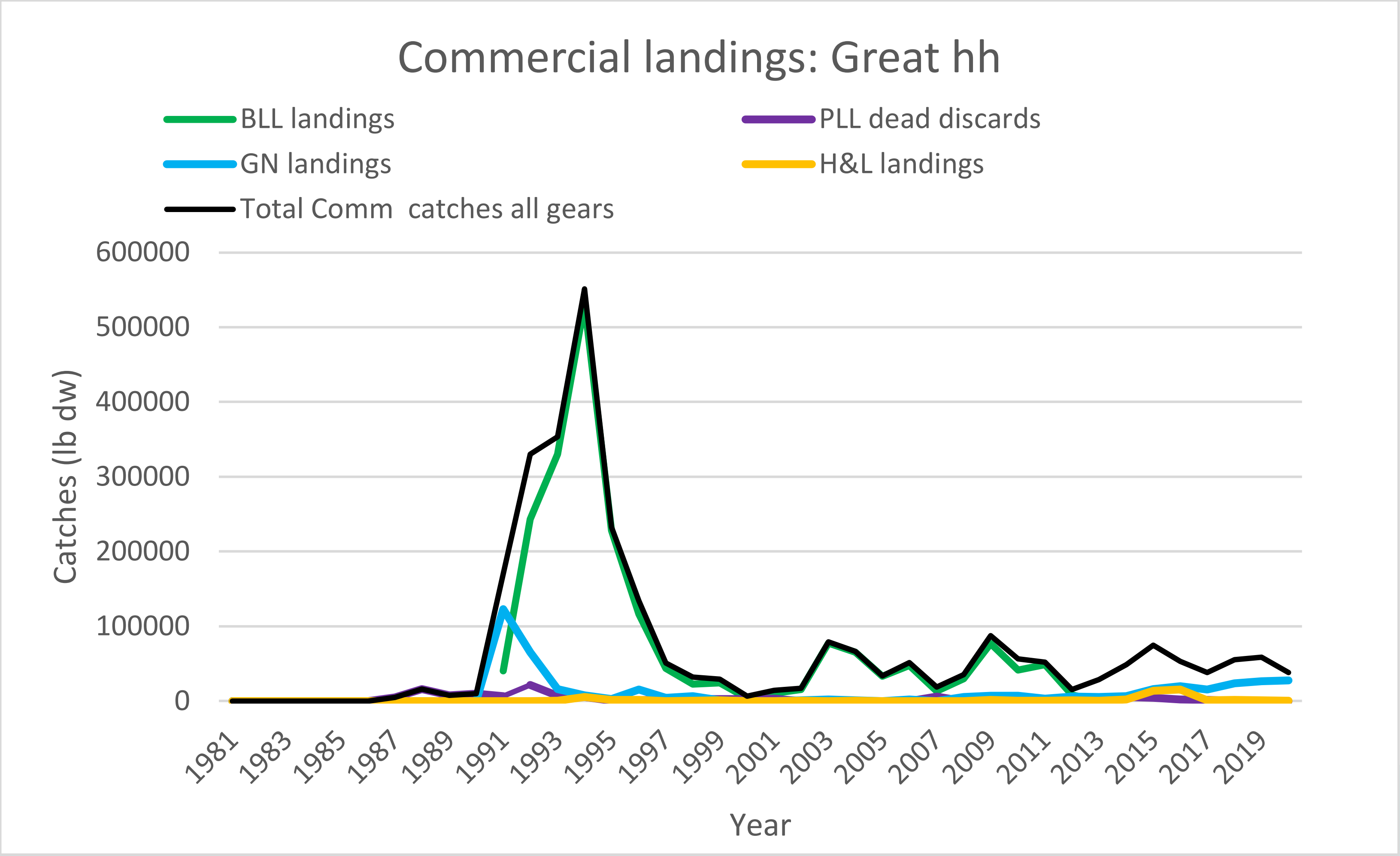
Decision: There are no uncertainty estimates associated with published ICCAT pelagic longline dead discards and no live discard estimates. CVs are calculated by area/quarter but not overall, and are not included in the Task 1 data reported to ICCAT. The DW panel recommended using ICCAT pelagic longline dead discards in the base run.

Decision: Assume a linear increase in discards from 0 in 1981 to 83.4% of the mean of the entire time series in the year preceding the first year of bycatch estimates (1987) to parallel the approach used for back-calculating landings and other commercial discard series.

3.1.2 Commercial Datasets and Decisions

Commercial landings

Total commercial landings of great hammerheads peaked at over 550,000 lb dw in 1994, but rapidly decreased thereafter remaining under 90,000 lb dw since 1997 (**Figure 10.** Commercial landings (lb dw) of great hammerheads by gear, including dead discards from the pelagic longline fishery. BLL=bottom longline; PLL=pelagic longline; H&L=hook and line.).



3.1.3 Recreational Catch Datasets and Decisions

Recreational catches

Recreational catches of hammerhead sharks reported herein are the sum of estimates from the Marine Recreational Information Program (MRIP), the Southeast Region Headboat Survey (SRHS) operated by the SEFSC Beaufort Laboratory, and the Texas Parks and Wildlife Department (TPWD) Survey.

Annual recreational catch estimates of hammerhead sharks were computed as the sum of type A (number of fish killed or kept seen by the interviewer), type B1 (number of fish killed or kept reported to the interviewer by the angler), and type B2 (number of fish released alive reported by the fisher) estimated to have died.

Since the native form of recreational catches is numbers, it is more appropriate to use catch in numbers in models where catches can be entered either in numbers or in weight (e.g., Stock Synthesis).

Recreational catches

Decision: 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***

Decision: Smooth the AB1 and B2 recreational catch series with a three-year geometric moving average

Decision: Smooth individual years with noticeable peaks by setting them equal to the geometric mean of the 3 preceding and ensuing years (as available)

Recreational post-release live discard mortality

Decision: Use the PRLDM obtained from meta-analysis for pelagic sharks (26.8%, Musyl and Gilman 2019) as the best estimate of the PRLDM rate for hammerheads captured and released alive with recreational gear.

3.1.3 Recreational Catch Datasets and Decisions

Great hammerhead

The vast majority of great hammerhead catches were from MRIP. Catches showed a decreasing trend punctuated by some peaks, notably in 1982 for the AB1 series. Upon further examination, it was found that of the original AB1 estimate of 105,497 sharks for 1982, 87,791 sharks corresponded to an A estimate of 19,282 sharks (LA, W3, Shore, Ocean), an A estimate of 10,865 sharks (east coast of FL, W4, Shore, Ocean), a B1 estimate of 42,876 sharks (East coast of FL, W2, Shore, Ocean), and a B1 estimate of 14,768 sharks (east coast of FL, W4, Shore, Ocean). The 19,282 estimate was based on 1 angler reporting 1 shark, the 10,865 estimate was based on 1 angler reporting 1 shark, the 42,876 estimate was based on 1 angler reporting 1 shark (which was an unusually large effort extrapolation), and the 14,768 estimate on 1 angler reporting 1 shark. Based on this the recommendation was to remove the 42,876 B1 estimate and to further smooth the 1982 estimate. **Figure 39** shows the recreational catches before (top) and after (bottom) smoothing the individual points and the general smoothing.

Decision: Remove the Florida east coast B1 estimate of 42,876 sharks from the original AB1 estimate of 105,497 for the 1982 AB1 estimate in numbers and smooth that 1982 AB1 estimate (in numbers and weight) by setting it equal to the geometric mean of the 3 ensuing years (1981 value was 0)

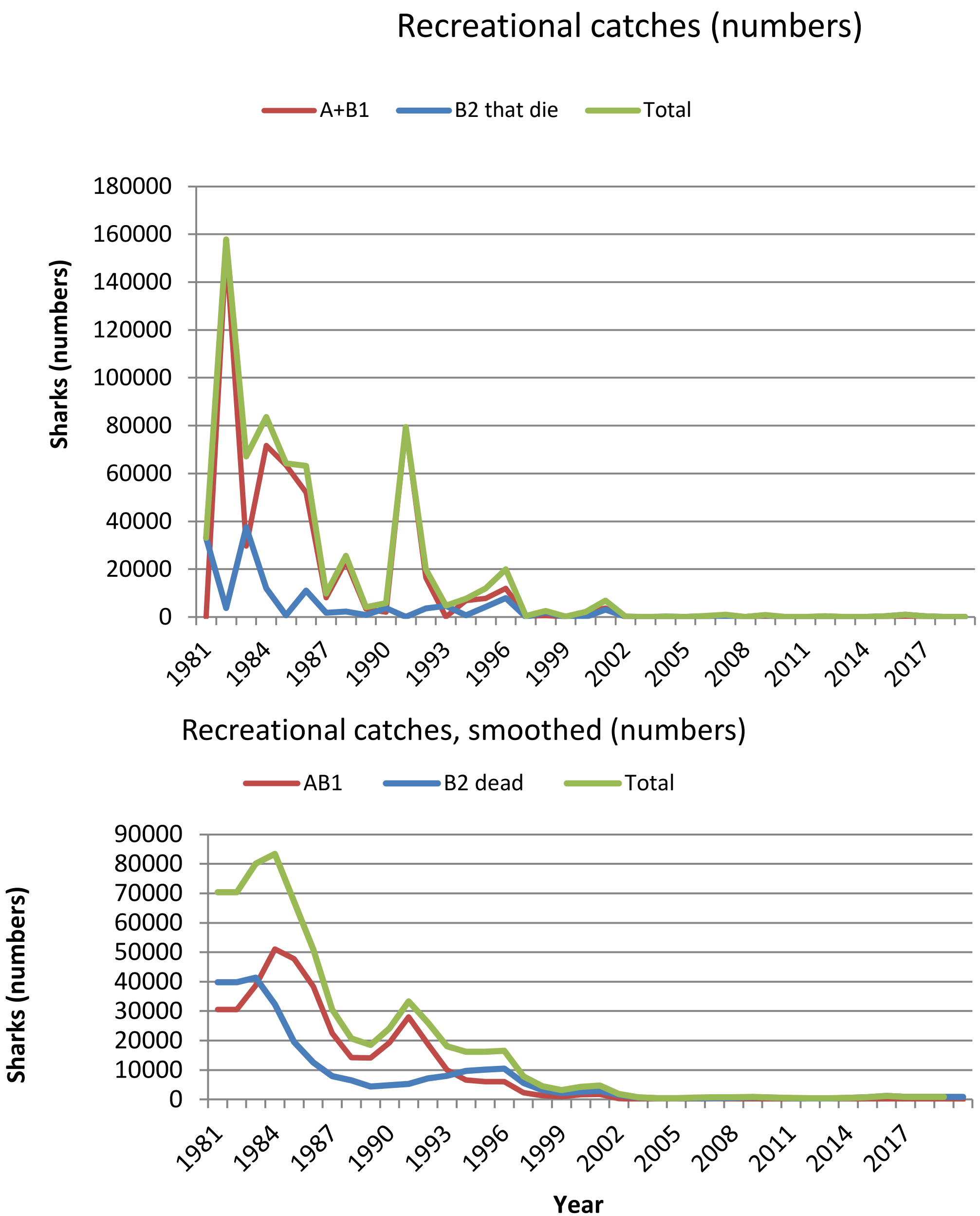
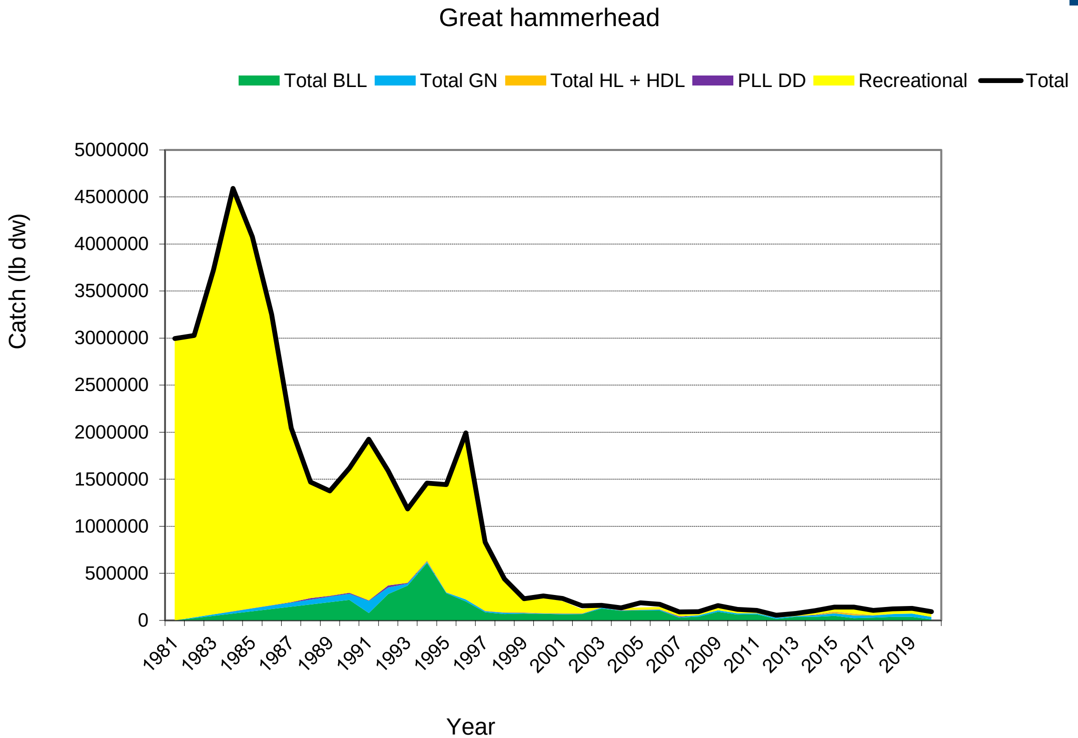


Figure 39. Recreational catches in numbers (AB1 and B2s that die assuming an initial arbitrary post-release mortality rate of 10%) of great hammerheads before smoothing (top) and after adjusting and smoothing the 1982 AB1 estimate, smoothing the entire series using a three-year moving geometric average, and using the recommended post-release mortality rate of 26.81% (bottom).



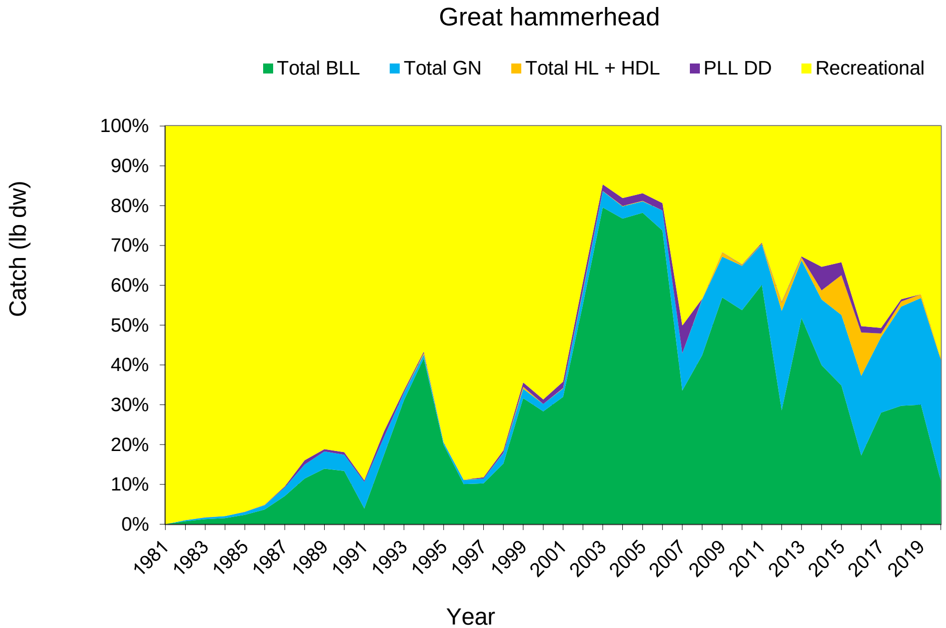


Figure 51. Commercial catches and smoothed recreational catches of great hammerheads in weight (lb dw), 1981-2020. Top panel: stacked catches by year; bottom panel: proportions by year.

Indices of Population Abundance

4.1 Overview

During the initial webinars for SEDAR77, data sources were preliminary examined in terms of their usefulness in developing an index of abundance. Thirty-one (31) data sources were initially considered for use in developing indices of abundance (Table 1). No data sources were considered for Carolina hammerhead due to the difficulty in differentiating the species in the field without genetic analysis. Indices were constructed using both scientific survey and fishery-dependent data.

- 10 out of 31 data sources were related for great HH
- 6 indices were recommended

4.8 Tables

Table 1. Data sources initially examined as potential indices of abundance for hammerhead sharks. Area(s)=the area the data source covered following recommendations from the stock identification process for all hammerheads.

Data source	Area(s)	Hammerhead Species Considered	Further develop as an index	Factors for not developing as an index
Shark bottom longline observer program and shark research fishery	All	Scalloped/Great	Yes	
Southeast gillnet observer program	All	Scalloped	Yes	
	Gulf of Mexico	Scalloped	No	Low catches
	Atlantic	Scalloped	Yes	
	All	Great	No	Low catches
Pelagic longline observer program	All	Scalloped	Yes	
	All	Smooth	No	Low proportion positive, No catches in many years
SEFSC Bottom Longline Survey	All	Great/Scalloped	Yes	
Texas Parks and Wildlife Gillnet	All/Gulf of Mexico	Scalloped	Yes	
Everglades National Park Creel Census	Gulf of Mexico	Scalloped	No	Low catches, species identification
Mote Marine Laboratory Longline	Gulf of Mexico	Great/Scalloped	No	Low catches
Mote Drumline Survey	Gulf of Mexico	Great	No	Low catches

Table 1 Continued: Data sources initially examined as potential indices of abundance for hammerhead sharks. Area(s)=the area the data source covered following recommendations from the stock identification process for all hammerheads.

Dauphin Island Sea Laboratory Longline Survey	All/Gulf of Mexico	Scalloped	Yes	
GULFSPAN Gillnet Series	All/Gulf of Mexico			
NMFS-Panama City		Scalloped	Yes	
Mote Marine Laboratory		Great/Scalloped	No	Low catches; Limited temporally
Havenworth Consulting		Scalloped	No	Low catches; Limited temporally
Florida State University		Scalloped	No	Low catches
New College		Scalloped	No	Low catches; Limited temporally
Gulf Coast Research Laboratory		Scalloped	Yes	
Virginia Institute of Marine Science Longline	Atlantic	Scalloped	No	Low catches
SEAMAP Coastal Bottom Longline	Gulf of Mexico	Scalloped	No	Low catches/Survey(s) already present in the area
	All	Great	Yes	
SEAMAP Trawl	Atlantic	Scalloped	No	Low catches
Florida State University Longline Sawfish	All/Gulf of Mexico	Great/Scalloped	Yes	
Mark Sampson Logbook Recreational Series	Atlantic	Scalloped/Smooth	No	Database not complete
Rosenstiel School of Marine and Atmospheric Science Drumline	All	Great	Yes	

Table 1 Continued: Data sources initially examined as potential indices of abundance for hammerhead sharks. Area(s)=the area the data source covered following recommendations from the stock identification process for all hammerheads.

Electronic Monitoring of Gulf of Mexico reeffish fishery	Gulf of Mexico	Scalloped	No	Data was preliminary
NEFSC-Bottom Longline Survey	All/Atlantic	Scalloped	Yes	
		Great	No	Low catches
South Carolina SEAMAP longline	Atlantic	Scalloped	No	Low proportion positive, No catches in many years
COASTSPAN Series				
Bottom Longline	All/Atlantic	Scalloped	Yes	
South Carolina Large Gillnet	All/Atlantic	Scalloped	Yes	
South Carolina Small Gillnet	All/Atlantic	Scalloped	Yes	
South Carolina Red Drum Survey	Atlantic	Scalloped	No	Low proportion positive, No catches in many years
University North Carolina Longline	All/Atlantic	Scalloped	Yes	
GA Seamap Longline	Atlantic	Scalloped	No	Low proportion positive, No catches in many years
NEFSC Observer Gillnet	Atlantic	Smooth	No	Low catches

Recommended Indices

4.3.1 Fishery-Dependent Indices

Shark Bottom Longline Observer Program (SEDAR77-DW12)

Decision: The Group determined that because this series is stock wide and used in previous stock assessments for sharks, the series should be retained for use in the stock assessment. The recommendation is for the stock wide great hammerhead stock assessment base run (Table 10), including both the non-research (≤ year 2007) and the research (≥ year 2008) time series.

Recommended Indices

4.3.2 Scientific Survey Indices

Florida State University Bottom Longline Survey (SEDAR77-DW14)

Decision: The initial analysis of these data resulted in high CVs and a low proportion positive. The Group decided that a post-analysis be conducted on a subset of data based on habitat (i.e. samples were only included if they represented habitat where great hammerheads would be expected to be found) to reduce true zeros from areas where hammerheads are not available. The revised indices were recommended for use in the stock wide great hammerhead stock assessment base run (Table 10).

Recommended Indices

4.3.2 Scientific Survey Indices

Rosenstiel School of Marine and Atmospheric Science Drumline Survey (SEDAR65-DW15)

Decision: Similar to the Florida State University longline series, the initial analysis of these data resulted in high CVs and a low proportion positive. The Group decided that a post-analysis be conducted on subset of data based on habitat (i.e. samples were only included if they represented habitat where great hammerheads would be expected to be found) to reduce true zeros from areas where hammerheads are not available. The revised indices were recommended use in the for stock wide great hammerhead stock assessment base run (Table 10).

Recommended Indices

4.3.2 Scientific Survey Indices

NOAA Fisheries-Southeast Fisheries Science Center- Bottom Longline Survey (SEDAR77-DW24)

Decision: The Group determined that because this series is stock wide and used in previous stock assessments for sharks, the series should be retained for use in the stock assessment. The recommendation is for use in the stock wide great hammerhead stock assessment base run (Table 10).

Recommended Indices

4.3.2 Scientific Survey Indices

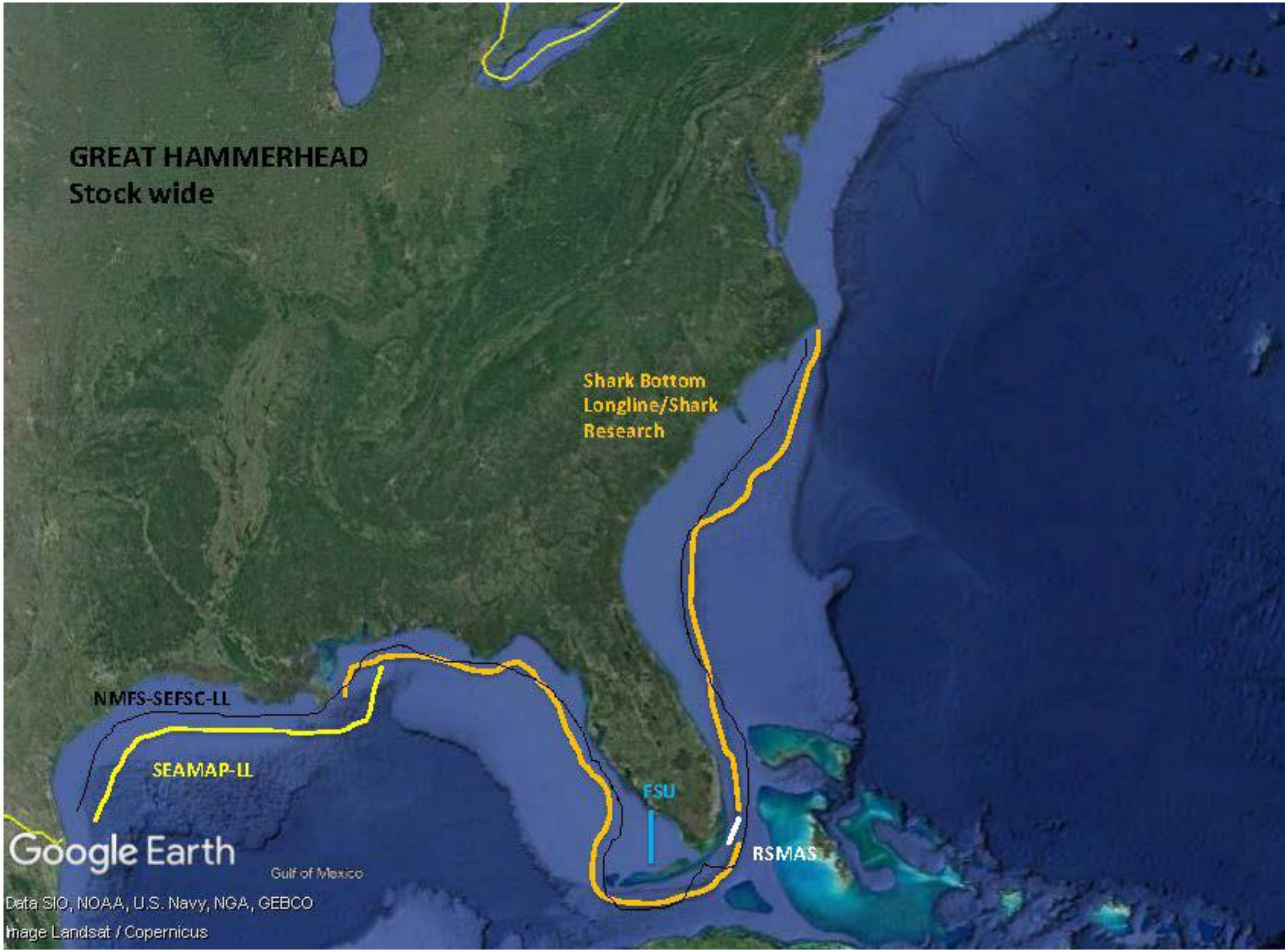
SEAMAP Bottom Longline Survey (SEDAR77-DW25)

Decision: The Group recommended that this series be retained for use in the assessment. It was noted that the time series represents sampling with the spatial distribution of great hammerhead where there are few indices. The recommendation is for use in the stock wide great hammerhead stock assessment base run (Table 10).

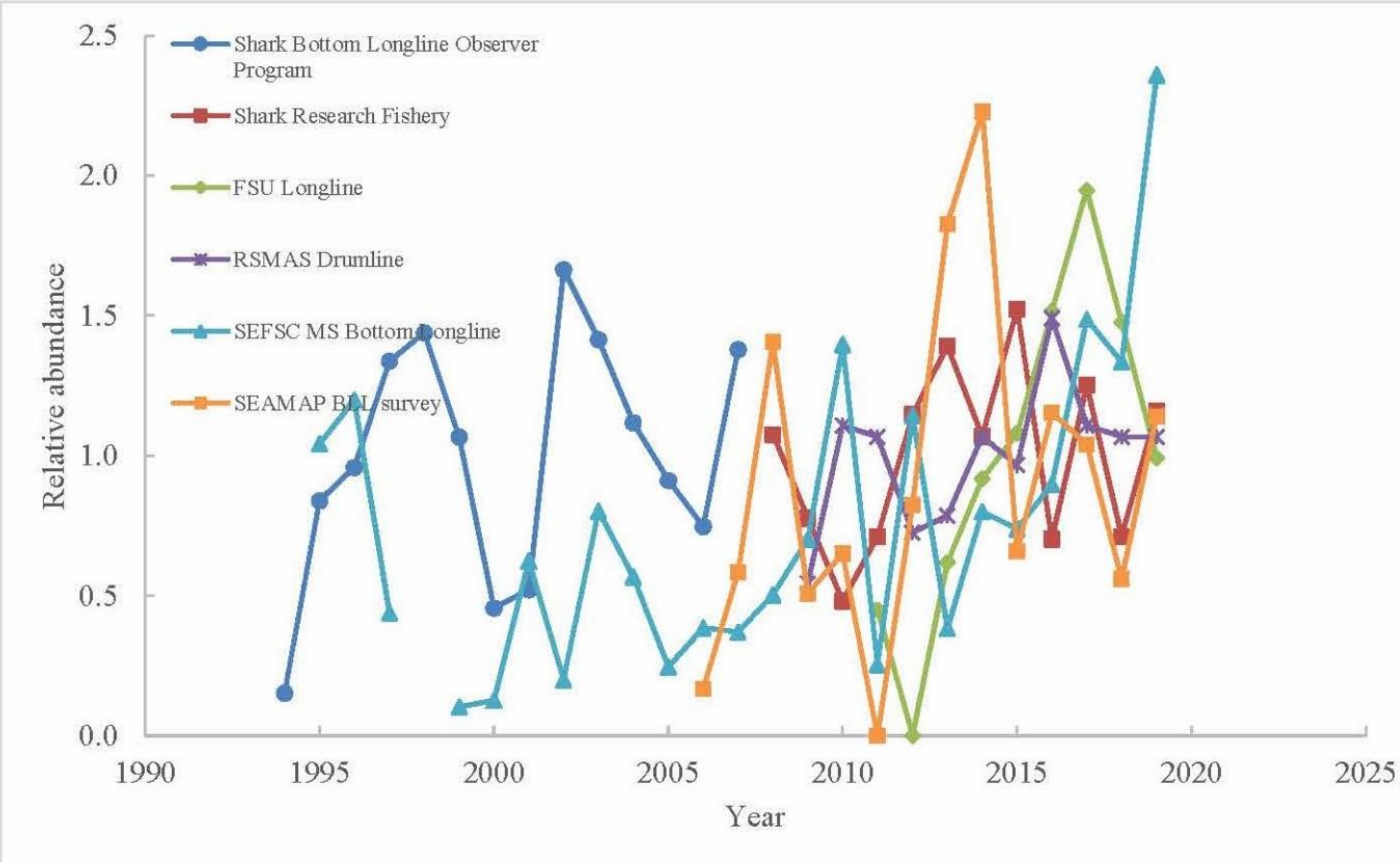
Recommended Indices

4.3.3 Summary-Great Hammerhead

The geographic coverage of the abundance indices for great hammerhead shark are in Figure 12 and plots of the relative indices (index/mean index of the time series) by year are in Figures 13. The Indices Working Group recommends compiling indices for use in stock assessment consistent with great hammerhead Stock ID Workshop recommendations:



Approximate linear coverage of the stock wide abundance indices for the great hammerhead shark. Colors of the labeled abundance series correspond to the linear coverage



Indices of abundance used for the base run. All indices are statistically standardized and scaled (divided by the average of all annual values for that specific time series for plotting purposes).

Length Composition Section

Table 1. Summary of available length composition data for scalloped (*S. lewini*), great (*S. mokarran*), smooth (*S. zygaena*), and Carolina (*S. gilberti*) hammerheads from 1973-2019. Data were broken into fishery-independent and fishery-dependent data sources and 'estimated' refers to fork lengths (FL cm) that were estimated and thus not exact measurements. Age 0 refers to scalloped hammerheads (<61 cm FL) and Age 1+ scalloped hammerheads refers to (>61 cm FL). If not noted, ages are combined for species. Abbreviations are as follows: SHH = scalloped hammerheads, GHH = great hammerheads, SMH = smooth hammerheads, and CHH = Carolina hammerheads.

Data Sources	Age 0 SHH	Age 1+ SHH	All GHH	All SMH	All CHH	Total
Fishery-Independent	4234	2216	981	30	64	7525
Estimated Fishery-Independent	0	1440	57	2	-	1499
Total	4234	3656	1038	32	64	9024
Fishery-Dependent	1191	5172	1820	269	26	8478
Estimated Fishery-Dependent	116	3814	453	223	-	4606
Total	1307	8986	2273	492	26	13084
Grand Total	5541	12642	3311	524	90	**22108**

The length composition data are limited for great hammerhead (n=3311 from 1973-2019 and n=2714 from 1981-2019) and were not recommended for use in the age-structured, length-based stock assessment models (e.g. with SS).

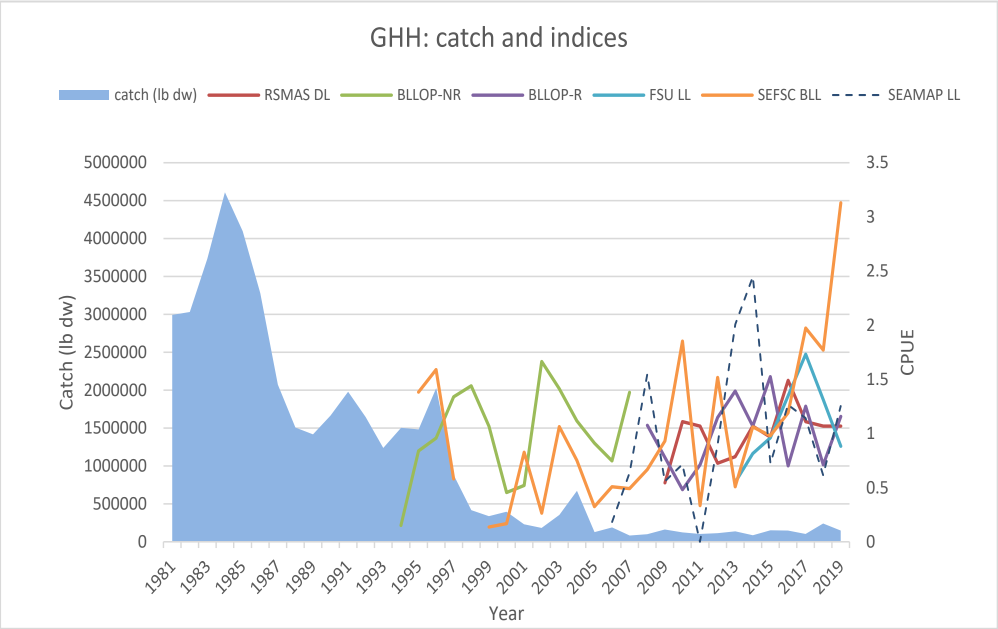
Assessment Report: Great Hammerhead Shark (June 2023)

- 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.

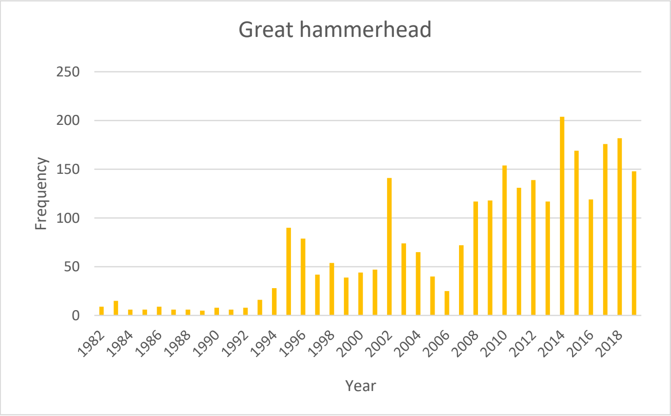
Working Papers			
SEDAR77-AW01	Exploratory analysis of U.S Atlantic and Gulf of Mexico scalloped hammerhead recruitment indices	Henning Winker	5/27/2022
SEDAR77-AW02	Hierarchical analyses of U.S. Atlantic and Gulf of Mexico scalloped hammerhead recruitment indices	Camilla T. McCandless and John K. Carlson	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

Data availability
Great hammerhead



- Catches
- 6 indices
- Life history
- Length compositions (n=2,714 from 1981-2019)



Proposed assessment models: JABBA

Fisheries Research 204 (2018) 275–288

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JABBA: Just Another Bayesian Biomass Assessment

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[d] Joint Institute for Marine and Atmospheric Research, University of Hawaii, 1845 Wasp Boulevard, Building 176, Honolulu, HI, 96818, United States

Proposed assessment models: JABBA

- Bayesian state-space production model
- Used in several stock assessments of tuna, billfishes, and sharks
- Main features include:
  - An integrated state-space tool for averaging and automatically fitting multiple CPUE time series
  - Data-weighting through estimation of additional observation variance for individual or grouped CPUE
  - Selection of Fox, Schaefer, or Pella-Tomlinson production functions
  - Options to fix or estimate process and observation variance components
  - Can include uncertainty in catches now too
  - Model diagnostic tools
  - Future projections for alternative catch regimes
  - A suite of inbuilt graphics illustrating model fit diagnostics and stock status results

Proposed assessment models: SPiCT

FISH and FISHERIES

FISH and FISHERIES, 2017, **18**, 226–243

A stochastic surplus production model in continuous time

Martin W Pedersen & Casper W Berg

National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund Slot, Jægersborg Allé 1, 2920 Copenhagen, Denmark

Proposed assessment models: SPiCT

- Bayesian state-space production model: Surplus Production in Continuous Time
- Has been extensively adopted by ICES to assess stocks and provide short-term catch advice
- Main features include:
  - Process error in F (so considers uncertainty in catches) in addition to Biomass
  - Selection/estimation of shape parameter of the production curve (e.g. Fox, Schaefer, or Pella-Tomlinson production functions)
  - Can scale uncertainty of individual (catch and CPUE) data points
  - Can analyze sub-annual data
  - All priors are lognormal
  - Extensive model diagnostic tools and stock status results
  - Can do (short-term) forecasting and management scenarios
  - Can set estimation phases



The Panel recommended assessment model

This stock assessment is implemented with the Bayesian state-space surplus production model framework JABBA (Winker *et al.*, 2018) version v.2.2.8.

2. DATA REVIEW AND UPDATE

2.1 CATCHES

No changes were introduced to the catch streams presented and approved at the DW. The vast majority of great hammerhead catches were recreational catches (**Table 2.5.1**; **Figure 2.6.1**).

Table 2.5.1. Stock wide catches of great hammerheads in numbers used for the base run. Total commercial catch is the maximum of the sum of commercial catches by gear and total commercial catches not disaggregated by gear; total recreational catch is the sum of total recreational AB1 catch and LPRM; total catch is the sum of total recreational and total commercial catch. Abbreviations for recreational catches are as follows: AB1=fish killed or kept either seen by the interviewer or reported to the interviewer by the angler; LPRM=live post-release mortality.

Year	Total Bottom longline catch	Total Gillnet catch	Total hook and line + hand line catch	Pelagic longline dead discards	Total commercial catch	Total AB1 recreational catch	Total recreational LPRM	Total recreational catch	Total catch
1981	0	0	0	0	0	30549	39786	70335	70335
1982	133	136	0	5	274	30549	39786	70335	70609
1983	267	271	0	10	548	38694	41373	80067	80615
1984	400	407	0	15	822	51047	32318	83365	84187
1985	534	543	0	20	1096	47728	19483	67211	68307
1986	667	678	0	25	1370	38331	12598	50929	52300
1987	801	814	0	38	1652	22539	7978	30517	32169
1988	934	999	0	122	2055	14205	6536	20740	22796
1989	1067	1085	1	57	2210	14079	4412	18491	20701
1990	1201	1221	1	73	2495	19278	4844	24121	26616
1991	366	1882	0	49	2298	28009	5285	33294	35591
1992	1562	1330	1	254	3145	18896	7211	26107	29252
1993	2105	857	1	41	3005	9996	8054	18050	21055
1994	3110	779	29	24	3942	6592	9652	16243	20185
1995	2164	730	11	3	2908	6097	10140	16237	19145
1996	1422	852	12	11	2297	6086	10473	16559	18857
1997	515	744	0	24	1283	2299	5563	7862	9145
1998	378	63	1	16	457	1273	3204	4476	4934
1999	361	1259	8	17	1644	998	2186	3184	4829
2000	200	1599	0	21	1820	1650	2598	4247	6067
2001	242	206	1	31	479	1765	2950	4715	5194
2002	345	686	2	20	1053	377	1534	1910	2964
2003	769	1521	1	38	2328	97	705	803	3131
2004	642	5327	1	30	6000	33	408	442	6442
2005	132	178	0	24	335	87	389	477	812
2006	301	786	0	17	1104	188	419	606	1710
2007	94	146	0	18	258	358	449	808	1066
2008	191	286	1	0	478	182	585	767	1245
2009	476	296	10	1	783	111	741	852	1635
2010	302	282	1	1	587	58	622	679	1266
2011	326	170	1	3	500	60	464	524	1024
2012	53	778	7	1	839	36	373	410	1249
2013	271	561	3	2	837	26	354	381	1218
2014	176	132	10	65	383	19	530	549	932
2015	237	449	77	39	802	19	789	808	1610
2016	108	368	79	16	571	7	1171	1178	1749
2017	194	170	6	16	387	2	893	895	1282
2018	385	1214	10	5	1614	2	893	895	2509
2019	256	501	7	0	764	2	893	895	1659

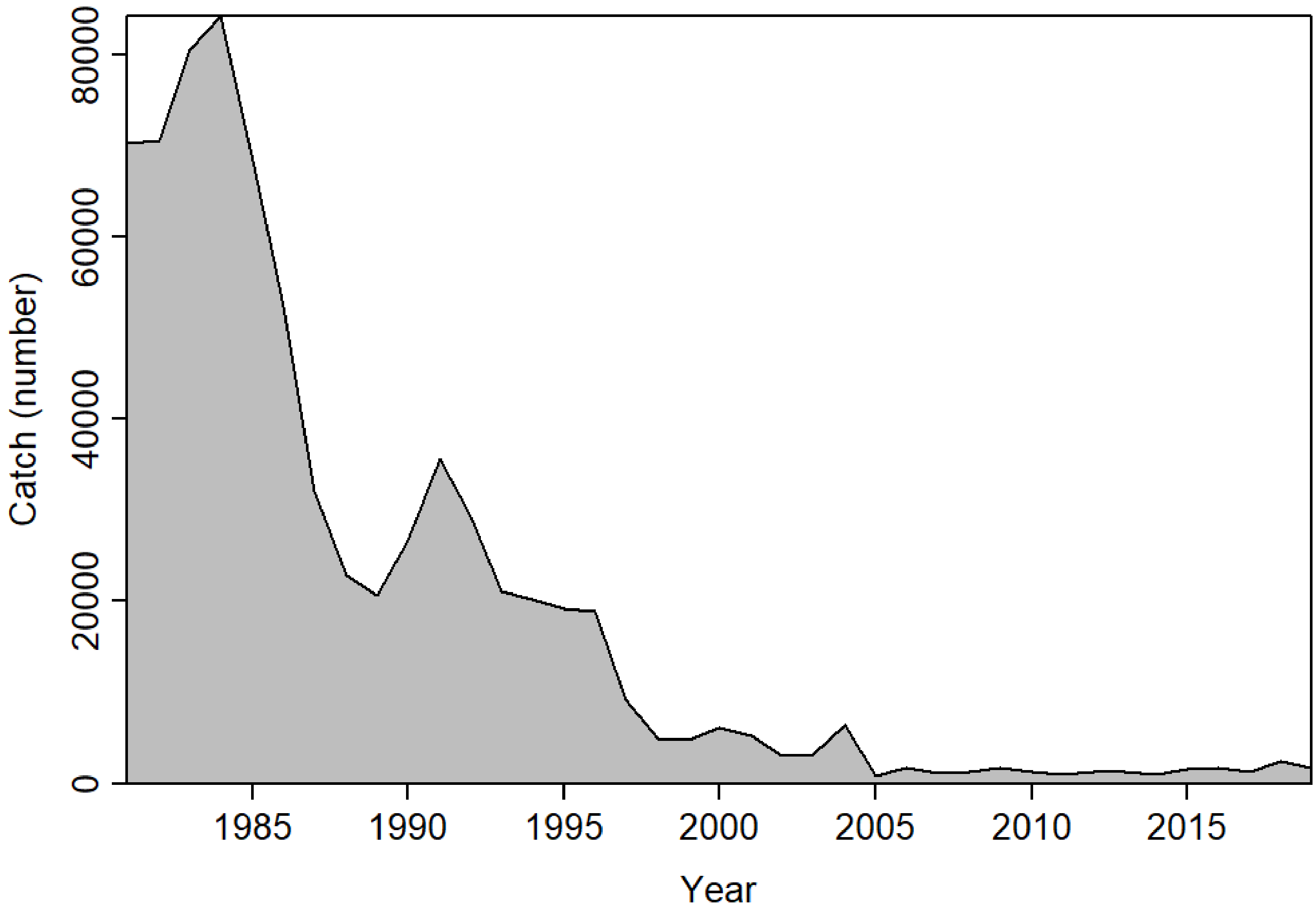
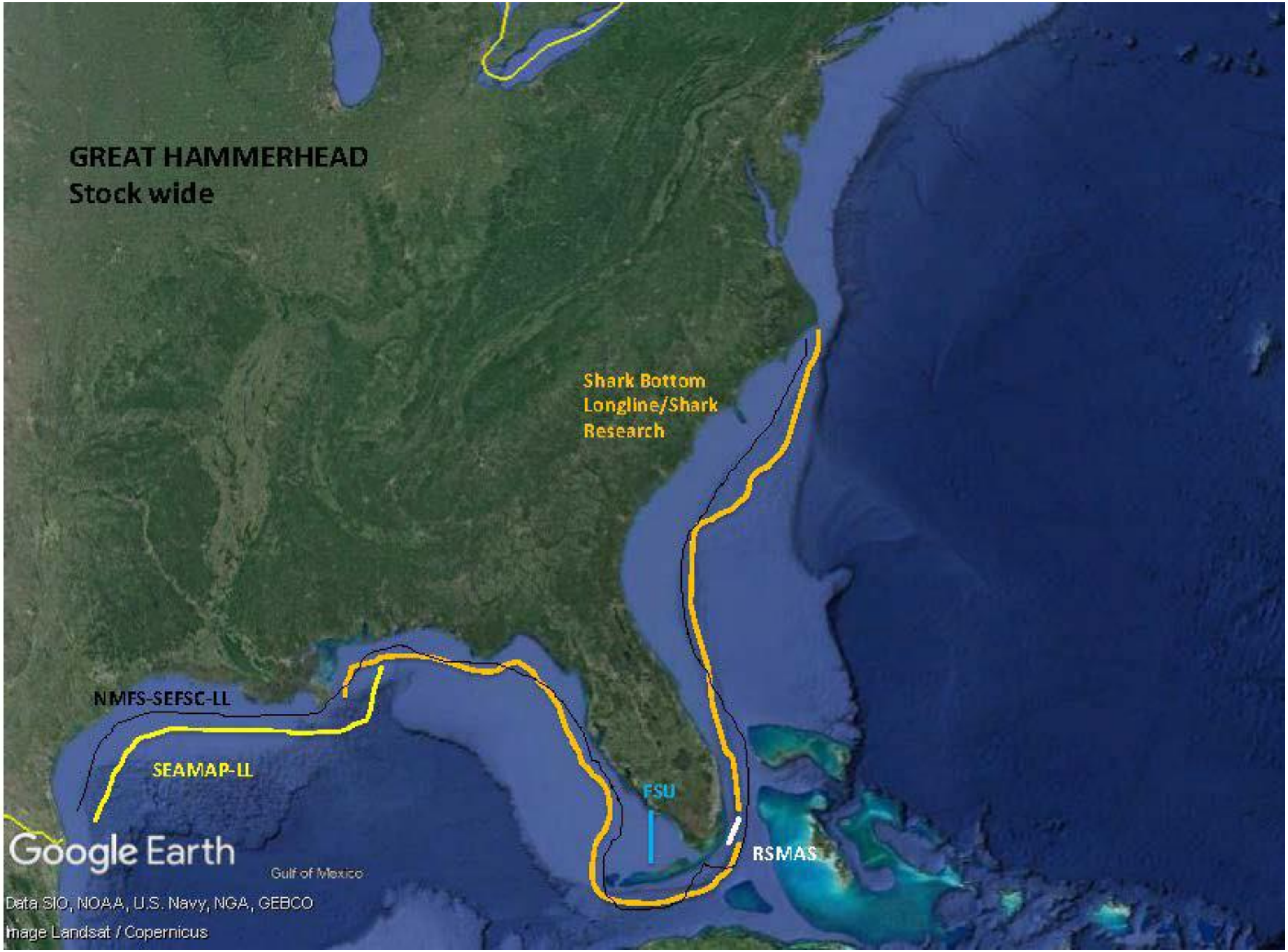


Figure 2.6.1. Stock wide total catch of great hammerheads in numbers used for the base run. Total catch is the sum of total recreational and total commercial catch.

2. DATA REVIEW AND UPDATE

2.2 INDICES OF ABUNDANCE

The six standardized indices of abundance used in the assessment are presented in **Table 2.5.2** and **Figure 2.6.2**. These indices cover Atlantic and Gulf of Mexico GOM. All these indices were standardized by the respective authors through general linear model (GLM) techniques (see SEDAR 77 DW Report). The coefficients of variation (*CV*) associated with the standardized indices are also listed in **Table 2.5.2**.



Approximate linear coverage of the stock wide abundance indices for the great hammerhead shark. Colors of the labeled abundance series correspond to the linear coverage

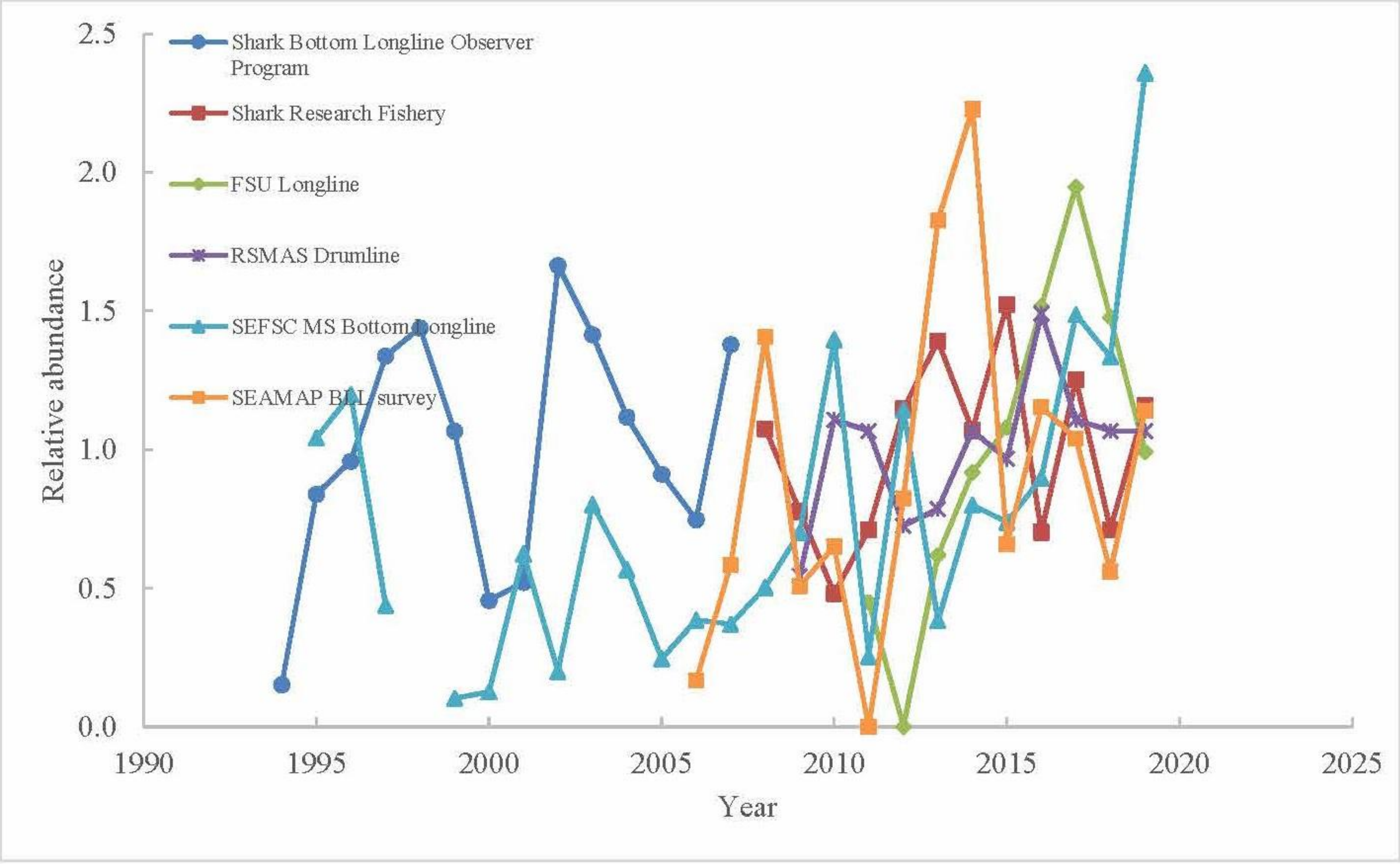


Figure 2.6.2. Indices of abundance used for the base run. All indices are statistically standardized and scaled (divided by the average of all annual values for that specific time series for plotting purposes).

Table 2.5.2. Stock wide indices of abundance for great hammerheads used for the base run including index name and SEDAR document number. *CV* is the coefficient of variation for the annual index value. Missing values in a given year correspond to zero catches (index value of 0 and no *CV*), where no sampling occurred (ns), or when the model did not converge (nc).

	Shark Bottom Longline		Shark Research		FSU Longline		RSMAS Drumline		SEFSC MS Bottom Longline		SEAMAP BLL survey	
	SEDAR77-DW12		SEDAR77-DW12		SEDAR77-DW14		SEDAR77-DW15		SEDAR77-DW24		SEDAR77-DW25	
	sharks per 10000 hooks		sharks per 10000 hooks		sharks per 100 hook hour		number of sharks per 10 drumlines per hour		number sharks per hook-hour		number sharks per hook-hour	
year	index	CV	index	CV	index	CV	index	CV	index	CV	index	CV
1994	1.071	0.478										
1995	5.908	0.206							0.016	0.518		
1996	6.749	0.229							0.018	0.556		
1997	9.424	0.303							0.007	0.497		
1998	10.140	0.246							ns			
1999	7.511	0.270							0.002	1.081		
2000	3.207	0.473							0.002	0.784		
2001	3.674	0.371							0.009	0.482		
2002	11.726	0.212							0.003	0.648		
2003	9.966	0.207							0.012	0.454		
2004	7.873	0.226							0.009	0.486		
2005	6.425	0.293							0.004	1.074		
2006	5.261	0.300							0.006	0.650	0.013	1.062
2007	9.718	0.272							0.006	0.782	0.045	0.525
2008			40.370	0.226					0.008	0.655	0.109	0.344
2009			29.215	0.244			0.027	0.707	0.011	0.519	0.039	0.728
2010			18.072	0.221			0.055	0.297	0.021	0.477	0.050	0.716
2011			26.748	0.190	0.001	0.291	0.053	0.265	0.004	0.648	0.000	.
2012			43.110	0.308	ns		0.036	0.317	0.017	0.479	0.064	0.532
2013			52.307	0.199	0.001	0.734	0.039	0.268	0.006	0.651	0.142	0.456
2014			40.176	0.218	0.002	0.729	0.053	0.241	0.012	0.650	0.173	0.323
2015			57.252	0.174	0.002	0.598	0.048	0.255	0.011	0.489	0.051	0.421
2016			26.352	0.294	0.003	0.296	0.074	0.194	0.014	0.485	0.089	0.335
2017			47.025	0.193	0.004	0.293	0.055	0.180	0.023	0.414	0.081	0.451
2018			26.739	0.250	0.003	0.302	0.053	0.197	0.020	0.416	0.043	0.521
2019			43.489	0.220	0.002	0.519	0.053	0.184	0.036	0.372	0.088	0.449

2.3 LIFE HISTORY INPUTS

The life history inputs used to compute productivity (i.e. maximum population growth rate r_{max}), natural mortality at age, generation time, and the inflection point of the surplus production curve (B_{MSY}/K) for great hammerheads in **Table 2.5.3** are as reported in SEDAR77-AW04 (Cortés 2022).

For the computation of deterministic estimates of r_{max}, annual natural mortality at age was obtained from a method developed by Dureuil *et al.* (2021) based on Lorenzen (2000).

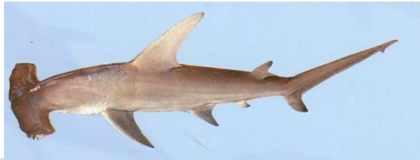
For the computation of stochastic estimates of r_{max}, annual survival at age (obtained from the instantaneous natural mortality rate at age as e^{-M}) was obtained through six alternative life history invariant estimators: Jensen's (1996) *K*-based and age at maturity estimators, a modified growth-based Pauly (1980) estimator (Then *et al*. 2015), a modified longevity-based Hoenig (1983) estimator (Then *et al*. 2015), Chen and Yuan's (2006) estimator, and the mass-based estimator of Peterson and Wroblewski (1984) (see **Appendix 1** of Cortés 2022 for details).

The mean estimate of r_{max} (0.144 yr^{-1}), obtained from fitting a normal distribution to the values of r_{max} obtained from the stochastic simulation of a Leslie matrix, was used to develop the prior for the base run (see **Section 3.1.4**). The median estimates of the average (age 1 to maximum age) natural mortality rate (M=0.156 yr^{-1}) from the six mortality estimators, generation time (14.5 years), and the inflection point of the surplus production curve (B_{MSY}/K=0.48) obtained in the Leslie matrix stochastic analyses were used to develop the prior of B_{MSY}/K for the base run (see **Section 3.1.4**), to calculate *MSST* to assess stock status (see **Section 3.1.7**), and to use in projections (generation time; see **Section 3.1.9**).

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 Linf)	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.



Population dynamics parameters of interest

r_{max} : intrinsic rate of increase (maximum population growth rate in ideal conditions after exploitation has ceased)

Generation time : multiple definitions. Will report here $\bar{A}$

(mean age of parents of offspring produced by a population in a stable age distribution)

Net reproductive rate (R_0) : average number of females produced by each female over her lifetime. Is also used to compute the maximum lifetime reproductive rate:

$$\hat{\alpha} = S_0 R_0$$

Steepness *:* another measure of productivity used in fisheries, ranges from 0.2 to 1, uses alpha hat in its computation: $h = \frac{\hat{\alpha}}{4 + \hat{\alpha}}$

Population dynamics parameters of interest

SPR_{MER} : analogous to steepness. Spawning Potential Ratio at Maximum Excess Recruitment (the closer to 100% the less exploitation permitted):

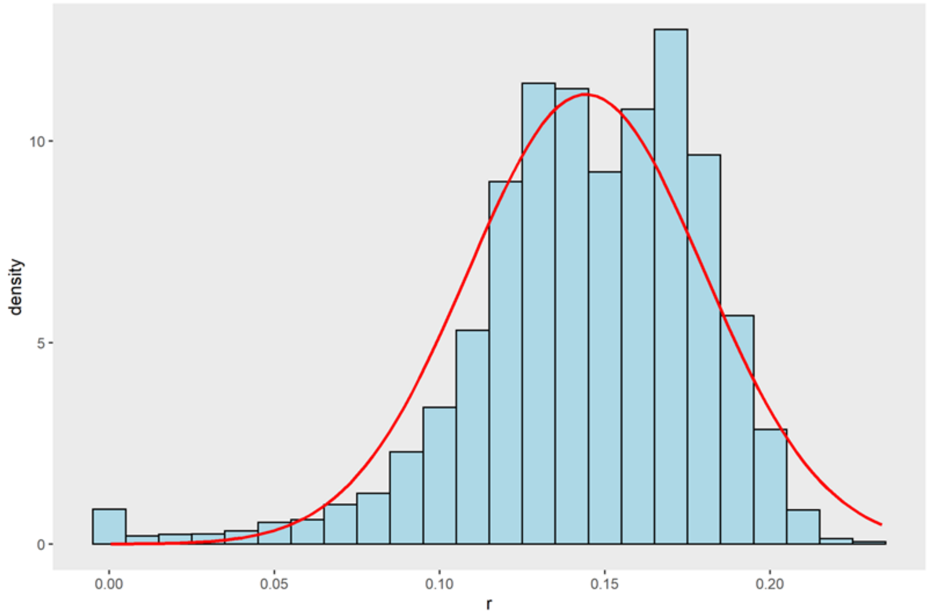
$$SPR_{MER} = \frac{1}{\sqrt{\hat{\alpha}}}$$

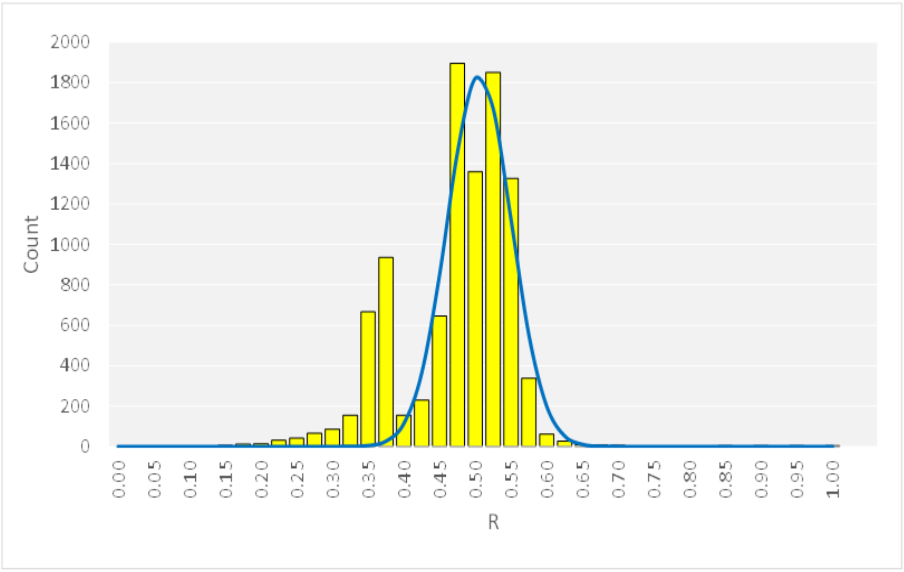
R : analogous to SPR_{MER}. It's the position of the inflection point of population growth curves/production curves (assumed to be 0.5 in Schaefer production model): the closer to 1, the less exploitation permitted

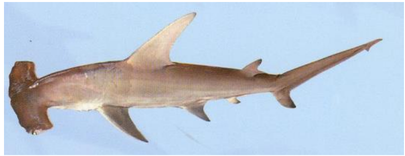
n : shape parameter of the production curve. Is obtained from *R* as:

$$R = n^{\left(-\frac{1}{n-1}\right)}$$

Distribution of simulated r_{max} (left) and R (right) values obtained from a Leslie matrix approach with fitted normal distribution for r_{max} and normal distribution for R for great hammerhead







STOCK ASSESSMENT MODEL AND RESULTS

3.1 JABBA ASSESMENT MODEL

3.1.1 Overview

This stock assessment is implemented with the Bayesian state-space surplus production model framework JABBA (Winker *et al.*, 2018) version v.2.2.8. JABBA has been widely applied in a number of recent ICCAT stock assessments, including South Atlantic blue shark (ICCAT, 2016), Mediterranean albacore (ICCAT, 2017c), South Atlantic swordfish (ICCAT, 2017a; Winker *et al.*, 2018), Atlantic shortfin mako shark stocks (south and north) (ICCAT, 2017d; Winker *et al.*, 2017, 2019a), Atlantic blue marlin (Mourato *et al.*, 2019), Atlantic bigeye tuna (Winker *et al.*, 2019b), Atlantic white marlin (Mourato *et al.*, 2020), Atlantic yellowfin tuna (Sant'Ana *et al.*, 2020), and Mediterranean swordfish (Winker *et al.* 2020; ICCAT, 2017b).

3.1 JABBA ASSESMENT MODEL

3.1.1 Overview

JABBA is formulated on the Bayesian state-space estimation framework proposed by Meyer and Millar (Meyer and Millar, 1999a). It estimates both process error variance and observation error variance. JABBA is an open-source modelling software and is available as an 'R package' that can be installed from github.com/jabbamodel/JABBA. JABBA uses R (R Foundation for Statistical Computing, Vienna, 2011) to set up the model and call up the software program JAGS (Just Another Gibbs Sampler, Plummer, (2003)) using the R package 'rjags' (Plummer, 2016). JABBA estimates Bayesian posterior distributions of model outputs by means of a Markov Chain Monte Carlo (MCMC) simulation.

JABBA presents a unifying, flexible framework for biomass dynamic modelling, runs quickly, and generates reproducible stock status estimates and diagnostic tools.

Why use state-space Bayesian surplus production model for great hammerhead?

- State-space Bayesian surplus production models remain an as a predominant assessment tool for large pelagic tuna, shark, and billfish assessments due to their low data requirements, <u>especially for size/age data-limited situations</u>
- State-space models simultaneously account for both process and observation errors
- Bayesian methods combine the *likelihood* with the *prior* distributions of each parameter to calculate a *posterior* distribution including both sources of information
- Demographic information allows us to develop an informative priors for r and B_{MSY}/K for hammerhead sharks

3.1 JABBA ASSESMENT MODEL

3.1.2 Data sources

The catch stream, indices of abundance and associated *CVs*, and biological inputs used to derive productivity in the application of JABBA are described in **Section 2**. Catch data (in numbers) were available from 1981 to 2019 (**Table 2.5.1**) and of the six CPUE series used in the base run, the earliest year represented was 1994 (**Table 2.5.2**). Due to remaining uncertainty about the catch time series we admitted catch observation error with a *CV*=0.1. Here are name abbreviations for the six CPUE series used in this report:

Shark Bottom Longline Observer Program (BLLOP.NR, 1994 – 2007)

Shark Research Fishery (BLLOP.R, 2008 – 2019)

FSU Longline (FSU.LL, 2011 – 2019)

RSMAS Drumline (RSMAS.DL, 2009 – 2019)

SEFSC MS Bottom Longline (SEFSC.BLL, 1995 – 2019)

SEAMAP BLL survey (SEAMAP.BLL, 2006 – 2019)

3.1 JABBA ASSESMENT MODEL

3.1.3 Model configuration

- JABBA provides a generalized Bayesian state-space estimation framework for surplus production models (SPMs) by building on previous formulations by Pella and Tomlinson (1969).
- Fox, Schaefer, and Pella-Tomlinson production functions were explored. Pella-Tomlinson production function was recommended by the assessment Panel to be used for this assessment.
- The model started in 1981 and ended in 2019.
- The first year in which both CPUE and catch data were available was 1994.
- Estimated parameters were r, K, the abundance (in numbers) in 1981 relative to K (B_{81}/K or initial depletion at the beginning of the model *psi*), process and observation error variances, the time series of proportions of carrying capacity (P_t terms; see eq. 1 below), catchability coefficient associated with each CPUE time series and shape parameter (m).
- Surplus production models are frequently implemented to estimate sustainable levels of harvest (biomass removals) at corresponding levels of stock biomass. Maximum sustainable yield (*MSY*) is the maximum level of catch that can be removed from a stock over time while maintaining biomass at B_{MSY}, the biomass to produce *MSY*.

JABBA model formulation

$$P_t = \left(P_{t-1} + \frac{r}{(m-1)} P_{t-1}(1 - P_{t-1}{}^{(m-1)}) - \frac{C_{t-1}}{K} \right) e^{P\varepsilon_t}$$

where $P_t = B_t/K$, B_t is the abundance (number) in year *t*, *K* is the carrying capacity (number), *r* is the intrinsic rate of population growth (yr^{-1}), *Ct-1* is the catch (number) in year *t*-1, and *m* is a shape parameter that determines where maximum surplus production is attained. If the shape parameter *m*=2, the model reduces to the Schaefer form, with the surplus production attaining maximum surplus production, or *MSY* at exactly a stock biomass level corresponding to *K*/2. If $0 < m < 2$, *MSY* occurs when biomass values are smaller than *K*/2; when $m > 2$, *MSY* occurs when biomass values are greater than *K*/2.

See Winker et al. (2018) for details of JABBA model formulation

Parameter estimation

Prior distributions

Prior distributions were used to quantify the degree of existing knowledge on each of the model parameters to be estimated under the Bayesian approach. Here are the key priors required to be specified in JABBA.

Carrying capacity (K)—Vaguely informative lognormal priors with a mean of 400, 40, and 6 times the maximum observed catch (33,670,000, 3,367,000, and 505,000 sharks), and the JABBA default prior *K* setting (*K* was assumed to equal 8 times the maximum observed catch with a *CV*=1) were explored. The JABBA default prior *K* setting was recommended by the Panel to be used for the base run.

Intrinsic rate of population growth (r)—An informative, lognormally distributed prior (mean=0.144 yr^{-1}, *CV*=0.244) was used for *r* to take advantage of the available biological information reported in **Section 2.3** for the base run (see **Section 2.3** and SEDAR77-AW04 (Cortés 2022) for details).

Initial depletion (psi)—An informative prior was also used for B_{81}/K *(i.e. psi)* defined with a beta distribution with the mean=0.9 and *CV*=0.1 to reflect some depletion with respect to virgin levels. Considering initial depletion in 1981 is justified because previous input from the commercial shark fishing industry provided for SEDAR 65 stated that “there was very little commercial shark fishing effort in the early 1980s".

Parameter estimation

Prior distributions

Inflection point of the surplus production curve (B_{MSY}/K)—An informative prior for the inflection point of the surplus production curve (B_{MSY}/K =0.48) was used for the base run. This prior was derived from the Leslie matrix stochastic analyses (see **Section 2.3** and SEDAR77-AW04 (Cortés 2022) for details).

Priors for error variances—Priors for both the observation error variance and process error variance were used in JABBA. The observation variance consists of both an assumed minimum fixed observation error component (0.001) and an estimable "additional" observation variance component (Winker *et al.* 2018). Both the estimable "additional" observation variance and the process error variance were specified as inverse-gamma distributions (shape = 0.001 and rate = 0.001), assuming fairly low stochastic biomass variation considering the long generation length (Winker, 2018).

Base model specifications

- model.type = c("Pella_m") #estimate the shape m parameter
- Catch and Indices of relative abundance are based on numbers
- catch time series without associated standard errors, assumed catch.cv = 0.1
- Indices of relative abundance time series with associated standard errors
- K.dist = c("lnorm"), K.prior = Default #i.e. K.prior = c(8*max(Catch), 1)
- r.dist = c("lnorm"), r.prior = c(0.144, 0.244)
- psi.dist = c("beta"), psi.prior = c(0.9, 0.1)
- B_{MSY}/K = 0.476 #Inflection point of the surplus production curve, requires Pella-Tomlinson(model = 3 | model 4) #model 4 = estimate the shape m parameter
- shape.CV = 0.3 #CV of the shape m parameter, if estimated with Pella-Tomlinson (Model 4)
- igamma = c(0.001, 0.001), #prior for additional observation variance and process error variance
- estimate catchability q for each index (default)
- sigma.est = TRUE, # default, estimate additional observation variance
- fixed.obsE = 0.001 #Minimum fixed observation error
- sigma.proc = TRUE, #Estimate process error
- proc.dev.all = TRUE, #All year, year = starting year

Model execution

JABBA is implemented in R (R Development Core Team, https://www.r-project.org/) with the JAGS interface (Plummer, 2003) to estimate the Bayesian posterior distributions of all quantities of interest by means of a MCMC simulation. The JAGS model is executed from R using wrapper function jsgs() from the library r2jags (Su and Yajima, 2012), which depends on rjags. In this study, three MCMC chains were used. Each model was run for 30,000 iterations, sampled with a burn-in period of 5,000 iterations for each chain and thinning rate of five iterations. JABBA inbuilt functions used to fit the model are build_jabba() and fit_jabba().

Model performance diagnostics

Here is a brief description of JABBA's inbuilt options of diagnostic procedures and associated plots that were used in this assessment.

Goodness of CPUE fits—To evaluate CPUE fits, the model predicted CPUE indices were compared to the observed CPUE. R plots were developed in JABBA as an aid to visualize results.

Posterior predictive check—Posterior predictive check of CPUE fits was compared to the posterior predictive distribution (new JABBA feature recommended by A.E. Punt) of each of the six indices of abundance and the combined six indices of abundance. In essence the posterior predictive check tests if the model error assumptions are consistent with the underlying data generation process. R plots were developed in JABBA as an aid to visualize results. A general rule of thumb is that p = 0.5 is ideal and a range 0.2-0.8 is acceptable.

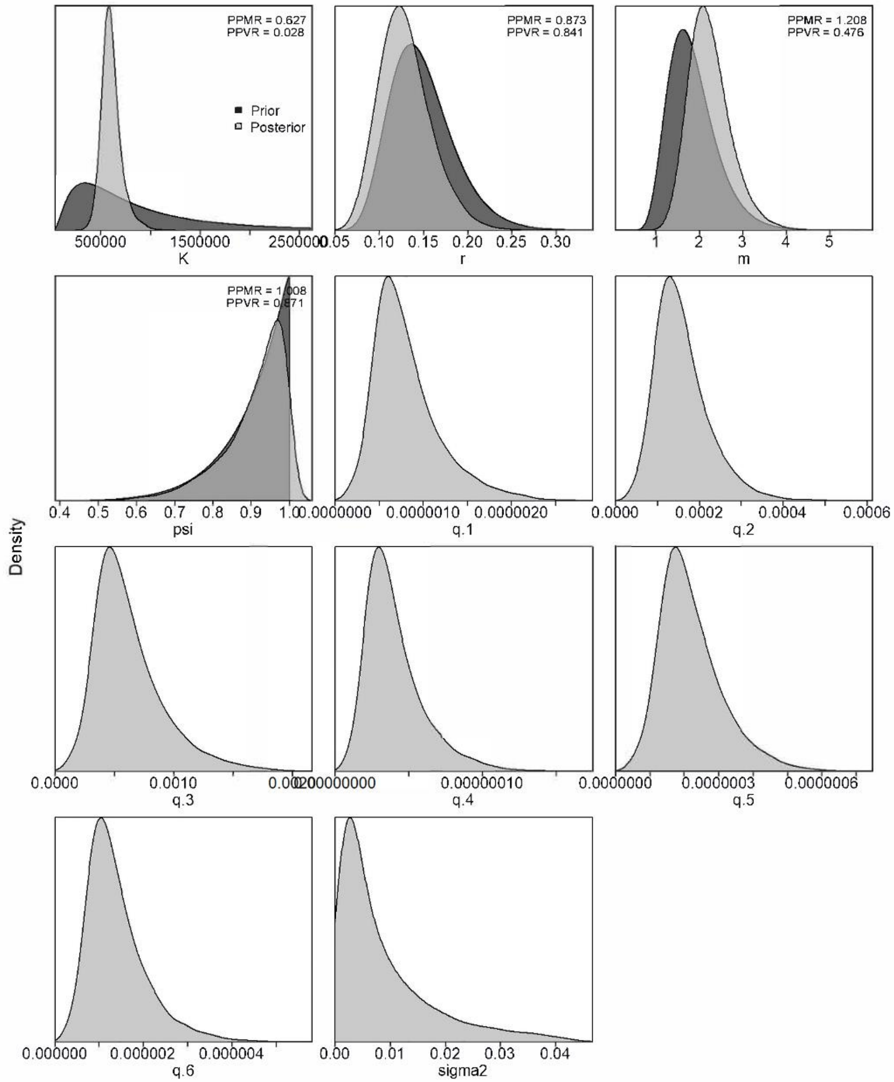
Runs test—Runs test was applied to the residuals of each abundance index fit to quantitatively evaluate the randomness of the time-series of abundance residuals by index (Carvalho *et al*. 2017). R plots were developed in JABBA as an aid to visualize results obtained from residuals runs tests. The plots identify individual time-series data points farther than three standard deviations away from the mean (the three-sigma rule), which is a test used to detect non-random time series (e.g., see Anhøj and Olesen 2014).

Stock status

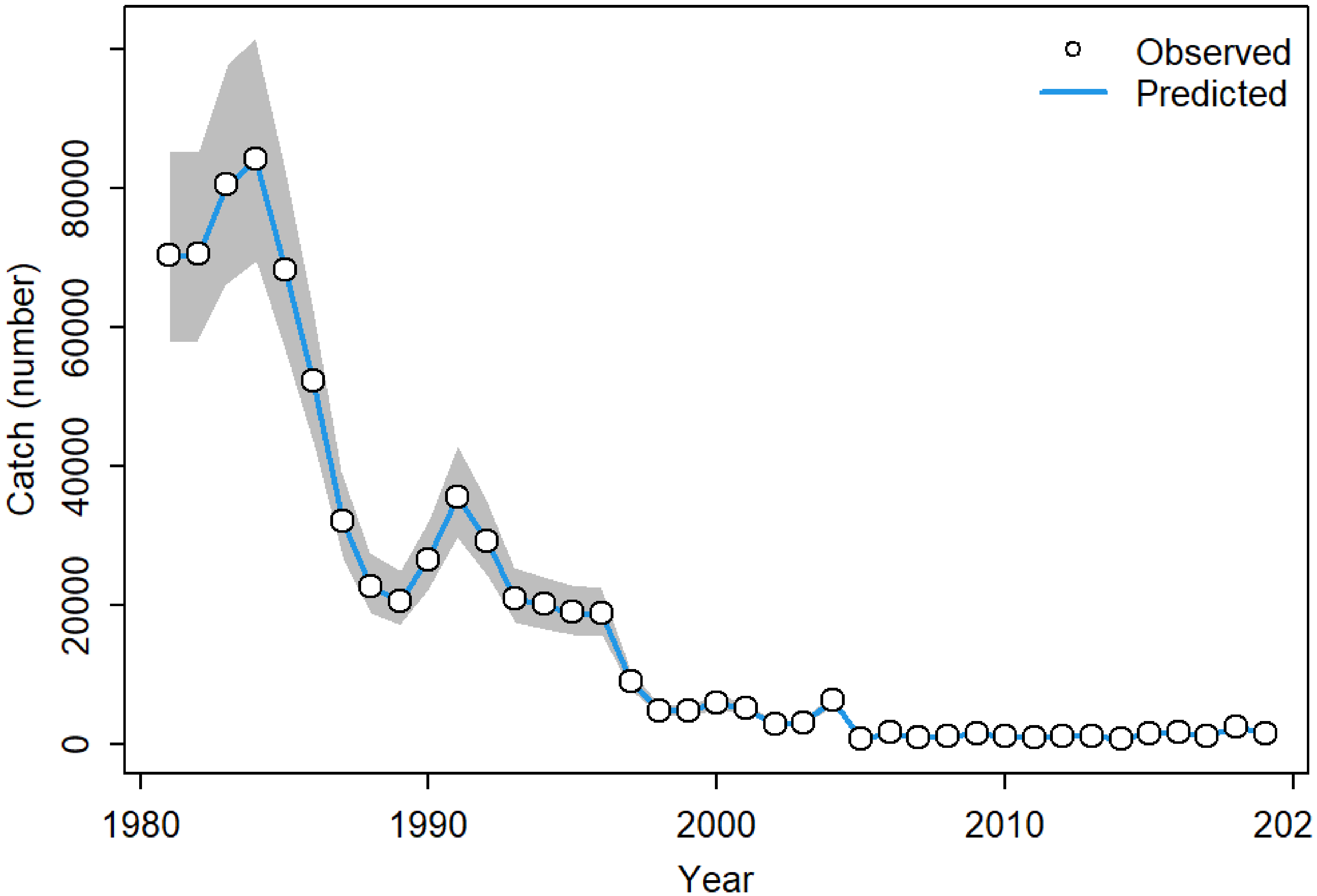
Reference points for this assessment are based on *MSY* (F_{MSY}, B_{MSY}), and current status relative to *MSY* levels. In addition, trajectories for predicted abundance (B_{year}) and harvest rate (F_{year}), B_{year}/B_{MSY}, and F_{year}/F_{MSY} were produced and plotted. Phase plots of stock status, including *MSST* (Minimum Stock Size Threshold) were also included. The average (age 1 to maximum age) natural mortality rate (M=0.156 yr^{-1}) was used for the base run. Because M<0.5, *MSST* is computed as $(1-M)B_{MSY}$ (Restrepo *et al.* 1998). Phase plots depicting the combined F_{year}/F_{MSY} and B_{year}/B_{MSY} trajectories were also produced for every year considered in the base model.

Base model: posteriors-priors for model parameters

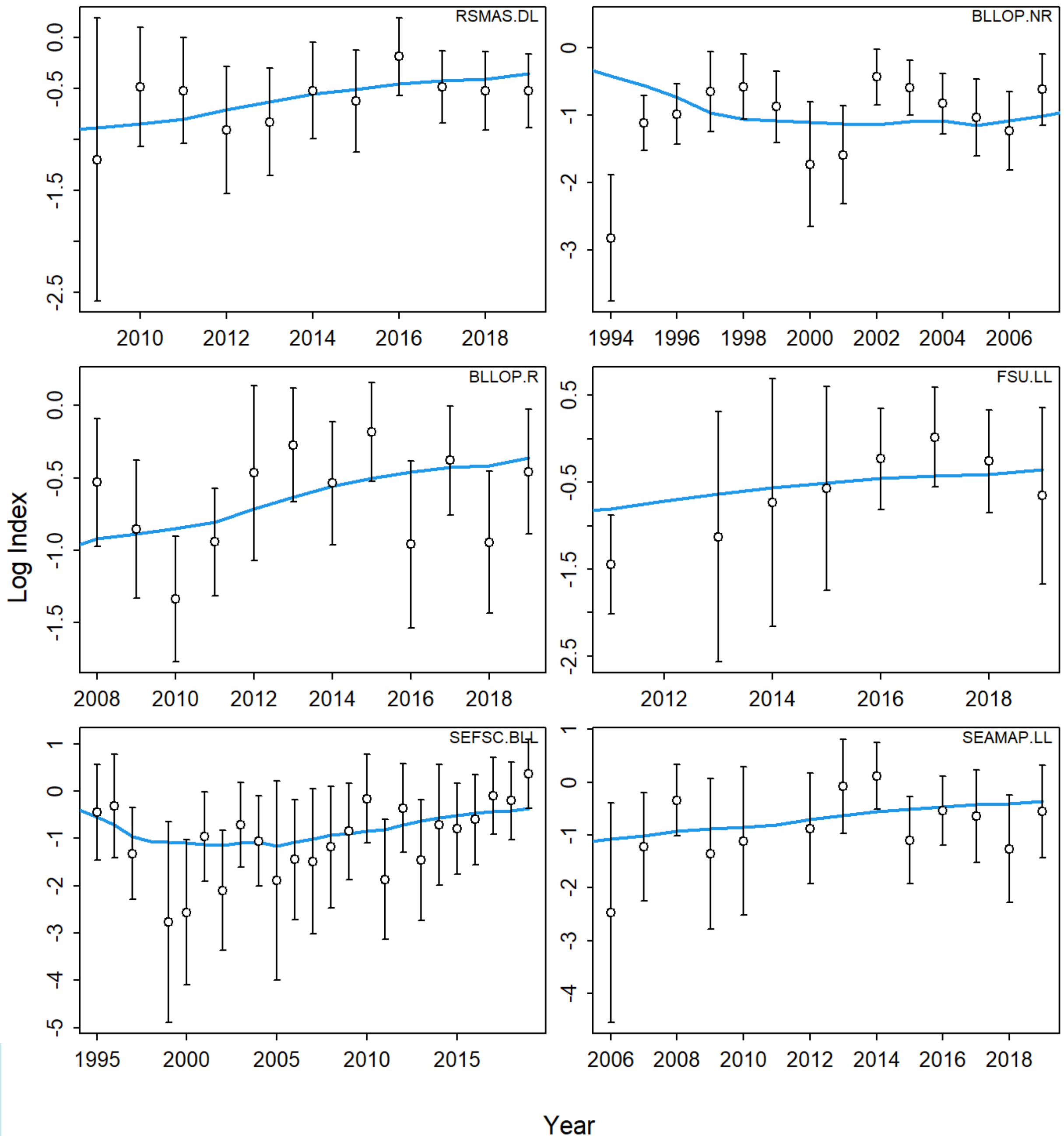
Posterior: K=592,637; r=0.126; m=2.17; psi=0.93; proc=0.073



Base model: Measures of model fit

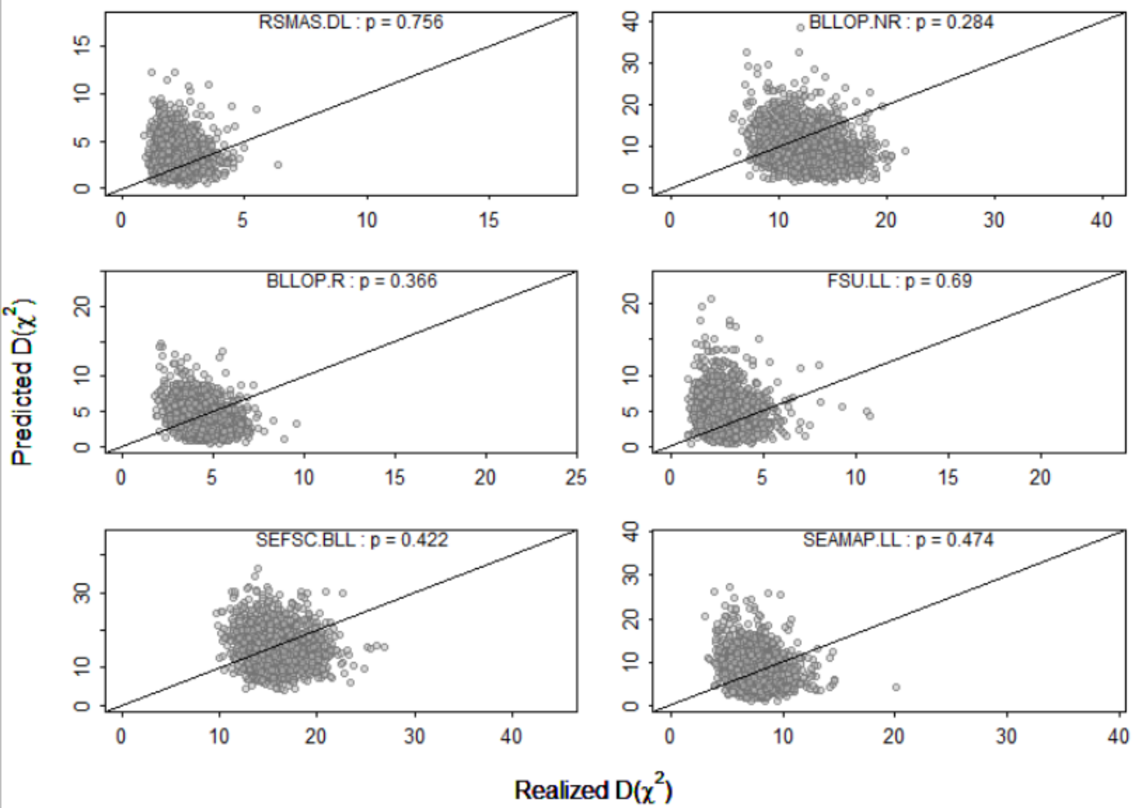


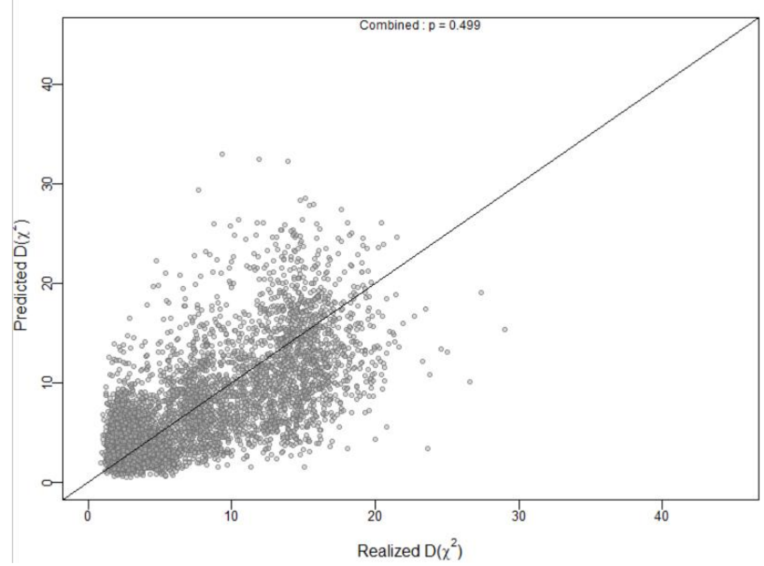
Base model: Measures of model fit



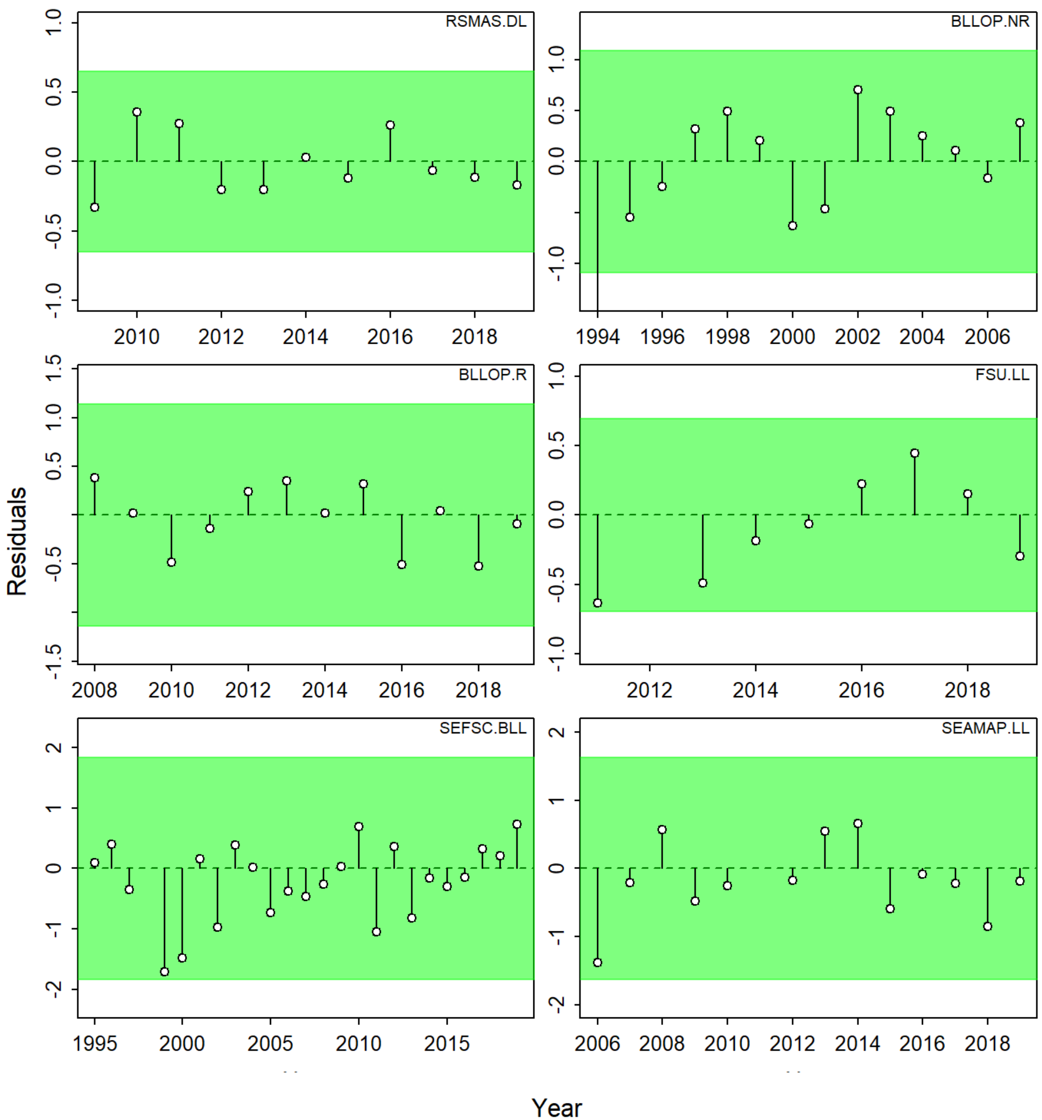
Base model: Measures of model fit

each of the six indices of abundance and the combined six indices of abundance

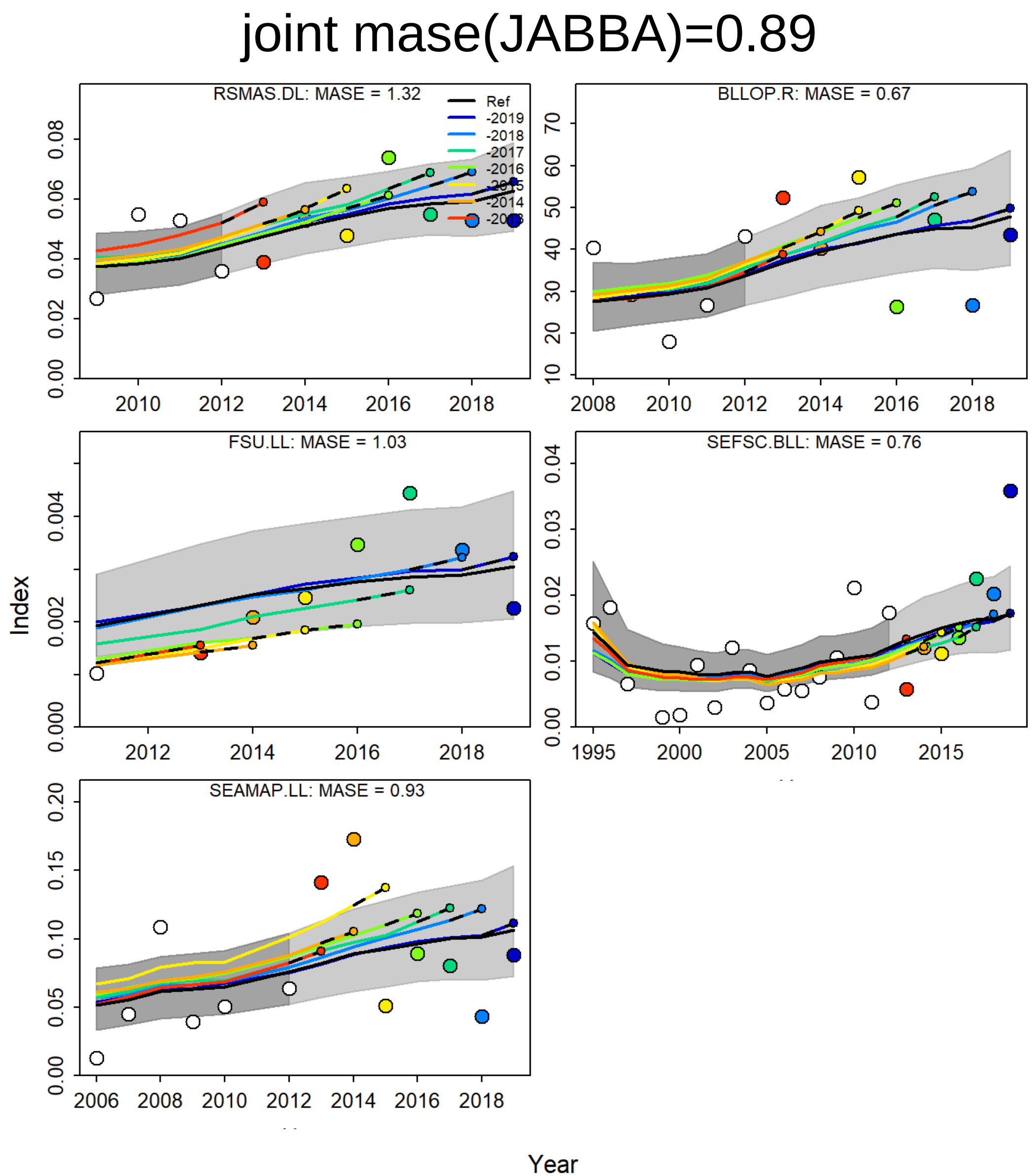




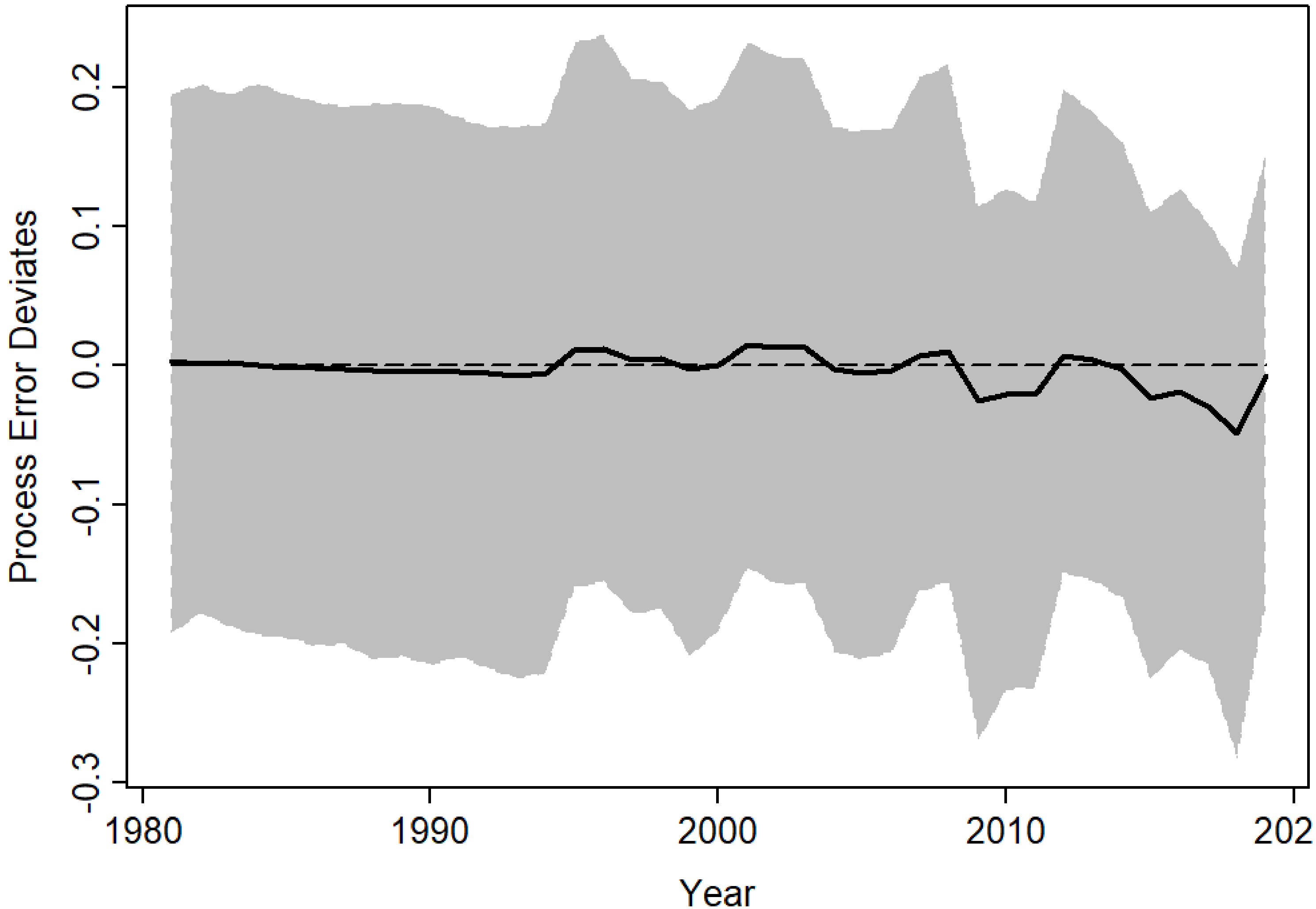
Base model: runs tests



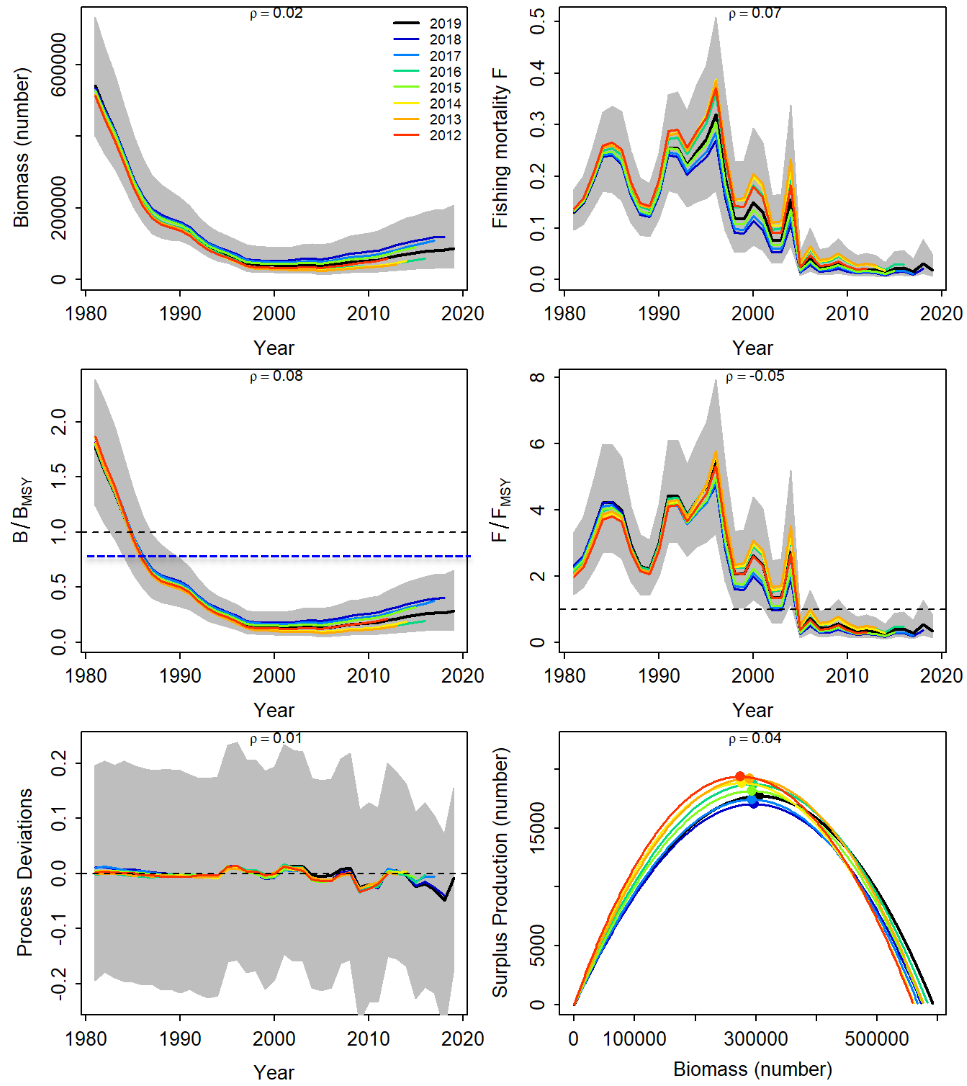
Base model: hindcasting cross-validation (JABBA)



Base model: Trajectory for process error deviates



Base model: Retrospective analysis



Stock status:

overfished,

but not overfishing

Table 3.2. Summary of posterior quantiles presented in the form of marginal posterior medians and associated the 95% credibility intervals of parameters for the base run.

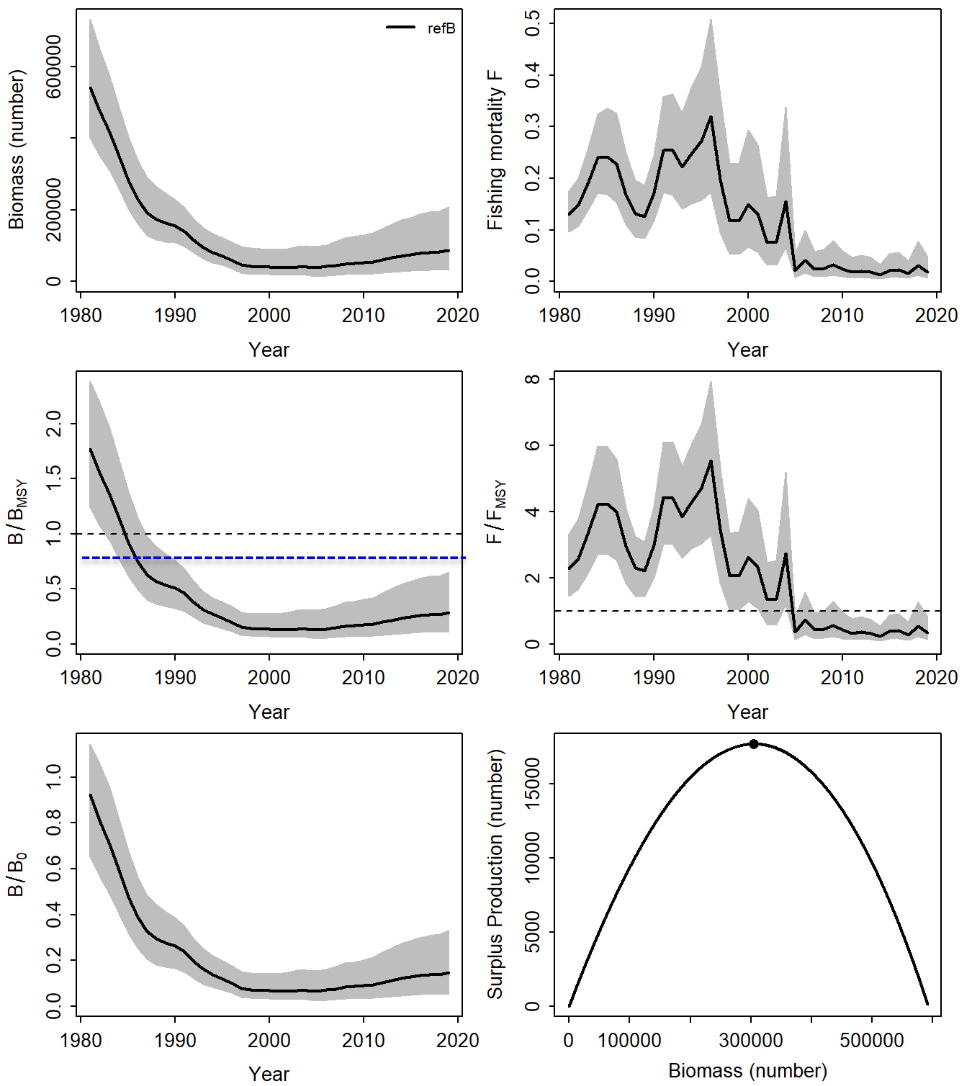
Run	**refB(Base)**		
Estimates	Median	LCI	UCI
K	592637	437837	853215
r	0.126	0.081	0.195
psi	0.931	0.689	0.997
sigma.proc	0.073	0.025	0.184
m	2.173	1.447	3.350
F_{MSY}	0.058	0.037	0.088
B_{MSY}	307024	209347	456490
MSY	17559	12161	27253
B_{MSY}/K	0.516	0.438	0.598
B_{2019}/B_{MSY}	0.284	0.112	0.652
F_{2019}/F_{MSY}	0.338	0.141	0.807
M	0.156		
MSST((1 -M)*B_{MSY})	259128		
OFL_{2020}	5900	2096	13118

Stock status:

overfished,

but not overfishing

Base model: Summary

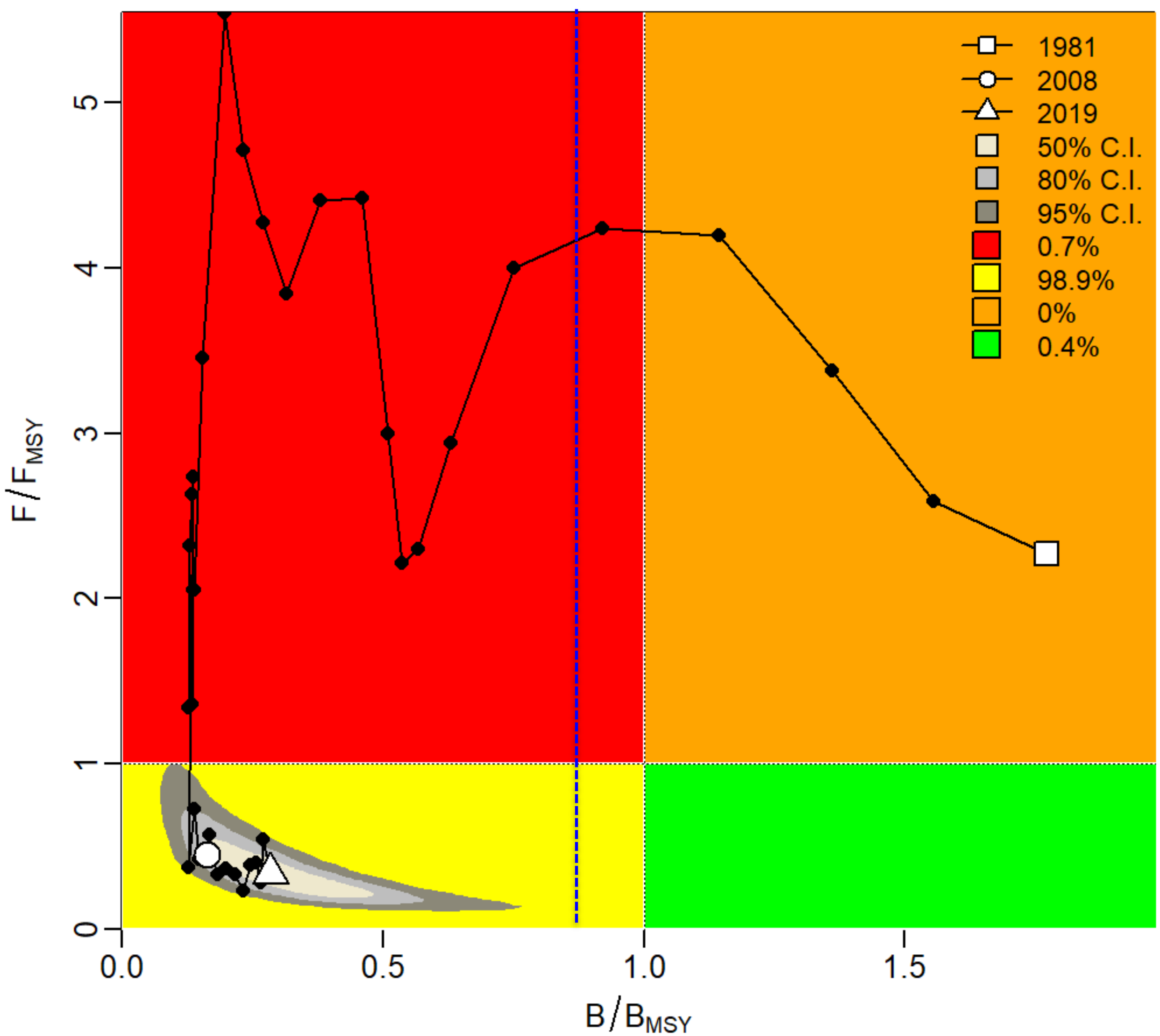


Stock status:

overfished,

but not overfishing

Base model: Estimated stock status



Stock status:

overfished,

but not overfishing

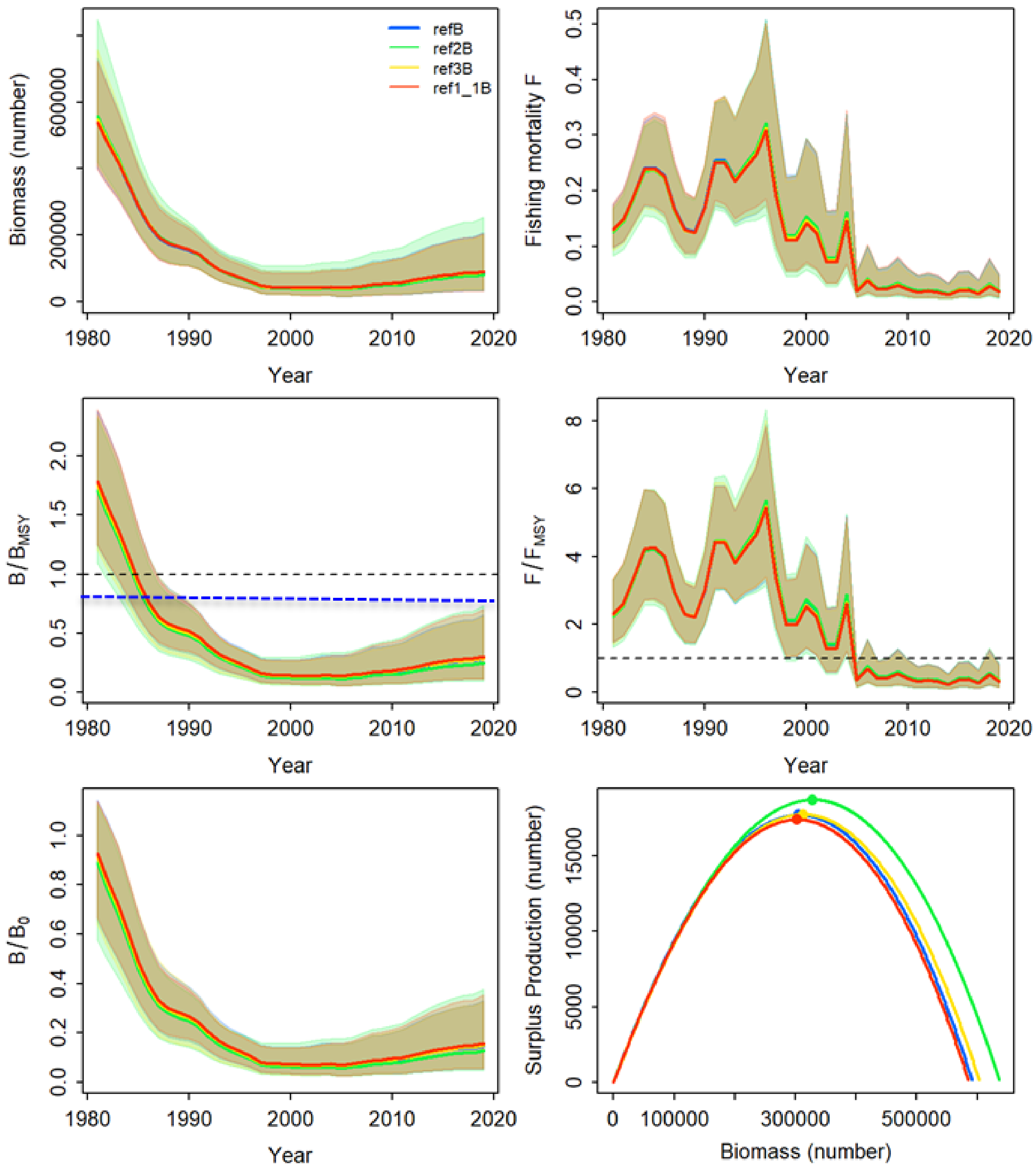
Evaluation of uncertainty

1. K
   - refB, *K.prior = default (K=B_0),* r.prior= c(0.144, 0.244), igamma=c(0.001,0.001). *Posterior r is lower than prior and PPMR=0.653*
   - ref2B, K.prior = c(33,670,000, 2), assumed 400X max observed catch. *Unrealistic PPMR=0.009*
   - ref3B, K.prior = c(3,367,000, 2), assumed 40X max observed catch. *Unrealistic PPMR=0.083*
   - ref1_1B, K.prior = c(505,000, 2), assumed 6X max observed catch. *PPMR=0.532 (very similar to refB)*
   - ref1_2B, K.prior = c(505,000, 200), assumed 6X max observed catch. *Unrealistic PPMR=0.008*
   - ~~ref1_3B, K.prior = c(505,000, 0.5), assumed 6X max observed catch. *PPMR=1.044 (good), but cannot do hindcasting*~~
2. r
   - refB, K.prior = default (K=B_0), *r.prior= c(0.144, 0.244),* igamma=c(0.001,0.001). *Posterior r is lower than prior and PPMR=0.873*
   - ref12BB, higher mean, r.prior= c(0.199, 0.244). *Posterior r is higher than refB and r PPMR=0.821*
   - ref13BB, lower mean, r.prior= c(0.099, 0.244). *Posterior r is lower than refB and r PPMR=0.921*
   - ref3_2BB, base mean with 2xCV, r.prior = c(0.144, 0.488). *Posterior r is lower than refB (CV=0.244) and r PPMR=0.656*
   - ref12_2BB, higher mean with 2xCV, r.prior= c(0.199, 0.488). *Posterior r is lower than ref12BB (CV=0.244) and r PPMR=0.581*
   - ref13_2BB, lower mean with 2xCV, r.prior= c(0.099, 0.488). *Posterior r is lower than ref13BB (CV=0.244) and r PPMR=0.786*
3. K&Process error (lower to facilitate shape estimation with Pella_m)
   - refB, *K.prior = default (K=B_0),* r.prior= c(0.144,0.244), *igamma=c(0.001,0.001)*
   - ~~ref4BB, smaller igamma=c(4, 0.01). *Cannot do hindcasting*~~
   - ~~ref9_2BB, smaller fixed sigma.proc=0.052. *Cannot do hindcasting*~~
   - ~~ref14BB, fixed SE for all input CPUEs at 0.5 with base igamma=c(0.001, 0.001). *Index fitting, runs test, hindcasting*~~
   - ~~ref14_2BB, fixed SE for all input CPUEs at 0.5 with smaller igamma=c(4, 0.01). *Index fitting, runs test, hindcasting*~~
   - ~~ref14_3BB, fixed SE for all input CPUEs at 0.5 with smaller fixed sigma.proc=0.052. *Index fitting, runs test, hindcasting issues*~~
   - ~~ref1_4BB, smaller igamma=c(4,0.01) and K.prior = c(505,000, 2). *Cannot do hindcasting*~~
   - ~~ref1_5BB, smaller igamma=c(4,0.01) and K.prior = c(505,000, 200). *Cannot do hindcasting*~~

Table 3.1. *K* and *r* priors of each of the Panel-approved sensitivity runs.

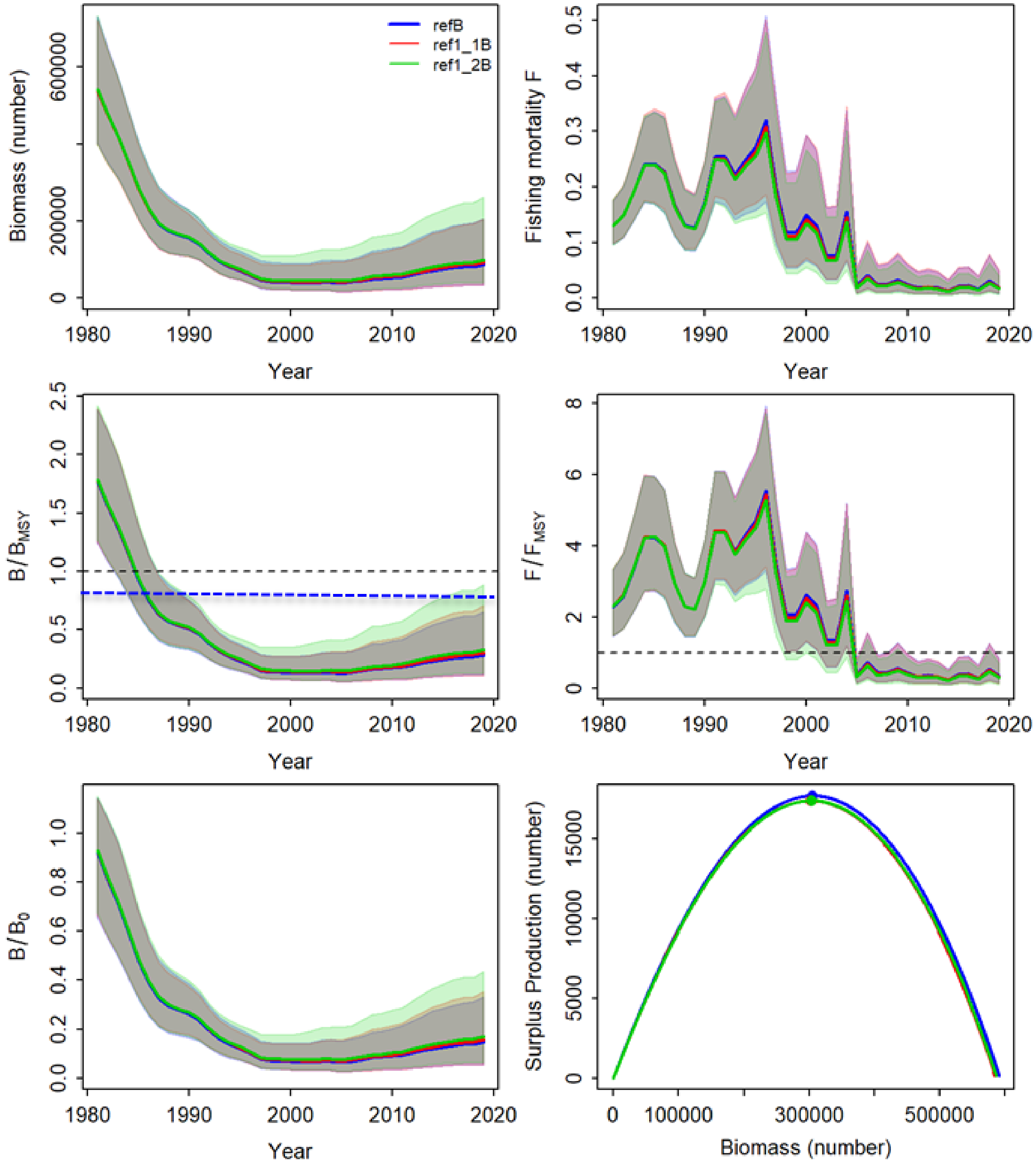
Run	*K*	*r*
refB(Base)	Default in JABBA ($K=B_0$)	Lognormal (0.144, 0.244)
1) ref2B (400xC_{MAX}, CV=2)	Lognormal (33670000, 2)	Lognormal (0.144, 0.244)
2) ref3B (40xC_{MAX}, CV=2)	Lognormal (3367000, 2)	Lognormal (0.144, 0.244)
3) ref1_1B (6xC_{MAX}, CV=2)	Lognormal (505000, 2)	Lognormal (0.144, 0.244)
4) ref1_2B (6xC_{MAX}, CV=200)	Lognormal (505000, 200)	Lognormal (0.144, 0.244)
5) ref12BB (High r)	Default in JABBA ($K=B_0$)	Lognormal (0.199, 0.244)
6) ref13BB (Low r)	Default in JABBA ($K=B_0$)	Lognormal (0.099, 0.244)
7) ref3_2BB (High CV)	Default in JABBA ($K=B_0$)	Lognormal (0.144, 0.488)
8) ref12_2BB (High r & High CV)	Default in JABBA ($K=B_0$)	Lognormal (0.199, 0.488)
9) ref13_2BB (Low r & High CV)	Default in JABBA ($K=B_0$)	Lognormal (0.099, 0.488)

Base run and the Panel-approved sensitivity runs with various mean values of *K* priors



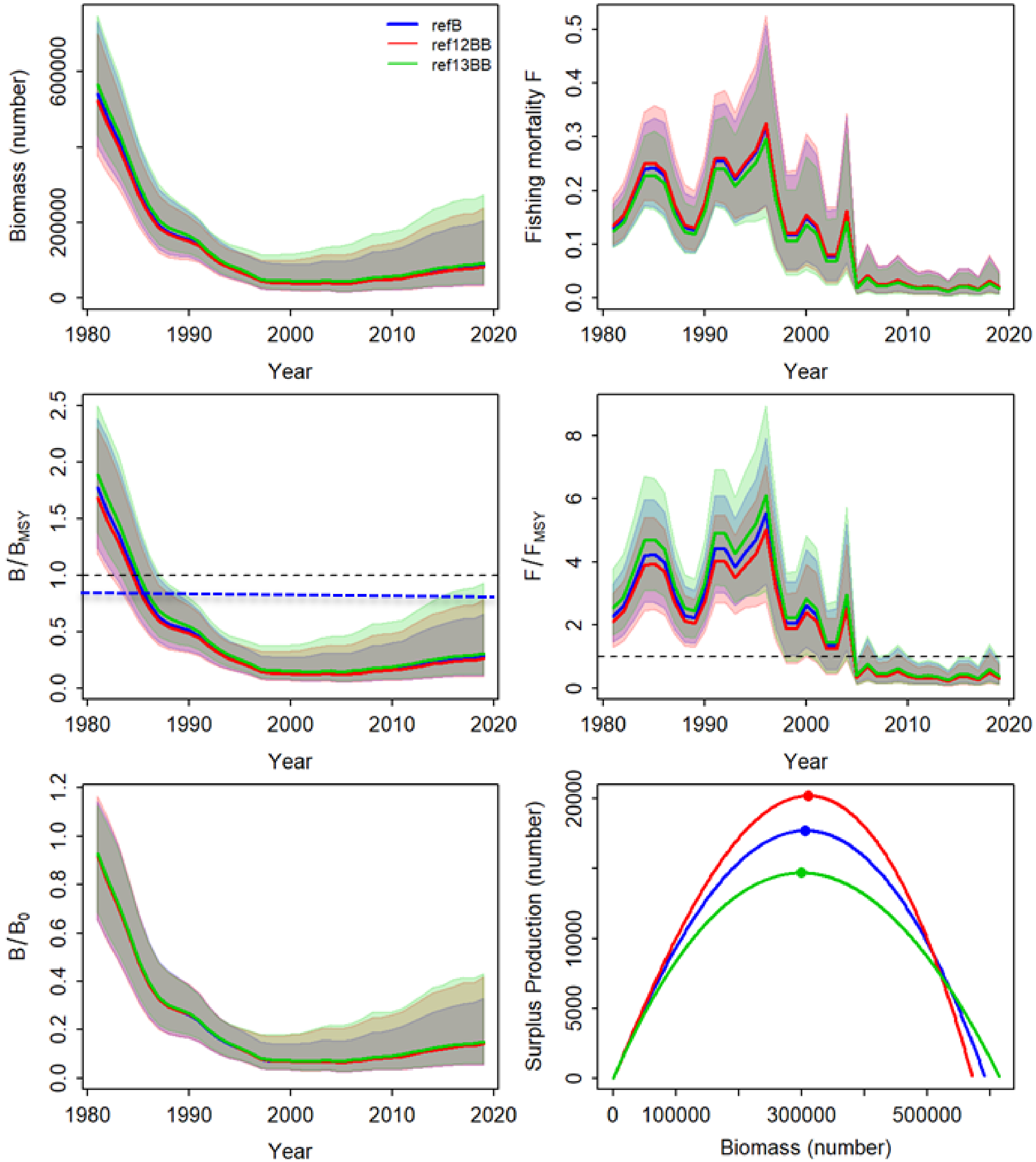
Stock status:
overfished,
but not overfishing

Base run and the Panel-approved sensitivity runs a best-guess mean of 6 times the maximum observed catch (505,000) with the base *CV* and a high *CV* values of *K* priors



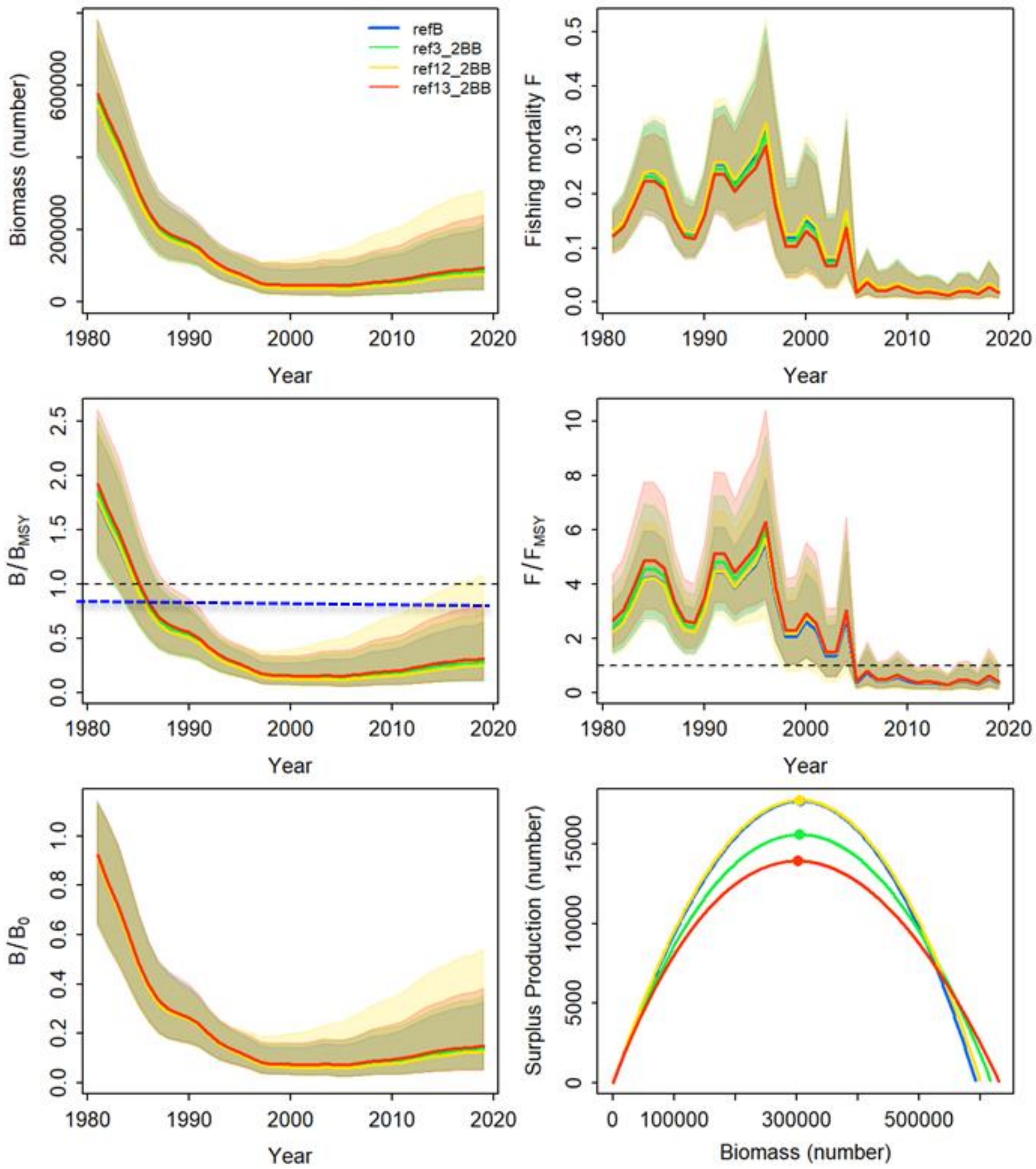
Stock status:
overfished,
but not overfishing

Base run and the Panel-approved sensitivity runs with high and low mean values of *r* priors



Stock status:
overfished,
but not overfishing

Base run and the Panel-approved sensitivity runs with the base, high and low mean values of *r* priors associated with 2 times the base run *CV* value



Stock status:
overfished,
but not overfishing

Table 3.4. Summary of posterior quantiles presented in the form of marginal posterior medians and associated the 95% credibility intervals of parameters for the base run and the Panel-approved sensitivity runs with various *K* priors.

Run	refB(Base)			ref2B (400xC_{MAX}, CV=2)			ref3B (40xC_{MAX}, CV=2)			ref1_1B (6xC_{MAX}, CV=2)			ref1_2B (6xC_{MAX}, CV=200)		
Estimates	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI
K	592637	437837	853215	637182	466748	1062049	604499	441853	948605	586529	428261	829888	588478	420672	843341
r	0.126	0.081	0.195	0.124	0.080	0.191	0.125	0.080	0.194	0.125	0.081	0.195	0.125	0.081	0.191
psi	0.931	0.689	0.997	0.913	0.618	0.996	0.927	0.669	0.997	0.933	0.688	0.998	0.934	0.699	0.997
sigma.proc	0.073	0.025	0.184	0.077	0.028	0.188	0.074	0.025	0.186	0.072	0.022	0.183	0.071	0.023	0.182
m	2.173	1.447	3.350	2.182	1.470	3.337	2.185	1.450	3.368	2.182	1.447	3.363	2.179	1.430	3.311
F_{MSY}	0.058	0.037	0.088	0.057	0.036	0.086	0.057	0.036	0.087	0.057	0.037	0.089	0.057	0.037	0.088
B_{MSY}	307024	209347	456490	330668	224608	571386	314003	210951	499815	304443	202659	450012	305100	201104	458104
MSY	17559	12161	27253	18668	12634	32678	17706	12172	30061	17282	12006	26541	17261	11829	26863
B_{MSY}/K	0.516	0.438	0.598	0.517	0.441	0.597	0.517	0.438	0.599	0.517	0.437	0.599	0.516	0.435	0.596
B_{2019}/B_{MSY}	0.284	0.112	0.652	0.246	0.094	0.734	0.288	0.115	0.640	0.301	0.112	0.704	0.329	0.129	0.887
F_{2019}/F_{MSY}	0.338	0.141	0.807	0.359	0.118	0.837	0.327	0.144	0.733	0.320	0.131	0.795	0.295	0.104	0.697
M	0.156			0.156			0.156			0.156			0.156		
MSST((1 -M)*B_{MSY})	259128			279084			265019			256950			257505		

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Table 3.5. Summary of posterior quantiles presented in the form of marginal posterior medians and associated the 95% credibility intervals of parameters for the base run and the Panel-approved sensitivity runs with various *r* priors.

Run	refB(Base)			ref12BB (High r)			ref13BB (Low r)			ref3_2BB (High CV)			ref12_2BB (High r & High CV)			ref13_2BB (Low r & High CV)		
Estimates	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI	Median	LCI	UCI
K	592637	437837	853215	572326	404103	810238	615371	466633	853216	617722	442276	924793	600028	426589	888346	630619	450420	945830
r	0.126	0.081	0.195	0.163	0.106	0.253	0.091	0.059	0.140	0.099	0.049	0.200	0.121	0.060	0.249	0.081	0.040	0.168
psi	0.931	0.689	0.997	0.930	0.684	0.997	0.935	0.706	0.997	0.929	0.670	0.997	0.926	0.678	0.997	0.929	0.661	0.997
sigma.proc	0.073	0.025	0.184	0.080	0.025	0.190	0.064	0.021	0.176	0.071	0.023	0.182	0.076	0.024	0.186	0.066	0.023	0.178
m	2.173	1.447	3.350	2.495	1.652	3.800	1.862	1.234	2.847	1.938	1.185	3.166	2.091	1.267	3.394	1.776	1.082	2.943
F_{MSY}	0.058	0.037	0.088	0.065	0.042	0.103	0.049	0.031	0.074	0.051	0.030	0.087	0.058	0.035	0.098	0.046	0.026	0.077
B_{MSY}	307024	209347	456490	312171	204573	455667	300031	209194	438970	304301	204590	477503	304589	203686	469280	300813	200450	472847
MSY	17559	12161	27253	20035	13933	31709	14600	10040	22202	15559	9284	27476	17662	11073	30084	13835	8016	24016
B_{MSY}/K	0.516	0.438	0.598	0.542	0.463	0.621	0.486	0.407	0.568	0.494	0.400	0.587	0.509	0.412	0.600	0.477	0.382	0.574
B_{2019}/B_{MSY}	0.284	0.112	0.652	0.262	0.106	0.785	0.308	0.127	0.928	0.282	0.111	0.732	0.255	0.106	1.085	0.313	0.113	0.821
F_{2019}/F_{MSY}	0.338	0.141	0.807	0.313	0.108	0.717	0.373	0.115	0.893	0.375	0.143	0.928	0.363	0.088	0.872	0.390	0.133	1.048
M	0.156			0.080			0.182			0.156			0.080			0.182		
MSST($(1-M)*B_{MSY}$)	259128			287197			245425			256830			280222			246065		

Compared with Jiao et al. (2011)

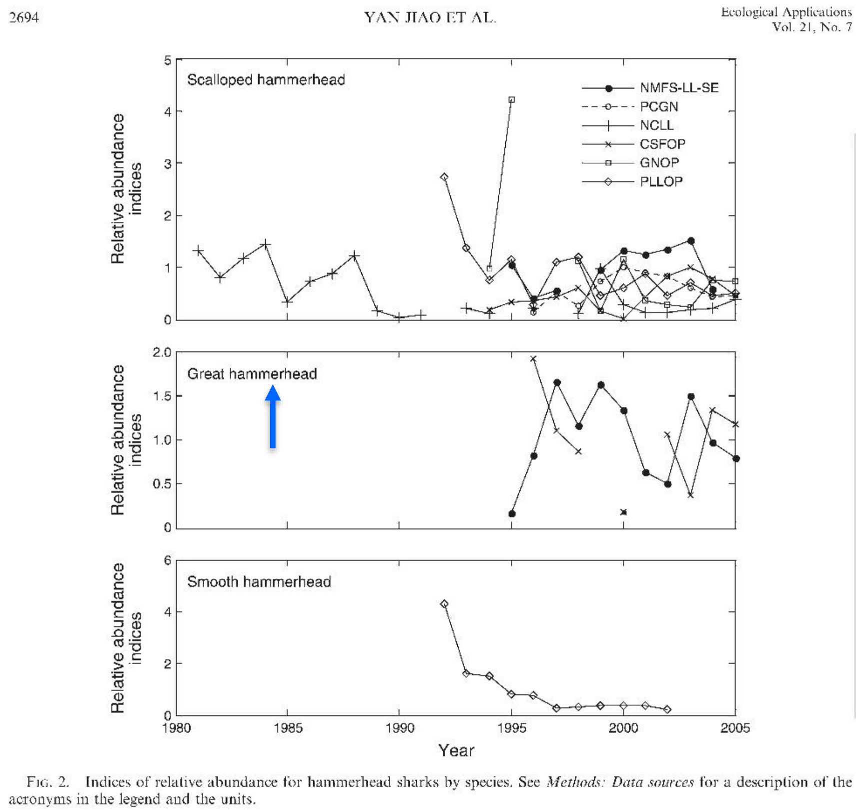
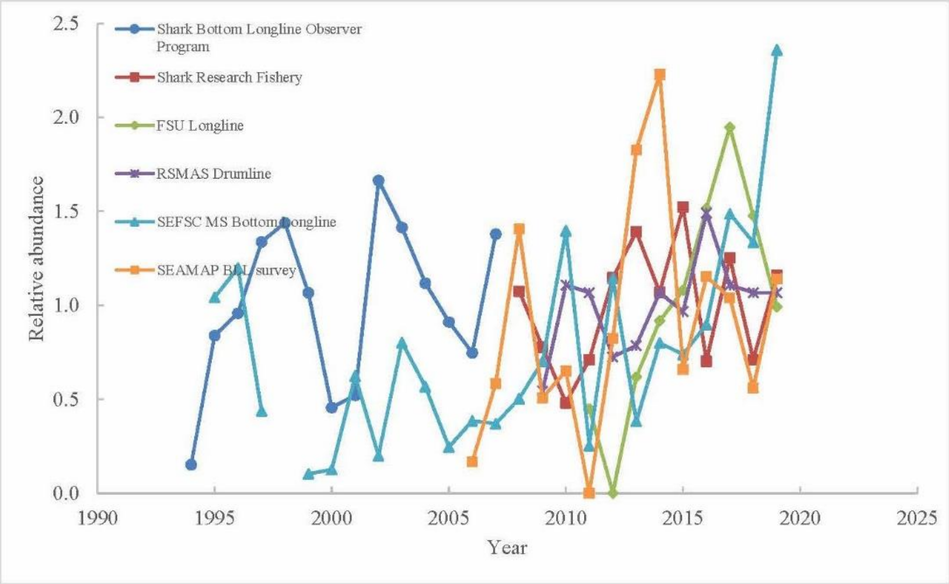


FIG. 2. Indices of relative abundance for hammerhead sharks by species. See *Methods: Data sources* for a description of the acronyms in the legend and the units.



Great HH (left middle panel):

2 vs. 6 CPUEs (4 new CPUE after 2005) and 14 more years of catch

Compared with Jiao et al. (2011)

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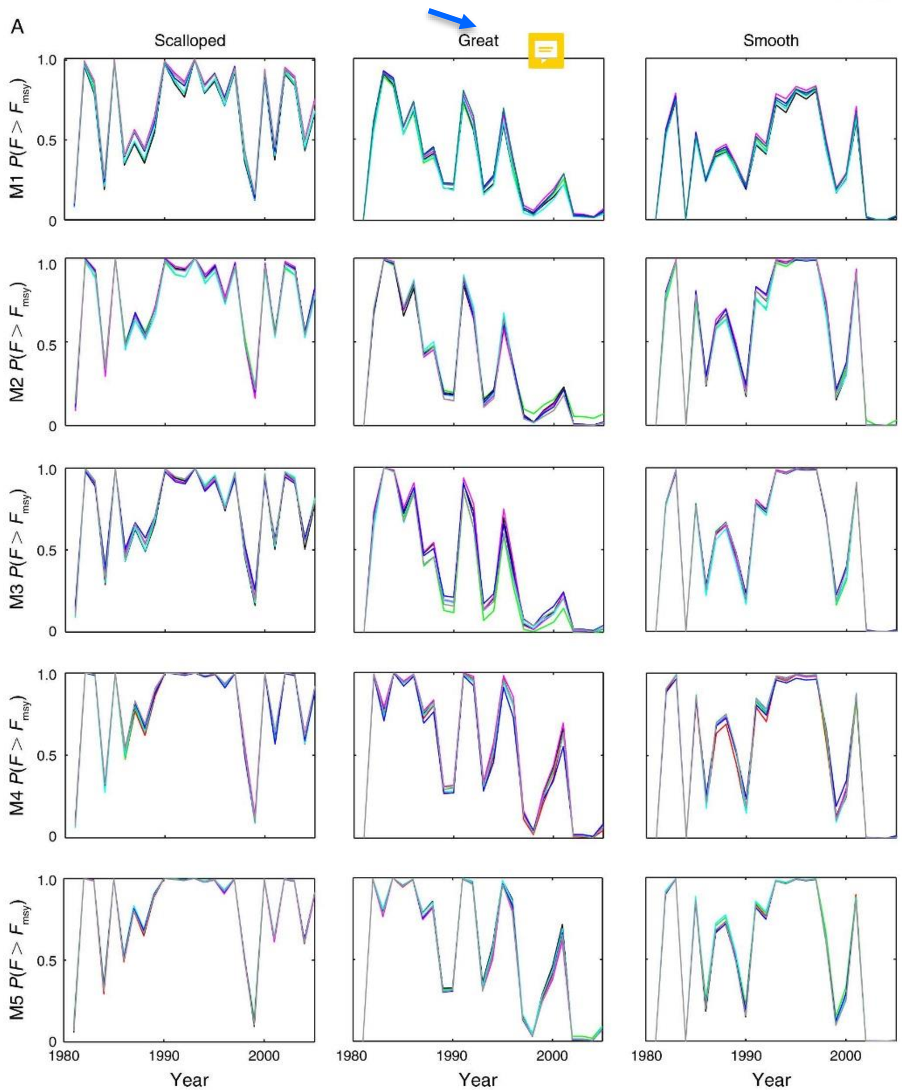
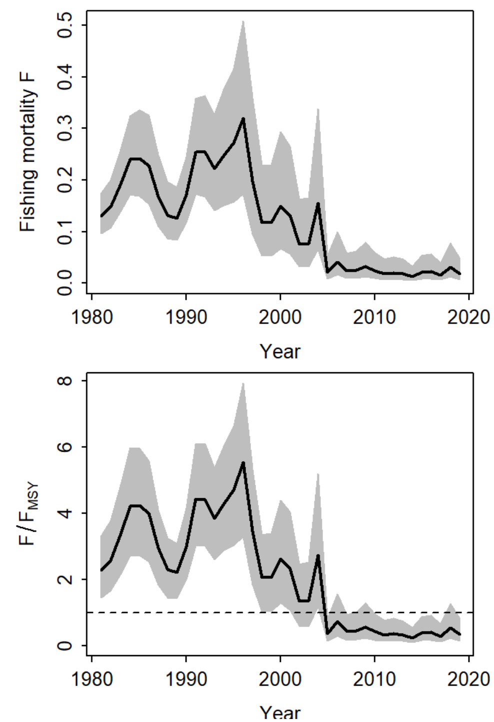


FIG. 6. (A) Probability of fishing mortality, F, being larger than F_{msy} and (B) probability of population size, N, being smaller than N_{msy} for the three hammerhead shark species under seven scenarios, where the subscript msy denotes the value at maximum sustainable yield. Different scenarios are denoted by different colors, which are the same as in Fig. 3.



Stock status in 2005:

not overfishing

M1: nonhierarchical priors

Compared with Jiao et al. (2011)

October 2011 ASSESSING DATA-POOR SPECIES 2705

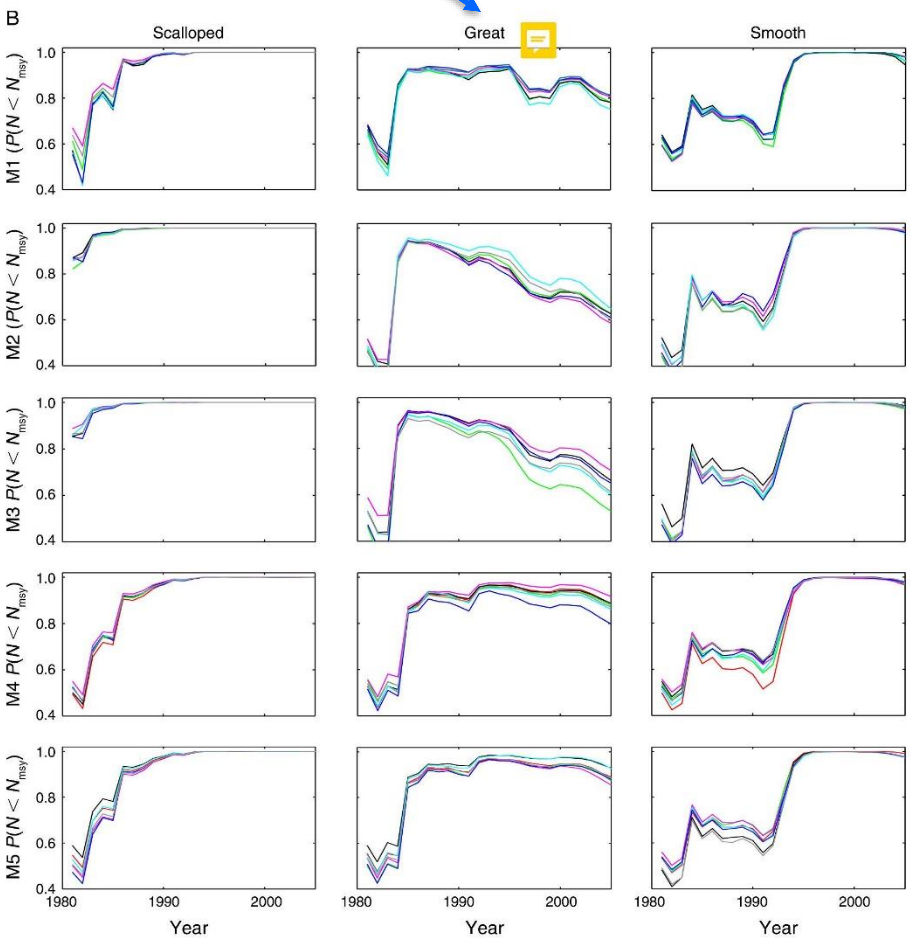
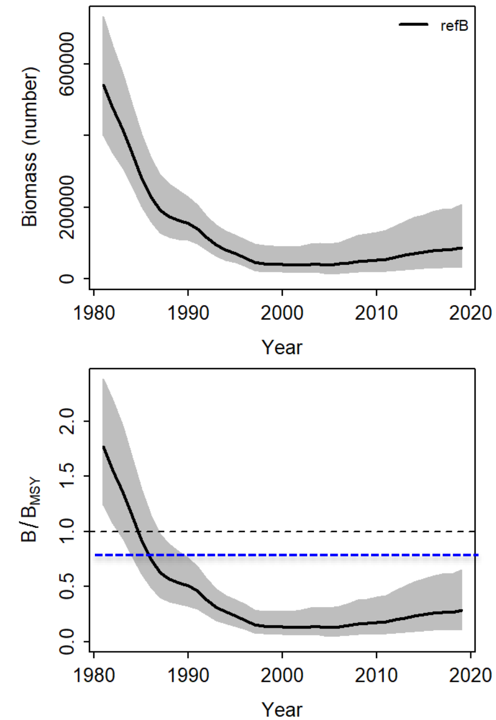


FIG. 6. Continued.



Stock status in 2005:

Overfished

M1: nonhierarchical priors

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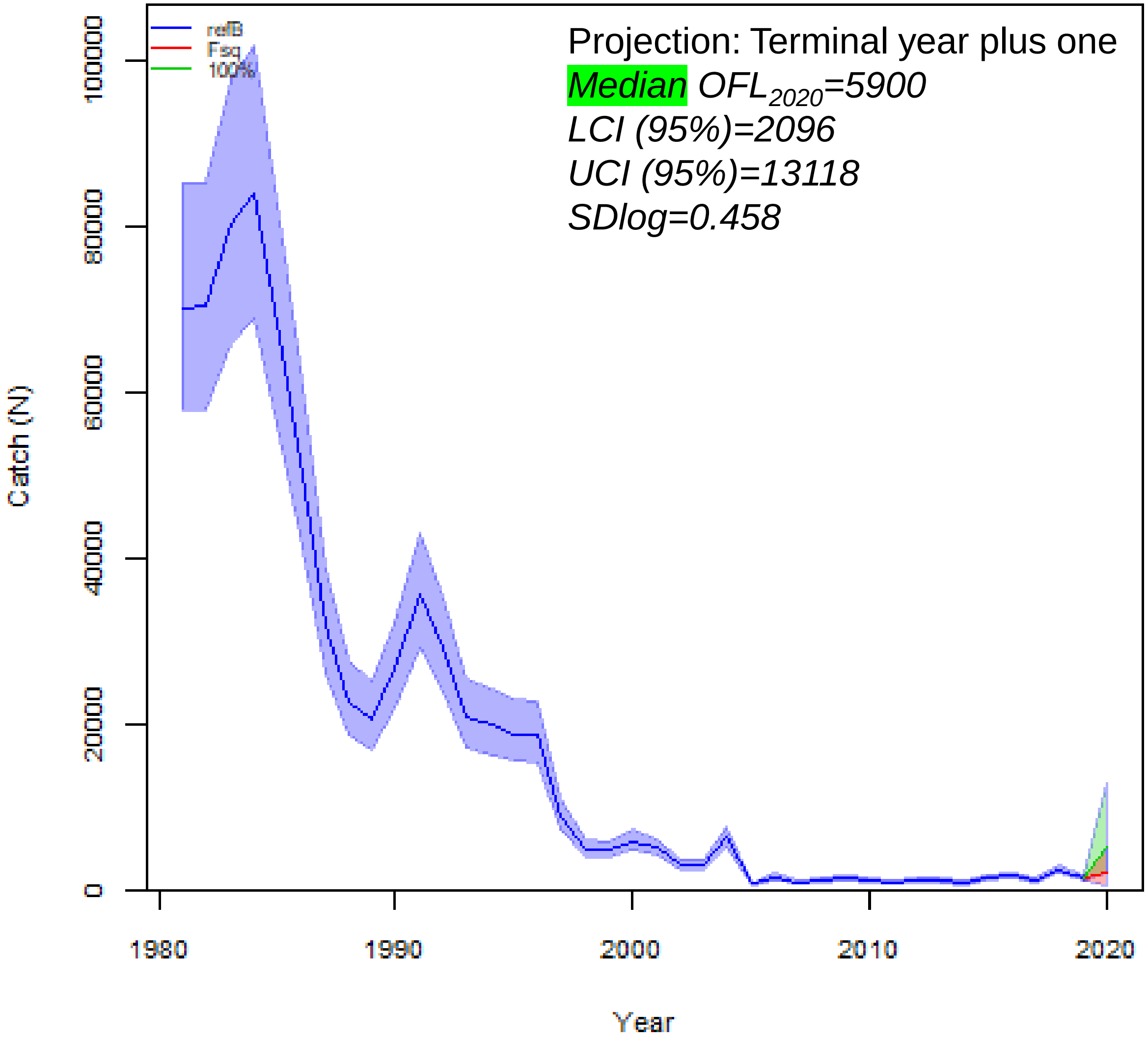
Conclusions on stock status

- Base model is pretty stable
- Stock status is overfished, but not overfishing in all runs
- CIs of some the Panel-approved sensitivity runs are much wider than the base model
- Same stock status (overfished, but not overfishing) in 2005 was suggested by both this assessment and Jiao et al. (2011)

Base model: OFL_{2020}



OFL_{2020} is the amount of catch in 2020 that corresponds to the estimate of F_{MSY} applied to the stock biomass in 2020 estimated with the terminal year plus one projection in JABBA for the base run.

As this stock is overfished, FMP requires to rebuild the stock within the rebuilding period with a >=50% probability.

Assessment Process Terms of Reference

9. Project future stock conditions and develop rebuilding schedules, if warranted. Provide the estimated generation time for the stock. Stock projections shall be developed in accordance with the following:

    a. If the preliminary stock status is overfished, then utilize projections to determine:

    i. Year in which F=0 results in a 70% probability of rebuilding (Year $F=0_{p70}$).

    ii. Target rebuilding year (Yearrebuild).

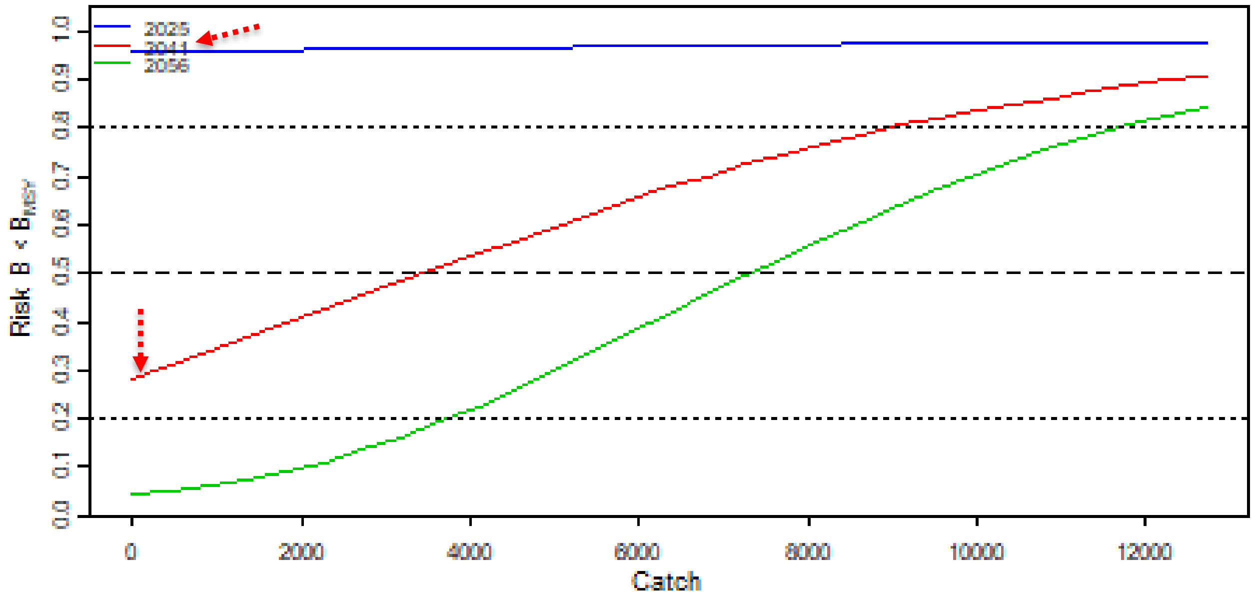
    1. Year $F=0_{p70}$ if Year $F=0_{p70} \leq 10$ years, or

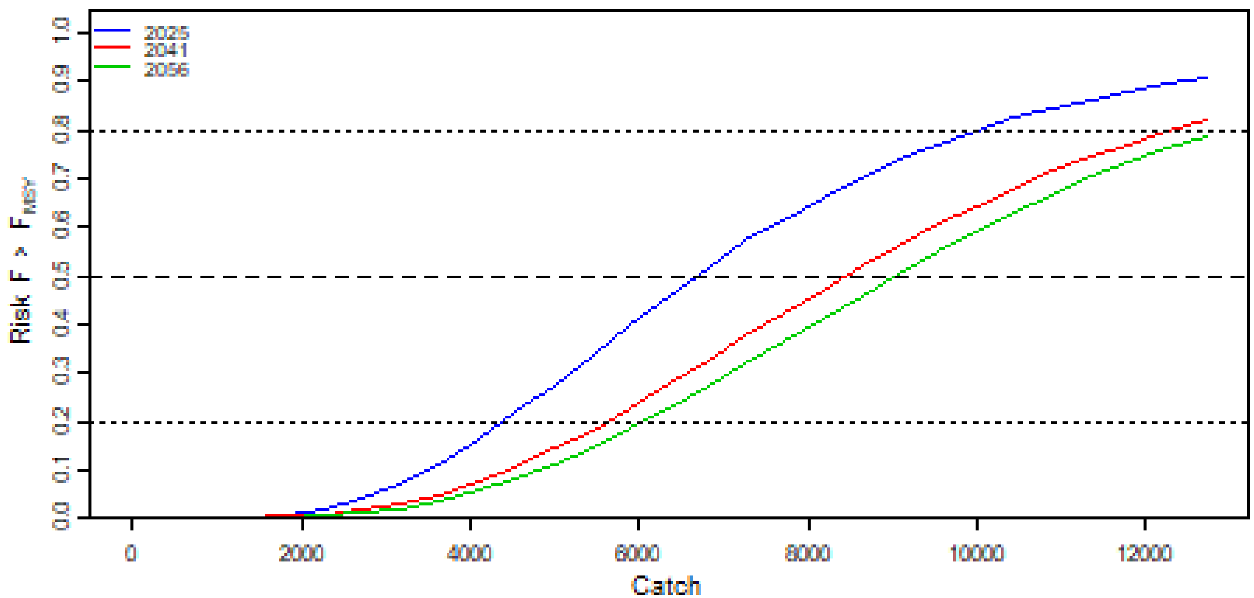
    2. Year $F=0_{p70}$ + 1 generation time if Year $F=0_{p70} > 10$ years.

    iii. F resulting in 50% and 70% probability of rebuilding by Yearrebuild.

    iv. Fixed level of removals allowing rebuilding of stock with 50% and 70% probability.

Base model: Catch based projections for rebuilding



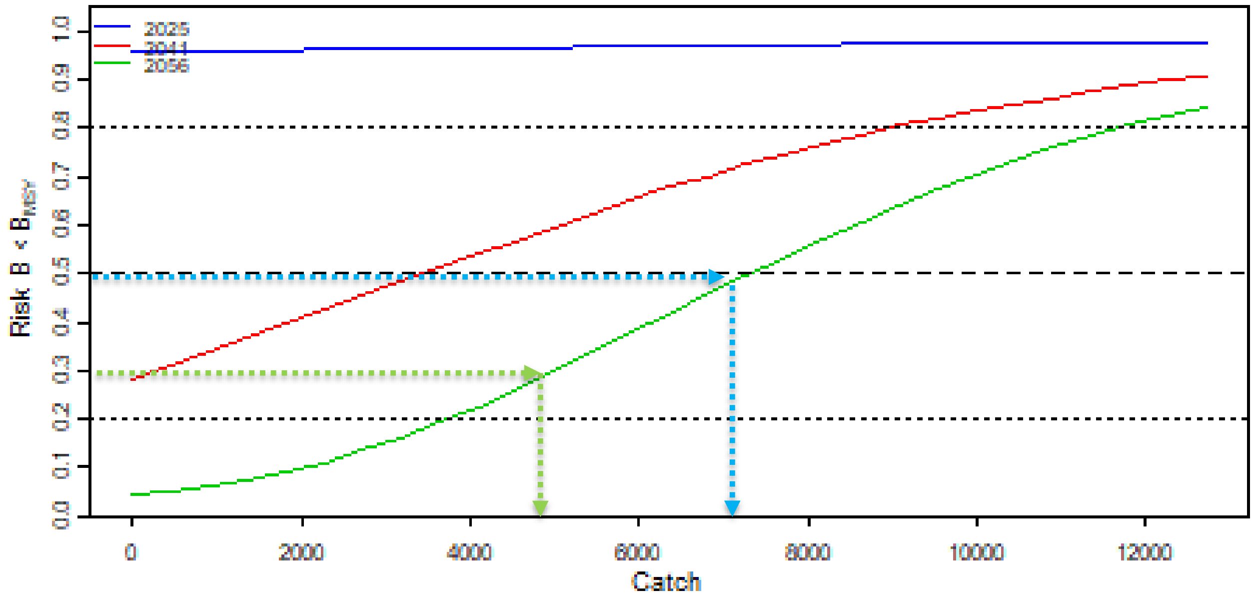


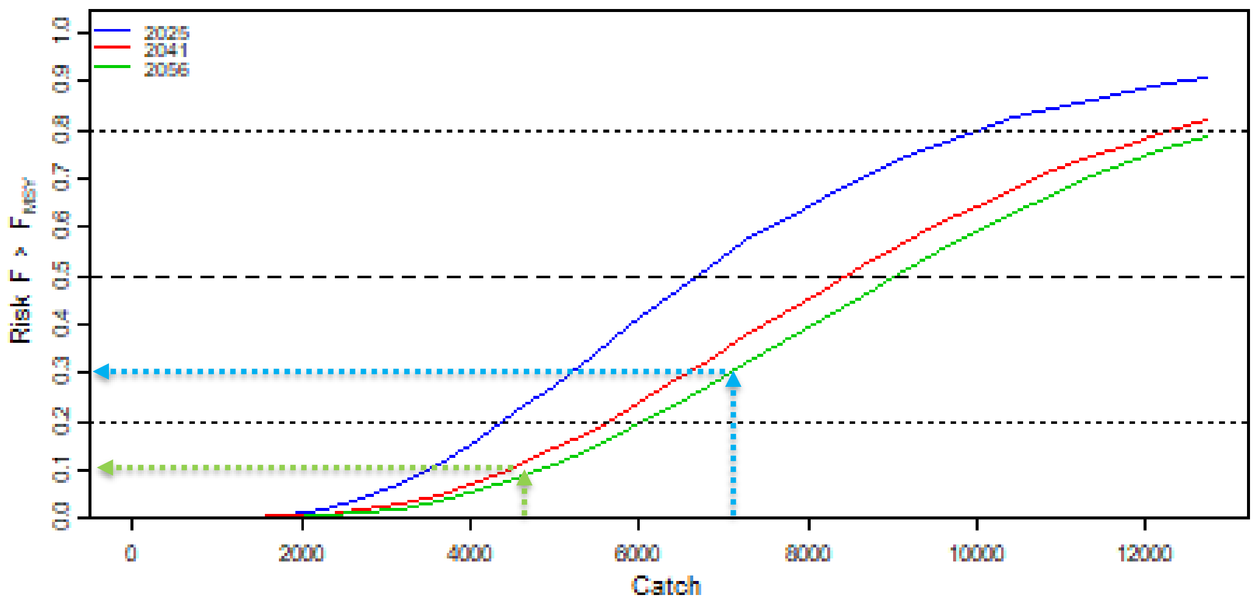
Year in which F=0 results in a 70%

probability of rebuilding (red arrows) (Year $F=0_{p70}$ = 2041 which is > 10 years).

Target rebuilding year (Yearrebuild) 2056 (2041 plus 1 generation time,15 years)

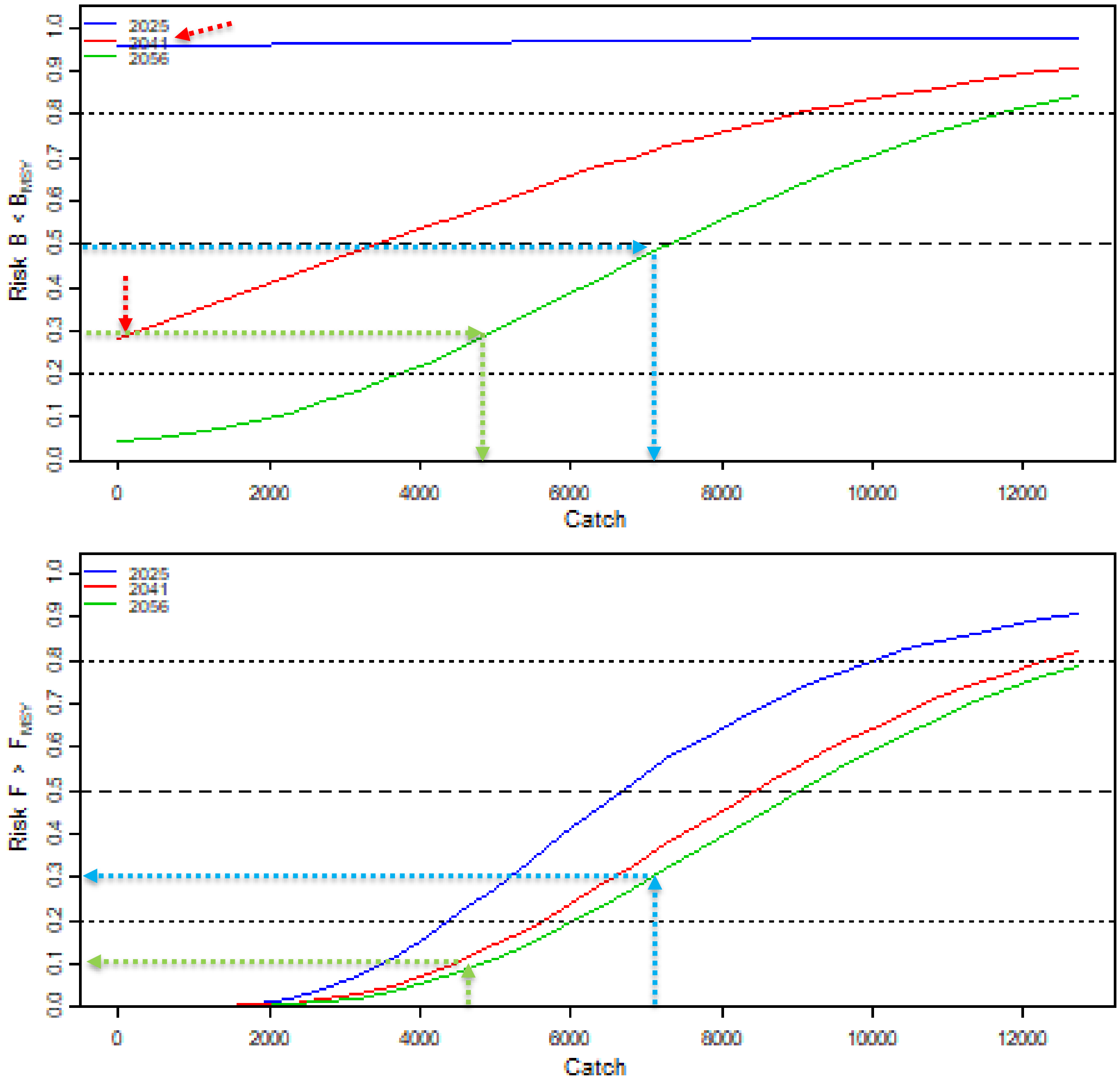
Base model: Catch based projections for rebuilding





Fixed level of removals allowing rebuilding of stock with 50% (blue arrows, 7264) and 70% (green arrows, 4994) probability by Yearrebuild

Base model: Catch based projections for rebuilding



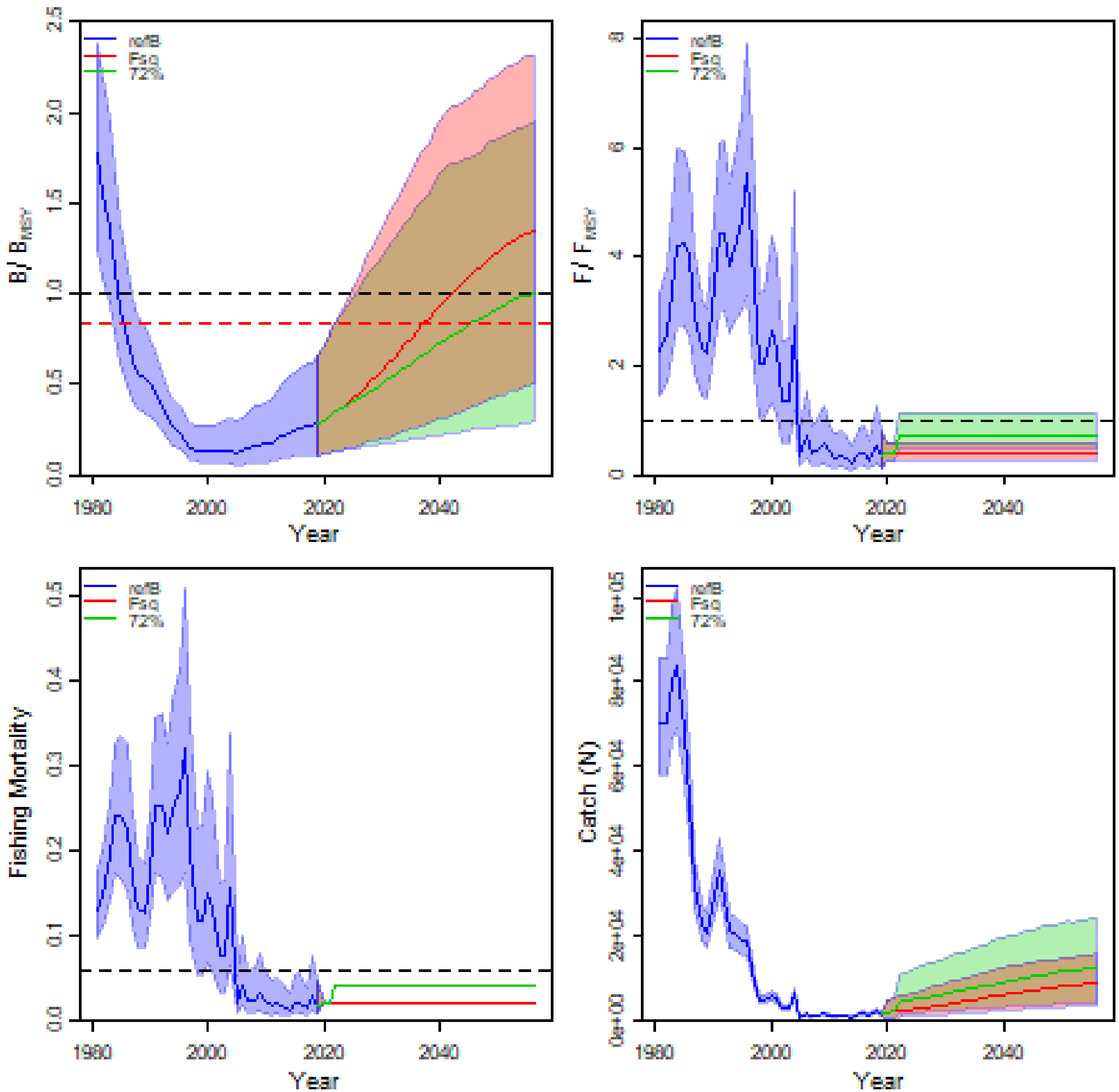
Year in which F=0 results in a 70%

probability of rebuilding (red arrows) (Year F=0$_{p70}$ < 2041 which is > 10 years).

Target rebuilding year (Yearrebuild) 2056 (2041 plus 1 generation time,15 years)

Fixed level of removals allowing rebuilding of stock with 50% (blue arrows, 7264) and 70% (green arrows, 4994) probability by Yearrebuild

Base model: F based projections for rebuilding with p>=50%

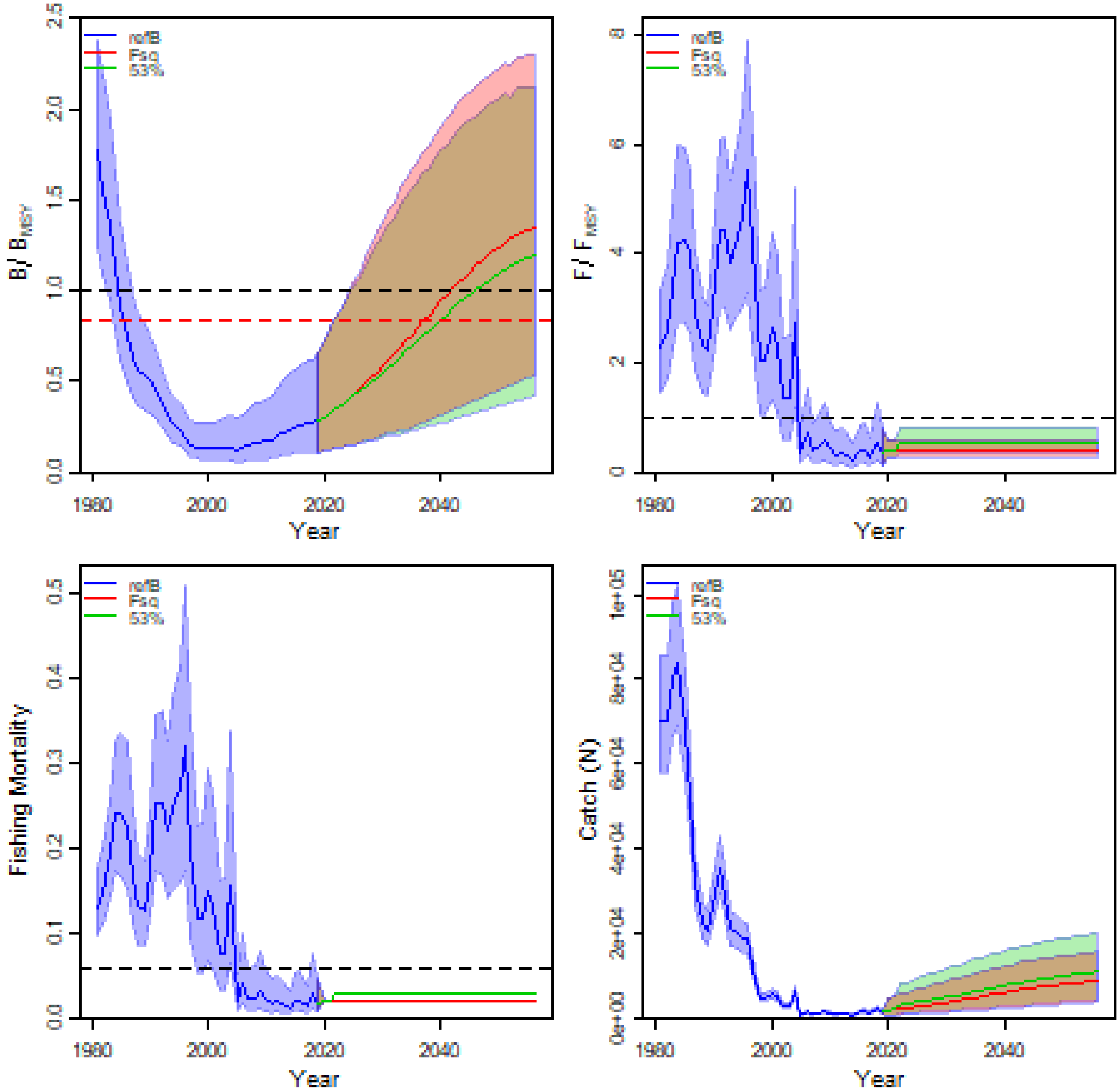


Year in which F=0 results in a 70% probability of rebuilding (Year $F=0_{p70}$ < 2041 which is > 10 years).

Target rebuilding year (Yearrebuild) 2056 (2041 plus 1 generation time,15 years)

Fixed level of F (72%*Fmsy=0.042) allowing rebuilding of stock with 50% probability by Yearrebuild

Base model: F base projections for rebuilding with p>=70%



Year in which F=0 results in a 70% probability of rebuilding (Year $F=0_{p70}$ < 2041 which is > 10 years).

Target rebuilding year (Yearrebuild) 2056 (2041 plus 1 generation time,15 years)

Fixed level of F (53%*Fmsy=0.031) allowing rebuilding of stock with 70% probability by Yearrebuild

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 there are insufficient length composition data, programs to collect lengths to allow for a length-based, age-structured assessment in the future assessments should be developed.

Questions?

Additional slides

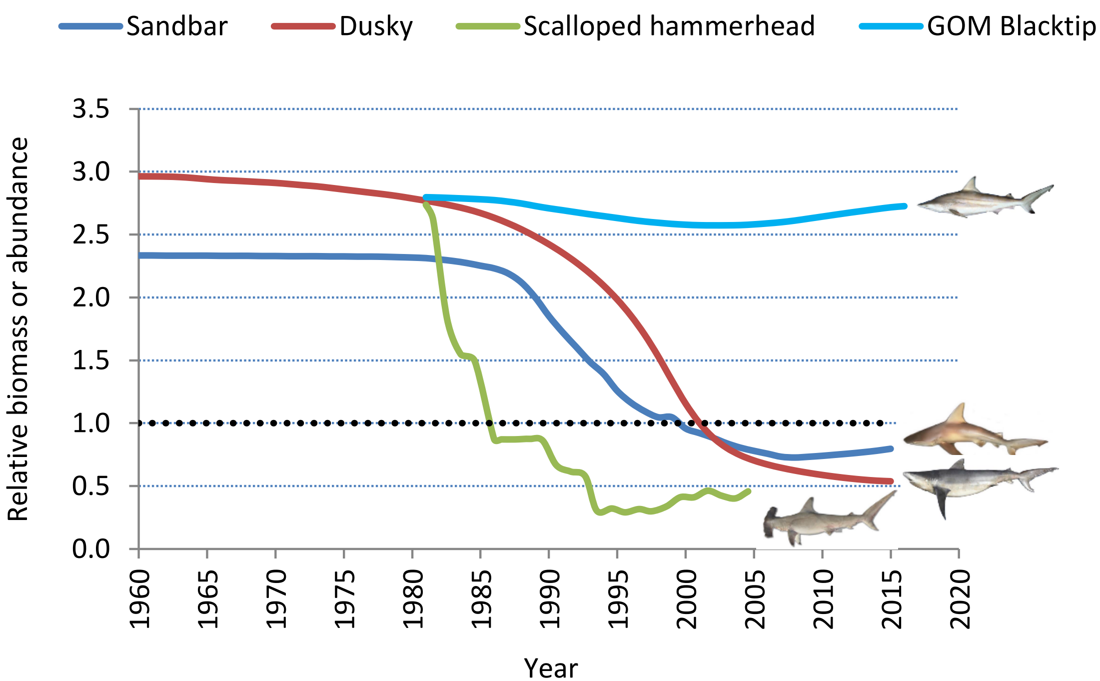
Catches: decisions made and implemented

- ✓ 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

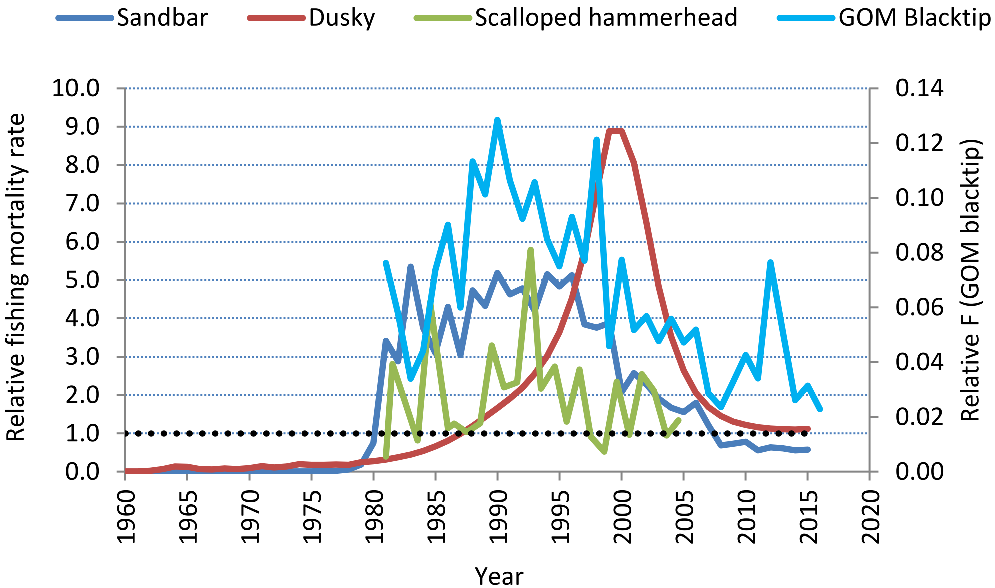
Stock status of large coastal sharks

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